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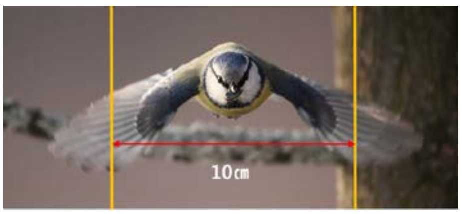
Using Sunshades to Reduce Bird Collisions with Glass

Christine Sheppard, American Bird Conservancy

June 7, 2018

The 2x4” spacing guideline commonly referred to for collisions solutions applies to patterns created in/on the plane of the glass and relates persuasively to bird body dimensions (Klem, 2009; Sheppard and Phillips, 2015).




Because sunshades are three dimensional and from many angles of view reduce the amount of visible glass, it is likely that larger spacing will still produce reductions in collisions, but very little data is available to use as a basis for recommendation of dimensions. Because there is strong evidence that many bird species are comfortable flying through small spaces, we should be relatively conservative, to obviate the necessity for future retrofitting.

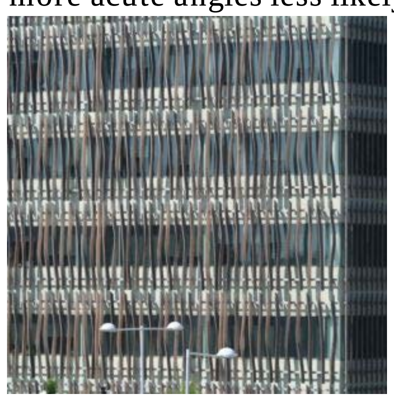
Sunshades work as an effective bird collisions deterrent by physically blocking the view of some or all of a glass area from some range of viewing angles. The extent to which this happens is a function of both spacing and depth of shades, in addition to the area of glass and any offset of shades from the glass itself. For vertical louvers, seen head on, the only deterrent effect will be the edge on view of the shades, delineating spaces that birds might or might not perceive as a flight route. In this case, line/louver width of 0.25 inches is sufficient for birds to see a pattern. Head on or near head on flight angles are the most dangerous, because the energy of a collision is greatest at an incident angle of 90 degrees (Klem et al., 2005).

From very acute angles, the entire glass surface may appear covered by the same shades – like closing shutters - and there is less energy in a bird impact. As birds progress in flight, they presumably perceive a changing landscape of different sized areas of glass and non-glass areas.

Recent research with budgies (Schiffner et al., 2014; Vo et al., 2016) has shown that birds have an accurate understanding of their body size, particularly their wingspan, when presented with gaps of different widths. Once gaps reach wingspan+6%, birds either help their wings up, or close to the body, to pass through. Working with pigeons flying through an obstacle course of vertical elements, Lin and Biewener (2016) found that course changes were made about 1.5 meters before gaps, and that birds steered preferentially towards wider gaps. Of the taxa most frequently killed by glass, warblers are the smallest and have wingspans ranging 7-9". This provides a basis for an initial recommendation for shade spacing: approximately 9" for vertical shades, with depth = spacing. It is likely that a narrower spacing would be more effective for horizontal, parallel shade structures.

Data are available for one installation of horizontal louvers on a monitored building. In this case, spacing was 15", with a depth of 9"and multiple collisions are reported each year.

Sunshades can take many other forms. Again, perceived size of spaces will vary with angle of view, with spaces viewed from more acute angles less likely to appear as viable flight paths.



## References

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| Project Name | Status | City | State | Total Building Cost | BirdSafe measure(s) | Glazing | Cost | of budget |
|---|---|---|---|---|---|---|---|---|
| Oregon Zoo, Forest Hall | Complete | Portland | OR | $20,500,000 | Ornilux Glass | $149,900 | $84,688 | 0.4% of total budget |
| Oregon Zoo, Education Ctr | Complete | Portland | OR | $13,341,472 | AviProtek Custom by Walker | | $100,000 | 0.75% |
| FireStation 21 | Complete | Portland | OR | $6,227,520 | shrinkage | N/A | $52,311 | 0.84% of total budget |
| Oxbow Regional Park Office | Design phase/on hold | Portlland | OR | | yet unset | | | |
| Hannah Mason Pump Station | Under construction | Portland | OR | 10.55M | nightly | | | |
| Oregon Zoo, VMC | retrofit planned | Portland | OR | | facade | | | |
| Columbia Building | retrofit planned; (timelir | Portland | OR | 11.5 M | Solyx horizontal | | $20,000-30,000 | |

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| Notes |
| --- |
| 4820 sf glass; 31.10/sqft with shipping; Solarban 70 would have been 13.70/sq foot |
| awaiting numbers |
| Project included metal fin screen on west facing window wall, which was a public art piece as Portland's 2% for the arts contribution. Bird safety wasn't explicitly intended, though the project did get the LEED BCD 55 credit |
| on hold indefinitely |
| awaiting numbers |
| awaiting numbers |
| timeline by October? slowdown: procurement process, (Robert Pile) staff at plant's bandv warranty 5 years, lifetime 7 years |

| Product Name | Manufacturer | Treatment |
|---|---|---|
| Control Low e | Vitro/PPG | N/A |
| AviProtek | Walker Textures | acid etch |
| Control Low e | Vitro/PPG | N/A |
| Ornilux Bird Protection | Arnold Glas | UV pattern |
| | Viracon | silk screen frit |
| W&W Glass | Pilkington Planar | N/A point supported, frameless |

| **Webpage** | **Spec Sheet** | **MTFR** |
| --- | --- | --- |
| US/Glass/Products/Low-E-Glass/SOLARBAN-Solar- | 85635fbb-52cd-415e-a92d- | N/A |
| friendly-glass/#.WQOYPlPyvR0 | technical-litterature.pdf | 30+ |
| US/Glass/Products/Low-E-Glass/SOLARBAN-Solar- | ca013ae1-3462-4413-af87- | N/A |
| http://www.ornilux.com/technical-specs.html | brochure_rev0417.pdf | ca 34 |

http://www.wwglass.com/

| Reflectance | Warranty | |
|---|---|---|
| 13% | | |
| 15% | 10 year limited | |
| 4%-24% | | |
| 10-24% | | 15 years R+D |

| Places | Year Implemented | Mandatory? | Max height of . treatment | Maximum reflectance allowed | % bird-safe treatment required | Minimum glazing to trigger requirements | Specific geography | Monitoring requirments | Unique features | Comments from local advocates / nonprofits |
|---|---|---|---|---|---|---|---|---|---|---|
| City and County of San Francisco | 2011 by Ordinance | Yes | 60 feet | Btwn. 10-20%. Higher reflectance allowed if UV/frit/ grilles, etc. are included. 30% or mirrored prohibited by Planning Code | 90% of all glazing | triggered at 50% glazing replacement | ALL 'feature-related' hazards & wi 300' of 2 ac. open space, forest, meadows, grassland, water features or wetlands; open water; and green rooftops | None | | |
| Toronto | 2007 by incorporation into building code | Yes | 36 ft. / Top of tree canopy (or 36 ft., whichever greater) in ravines & natural areas | 15% or less, but must be in conjunction w/ other strategies | 85% of all glazing. | None. However, guidelines suggest 20-40% glazing "safe" threshold for reducing bird mortality | All new non-residential development; residential 4+ stories; low-rise residential 5+ units near ravine or nat. area / All fly-through conditions, paralell glass & near rooftop vegetation | None | All public buildings required to treat all glazing up to 16 meters | |
| Oakland | 2013 by incorporation into building code | Yes | 60 feet | N/A | 90% of all glazing | None | immediately adjacent to 1 ac. water,park, open space. Projects incl. green roof, wall, atrium | Continued implementation of Bird Collission Reduction Plan | | |
| Portland, Or | 2013 by City Council resolution | Required on all new city-owned structures and facilities > 500 sq. ft. | 60 feet / Multifamily with <50% exterior glazing must treet ground floor and 1st story above vegetated roof | N/A | 90% of all glazing | Projects with > 10% exterior glass | N/A | None | | |
| Cook County/Chicago | 2008 by resolution | Yes | None | N/A | None | None | N/A | Select public facilities shall incorporate bird safe strategies and undergo 1 year of monitoring | No specific requirements beyond incorporation of some bird safe strategies | |
| State of Minnesota | 2009 by state legislation | Required on all projects that receive general obligation bond funding from the State of Minnesota | First 3 stories | N/A | Only 15% of glazing can be "high risk surface" (TF => 75) / Whole building TF must =< 45 | None | Buildings in "critical sites" must have TF =< 15 | 1 year mandatory monitoring | Based upon LEED Pilot Credit 55 | |
| Sunnyvale, CA | 2014 by City Council adoption | No | 60 feet | Recommended "safe" threshold of 25% or less reflectance | | None | Separate options for sites wi 300' of 1 ac. Open space, water body, park and all others | non-mandatory suggestions | | |

**What is the issue / why is glass so dangerous for birds?**
Window collisions are the second largest anthropogenic cause of avian fatalities, just behind habitat destruction (Klem, 2008). In particular, the reflective and transparent properties of glass pose as a physical threat to birds. Research shows that the percentage of unmarked glass on a building is the strongest predictor of bird mortality. Collisions account for up to one billion deaths in the U.S. alone.

**Why are birds valuable and important to Portlanders?**
Portland is part of the Pacific Flyaway, and is an important stopping ground for hundreds of migrating bird species. Birds (both migratory and non-migratory) provide essential ecosystem services such as pollinating plants, dispersing seeds, and eating pests. In addition, birdwatching is a $40 billion per year industry in the U.S. (USFWS, 2011).

As future developments occur in the Central City, mandating bird-friendly building design is an important step to protecting birds, while also upholding Portland's role as a leader in sustainable and ecological development.

**Are there synergies between Bird Safe design and other sustainability and design objectives?**
Bird-safe building design complements a suite of other sustainability and design objectives such as mitigating solar heat gain, reducing building cooling costs, reducing glare, and improving privacy. Additionally, bird-safe building design supports larger, city-wide policies such as the 2015 Climate Action Plan (Sections 13D, 13F) and the 2035 Comprehensive Plan (Policy 4.67).

**What is the proposed CC2035 bird-safe zoning code?**
Currently all new city-owned and occupied buildings must incorporate bird-safe building and lighting design practices. The proposed revision to the CC2035 zoning code requires new developments and major remodels that alter at least 75% of the building's façade to treat the first 60′ of the building with bird-safe glazing (Figure 1). The standards apply per façade, only if the total amount of glazing exceeds 30% of the façade (Figure 2).

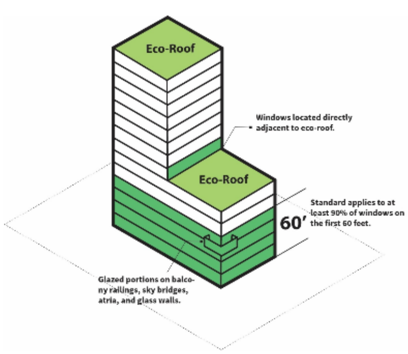


Figure 1.

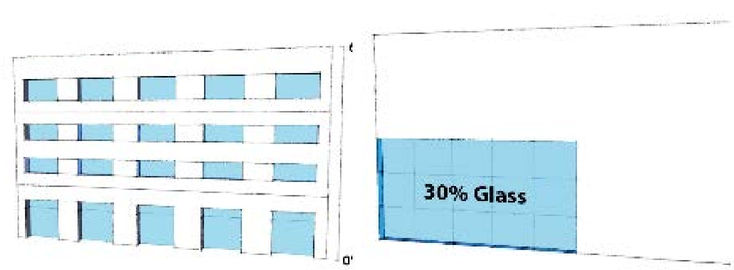


Figure 2.

**Are the proposed CC2035 Bird-safe Glazing Standards intended to be integrated and balanced with other development goals for affordable housing and industrial development?**
Affordable housing projects tend to have less than 30% glazing given additional state requirements should projects have more than 30% glazing. Traditional industrial buildings

generally don't exceed 30% glazing, although newer industrial buildings may exceed that percentage and will require bird-safe building designs.

**What are the costs of bird-safe approaches?**
Depending on the design option and time of implementation, the cost of bird-safe approaches can vary. Typical bird-safe window treatments will fall between being cost-neutral to less than 1% of total project costs. Integrating bird-safe treatments with energy efficiency, building performance, and design objectives can help achieve cost efficiency.

**What are examples of bird-safe buildings in Portland?**
Oregon Zoo upgraded their windows to Ornilux Glass, costing $85,000 (0.4% of total budget costs). Fire Station 21 who installed sonitubes and skylights to offset window shrinkage, costing $52,000 (0.8% of total budget costs).

For other local and national examples of bird-safe buildings and design strategies, please visit Audubon's Bird-Safe Building Design web page.

**What other North American cities or other agencies have mandatory bird safe building regulations?**
San Francisco passed an ordinance in 2011 that requires the first 60' of new buildings and buildings replacing 50% of its glazing to be treated with bird-safe glazing.

Toronto implemented a mandatory program in 2010 requiring nearly all new construction to treat the first 12 meters of the building above grade with bird-friendly glazing.

**What outreach and collaboration have been done with local architects?**
- Collaboration resulted in 2012 Resource Guide for Bird-friendly Building Design
- Any recent updates?

| | | | | | | | | Four floors | | | | | | | | | | | | First floor | | | | | | | | | | | | Glazing info | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Building area | | | | Glazing area | | | | Percent glazing | | | | Building area | | | | Glazing area | | | | Percent glazing | | | | Type/description | | | | Reflectance | | | |
| Priority | Project | Address | Architect | Staff | Phone | Contact | Status | N | S | E | W | N | S | E | W | N | S | E | W | N | S | E | W | N | S | E | W | N | S | E | W | N | S | E | W | N | S | E | W |
| N | Hyatt House<br>14-201514 BRIB-1 (6th floor) | 2098 SW RIVER PARKWAY | SERA | | (503) 445-7372 | | | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| N | Canopy by Hilton<br>15-265536 CO TRIM | 485 NW 9TH AVE | Lever | | (503) 928-6040 | | | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| Y | Ramona Apartments<br>2008 191285 000 00 LU<br>2009 117825 000 00 CO << | 1550 NW 14TH AVE | Ankrom Moisan | **DH** | (503) 245-7100 | Isaac Johnson | 10/19 - Left voicemail but need to call back | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| N | Broadway Tower<br>16-120532 (under review) AX14-0 (2nd floor) | 710 SW COLUMBIA ST | GBD | | (503) 224-9656 | | | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| Y | Framework (Pearl)<br>2016 128835 000 00 LU << (not permitted yet)<br>2016 216642 000 00 PJ | 430 NW 10TH AVE | Lever | **DD** | (503) 928-6040 | jonathan@leverarchitect ure.com | 10/24: Sent email to arrange a call; 11/8 talked to on the phone, will get data. | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | Solarban 60 - Asked for specific product. | | | | | | | |
| N | Park Avenue West<br>D8-102777 REV 3MG (complicated with lots of revisions) - In storage 6th floor | 760 SW 9TH AVE | TVA | | (503) 220-0668 | | | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| Y | Block 136 (brick building on west half of block)<br>2014 230014 000 00 LU<br>2015 131540 000 00 CO <<TRIM | 1241 NW JOHNSON ST | Mithun | **DD** | (206) 623 3344 | Daniel Schwab<br>daniels@mithun.com | 10/19 - Spoke to on phone, sent email, he will send info in 1-2 weeks; 11/8 followed up by email. | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| N | University Pointe at College Station<br>2010 100261 000 00 LU (DZM)<br>2010 133698 000 00 LU (CU)<br>2010 135978 000 00 CO | 550 SW COLLEGE ST | SERA | | (503) 445-7372 | | | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| N | PSU Urban Center Building<br>1997 014351 000 00 LU | 510 SW MILL ST | Hacker | | (503) 227-1254 | | | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| Y | OHSU Center for Health and Healing<br>2004 004682 000 00 LU<br>03-172391 Core & Shell (Microfiche 1st floor permit center) | 3303 SW BOND AVE | GBD | **DH** | (503) 224-9656 | Bruce Brown<br>bruce@gbdarchitects.co m | 10/24 - Spoke via telephone and sent email with detailed request.<br>11/16 -- Sent reminder email (11/8 as well). No response | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| N | PSU Viking Pavilion / Stott<br>15-243776-PJ<br>16-128461 STR 1&2 Exterior in TRIM | 930 SW HALL ST | Woofter Architecture, Sink Combs Dethlefs Architects | | (503) 724-0111<br>(303) 308-0200 | | | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| Y | The Pitman Building<br>2012 105687 000 00 CO<br>(MiroficHe 1st floor - 5/28/12) | 1650 SE 3RD AVE | DECA | **DD** | (503) 239-1987 | David Hyman<br>hyman@deca-inc.com | 10/24: Talked with David Hyman and will be getting data; 11/7 received data. | 2100.01 | 1901.24 | 6683.95 | 6478.57 | 253.96 | 100.17 | 66.37 | 1359.26 | 12% | 5% | 1% | 21% | 1499.19 | 1280.00 | 5483.84 | 5085.25 | 171.20 | 0.00 | 0.00 | 1078.87 | 11% | 0% | 0% | 21% | PPG Solarbean 60 glass - ALL | | | | 11% | | | |
| Y | 129 SE Alder<br>2016 196658 000 00 CO (under review - AX 24.1) | 129 SE ALDER /<br>110 SW WASHINGTON ST | Works Progress Architecture | **DD** | (503) 234-2945 | Lucy O'Sullivan<br>Lucy@worksarchitecture .net | 10/24: Called and spoke to the Architect and MAY be getting data; 11/8 followed up by email. | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| Y | The Yard<br>2013 192030 000 00 LU<br>2014 151030 000 00 CO<br>2015 169321 000 00 LU (revision)<br>Plans on 6th floor BRIC-3 | 33 NE 3RD AVE | Skylab | **DH** | | | WILL NOT PARTICIPATE | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| Y | 5 MLK<br>2016 175010 000 00 EA<br>2016 188383 000 00 EA<br>Expected in January | 5 SE M L KING BLVD | GREC | **DD** | (312) 661-1500 | Joe Dietz<br>312-768-6236<br>dietz@grecstudio.com | 10/26: Spoke to on phone and will be sending data (no glazing) if their management approves; 11/8 followed up by email. | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | | | | | | | | |
| Y | The Cosmopolitan on the Park<br>LU 13-139762 DZM,AD<br>14-118643 CO BRIG-1 (6th floor) | 1015 NW NORTHRUP ST | Bora | **DH** | (503) 226-1575 | Leslie Cliffe<br>cliffe@bora.co | 10/24 - Spoke via telephone and sent email with detailed request. | 13510 | 12494 | 14575 | 14392 | 10696 | 8979 | 11929 | 9433 | 79% | 72% | 82% | 66% | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | VRE 1-38 | VRE 1-38 | VRE 1-38 | VRE 1-38 | 44% | 44% | 44% | 44% |
| Y | Towne Storage Rehab<br>2015 262061 000 00 LU<br>2016 175517 000 00 PJ<br>2016 175526 000 00 CO << TRIM | 17 SE 3RD AVE | LRS | **DH** | (503) 221-1121 | Michael Roberts<br>mroberts@lrsarchitects. com | 10/24 - Spoke via telephone and sent email with detailed request. | 6189 | 11145 | 4998 | 6181 | 42 | 3666 | 1397 | 1645 | 1% | 33% | 28% | 27% | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | Cardinal IG ¾" Low E 272 / Clear ARG | Cardinal IG ¾" Low E 272 / Clear ARG | Cardinal IG ¾" Low E 272 / Clear ARG | Cardinal IG ¾" Low E 272 / Clear ARG | 11% | 11% | 11% | 11% |
| Y | Field Office<br>2015 238635 000 00 LU<br>2016 107451 000 00 CO<br>2016 172958 000 00 LU (revision)<br>Under view AX 13-1 - 2nd floor in Bin AX 13-1 | 2030 NW 17TH AVE | Hacker | **DH** | (503) 227-1254 | Joe Swank | 10/24 - Spoke with Joe via telephone and sent him an email with detailed request<br><br>**10/24** - Joe confirmed he will have data before Nov. 3 | 24764 | 22363 | 12635 | 17815 | 9339 | 7785 | 6410 | 7637 | 38% | 35% | 51% | 43% | | | | | | | | | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | PPG Solarban 70 XL | PPG Solarban 70 XL | PPG Solarban 70 XL | PPG Solarban 70 XL | 12% | 12% | 12% | 12% |
| Y | Ladd Tower | 1300 SW Park Ave | Ankrom Moisan | DH | 503.952.1548 | Scott Passman | 11/14 -- Received confirmation that they will participate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

RESEARCH ARTICLE

# Bird-Window Collisions at a West-Coast Urban Park Museum: Analyses of Bird Biology and Window Attributes from Golden Gate Park, San Francisco

**Logan Q. Kahle, Maureen E. Flannery, John P. Dumbacher***

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**Citation:** Kahle LQ, Flannery ME, Dumbacher JP (2016) Bird-Window Collisions at a West-Coast Urban Park Museum: Analyses of Bird Biology and Window Attributes from Golden Gate Park, San Francisco. PLoS ONE 11(1): e0144600. doi:10.1371/journal.pone.0144600

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**Competing Interests:** The authors have declared that no competing interests exist.

## Abstract

Bird-window collisions are a major and poorly-understood generator of bird mortality. In North America, studies of this topic tend to be focused east of the Mississippi River, resulting in a paucity of data from the Western flyways. Additionally, few available data can critically evaluate factors such as time of day, sex and age bias, and effect of window pane size on collisions. We collected and analyzed 5 years of window strike data from a 3-story building in a large urban park in San Francisco, California. To evaluate our window collision data in context, we collected weekly data on local bird abundance in the adjacent parkland. Our study asks two overarching questions: first–what aspects of a bird's biology might make them more likely to fatally strike windows; and second, what characteristics of a building's design contribute to bird-window collisions. We used a dataset of 308 fatal bird strikes to examine the relationships of strikes relative to age, sex, time of day, time of year, and a variety of other factors, including mitigation efforts. We found that actively migrating birds may not be major contributors to collisions as has been found elsewhere. We found that males and young birds were both significantly overrepresented relative to their abundance in the habitat surrounding the building. We also analyzed the effect of external window shades as mitigation, finding that an overall reduction in large panes, whether covered or in some way broken up with mullions, effectively reduced window collisions. We conclude that effective mitigation or design will be required in all seasons, but that breeding seasons and migratory seasons are most critical, especially for low-rise buildings and other sites away from urban migrant traps. Finally, strikes occur throughout the day, but mitigation may be most effective in the morning and midday.

## Introduction

Each year, between 365 million and a billion birds die from window collisions in the United States of America alone [1–3], suggesting that bird-window collisions are the second largest anthropogenic cause of bird mortality, behind outdoor domestic cats. These strikes are a major conservation issue [3–6] and many species–including vulnerable or declining species–are susceptible to collisions [1].

Due to concerns about impacts on avian populations and preventing window collisions, research has been conducted to understand why birds strike windows [1, 4, 6]. In order to understand why collisions occur, we asked two questions: first, what aspects of a bird's biology makes them more likely to fatally strike windows; and second, what characteristics of a building's design tend to cause bird strikes.

Multiple aspects of a bird's biology have been implicated in fatal window strikes. For example, Hager et. al [7] found that juveniles were more susceptible to striking than adults. Klem et al. [4] found no significant difference in the age or sex of the birds or the seasonality of strikes. O'Connell [8] found that window strikes peaked during migration, suggesting that birds are highly susceptible along their migratory flyways. Nocturnal migrants are especially susceptible to striking tall communication towers [9, 10], indicating that high-rise buildings may have qualitatively different dynamics of which birds strike and when. There may be many aspects of bird biology and life history, such as size, territorial displays, and feeding and migratory behaviors that might affect their susceptibility to fatally strike windows.

Likewise, many characteristics of windows and building design have been implicated in increased bird strikes. Studies show that birds do not recognize clear or reflective windows as fatal barriers [2], and windows are most dangerous when the surrounding habitat and sky is clearly visible through or reflected in the glass [2]. Strikes occur more frequently on lower windows during the day due to the increased bird activity closer to the ground [11], but tall towers threaten migrants moving at night [9]. Environmental factors can also affect window strikes, including whether bird feeders or desirable avian habitat is located near windows [2, 7]. The orientation of windows to sunlight might affect glare and reflection at key times of day, thus affecting strike rates [12]. Furthermore, some characteristics of windows themselves may affect the likelihood of bird strikes, for example, strike fatalities may decrease with angled windows [2, 12], although this may be highly dependent upon which direction birds are flying and the reflections that are seen by them.

Understanding which birds strike and why is important for guiding management decisions to prevent window strikes at existing buildings and to minimize collisions at newly designed buildings. Costly mitigation efforts can be more appropriately targeted and be more effective if we know more about which birds strike, at what times of year, during which times of day, and against what types of windows. Furthermore, many places–such as San Francisco, Toronto, New York, and Chicago–have considered bird-safe building regulations for future projects [5, 13]. Such efforts are strengthened by data that can demonstrate the scale of the problem, can help elucidate the most problematic building structures, and can suggest alternative designs that reduce strikes.

Of the studies published to date, few included year-round or multi-year data, and even fewer have been conducted along western United States flyways [1]. Year-round data are important for examining seasonal differences, examining relative contributions of migrating birds and resident birds, and evaluating differences between young and adult birds. Here, we hypothesized that more birds would strike during active migration than during summer or winter, and that immature birds would be more likely to strike than adults. Multi-year data are also important for increasing sample sizes and for assessing variation among years.

Additionally, there are data suggesting that the western flyways have fewer migrating birds [14], as well as a different species composition of resident birds, thus questioning the applicability of results from studies done elsewhere. Most published studies only document standardized surveys, usually conducted in the early morning, that assumes a majority of strikes occur during overnight migration [1]. These data do not address the issue of window strikes over a 24-hour period. Hager and Craig [15] determined that daily mortality was highest between sunrise and 1600h, thus highlighting the importance of documenting window strikes throughout the day. We hypothesized that window strikes would peak early in the day during peak bird activity periods.

Here, we report a continuous five-year study of window strikes from a large building with significant glass exterior and a living roof. The building is the California Academy of Sciences (CAS), a 3-story public natural history museum, aquarium, and planetarium on the west coast flyway. The building was recently rebuilt and opened to the public in October 2008 in Golden Gate Park, a 412-hectare park in San Francisco, California. Golden Gate Park, a small strip of park habitat in a large city, attracts a variety of migrant bird species as well as residents. The glass exterior of CAS poses a potential collision threat for birds utilizing parkland habitat surrounding the building and the habitat provided by the living roof. Window strikes were first noticed shortly after museum staff moved into the building in the Spring of 2008. We have since accumulated data and specimens from over 355 total strikes (308 documented fatal strikes), involving more than 30 species, averaging about 60 fatal strikes per year. This number is relatively high for a single building of this size given data from other parts of the country [1]. Loss et al. [1] additionally noted the lack of studies from the western flyway, and used some of our preliminary data for their analyses. Our multi-year year-round study will provide a useful comparison between the strikes in Eastern and Western North America

As a museum, we were able to collect and prepare voucher specimens of all bird carcasses that were recovered after building strikes. Thus, we could document the age, sex, and species of most birds that died. We also documented where and when they struck the building. This allowed us to evaluate a number of hypotheses about the timing of strikes including seasonality and time of day and whether there were differences in species, sex, age, or migrant status of birds that struck windows. We hypothesized that males would be over-represented due to more aggressive and territorial tendencies and increased movement. Juveniles were predicted to be more susceptible than adults due to lack of experience with the area and the windows. Similarly, we predicted migratory birds would be more susceptible than residents due to unfamiliarity. While we were uncertain if any particular side of the building would experience proportionally more strikes than the other sides, we hypothesized that strikes would occur in proportion to window area. In order to provide a comparison to expected values for some of these variables, we completed a full year of weekly area search surveys of birds on each side of the building and the living roof. In addition, the building had different window types that allowed us to address various impacts of window construction, including pane size and total window area. Finally, midway through the study, we utilized external window shades on some windows to reduce window strikes, allowing us to assess the effectiveness of this measure.

## Methods

### Ethics statement

No birds were intentionally harmed or disturbed during the course of this study. All surveys were done from established trails or recreational spaces on public land in Golden Gate Park following standard guidelines for the use of wild birds in research [16]. The Institutional Animal Care and Use Committee at CAS reviewed and approved the salvaging of window collision casualties under protocol number 2012–03. Dead birds were labeled and accessioned into the CAS Ornithology collection as soon as possible after they were found. Any injured or stunned birds found under windows were transferred to the Steinhart Aquarium veterinarian to evaluate, treat, and release or euthanize. If injured or stunned birds died in the vet's care, he returned the carcasses and they were accessioned into the collections. Carcasses were salvaged under California Department of Fish and Wildlife Scientific Collecting Permit (SC-7293) and federal U.S. Fish and Wildlife Service Scientific Collecting permit (MB-680765-1).

## Study location

We studied window strikes at CAS, a public museum, aquarium, and planetarium located in Golden Gate Park, San Francisco, California (latitude and longitude 37.77 x -122.466). This Double Platinum LEED-certified building is rectangular in shape with a roof area of approximately 1.5 hectares including overhang, and is three stories tall above the ground level. The building is topped with a living roof and planted with native Californian plants. The building was under construction from 2004 through 2008, and officially opened to the public in October 2008.

As part of the initial design, the building has extensive exterior windows on all four sides to allow natural light to enter, thus reducing the need for electrical lighting and heat. Window dimensions were measured by hand and the numbers of windows and their sizes were counted and confirmed using the designers' building plan. Windows were divided into two main types: small panes (0.5 m or less in width) and large panes (1 m or larger in width; Fig 1). The east and west sides of the building and the north and south entrances are composed of many large panes, each approximately 3.4 m high by 2.3 m wide, or about 7.8 $m^2$. The large pane windows are separated from each other by 15 cm wide metal mullions. Together, these large panes present a wall of windows with a combined surface area of about 205 $m^2$ on the north and south, and 368 $m^2$ on the east and west (Table 1). The remaining south side of the building, which houses the Administrative offices, is made up of over 800 small window panes that are 0.48 m wide and separated by metal mullions, each 13 cm wide. These smaller paned windows cover a total surface area of 1237 $m^2$. In general, night-time lighting is reduced building-wide to the minimum necessary security lights at each entrance and throughout interior spaces, and offices are darkened to save power. Interior lights in exhibit spaces are mostly turned off to provide darkness for aquarium exhibit plants and animals. The lighting at each side of the building and at large and small panes is qualitatively similar.

## Strike data

We began collecting window strike data on 10 February 2008. Data were collected opportunistically until daily surveys were instituted on 03 March 2009 and continued until the end of 2013. Daily surveys were conducted in the morning before the building opened to the public when staff members were present, generally Monday through Friday, but also included some weekend days. Our standard carcass survey consisted of a single staff member searching for dead or injured birds under all large pane windows and under small paned windows on the south side of the building.

Additionally, many carcasses were found by other museum staff outside of the morning carcass surveys. To capture data about these birds, we devised a simple protocol, and all staff were informed about how to respond if they encountered a dead bird. A small freezer was designated for the study and placed where any staff member could access it. Bags and forms were provided for collecting the carcasses and recording collection data including date, time, the location where the bird was found, the collector's name, and the tentative species identification, if

A.

B.

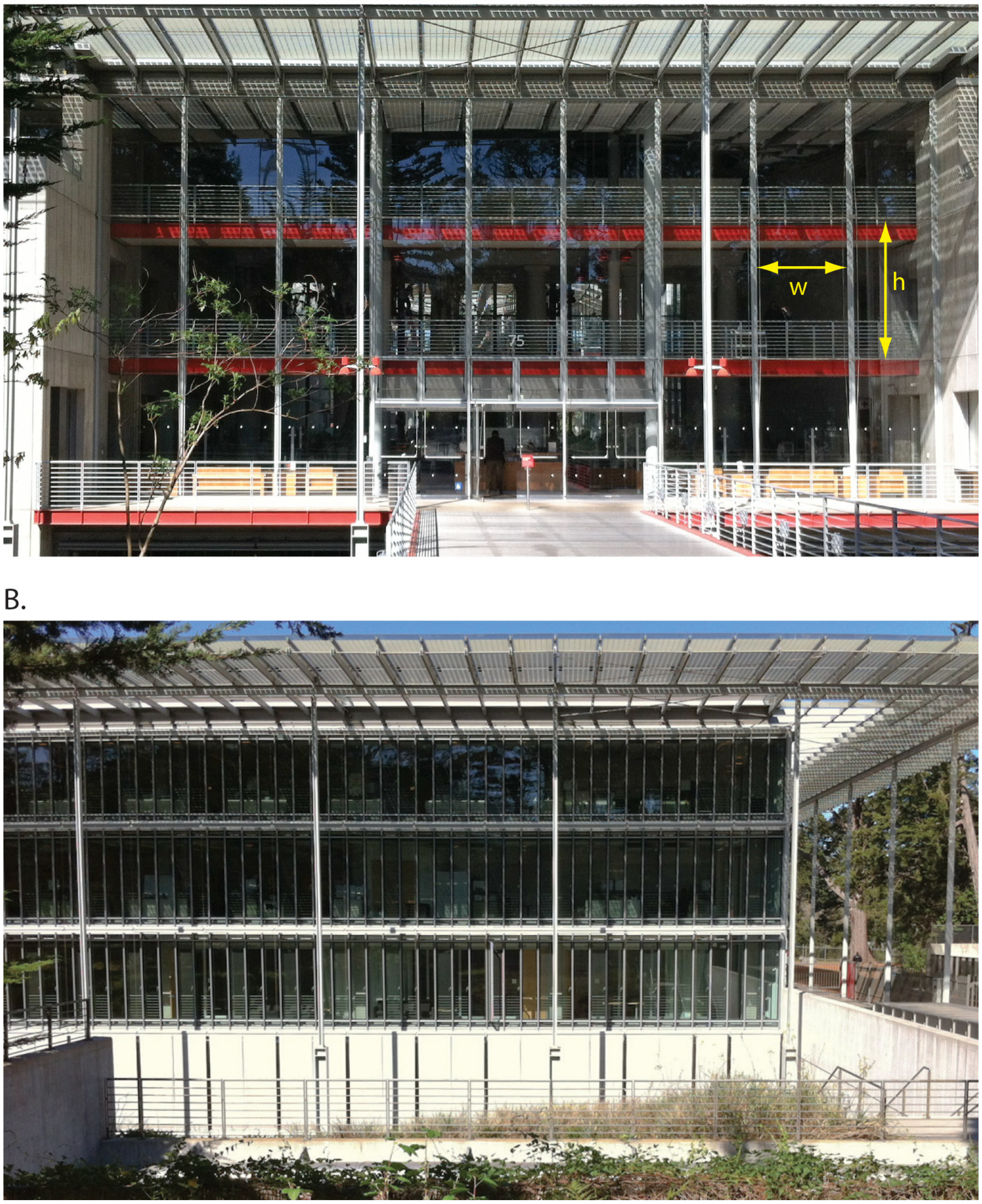


**Fig 1. Photos of the different window pane types found at CAS.** (A) shows the large panes at the south side business entrance. (B) shows the bank of small pane windows on the south side of the building with panes less than 0.5 m wide.

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known. Birds and completed forms were placed in the freezer. All birds collected were prepared as museum specimens with complete data on weight, age, sex, and are permanently housed at CAS. Strike data are available as online supporting information, S1 Data: Window Strike Data, in spreadsheet format.

**Table 1. Window locations, total area, number of fatal strikes per area, and an estimate of the number of strikes per unit area per day.** After 812 days of the study, shades were extended over the top two-thirds of the east and west windows to mitigate bird strikes. This mitigation continued for 1016 days. East and west side mortalities were tallied for the periods pre- and post-mitigation.

| Glass Window Location | Window Area [$m^2$] | Fatal strikes | strikes/$m^2$/day |
|---|---|---|---|
| North Public Entrance | 202.33 | 81 | 2.19E-04 |
| South Staff Entrance | 205.42 | 38 | 1.01E-04 |
| East Garden (totals) | 367.85 | 74 | |
| Pre-mitigation | | 70 | 2.34E-04 |
| Post-mitigation | | 4 | 1.07E-05 |
| West Garden (totals) | 367.85 | 77 | |
| Pre-mitigation | | 63 | 2.11E-04 |
| Post-mitigation | | 14 | 3.75E-05 |
| South Small Windows | 1237.17 | 24 | 1.06E-05 |
| Unknown Location | | 14 | |
| **TOTAL** | **2380.62** | **308** | **7.08E-05** |

doi:10.1371/journal.pone.0144600.t001

## Area search surveys

To estimate relative abundance of bird species using the adjacent park, we surveyed birds using standard area search protocol [17 page 35]. We surveyed four different habitat patches, each adjacent to one side of the building. Each study area around the building was approximately 1.5 hectares to match the size of the living roof with roof overhang. Surveys were conducted primarily on Tuesdays and Thursdays within 2.5 hours of sunrise. Each survey lasted 30-minutes and covered the prescribed area as thoroughly as possible. Each area was surveyed once per week throughout calendar year 2013. We conducted a minimum of 14 and a maximum of 20 surveys in a month. Low counts were caused by cancelled surveys due to inclement weather (i.e. heavy rain). If surveys were scheduled on a day with poor weather, they were postponed and completed as soon as possible that week. If poor weather persisted into the next week, the survey was canceled for the week. To adjust for the differences in the numbers of surveys completed, we used the average numbers of birds per survey per month for analyses.

Every bird encountered within the area was identified to species, sex and age when possible, and recorded as a visual, song, or call encounter. Birds that were observed immediately outside the area or flying over were recorded, but not used in analyses. All area search survey data were entered into eBird (eBird.org), a public bird sighting database. Data were then downloaded from eBird in tabular form for analysis. Data included fields on species, age, sex, date, and location, all of which could be tallied and searched. We analyzed a full year of survey data collected from January 1, 2013 to December 31, 2013. Area search data are available as online supporting information, S2 Data: Area Search Data, in spreadsheet format.

## Hypothesis testing

We performed a variety of exploratory statistical analyses to test for correlates of a bird's biology that might relate to strikes, including which species were most prone to striking, when birds were most likely to strike (time of year as well as time of day), and whether a bird's sex or age affected striking.

To test hypotheses regarding which species were over- or underrepresented in fatal window strike data, we used data from the area surveys for information on the relative abundance of each species in the adjacent park. Under the null model, birds should be striking in proportion to their frequency in the environment [18]. We used the cumulative binomial distribution to assess the significance of deviations from the expected frequencies, i.e. whether particular species were significantly over- or underrepresented in the fatal strike data.

We hypothesized that migratory bird species might strike more frequently than non-migratory species due to resident birds' familiarity with the area as well as resident birds more sedentary habits. We designated a species as "migratory" if individuals of the species are not year-round residents of Golden Gate Park. Thus, this considered only whether bird species were migratory or not, and not whether these individual birds were actively migrating through the park. To test whether or not migratory species were over or underrepresented, we ranked each species by how over- or underrepresented they were in the strike data (for ranked order and for designation of migratory or non-migratory status, see S1 Table: Table of all fatally striking bird species.) We then used the Mann-Whitney U test for ranked unpaired observations [19] to test for an association of migratory status and overrepresentation in the strike data.

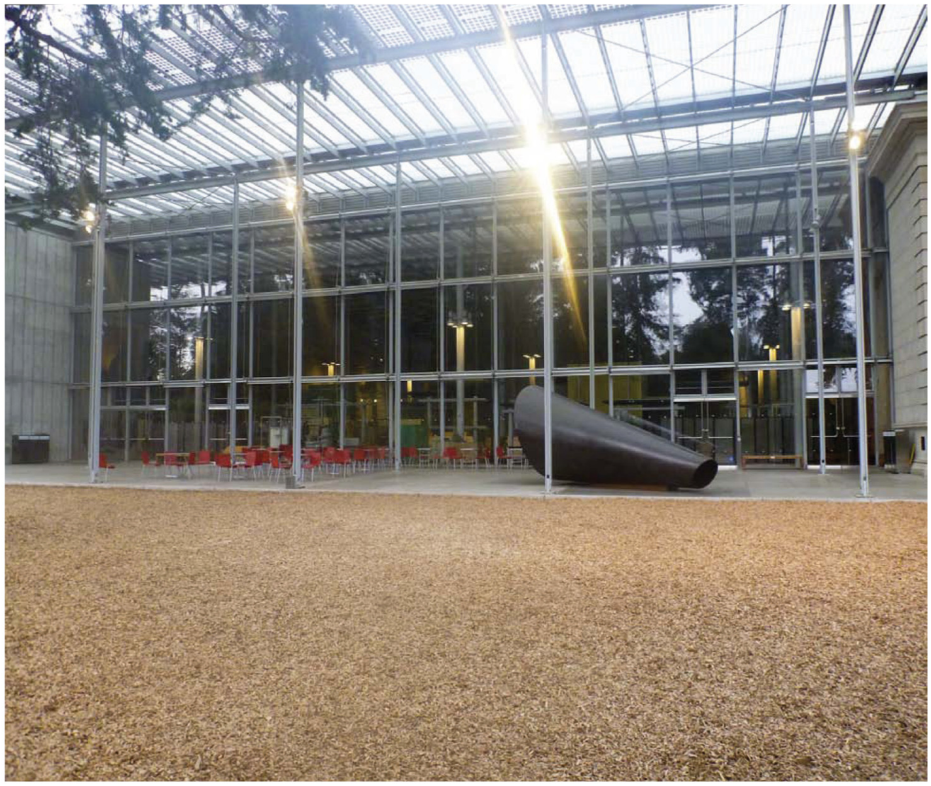
We tested whether sex or age affected the probability of striking windows. Only bird carcasses from fatal strikes could be reliably aged and sexed. Consequently, only fatal strikes were used for these analyses. During specimen preparation, birds were sexed by examining and measuring gonads, as well as by examining plumage characteristics [20, 21]. Birds were aged by examining skull ossification, bill serration length (hummingbirds), gape characteristics, plumage, molt limits, and other external characteristics [20, 21]. We scored each carcass for its age class, using two age classes, Hatching-year (HY) and After-hatching-year (AHY) birds, corresponding to immature and adult birds respectively. As convention, birds become AHY as of January 1 each year. To test the hypothesis that males were more likely to strike than females, we assumed that the ratio of males to females was 50:50, and used the binomial distribution to test for deviations from expected values. To test the hypothesis that young birds were more likely to strike windows than adults, we used unpublished data from Point Blue Conservation Science (formerly Point Reyes Bird Observatory) to assess the expected ratio of HY and AHY birds in the habitat, and the binomial distribution to test for deviations from expected values.

We additionally performed a variety of exploratory statistical analyses to test for correlates of window construction and placement. To examine whether different window pane types had different effects on bird strikes, we converted the number of strikes to units of strikes per $m^2$ of glass per day for the duration of the project [strikes/$m^2$/day] to provide a simple comparison. To test whether there was a particular side of the building that birds were more likely to strike, we used the Chi-squared goodness of fit tests. For analyses that account for window area and orientation, we calculated the expected number of strikes for each side by multiplying the total number of birds that struck the entire building by the proportion of window area on that particular side of the building. For analyses based upon bird abundance and activity on each side of the building, we calculated the expected values by multiplying the total number of fatal strikes by the ratio of total birds observed in the adjacent area to the total number of birds in all areas.

## Mitigation efforts

To reduce bird strikes on the windows, we used retractable shades on the outside of the east and west large pane windows (Fig 2). These were vertical shades extending over the windows on levels 2 and 3 and effectively blocked all of the glass more than 3.5 m above the ground, which was also 2/3rds of the total window area. Shades were programmed to extend for 24 hours per day, wind speed permitting, from 22 March 2011 onward. On windy days, which were rare, the shades would automatically retract and stay retracted until wind speeds allowed for the shades to be re-extended. Thus, strikes on the east and west sides after 22 March 2011 correspond to a 2/3rds reduction in glass area.

A.



B.

**Fig 2. Photos of the east side windows without exterior shades (A) and with exterior shades (B).** Note that the shades cover only the top 2/3rds of window area, and completely block the windows. Shades were originally designed to shade and control interior lighting.

doi:10.1371/journal.pone.0144600.g002

## Carcass persistence study

The presence of scavengers may affect carcass detection and overall estimates of bird-window collisions [7, 12, 22–24]. To test how effectively we detected and recovered window strikes around the building, we set out a motion-triggered digital camera trap and a bird carcass as bait to evaluate whether window casualties were being removed or not reported. We set the camera and carcass five times on each of six windowed sections of the building, the east and west sides, the north and south entrances, and the Administrative office windows. The camera was set for a total of 30 nights over the course of a 70-week period. The bait carcass was an uncatalogued specimen, either a passerine (n = 27) or a hummingbird (n = 3), placed on the bare ground below a window and within 1m of the window. The specimen was set between 1700 h and 2000 h, and if not removed, retrieved the next morning, usually between 0800 h and 1000 h. The average duration that the camera trap and carcass were deployed was 14.75 hours.

We used a Bushnell 8MP Trophy Cam HD Hybrid Trail Camera with Night Vision programmed to include the date, time, and temperature on each image. Once activated by motion, the camera took three pictures at five second intervals. A manufacturer's setting on the camera rendered it inoperable for one minute after taking the third picture. The camera was mounted on a stanchion within one foot of the ground and 15–20 feet from the carcass, depending on the space available. The camera and stanchion were removed after the morning survey and all images were downloaded. During morning surveys, we recorded a carcass as being removed if we did not locate body parts containing flesh, bones, or more than 10 disarticulated feathers and photos included (1) images of the scavenger with the bird in its mouth, (2) an initial image of the scavenger and the carcass in the same frame followed by an image of the scavenger only with the carcass missing, or (3) an image of the scavenger only with the specimen missing. We recorded a carcass as a reported window collision if (1) any CAS staff member, other than the staff member who set up the camera and carcass, collected the specimen or (2) if any staff members reported the carcass directly to Ornithology and Mammalogy staff or to the CAS Receptionist, or (3) it remained on the ground when we performed our standard morning window surveys.

# Results

## Area survey data

We recorded 6280 bird-observations during 202 area surveys conducted during 2013, documenting 72 species inhabiting or using the areas immediately adjacent to the CAS building. Data from these surveys provided information of which bird species were present in the area and might be exposed to the building and its glazed windows, and were used to calculate expectations for various fatal window strike probabilities.

## Window strike overview by species

Throughout the study (10 Feb 2008 to 31 December 2013), 355 birds struck the windows and were stunned enough to be found and counted. Of these, 308 resulted in mortalities (87%), while the remaining 47 were released with a good prognosis of survival. 40 species, four of which never struck fatally, were documented among these strikes (see Table 2 and supplemental materials). Using the binomial expectation to identify species that fatally struck more often than expected, 14 species were significantly more abundant in window strikes than in the adjacent bird populations (Table 2). Hummingbirds struck most frequently with Anna's Hummingbird (*Calypte anna*) accounting for over 42% of all strikes ($n$ = 131, $P<0.001$). *Selasphorus*

**Table 2. A list of bird species fatally striking the windows at CAS.** Probability of *n* strikes is the cumulative binomial probability of *n* strikes, which indicates if birds are over-represented in window strike data (P<0.05) or under-represented (P>0.95). Some birds that did not fatally strike were included if they were very common in area surveys, and they were significantly under-represented in the strike data (P>0.95). Four species of birds struck the windows, but were never fatally injured (*Buteo jamaicensis*, *Accipiter cooperii*, *Charadrius vociferus*, and *Troglodytes pacificus*.) See supplemental materials for more information.

| Species | Number of fatal strikes (*n*) | Probability of *n* strikes |
|---|---|---|
| *Calypte costae* | 1 | <0.001 |
| *Passerculus sandwichensis* | 2 | <0.001 |
| *Geothlypis trichas* | 3 | <0.001 |
| *Selasphorus sasin* | 37 | <0.001 |
| *Selasphorus rufus* | 4 | <0.001 |
| *Calypte anna* | 131 | <0.001 |
| *Zenaida macroura* | 6 | <0.001 |
| *Setophaga petechia* | 7 | <0.001 |
| *Catharus ustulatus* | 1 | 0.001 |
| *Melospiza lincolnii* | 6 | 0.002 |
| *Cardellina pusilla* | 3 | 0.002 |
| *Catharus guttatus* | 8 | 0.020 |
| *Empidonax difficilis* | 1 | 0.025 |
| *Vireo gilvus* | 1 | 0.025 |
| *Setophaga coronata* | 7 | 0.083 |
| *Sayornis nigricans* | 3 | 0.086 |
| *Columba livia* | 1 | 0.166 |
| *Oreothlypis celata* | 2 | 0.169 |
| *Molothrus ater* | 1 | 0.567 |
| *Passerella iliaca* | 6 | 0.590 |
| *Spinus psaltria* | 1 | 0.632 |
| *Junco hyemalis* | 22 | 0.680 |
| *Certhia americana* | 1 | 0.721 |
| *Setophaga townsendi* | 3 | 0.726 |
| *Melozone crissalis* | 1 | 0.939 |
| *Haemorhous mexicanus* | 5 | 0.949 |
| *Sturnus vulgaris* | 1 | 0.960 |
| *Haemorhous purpureus* | 0 | 0.960 |
| *Bombycilla cedrorum* | 0 | 0.973 |
| *Zonotrichia atricapilla* | 3 | 0.996 |
| *Regulus calendula* | 0 | 0.999 |
| *Spinus pinus* | 0 | 0.999 |
| *Poecile rufescens* | 1 | >0.999 |
| *Sitta pygmaea* | 1 | >0.999 |
| *Zonotrichia leucophrys* | 1 | >0.999 |
| *Turdus migratorius* | 3 | >0.999 |
| *Agelaius phoeniceus* | 1 | >0.999 |
| *Euphagus cyanocephalus* | 25 | >0.999 |
| *Melospiza melodia* | 5 | >0.999 |
| *Aphelocoma californica* | 0 | >0.999 |
| *Psaltriparus minimus* | 1 | >0.999 |
| Unknown species | 2 | |
| TOTAL | 308 | |

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hummingbirds, both Allen's Hummingbird (*Selasphorus sasin*) and Rufous Hummingbird (*S. rufus*), were the second most frequently represented species ($n = 42$, one *Selasphorus* specimen could not be identified to species, and appears in the tally in Table 2 as "unknown species", $P<0.001$). We found that migratory species were over represented in comparison to year-long residents (Mann-Whitney U test for large samples and multiple ties [19], $t_s = 3.629$, $P<0.01$).

In addition, 15 species were determined to be significantly underrepresented in window strikes because they were detected in larger relative proportions in the habitat surveys than in window strikes. These include five species that were not observed striking the windows at all (Table 2). Two species were underrepresented despite significant numbers of strikes, because they were common in the habitat. These included Brewer's Blackbirds (*Euphagus cyanocephalus*) with 25 fatal strikes and Dark-eyed Juncos (*Junco hyemalis*) with 22 fatal strikes.

## Sex of birds striking

For comparisons of sex and age classes in window strikes, we pooled all fatal strike data from all years, for a total of 308 observed mortalities. Of the 277 birds that were sexed (31 were left undetermined), 93 (34%) were female and 184 (66%) were male (see Table 3). Assuming there was an equal number of males and females in the perimeter, males were significantly overrepresented (binomial probability, $P = 2.44 \times 10^{-8}$). Also, similar binomial tests were conducted independently for each month to test whether the sex bias differed throughout the year (see Table 3.) Even if all birds of unknown sex were scored as females, there is no month of the year that we observed more females than males striking windows, and August through October had the highest ratio of male to female strikes with a ratio of 2.5 males to each female during this period.

## Age of birds striking

For comparisons of age classes in window strikes, 64 of 308 birds were classified as unknown age class (mostly late year birds or hummingbirds.) 244 fatal strikes were assigned to age class,

**Table 3. Number of fatal window kills by month and sex**

| Month | Females | Males | Unk | Total |
|---|---|---|---|---|
| January | 4 | 8 | | 12 |
| February | 1 | *7 | 1 | 9 |
| March | 5 | 6 | | 11 |
| April | 7 | 15 | 3 | 25 |
| May | 5 | *14 | 5 | 24 |
| June | 11 | 14 | 1 | 26 |
| July | 15 | 21 | 4 | 40 |
| August | 8 | *21 | 3 | 32 |
| September | 8 | *21 | 4 | 33 |
| October | 14 | **32 | 9 | 55 |
| November | 10 | 19 | 1 | 30 |
| December | 5 | 6 | | 11 |
| **Total** | **93** | ****184** | **31** | **308** |

We used * to indicate where observed numbers of males were significantly higher than expected based upon the binomial distribution. We assumed a 50:50 ratio of males to females in the areas adjacent to the building (** P<0.01, *P<0.05).

doi:10.1371/journal.pone.0144600.t003

**Table 4. Number of fatal window kills by month and age.** We used ** to indicate where observed numbers were significantly higher than expected based upon banding data from nearby Palomarin field station (binomial probability < 0.01).

| Month | AHY | HY | Unk | Totals |
|---|---|---|---|---|
| January | 12 | | | 12 |
| February | 9 | | | 9 |
| March | 11 | | | 11 |
| April | 16 | **5 | 4 | 25 |
| May | 8 | **14 | 2 | 24 |
| June | 1 | **21 | 4 | 26 |
| July | 4 | **34 | 2 | 40 |
| August | 2 | 23 | 7 | 32 |
| September | 2 | 22 | 9 | 33 |
| October | **16 | 19 | 20 | 55 |
| November | **10 | 9 | 11 | 30 |
| December | **5 | 1 | 5 | 11 |
| **Age Totals** | **96** | **148** | **64** | **308** |

doi:10.1371/journal.pone.0144600.t004

with 148 HY birds and 96 AHY birds recorded (Table 4). To evaluate whether HY birds struck windows more often than randomly expected, we used monthly banding data from Point Blue's Palomarin Field station in nearby Marin County, CA, during this same period (2008 through 2013) to estimate the ratio of HY to AHY birds in the environment, and we used the binomial probability test to test for significant deviations from expectation. Although fewer HY than AHY birds struck in April, HY birds were still significantly overrepresented since they should be so rare in the habitat in April. From May through October, more HY birds struck than AHY birds, and numbers of HY birds were greater than expected in April through July (binomial probability test, $P<0.01$, Table 4). We recorded over 10 times more HY than AHY birds in August and September, and although this represented more HY than expected, the deviation was not statistically significant. The ratio of HY to AHY birds dropped drastically in October, November, and December (Table 4), and in fact AHY birds were statistically overrepresented, however this may be due to the large numbers of birds that could not be reliably aged at this time of year, many of which were likely HY.

Because hummingbirds represented over half of our window strikes, we excluded hummingbirds from a copy of the data and re-ran many of our analyses. The ratio was 58 HY to 30 AHY passerines with 46 individuals of unknown age. AHY birds were still significantly overrepresented ($P < 2.0 \times 10^{-6}$) overall. The sex ratio in passerines was 70 males to 42 females with 22 unknowns. Males were still significantly overrepresented ($P<0.006$). The overall strikes of passerines followed a similar yearlong trajectory as the dataset that included hummingbirds. The only discernible differences were a reduced peak in mid-Summer and a more obvious peak in late Fall.

## Time of day

We began recording time of day of each strike systematically in March 2009, resulting in 212 carcasses with reliable data on the time that they were found. Carcasses were found during all daylight hours (see Fig 3) with the greatest number of carcasses between 0900 h and 1100 h (n = 49), but strikes occurring at other times: before 0900 h (n = 37), and from 1100 h to 1300 h (n = 41). Strike recoveries before 0900 h were mostly collected during our standardized surveys, although these accounted for only 17% of total strikes. Another study found that most

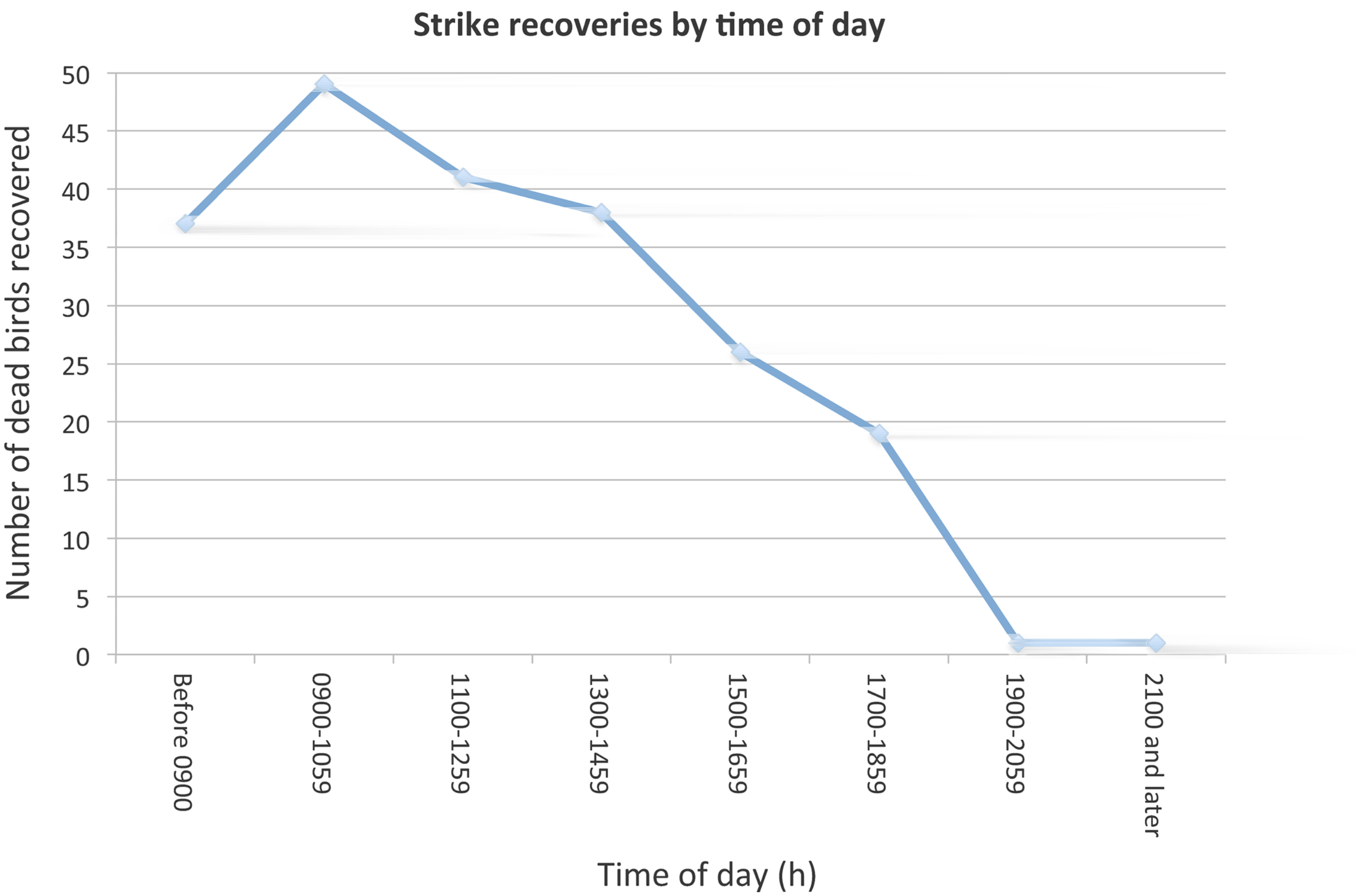


**Fig 3. Strike recoveries by time of day.** The standard survey took place prior to 0900 h and would recover any carcasses from strikes overnight. Any birds reported after 0900 h would be from incidental recoveries from other museum staff outside of our standard morning surveys.

doi:10.1371/journal.pone.0144600.g003

strikes occurred in early and late morning, and were as much as four times greater than at other times of the day [4]. Similarly, Hager and Craig [15] found that the majority of birds died between sunrise and 1600 h with a peak in the midday. Our study had similar results overall, with higher strike rates throughout the day but a steady decline of strikes after the morning hours.

## Time of year

We summarize bird mortality by month (see Tables 3 and 4), and plotted those data with avian abundance from the area search survey data (Fig 4). Avian abundance was derived from the average number of birds detected per survey for each month, scaled so that totals across all months equaled the total number of fatal strikes. Thus scaled abundance could alternatively be viewed as an "expected number of strikes per month" based upon abundance, and it could be easily seen whether fatal strikes simply track the abundance of birds detected in the survey data.

Avian abundance varied throughout the year. The average number of birds detected per area survey ranged from a low of 20 birds/survey in July to a high of over 49 birds/survey in December. The bird numbers detected in the surveys remained relatively constant from October to February, but dropped steadily into April and May.

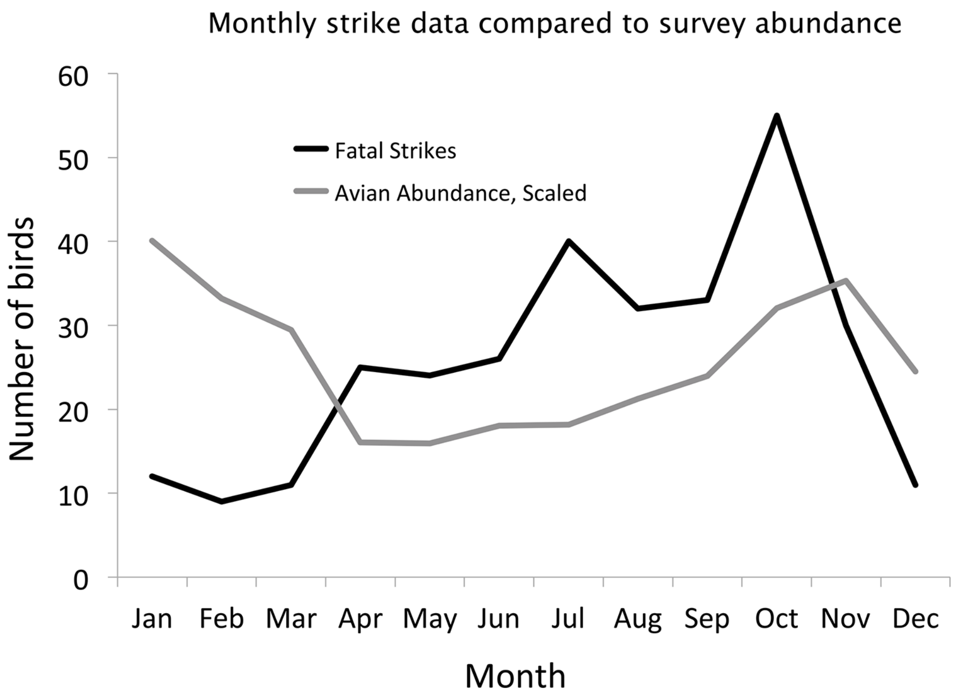


**Fig 4. Monthly strike data compared to survey abundance.** Although avian abundance is highest in November through March, fatal strikes are relatively lower during this period.

doi:10.1371/journal.pone.0144600.g004

During the breeding season (April—October), fatal strikes exceeded expectations based upon avian abundance, although both generally increased as the year progressed and birds produced more young. Between November and March, fatal strikes were fewer than expected (Fig 4), despite the increase in avian abundance with the influx of winter residents. There were three distinct peaks in fatal strike numbers corresponding to April (25), July (40), and October (55).

## Total window area and type of window

The building has two window types that we classified as large pane and small pane windows. These two window types killed birds at very different rates. Overall, the small pane glass had a lower strike rate of $1.06 \times 10^{-5}$ fatal strikes/m$^2$/day. Large pane glass had an average strike rate $1.79 \times 10^{-4}$ fatal strikes/m$^2$/day–almost 17 times more fatal strikes per unit glass than the small paned glass. To control for other factors (direction, amount of light, bird species in the habitat, etc.), we also compared large and small paned glass on only the south side of the building, because the south side had both types of windows. South side large paned glass had nearly 10 times more fatal strikes ($1.01 \times 10^{-4}$ strikes/m$^2$/day) than the south side small paned glass ($1.06 \times 10^{-5}$ fatal strikes/m$^2$/day). Overall, CAS has approximately equal total area of the two window types with the total area of large-paned glass equaling 1143 m$^2$ and the total area of small paned glass at 1237 m$^2$. Nearly all (91.11%) of fatal window collisions occurred at large paned windows and only 8.89% occurred at the small paned windows (see Table 1.)

## Orientation of windows

To compare the effect of window orientation (north, south, east, west), we used only large paned window strikes during the pre-mitigation period (before shades were deployed on the



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east and west sides to prevent strikes). Bird-window collisions were not evenly distributed around the building by window area (chi-squared test, $X^2_{df = 3} = 12.9$, $P<0.005$). The most significant deviation from the expected number of strikes was the paucity of strikes on the south side staff entrance. The east side had the highest strike rate, at 2.34 x $10^{-4}$ strikes/m$^2$/day, while the north and west sides were slightly higher than the expected values (see Table 1 for strike rates).

Each side of the building differed qualitatively in habitat type, disturbance and human activity, and therefore the amount of bird activity. We derived expectations based upon the numbers of birds from area survey data on each side of the museum and found that birds did not strike windows in proportion to their abundance in the adjacent habitat (chi-squared test, $X^2_{df = 3} = 55.2$, $P<0.001$). Fewer birds struck the north and south large windows than expected, and more birds struck the east and west sides than expected.

## Effects of mitigation

After shades were deployed to cover the top 2/3rds of the windows, bird strikes dropped significantly on both the east and west sides of the building, and there was a difference in response between the east and west sides (see Fig 5). The east side encountered a drastic reduction in

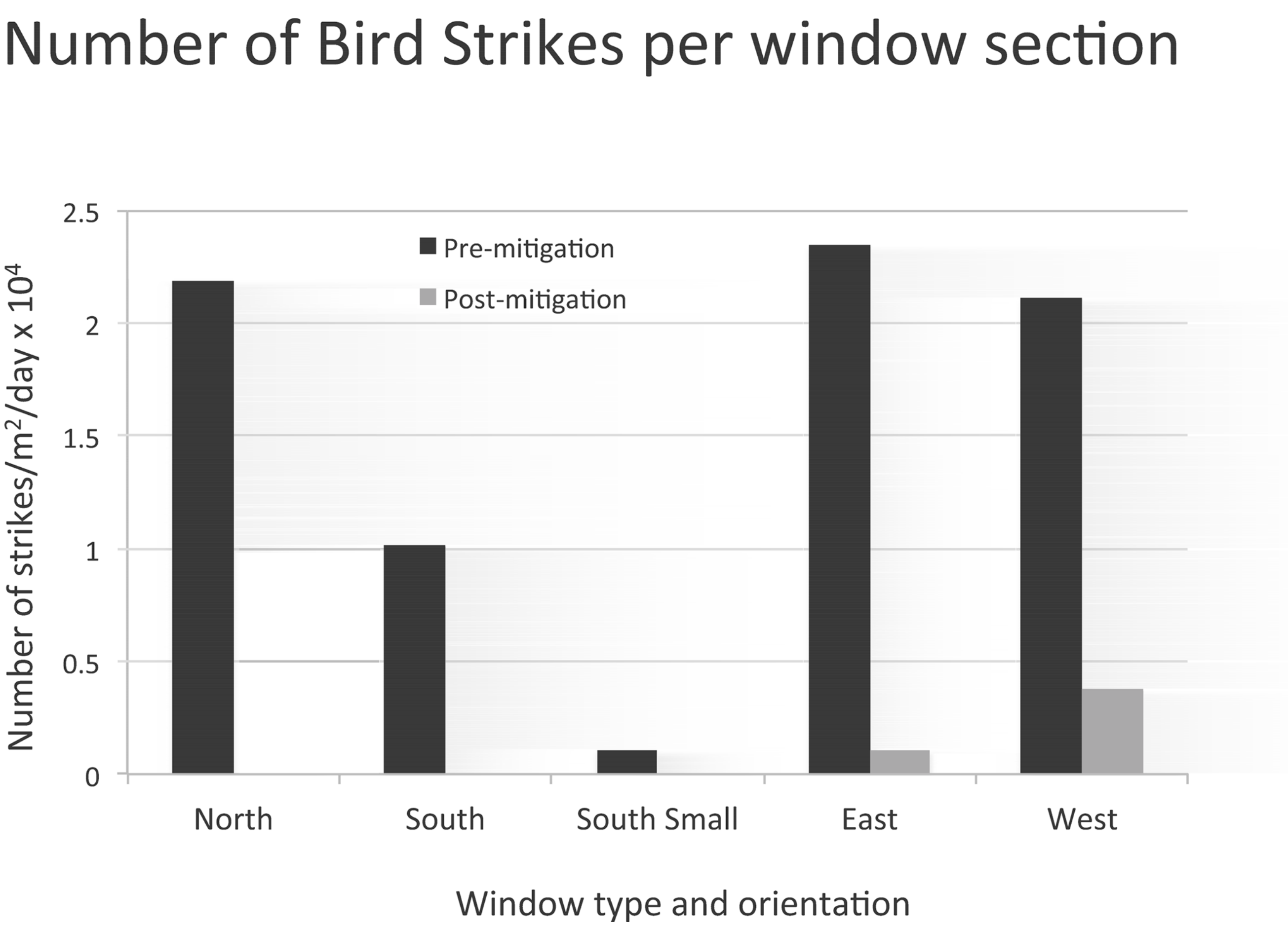


**Fig 5. Number of bird strikes per window section, in units of strikes/m$^2$/day x $10^4$.** Effects of mitigation (shades deployed on the upper 2/3rds of the window area) are also shown for the east and west sides.

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strikes from 2.34 x $10^{-4}$ to 1.01 x $10^{-5}$ strikes/$m^2$/day. Thus pre-mitigation strike rates on the east side were almost 22 times higher than post-mitigation. Mitigation reduced strikes on the west side, but only by a factor of 5.6, from 2.11 x $10^{-4}$ to 3.75 x $10^{-5}$ strikes/$m^2$/day. Both east and west sides had the same amount of glass exposed before and after mitigation, thus suggesting that differences may be due to orientation, adjacent habitat, or other factors. Although the total glass area was only reduced to 2/3rd of the original area, the strikes were reduced by a much greater factor, suggesting a non-linear response to the reduction in glass area.

### Carcass persistence

We deployed the camera trap and bait carcass for a total of 441 hours and 40 minutes over 30 nights between March 25, 2013 and July 22, 2014. We recorded six removal events, four along the west side of the building, one on the east side, and one at the front entrance. Striped skunks (*Mephitis mephitis*) were the primary scavenger species, taking four of the six carcasses. Less than 10 disarticulated feathers, too few to identify a window collision, were found after only one of the carcasses was scavenged by a skunk and before custodial staff had cleaned the area. Humans (*Homo sapiens*) removed the other two carcasses, one carcass was disposed of by early morning custodial staff and one was removed by a member of the public in the middle of the night. The camera trap photographed two other species, one raccoon (*Procyon lotor*) and one domestic cat (*Felis catus*), that both visited the bait but did not remove it. We received 12 reports of carcasses from museum staff members other than the person who set and retrieved the camera. Overall the carcass recovery rate was 80% with a removal rate of 20%. 50% of the available carcasses were recovered by museum staff not involved with the study, and the others were retrieved by Ornithology staff in the morning, at the time of our standard morning surveys.

## Discussion

Window collision studies have varied immensely with respect to locality and flyways, proximity to habitat, time of year, and methods of study; however most studies, if not all, document significant numbers of window strikes [1, 7, 8, 24–27]. Our study differs from many other window strike studies in that it is one of only a few empirical studies along the western US flyway [1], the study is continuous throughout the year and for multiple years, it examines a building surrounded by woodland and park, and it uses extensive comparative data about the local bird populations. By combining data from multiple years, our sample size of fatal strikes (n = 308) was large enough to critically examine several hypotheses, including: 1) how annual cycles of territoriality, breeding, and migration might affect strike rates, 2) how the age and sex of birds affect their susceptibility to strike, and 3) how different building characteristics contribute to bird strikes.

### Differences among bird species in strike rate

As early as 1931, ornithologists realized that certain species and families were more susceptible to fatal window strikes than others [4, 28]. In our dataset, hummingbirds were highly overrepresented in the fatal strike data with 56% (n = 174) of all fatal strikes involving hummingbirds (Table 2). Researchers across the country similarly reported that hummingbirds and swifts were overrepresented in window strike data [1, 27] and could constitute over half of their total strikes [27]. Factors that may contribute to hummingbird susceptibility include their relative fragility, high flight velocities, male territoriality and aggression, and traplining (traveling long distances to undefended nectar resources) [29]. Male (n = 114) hummingbird strikes were over twice as common as females (n = 51; with n = 9 unknown sex birds; Table 3). We documented ten independent instances in which two hummingbirds struck at the same location at the same time, suggesting an aggressive interaction or chase. Six of these were male-male pairs, three were male-female pairs, and one was a male-unknown pair.

Species that occur primarily in flocks were also underrepresented in our window collision data. Several of the most underrepresented species (European Starling *Sturnus vulgaris*, Cedar Waxwing *Bombycilla cedrorum*, White-crowned Sparrow *Zonotrichia leucophrys*, Pine Siskin *Carduelis pinus*, Brewer's Blackbird *Euphagus cyanocephalus*, and Bushtit *Psaltriparus minimus*) form flocks at least during migration and winter. We hypothesize that during the day, flocking species may be better at avoiding windows if one or more flock member detects the window and can signal to others. Because flock members can share predator vigilance activities, they may have more free time to become aware of their immediate environment and its potential threats. If flocking behavior makes birds less vulnerable to striking buildings, this may contribute to the lower numbers of strikes in winter, when many species form flocks (e.g. parids, warblers, and some sparrows). We documented more than the expected number of strikes between April and October when birds flock less, and less than the expected number of strikes between November and March (Fig 4). Conversely, none of the overrepresented species from our collision data were found in flocks near the building. Additionally, hummingbirds and locally breeding warblers were overrepresented in our study, possibly due to lack of flocking tendencies during times when they are present.

Similar to our results, Loss et al. [1] found that blackbirds were underrepresented, though that same study also found, contrary to our findings, that some parids and sparrows were overrepresented. Many parids and sparrows are seasonal flockers in winter, and parts of Loss et al.'s sparrow and parid dataset may have been collected during Summer when flocking is less common, or while migrating (when they might strike high-rise buildings or towers at night when flocking could not benefit birds in the same way as daytime ground-foraging flocks.) This may imply variation in susceptibility within families, at different times of year, and/or in other parts of the country and by building height.

Migratory species were more susceptible to striking than year-round residents. This may be because residents rarely or never leave a small area of habitat, and thus are more familiar with their territory and its hazards. Migratory species may be less familiar with the area, or may have other behavioral correlates that increase window strikes. Of the three species that were found in the strike data and not the survey data (Common Yellowthroat *Geothlypis trichas*, Costa's Hummingbird *Calypte costae*, and Savannah Sparrow *Passerculus sandwichensis*), all were passing migrants. Other studies have concluded that migrating birds comprise the bulk of window strikes [8–10, 27], but our data from this low-rise building suggest that strikes can occur throughout the year and involve significant numbers of residents as well as migrants.

Although previous reports suggest that all birds, large and small alike, are involved in fatal strikes [2, 4], smaller species were more susceptible to fatally striking in this study. Larger birds (hawks, owls, gulls, etc.) were rarely found stunned or dead, and of the five largest birds to be documented striking CAS, including Red-tailed Hawk (*Buteo jamaicensis)*, Cooper's Hawk (*Accipiter cooperii*), Ring-necked Pheasant (*Phasianus colchicus*), Mourning Dove (*Zenaida macroura*), and Killdeer (*Charadrius vociferus*), only Mourning Dove struck fatally. Furthermore, the smallest birds in the study (hummingbirds) had the highest mortality. Future studies may want to focus on the physics of why larger birds are less likely to strike or die in window strikes.

## Differences between sexes in strike rate

At CAS, males fatally struck windows significantly more than females (Table 3). Evaluating strikes one month at a time, males outnumbered females in every month of the year, however differences were only statistically significant in February, May, and August through October. Males may be more likely to strike because they are more aggressive, more active in defending territories, and more actively pursuing mates, resulting in greater activity levels overall.

Previous literature stated that the differences between the number of male and female strikes was not significant [4], though this is possibly due to the tendency of Klem [4] to focus on strikes during migration. Male Common Terns at Belgian wind farms struck more often than females [30], showing that the sex bias can be found in strike rates.

## Differences in the ages of birds that strike

In our data, HY birds struck windows more often than AHY birds throughout much of the year, especially shortly after fledging. This suggests that locally breeding species are susceptible to striking, and that for many buildings, window strikes may be driven by local residents rather than actively migrating birds. Hager et al. [7] also found that HY birds were highly represented in their data, but they did not test whether they were overrepresented with respect to the numbers of HY and AHY birds in the habitat.

Klem did not find differences in age classes in strike data [4], but we believe that our results are stronger for two reasons. First, earlier studies sometimes summed data over the entire year. Because all striking birds are considered AHY birds in early parts of the year and because trends shift throughout the year, an average effect is less perceptible. Second, earlier work used a baseline of three to one ratio of HY to AHY birds as a standard for testing [4], and we used more accurate monthly estimates derived from nearby banding stations (often with an even higher expected ratio than three to one).

Because HY birds are most overrepresented from April through July when HY birds are youngest, the data suggest that less experienced HY birds early in the season are more susceptible to strikes than more experienced HY birds later in the season, i.e. November or December. Although the ratio of HY to AHY strikes drops later in the year and is less statistically significant, we think that this is primarily due to the greater numbers of unknown age birds, many of which are likely HY. Later in the year, HY birds may have fully ossified skulls, and Fall HY plumages cannot be distinguished from Fall AHY plumages for many species.

## Time of day

The majority of dead birds (83%) were collected by museum staff throughout the day rather than during standardized morning surveys (17%), suggesting that bird strikes at CAS occur all day long. Our results were similar to those from Hager et al. [15], who also found strikes were concentrated during daylight hours. The strikes increase steadily through the morning, peaking around 1000 h or 1100 h, and then declining through the afternoon (Fig 3). This is different from our initial assumption that morning surveys would exploit both overnight mortality and the peak activity of birds around first light, and that strikes would be concentrated in that time period. Given our data, surveys that take place throughout a 24-hour period will provide a more accurate count of window collision casualties than those only restricted to early morning hours.

## Strikes by month and seasonality

The number of strikes with respect to the numbers of birds in surveys suggests that birds are not simply striking more when they are more common in the environment. Throughout the year, there are distinct peaks in the numbers of fatal strikes relative to the number of birds in the habitat, especially in July and October. Migration has been considered a cause of bird strikes throughout the country [4, 8, 24, 31], and our October peak coincides with large migratory movements of many species, including certain species that are overrepresented in the strike data such as Hermit Thrush (*Catharus guttatus)*, Swainson's Thrush (*C. ustulatus)*, and Lincoln's Sparrow (*Melospiza lincolnii*). The July peak, however, is not associated with migration, but may be generated by the abundance of naive fledglings and their over-susceptibility to striking windows, as July has the highest number of HY landbirds present (data from Palomarin station, Point Blue Conservation Science). During the breeding season, residents generate many strikes, possibly due to their abundance in nearby habitat. In contrast, in urban settings with minimal or no surrounding vegetation [25] and only a few urban-adapted seasonal residents, the majority of strikes may occur during migration periods, when disoriented migrant birds lose their way in the urban or suburban cityscape with taller buildings that are illuminated at night [32]. Additionally, most other studies were conducted in the eastern United States and Canada, where several factors may be qualitatively different, including the difference in scale of the migratory movements, different bird species, more urban environments, more tall buildings, etc.

## Building characteristics and window orientation

One major finding was that even large expanses of windows had significantly reduced strike rates if they were broken up with mullions every 0.5 m. Our large paned windows have almost 17 times higher strike rate per unit glass than our small paned windows. Thus, one simple solution that may significantly decrease strikes is to either design smaller windows in new buildings or apply stickers that mimic mullions to existing structures. Although we were unable to study the optimal distance of mullions for preventing strikes, our data suggests that smaller units of glass allow birds to detect and avoid the glass surface.

Distinct discrepancies were found in the number of large-pane window strikes on different sides of the building. Other studies suggest that there is no one direction or side of the building that birds tend to strike [25]. We found it difficult to explain the differences based on any single factor, but we believe that there is a complex interaction among the amount of human activity, the amount of avian activity, the proximity of avian habitat, and bird species that frequent each side, and all of these may affect strike rates. The north and south large-paned windows are located at the two busiest entrances with most bird activity further from the glass, which might explain the relative lack of strikes on those sides. The largest discrepancy between sides was due to the relative lack of strikes on the south side. That paucity could be due to extensive human traffic during the daytime, when most birds appear to strike. Both the east and west sides have more avian habitat closer to the windows (15 and 25 m respectively) than the north side (30 m) but farther than the south side (10 m) which has extensive native plantings. The west side has a restaurant with outdoor seating, and although the area is busy during the day, blackbirds and juncos feed even when people are present, and there are food scraps that may attract birds nearer to windows. The east and west sides had very different numbers of strikes post-mitigation, as the east side had a much more drastic reduction. Thus local habitat differences are likely the primary causes of differences in strike numbers on each side of the building, though one other study states that bird behavior and window related factors were the largest drivers of strikes as opposed to abundance of bird species in nearby habitat [27].

## Mitigation efforts

Mitigation efforts using exterior shades significantly reduced window strikes. The number of strikes decreases non-linearly with window area, such that reducing exposed window area to

33% of unmitigated window area actually reduced strikes to 6–10% of unmitigated strike rate. It is possible that there is an "edge effect" such that birds can detect and avoid window surfaces if they are sufficiently close to an edge (a mullion, the ground, or some other visible object.) This may explain the non-linear response as well as the reduced strike rate at our small-paned windows. Another study supported the idea that exterior shades eliminate strikes of the covered area [2]. The effectiveness of exterior shades was larger on the east than the west side, though on both sides there was a significant reduction of strikes.

Our primary findings are that reduction in pane size and exterior shades can both reduce strikes, and these tools are applicable to other buildings. For existing buildings, it is possible that even false mullions—perhaps tape, paint, or wood—could be applied to the windows to increase the visibility of windows. Future studies should seek to understand the effect of pane size and window continuity on strikes, factors that have not been thoroughly examined in other studies, that could be critical in helping building designers provide existing buildings with more cost-effective, less disruptive approaches to reducing strikes.

Our study can inform future building design and management to decrease the number of bird strikes. Understanding strike seasonality and patterns could help additionally focus efforts, especially aesthetically unpleasing mitigation efforts, to the most important times of year and implement the most successful mitigation technique. While our data only represent the strikes at our study site, our findings are relevant to other low-rise buildings that are surrounded by avian habitat. Our data show that significant numbers of strikes can occur even in low-rise buildings, and that window mortality affects all birds in virtually all seasons and all times of day.

Based on our carcass persistence study, it is possible we are only retrieving 80% of the night and early-morning strikes. We believe that our overall detection numbers are actually higher than 80% because most carcasses were collected during the mid-morning hours outside of a morning survey. Only 17% of our window collision carcasses were found during morning surveys suggesting that only a small number of strikes occur during night and early-morning hours and even fewer would be removed by predators (see Fig 3). Thus, if we estimated overall window strikes with the addition of 20% more early morning strikes, the extrapolated number of total strikes during the five-year period would be approximately 319 window kills rather than 308. Alternatively, if carcass removal continues throughout the day at the same level (and we have no evidence for or against), then we estimate actual strike numbers at approximately 370 window kills. While our data are relatively complete, there may be additional undetected strikes.

## Supporting Information

**S1 Data. Window Strike Data.**
(XLSX)

**S2 Data. Area Search Data.**
(XLSB)

**S1 Table. Table of all fatally striking bird species.**
(DOCX)

**S2 Table. Table of bird species that struck windows non-fatally.**
(DOCX)

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## Author Contributions

Conceived and designed the experiments: JPD LQK MEF. Performed the experiments: LQK MEF JPD. Analyzed the data: LQF JPD MEF. Contributed reagents/materials/analysis tools: JPD LQK MEF. Wrote the paper: JPD LQK MEF.

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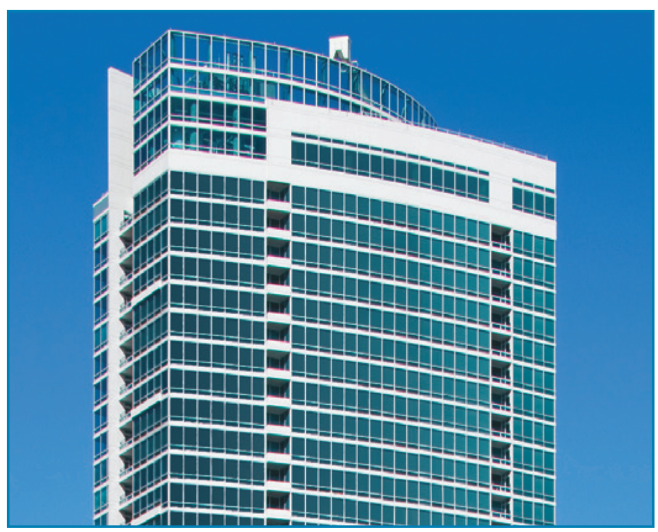
***Product: Solarban*** *60 Glass*
***Architect:*** *Morris Adjmi Architects*
***Glass Contractor:*** *Josloff Glass*
***Glass Fabricator:*** *J.E. Berkowitz, LP*



*Streeter Place*
***Location:*** *Chicago, IL*
***Product: Solarban*** *60 Glass*
***Architect:*** *Solomon Cordwell Buenz and Associates*
***Owner/Developer:*** *Golub and Company*
***Glass Fabricator:*** *Northwestern Industries, Inc.*
***Glazing Contractor:*** *Custom Windows and J&D Erectors*

With ***Solarban***® 60 glass, sustainable design and LEED® credit opportunities are provided according to the following criteria:

| LEED / Green Design Category | Feature | Benefit |
|---|---|---|
| Optimizing Energy Performance | Excellent SHGC, U-value, and Tvis performance | Enhance energy performance of building design |
| Daylight & Views | High VLT | Connectivity to natural lighting and the outdoors |
| Innovation in Design | Cradle to Cradle Certification℠ | Selection of environmentally-focused product evaluation |

57906

# SOLARBAN® 60

Solar Control Low-E Glass

## Fabrication and Availability

*Solarban*® 60 glass is available exclusively through the ***PPG Certified Fabricator*® *Network***. PPG Certified Fabricators can meet tight construction deadlines and accelerate the delivery of replacement glass before, during and after construction. ***Solarban*®** 60 glass is manufactured using the sputter-coating process and is available for annealed, heat-strengthened and tempered applications.

**PPG Certified**
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PPG is the first U.S. float glass manufacturer to have its products recognized by the ***Cradle to Cradle Certified**[CM]* program, and it offers more C2C-certified architectural glasses than any other float glass manufacturer.

**PPG *IdeaScapes*.® Integrated products, people and services to inspire your design and color vision.**

## Additional Resources

### *Solarban*® 60 Glass Performance — Commercial Insulating Glass Unit Comparisons Using 1/4" (6mm) Glass

**Insulating Vision Unit Performance Comparisons** 1-inch (25mm) units with 1/2-inch (13mm) airspace and two 1/4-inch (6mm) lites; as shown below

| Glass Type | Transmittance | | | Reflectance | | U-Value (Imperial) | | European U-Value | Shading Coefficient | Solar Heat Gain Coefficient | Light to Solar Gain (LSG) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ultra-violet % | Visible % | Total Solar Energy % | Visible Light % | Total Solar Energy % | Winter Night-time | Summer Day-time | | | | |
| ***SOLARBAN*® 60 Solar Control Low-E Glass** | | | | | | | | | | | |
| *SOLARBAN* 60 (2) Clear + Clear | 18 | 70 | 34 | 11 | 28 | 0.29 | 0.27 | 1.6 | 0.45 | 0.39 | 1.79 |
| *SOLARBAN* 60 (2) *STARPHIRE** | 24 | 74 | 39 | 11 | 41 | 0.29 | 0.27 | 1.6 | 0.48 | 0.41 | 1.80 |
| *SOLARBAN* 60 (2) *ATLANTICA* + Clear | 5 | 53 | 20 | 8 | 7 | 0.29 | 0.27 | 1.6 | 0.32 | 0.27 | 1.96 |
| *SOLARBAN* 60 (2) *AZURIA* + Clear | 13 | 54 | 21 | 8 | 6 | 0.29 | 0.27 | 1.6 | 0.32 | 0.28 | 1.93 |
| *SOLARBAN* 60 (2) *OPTIGRAY* + Clear | 10 | 50 | 23 | 8 | 14 | 0.29 | 0.27 | 1.5 | 0.35 | 0.30 | 1.67 |
| *SOLARBAN* 60 (2) *PACIFICA* + Clear | 5 | 34 | 15 | 6 | 6 | 0.29 | 0.27 | 1.6 | 0.26 | 0.22 | 1.55 |
| *SOLARBAN* 60 (2) *SOLARBLUE* + Clear | 10 | 45 | 21 | 7 | 12 | 0.29 | 0.27 | 1.6 | 0.33 | 0.28 | 1.61 |
| *SOLARBAN* 60 (2) *SOLARBRONZE* + Clear | 8 | 42 | 21 | 7 | 15 | 0.29 | 0.27 | 1.6 | 0.32 | 0.28 | 1.50 |
| *SOLARBAN* 60 (2) *SOLARGRAY* + Clear | 8 | 35 | 18 | 6 | 12 | 0.29 | 0.27 | 1.6 | 0.29 | 0.25 | 1.40 |
| *SOLARBAN* 60 (2) *SOLEXIA* + Clear | 10 | 61 | 25 | 9 | 10 | 0.29 | 0.27 | 1.6 | 0.37 | 0.32 | 1.91 |
| *ATLANTICA*® + *SOLARBAN* 60 (3) Clear | 5 | 53 | 20 | 9 | 7 | 0.29 | 0.27 | 1.6 | 0.36 | 0.31 | 1.71 |
| *AZURIA*® + *SOLARBAN* 60 (3) Clear | 13 | 54 | 21 | 9 | 7 | 0.29 | 0.27 | 1.6 | 0.36 | 0.31 | 1.74 |
| *GRAYLITE*® II + *SOLARBAN* 60 (3) Clear | 1 | 7 | 4 | 4 | 5 | 0.29 | 0.27 | 1.6 | 0.14 | 0.13 | 0.54 |
| *OPTIGRAY*® + *SOLARBAN* 60 (3) Clear | 10 | 50 | 23 | 8 | 15 | 0.29 | 0.27 | 1.5 | 0.40 | 0.35 | 1.43 |
| *PACIFICA*® + *SOLARBAN* 60 (3) Clear | 5 | 34 | 15 | 6 | 7 | 0.29 | 0.27 | 1.6 | 0.29 | 0.25 | 1.36 |
| *SOLARBLUE*® + *SOLARBAN* 60 (3) Clear | 10 | 45 | 21 | 7 | 13 | 0.29 | 0.27 | 1.6 | 0.38 | 0.33 | 1.36 |
| *SOLARBRONZE*® + *SOLARBAN* 60 (3) Clear | 8 | 42 | 21 | 7 | 16 | 0.29 | 0.27 | 1.6 | 0.37 | 0.32 | 1.31 |
| *SOLARGRAY*® + *SOLARBAN* 60 (3) Clear | 8 | 35 | 18 | 7 | 13 | 0.29 | 0.27 | 1.6 | 0.33 | 0.29 | 1.21 |
| *SOLEXIA*® + *SOLARBAN* 60 (3) Clear | 10 | 61 | 25 | 10 | 10 | 0.29 | 0.27 | 1.6 | 0.42 | 0.37 | 1.65 |
| ***VISTACOOL*® Glass with *SOLARBAN*® 60 Solar Control Low-E (3)** | | | | | | | | | | | |
| *VISTACOOL* (2) *AZURIA* + Low-E | 11 | 42 | 16 | 20 | 11 | 0.29 | 0.27 | 1.6 | 0.30 | 0.26 | 1.62 |
| *VISTACOOL* (2) *PACIFICA* + Low-E | 4 | 26 | 12 | 11 | 9 | 0.29 | 0.27 | 1.6 | 0.25 | 0.21 | 1.24 |
| ***SOLARCOOL*® Glass (Reflective) with *SOLARBAN*® 60 Solar Control Low-E (3)** | | | | | | | | | | | |
| *SOLARCOOL* (2) *AZURIA* + Low-E | 4 | 21 | 8 | 19 | 10 | 0.29 | 0.27 | 1.6 | 0.19 | 0.17 | 1.24 |
| *SOLARCOOL* (2) *PACIFICA* + Low-E | 2 | 13 | 6 | 10 | 8 | 0.29 | 0.27 | 1.6 | 0.17 | 0.15 | 0.87 |
| *SOLARCOOL* (2) *SOLARBLUE* + Low-E | 3 | 17 | 9 | 14 | 15 | 0.29 | 0.27 | 1.6 | 0.21 | 0.18 | 0.94 |
| *SOLARCOOL* (2) *SOLARBRONZE* + Low-E | 2 | 17 | 9 | 14 | 18 | 0.29 | 0.27 | 1.6 | 0.21 | 0.18 | 0.94 |
| *SOLARCOOL* (2) *SOLARGRAY* + Low-E | 2 | 14 | 8 | 11 | 14 | 0.29 | 0.27 | 1.6 | 0.20 | 0.17 | 0.82 |
| *SOLARCOOL* (2) *SOLEXIA* + Low-E | 3 | 24 | 10 | 24 | 15 | 0.29 | 0.27 | 1.6 | 0.22 | 0.19 | 1.26 |

* Data based on using ***STARPHIRE*®** glass for both interior and exterior lites.

All performance data calculated using LBNL Window 6.3 software, except European U-value, which is calculated using WinDat version 3.0.1 software. For detailed information on the methodologies used to calculate the aesthetic and performance values in this table, please visit www.ppgideascapes.com or request our Architectural Glass Catalog.



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PART 2 - PRODUCTS

## 2.1 APPROVED GLASS MANUFACTURERS

A. Cardinal Glass, hereinafter called CG.
B. Ford Glass, hereinafter called FG.
C. Guardian Glass, hereinafter called GG.
D. Libbey, Owens, Ford, hereinafter called LOF.
E. Pilkington North American, hereinafter called PLK
F. Pittsburgh Plate Glass, hereinafter called PPG.
G. Saint-Gobain Glass, hereinafter called SG.
H. Vitro America, hereinafter called VA
I. Other Manufacturers may be approved by request in accordance with Section 01630.

## 2.2 GLASS-GENERAL

A. Color & Pattern: All Glass shall be clear and smooth, unless otherwise specified herein.
B. Thickness: Follow Building Code requirements.

## 2.3 FLOAT GLASS

A. Approved Manufacturers: AFG, AHC, FG, GG, LOF, PLK, PPG, SG, VA, or approved.
B. Manufacturing Standard: ASTM C-1036
C. Quality: Glazing Select

## 2.4 TEMPERED GLASS

A. Manufacturing Standard: ASTM C-1048
B. Safety Performance Standard: CPSC 16-CFR-1201-C11
C. Glass Type & Thickness: As specified above
D. Extent of Work: See Glazing Schedule

## 2.5 INSULATING GLASS (TYPE CTG)

A. Manufacturer: PPG Solarban 60
B. Manufacturing Standard: SIGMA CBA
C. Edge Material: Sealant conforming to ASTM E-6-P3
D. Assembly Type: Soft Coat Low-E (Vacuum Deposition) on Surface #2
E. National Fenestration Rating Council (NFRC) Certified Performance Requirements:
    1. In Metal Framed Units:
    2. Maximum Summer "U" Value: 0.42
    3. Maximum Shading Coefficient: 0.40
    4. Minimum Light Transmission: 0.50
F. Glass Layers: 2
G. Metal Spacer Type: Thermally broken
J. Metal Spacer Finish: Natural Anodic

# Preliminary Results for Avian Building Strike Studies at the California Academy of Sciences

Logan Kahle, Maureen Flannery, John P. Dumbacher
Student Science Fellow Program, Department of Ornithology and Mammalogy

August 2013

Window collisions are the second largest anthropogenic cause of bird mortality [1,2], consequently, there is a need to understand which birds strike windows, when, and why [3,4,5]. Here, we examine five years of avian window strike data from the California Academy of Sciences (CAS) in San Francisco. The building has significant glass façade or glazing on all four sides of building, varying glass area per side, varying pane sizes, and varying proximity to vegetation. All fatal strikes have associated voucher specimens in CAS's collections. We tested these hypotheses about the strikes:

**Hypothesis I**: Males are more likely to hit than females (possibly due to males' aggressive behavior). ($H_0$: There are no differences in strike numbers between sexes)

**Hypothesis II**: Bird mortality will be highest in Spring and Fall, during migration. ($H_0$: Strike rates do not vary significantly by season)

**Hypothesis III**: Amount (total area), presentation (size of panes or presence of mullions), and orientation (north, south, east or west) of glazing has an effect on the number of strikes. Each of these factors has been suggested as being important correlates of avian window strikes ($H_0$: Amount, presentation, and orientation of glazing had no effect on strikes).

**Hypothesis IV**: Mitigation efforts (external shades covering glass) were effective at reducing strikes. ($H_0$: Mitigation efforts had no effect on strikes)

## Methods

To measure and document building strikes, we conducted daily surveys early in the morning around the building's perimeter, searching for dead or injured birds. Each dead or injured bird was collected, identified, aged, and sexed. If the bird was found dead, it was prepared for the permanent scientific collections of the museum. Injured birds were given to our staff veterinarian for care, and released when they recovered, or collected if they did not recover. For this study, guest services, custodial, and security staff were trained on proper reporting, documentation, and storage of any bird found dead throughout the day.

To document wild bird use of the surrounding habitat, we established five area search plots on and near the museum. One of the survey areas was the building's living roof, with four other survey areas adjacent to each side of the building (see aerial view). Each survey area was approximately 1.54 ha in size, to match the size of the living roof (canopy included). Each patch covered a variety of habitats and floral composition, and thus had varying avifauna. Each survey lasted 30-minutes, and we identified, counted, aged, and sexed every bird encountered in the area. These area searches provided information on local species and relative abundances that was used to compare to birds striking windows. Appropriate statistics (often Chi-squared goodness of fit) were used to compare expected to actual values.

## Results

We documented a total of 326 avian window strikes from February 2008 to April 2013; 288 of these were fatal strikes. All dead birds were prepared and added to the CAS scientific collections. Due to partial year data from 2008 and 2013, data from these years were excluded from some analyses.

The list of species colliding with windows are shown in TABLE 1. Several species hit windows significantly more commonly than expected based upon area search census numbers (species bounded in red or orange, TABLE 1).

**Hypothesis I:** Males were significantly more likely to strike windows than females (p < 0.001, Binomial expectation, Figure 1). Almost 3 times as many males as females hit the windows (total males : total females = 186 : 66).

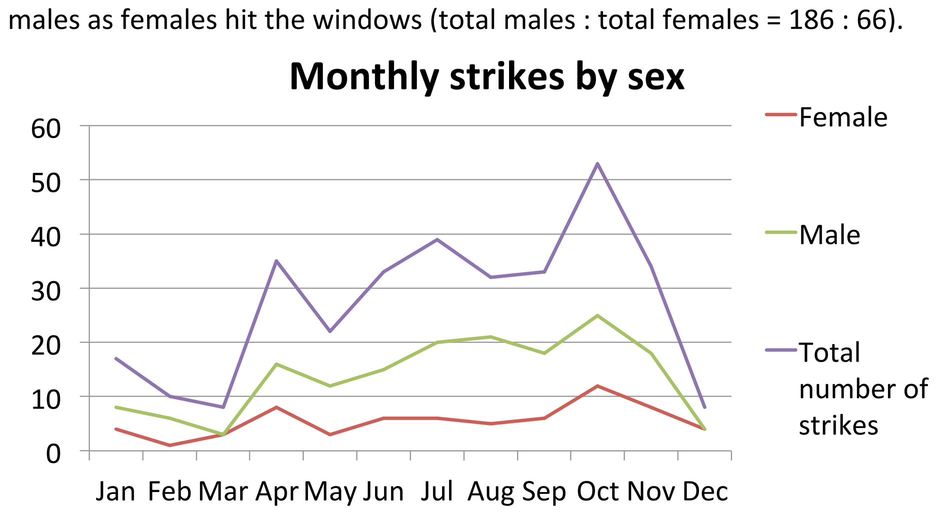
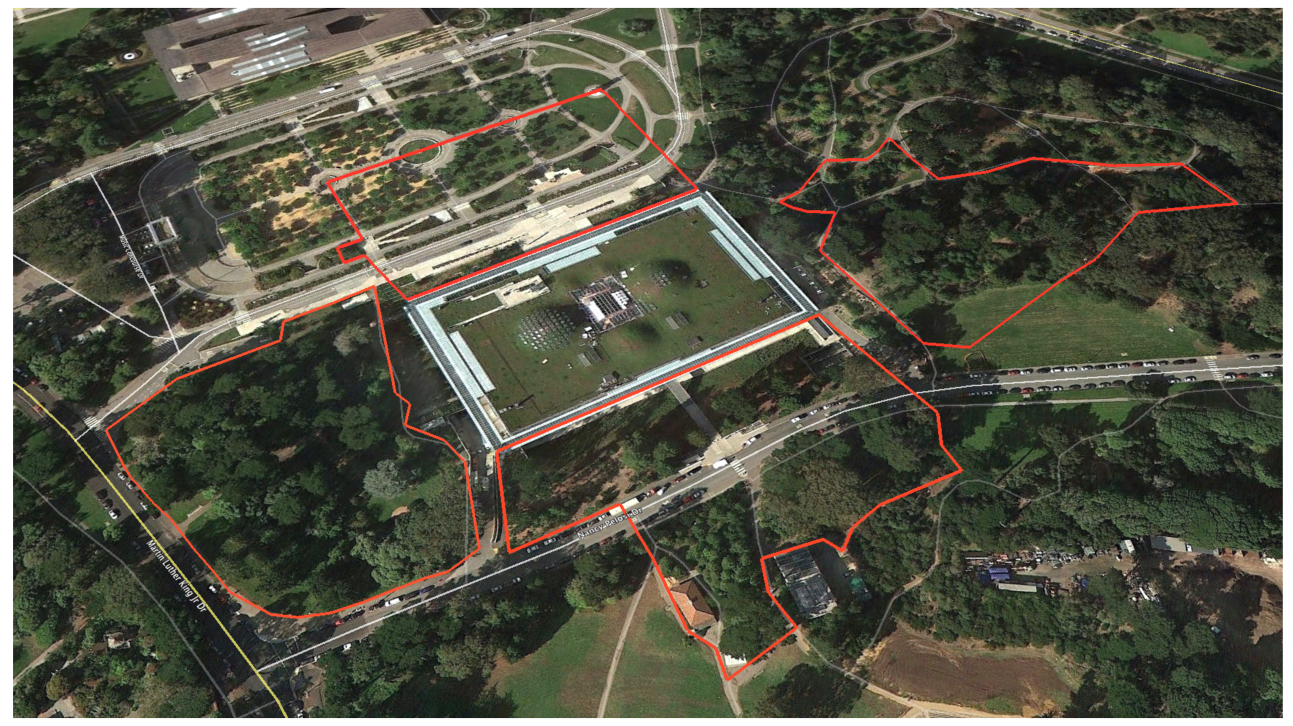
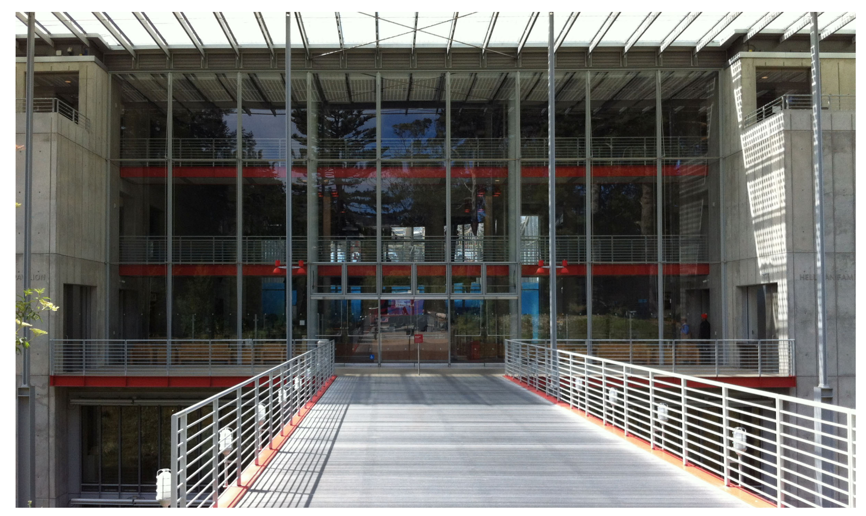



**Figure 1**. Note that every month of the year, more males collided with windows than females. At some points, more than four times as many males collided than females. Note also that peaks in collision numbers occurred in April, throughout summer, and October. Winter months experienced the lowest collision numbers.



Aerial view of the California Academy of Sciences and the four adjacent 1.5 Ha area-search plots. Note the proximity of vegetation to the building, and our LEED certified platinum green roof.



South entrance (above) with large panes of glass. These panes experienced larger numbers of strikes (39), even though the total area was only 176.4 m$^2$ (or 0.0468 strikes/m$^2$/yr.)

The extensive glazing on the building's south side, immediately adjacent grassy habitat (Left image). These small panes (681.2 m$^2$ total area) experienced fewer strikes (14 strikes) even though there was over 3 times more glazing (or 0.0048 strikes/m$^2$/yr).

| Species | Number of Strikes |
|---|---|
| *Calypte anna* | 137 |
| *Selasphorus sasin* | 40 |
| *Euphagus cyanocephalus* | 31 |
| *Junco hyemalis* | 21 |
| *Catharus guttatus* | 9 |
| *Setophaga coronata* | 9 |
| *Setophaga petechia* | 7 |
| *Zenaida macroura* | 7 |
| *Melospiza lincolnii* | 6 |
| *Passerella iliaca* | 6 |
| *Melospiza melodia* | 5 |
| *Zonotrichia atricapilla* | 4 |
| *Carpodacus mexicanus* | 3 |
| *Geothlypis trichas* | 3 |
| *Selasphorus rufus* | 3 |
| *Wilsonia pusilla* | 3 |
| *Dendroica townsendi* | 2 |
| *Hirundo rustica* | 2 |
| *Hummingbird sp.* | 2 |
| *Passerculus sandwichensis* | 2 |
| *Poecile rufescens* | 2 |
| *Turdus migratorius* | 2 |
| *Accipiter cooperii* | 1 |
| *Calypte costae* | 1 |
| *Cardellina pusilla* | 1 |
| *Carduelis psaltria* | 1 |
| *Catharus ustulatus* | 1 |
| *Certhia americana* | 1 |
| *Columba livia* | 1 |
| *Dendroica coronata* | 1 |
| *Molothrus ater* | 1 |
| *Phasianidae* | 1 |
| *Phasianus colchicus* | 1 |
| *Pipilo crissalis* | 1 |
| *Psaltriparus minimus* | 1 |
| *Sayornis nigricans* | 1 |
| *Sitta pygmaea* | 1 |
| *Sturnus vulgaris* | 1 |
| *Troglodytes troglodytes* | 1 |
| *Vermivora celata* | 1 |
| *Vireo gilvus* | 1 |
| *Zonotrichia leucophrys* | 1 |
| Total | 326 |

**Table 1.** List of species that struck windows. Those species that are represented at levels greater than or less than expected are noted as follows: Over-represented: P<0.01 , P<0.05 ; Under-represented: P<0.01, P<0.05; and those that do not differ from expected.

## Results (cont.)

**Hypothesis II:** Strike intensity varied significantly by season ($p < 0.0001$, $X^2_{df=3}$). Fall had the most strikes of any season (120), though Summer (104) and Spring (65) also had many (also TABLE 1). Winter, however, had notably fewer strikes (35), potentially due to fewer young birds and migrants in the area.

**Hypothesis III Results:** The direction that the glass faced had no significant effect, despite differences in total glass area ($p > 0.1$, $X^2_{df=3}$). However, we documented 12 times more collisions per unit area with windows with large, continuous panes (larger than two feet in every dimension) as opposed to windows broken up by mullions. The south side of the building has significant areas of both large and small pane glass, and three times more birds struck the large panes than small panes (large pane strikes : small pane strikes = 39:14), despite the fact that there is almost four times more surface area of glass on the small panes. On other sides of the building, where the majority of the glass exterior is in large panes, overall strikes per m$^2$ were much higher than the total south side.

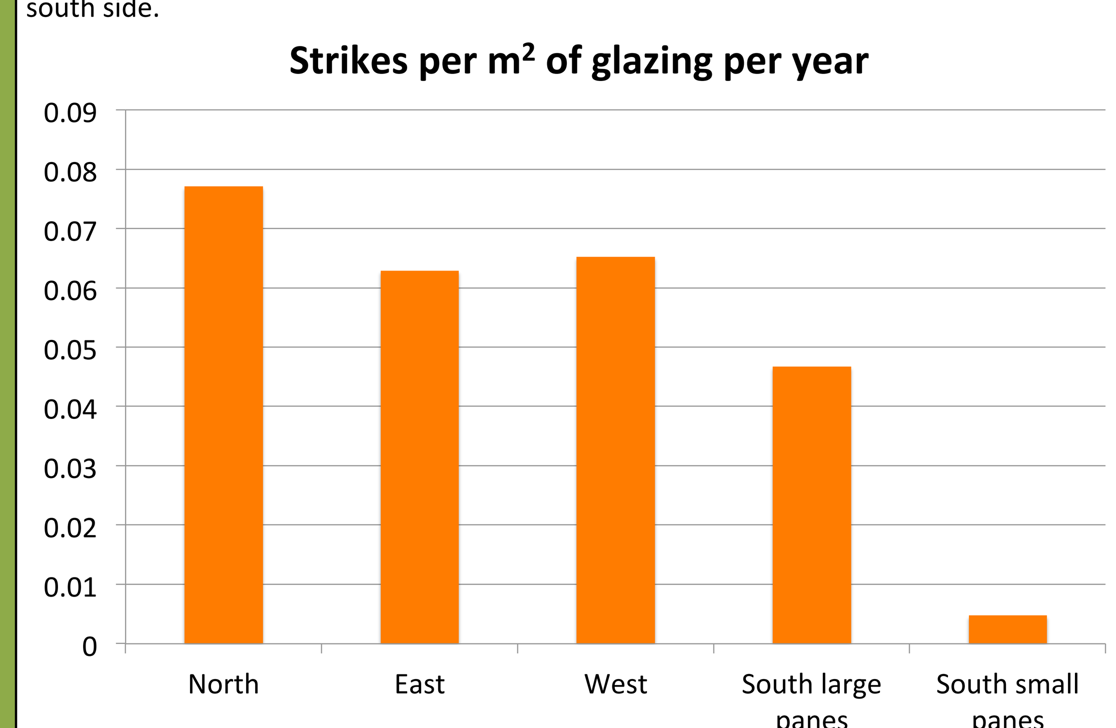



**Figure 2** (left) shows the significance of large panes over small panes. The south side, for instance, has roughly half as much area of large panes as other sides, though it had much more area in small panes. However, most of the strikes from the south were against the large panes, and over 12 times more birds collided with the large panes per unit area. The other sides appeared relatively uniform.

**Table 2**. Window area and collisions by side of the building

| Side of building | area [m2] | # collisions | collisions/m2/yr |
|---|---|---|---|
| East | 421 | 56 | 0.0629 |
| West | 406 | 70 | 0.0652 |
| North | 198 | 61 | 0.0771 |
| South small panes | 681 | 13 | 0.00477 |
| South large panes | 176 | 33 | 0.0468 |

## Results (cont.)

**Hypothesis IV Results:** The use of exterior shades 24 hours per day seven days per week, significantly reduced the number of window collisions. After deploying the shades in 2011, the number of strikes dropped to less than one third of their previous rate. Raptor silhouettes, used prior to shades, appeared to have relatively little effect on bird collisions.

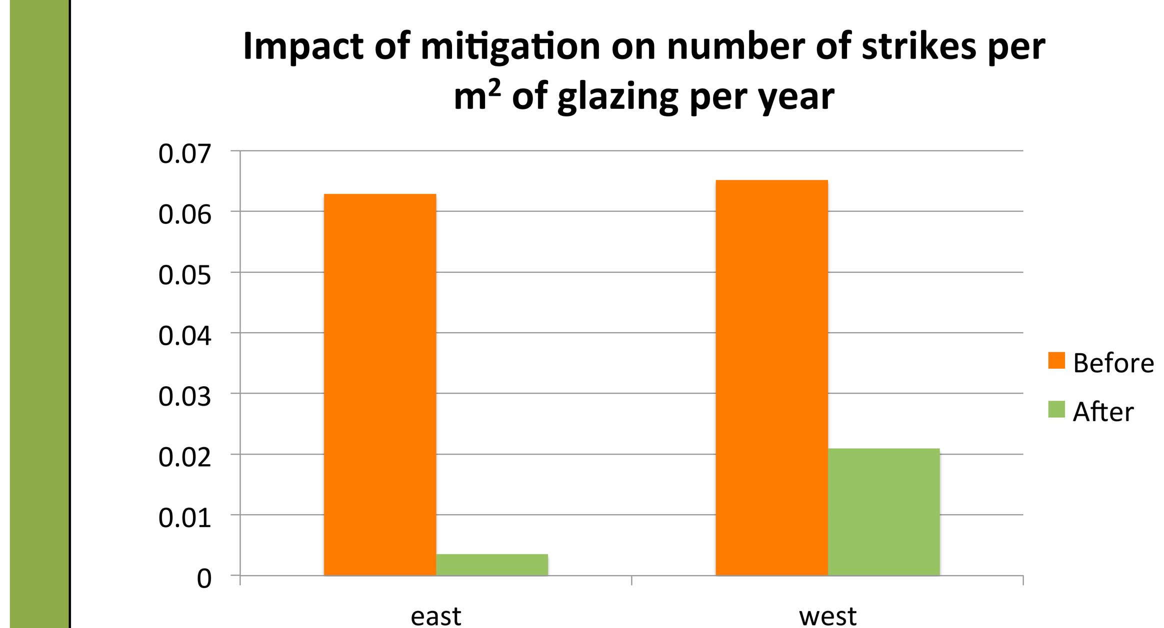



Figure 5, Average monthly window strikes in our east and west garden, where shades were used. Years 2008-2010 were unmitigated ("before"), but 2011 and 2012 were mitigated by dropping external shades over the windows ("after").

## Discussion and conclusions:

- A variety of birds were impacted by window collisions, with Anna's and Allen's Hummingbirds highly represented in our window collision data.
- Collisions were common all year round, with the greatest numbers of collisions in the Fall, and the least in the Winter.
- Three times more males struck windows than females.
- The orientation (north, south, east, west) appeared to have no effect on collision numbers.
- Total window area was important, but larger panes of glass killed up to 12 times more birds than smaller windows (narrower than 20" wide) separated by mullions.
- The only effective mitigation that we have tried has been dropping external shades over windows, 24 hours per day.
- Also, juvenal birds were much more common in the window strike dataset than adults during summer and fall (up to three times more common), but we will be testing whether this is significant in the future.

## Next Steps

- Study whether hatch-year birds are more likely to hit than adult birds. We have found that, between April and December (when hatch-year birds are present in significant numbers), 73% (80 birds) of window strikes were juveniles, and 27% (29 birds) were adults. However, due to the unreliability of aging birds during observational surveys in the field, we have yet to assess of the age distribution of birds in the area. We will utilize banding data from local sources to determine the expected age distribution in the region.
- Determine whether habitat adjacent to the building and the distance from the habitat has a significant effect on the strikes.
- Test the reliability of window strike detection by conducting a carcass persistence study using camera traps.
- Continue collecting strike data and area search data through 2013.

## Acknowledgements:

California Academy of Sciences, Bird and Mammal Collections, Student Science Fellows, Roberta Brett, Senior Science Content Specialist Education Division.

## Literature cited:

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BORA

# HOYT. - COSMOPOLITAN

**Bird Safe Glazing Calculations**

October 28, 2016

| Façade | Levels | Façade SF | Glazing SF (incl spandrel) | % Glazing |
|---|---|---|---|---|
| | | | | |
| North (NW Overton) | Levels 1-4 | 10,476 | 8,605 | 82.14% |
| North (Tower) | Levels 4-5 | 1,917 | 1,787 | 93.22% |
| North (Terrace south bar) | Levels 4 | 1,117 | 304 | 27.22% |
| | | | | |
| North total | | 13,510 | 10,696 | 79.17% |
| | | | | |
| South (NW Northrup) | Levels 1-5 | 10,940 | 8,567 | 78.31% |
| South (Terrace east bar) | Level 4 | 507 | 116 | 22.88% |
| South (Terrace north bar) | Level 4 | 1,047 | 296 | 28.27% |
| | | | | |
| South total | | 12,494 | 8,979 | 71.87% |
| | | | | |
| East (NW 10th) | Levels 1-4 | 10,547 | 9,358 | 88.73% |
| East (Tower - 76 degree angle) | Levels 3-5 | 1,598 | 1,539 | 96.31% |
| East (Tower - 70 degree angle) | Levels 4-5 | 964 | 732 | 75.93% |
| East (Terrace north bar) | Level 4 | 765 | 112 | 14.64% |
| East (Terrace west bar) | Level 4 | 701 | 188 | 26.82% |
| | | | | |
| East total | | 14,575 | 11,929 | 81.85% |
| | | | | |
| West (NW 11th) | Levels 1-5 | 11,894 | 8,955 | 75.29% |
| West (Terrace east bar) | Level 4 | 1,769 | 451 | 25.49% |
| West (Terrace south bar) | Levels 3-4 | 729 | 27 | 3.70% |
| | | | | |
| West total | | 14,392 | 9,433 | 65.54% |
| | | | | |
| **TOTAL** | | **54,971** | **41,037** | **74.65%** |
| | | | | |

N:\work\central_city\Central_City_2035\Appeals\Record\7.0 Specific Topics\Bird_Safe\Background_Data\BIRD-FRIENDLY_Literature\Cosmpolitan - Bird safe glazing calc

| Brand | Reflectance % | Transmittance % | U-value | Solar Heat Gain Coefficient |
|---|---|---|---|---|
| Optigray w/ low-e coating | 5 | 23 | 5.78 | 0.42 |

| Brand | Reflectance % | Transmittance % | U-value | Solar Heat Gain Coefficient |
|---|---|---|---|---|
| Starphire ultra clear | 8 | 91 | 5.78 | 0.90 |

| Brand | Reflectance % | Transmittance % | U-value | Solar Heat Gain Coefficient |
|---|---|---|---|---|
| Starphire w/ Solarban low-e coating | 11 | 74 | 1.55 | 0.40 |

| Brand | Reflectance % | Transmittance % | U-value | Solar Heat Gain Coefficient |
|---|---|---|---|---|
| Solarban R100 / Optiblue | 19 | 30 | 1.55 | 0.20 |

| Brand | Reflectance % | Transmittance % | U-value | Solar Heat Gain Coefficient |
|---|---|---|---|---|
| Solarcool Azuria | 20 | 27 | 5.81 | 0.38 |

| Brand | Reflectance % | Transmittance % | U-value | Solar Heat Gain Coefficient |
|---|---|---|---|---|
| Solarcool Pacifica | 20 | 27 | 5.81 | 0.38 |


| Brand | Reflectance % | Transmittance % | U-value | Solar Heat Gain Coefficient |
|---|---|---|---|---|
| Solarban Solexia | 25 | 36 | 1.55 | 0.21 |

**REFLECTANCE RESEARCH:**

***Measuring and understanding reflectance***

ASTM E 903-1996 specifies the "*Standard Test Method for Solar Absorptance, Reflectance and Transmittance of Materials Using Integrating Spheres".*

- Measures of reflectance / *visible reflectance* / *daylight reflectance*: % of light striking the glazing that is reflected back
- The *reflection coefficient:* $N_0$ = refractive index of air / $N_G$ = refractive index of glass

$$R = \frac{(n_0 - n_G)^2}{(n_0 + n_G)^2}$$

- In practice, reflectance is measured by computer software
- Because light is reflected on *both sides* (front/back) of a single glass pane, the total reflectance through a glass window is 2·R / (1+R).

***Reflectance and bird-safe***

- Low reflectance = high transparency. Both reflectance and transparency are a problem for bird safe;
- Problems of reflectance are mainly rooted in habitat being reflected in glazing;
- Transparency in industry lingo = *visible transmittance*, % visible light striking glazing that will pass through.

***Bird-safe technologies and reflectance***

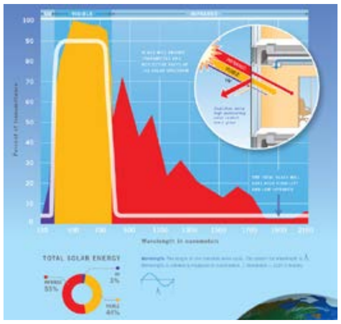
- Technologies that completely disrupt reflected habitat:
    a) Facades;
    b) Netting & grilles;
    c) *External* patterns or ceramic frit patterns (of sufficient prominence);
    d) *External* versions of the following: shutters, shades, screens and frit;
    e) Opaque or frosted glass;

- Technologies that are likely to at least partially disrupt reflected habitat:
    a) Interior glazing or ceramic frit;
    b) UV-patterned glass

- Technologies that do not disrupt reflected habitat:
    a) Awnings and overhangs;
    b) Angled glass;
    c) Internal shades, blinds, curtains

***Energy efficiency and reflectance***

- Glazing energy performance is measured in multiple ways:
    a) U-Value;
    b) Solar heat gain coefficient;
    c) E (emissivity) value
- Spectral selectivity allows low reflectance and high energy performance (low e):



- **Low e = reflect heat away.** Low e (emissivity) coatings prioritize energy savings, and can enable passage of visible light, but blockage of infrared and UV;
- Low e coatings appropriate for Portland's climate will most likely incorporate argon gas filling. This technology can warp inner glass panes (due to pressure difference) and create "magnifying glass-like" reflections of intense, concentrated heat;
- *Current energy saving low-emissivity glass, or glazing with low solar heat gain coefficients often contribute to increased reflectivity*" (NYC Audubon, 2007);
- Buildings that prioritize low glare + energy efficiency will have more reflective glazing;

***Other ordinances & reflectance***

- SF planning code prohibits mirrored or visible light reflectance above 30%;
- Toronto requires glazing with reflectance > 15% to include other mitigation measures;
- LEED Pilot Bird-Collision Deterrence Credit does not specify measure or standard of reflectance;
- New York code does not specify standards re: reflectance;
- Oakland bird-safe measures do not deal with reflectance (http://goldengateaudubon.org/wp-content/uploads/Oakland-Bird-Safety-Measures.pdf);
- San Jose has voluntary guidelines that do not specify reflectance thresholds;
- State of Minnesota follows LEED Credit & does not specify reflectance thresholds

***Portland's reflectance-related code:***

**33.218.140 Standards for All Structures in the RH, RX, C and E Zones/ Q. Additional standards for historic resources.** The following standards are additional requirements for conservation districts and conservation landmarks**. / 4. Ground level glass.** All glass in ground level **street-facing windows and doors must be clear or ornamental stained glass. Restrooms may have reflective or opaque glass.**

**33.262 Off-site impacts / .080 Glare. / A. Glare standard.** Glare is illumination caused by all types of lighting and from high temperature processes such as welding or metallurgical refining. Glare may not directly, or indirectly from reflection, cause illumination on other properties in excess of a measurement of 0.5 foot candles of light. **[No mention of window-based glare in this section]**

**33.480.040. Scenic resources development standards / B. Scenic corridors / 2.d. Limiting blank facades (3)** Facades facing the scenic corridor must have a minimum of 40 percent of surface area in glass. **Mirrored glass with a reflectance greater than 20 percent is prohibited.**

References:

ABC (American Bird Conservancy), *Bird-Friendly Building Design.* https://abcbirds.org/wp-content/uploads/2015/04/Bird-friendly_Building_Guide_WEB.pdf

Klem Jr., Daniel, et al., 2009. *Architectural and Landscape Risk Factors Associatede with Bird-Glass Collisions in an Urban Environment.* The Wilson Journal of Ornithology. 121(1):126–134.

Loss, Scott R., et al., 2014. *Bird–building collisions in the United States: Estimates of annual mortality and species vulnerability.* The Condor: Orthnithological Applications. 116(1):8-23.

NYC Audubon, 2007. *Bird-Safe Building Guidelines.* http://www.nycaudubon.org/pdf/BirdSafeBuildingGuidelines.pdf

| Characteristic Value | Analytical Instrument [Note 1)] | Description | Equation | |
|---|---|---|---|---|
| Visible light transmittance $\tau_v$ | UV-VIS-NIR | Obtained by measuring the spectral transmittance τ(λ) in the 380 to 780 nm wavelength range, and using Equation (1) that multiplies by the weighting coefficients (Dλ, V(λ), Δλ) and takes the weighted average. | $\tau_v = \frac{\sum_\lambda \tau(\lambda) \cdot D\lambda \cdot V(\lambda) \cdot \Delta\lambda}{\sum_\lambda D\lambda \cdot V(\lambda) \cdot \Delta\lambda}$ (1) | Dλ: Spectral distribution at CIE illuminant D65<br>V(λ): CIE standard photopic luminous efficiency<br>Δλ: Wavelength interval |
| Shading coefficient S | UV-VIS-NIR, FTIR | Indicator of solar shading performance. This coefficient expresses the ratio of the transmitted solar radiation incident on 3 mm-thick flat glass with film attached, including the amount initially absorbed and then re-emitted at the face opposite the entrance face, taking the amount transmitted by the glass alone as 1. | $S = \frac{\tau_e + Ni(100 - \tau_e - \rho_e)}{\tau_{e0} + 0.35(100 - \tau_{e0} - \rho_{e0})}$ (2)<br>$Ni = \frac{6.3\varepsilon_i + 3.9}{(6.3\varepsilon_i + 3.9) + (6.5\varepsilon_e + 12.2)}$ (3) | $\tau_e$: Solar transmittance<br>$\rho_e$: Solar reflectance<br>$\varepsilon_e$: Corrected emittance Outdoor surface (glass surface)<br>$\varepsilon_i$ : Corrected emittance Indoor surface (film surface)<br>$\tau_{e0}$: Solar transmittance of 3 mm-thick glass<br>$\rho_{e0}$: Solar reflectance of 3 mm-thick glass |
| Solar transmittance $\tau_e$ | UV-VIS-NIR | Obtained by measuring the spectral transmittance τ(λ) in the 300 to 2500 nm wavelength range, and using Equation (4) that multiplies by the weighting coefficients (Eλ, Δλ) and takes the weighted average. | $\tau_e = \frac{\sum_\lambda \tau(\lambda) \cdot E\lambda \cdot \Delta\lambda}{\sum_\lambda E\lambda \cdot \Delta\lambda}$ (4) | Eλ: Solar relative spectral distribution<br>Δλ: Wavelength interval |
| Solar reflectance $\rho_e$ | UV-VIS-NIR | Obtained by measuring the spectral reflectance ρ(λ) in the 300 to 2500 nm wavelength range, and using Equation (5) that multiplies by the weighting coefficients (Eλ, Δλ) and takes the weighted average. | $\rho_e = \frac{\sum_\lambda \rho(\lambda) \cdot E\lambda \cdot \Delta\lambda}{\sum_\lambda E\lambda \cdot \Delta\lambda}$ (5) | Eλ: Solar relative spectral distribution<br>Δλ: Wavelength interval |
| Normal emittance $\varepsilon_n$ | FTIR | Calculated from the equation shown using spectral reflectance $\rho_n(\lambda)$ obtained by specular reflection measurements using an infrared spectrophotometer. | $\varepsilon_n = 1 - \rho_n$<br>$\rho_n = \frac{1}{30} \sum_{i=1}^{30} \rho_n(\lambda_i)$ | Refer to JIS R3106 for details. |
| Corrected emittance<br>$\varepsilon_e$:Outdoor surface (glass surface)<br>$\varepsilon_i$:Outdoor surface (film surface) | FTIR | Normal emittance value corrected using the coefficients prescribed in JIS A5759. | Refer to JIS A5759 for details. | |
| Heat transfer coefficient U [W/m²K] | FTIR | Expresses the thermal insulation performance. The value expresses the amount of heat that flows in unit time through 1 m² of 3 mm-thick flat glass with film attached that has a 1 °c difference in air temperature on each side. | $\frac{1}{U} = \frac{1}{4.9\varepsilon_e + 16.3} + 0.003 + \frac{1}{5.4\varepsilon_i + 4.1}$<br>$\varepsilon_e$: Corrected emittance Outdoor surface (glass surface)<br>$\varepsilon_i$: Corrected emittance Indoor surface (film surface) | |
| Ultraviolet transmittance $\tau_{UV}$ | UV-VIS-NIR | Obtained by measuring the spectral transmittance $f(\lambda)$ in the 300 to 380 nm wavelength range, and using Equation (6) that multiplies by the weighting coefficients (Uλ, Δλ)) and takes the weighted average. | $\tau_{UV} = \frac{\sum_\lambda \tau(\lambda) \cdot U\lambda \cdot \Delta\lambda}{\sum_\lambda U\lambda \cdot \Delta\lambda}$ (6) | Uλ: UV relative spectral distribution<br>Δλ : Wavelength interval |

**Bird-safe standards from other places**

**MANDATORY:**

*San Francisco:*

- Bird safe standard has separate sections for "building related" and "feature related" hazards;
- ***Building related*****:** applies within 300' of "*open spaces 2 acres or larger dominated by vegetation, including vegetated landscaping, forest, meadows, grassland, water features or wetlands; open water; and green rooftops 2 acres or greater*"
- Applies to new construction, remodels and 50% + replacement of glazing;
- 90% of all glazing up to 60 feet from ground level must be bird-safe;
- Includes bird-safe lighting provisions;

- ***Feature related:*** applies throughout the city.
- Bird safe glazing required for all free standing clear-glass walls, greenhouse or other clear barriers on rooftops or balconies, free standing clear-glass landscape feature or bus shelters;
- Planning code prohibits mirrored or visible light reflectance above 30%;
-

*Toronto:*

- Applies to first 12 meters above grade for: new construction, major renovations, and glazing replacements. All non-res., residential of 4 stories + and low-rise residential near bird habitat;

*Minnesota*

- Utilizes LEED threat-factor framework;
- Most rigorous standards (TF 25) for transparent "features" (walkways, atrium, railings, etc.);
- High risk surfaces (within 50 ft of –*seemingly any*—vegetation, grassland, open water, trees, shrubs; and see through w/ 20 linear ft) can have only 15% of building surface = TF 75 or more;
- Whole building TF must be <= 45 / <= 15 for critical sites (defined elsewhere in Green B3 Guidelines);
- Includes "lights out" management program, from midnight – dusk during critical migration periods;

**VOLUNTARY:**

*Vancouver, BC:*

- Bird safe strategy part of 10-goal Greenest City Action Plan;
-

**Evidence and commentary from local advocacy groups**

*Contacts:*

- John Takekawa- Dir. Bird Conservation SF Audubon: 415.644.4610
- Andrea Jones—Dir. Bird Conservation Headquarters SF Audubon: 415.388.2524 ext 113
- Patrick Smith – Minnesota B3 tracking contact: 612-626-9709

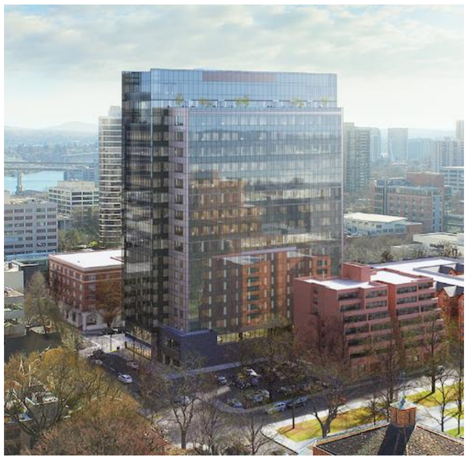
# Central City Building Types (10/13/2016)

General Types

| Priority | Image | Building Type (sort) | Project | Address |
|---|---|---|---|---|
| N |  | Hotel – 5-10 stories | Hyatt House | 2098 SW RIVER PARKWAY |
| N |  | Hotel – 10-15 stories | Canopy by Hilton | 485 NW 9TH AVE |
| Y |  | Housing (affordable) – 5-over-1 | Ramona Apartments<br>2008 191285 000 00 LU<br>2009 117825 000 00 CO | 1550 NW 14TH AVE |

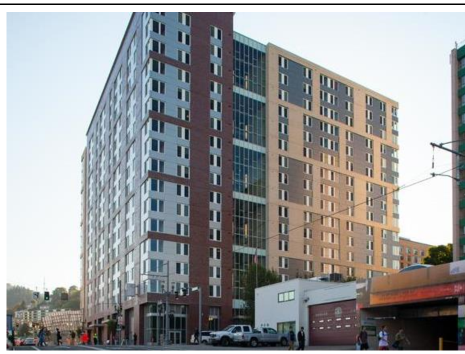


57924

| Priority | Image | Building Type (sort) | Project | Address |
|---|---|---|---|---|
| Y |  | Point tower – 20-30 stories | The Cosmopolitan on the Park<br>LU 13-139762 DZM,AD<br>Had difficulty accessing through TRACS | 1015 NW NORTHRUP ST |
| N |  | Office and housing – 10-20 stories | Broadway Tower (Radisson on the Park Blocks) | 710 SW COLUMBIA ST |
| Y |  | Office and housing – 10-20 stories | Framework (Pearl)<br>2016 128835 000 00 LU<br>2016 216642 000 00 PJ | 430 NW 10TH AVE |



57925

| Priority | Image | Building Type (sort) | Project | Address |
|---|---|---|---|---|
| N |  | Office and housing – 20-30 stories | Park Avenue West | 760 SW 9TH AVE |
| Y |  | Office – 5-10 stories | Block 136 (brick building on west half of block)<br>2014 230014 000 00 LU<br>2015 131540 000 00 CO | 1241 NW JOHNSON ST |
| N |  | University housing – 5-10 stories | University Pointe | 1955 SW 5TH AVE |
| N |  | University academic – 5-10 stories | PSU Urban Center Building | 1715 SW 5th Avenue |

| Priority | Image | Building Type (sort) | Project | Address |
|---|---|---|---|---|
| Y |  | University academic – 10-20 stories | OHSU Center for Health and Healing<br>2004 004682 000 00 LU | 3303 SW BOND AVE |
| N |  | Entertainment venue - <5 stories | PSU Viking Pavilion (Stott Center) | 930 SW HALL ST |

Industrial Types

| Priority | Image | Building Type (sort) | Project | Address |
|---|---|---|---|---|
| Y |  | Industrial | The Pitman Building<br>2012 105687 000 00 CO | 1650 SE 3RD AVE |
| Y |  | Industrial office – Less than 10 stories | Towne Storage Rehab<br>2015 262061 000 00 LU<br>2016 175517 000 00 PJ<br>2016 175526 000 00 CO | 17 SE 3RD AVE |
| Y |  | Industrial office – 5-10 stories | 129 SE Alder<br>2016 196658 000 00 CO | 129 SE ALDER /<br>110 SW WASHINGTON ST |

Notable/Unique Projects

| Priority | Image | Building Type (sort) | Project | Address |
|---|---|---|---|---|
| Y |  | Dark façade with vertical glazing – 10-20 stories | The Yard<br>2013 192030 000 00 LU<br>2014 151030 000 00 CO<br>2015 169321 000 00 LU (revision) | 33 NE 3RD AVE |
| Y |  | Tree canopy and habitat on roof – 10-20 stories | 5 MLK<br>2016 175010 000 00 EA<br>2016 188383 000 00 EA | 5 SE M L KING BLVD |
| Y |  | Tree canopy and habitat on roof – Less than 10 stories | Field Office<br>2015 238635 000 00 LU<br>2016 107451 000 00 CO<br>2016 172958 000 00 LU (revision) | 2030 NW 17TH AVE |



57929

**The Pacific Flyway:**

- More than 1 billion birds traverse the Pacific Flyway annually;
-

**From PP&R, BES , 2011 "Portland, Oregon's Bird Agenda"**

In May 2003, Portland City Commissioner Jim Francesconi and Dave Allen, Regional Director of the U.S. Fish and Wildlife Service, signed the Urban Conservation Treaty for Migratory Birds as part of the International Migratory Bird Treaty festivities, and 21 organizations signed on as Treaty partners. ***(Portland received a $50,000 USFS grant for participating…in 2011, a $10,000 renewal)***

In May 2006, City Mayor Tom Potter and Miel Corbett, Assistant State Supervisor with the Service renewed the Treaty commitment and ten new organizations signed on as partners.

*Convinced of the urgency of taking appropriate measures to protect and promote Migratory birds, on this day of May 13, 2006, the U.S. Fish and Wildlife Service and the City of Portland reaffirm their Urban Conservation Treaty for Migratory Birds and acknowledge the importance of local efforts and partnerships to achieve migratory bird conservation throughout the greater Portland metropolitan region.*
**~ Excerpt from the 2006 signed Treaty reaffirmation**

Between 2003 and 2006, 31 other agencies and organizations in the Portland metropolitan area signed on as partners.

**<u>Actions under the UCTMB:</u>**

- Many of these actions have been conducted as part of the Portland Watershed Management Plan (PWMP) implementation, and specifically as part of the Terrestrial Ecology Enhancement Strategy (TEES), which is part of the PWMP
- Applied for, and was awarded, a grant from the USFWS to convene a working group and summit of architects, developers, representatives from other cities to help guide the development of Bird-Friendly Building Guidelines and to raise awareness about the risks associated with residential windows through demonstration projects, interpretive signage and brochures about birds and windows
- Held annual Migratory Bird Day Festivals to celebrate migratory birds and raise public awareness about the plight of migratory birds

**<u>Facts about birds & bird deaths in PDX:</u>**

In the Portland, Oregon – Vancouver, Washington region, over 209 species of birds are regularly observed and recorded…Of the birds known to occur in the Portland region, 23 are migratory species that have been designated with some type of state or federal status for being at-risk due to population declines and on-going threats. …Many of the migratory birds found in Portland show declining population trends based on 40 years of Breeding Bird Surveys and Christmas Bird Count data.

In the U.S. alone, it is estimated that 100 million to 1 billion birds die every year after colliding with windows—a mortality rate second only to habitat destruction

Surveys coordinated by Audubon Society of Portland have evaluated window collisions since fall 2009. While these surveys represent a small sampling effort, the data indicates that window glass undoubtedly poses a hazard to our urban bird populations. Downtown surveys catalogued a diverse array of native warblers, hummingbirds, flycatchers, and sparrows that fatally collided with buildings, 36 species to date

**Bird Safe Glazing Research Direction: October 2016**

I. Review articles/research on highly reflective glass and its relationship to bird strikes.

II. Research appropriate reflectivity range / Where should we set the bar?
   a. Look at how other cities have addressed this issue, especially cities that already have bird safe ordinances on the books. i.e. San Francisco, Toronto
      i. Toronto's Green Standard specifies reflective or low e coatings that have an outside reflectance of 15% or less. For example, Spandrel glass with reflective or low e coating that have an outside reflective of greater than 15% should be used in combination with other strategies.
   b. Review City of Portland Building Code and see what is currently permitted.

III. Research appropriate glazing threshold for when standards should be triggered.
   a. Create a matrix showing the glazing % where bird safe standard applies for other cities, counties, states.
      i. Cities of San Francisco, Toronto, Oakland, State of Minnesota E3 Facilities, Cook County Ill, and any others you can find.
   b. Review plan documents via TRACS for the Central City projects to be identified by Marc, Derek, Troy, and Rachael. At a later stage, we may want to look at all new CC2035 development over the past 5-7 years to gage how much exterior glazing is being applied.

IV. Standards
   a. Investigate status of ASTM (American Society for Testing Materials) bird collision deterrence factor which is currently under development.
   b. Investigate whether or not US Green Building Council's pilot credit for bird friendly glazing is going to become a permanent credit.

Later: Provide more information regarding the industry's glazing reflectivity measurements / visible light reflectance value.

   a. How does the exterior reflectance value sync up with other sustainability objectives like energy efficiency? For Example, the memo from Prendergast Laurel provided by City of SF states that most energy coated glazing choices fall under 10% VLR.

Marc:

I. Continue additive cost research
   a. Get a better understanding of the cost range per sq.ft. for all allowed treatments.
   b. Put a focus on list of available vendors and average costs per sq.ft. for ground floor more transparent treatments i.e. UV Glazing, Acid Etch Glass, Ceramic Frit.
   c. Provide case studies with cost analysis for recent development
   d. Market capacity for this level of uptake of bird friendly glazing? Mark R says not likely to be a problem.

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# Annual energy window performance vs. glazing thermal emittance — the relevance of very low emittance values

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**Abstract**

This paper investigates the heating and cooling energy impact of low thermal emittance values for architectural glazings. The importance of low emittance values and the sensitivity for small changes in the emittance is investigated for three very different climates and for two different types of buildings. Our results imply that minor changes in the parameter values lead to very small changes in the energy performance and are mostly insignificant for the end user. Furthermore, the relative importance of the solar transmitting properties is recognized. For instance, if the thermal emittance is reduced by 2–3% and at the same time the total solar energy transmittance is also reduced by 2–3%, the energy performance of the window is worse if it is used in a south facing position in a residential building in a heating dominated location (Stockholm). © 2001 Elsevier Science B.V. All rights reserved.

*Keywords:* Coatings; Glazings; Thermal emittance; Energy

## 1. Introduction

After the introduction of the low emittance (low-e) windows in the early 1980s [1] the glazing market has gone through a radical change. In some countries it is already standard to install coated windows, either low-e for a reduced heating bill, solar control windows for a reduced cooling bill or a combination thereof. The energy saving potentials are considerable either way, and virtually always accompanied by significant comfort improvements. The, now very mature, technology to apply durable thin films on large area glazings has opened many new possibilities for architects but also introduced a new kind of competition between glazing manufacturers. From a customers point of view this new situation has also made it extremely difficult to interpret the different window properties, such as thermal emittance ($\varepsilon_{th}$), total solar energy transmittance, visual transmittance and to understand what these properties really mean in terms of energy, visual or comfort performance. Especially in heating dominated (cold) regions it has been common to use the glazing *U*-value as the only measure of how energy efficient the window will be. One reason for this is probably the fact that it is reasonably simple to convert a *U*-value to an energy performance value, which means that it is possible to compare the thermal leakage of windows on a kWh/m$^2$ per year level. Such an energy measure can easily be interpreted in economical terms for the house owner or be accumulated to assess energy saving potentials on a national level. The problem with this approach is that it is not only the *U*-value that determines the energy performance of a window, but also the solar and visual transmittance. Considering only the thermal performance induces errors in such window energy performance assessments, and if this is the only way of comparing the windows, manufacturers may be tempted to reduce the *U*-value at the expense of transmittance factors and thus produce windows with impaired energy performance. From a commercial point of view it seems as if the thermal emittance of

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the low-e coating is used as a measure of competition between companies. The thermal emittance, however, is at a more detailed level than the *U*-value and thus gives even less information for the customer. The thermal emittance of uncoated glass is approximately 84%, which by the first available coatings could be reduced to approximately 15% (doped tin oxide). Thus, a radical improvement in energy performance was achieved, considering that most of the heat leakage through the uncoated window consists of thermal radiation. By the introduction of the dielectric–metal–dielectric coatings it was possible to reduce the emittance to below 10% and with state of the art technology it is now possible to achieve a thermal emittance even below 5%. The potential of improvements in the thermal emittance is approaching its limits. The thermal hemispherical emittance is usually obtained from measurements of the near normal reflectance ($R$) in the wavelength range 3–45 μm. The limited accuracy of commercial reflectance accessories makes it hard to obtain emittance values with an accuracy of better than $\pm 1$ percentage point. The emittance is obtained as $\varepsilon_{th} = 1 - R$ and an error of 1% at $R = 0.95 \pm 0.01$ becomes an error of 20% in the emittance value $\varepsilon_{th} = 0.05 \pm 0.01$. In order to achieve an emittance value with a two-digit precision, the reflectance must be measured with an accuracy of 0.1%. Furthermore, the *U*-value for the whole window can normally only be measured within an accuracy of approximately 6% [2]. For the customer it may be questionable if a window with 3% thermal emittance has a noticeably better energy performance than a window with 4% thermal emittance. Furthermore, a race to obtain coatings with very low emittance may reduce the performance of the glazing by other means, such as reduced solar or visual transmittance. In this paper we assess how small variations in thermal emittance affect the energy performance of windows and to which extent it is relevant from an energy point of view to claim that the best window is the window that has the lowest thermal emittance.

## 2. Glazing performance vs. thermal emittance

According to the standard EN 673 the center of glass *U*-value of a double glazed unit (DGU) depends on the emittance of the third surface (counted from the outside) as in Fig. 1 [3]. It is seen that the glazing *U*-value is drastically reduced by the use of low emittance coatings.

The reduction of the heat loss through the window leads to an improvement of the energy performance of the window and it also increases the comfort close to the window. However, how much the window improves the energy performance depends not only on the properties of the window but also strongly on in which type of building and climate it is used. In Fig. 2 the energy performance [4] of an argon filled DGU is plotted vs. the emittance of the third surface for two different types of buildings, one residential and one commercial with a high internal load, in three very different climates. In order to study only the effect of the reduced thermal emittance via the *U*-value, the total solar energy transmittance, the *g*-value, is kept constant at 50% in all cases. On the *y*-axis the total amount of saved energy compared to an uncoated argon filled DGU, heating plus cooling is given, and on the *x*-axis the emittance of the third surface is varied from 1 to 84%. It is seen that in most cases the lower the emittance value is, the higher is the saved energy per square meter glazed area. The highest saving is obtained in the heating dominated climate of Stockholm and in a residential building. This is because in a cold climate the heat losses through the envelope are high and in a residential building there is less free

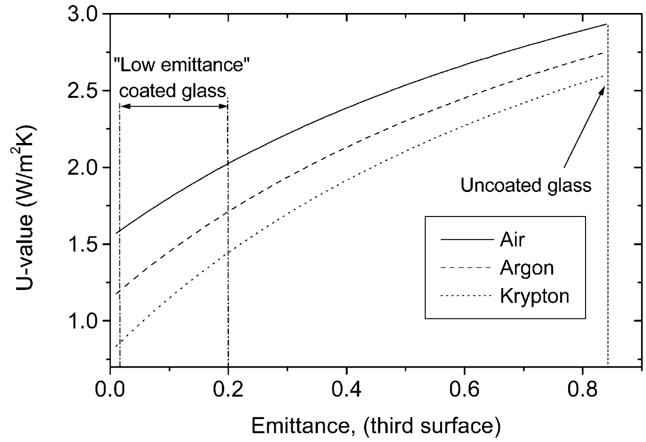


Fig. 1. *U*-value calculated according to EN 673 vs. emittance for the third surface (counted from the outside) and for different gas fill. Low emittance glazings have emittance values below 20% and uncoated glass has approximately 84%.

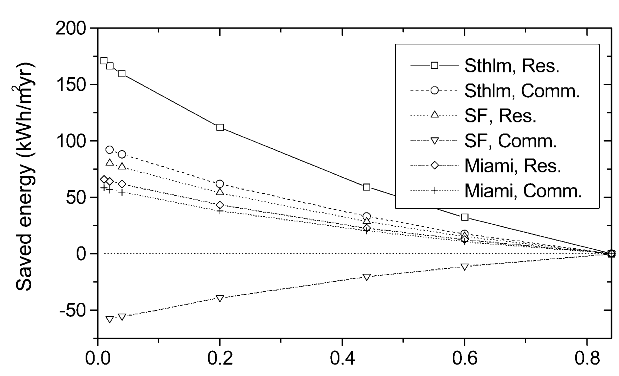


Fig. 2. Total saved energy, heating plus cooling, per square meter glazed area vs. emittance of the third surface for an argon filled double glazed unit. The curves represent results from two different types of buildings, one residential (Res.) and one commercial (Comm.), in three very different climates: Stockholm (Sthlm), San Francisco (SF) and Miami.

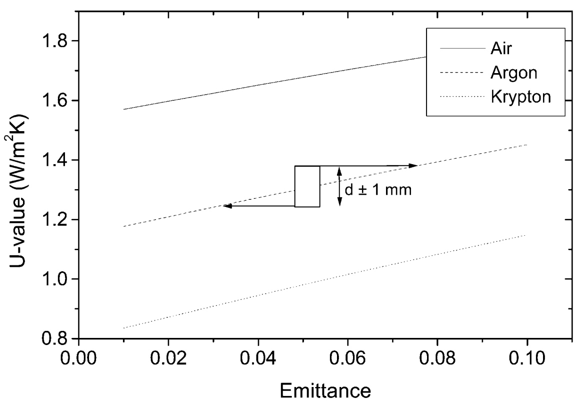


Fig. 3. $U$-value for low-e windows ($\varepsilon_{th} < 10\%$) calculated according to EN 673 vs. emittance for the third surface and for different gas fill. The shaded box indicates the difference in $U$-value if glazing distance is changed by $\pm 1$ mm for an argon filled DGU with $\varepsilon_{th} = 5\%$.

available heat than in a commercial building. The unexpected result for the commercial building in the San Francisco climate ('SF, Comm.' in Fig. 2) is explained by the fact that this climate often has outdoor temperatures in the order of some degrees below (approx. 16°C) the indoor temperature set point (20°C in this case). Furthermore, in the simulation the windows were closed all the time, which means that the internal heat of the commercial building became more trapped for windows with low $U$-values than for windows with higher $U$-values. In the extreme Miami climate the outdoor temperatures are almost always above the indoor temperature set points, which in turn means that the closed windows with low $U$-values prevent the heat from going into the building. In the San Francisco and especially in the Miami climate a reduced $g$-value is of much greater importance than a reduced $U$-value [4].

These results illustrate that in the best case the low emittance coating can achieve large savings up to, the order of approximately 150 kWh/m$^2$ glazed area per year. The thin film technology has reached high maturity and glazings having thermal emittance well below 10% are today produced on a regular basis. Such high-performing low-e windows provide a cost-effective way of reducing the energy use for buildings in most cases [5].

In Fig. 3 the same curves as in Fig. 1 are plotted but enlarged for the low thermal emittance region (0–10%). It is seen that according to the EN 673 standard the $U$-value depends almost linearly with the emittance with a change of approximately 0.1 W/m$^2$K for a change of 3% in the emittance. For comparison, the shaded box in Fig. 3 indicates the difference in $U$-value that would have been obtained by a change of the glazing distance by $\pm 1$ mm in an argon filled DGU with $\varepsilon_{th} = 5\%$ (third surface). Such a change affects the $U$-value equally as much as a change in emittance of approximately $\pm 2$ percentage points.

Fig. 2 illustrates that the most important case for low emittance glazings are for residential buildings in heating dominated climates. In Fig. 4 the same figure is plotted for low emittance values for a residential building in Stockholm. The saved energy refers to the saved energy compared to an argon filled DGU with a thermal emittance of 10%. The $g$-value is also varied in order to see the impact of a lowered $g$-value when the emittance is lowered. It is seen that when the $g$-value is kept constant a 2% change in emittance will at best save approximately 6 kWh/m$^2$ per year. If the $g$-value is lowered by 2% for a corresponding 2% reduction in the thermal emittance, the saving will be reduced to approximately 3 kWh/m$^2$ per year for a north facing window and the saving for a south facing window becomes a loss because of decreased useful solar throughput.

These results are confirmed by simulations on several 'real' windows as seen in Fig. 5 in which a triple glazed window with two tin oxide coatings and gas fill was the best alternative for a residential building in Stockholm, except for the north facing window. A tin oxide coating has a thermal emittance of approximately 15% but still it performed better under the given circumstances than its lower (less than half) emitting counterparts because of its higher $g$-value.

## 3. Conclusions

The thermal emittance by itself is not a sufficient parameter to judge whether the window will be energy efficient or not. Small reductions of the thermal emittance do not necessarily mean that the window performs better or worse from an energy point of view. This depends on many other parameters, such as the solar and visual transmittance, glazing distance, type of gas fill, etc. Furthermore, the energy performance of

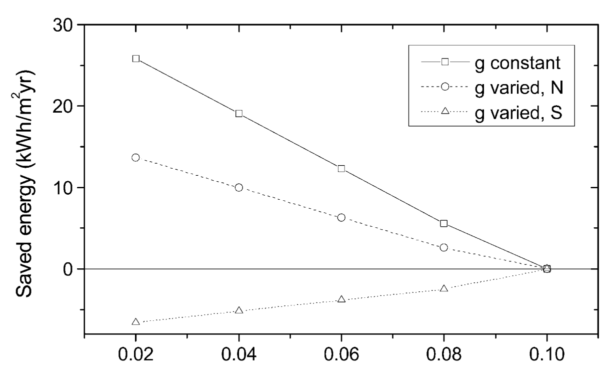


Fig. 4. Total saved energy, heating plus cooling, per square meter glazed area vs. emittance of the third surface for an argon filled double glazed unit in a residential building in Stockholm. The total solar energy transmittance ($g$) is kept constant and varied for a north (N) and south (S) facing window, respectively.

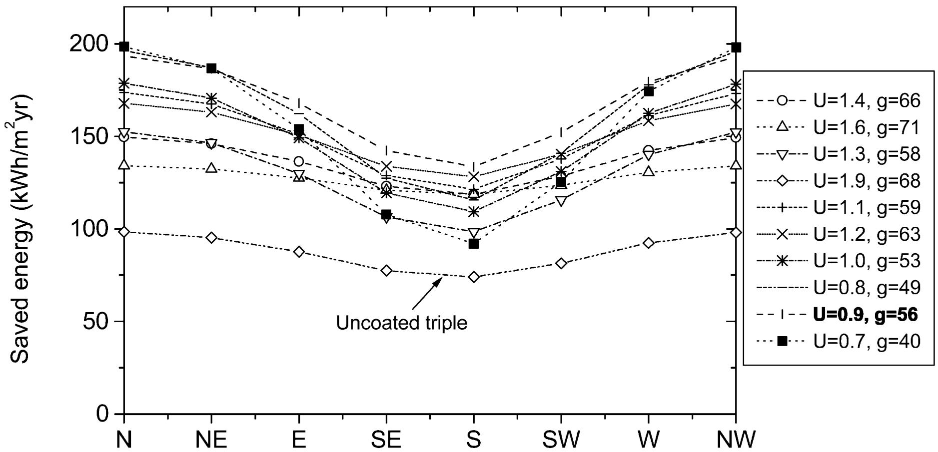


Fig. 5. Saved energy (heating plus cooling) for different low-e windows in a residential building in Stockholm. The *y*-axis gives saved kWh/m$^2$ per year compared an uncoated DGU. The 'best' alternative is a triple glazed alternative with gas fill and two low-emitting tin oxide coated glazings (bold text in legend).

the window depends highly on where the window is used, such as in which type of building, orientation and climate. In a heating dominated climate it is only relevant to strive for very low emittance values if the other important parameters, the *g*-value and the visual transmittance can be kept high. In cooling dominated climates or in commercial buildings with a high cooling need the relevance of the thermal emittance is inferior to the relevance of the solar transmittance. The energy saving caused by a reduction of the thermal emittance from approximately 0.06 to 0.04 is, at the most, of the order of a few kWh/m$^2$ of glazing per year. For the customer this is worth much less than 1 euro (or 1 US$)/m$^2$ glazed area per year. This is small compared to the saving that is obtained by reducing the emittance from 0.84 (uncoated) to approximately 0.1 and also small compared to the variation caused by climate variations from 1 year to another. In Fig. 5 the hard-coated (doped tin oxide) windows were a little better than the soft-coated windows (oxide/silver/oxide) but if, for instance, some external shading were applied, the importance of the *g*-value would be reduced and perhaps the soft-coated low-e would be the better one. This clearly illustrates that it is important to use low-e windows in cold climates but that small differences in the emittance value are irrelevant for the energy balance of the window. A 'window consumer', such as an architect or a builder, has no specific use of knowing the thermal emittance value in itself. Values of importance for energy performance are the *U*-value, the *g*-value and the visual transmittance. In a pre-design stage these values can be inserted in simplified window energy rating tools [2,4,6–9] in order to assess the 'actual' energy performance and economical impact of the window. It is important to introduce low-e glazings on the market in order to save energy, but it is also important to recognize the limitations (partly due to limited measurement accuracy) of the emittance value itself as a measure of the quality or of the performance of a window.

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# Bird–building collisions in the United States: Estimates of annual mortality and species vulnerability

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RESEARCH ARTICLE

# Bird–building collisions in the United States: Estimates of annual mortality and species vulnerability

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## ABSTRACT

Building collisions, and particularly collisions with windows, are a major anthropogenic threat to birds, with rough estimates of between 100 million and 1 billion birds killed annually in the United States. However, no current U.S. estimates are based on systematic analysis of multiple data sources. We reviewed the published literature and acquired unpublished datasets to systematically quantify bird–building collision mortality and species-specific vulnerability. Based on 23 studies, we estimate that between 365 and 988 million birds (median = 599 million) are killed annually by building collisions in the U.S., with roughly 56% of mortality at low-rises, 44% at residences, and <1% at high-rises. Based on >92,000 fatality records, and after controlling for population abundance and range overlap with study sites, we identified several species that are disproportionately vulnerable to collisions at all building types. In addition, several species listed as national Birds of Conservation Concern due to their declining populations were identified to be highly vulnerable to building collisions, including Golden-winged Warbler (*Vermivora chrysoptera*), Painted Bunting (*Passerina ciris*), Canada Warbler (*Cardellina canadensis*), Wood Thrush (*Hylocichla mustelina)*, Kentucky Warbler (*Geothlypis formosa)*, and Worm-eating Warbler (*Helmitheros vermivorum)*. The identification of these five migratory species with geographic ranges limited to eastern and central North America reflects seasonal and regional biases in the currently available building-collision data. Most sampling has occurred during migration and in the eastern U.S. Further research across seasons and in underrepresented regions is needed to reduce this bias. Nonetheless, we provide quantitative evidence to support the conclusion that building collisions are second only to feral and free-ranging pet cats, which are estimated to kill roughly four times as many birds each year, as the largest source of direct human-caused mortality for U.S. birds.

*Keywords:* anthropogenic mortality, Birds of Conservation Concern, individual residence, low-rise, high-rise, systematic review, window collision

### Colisiones entre aves y edificios en los Estados Unidos: Estimaciones de mortalidad anual y vulnerabilidad de especies

## RESUMEN

Colisones con edificios, en particular contra ventanas, presentan una amenaza antropogénica importante para las aves, y se estima que causan la muerte de entre 100 millón a mil millones de aves anualmente. Sin embargo, no existen estimaciones para los Estados Unidos que estén basadas en un análisis sistemático de datos provenientes de multiples fuentes. Revisamos datos publicados y tambien adquirimos bases de datos inéditos para cuantificar de una manera sistemática la mortalidad causada por colisones entre aves y edificios, y la vulnerabilidad de diferentes especies. Basado en 23 estudios, estimamos que entre 365 y 988 millones de aves (promedio = 599 millones) mueren anualmente como consecuencia de colisiones con edificios en los Estados Unidos, con aproximadamente 56% de la mortalidad en edificios de baja altura, 44% en residencias, y <1% en edificios de muchos pisos. Basado en >92,000 fatalidades registradas, y luego do controlar por abundancia poblacional y solapamiento de rango con area de estudio, identificamos varias especies que son desproporcionalmente vulnerables a colisiones con todos los tipos de edificio. Además, varias especies listadas nacionalmente como Aves de Interés para la Conservación debido a sus poblaciones en declive fueron identificadas como altamente vulnerables a colisiones, incluyendo *Vermivora chrysoptera*, *Passerina ciris*, *Cardellina canadensis*, *Hylocichla mustelina*, *Geothlypis formosa*, y *Helmitheros vermivorum*. La identificación de estas cinco especies migratorias con rangos geográficos restringidos a Norteamérica oriental y central refleja sesgos estacionales y regionales en la disponibilidad de datos actuales disponibles de colisiones con edificios. La mayoría del muestreo ha ocurrido durante la época de migración y en el este de los Estados Unidos. Hacen falta investigaciones adicionales a través de estaciones y en regiones poco representadas par reducir este sesgo. Sin embargo, presentamos



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evidencia cuantitativa que apoya la conclusión que, como causa de mortalidad ligada derectamente a los humanos en los Estados Unidos, las colisiones con edificios son superados solamente por los gatos mascotas libres, los cuales matan aproximadamente cuatro veces la cantidad de aves anualmente.

*Palabras clave:* mortalidad antropogénica, Aves de Interés para la Conservación, residencia particular, edificio de baja altura, edificio de muchos pisos, revisión sistemática, colisión con ventana

## INTRODUCTION

Collisions between birds and man-made structures, including communication towers, wind turbines, power lines, and buildings, collectively result in a tremendous amount of bird mortality. Buildings are a globally ubiquitous obstacle to avian flight, and collisions with buildings, especially their glass windows (Figure 1), are thought to be a major anthropogenic threat to North American birds (Klem 1990a, 2009, Machtans et al. 2013). Estimates of annual mortality from building collisions range from 100 million to 1 billion birds in the United States (Klem 1990a, Dunn 1993) and from 16 to 42 million birds in Canada (Machtans et al. 2013). This magnitude of mortality would place buildings behind only free-ranging domestic cats among sources of direct human-caused mortality of birds (Blancher 2013, Loss et al. 2013).

Research on bird–building collisions typically occurs at individual sites with little synthesis of data across studies. Conclusions about correlates of mortality and the total magnitude of mortality caused by collisions are therefore spatially limited. Within studies, mortality rates have been found to increase with the percentage and surface area of buildings covered by glass (Collins and Horn 2008, Hager et al. 2008, 2013, Klem et al. 2009, Borden et al. 2010), the presence and height of vegetation (Klem et al. 2009, Borden et al. 2010), and the amount of light emitted from windows (Evans Ogden 2002, Zink and Eckles 2010). In the most extensive building-collision study to date, per-building mortality rates at individual residences were higher in rural than urban areas and at residences with bird feeders than those without feeders (Bayne et al. 2012). However, compared with larger buildings in urban areas (e.g., skyscrapers and low-rise buildings on office and university campuses), detached residences appear to cause lower overall mortality rates and relatively high amounts of mortality during non-migratory periods (Klem 1989, Dunn 1993, O'Connell 2001, Klem et al. 2009, Borden et al. 2010, Machtans et al. 2013).

**FIGURE 1.** A Swainson's Thrush killed by colliding with the window of a low-rise office building on the Cleveland State University campus in downtown Cleveland, Ohio. Photo credit: Scott Loss

Despite the apparently large magnitude of bird–building collision mortality and the associated conservation threat posed to bird populations, there currently exist no U.S. estimates of building-collision mortality that are based on systematic analysis of multiple data sources. The most widely cited estimate (100 million to 1 billion fatalities per year) was first presented as a rough figure along with qualifications (Klem 1990a) but is now often cited as fact (Best 2008). Assessment of species-specific vulnerability to collisions is also critical for setting conservation priorities and understanding population impacts; however, existing estimates of species vulnerability are limited in spatial scope. In the most systematic U.S. assessment of building collisions to date, species vulnerability was calculated using data from only three sites in eastern North America, but vulnerability values from this limited sample were used to conclude that building collisions have no impact on bird populations continent-wide (Arnold and Zink 2011, but see Schaub et al. 2011, Klem et al. 2012).

We reviewed the published literature on bird–building collisions and also accessed numerous unpublished datasets from North American building-collision monitoring programs. We extracted >92,000 fatality records—by far the largest building collision dataset collected to date—and (1) systematically quantified total bird collision mortality along with uncertainty estimates by combining probability distributions of mortality rates with estimates of numbers of U.S. buildings and carcass-detection and scavenger-removal rates; (2) generated estimates of mortality for different classes of buildings (including residences 1–3 stories tall, low-rise non-residential buildings and residential buildings 4–11 stories tall, and high-rise buildings $\geq$12 stories tall); (3) conducted sensitivity analyses to identify which model parameters contributed the greatest uncertainty to our estimates; and (4) quantified species-specific vulnerability to collisions across all buildings and for each building type.

## METHODS

### Literature Search

We searched Google Scholar and the Web of Science database (using the Web of Knowledge search engine) to locate peer-reviewed publications about bird–building collisions. We used the search terms "bird window collision" and "bird building collision" and both terms with "bird" replaced by "avian." We checked reference lists and an annotated bibliography (Seewagen and Sheppard 2012) to identify additional studies. Data from collision-monitoring programs were located using a Google search with the term "window collision monitoring program" and by contacting program coordinators listed on project websites. We cross-checked the datasets we found with a comprehensive list of "Lights Out" programs provided by C. Sheppard. Additional unpublished datasets were located based on our knowledge of ongoing studies presented at professional conferences or in published abstracts. Finally, we learned of unpublished datasets when contacting first authors of published studies; these additional datasets were either more extensive versions of authors' published datasets, completely new datasets, or in one case, a dataset from an independent citizen scientist.

### Inclusion Criteria and Definition of Fatality

Different studies employed different sampling designs and data collection protocols. To reduce this variability, to ensure a baseline for the rigor of studies we used, and to minimize bias in our analyses, we implemented inclusion criteria to filter data at both the study and record levels. Inclusion criteria were different for the analyses of total mortality and species vulnerability. As a first step, we only included studies for in-depth review if they were conducted in the U.S. or Canada and provided original data on bird–building collisions. We implemented study-level inclusion criteria for the estimate of total mortality as follows. We excluded studies that were based on sampling at a single structure; these studies often focus only on unique building types with non-representative mortality rates (e.g., museums, convention centers, or exceptionally tall high-rises). We included datasets that were based on systematic carcass surveys or systematic surveys of home-owners, but we excluded those that were based on sampling in response to predicted building kills, incidental observations, opportunistically sampled collections, or undocumented methods. Because estimating per-building mortality rates was a major component of the mortality estimate, we also excluded studies if they did not record numbers of buildings monitored or provide street addresses of buildings that would have allowed us to estimate numbers of buildings.

Because the species vulnerability analysis was based on count proportions rather than on per-building mortality rates, we implemented a different set of inclusion criteria than that used for the total mortality estimate. This resulted in the use of some studies that were excluded from the total mortality estimate. Studies were only included in the species analysis if they identified carcasses to species. We excluded studies documenting fewer than 100 collision records because proportions based on small samples are more likely to be abnormally high or low. As with the total mortality estimate, we excluded data that were based on incidental or opportunistic sampling or undocumented methods. However, we did include studies even if data were based on sampling of a single structure or if we could not determine the number of buildings sampled. Thus, we assume that species composition within a site is independent of the number of buildings sampled. The study-level inclusion criteria resulted in 23 and 26 datasets used for the total mortality and species vulnerability estimates, respectively (Table 1). Seven studies were excluded from all analyses (Table S1 in Supplemental Material Appendix A).

Many datasets include some collision records that were collected during standardized surveys and others found incidentally. In addition, definitions of fatalities differ among studies. We therefore applied inclusion criteria to filter individual records and set our own definition of what constitutes a fatality. The record-level inclusion criteria were the same for all of our analyses. We excluded records clearly denoted as incidental finds (i.e. not collected during surveys), records with a disposition of "alive" or "survived," and records of released birds. We also excluded records of blood and/or feather spots on windows with no carcass found. From the remaining records, we defined fatalities to include any record with a disposition including "dead," "collected," or any disposition indicating severe injury (e.g., "disabled," "squashed," "fracture," or "injured"). All other records were considered to have unknown disposition (e.g., "stunned," "exhausted," "weak," "dis-oriented," or any disposition indicating a bird was sent to rehabilitation) and were excluded from all analyses. The record-level criteria resulted in 92,869 records that we used to generate total mortality and species vulnerability estimates. It was not possible to confirm whether fatalities were caused by collisions with windows or with other non-reflective portions of buildings; therefore, for the purposes of this study, we treated all records as building–collision fatalities. Nonetheless, the majority of bird mortality at buildings likely occurs due to collision with windows or other reflective surfaces (Klem 2009).

**TABLE 1.** Sampling coverage, number of buildings sampled, and mortality rates documented in studies meeting inclusion criteria for estimation of total annual U.S. mortality from bird–building collisions and/or calculation of species-specific collision vulnerability.

| Building class | Location | Year-round sampling? | Used for mortality estimate? | Used for vulnerability analysis? | Buildings sampled | Mortality per building: Average | Mortality per building: Range | Study |
|---|---|---|---|---|---|---|---|---|
| Residences (1–3 stories) | Alberta | Yes | Yes | No[c] | 1,747 | 0.7 | 0–43 | Bayne et al. 2012 |
| | U.S. & Canada | No | Yes | Yes | 1,165 | 0.85 | 0–21 | Dunn 1993 |
| | Duluth, MN | No | Yes | Yes | 42 | 2.3[f] | ? | Bracey 2011 |
| | Illinois | Yes | Yes | No[c] | 242 | 1.5 | ? | Weiss & Horn 2008 |
| | Carbondale, IL | Yes | No[a] | Yes[h] | 1 | 33.0 | NA | Klem 1979 |
| | Purchase, NY | Yes | No[a] | Yes[h] | 1 | 26.0 | NA | Klem 1979 |
| Low-rises | Richmond, VA | Yes | Yes | Yes | 4 | 29.0 | 21–38 | O'Connell 2001 |
| | Cleveland, OH | Yes | Yes | Yes | 18 | 15.1 | ? | Borden et al. 2010 |
| | Elsah, IL | Yes | Yes | Yes | 4 | 24.0 | ? | Hager et al. 2008 |
| | Decatur, IL | Yes | Yes | Yes | 11 | 7.5[f] | ? | Collins & Horn 2008 |
| | Washington, DC | No | Yes | Yes | 21–38[e] | 4.0 | 1–30 | Lights Out DC 2010–2012 |
| | Rock Island, IL | No | Yes | No[d] | 20 | 2.6 | 0.3–52.1 | Hager et al. 2013 |
| | Decatur, IL | No | Yes | No[d] | 11 | 4.8 | ? | Horn personal communication |
| | Murray, KY | No | Yes | No[d] | 13 | 1.6 | 0–7 | Somerlot 2003 |
| | Stillwater, OK | Yes | No[a] | Yes | 1 | 32.0 | NA | O'Connell personal communication |
| | Rock Island, IL | Yes | No[a] | Yes | 1 | 54.8 | NA | Hager et al. 2008 |
| | Chicago, IL | No | No[a] | Yes | 1 | 1,028.0[g] | NA | McCormick Place 1978–2012 |
| | Rochester, MN | No | No[b] | Yes | ? | ? | ? | Project Birdsafe Minnesota 2010–2011 |
| | San Francisco, CA | Yes | No[a] | Yes | 1 | 47.2[g] | NA | California Academy of Sciences 2008–2012 |
| High-rises | Indianapolis, IN | No | Yes | Yes | 48 | 3.3 | 1–14 | Lights Out Indy 2009–2010 |
| | Atlanta, GA | No | Yes | Yes | 53 | 8.4 | 0–40 | Sexton 2006 |
| | Calgary, AB | No | Yes | Yes | 15–36 | 5.5[g] | 1–89 | Collister et al. 1996, 1997, Booth & Collister 1998 |
| | Baltimore, MD | No | Yes | Yes | 16–48[e] | 7.1[g] | 1–81 | Lights Out Baltimore 2008–2012 |
| | Twin Cities, MN | No | Yes | Yes | 118 | 3.0[g] | ? | Project Birdsafe Minnesota 2007–2012 |
| | New York, NY | No | Yes | Yes | 17–31[e] | 5.5[g] | 1–52 | Project Safe Flight New York 2009–2011 |
| | Philadelphia, PA | No | Yes | Yes | 10 | 13.2[g] | ? | Pennsylvania Audubon 2008–2011 |
| | Columbus, OH | No | Yes | No[d] | 20[e] | 1.4 | 0–5 | Lights Out Columbus 2012 |
| | Portland, OR | No | Yes | No[d] | 21–44 | 1.0[g] | ? | Bird Safe Portland 2009–2011 |
| | Toronto, ON | No | Yes | Yes | 74–194[e] | 17.4[g] | 1–535 | Fatal Light Awareness Program 2000–2010 |
| | Winston-Salem, NC | No | Yes | Yes | 16 | 3.6[g] | 0–10 | Lights Out Winston-Salem 2011–2012 |
| | Toronto, ON | No | No[a] | Yes | 1 | 157.0 | NA | Ranford & Mason 1969 |
| | Chicago, IL | No | No[b] | Yes | ? | ? | ? | Chicago Bird Collision Monitors 2002–2012 |
| | Milwaukee, WI | No | No[b] | Yes | ? | ? | ? | Wisconsin Night Guardians 2007–2011 |
| | Toronto, ON | No | No[b] | Yes | ? | ? | ? | Fatal Light Awareness Prog. 2007, 2011 |
| | New York, NY | No | No[b] | Yes | ? | ? | ? | Klem 2009 |

[a] Study excluded from total mortality estimate because sampling conducted at a single building.
[b] Study excluded from total mortality estimate because number of buildings sampled not recorded and no information provided to calculate this number.
[c] Study excluded from species estimates because species data not provided.
[d] Study excluded from species estimates because sample size <100.
[e] Number of buildings is an estimate based on the average of potential minimum and maximum (see text); range indicates year-to-year variation in number of buildings sampled.
[f] Mortality rate is corrected for scavenger removal and searcher detection rates.
[g] Mortality rate is an average per-building rate across all years of the study/monitoring program.
[h] Study used for species risk assessment for building class but not assessment across all building classes (sample size <100).

**Data Extraction**

We classified studies into three building classes thought to cause different mortality rates (Machtans et al. 2013) and for which data on the number of U.S. buildings is available. These classes include residences 1–3 stories tall (detached houses and multi-unit residences; hereafter, "residences"), low-rise non-residential buildings and residential buildings 4–11 stories tall (hereafter, "low-rises"), and high-rise buildings $\geq$12 stories tall (hereafter, "high-rises"). For unpublished data from downtown areas of major cities, we assumed that all data came from high-rises because it was not possible to determine building height without visiting each site. For all other data sources, we were able to confirm the building type from which data were collected. Published studies that met our inclusion criteria either reported an annual mortality rate per building (averaged across buildings) or presented both the number of dead birds found and the number of buildings sampled, thus allowing us to calculate this rate. For published studies, we extracted a single annual mortality rate for each study unless the study included data from more than one non-adjacent site, in which case we extracted a separate rate for each site (e.g., Klem 1979). For unpublished datasets that included the number of buildings sampled, we always extracted a single mortality rate. This value was generated by first calculating a single-year per-building mortality rate (averaged across buildings) for each year of the study and then averaging these rates across years. In some cases, we determined that two or more sources presented duplicate data when we observed that the data were collected at the same study sites and during the same range of dates. In these instances, we extracted the data from the source that provided more detailed methods or more extensive fatality data, and we excluded the duplicated data when extracting from the other source.

Data from collision-monitoring programs often include the street address or intersection where a carcass was found but not the number of buildings sampled. Single buildings can have more than one address, and a single address can include more than one building. In addition, some monitoring programs have no systematic protocol for recording addresses, resulting in multiple similar entries for an address (e.g., 1 Main, 1 Main St., and 1 Main—Smith Tower). To account for these issues, we entered addresses into Google Maps and used satellite view to determine if addresses referred to one or more buildings. If it was still unclear from mapping whether an address referred to one or more buildings, we assumed it referred to one. Likewise if we could not confirm that two or more similar addresses referred to one building, we assumed they were separate buildings. If addresses with different cardinal directions were possible (e.g., 1 Main E and 1 Main W), we assumed they referred to separate buildings, but if they were not possible (i.e. only 1 Main exists), we assumed data entry error and combined addresses.

Recognizing that these methods could not account for all duplicate addresses and data entry errors, we estimated a minimum and maximum number of buildings sampled in each year. We estimated a maximum number based on the number of unique addresses remaining after following the above steps and the assumption that intersections referred to a number of buildings equal to the number of carcasses found up to four (i.e. four or more carcasses may result from collision with four separate buildings, one at each intersection corner). We estimated a minimum number by combining similar addresses that may have been from one building, even if we could not confirm this with mapping, and assuming that all intersections referred to one building. We used the average of the minimum and maximum number to estimate per-building mortality rates.

**Quantification of Annual Mortality from Building Collisions**

The studies we used cover varying portions of the year, but most focus all or most of sampling effort on migration periods. Using raw per-building mortality rates would therefore result in a national estimate that is only relevant to spring and fall migration periods. We sought to account for partial-year sampling and to generate estimates that reflected the entire year, because several studies have indicated that building collision mortality can be substantial during summer and winter (Dunn 1993, Klem 2009, Bayne et al. 2012, Hager et al. 2013). Given enough year-round studies, partial-year mortality rates can be standardized to year-round estimates using year-round studies as a baseline (Longcore et al. 2012, Loss et al. 2013). However, there were few year-round studies that met inclusion criteria (Table 1), so we could not adjust individual studies to year-round estimates. Instead, we accounted for this limitation in our estimation model (details below) by only using a year-round study for residences, repeating estimation using a subset of studies that sampled year-round for low-rises, or incorporating a correction factor to account for mortality during periods other than migration for high-rises, a building type for which little data exists for summer and winter (see definition of and rationale for this correction factor in Supplemental Material Appendix B). Despite the limitation of applying a post hoc correction factor to the high-rise estimate, we argue that this approach is preferable to assuming that no mortality occurs during the summer and winter.

We estimated mortality in each building class by multiplying data-derived probability distributions of per-building mortality rates by distributions of numbers of buildings. For residences, we followed Machtans et al.

(2013), which based mortality rates on the only year-round building collision survey to date that sampled across a large number of residences, a study of 1,458 Alberta residents in single and multi-unit residences (Bayne et al. 2012). This study documented higher mortality rates at rural residences compared with urban residences and at residences with bird feeders compared with those without feeders. The study also documented increasing mortality with increasing age of urban residences. We incorporated these elements into our residence sub-model:

$$\mathrm{Mortality}_{\text{rural with feeder}}(M_{\mathrm{RF}}) = N_{\text{residence}} \times R \times F \times K_{\text{rural with feeder}} \times D_{\text{residence}} \tag{1}$$

$$\mathrm{Mortality}_{\text{rural no feeder}}(M_{\mathrm{RNF}}) = N_{\text{residence}} \times R \times (1-F) \times K_{\text{rural no feeder}} \times D_{\text{residence}} \tag{2}$$

$$\mathrm{Mortality}_{\text{urban with feeder}}(M_{\mathrm{UF}}) = N_{\text{residence(age)}} \times (1-R) \times F \times K_{\text{urban with feeder(age)}} \times D_{\text{residence}} \tag{3}$$

$$\mathrm{Mortality}_{\text{urban no feeder}}(M_{\mathrm{UNF}}) = N_{\text{residence(age)}} \times (1-R) \times (1-F) \times K_{\text{urban no feeder(age)}} \times D_{\text{residence}} \tag{4}$$

$$\mathrm{Mortality}_{\text{residences}}(M_{\mathrm{R}}) = M_{\mathrm{RF}} + M_{\mathrm{RNF}} + M_{\mathrm{UF}} + M_{\mathrm{UNF}} \tag{5}$$

where $N$ is the number of residences in the U.S., $R$ is the percentage of residences in rural areas, $F$ is the percentage of residences with bird feeders, $K$ is the annual per-building mortality rate, and $D$ is a correction factor to account for two biases that lead to underestimation of mortality (Hager et al. 2013): removal of carcasses by scavengers prior to fatality surveys and imperfect detection of the carcasses remaining at the time of surveys. For Equations (3) and (4), we calculated mortality by building age classes (0–8, 9–18, and 19–28 years, and all ages $\geq$29 years), and summed estimates across age classes. These age classes correspond closely to those in Machtans et al. (2013), but we shifted classes slightly (e.g., 9–18 years instead of 10–20 years) to match housing age data from the U.S. Census Bureau.

For low-rises, we generated two separate estimates of collision mortality, one using mortality rates based on all eight studies meeting our inclusion criteria and one based only on four year-round studies. We used the following sub-model for both estimates:

$$\mathrm{Mortality}_{\text{low-rise}}(M_{\mathrm{L}}) = N_{\text{low-rise}} \times K_{\text{low-rise}} \times D_{\text{low-rise}} \tag{6}$$

For high-rises, there are no datasets based on year-round systematic sampling. We incorporated a correction factor ($Y$) into the mortality estimation sub-model to account for additional fatalities occurring outside of migration periods:

$$\mathrm{Mortality}_{\text{high-rise}}(M_{\mathrm{H}}) = N_{\text{high-rise}} \times K_{\text{high-rise}} \times Y \times D_{\text{high-rise}} \tag{7}$$

We estimated total annual building collision mortality by summing estimates for individual building classes; we conducted estimation twice, once using each of the low-rise estimates:

$$\mathrm{Mortality}_{\text{total}} = M_{\mathrm{R}} + M_{L} + M_{\mathrm{H}} \tag{8}$$

All of the above parameters were treated as probability distributions. From the probability distribution of each parameter (see Table 2 for specific distributions, Supplemental Material Appendix B for rationale for all distributions, and Table S2 in Supplemental Material Appendix C for numbers of buildings), we randomly drew one value and used the above formulas. We used "runif" and "rnbinom" commands (for uniform and negative binomial distributions, respectively) in Program R and conducted 10,000 iterations to generate a range of estimate uncertainty.

### Sensitivity Analysis

We used multiple linear regression analyses assuming a normal error distribution (function "lm" in Program R) to investigate the percentage of uncertainty in mortality estimate ranges explained by each model parameter (Blancher 2013, Loss et al. 2013). We treated the 10,000 mortality-estimate replicates as the values of the dependent variable and randomly drawn values of each parameter as values of predictor variables. We used partial $R^2$ values to interpret the percentage of variance in the estimate range explained by each parameter. We repeated this regression analysis four times: once for the total mortality estimate (including all parameters) and once for each of the three building class estimates (with each regression model only including the parameters relevant to that building class).

### Quantification of Species Vulnerability

In addition to estimating total annual mortality, we calculated vulnerability for species and taxonomic groups. We followed Arnold and Zink (2011), who identified "super-collider" and "super-avoider" species using collision records from three unpublished datasets. We greatly expanded upon the earlier study by using 26 datasets from across North America (Table 1). All analyses described below were conducted across all datasets to estimate overall building collision vulnerability, as well as separately

**TABLE 2.** Probability distributions used to estimate total annual U.S. mortality from bird–building collisions. We defined uniform distributions for most parameters because not enough data exist to ascribe higher probability to particular values in the defined range. We defined negative binomial distributions for the low-rise and high-rise mortality rate distributions because they allowed the majority of probability density to match the confidence intervals indicated by the data while also allowing for a small probability of higher collision mortality rates, reflecting the exceptionally high mortality rates that have been documented at some low-rises and high-rises (see mortality rates in Table 1).

| Parameter | Distribution type | Distribution parameters | Source |
|---|---|---|---|
| Residences (1–3 stories) | | | |
| Number of residences | Uniform | Varies by age (Supplemental Material Appendix C) | U.S. Census Bureau 2011 |
| Percentage in urban areas | Uniform | Min = 72.6%; Max = 88.8% | U.S. Census Bureau 2012 |
| Percentage with bird feeders | Uniform | Min = 15%; Max = 25% | Dunn 1993 |
| Mortality rate | | | |
| Rural with feeders (all ages) | Uniform | Min = 2.17; Min = 4.03 | Bayne et al. 2012, Machtans et al. 2013 |
| Rural without feeders (all ages) | Uniform | Min = 0.98; Max = 1.82 | Bayne et al. 2012, Machtans et al. 2013 |
| Urban with feeders | | | |
| Age 0–8 | Uniform | Min = 0.28; Max = 0.52 | Bayne et al. 2012, Machtans et al. 2013 |
| Age 9–18 | Uniform | Min = 0.42; Max = 0.78 | Bayne et al. 2012, Machtans et al. 2013 |
| Age 19–28 | Uniform | Min = 0.56; Max = 1.04 | Bayne et al. 2012, Machtans et al. 2013 |
| Age 29+ | Uniform | Min = 0.63; Max = 1.17 | Bayne et al. 2012, Machtans et al. 2013 |
| Rural without feeders | | | |
| Age 0–8 | Uniform | Min = 0.11; Max = 0.20 | Bayne et al. 2012, Machtans et al. 2013 |
| Age 9–18 | Uniform | Min = 0.18; Max = 0.33 | Bayne et al. 2012, Machtans et al. 2013 |
| Age 19–28 | Uniform | Min = 0.25; Max = 0.46 | Bayne et al. 2012, Machtans et al. 2013 |
| Age 29+ | Uniform | Min = 0.28; Max = 0.52 | Bayne et al. 2012, Machtans et al. 2013 |
| Scavenging/detectability correction | Uniform | Min = 2; Max = 4 | Dunn 1993 |
| Low-rises | | | |
| Number of low-rises | Uniform | Min = 14.0 million; Max = 16.2 million | Multiple sources (see Supplemental Material Appendix C) |
| Mortality rate (all studies) | Neg. bin. | $n = 4.6$; $p = 0.35$ | 95% of distribution prob. density = 4–18[a] |
| Mortality rate (year-round studies) | Neg. bin. | $n = 5.1$; $p = 0.26$ | 95% of distribution prob. density = 5–28[b] |
| Scavenging/detectability correction | Uniform | Min = 1.28; Max = 2.56 | Hager et al. 2012, 2013 |
| High-rises | | | |
| Number of high-rises | Uniform | Min = 19,854; Max = 21,944 | Sky Scraper Source Media 2013 |
| Mortality rate | Neg. bin. | $n = 4.0$; $p = 0.37$ | 70% of distribution prob. density = 4–11[b] |
| Partial-year sampling correction | Uniform | Min = 1.05; Max = 1.20 | Additional 5–20% mortality outside of migration |
| Scavenging/detectability correction | Uniform | Min = 1.37; Max = 5.19 | Ward et al. 2006, Hager 2012, 2013 |

[a] Range represents 95% confidence interval of mortality rates calculated across all eight studies of low-rises meeting inclusion criteria.

[b] Range represents 95% confidence interval of mortality rates calculated from four year-round studies of low-rises meeting inclusion criteria.

[c] Range represents 95% confidence interval of mortality rates calculated from 11 studies of tall buildings meeting inclusion criteria.

for each building class to estimate class-specific vulnerability. As described previously, we only included datasets with more than 100 records for the overall vulnerability analysis. However, because there were only two datasets for residences that had more than 100 records, we also included two smaller datasets to calculate collision vulnerability for this building class.

Numbers of fatalities can vary among species due to population abundance and the degree of range overlap with study locations (Arnold and Zink 2011). To account for population abundance, we extracted national population size estimates from the Partners in Flight Population Estimates Database (Rich et al. 2004), which includes North American population estimates generated using U.S. Breeding Bird Survey data (Sauer et al. 2012). We used North American abundance rather than regional abundance because it is difficult to link study sites where mortality occurs to the affected regional subsets of bird populations, especially for species that are killed primarily during migration (Loss et al. 2012). To account for range overlap with study sites, we counted the number of sites overlapping with each species' breeding, wintering, and/or migration range (Sibley 2000). We followed Arnold and Zink's (2011) approach for calculating species vulnerability. To give each site equal weighting, we first standardized each dataset to 36,000, the largest single-site total

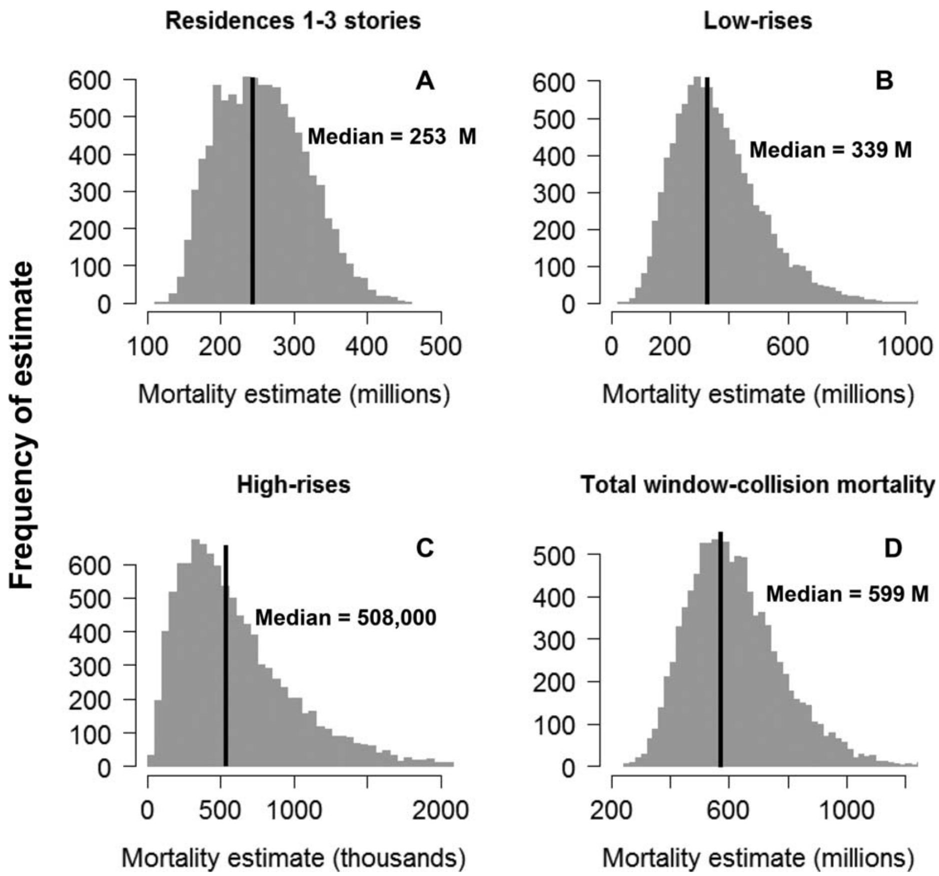


**FIGURE 2.** Frequency histograms for estimates of annual U.S. bird mortality caused by collisions with (**A**) residences 1–3 stories tall, (**B**) low-rises (residences 4–11 stories tall and all non-residential buildings $\leq$11 stories tall), (**C**) high-rises (all buildings $\geq$12 stories tall), and (**D**) all buildings. Estimates for low-rises and for all buildings are based on the average of two estimates: one calculated with all eight low-rise studies meeting inclusion criteria and one calculated with a subset of four low-rise studies that conducted year-round sampling.

number of fatalities, and then summed standardized counts across studies for each species. We regressed $\log_{10}(X+1)$ species counts ($X + 1$ transformation to account for zero counts for some species at some sites) on $\log_{10}$ population size and $\log_{10}$ range overlap. Vulnerability was estimated by fixing coefficients for population size and range overlap to 1.0 (this assumes that, for example, a 10-fold increase in abundance is associated with a 10-fold increase in collision mortality, all else being equal; Arnold and Zink 2011), calculating residuals, and raising 10 to the power of the absolute value of residuals. This approach of fixing model coefficients was taken because there was an unknown level of error in both the dependent and independent variables and, therefore, standard regression models could not produce unbiased slope estimates (Warton et al. 2006, Arnold and Zink 2011). Calculated vulnerability values indicate the factor by which a species has a greater chance (positive residuals) or smaller chance (negative residuals) of experiencing building collision mortality compared with a species with average vulnerability. We estimated vulnerability for taxonomic groups by averaging residuals across species occurring in at least two studies.

## RESULTS

### Estimates of Bird–Building Collision Mortality

The 95% confidence interval of annual bird mortality at residences was estimated to be between 159 and 378 million (median = 253 million) (Figure 2A and Table 3) after correcting for scavenger removal and imperfect detection. This equates to a median annual mortality rate of 2.1 birds per building (95% CI = 1.3–3.1). Reflecting the large number of residences in urban areas and residences without bird feeders, we estimate that urban residences without feeders cumulatively account for 33% of mortality at residences, followed by rural residences without feeders (31%), urban residences with feeders (19%), and rural residences with feeders (17%).

**TABLE 3.** Estimates of annual bird mortality caused by building collisions at U.S buildings. For low-rises (and therefore, for the total mortality estimate), we generated two separate estimates of collision mortality, one using mortality rates based on all eight low-rise studies meeting our inclusion criteria and one based on a subset of four low-rise studies that sampled mortality year-round.

| | | Point estimate | | 95% CI | |
|---|---|---|---|---|---|
| Building class | Mean no. of buildings in U.S. | Total | Per building | Total | Per building |
| Residences (1–3 stories) | 122.9 million | 253.2 million | 2.1 | 159.1–378.1 million | 1.3–3.1 |
| Low-rises | 15.1 million | 245.5 million[a] | 16.3[a] | 62.2–664.4 million[a] | 4.1–44.0[a] |
| | | 409.4 million[b] | 27.1[b] | 114.7–1,028.6 million[b] | 7.6–68.1[b] |
| High-rises | 20,900 | 508,000 | 24.3 | 104,000–1.6 million | 5.0–76.6 |
| Total | 138.0 million | 507.6 million[a] | 3.7[a] | 280.6–933.6 million[a] | 2.0–6.8[a] |
| | | 667.1 million[b] | 4.8[b] | 349.9–1,296 million[b] | 2.5–9.4[b] |

[a] Estimate based on low-rise estimate using all eight studies meeting inclusion criteria.
[b] Estimate based on low-rise estimate using subset of four year-round studies meeting inclusion criteria.

The 95% confidence interval of annual low-rise mortality based on all studies meeting inclusion criteria was estimated to be between 62 and 664 million birds (median = 246 million). The 95% confidence interval based on the four year-round low-rise studies was estimated to be between 115 million and 1.0 billion birds (median = 409 million). The average of the two median figures is 339 million (95% CI = 136–715 million) (Figure 2B), equating to a median annual rate of 21.7 birds per building (95% CI = 5.9–55).

The 95% confidence interval of high-rise mortality was estimated to be between 104,000 and 1.6 million birds (median = 508,000) (Table 3 and Figure 2C) after correcting for scavenger removal, imperfect carcass detection, and mortality during periods other than migration. Despite causing the lowest total mortality, high-rises had the highest median annual mortality rate: 24.3 birds per building (95% CI = 5–76). Combining estimates from all building classes (using the average of the two low-rise estimates) results in an estimate of 599 million birds killed annually across all U.S. buildings (95% C.I. = 365–988 million) (Figure 2D).

## Factors Explaining Estimate Uncertainty

Due to the large number of low-rises and uncertainty about low-rise mortality rates, sensitivity analyses indicated that the low-rise mortality rate explained a large amount of uncertainty for the estimates of both low-rise mortality (85%) and total mortality (75%). Other parameters explaining substantial uncertainty for the total estimate included the correction factors for scavenger removal and carcass detection at low-rises (10%) and residences (9%). For residences, 70% of uncertainty was explained by the correction factor for scavenging and detection and 15% was explained by the proportion of residences in urban areas. For the high-rise estimate, the greatest uncertainty was explained by the mortality rate (67%), followed by the correction factor for scavenging and detection (25%).

## Species Vulnerability to Building Collisions

Of 92,869 records used for analysis, the species most commonly reported as building kills (collectively representing 35% of all records) were White-throated Sparrow (*Zonotrichia albicollis*), Dark-eyed Junco (*Junco hyemalis*), Ovenbird (*Seiurus aurocapilla*), and Song Sparrow (*Melospiza melodia*). However, as expected, there was a highly significant correlation between fatality counts and population size ($r = 0.53$, $P < 0.001$, df =213) and between counts and range overlap with study sites ($r = 0.25$, $P < 0.001$, df = 223). After accounting for these factors, estimated vulnerability across all buildings was highly variable, ranging from 1,066 times more likely to collide than average to 273 times less likely to collide than average (high vulnerability species in Table 4; all values in Tables S3–S6 in Supplemental Material Appendix D).

Several species exhibit disproportionately high vulnerability to collisions regardless of building type, including Ruby-throated Hummingbird (*Archilochus colubris*), Brown Creeper (*Certhia americana*), Ovenbird, Yellow-bellied Sapsucker (*Sphyrapicus varius*), Gray Catbird (*Dumetella carolinensis*), and Black-and-white Warbler (*Mniotilta varia*). Seven species that are disproportionately vulnerable to building collisions are national Birds of Conservation Concern and 10 are listed regionally (Table 4; U.S. Fish and Wildlife Service 2008). Species in the former group include Golden-winged Warbler (*Vermivora chrysoptera)* and Canada Warbler (*Cardellina canadensis*) at low-rises, high-rises, and overall, Painted Bunting (*Passerina ciris*) at low-rises and overall, Kentucky Warbler (*Geothlypis formosa*) at low-rises and high-rises, Worm-eating Warbler (*Helmitheros vermivorum*) at high-rises, and Wood Thrush (*Hylocichla mustelina*) at residences. For species with vulnerability indices calculated from a

**TABLE 4.** Estimates of species vulnerability to building collisions. Risk values indicate the factor by which species are at a greater risk of collision compared with a species with average risk. Species in boldface italics are Birds of Conservation Concern at the national level and species in boldface are Birds of Conservation Concern in at least one U.S. region (U.S. Fish and Wildlife Service 2008). Scientific names are in Supplemental Material Appendix D.

| All buildings | | Residences (1–3 stories) | | Low-rises | | High-rises | |
|---|---|---|---|---|---|---|---|
| Species | Risk | Species | Risk | Species | Risk | Species | Risk |
| Anna's Hummingbird[a] | 1,066.4 | **Purple Finch** | 257.2 | ***Golden-winged Warbler*** | 141.7 | Townsend's Solitaire | 167.4 |
| Black-throated Blue Warbler | 45.5 | Ruby-throated Hummingbird | 174.7 | ***Painted Bunting*** | 129.3 | Black-throated Blue Warbler | 78.5 |
| Ruby-throated Hummingbird | 37.0 | Ovenbird | 112.1 | Ruby-throated Hummingbird | 103.7 | Connecticut Warbler | 52.0 |
| Townsend's Solitaire | 36.3 | Brown Creeper | 81.1 | Black-throated Blue Warbler | 86.4 | Brown Creeper | 44.3 |
| ***Golden-winged Warbler*** | 35.3 | House Finch | 80.1 | Swamp Sparrow | 50.6 | Ovenbird | 43.7 |
| ***Painted Bunting*** | 32.1 | Black-and-white Warbler | 68.7 | ***Canada Warbler*** | 46.7 | Ruby-throated Hummingbird | 43.4 |
| Brown Creeper | 26.2 | Cedar Waxwing | 50.5 | **Louisiana Waterthrush** | 46.4 | ***Worm-eating Warbler*** | 26.5 |
| Connecticut Warbler | 22.9 | **Field Sparrow** | 48.3 | Brown Creeper | 44.8 | ***Canada Warbler*** | 25.8 |
| Ovenbird | 21.8 | ***Wood Thrush*** | 41.0 | **Yellow-bellied Sapsucker** | 38.3 | Gray Catbird | 23.9 |
| ***Canada Warbler*** | 17.9 | Swainson's Thrush | 34.7 | Connecticut Warbler | 35.7 | **Yellow-bellied Sapsucker** | 23.7 |
| Swamp Sparrow | 16.7 | Northern Cardinal | 27.5 | Ovenbird | 30.4 | ***Golden-winged Warbler*** | 23.1 |
| **Yellow-bellied Sapsucker** | 16.2 | Blue Jay | 26.5 | Sharp-shinned Hawk | 27.8 | American Woodcock | 22.1 |
| **Louisiana Waterthrush** | 14.3 | White-breasted Nuthatch | 25.0 | Rose-breasted Grosbeak | 24.1 | Common Yellowthroat | 20.4 |
| Gray Catbird | 12.8 | **Yellow-bellied Sapsucker** | 22.6 | Gray Catbird | 23.2 | Scarlet Tanager | 18.5 |
| Pine Grosbeak[a] | 12.4 | Northern Waterthrush | 22.5 | Black-and-white Warbler | 22.7 | Black-and-white Warbler | 18.3 |
| American Woodcock | 11.7 | Nashville Warbler | 22.2 | American Woodcock | 21.1 | Swamp Sparrow | 18.1 |
| Pygmy Nuthatch[a] | 11.4 | Gray Catbird | 20.7 | ***Kentucky Warbler*** | 20.2 | Rose-breasted Grosbeak | 16.2 |
| Black-and-white Warbler | 11.1 | **Northern Flicker** | 20.2 | Mourning Warbler | 19.3 | ***Kentucky Warbler*** | 14.0 |
| **Pied-billed Grebe**[a] | 11.0 | Downy Woodpecker | 18.7 | Common Yellowthroat | 18.4 | **Northern Goshawk** | 13.6 |
| Common Yellowthroat | 10.9 | Black-capped Chickadee | 14.9 | Cape May Warbler | 16.7 | **Eastern Whip-poor-will** | 13.4 |

[a] Species is ranked for all buildings but not individual classes because it occurs in $\geq 2$ total studies, but $<2$ studies within building class.


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relatively small sample of studies (e.g., those noted with a superscript in Table 4), vulnerability indices may be biased. For example, the exceptionally high vulnerability value for Anna's Hummingbird (*Calypte anna*) likely results from this species occurring in only two studies and experiencing exceptionally high mortality in one of these studies.

Vulnerability estimates for taxonomic groups are in Table 5. Several high-risk bird groups are represented in our dataset by only one or two species (e.g., grebes, shorebirds, kingfishers, and gulls and terns); average risk values for these groups may not represent the entire taxonomic family. Other taxa, particularly the hummingbirds and swifts and the warblers, appear especially vulnerable to building collisions, with more than one species ranking in the overall high-vulnerability list. In particular, warblers experience disproportionately high collision risk, with 10 species ranking among the 25 most vulnerable species overall and 12 and 14 species ranking among the 25 most vulnerable species for low-rises and high-rises, respectively. Taxonomic groups with particularly low collision risk include ducks and geese, swallows, herons, upland game birds, and blackbirds, meadowlarks, and orioles.

**TABLE 5.** Average vulnerability of bird groups to building collisions across all building types. Risk values indicate the factor by which a species has a greater chance (for positive residuals) or a smaller chance (for negative residuals) of mortality compared with a species with average risk.

| Group | Residual | Risk |
|---|---|---|
| Hummingbirds and swifts | 1.52 | 33.2 |
| Grebes | 1.04 | 11.0 |
| Shorebirds | 0.68 | 4.7 |
| Kingfishers[a] | 0.56 | 3.6 |
| Waxwings | 0.55 | 3.6 |
| Warblers | 0.54 | 3.4 |
| Gulls and terns[a] | 0.52 | 3.3 |
| Nuthatches, tits, and creeper | 0.50 | 3.1 |
| Cuckoos | 0.46 | 2.9 |
| Mimic thrushes | 0.41 | 2.6 |
| Diurnal raptors | 0.40 | 2.5 |
| Cardinaline finches | 0.36 | 2.3 |
| Kinglets | 0.36 | 2.3 |
| Thrushes | 0.25 | 1.8 |
| Cardueline finches | 0.23 | 1.7 |
| Nightjars | 0.16 | 1.4 |
| Woodpeckers | 0.15 | 1.4 |
| Owls | 0.10 | 1.3 |
| Doves and pigeons | 0.08 | 1.2 |
| Sparrows | 0.08 | 1.2 |
| House Sparrow[a] | −0.15 | 1.4 |
| Wrens | −0.20 | 1.6 |
| Coots and rails | −0.24 | 1.7 |
| Flycatchers | −0.41 | 2.6 |
| Vireos | −0.55 | 3.6 |
| Starling[a] | −0.56 | 3.6 |
| Corvids | −0.61 | 4.1 |
| Blackbirds, meadowlarks, and orioles | −0.64 | 4.4 |
| Upland game birds | −0.77 | 5.9 |
| Herons | −1.05 | 11.3 |
| Swallows | −1.07 | 11.6 |
| Ducks and geese | −1.25 | 17.9 |
| Gnatcatchers[a] | −1.68 | 48.1 |

[a] Values based on data from a single species.

## DISCUSSION

### Comparison of Mortality Estimate to Previous Estimates

Our estimate of 365–988 million birds killed annually by building collisions is within the often-cited range of 100 million to 1 billion (Klem 1990a). Other estimates are either outdated (3.5 million, Banks 1979) or are simply a mid-point of the above range (550 million, Erickson et al. 2005). Our larger estimate of low-rise mortality based only on year-round studies suggests that total annual building collision mortality could exceed one billion birds, as suggested by Klem (2009). Using the year-round low-rise estimate results in an annual mortality estimate of up to 1.3 billion birds. Regardless of which figure is interpreted, our results support the conclusion that building collision mortality is one of the top sources of direct anthropogenic mortality of birds in the U.S. Among other national estimates that are data-driven and systematically derived, only predation by free-ranging domestic cats is estimated to cause a greater amount of mortality (Loss et al. 2013). A similar ranking has been made for anthropogenic threats in Canada (Blancher et al. 2013, Machtans et al. 2013). Major sources of direct anthropogenic bird mortality currently lacking systematically derived estimates include collisions with automobiles and other vehicles, collisions and electrocution at power lines, and poisoning caused by agricultural chemicals, lead, and other toxins. Additional systematic quantification of mortality is needed to allow rigorous comparisons among all mortality sources.

A general pattern across and within building classes is that a large proportion of all mortality occurs at structures that kill small numbers of birds on a per-building basis but collectively constitute a high percentage of all buildings (e.g., residences compared to low-rises and high-rises; urban compared to rural residences; residences without feeders compared to those with feeders). This finding suggests that achieving a large overall reduction in mortality will require mitigation measures to be applied across a large number of structures (e.g., urban residences). Our conclusion about the relative importance of residences for causing U.S. mortality is similar to that made for Canada by Machtans et al. (2013). This similarity arises because residences are estimated to comprise a similar proportion of all buildings in both countries (87.5% in the U.S and 95.3% in Canada). Even assuming the low-end mortality estimate for residences (159 million), total mortality at high-rises would have to be 100 times greater than our high-end estimate for that building class (1.6 million) for the two building classes to cause equivalent mortality. On a per-building basis, if each residence killed one bird per year, each high-rise would have to kill >5,800 birds per year to cause equivalent mortality. No evidence exists that high-rises kill this large number of birds.

The species composition of window collision mortality also differs by building class. While the high risk group for individual residences includes several non-migratory resident species—including Downy Woodpecker (*Picoides pubescens*), Black-capped Chickadee (*Poecile atricapillus*), and Northern Cardinal (*Cardinalis cardinalis*)—nearly all high-risk species for low-rise and high-rise buildings are migratory. Compared with resident species, migratory species traverse longer distances, use a greater diversity of habitat types, and encounter more building types and total buildings during the annual cycle. Additionally, migratory species are attracted to large lighted buildings during their nocturnal migration; this attraction causes a large amount of mortality at low-rises and high-rises as birds either immediately collide with lighted buildings or become entrapped before later dying of collision or exhaustion (Evans Ogden 1996). The greater representation of resident species in the high-risk group for residences may be due to the propensity for many of these species to congregate at bird feeders, a behavior that may place them at a greater risk of colliding with windows (Dunn 1993, Klem et al. 2004, Bayne et al. 2012).

Despite the critical importance of reducing mortality at residences, mitigation measures targeted at a relatively small number of buildings with high per-building mortality rates (e.g., some high-rises and low-rises) will likely result in large per-building reductions in mortality and therefore may represent a cost-efficient starting point for reducing mortality. The mortality proportions that we attribute to different residence types are similar to those estimated by Machtans et al. (2013). This result arises from both the previous study and ours basing analysis on Bayne et al. (2012), a Canadian study that provides a reasonable approximation of U.S. mortality rates as evidenced by rates documented in U.S. studies (Dunn 1993, Weiss and Horn 2008, Bracey 2011).

### Species Vulnerability to Building Collisions

Our vulnerability analysis indicates that several species experience a disproportionately high risk of building collision mortality. Of particular concern within the list of high-risk species (Table 4) are those identified as national Birds of Conservation Concern (species likely to become candidates for listing under the U.S. Endangered Species Act without further action based on population trends, threats to populations, distribution, abundance, and relative density; U.S. Fish and Wildlife Service 2008). For species that are vulnerable to collisions at more than one building class or overall, including Golden-winged Warbler, Painted Bunting, Kentucky Warbler, and Canada Warbler, building collision mortality appears substantial and may contribute to or exacerbate population declines. For species identified as highly vulnerable to collision for one building class but not across building types (Wood Thrush at residences, Worm-eating Warbler at high-rises), building collisions may still represent a threat. However, risk rankings for these species are more likely to be inflated by high mortality rates at a few sites, and further research is required to clarify the degree to which populations of these species are threatened by collision mortality.

Inferences about population impacts of a mortality source should ideally be based on incorporating mortality estimates into demographic models (Loss et al. 2012) or comparing estimates to population abundance (Longcore et al. 2013). Data limitations preclude intensive population modeling of building collision impacts. Sampling bias toward densely populated areas east of the Mississippi River, and therefore toward certain bird species, prevented us from estimating species-specific annual mortality. We initially attempted to apply average species proportions to the overall mortality estimate following Longcore et al. (2013), but this method returned unrealistically high estimates for species that comprised a high percentage of counts in many studies (e.g., 140% of the total population of Ovenbirds estimated to be killed each year by building collisions). Our vulnerability estimates controlled for abundance and range overlap with study sites and therefore provide a less biased approximation of species-specific collision risk.

Our vulnerability analysis expanded upon the analysis of Arnold and Zink (2011), which was based on three sites in the northeastern U.S. and adjacent Canada. Nonetheless, we documented some of the same vulnerable species, including Brown Creeper, Black-throated Blue Warbler (*Setophaga caerulescens*), and Swamp Sparrow (*Melospiza georgiana*), and similar high- and low-risk taxonomic groups (e.g., warblers and swallows, respectively). As in the previous study, the vast majority of highly vulnerable species were long-distance migrants. Unlike the previous study, we did not assess whether population trends were correlated with building collision vulnerability. This approach has received criticism (Schaub et al. 2011, Klem et al. 2012) and shifts focus away from identifying which individual species of conservation concern face a high risk of colliding with buildings.

### Research Needs and Protocol Improvements

Sensitivity analyses indicated that more research of mortality rates at low-rises will contribute greatly to improving mortality estimates. Future research should sample a variety of low-rise types, including residential, commercial, and industrial buildings. Research at low-rises has occurred mostly at buildings that are known to cause large numbers of fatalities (e.g., office or university campus buildings with many windows and/or near favorable bird habitat). Random selection of buildings for monitoring (for all building classes) allows for less-biased conclusions about local mortality rates and more reliable extension of results within study areas and across regions. Mortality data specific to different low-rise building types will allow improvement upon the current approach of assuming that all low-rise buildings have similar mortality rates. Because we based our low-rise estimate on the number of U.S. "establishments," and because the relationship between numbers of establishments and numbers of buildings is unknown, we suggest that improved data be collected and made available for the number of U.S. low-rise buildings. Non-residential low-rises are not currently included in assessments by the U.S. Census Bureau.

Sensitivity analyses also indicate that mortality estimates will benefit from quantification of searcher efficiency and scavenger removal rates. Recent research has resulted in major advancements in understanding these biases, including studies that estimate carcass detection and/or scavenger removal rates (Collins and Horn 2008, Hager et al. 2012, 2013) or apply methods to simultaneously account for both biases (Bracey 2011, Etterson 2013). In the future, studies should account for these biases when possible and investigate how these rates are affected by size and species of carcasses, abundance and community composition of scavengers, and characteristics of vegetation and habitat near buildings.

A large portion of the unpublished data we used were collected by volunteer-led collision-monitoring programs in major cities. These citizen-science programs have contributed greatly to the understanding of bird–building collisions; however, standardization of data collection and recording procedures is necessary to make these data more comparable across programs and across years within programs. As a first step, all monitoring programs should record sampling effort, including (1) a record of all surveys conducted, even those with zero fatalities found; (2) the number of person-hours of sampling in every survey; (3) the number of buildings and building facades sampled; (4) street addresses of buildings (with attention to avoiding multiple addresses referring to one building and clarifying when one address includes >1 building); and (5) separate records of fatalities found during surveys on official routes and those found incidentally outside of survey periods and/or off of routes. This information will allow increased comparability of data among regions, improved understanding of seasonal and regional mortality patterns, and reduced bias in estimates of per-building mortality rates and overall mortality. Combining effort-corrected mortality data with information about buildings (e.g., height in stories and meters; orientation and area of building facades; glass area, type, extent, and reflectivity; vegetation presence, type, density, and height; and amount of light emitted), will allow identification of mortality rate correlates, prediction of mortality rates from building characteristics, and implementation of techniques to reduce mortality. Monitoring programs could also expand to incorporate sampling at multiple building types, including individual residences and additional types of low-rises and high-rises. A national reporting system and database for bird mortality data would facilitate standardization of data collection for building collisions and other mortality sources (Loss et al. 2012). Until this type of comprehensive system is developed and launched, window collision monitoring programs can use simple user-defined data entry portals that will increase standardization of data recording, formatting, and compilation (see example at https://docs.google.com/spreadsheet/viewform?usp=drive_web&formkey=dDA1dDVTSVUzS1NfX0NxWmZxTEctbHc6MQ#gid=0), and therefore benefit research that synthesizes multiple datasets.

## Model Limitations

Because data collection methods varied greatly among studies, we could not account for all differences among the datasets we synthesized. How this limitation influenced our estimates is unclear. Nonetheless, our inclusion criteria removed studies that lacked a systematic component to sampling, and we accounted for partial-year sampling by either estimating mortality using only year-round studies or applying correction factors to mortality estimates. We also accounted for sample size differences when estimating species vulnerability. However, the data we analyzed overrepresented the eastern U.S. and underrepresented the Great Plains, Interior West, and West Coast. Because of this data limitation, the mortality rate distributions that we applied to all U.S. buildings were primarily based on data from the eastern U.S. This could have biased our estimates if mortality rates in the West differ consistently from those documented in the East; however, the lack of western data prevents conclusions about such regional variation. In addition, our species vulnerability estimates do not cover species with a large proportion of their range in the West. Further research of bird–building collisions in areas west of the Mississippi River is needed to document whether per-building mortality rates differ consistently from those in well-studied regions of the east and to assess building collision vulnerabilities for western bird species. Our mortality estimates are limited by the assumption that all non-residential establishments listed by the U.S. Census Bureau are ≤11 stories tall and that all buildings sampled by monitoring programs in major downtown areas are >12 stories tall. These assumptions were unavoidable because U.S. low-rise building data are not available and building height information was not recorded in most studies.

Our mortality estimates may be conservative because data from buildings that cause exceptionally high annual rates of collision were removed from our analysis before extending average rates to the scale of the entire U.S. Hundreds to greater than one thousand birds per year have been found at intensively monitored buildings in or near areas with a high concentration of birds during migration (e.g., Taylor and Kershner 1986, M. Mesure and D. Willard personal communication). Other factors that may have contributed to underestimation include crippling bias (e.g., an uncertain percentage of birds fly away from sampling areas before dying) and sub-lethal effects that may influence social interactions and migration behavior even if not causing eventual death (Klem 1990b). Further research to quantify crippling bias and sub-lethal effects is crucial for continued improvement in the accuracy of mortality and species vulnerability estimates.

Finally, we were unable to quantify seasonal patterns of mortality due to a limited sample of studies that surveyed throughout the year. Additionally, several studies employed varying sampling effort across seasons and did not record effort data that could be used to account for this variation. Among records meeting our inclusion criteria, 60.0% were found during fall migration (August–November) and 37.0% were found during spring migration (March–May). These figures are likely inflated relative to non-migratory periods because most studies sampled only during spring and fall. Despite varying sampling effort among seasons, mortality during fall migration appears to be consistently greater than during spring migration; this pattern was seen in most of the datasets and could be related to larger populations of birds in the fall due to presence of young-of-the-year birds. Notably, several studies have indicated substantial building collision mortality during periods outside of migration, including in winter at individual residences (Dunn 1993, Klem 2009) and in summer at low-rise buildings (Bayne et al. 2012, Hager et al. 2013). Our methods accounted for partial-year sampling by either using only year-round studies (for residences and low-rises) or applying a correction factor that assumed additional mortality during summer and winter (for high-rises, a building type for which little data exists for non-migration periods). Species vulnerability estimates were also likely to be influenced by seasonal sampling biases, with in-transit migratory species likely overrepresented compared with summer and winter residents. Additional year-round studies are needed at all building types to clarify how mortality rates and species composition of fatalities vary by season.

### Conclusions

As human populations and numbers of buildings increase in the U.S. and globally, actions to reduce bird mortality from building collisions will be necessary at all types of buildings. For residences, mitigation techniques could include reducing vegetation near windows, angling windows to reduce reflection, and installing netting, closely spaced decals, or UV light-reflecting glass (Klem et al. 2004, Klem 2006, 2009). For low-rises and high-rises, mortality can be reduced by minimizing light emission at night (Evans Ogden 1996, 2002) and incorporating bird friendly design elements into new and existing buildings (e.g., Brown and Caputo 2007, Sheppard 2011). A long-term approach to reducing mortality is the continued adaptation of Green Building certification standards to include bird collision risks (Klem 2009).

We provide quantitative evidence of the large amount of bird mortality caused by building collisions in the U.S. Our estimates represent roughly 2–9% of all North American birds based on a rough estimate of 10–20 billion total birds in North America (U.S. Fish and Wildlife Service 2002). However, because our results illustrate that not all species are equally vulnerable to building collisions, and because considerable uncertainty remains regarding species-specific mortality and population abundance, the actual impacts of collisions on population abundance are uncertain. Despite this uncertainty, our analysis indicates that building collisions are among the top anthropogenic threats to birds and, furthermore, that the several bird species that are disproportionately vulnerable to building collisions may be experiencing significant population impacts from this anthropogenic threat.

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# Energy savings of office buildings by the use of semi-transparent solar cells for windows

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**Abstract**

The study investigated a PV window that consists of a double glazed window with semi-transparent solar cells. The window provides natural light transmission as well as electricity production. The effect of the PV window on energy consumption of office buildings was analyzed in terms of heating and cooling loads, daylighting, and electricity production. The purposes of the study were to find the optimum solar cell transmittance and window to wall ratio (WWR), and to estimate energy savings of the building. A standard floor of an office building was modeled to run computer simulation, and annual energy simulation was performed with *EnergyPlus*. The results showed that the solar cell transmittance of 40% and WWR of 50% achieved the minimum electricity consumption in the building when artificial lighting was controlled with daylighting. The optimum solar cell transmittance for PV windows in different orientation was also presented. By using the optimum PV window, the electricity consumption was reduced by 55% compared to the single glazed window with WWR of 30% and no lighting control.

*Key words:* Energy simulation, Office buildings, Windows, Semi-transparent

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photovoltaics, Daylighting

## 1 Introduction

Energy consumption in commercial sector is growing in spite of the development of energy efficient systems in Japan. This is mainly due to increasing floor area of buildings year by year[1]. To reduce energy consumption in buildings, it is necessary to contract energy demands as well as to install energy efficient supply systems. In modern architecture, windows play an important role to reduce energy demands in respect of heating and cooling loads and lighting requirement. Therefore, the interrelation between window design and thermal performance of buildings has been extensively investigated[2]-[9].

By advancement of computational capability, the optimum window size and types to minimize energy consumption of buildings have been explored by computer simulation. The south window size, as well as building aspect ratio, to minimize heating and cooling loads was analyzed by Mehlika et al.[2] From a computer simulation of a residential building in five different climate regions in Turkey, it was concluded that the south window size of 25%, which was required in Turkish Insulation Regulation, was the optimum in hot climates. While, the larger south window sizes were preferable in cold climates. Kontoleon et al.[3] investigated the optimum glazed openings percentage from the viewpoint of the indoor temperature and the energy consumption of the supply system. Al-Homoud[4] carried out an optimization study on building

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design variables to minimize annual energy consumption. Minimum glass area of 15% was the optimum in his research all but the cold climate where larger glass area was required to utilize solar gain for heating. The economically optimum window size and orientation were investigated by Johnson et al.[5] The conclusion was that glass to wall ratio of less than 20% resulted in the minimum life-cycle cost. In addition, the north orientation was preferred for large glass to wall ratios. These precedent studies showed that large window size resulted in the increase of a cooling load, while it causes the decrease of a heating load because of enhanced solar gain.

The use of daylight is one of the most important factors to be taken into consideration for window design. Daylighting affects heating and cooling loads of buildings in terms of solar gain as well as heat gain from artificial lighting when lighting control is installed. Bodart et al.[6] evaluated the impact of lighting energy savings on energy consumption of buildings by a combination of a daylighting simulation and a dynamic thermal simulation. The results showed that the primary energy saving due to daylighting was around 40%. Sullivan et al.[7] investigated a method for an evaluation of fenestration and lighting system. The relationship between solar aperture or effective daylighting aperture and electricity use for cooling and for lighting was presented. A similar technique was used by Lam et al.[8] for cooling dominated office buildings in Hong Kong. It was shown that the peak cooling load and the annual electricity consumption were reduced by 11% and by 13%, respectively, due to the use of daylighting. Zain-Ahmed et al.[9] showed that the energy saving of 10% could be achieved by using daylighting strategies in Malaysian buildings. Therefore, most researchers showed that energy savings of 10 to 40% could be achieved by a daylighting scheme depending on the shape of buildings and climate zones.

Windows acquire an additional function of electricity production when they are integrated with photovoltaics. The technology of semi-transparent photovoltaics has been developed, and glass integrated photovoltaic modules have been applied to glass facade or skylights[10][11], for example. To analyze the effect of photovoltaic glazing systems on energy consumption of buildings, a thermal aspect, an optical aspect, and electricity production have to be examined comprehensively. This type of approach has been practiced by Sylvester et al.[12], where an energy simulation was performed for high-rise buildings in four cities in the U.S. A photovoltaic glazed window with the transmittance of 40% was examined, and the results showed that the PV window significantly decreased the electricity use of the building. The optimum transmittance of the PV window was not investigated in his research, however.

It is necessary to explore the optimum design for the evaluation of PV windows because the thermal performance of the building and the electricity production from the photovoltaics are interrelated. In the study, the application of windows integrated with semi-transparent photovoltaics to buildings under the climate of Japan was investigated by a computer simulation. The purposes of the study were to find the optimum transmittance of the semi-transparent solar cell, and to estimate possible energy savings of office buildings, by taking into consideration the heating and cooling loads, daylighting, and electricity production.

## 2 Energy simulation of an office building

### 2.1 Heating and cooling loads calculation

Hourly heating and cooling loads were calculated by *EnergyPlus*[13], which is a building energy simulation software developed by the US Department of Energy. *EnergyPlus* calculates thermal loads of buildings by the heat balance method. The heat balance method takes into account all heat balances on outdoor and indoor surfaces and transient heat conduction through building fabric. It is more accurate than the weighting factor method, which is used in precedent thermal loads calculation software such as DOE-2, because the heat balance method allows the variation of properties with time steps[14]. The simulation results of *EnergyPlus* have been validated through analytical, comparative, and empirical tests[15][16].

Although *EnergyPlus* is capable of simulating heating, ventilation, and air conditioning (HVAC) systems, the details of HVAC systems were not modeled since the primary objective of the study was to examine the influence of PV windows on thermal loads of buildings.

### 2.2 Description of the building simulated in the study

An office building in Tokyo, Japan was used to run the computer simulation. The floor plan and the materials of the building elements were based on the Architectural Institute of Japan (AIJ) standard model[17] for thermal analysis of office buildings. In the study, only the standard floor was modeled to reduce computational loads. The indoor temperatures of the upper and the lower floors were assumed to be maintained at the same temperature as the standard floor. The floor plan, the south side and east side elevations are depicted in Fig. 1. The floor has four office zones, which are oriented to the northeast, northwest, southeast, and southwest, respectively. The east side zones and the west side zones are separated by a core zone. Each office zone is a square of 12 m in a side, and 3.6 m in height. The dimension of the core zone is 9 m $\times$ 24 m, and 3.6 m in height.

The properties of the wall, ceiling and floor materials are given in Table 1. The values were obtained from Cymap's software, *QuickSlab*. The estimated U-values of the components were 0.80, 2.90, and 1.20 W/(m $\cdot$ K) for the exterior wall, the interior wall, and the ceiling/floor, respectively. In *EnergyPlus*, the heat transfer by radiation, convection and conduction is calculated at each time step. The U-values are not constant through the simulation because the radiative and convective heat transfer is calculated by algorithms that take into account parameters such as temperature difference between the surface and the air[18].

The office zones have windows on their exterior walls. Window to wall ratio (WWR) of the office zones in the standard model is 30%. WWR was varied from 30% to 50% in parametric analysis.

Table 2 shows the design values of the internal heat gains, ventilation, and infiltration. The hourly variations of the internal heat gains were determined by the simulation schedules[17] that are shown in Fig. 2. The ventilation works from 8:00 to 18:00, whereas the infiltration is uncontrollable.

### *2.3 PV window*

A typical PV window consists of two panes of glass with a semi-transparent photovoltaics layer between them. An amorphous silicon solar cell type PV window was assumed in the study because of its aesthetic advantage for the application to windows. Sanyo Electric Co., Ltd. has developed a semi-transparent amorphous silicon solar cell, which is called the see-through a-Si solar cell[19]. The basic structure of the solar cell is the same as ordinary amorphous silicon solar cells. The microscopic holes in the solar cell make the solar cell semi-transparent, however. One of the advantages of the see-through a-Si solar cell is the natural light transmission because the spectrum of the transmitted light is almost the same as that of the incident light. The transmittance of the see-through a-Si solar cell is adjustable by changing the area of the holes. Power output reduction of the solar cell, because of the presence of the holes, is almost equal to the transmittance of the solar cell[19]. One can find an application of the see-through a-Si solar cell to windows or skylights in a few Japanese architecture[20][21].

The PV window investigated in the study consists of a double glazed window with a see-through a-Si solar cell layer between the panes. The schematic of the PV window is shown in Fig. 3. The transmittance of the solar cell was varied from 10% to 80% for parametric analysis.

To run the energy simulation by *EnergyPlus*, the optical properties of the glass and the solar cell layer were required. Table 3 shows the optical properties of a 6 mm clear glass and a 10 mm clear glass that were obtained from the glass library of *WINDOW 5*[22]. For the solar cell layer, the following assumptions were made.

- The solar and visible transmittances are equal to the solar cell transmittance.
- The reflectance of the front side glass substrate is constant. In other words, the sum of the transmitted light and the absorbed light is constant regardless of the transmittance.
- The back side reflectance of the solar cell varies in response to the transmittance of the solar cell. The reflectivity of the back side metal electrode is 90%.

Finally, the optical properties of the solar cell layer were determined as follows:

- The transmittance, $\tau_p = 0.1$ to 0.8.
- The front side reflectance, $R_p^f = 0.1$.
- The back side reflectance, $R_p^b = (1 - \tau_p) \times 0.9$.

Electricity output from the solar cell was calculated from the electricity conversion efficiency of the solar cell at standard test conditions, $\eta$, the glass layer transmittance, $\tau_g$, the solar cell absorptance, $\alpha_p$, the temperature coefficient of power output, $K$, the effective solar cell area, $A_p$, the solar cell temperature, $T_c$, and the solar radiation on the window, $G$. The electricity output, $P$, was calculated from the following equation:

$$P = G\eta\tau_g\alpha_p\{1 - K(T_c - 25)\}A_p. \tag{1}$$

Where, the effective area was defined as $A_p = A_w(1 - \tau_p)$. $A_w$ represents the window area. The electricity conversion efficiency of 9% and the solar cell absorptance of 0.9 were assumed. The temperature coefficient of power output was assumed as -0.2%/°C[23]. The solar radiation on the window and the solar cell temperature were obtained from the *EnergyPlus* output.

### *2.4 Daylighting and lighting control*

The artificial lighting output to achieve a required illuminance level in a zone can be decreased when daylight is available to a certain illuminance level. The continuous dimming control for artificial lighting was assumed in the study. The center of each zone at desk height was used as a reference point of the interior illuminance level, and the required illuminance level at the reference point was 700 lux[24].

Any shading on windows reduces the available daylight. It is, however, usual to use some shading device to avoid discomfort glare or to decrease excess solar heat gain. An interior blind was modeled as a shading device. The blind was on when the glare index at the reference point exceeded 22.

### *2.5 Electricity consumption of the heating and cooling systems of the building*

It is necessary to estimate the electricity consumption of the heating and cooling systems for the calculation of total electricity consumption of the building. The electricity consumption of the system was calculated by simply dividing the heating and cooling loads by COP of the system. An electric heat pump, which had the heating and cooling COPs of 4.3 and 3.3[25], respectively, was assumed as the heating and cooling system of the building.

## 3 Results and Discussion

### *3.1 Validation of the EnergyPlus results*

Annual heating and cooling loads of the standard building model were calculated by *EnergyPlus*, and were compared with reference values[26] for the validation of the results. The window was a single glazed, and WWR was 30%. The artificial lighting was not controlled with daylighting.

The monthly heating load and cooling load of the *EnergyPlus* results and the reference values are shown in Figs. 4 and 5, respectively. In Japan, the heating load occurs mainly from December to March, and the cooling load is substantial between June and September. The simulation results conformed to this climatic characteristics.

The heating and cooling loads of the core zone were notably smaller than the office zones because of the less internal, fabric, and ventilation heat gains in the summer, and the less fabric and ventilation heat losses in the winter. Although the calculation results were less than the reference values at many calculated points, the *EnergyPlus* results of office zones were reasonably close to the reference values, and followed the trend of the monthly variation. The reason of the smaller values of the calculation was that only the standard floor was modeled for the simulation. Therefore, the heat losses and gains through roofs and ground floors were ignored. It was concluded that the simulation results from *EnergyPlus* were acceptable for the purpose of the research, which was the comparison of the results between simulation cases.

### *3.2 Parametric analyses on the solar cell transmittance and the window size*

Parametric analyses on the solar cell transmittance and the window size were carried out to investigate the effect of those parameters on the thermal performance of the building, and to find the optimum combination of the solar cell transmittance and the window size. The solar cell transmittance was varied from 10% to 80%, and WWR was varied from 30% to 50%. The calculation was performed for both of the cases with and without lighting control. All the results including photovoltaic electricity output were presented by kilowatt-hours per unit floor area.

#### *3.2.1 The effect on the heating and cooling loads*

The hourly heating load and cooling load were obtained through annual simulation, and their integrations were the annual total heating and cooling loads. Figures 6 and 7 shows the annual total heating load and the cooling load as a function of solar cell transmittance, respectively. Without lighting control, higher solar cell transmittance resulted in a smaller heating load and a larger cooling load because of the increased solar gain through the window. With lighting control, the heating and cooling loads did not follow this trend. With the increase of the solar cell transmittance from 10% to a certain point, the heating load increased and the cooling load decreased because of the reduced heat gain from artificial lighting. The trend was reversed, however, as the transmittance was further increased because the influence of the solar gain became dominant.

The larger the WWR was, the larger the heating and cooling loads were.

The explanation is that the larger window area resulted in the larger U-value through building fabric, which caused the increase of heat losses or gains. The larger window size also caused the augmentation of the solar heat gain in the summer.

### *3.2.2 The effect on the lighting electricity*

Figure 8 depicts the lighting electricity consumption as a function of solar cell transmittance. Without lighting control, the lighting electricity consumption was constant. When the artificial lighting was controlled with daylighting, the annual total lighting electricity consumption was reduced as shown in Fig. 8. The lighting electricity consumption decreased with the increase of the solar cell transmittance and with the increase of WWR because of the enhanced daylight availability. The amount of the reduction was, however, gradually diminished because there was no potential of reduction once the required illuminance was achieved.

### *3.2.3 The effect on the electricity production from the photovoltaics*

The effects of the solar cell transmittance and WWR on the electricity production are shown in Fig. 9. The electricity production from the photovoltaics is identical regardless of lighting control. The electricity production reduced linearly when the solar cell transmittance was increased because the effective solar cell area was reduced. The electricity production increased with WWR because of the extension of the effective solar cell area.

### 3.2.4 The effect on the total electricity consumption

A comprehensive outcome of the PV window was examined by the total electricity consumption, which was the summation of electricity consumption for the electric heat pump and for lighting. To deduct the electricity production from the photovoltaics, the electricity production was subtracted from the lighting electricity consumption. Figure 10 shows the annual total electricity consumption for the cases with and without lighting control as a function of the solar cell transmittance. The solar cell transmittance of 10% resulted in the minimum electricity consumption when the artificial lighting was not controlled with daylighting. When the solar cell transmittance was low, larger WWR resulted in smaller electricity consumption despite the fact that larger WWR resulted in larger heating and cooling loads. This trend was inverted at higher solar cell transmittances. The result implies that the effect of the electricity production on the total electricity consumption was significant with lower solar cell transmittances at which the electricity production was large.

With lighting control, the minimum electricity consumption was attained at different solar cell transmittances depending on WWR. The optimum solar cell transmittances were 80% for WWR of 30%, 60% for WWR of 40%, and 40% for WWR of 50%. The combination of the solar cell transmittance of 40% and WWR of 50% achieved the minimum electricity consumption.

Figure 11 shows a stacked bar chart indicating end-uses of electricity consumption for WWR of 50% and the "With Lighting Control" case. The electricity production from the photovoltaics was denoted as negative values. It could be observed that the electricity consumption for lighting was the most significant factor among the electricity end-uses. The variation of the electricity consumption for heating and cooling was negligible through the transmittance of 10 to 80%. Therefore, the sum of the heating, cooling and lighting decreased with the rise of the transmittance. The electricity production reduced, however, at the same time, which resulted in the appearance of the optimum point to minimize the total electricity consumption.

If other systems, such as gas boilers and absorption chillers, are used for heating and cooling, the total primary energy consumption is different, and it can vary in response to COP or efficiency of the system. The optimum solar cell transmittance did not change, however, when the authors examined the systems of heat pumps for cooling and boilers for heating, and that of absorption chillers and boilers.

### *3.3 Comparison with conventional window types*

The PV window with the optimum solar cell transmittance was compared with a single glazed and a double glazed windows in terms of the total electricity consumption. The single glazed window consists of a 6 mm clear glass, and the double glazed window consists of a 6 mm clear glass layer, 6 mm air space, and a 10 mm clear glass layer from the outermost to the innermost.

The annual total electricity consumptions of three windows of the "Without Lighting Control" case were compared in Fig. 12. The details of each component are shown in Table 4. The PV window achieved the smallest electricity consumption among three window types because of the reduced cooling load and of the electricity production. Compared to the single glazed window, the double glazed window could reduce the total electricity consumption. The lower U-value of the double glazed window caused the reduction of the heating load even though the cooling load was slightly increased.

For the single and double glazed windows, the increase of WWR caused the rise of the total electricity consumption. By contrast, the total electricity consumption of the PV window fell with the increase of WWR because the electricity production was magnified with WWR. The PV window with WWR of 50% could reduced the total electricity consumption by 18 % compared with the single glazed window with WWR of 30 %.

The comparison between the single glazed, double glazed, and PV window under the "With Lighting Control" case is shown in Fig. 13. The details are shown in Table 5. It was remarkable that the lighting control considerably reduced the total electricity consumption. The effect of WWR on the total electricity consumption was similar to the "Without Lighting Control" case. The PV window with WWR of 50% reduced the total electricity consumption by 13% compared to the single glazed window with WWR of 30%. The reduction amounted to 54% when it was compared to the single glazed with WWR of 30% and no lighting control.

### *3.4 Effect of zone orientation on the heating and cooling loads, lighting electricity, and electricity production*

The heating and cooling loads, the lighting electricity consumption, and the electricity production of each office zone were calculated, and the effect of zone orientation was investigated for WWR of 50% with the lighting control.

### *3.4.1 The effect on the heating and cooling loads*

Figures 14 and 15 show the heating load and the cooling load as a function of solar cell transmittance, respectively. The difference between the northern zones and the southern zones was large, and was as much as 32% for the heating load at the solar cell transmittance of 80%. The difference between the eastern zones and the western zones was small, which indicated that the direct solar gain in the morning was almost equivalent to that in the evening. The maximum heating load occurred at the transmittance of 20% for the southern zones, while it occurred at the transmittance of 40% or 50% for the northern zones. The minimum cooling loads also occurred at different solar cell transmittances, and were 20% or 30% for the southern zones, and 30% or 40% for the northern zones.

The different transmittances at the maximum or minimum points were arisen from the significance of the direct solar gain through the window. In the southern zones, the direct solar gain overrode the reduction of heat gain from lighting at the solar transmittances of more than 30%. In the northern zones, the influence of the direct solar gain turned dominant at higher transmittance since the northern zones received less direct solar radiation.

### *3.4.2 The effect on the lighting electricity consumption*

The lighting electricity consumption is presented in Fig. 16. When the solar cell transmittance was less than 40%, the difference between the northern zones and the southern zones was more than 15%. The difference was attenuated with the increase in transmittance, and it was negligible at the solar cell transmittance of 80%.

### 3.4.3 The effect on the electricity production from the photovoltaics

Figure 17 depicts the electricity production from the photovoltaics as a function of solar cell transmittance. As for the electricity production from the photovoltaics, the difference between the eastern zones and the western zones was negligible, while the difference between the southern zones and the northern zones was significant. This is obviously due to the amount of direct solar radiation. The difference between the southern zones and the northern zones was about 33% at any transmittances.

### 3.4.4 The effect on the total electricity consumption

Figure 18 shows the total electricity consumption as a function of solar cell transmittance, where the electric driven heat pump was assumed as the heating and cooling system. The electricity consumption of the southern zones was smaller than the northern zones by more than 20% when the solar cell transmittance was between 10 and 40%. The minimum electricity consumption was achieved at the transmittance of 40% for the SW Zone and the SE Zone, at the transmittance of 50% for the NW Zone, and at the transmittance of 60% for the NE Zone.

The results implied that further reduction of the total electricity consumption would be possible by the use of appropriate solar cell transmittances for PV windows corresponding to the orientation. The optimum solar cell transmittances for PV windows of different orientation in each zone were investigated by parametric analysis, and are described in the next section.

### *3.4.5 The optimum solar cell transmittance of the PV window of different orientation*

Each zone except the core zone has PV windows of two different orientations on the exterior walls. Parametric analysis on the solar cell transmittance of the PV windows in each zone was carried out. The transmittance was varied from 10% to 80%, and WWR was constant at 50%. The lighting was controlled with daylighting.

Figure 19 depicts a 3-dimensional graph of the total electricity consumption as a function of the solar cell transmittances of the south and east side windows in the SE Zone. Contours are shown on the surface in the graph. It was shown that the total electricity consumption was less than 22 kWh/m$^2$ when the transmittance of the south side window was 30 to 40% and the transmittance of the east side window was around 50%. The minimum electricity consumption in the SE Zone was achieved with the south side transmittance of 30% and the east side transmittance of 50%.

The optimum transmittances, which minimize the total electric consumption, in the other zones could be obtained by similar parametric analyses. The optimum solar cell transmittance in each office zone was summarized in Table 6. The results revealed that the optimum transmittances of the southern zones were the same. That of the northern zones were also the same as each other.

The optimum solar cell transmittance of the south side PV window was 30%. The optimum transmittance of the south side PV window was lower than that of the other side PV windows because the south side window received the largest annual solar radiation to produce electricity. It also had an effect of the reduction of the excess solar heat gain. The optimum transmittance of the north side PV window was 80%. The transmission of daylight was more beneficial to the north side window because the north side window receives not direct solar radiation but diffuse solar radiation. It was also notable that the optimum transmittance of the east and west side PV windows in the southern zones were different from that in the northern zone. The transmittance of the east and west PV windows in the northern zones was low because the north side window had high transmittance to provide daylighting. In contrast, the southern zones accepted more daylighting through the east and west PV windows to compensate small daylight transmission through the south side PV window.

By the design with the optimum solar cell transmittance in each zone, the total electricity consumption of the building was reduced by 2.4% more compared to the best case of the uniform transmittance design, which was WWR of 50% and the transmittance of 40%. The reduction amounted to 55% compared to the standard model.

## 4 Conclusions

In the study, the application of the see-through solar cell to windows of office buildings was investigated. The parametric analyses on the solar cell transmittance and on window to wall ratio (WWR) were carried out, and the optimum values to minimize the annual total electricity consumption were found. The energy saving by the use of PV window was also estimated taking into account the effect of daylighting. The remarkable findings are listed below.

- Without the lighting control, smaller cell transmittance gives less electricity consumption irrespective of WWR.

- With the lighting control, the optimum solar cell transmittances were 80% for WWR of 30%, 60% for WWR of 40%, and 40% for WWR of 50%.
- The combination of the solar cell transmittance of 40% and WWR of 50% achieved the minimum primary energy consumption in the case of uniform transmittance for all window orientation. The energy saving of 54% was achieved compared to the standard model.
- The total electricity consumption was significantly reduced by the lighting control.
- A 2.4% more reduction was attained by the optimum design of the solar cell transmittance of each zone compared to the design with uniform transmittance at 40% and WWR of 50%. The reduction was 55% compared to the standard model.

It should be noted that the study did not consider the influence of shading by surrounding buildings, which would reduce the benefit of daylighting and the photovoltaic output. The results showed, however, possible energy savings under ideal conditions.

The total electricity consumption calculated in the study assumed a constant COP. Our work should incorporate HVAC systems for the analysis of energy efficient supply systems.

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## List of Figures

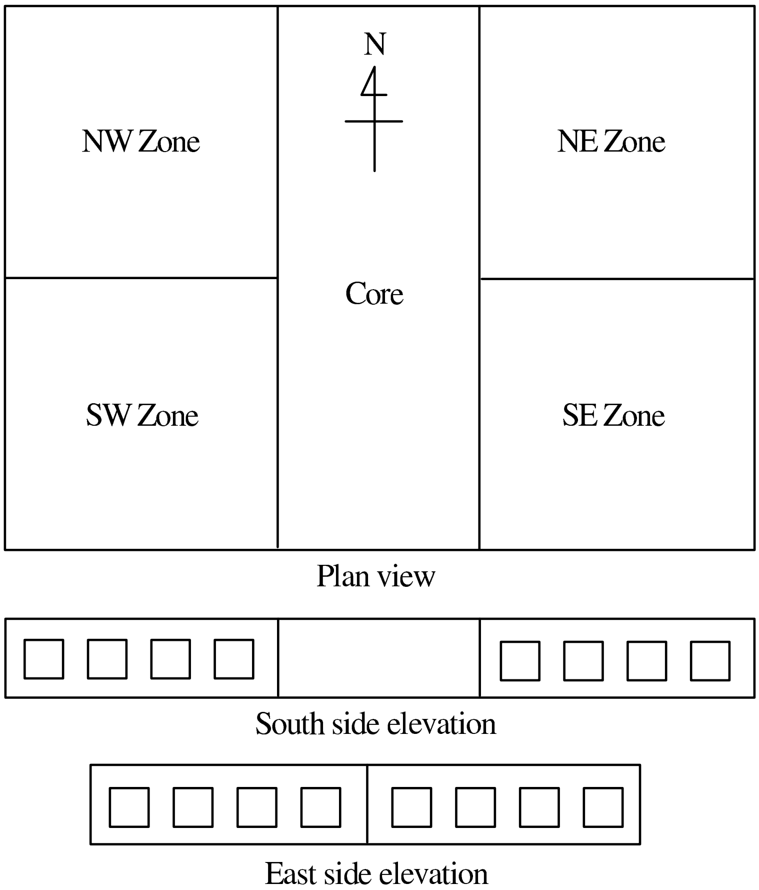
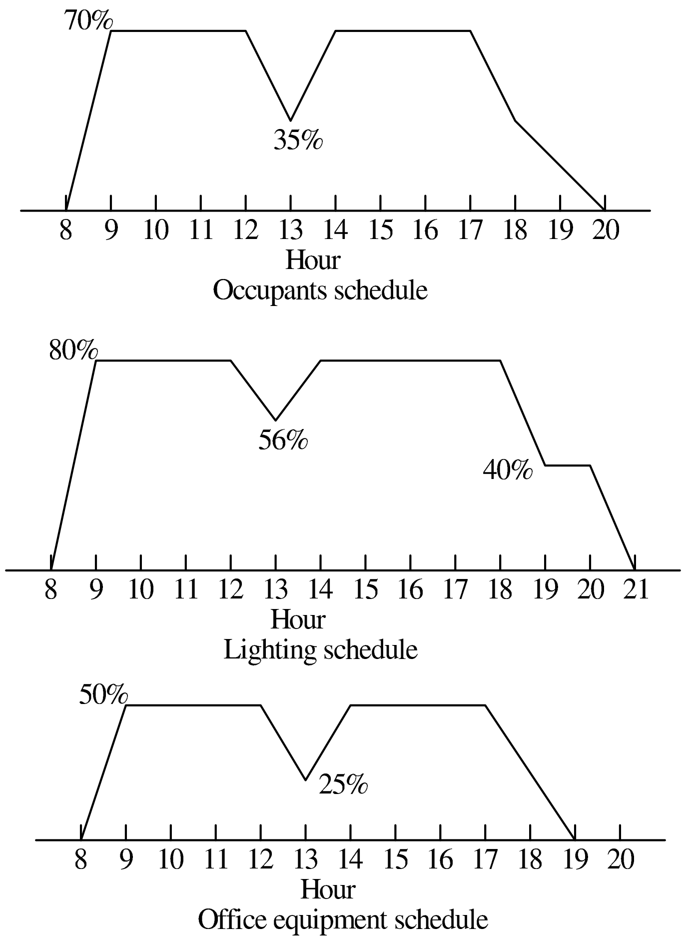



Fig. 1. Plan and elevation of the building

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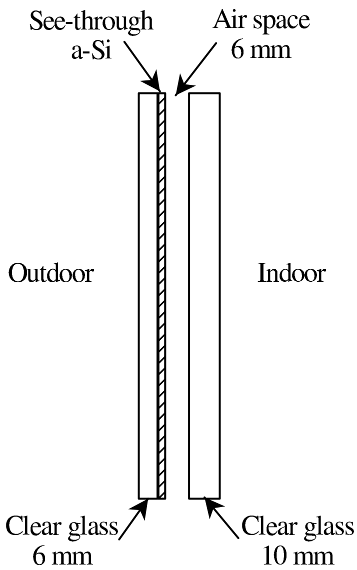


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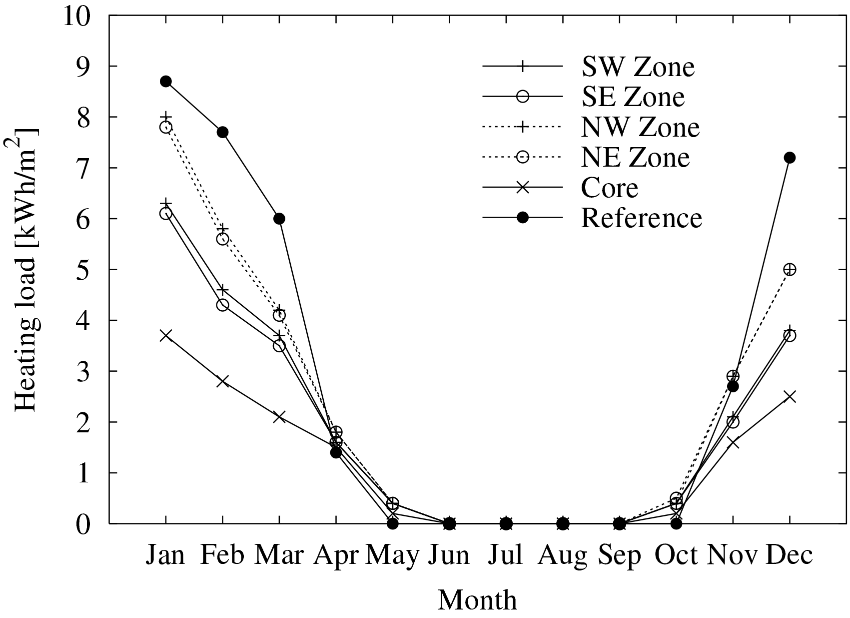


Fig. 4. Monthly heating load of the standard model

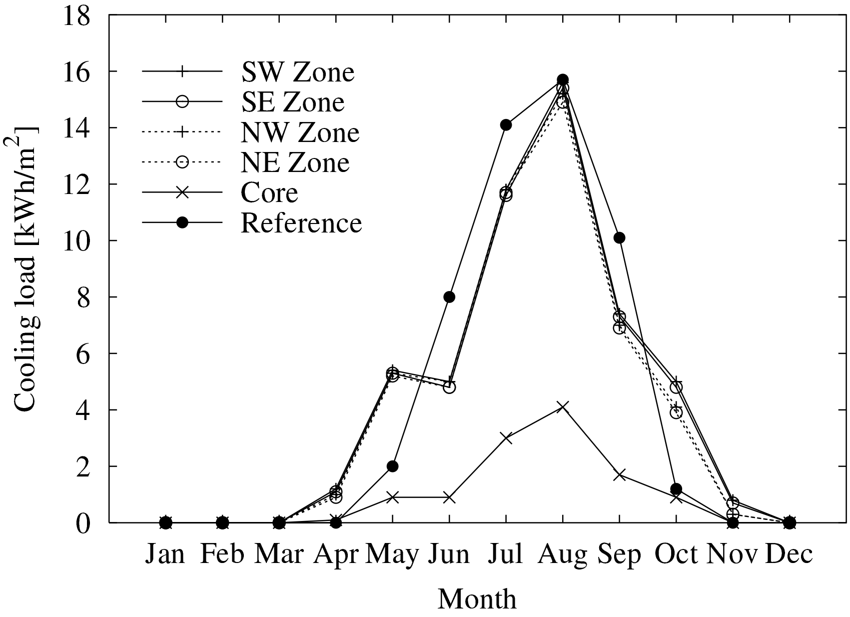


Fig. 5. Monthly cooling load of the standard model



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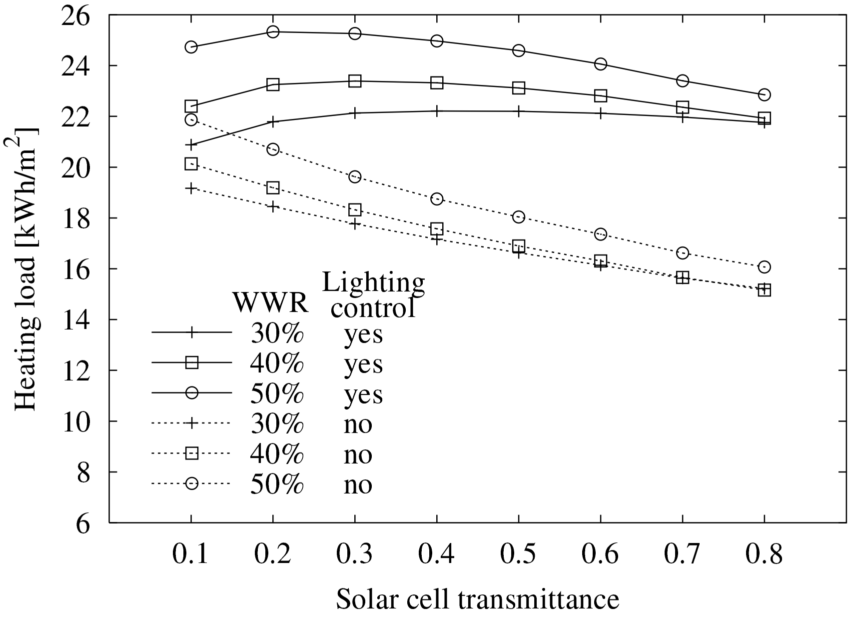


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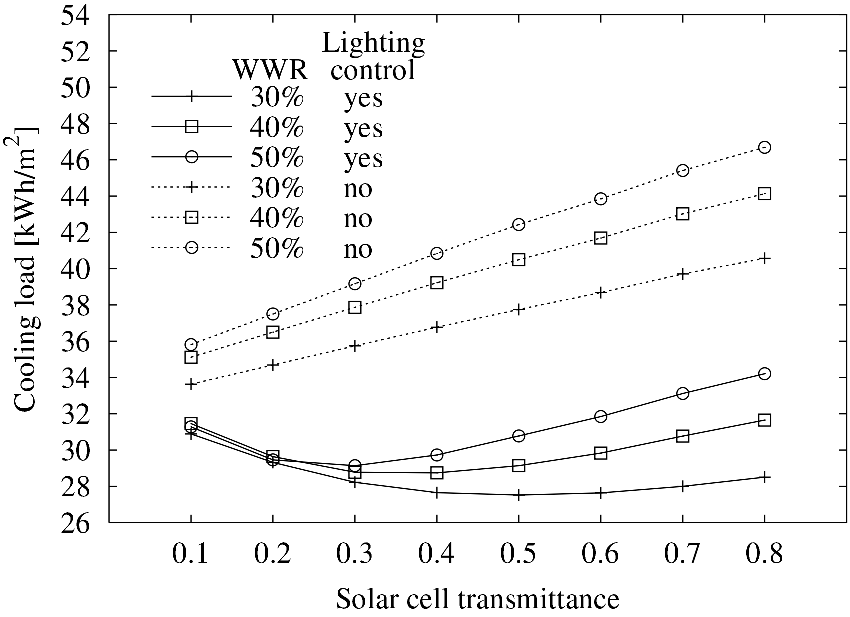


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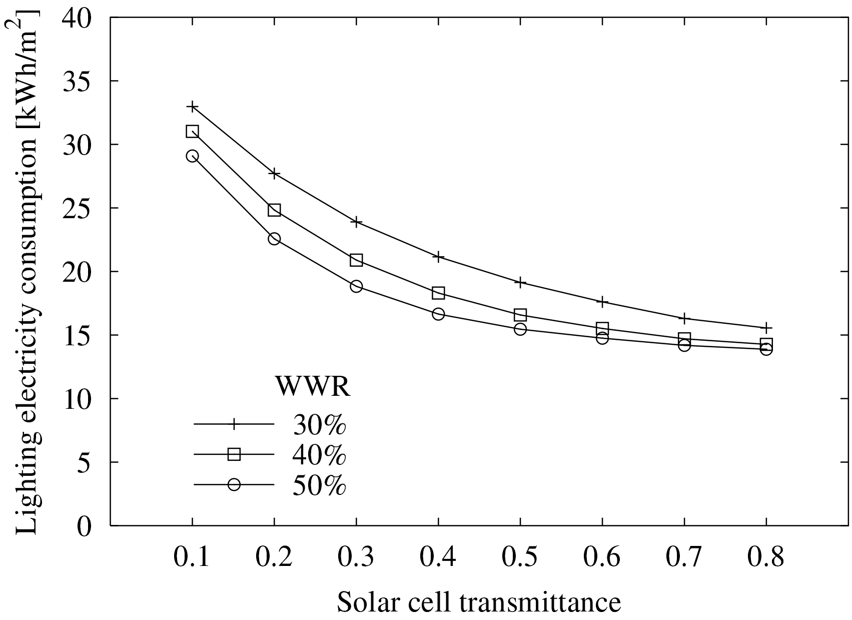


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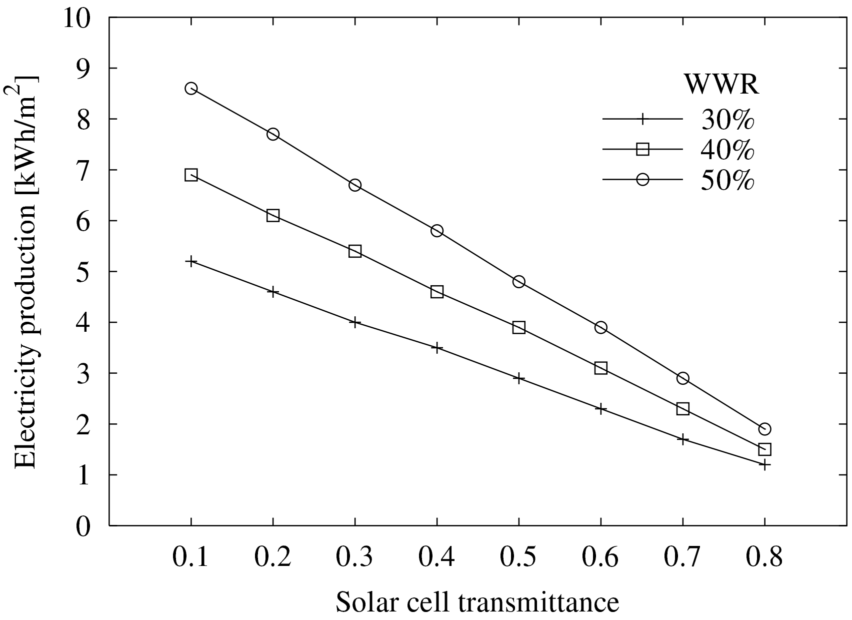


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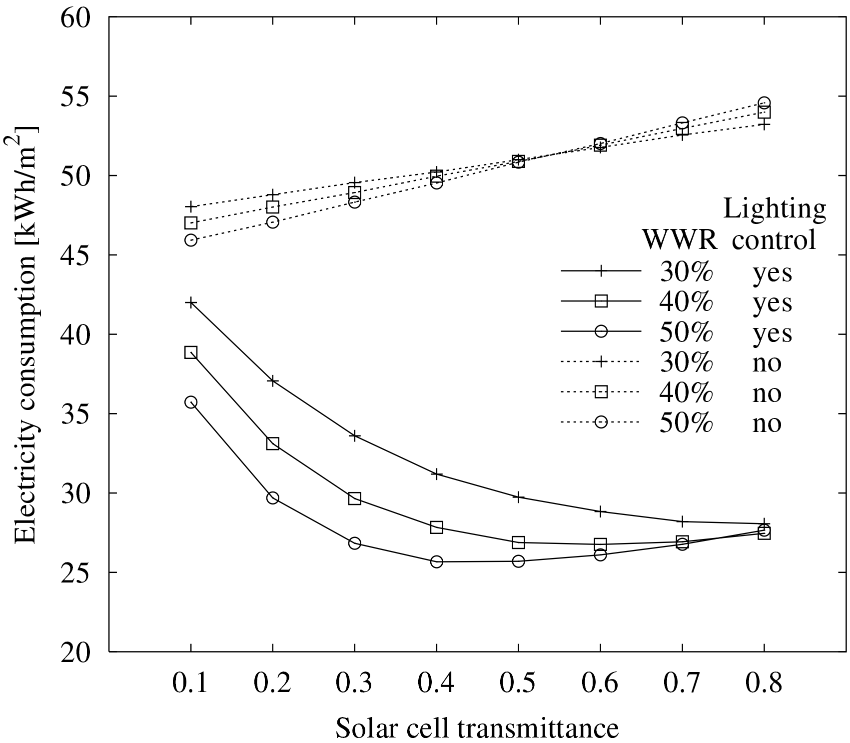


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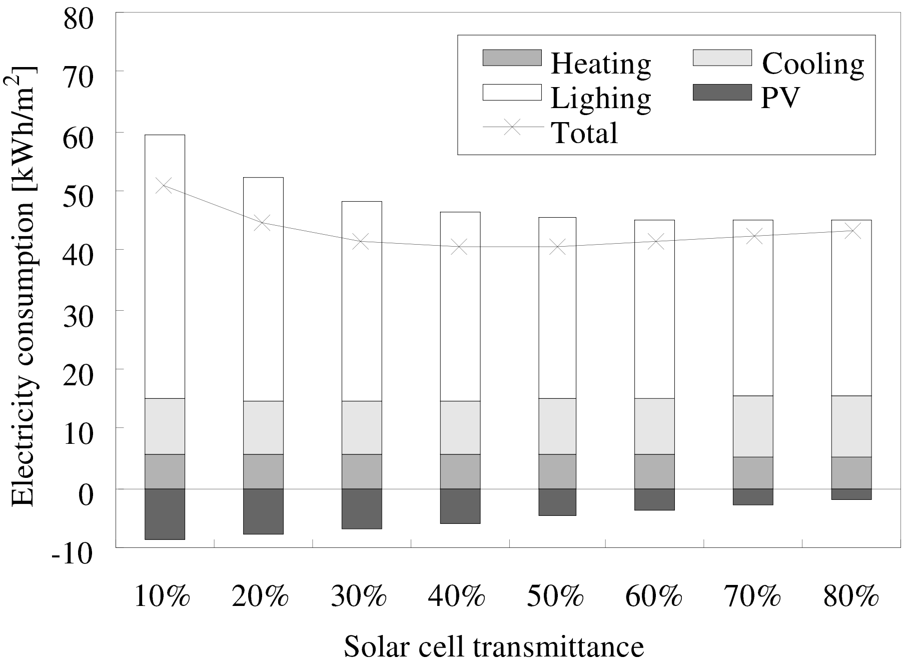


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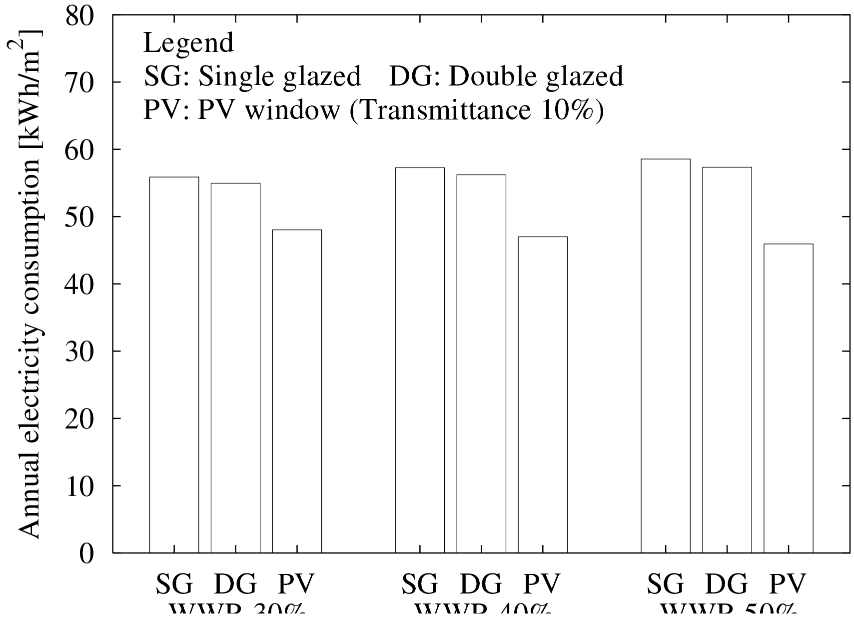


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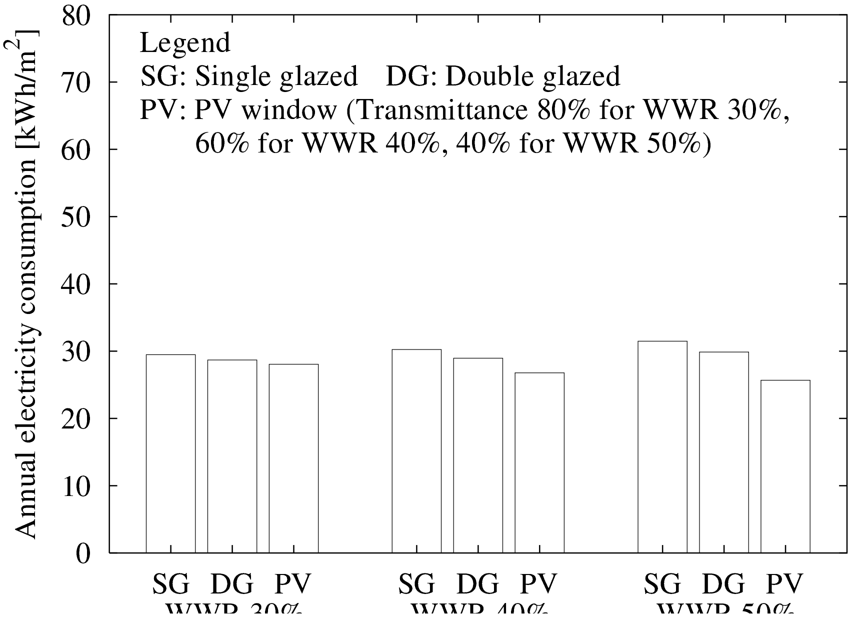


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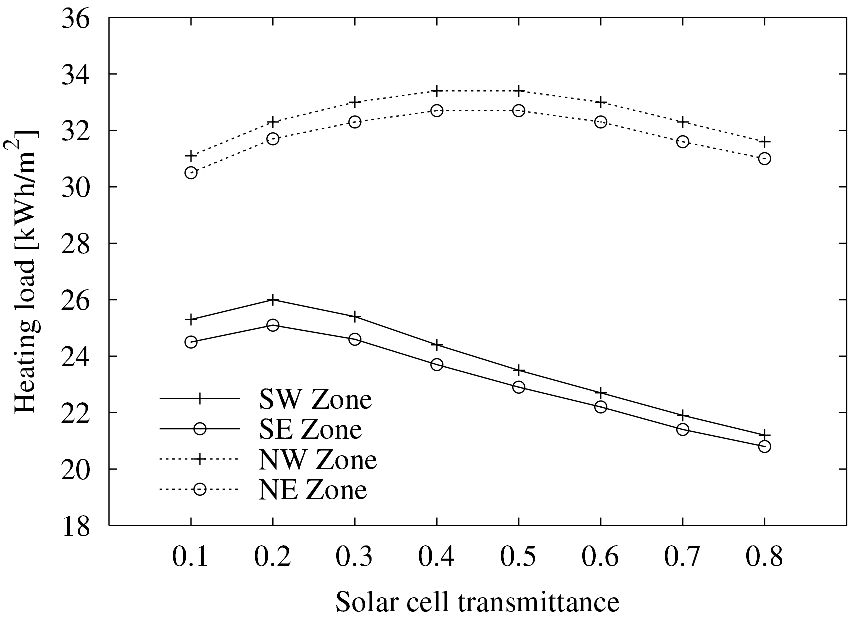


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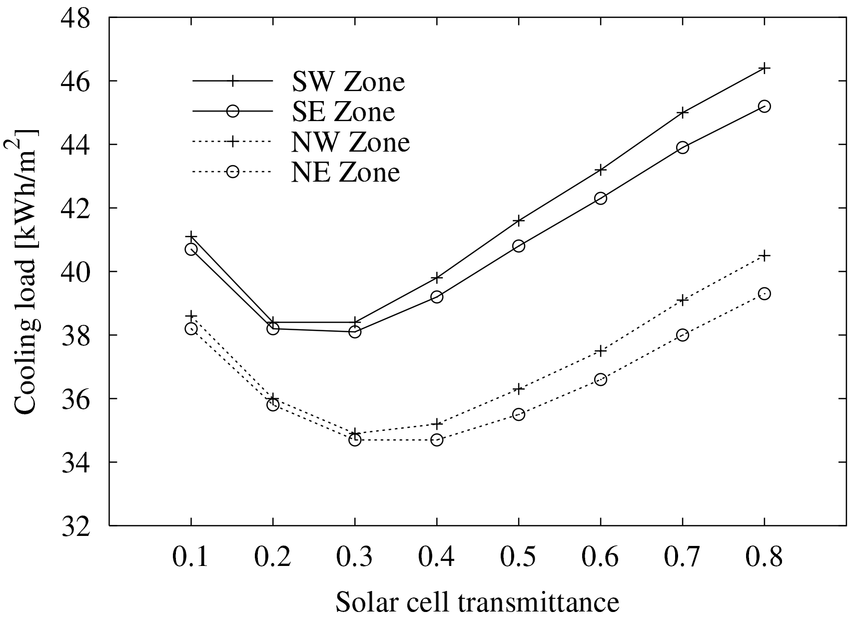


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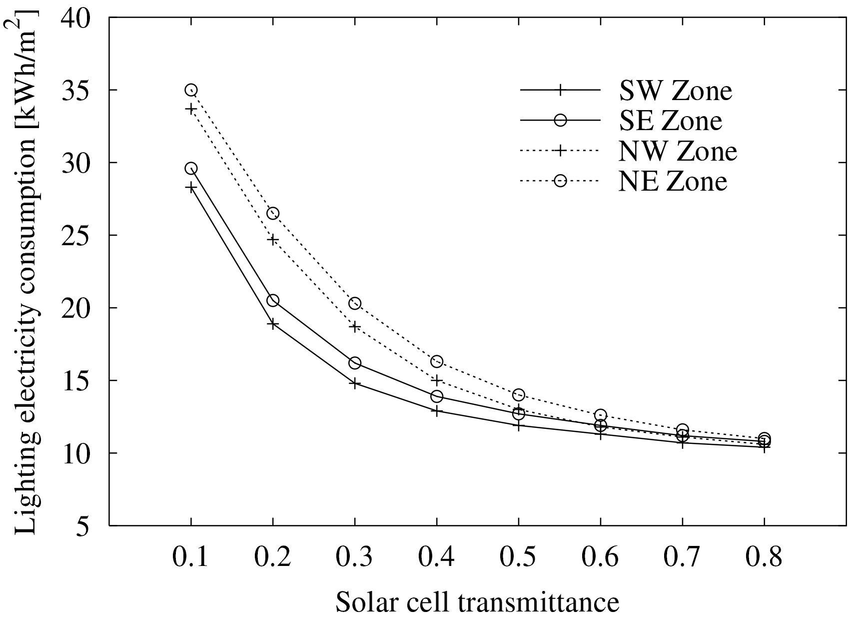


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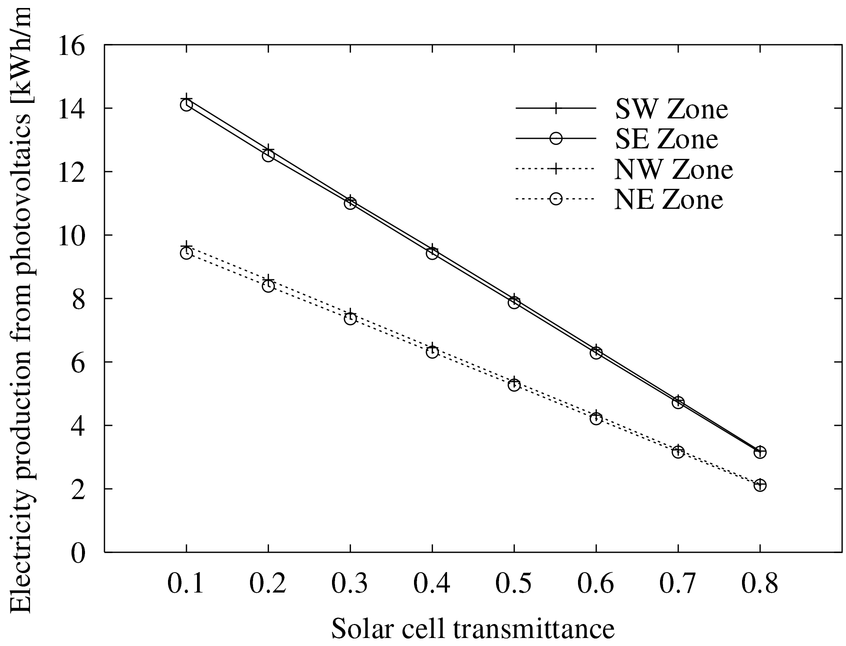


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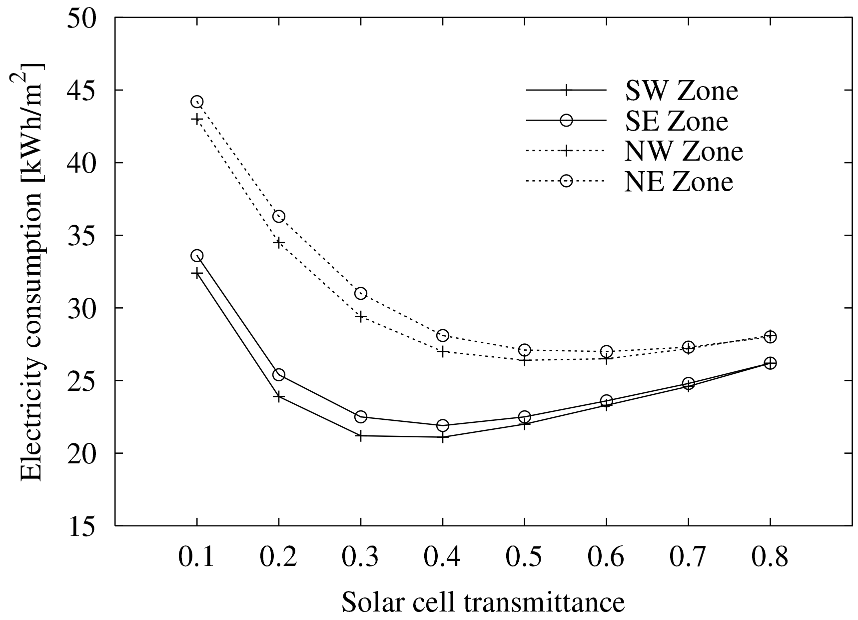


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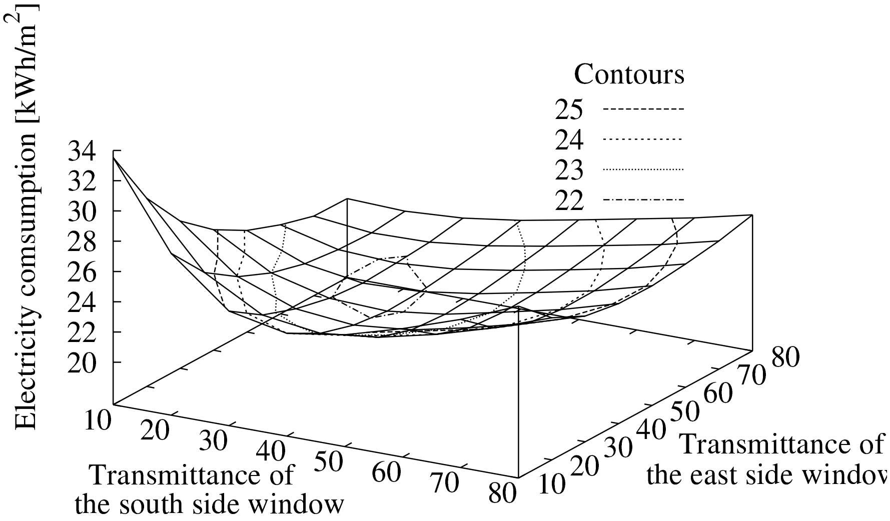


Fig. 19. The effect of the solar cell transmittance on the total electricity consumption of the SE Zone

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Table 1
Walls, ceiling and floor construction (the order of the floor materials is the reverse of that of the ceiling materials)

| | Layers (outer to inner) | Thickness [mm] | Thermal cond. [W/(m·K)] | Density [kg/m$^3$] | Specific heat [J/(kg·K)] |
|---|---|---|---|---|---|
| Exterior wall | Cast concrete | 150 | 1.4 | 2,100 | 840 |
| | EPS | 25 | 0.040 | 25 | 1,400 |
| | Air space | (Thermal resistance = 0.18 m$^2$·K/W) | | | |
| | Plasterboard | 12 | 0.16 | 950 | 840 |
| Interior wall | Cast concrete | 150 | 1.4 | 2,100 | 840 |
| Ceiling /floor | Cast concrete | 150 | 1.4 | 2,100 | 840 |
| | Air space | (Thermal resistance = 0.18 m$^2$·K/W) | | | |
| | Plasterboard | 9 | 0.16 | 950 | 840 |
| | Fiberboard | 12 | 0.06 | 300 | 1,000 |

Table 2
Design values of internal heat gains, ventilation, and infiltration

| | | Offices | Core |
|---|---|---|---|
| Occupants | [person/m$^2$] | 0.2 | 0.03 |
| Lighting | [W/m$^2$] | 25 | 15 |
| Office equipment | [W/m$^2$] | 20 | - |
| Ventilation | [m$^3$/(m$^2\cdot$ h)] | 4.0 | 0.6 |
| Infiltration | [air changes/h] | 0.1 | 0.1 |

Table 3
Optical properties of glass

| Glass type | Solar transmittance | Solar reflectance | | Visible transmittance | Visible reflectance | |
|---|---|---|---|---|---|---|
| | | Front | Back | | Front | Back |
| Clear 6 mm | 0.774 | 0.072 | 0.072 | 0.883 | 0.081 | 0.081 |
| Clear 10 mm | 0.698 | 0.066 | 0.066 | 0.861 | 0.080 | 0.080 |

Table 4
Annual Electricity Consumption by window type; Without Lighting Control

| | | WWR 30 % | | | WWR 40 % | | | WWR 50 % | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | SG | DG | PV | SG | DG | PV | SG | DG | PV |
| Heating | [kWh/$m^2$] | 5.2 | 3.4 | 4.5 | 5.8 | 3.4 | 4.7 | 6.6 | 3.6 | 5.1 |
| Cooling | [kWh/$m^2$] | 12.1 | 13.0 | 10.2 | 12.9 | 14.2 | 10.6 | 13.3 | 15.2 | 10.9 |
| Lighting | [kWh/$m^2$] | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 |
| PV output | [kWh/$m^2$] | 0 | 0 | 5.2 | 0 | 0 | 6.9 | 0 | 0 | 8.6 |

Table 5
Annual Electricity Consumption by window type; With Lighting Control

| | | WWR 30 % | | | WWR 40 % | | | WWR 50 % | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | SG | DG | PV | SG | DG | PV | SG | DG | PV |
| Heating | [kWh/m$^2$] | 7.1 | 5.0 | 5.1 | 7.6 | 4.9 | 5.3 | 8.5 | 5.1 | 5.8 |
| Cooling | [kWh/m$^2$] | 8.5 | 9.2 | 8.6 | 9.4 | 10.4 | 9.0 | 9.9 | 11.3 | 9.0 |
| Lighting | [kWh/m$^2$] | 13.9 | 14.5 | 15.6 | 13.3 | 13.6 | 15.5 | 13.1 | 13.4 | 16.6 |
| PV output | [kWh/m$^2$] | 0 | 0 | 1.2 | 0 | 0 | 3.1 | 0 | 0 | 5.8 |

Table 6
The optimum solar cell transmittance of the PV window in each zone

| | South/North side | East/West side |
|---|---|---|
| SE Zone | 30% | 50% |
| SW Zone | 30% | 50% |
| NE Zone | 80% | 30% |
| NW Zone | 80% | 30% |

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# Comparison of fatal bird injuries from collisions with towers and windows

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ABSTRACT. Birds killed by colliding with towers and windows were studied to describe the type and extent of injuries and, more precisely, to suggest the actual cause of death. A total of 502 specimens (247 tower kills, 255 window kills) were dissected, radiographed, and examined. Tower and window collision categories were further subdivided to consider age (subadult versus adult) and weight (<39 g, sparrow-size or smaller, versus > 39 g, cardinal size or larger) differences in injury and differential vulnerability. Injuries were classified as superficial, subdermal, or skeletal fractures. Comparisons of injuries between tower- and window-killed specimens indicate that the consequences of these two types of collisions are similar. Subdermal injuries were more severe in tower kills than in window kills. Subadults experienced more severe subdermal injuries than adult tower and window casualties. Among window kills, larger birds had more severe subdermal injuries than smaller birds. Collision victims may show blood or fluid in the mouth or nose cavities (30–60%), almost all have subdermal intracranial hemorrhaging (98–99%), and most lack any evidence of skeletal fractures (82–91%). Histological examination of the brain of two specimens revealed blood pools in the cerebrum and cerebellum. The extravascular bleeding in and around the brain is probably the actual cause of death in collision fatalities. Treatment to reduce brain edema if administered within 6–8 h shortly after impact can save some strike casualties.

SINOPSIS. **Comparación de heridas fatales producidas por el choque contra torres o ventanas**
Se estudiaron aves que perecieron a causa de choques con torres o ventanas para describir el tipo y extensión de las heridas y sugerir. con precisión la causa de la muerte. Un total de 502 cadáveres (247 que chocaron con torres y 255 que chocaron con ventanas) fueron disectados, radiografiados y examinados. Las choques con torres y ventanas fueron posteriormente subdivididos para considera la edad (adulto vs. juvenil), peso (≤39 g, tamaño de un pinzón o más pequeño vs. > 39 g. o el tamaño de un cardenal o mayor), diferencias en las heridas y vulnerabilidad diferencial. Las heridas fueron clasificadas como superficiales, subdermales o fracturas esqueletales. La comparación de las heridas en los cadáveres causadas por choques con torres o ventanas indicaron que las consecuencias de estos dos tipos de colisiones son similares. Las heridas subdermales fueron más severas en aves que chocaron con torres que con ventanas. Los subadultos experimentaron heridas subdermales más severas que los adultos tanto en choques con torres como con ventanas. Se encontraron además heridas subdermales más severas en aves grandes que en pequeñas, entre aquellas que chocaron con ventanas. Las víctimas de los choques mostraron sangre o fluidos en la boca o en la cavidad nasal (30–60%), y casi todas mostraron hemorragias subdermales intracraniales (98–99%); la mayoría no mostró evidencia de fracturas esqueletales (82–91%). El examen histológico del cerebro de dos cadáveres revelo sangre en el cerebro y el cerebelo. El sangramiento extravascular y alrededor del cerebro probablemente fue la causa de la muerte de las aves que chocaron. Se pueden salvar algunas de las aves que han sufrido colisiones aplicando un tratamiento para reducir la edema cerebral entre las primeras 6–8 h. luego de ocurrido el choque.

*Key words:* collision injuries, cooling towers, glass, tower kills, window kills

Avian collision casualties are receiving increased attention for their effect on certain species and bird populations in general (Klem 1989, 1991; Shire et al. 2000; Erikson et al. 2001). Where annual avian mortality at solid elevated structures is estimated in the millions of individuals, the kill at plate glass, from small garage panes to windows consisting of entire walls of multistory buildings, is in the hundreds of millions for the U.S alone (Banks 1979; Klem 1990a, 1991; Dunn 1993). The injuries, cause of death, and recuperation of window kills have been reviewed and described to an effective but limited degree (Klem 1990b). Here we quantitatively document and compare fatal injuries resulting from collisions with a concrete elevated nuclear power plant cooling tower and with plate glass windows, and provide a more specific explanation of cause of death. The findings provide additional mea-

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sures to aid rehabilitators, veterinary professionals, and others attempting to diagnose and treat avian collision casualties at impact sources.

## METHODS

Data were obtained from known tower and window collision specimens cataloged in the Natural History Museum, Department of Biology, Muhlenberg College, Allentown, Pennsylvania. Tower kills were collected after striking and falling to the base of cooling towers at the nuclear power plant in Limerick, Montgomery County, Pennsylvania in 1979 and 1980. Window kills were collected from several commercial and residential buildings in and around Carbondale, Jackson County, Illinois, and Allentown, Lehigh County, Pennsylvania, from 1971 to 1980. Tower kills occurred during nocturnal passage and were discovered as much as eight hours after death. Window kills occurred during daylight and were discovered immediately or within one to two hours after death. Detailed examinations were conducted to determine superficial, subdermal, and skeletal injuries in the head and neck regions of 255 tower kills of 22 species and 247 window kills of 58 species. Histological preparations from a window-killed Sharp-shinned Hawk (*Accipiter striatus*) and an American Robin (*Turdus migratorius*) were studied to determine internal soft tissue injuries to the brain. Only head and neck injuries were examined because previous work revealed no discernible injuries to other parts of the body (Klem 1990b).

Superficial injuries were ranked according to severity and consisted of the presence or absence of blood or fluid in the mouth, nasal cavity, or both. After removing the skin from the head, subdermal injuries were recorded by drawing the extent of visible blood pooling within the skull. Sagittal halves of the skull of each specimen were compared to determine if blood pooling was a consequence of typical postmortem change (Harrison and Harrison 1986). If blood pooling was symmetrical, non-collision bleeding was judged to have occurred; asymmetrical blood pooling was judged the result of collision injury. Additionally, impact injuries were recorded if blood pooling was so extensive that it obscured the double layer of cranial bone in adult specimens. Six subdermal injury categories were used to record the severity of impact based on the extent of blood pooling: (1) none, (2) <25%, (3) 26 < 50%, (4) 51 < 75%, (5) 76 < 99%, and (6) completely covered. Skeletal fractures were recorded by detailed analysis of radiographs; four aspects of each specimen were taken (dorsal and ventral, left and right lateral). A Vector brand Picker International X-ray Unit at the Allentown Osteopathic Hospital, Allentown, Pennsylvania was used with the following unit parameters: 40 kilovolts, 75 milliamps, 15 milliamp-s, and A9% anode; x-ray tube focal spot was extended to 94 cm to maximize definition and detail (Harrison and Harrison 1986). Specimens were placed directly on the film cassette to obtain the sharpest image. Kodak MIN-R film was used in a Kodak X-O-Matic cassette with single lanex fine screen, and developed using Kodak MGAW processor with a 90-s cycle.

The two window-killed histological specimens were preserved *in toto* immediately after death by immersion in Tellyesniczky's AAF fixative for 24 h, and then stored in 70% ethanol (Lillie 1965). Their brains were removed, embedded in paraffin, cut sagittally at 7 microns, and stained with hematoxylin and eosin using standard procedures (Lillie 1965; Humason 1979). Each serial slide was examined using a light microscope and photomicrographs were taken with an Olympus Vanox microscope.

All specimens were cataloged with a unique number, weighed, sexed by plumage and gonadal examination, and aged by plumage and the extent of skull pneumatization for passerines (Miller 1946). Anatomical terminology follows Baumel et al. (1993).

Chi-square tests of independence were used to compare superficial and subdermal injuries between tower and window casualties, subadult and adult age classes within the separate tower- and window-kill samples and select tower-killed species having sufficient samples sizes, and window-killed weight classes consisting of $0 \leq 39$ g (hummingbirds to sparrows) and >39 g (cardinal to bobwhite; SPSS 2002). All comparisons based on $2 \times 2$ contingency tables were evaluated after applying a correction for continuity (Siegel 1956).

## RESULTS

Superficial injuries differed between tower and window casualties ($\chi^2_3 = 50.8$, $P < 0.001$,

Table 1. Superficial injuries of tower and window collision bird fatalities.

| | | Presence of blood or fluid | | | |
|---|---|---|---|---|---|
| | | None | Mouth cavity | Nasal cavity | Mouth and nose |
| Category | *N* | *N* (%) | *N* (%) | *N* (%) | *N* (%) |
| Tower | | | | | |
| Total | 247 | 174 (70) | 71 (29) | 2 (1) | 0 (0) |
| Age | | | | | |
| Subadult | 167 | 113 (68) | 53 (32) | 1 (1) | 0 (0) |
| Adult | 72 | 54 (75) | 17 (24) | 1 (1) | 0 (0) |
| Window | | | | | |
| Total | 255 | 101 (40) | 143 (56) | 5 (2) | 6 (2) |
| Age | | | | | |
| Subadult | 97 | 43 (44) | 50 (52) | 3 (3) | 1 (1) |
| Adult | 121 | 42 (35) | 73 (60) | 2 (2) | 4 (3) |
| Weight class | | | | | |
| ≤39 g | 168 | 68 (41) | 93 (55) | 4 (2) | 3 (2) |
| >39 g | 87 | 33 (38) | 50 (58) | 1 (1) | 3 (3) |

Table 1). Differences were most evident in the amount of detectable blood and fluid in the mouth cavity: undetected in 70% of tower-kills, present in 56% of window-kills. There were no differences in superficial injuries between subadult and adult tower ($\chi^2_2 = 1.9$, $P = 0.39$, Table 1) or window ($\chi^2_3 = 3.7$, $P = 0.29$, Table 1) fatalities. Similarly, there were no superficial differences between subadult and adult tower-killed Red-eyed Vireo (*Vireo olivaceus*, subadult, 40% without blood in mouth, 54% with blood; adult, 64% without blood, 36% with blood; $N = 48$; $\chi^2_1 = 0.5$, $P = 0.49$) and Magnolia Warbler (*Dendroica magnolia*, subadult, 62% without blood, 36% with blood; adult, 83% without blood, 17% with blood; $N = 28$; $\chi^2_1 = 0.6$, $P = 0.43$). Comparison of window-killed weight classes revealed no differences in superficial injuries between small (≤39 g) and large (>39 g) birds ($\chi^2_3 = 1.3$, $P = 0.74$, Table 1).

Subdermal injuries differed between tower and window casualties ($\chi^2_5 = 13.4$, $P = 0.020$, Table 2). Tower-killed birds had proportionately greater amounts of intracranial blood pooling (>50%) than window-killed birds. Subadults differed from adults in having more blood pooling in both tower ($\chi^2_5 = 30.7$, $P < 0.001$, Table 2) and window ($\chi^2_5 = 16.4$, $P = 0.006$, Table 2) fatalities. There were no subdermal injury differences between subadult and adult tower-killed Red-eyed Vireo (subadult, 31% ≤ 50% intracranial blood pooling, 69% > 50% blood pooling; adult, 36% ≤ 50% blood pooling, 64% > 50% blood pooling; $N = 50$; $\chi^2_1 = 0.0$, $P = 0.99$), Magnolia Warbler (subadult, 56% ≤ 50% blood pooling, 44% > 50% blood pooling; adult, 85% ≤ 50% blood pooling, 15% > 50% blood pooling; $N = 29$; $\chi^2_1 = 1.5$, $P = 0.22$), and Common Yellowthroat (*Geothlypis trichas*, subadult, 44% ≤ 50% blood pooling, 56% > 50% blood pooling; adult, 88% ≤ 50% blood pooling, 12% > 50% blood pooling; $N = 26$; $\chi^2_1 = 2.6$, $P = 0.11$). Among window fatalities there were proportionately more low-level amounts of blood pooling in small (≤39 g) birds and proportionately more high-level amounts of blood pooling in large (>39 g) birds ($\chi^2_5 = 24.9$, $P = 0.001$, Table 2).

Most tower and window fatalities lacked skeletal fractures, and all fractures were in the mandible-anterior skull junction where individuals most likely first contacted the glass surface (Table 4). More tower-killed adults sustained fractures than subadults, but proportionately more window-killed subadults had fractures than adults. Small (≤39 g) and large (>39 g) window-killed birds did not differ in the proportionate number of fractures. In general, the

Table 2. Subdermal injuries of tower and window collision bird fatalities.

| | | Percent coverage of intracranial blood pooling | | | | | |
|---|---|---|---|---|---|---|---|
| | | None | ≤25 | 26 ≤ 50 | 51 ≤ 75 | 76 ≤ 99 | 100 |
| Category | *N* | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) | *N* (%) |
| Tower | | | | | | | |
| Total | 247 | 3 (1) | 89 (36) | 33 (13) | 19 (8) | 90 (36) | 13 (5) |
| Age | | | | | | | |
| Subadult | 167 | 0 (0) | 47 (28) | 19 (11) | 13 (8) | 76 (46) | 12 (7) |
| Adult | 72 | 3 (4) | 36 (50) | 14 (19) | 6 (8) | 12 (17) | 1 (1) |
| Window | | | | | | | |
| Total | 255 | 5 (2) | 112 (44) | 33 (13) | 34 (13) | 64 (25) | 7 (3) |
| Age | | | | | | | |
| Subadult | 97 | 0 (0) | 34 (35) | 9 (9) | 17 (18) | 33 (34) | 4 (4) |
| Adult | 121 | 5 (4) | 58 (48) | 19 (16) | 16 (13) | 22 (18) | 1 (1) |
| Weight class | | | | | | | |
| ≤39 g | 168 | 5 (3) | 88 (52) | 19 (11) | 17 (10) | 38 (23) | 1 (1) |
| >39 g | 87 | 0 (0) | 24 (28) | 14 (16) | 17 (20) | 26 (30) | 6 (7) |

type of fracture and their proportionate occurrence were similar in tower and window casualties.

Histological study of serial sagittal sections of the window-killed Sharp-shinned Hawk and American Robin revealed impact trauma to the brain. Extensive intracranial hemorrhaging and large blood pools were present in the cerebrum and cerebellum of both specimens.

## DISCUSSION

Overall, tower and window collision fatalities sustained similar superficial, subdermal, and skeletal injuries, and had the same cause of death. The differences in superficial injuries between tower and window casualties are best explained by the way specimens were discovered, collected, and recorded. Most tower kills were

Table 3. Skeletal injuries of tower and window collision bird fatalities.

| | | Fractures | | |
|---|---|---|---|---|
| | | None | One or more | Individuals with more than one |
| Category | *N* | *N* (%) | *N* (%) | *N* (%) |
| Tower | | | | |
| Total | 247 | 203 (82) | 44 (18) | 28 (11) |
| Age | | | | |
| Subadult | 167 | 141 (84) | 26 (16) | 17 (10) |
| Adult | 72 | 55 (76) | 17 (24) | 11 (15) |
| Window | | | | |
| Total | 255 | 232 (91) | 23 (9) | 11 (4) |
| Age | | | | |
| Subadult | 97 | 85 (88) | 12 (12) | 5 (5) |
| Adult | 121 | 118 (98) | 3 (3) | 2 (2) |
| Weight class | | | | |
| ≤39 g | 168 | 153 (91) | 15 (9) | 7 (4) |
| >39 g | 87 | 79 (91) | 8 (9) | 4 (5) |

Table 4. Species and cranial fractures of tower and window collision bird fatalities.

| Category | *N* | Bones fractured[a] |
|---|---|---|
| Tower | | |
| Ruby-throated Hummingbird (*Archilochus colubris*) | 1 | os dentale |
| Brown Creeper (*Certhia americana*) | 1 | os dentale |
| Ruby-crowned Kinglet (*Regulus calendula*) | 3 | os dentale, os nasale, os maxillare, os premax-os nasale |
| Red-eyed Vireo | 9 | os dentale, os nasale, os maxillare, os palatinum |
| Northern Parula (*Parula americana*) | 1 | os dentale, os maxillare |
| Magnolia Warbler | 5 | os dentale, os nasale, os maxillare |
| Black-throated Blue Warbler (*Dendroica caerulescens*) | 3 | os dentale, os premax-os nasale |
| Yellow-rumped Warbler (*Dendroica coronata*) | 1 | os dentale |
| Black-throated Green Warbler (*Dendroica virens*) | 1 | os palatinum |
| Blackburnian Warbler (*Dendroica fusca*) | 4 | os dentale, os nasale, os maxillare, os premax-os nasale, os premax-os max |
| Bay-breasted Warbler (*Dendroica castanea*) | 4 | os dentale, os maxillare |
| Blackpoll Warbler (*Dendroica striata*) | 1 | os dentale, os premax-os nasale |
| Ovenbird (*Seiurus aurocapilla*) | 4 | os dentale, os nasale, os maxillare, os premax-os nasale |
| Common Yellowthroat | 6 | os dentale, os nasale, os maxillare, os premax-os nasale |
| Window | | |
| Northern Bobwhite (*Colinus virginianus*) | 2 | os dentale, os palatinum |
| Mourning Dove (*Zenaida macroura*) | 2 | os dentale, os nasale, os maxillare |
| Tufted Titmouse (*Baeolophus bicolor*) | 1 | os premax-os nasale, os premax-os max |
| Gray-cheeked Thrush (*Catharus minimus*) | 1 | os dentale |
| Wood Thrush (*Hylocichla mustelina*) | 1 | os dentale |
| American Robin | 2 | os dentale, os premax-os nasale |
| Cedar Waxwing (*Bombycilla cedrorum*) | 2 | os dentale, os maxillare, os premax-os nasale |
| Red-eyed Vireo | 1 | os nasale, os maxillare |
| Tennessee Warbler (*Vermivora peregrina*) | 3 | os dentale |
| Blackburnian Warbler | 1 | os dentale |
| Ovenbird | 2 | os dentale, os nasale, os maxillare, os premax-os nasale |
| Canada Warbler (*Wilsonia canadensis*) | 1 | os dentale |
| Yellow-breasted Chat (*Icteria virens*) | 1 | os dentale |
| Scarlet Tanager (*Piranga rubra*) | 1 | os dentale, os maxillare |
| White-throated Sparrow (*Zonotrichia albicollis*) | 1 | os dentale |

[a] Abbreviations: region of processus frontalis of premaxillare and processus premaxillaris of os nasale (os premax-os nasale), and region of processus maxillaris of os premaxillare and os maxillare (os premax-os max).

discovered and collected hours after impact, and the amount of blood and fluid in the mouth and nasal cavities was recorded days later when this evidence would have been more difficult to measure due to drying. By contrast, all window kills were discovered within a few hours of death, and the presence or absence of fluids in the mouth and nose was recorded immediately. Subdermal injuries measured by the amount of intracranial blood pooling was more severe in tower kills than in window kills. These differences may result from the force with which birds strike the respective concrete and glass. Migrants aloft flying at more consistent speeds may strike concrete or metal towers with greater momentum, causing greater injury than for birds near the ground flying at more variable speeds from vegetation or feeders and striking glass where the momentum is enough to be fatal but less severe. Similarly, as expected, subadults with potentially incomplete cranial development differed from adults in the amount of subdermal injury within the tower and window samples, although no intraspecific age differences were evident for three species (Red-eyed Vireo, Magnolia Warbler, Common Yellowthroat). The same skeletal fractures to the mandible and other anterior skull bones indicate that collision victims most often hit both types of structures head first.

Most tower (82%) and window (91%) fatalities experienced no skeletal fractures, and no cervical fractures were found in either the tower- or window-kill samples, further confirming that the often cited cause of death of collision victims from a "broken neck" is clearly in error. However, documenting that broken necks can occur from high speed collisions, a detailed pathology report from Tufts University Veterinary Medical Center describes an immature Peregrine Falcon (*Falco peregrinus*,) who after striking a window in Boston, Massachusetts, sustained a cervical fracture (C6), was initially paralyzed from the neck down, and succumbed to this and other complications resulting from the impact (T. French, pers. comm.). Moreover, avian window collision injuries are known for body parts other than the head and neck. The rehabilitation program at the Raptor Trust in Millington, New Jersey, has recorded coracoid displacement and fractures in window strike casualties (L. J. Soucy, Jr., pers. comm.).

Our histological examination of internal brain damage in two window-killed specimens found substantial hemorrhaging in the cerebrum and cerebellum. Blood pools were most prominent in the cerebellar white matter. Fatalities resulting from collisions are most likely the result of damage to the cerebellar communicating fibers (vital afferent and effect tracts), breakage of blood vessels and subsequent rupturing of the blood—brain barrier at several sites, complications from herniation of parts of the cerebellum and medulla through the foramen magnum, and the extensive subdural bleeding followed by intracranial edema. Symptoms exhibited by collision survivors support this conclusion (Klem 1990b); prior to death, strike casualties are often completely or intermittently non-responsive, lack balance, normal posture, or coordinated muscle action, some exhibit ipsilateral drooping eye, wing, and dilated pupil, and rapid or slow heaving respiratory movements. These internal brain injuries best explain the cause of death of collision fatalities. Those treating survivors have had some success in administering the drug dexamethasone sodium phosphate as much as six to eight hours after impact to help limit brain swelling (R. Hunsinger, pers comm.).

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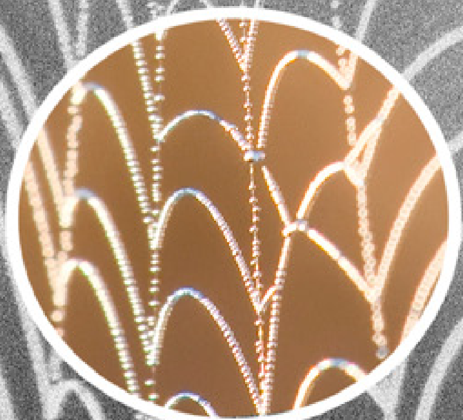

BIOMIMICRY 3.8

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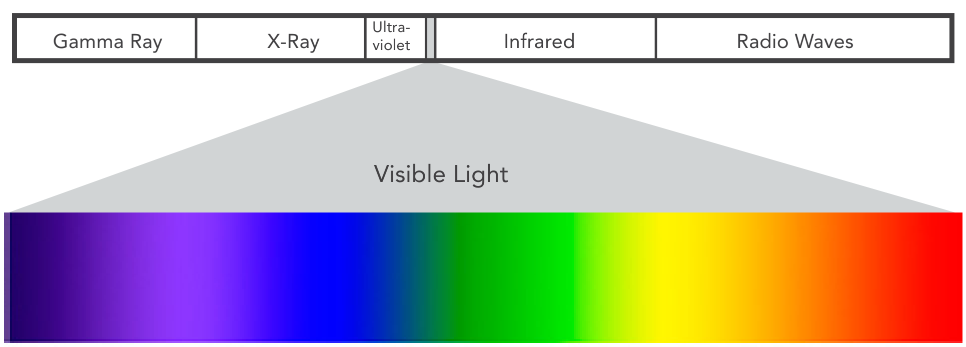
| INNOVATORS | Researcher \| Arnold Glas |
| | Company \| Arnold Glas |
| WEBSITE | www.ornilux.com/history-research.html |
| SUSTAINABILITY WIN | Reduces bird mortality due to window strikes |
| EMULATING FORM, PROCESS, OR SYSTEM? | Form / Process |
| LIFE'S PRINCIPLE MET | Use multi-functional design; be locally attuned and responsive |

## The Inspiration

Over 3,000 species of orb weaver spiders (family *Araneidae*) are found throughout the world, including the common garden spiders of North America and Europe. These spiders construct flat webs consisting of concentric circles with spokes radiating out from the center. Females typically build the webs and use them to capture prey. While the webs are known for their remarkable mechanical properties, even the best-built webs are subject to failure if a bird strikes them. In order to protect their investment, some orb weavers decorate their webs with UV-reflective threads called stabilimenta. Though humans cannot perceive UV light, birds can, and research has shown that these UV-reflecting threads reduce the incidence of large birds and wasps crashing into the webs.[1,2,3]




Visible light: the area of the electromagnetic spectrum visible to the human eye.

## The Innovators

The imprint left after a bird collided with a glass window.
Photo by Flickr user Billtacular

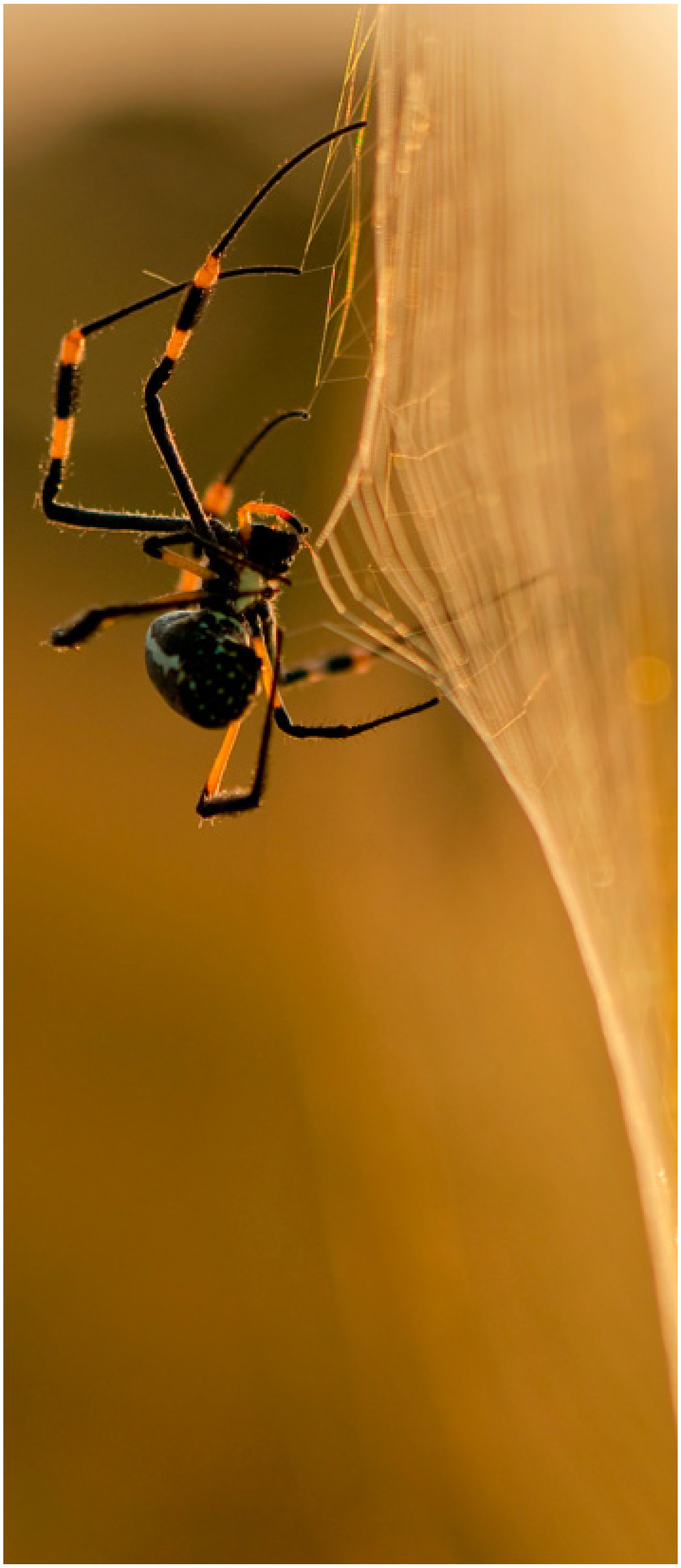
In the late 1990s Dr. Alfred Meyerhuber, a German attorney with a personal interest in birds and science, read an article in a magazine about orb weaver spiders and their use of stabilimenta. Dr. Meyerhuber was good friends with Hans-Joachim Arnold, the owner of Arnold Glas, a manufacturer of insulated glass products headquartered in Remshalden, Germany. Dr. Meyerhuber mentioned the article to Mr. Arnold and encouraged him to research how this biological phenomenon might be applied to glass to prevent birds from striking windows and killing or injuring themselves.

As a young business owner, Mr. Arnold was motivated by technical and environmental challenges and looked for ways to set Arnold Glas apart from its competition. The company motto in German is “Dinge anders tun,” which translates as “Doing things differently.” When Dr. Meyerhuber brought the orb weaver spider’s strategy to his attention, Mr. Arnold was intrigued.  Despite initial resistance by the board of directors, he convinced the company to undertake the necessary research and put his company to work developing a product that would have the same UV-reflecting qualities as spider silk.

### BIOLOGY TO DESIGN: MOTIVATION

Dr. Meyerhuber and Mr. Arnold knew that many birds, fooled by the reflection of trees and sky, simply do not perceive windows as a barrier. With the popularity of expansive windows and glass walls in modern high-rise architecture, bird strikes are a major cause of avian fatalities and kill an estimated 300 million to 1 billion birds globally each year.[4] Migratory songbirds are disproportionally affected, many of which are already threatened due to hunting and shrinking habitats.[5,6]

## The Design Process



Arnold Glas's Head of Research and Development, Christian Irmscher, led the technical product development of ORNILUX. His charge was to develop a UV-reflective glass coating that would balance visibility to birds and transparency to people by capitalizing on the human eye's inability to see UV light. The coating was developed together with technicians at Arnold Glas's sister company, arcon, located in Feuchtwangen, Germany, which specializes in thin low-e and solar coatings for architectural glass. Together they innovated the process and chemistry to apply a patterned coating to glass that is only visible to birds or other organisms that can detect UV light.

The companies tested many different coating types and patterns. The researchers found that a patterned coating (versus a solid coating) made the contrast of the glazing more intense: the coated parts reflected UV light while the interlayer sandwiched between two layers of glass absorbed the UV light. The two functions together enhanced the reflective effect. Although the specific pattern of a spider's web inspired the solution, Irmscher and his team had to design a unique pattern for the window coating in order to make the application process practical.

After patenting the transparent UV coating in 2001, Arnold Glas introduced ORNILUX SB1 Bird Protection Glass, its first commercial product using the technology, in 2006. The vertical lines of UV-reflective coating used in this product were sometimes perceptible but very subtle and not visually distracting. Three years later, the company introduced an improved second-generation product, ORNILUX Mikado. The name refers to the crisscrossed UV pattern of the design and comes from the German name for the game of pick-up sticks. The new pattern and improved coating of Mikado is nearly invisible to the human eye.



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## Why is this Product Better?

Independent pre-market testing by the Max Planck Institute for Ornithology in Radolfzell, Germany, demonstrated that ORNILUX windows are highly effective at protecting against bird strikes. To test the windows, a variety of bird species were released inside a 30′ flight tunnel with two glass windowpanes at the far end – one a control pane with standard glass and the other a pane of the test glass. (In total there were 1384 test flights from 2003 to 2010.) The birds then tried to fly out through one of the perceived "openings" (a net protected them from actually striking the glass), and researchers marked each bird's chosen flight path. The UV-patterned glass significantly reduced bird strikes compared to standard double-glazing.[7]

Remarkable differences in the number of bird strikes have been noted in building projects using ORNILUX as well. The first project in the USA to use ORNILUX was at the Center for Global Conservation at the Bronx Zoo and was completed in 2009. The architects specified ORNILUX SB1 for the entire building, but in the end it was used in only a corner conference room that had the biggest risk of bird strikes. An ongoing monitoring program has noted a dramatic difference between the portions of the building with and without the bird-safe glass.

A year later, Munich's Hellebrunn Zoo used ORNILUX Mikado in the design for a new outdoor polar bear exhibit. Due to the zoo's location near the Isarauen Nature Reserve, which harbors many wild kingfishers, bird collisions were a significant concern. The zoo had other outdoor glass enclosures with a history of bird strikes, and previous attempts to use hawk silhouettes and bamboo plantings to protect the birds had failed. ORNILUX Mikado was used for the polar bear enclosure and pelican house. Zoo officials were pleased to find a solution that did not block visitors' views of the animals and noted in the first months after it was installed that no birds had collided with the glass.

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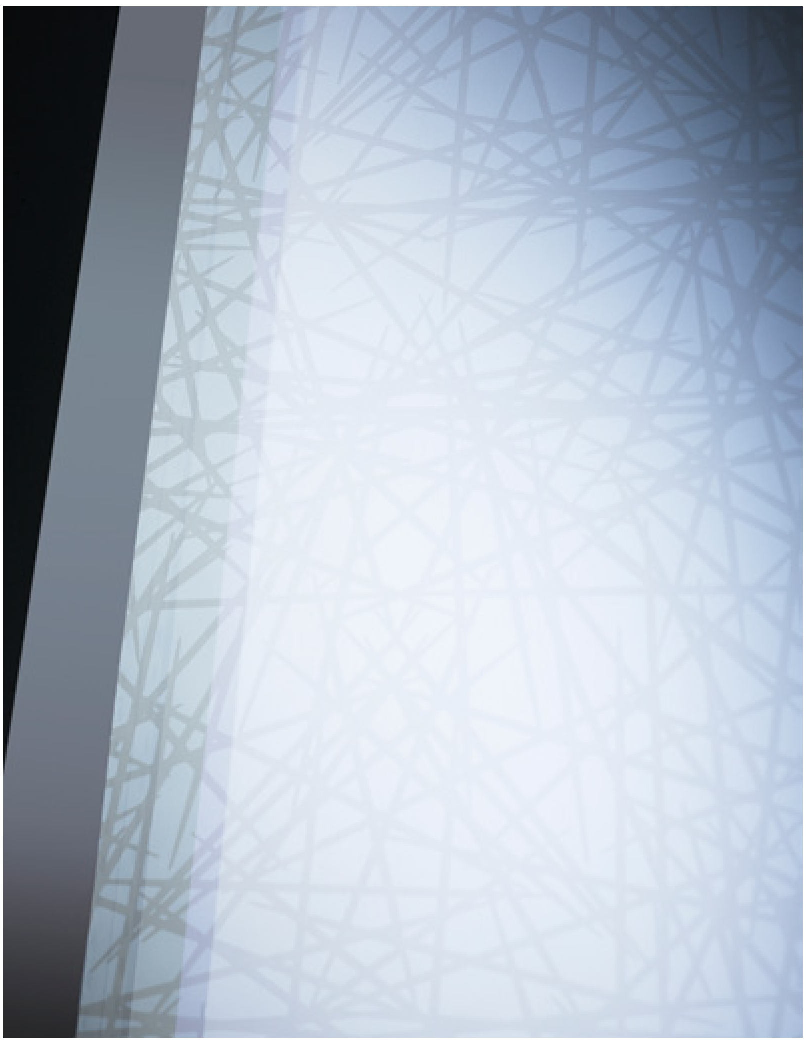
## Broader Impact

As urban planners, city officials, and architects become more aware of the dangers the use of glass in buildings presents to birds, a number of cities are promoting bird-safe design and implementing bird safety building requirements. As of fall 2011, several of the U.S. Green Building Council's LEED green building rating systems offer a Bird Collision Deterrence Pilot Credit, which recommends a number of different design considerations to prevent bird strikes, including products like ORNILUX.[8] Should these design standards become more common and if products like ORNILUX go into wider use, the deaths of hundreds of millions of birds could be avoided every year.



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**PRODUCT DEVELOPMENT TIMELINE**

*Late 1990's*
Dr. Meyerhuber shares the article about spider web stabilimenta with Hans-Joachim Arnold and R&D phase begins

*2001*
ORNILUX bird protection glass patented

*2003-2010*
R&D continues, including field and tunnel testing with the Max Planck Institute

*2006*
First commercial product available (ORNILUX SB1)

*2007*
ORNILUX installed in first building (an indoor swimming pool in Plauen, Germany)

*2009*
Improved product release, ORNILUX Mikado

*2009*
ORNILUX Mikado installed in first building (an office building in Hamburg-Wandsbek, Germany)

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BIOMIMICRY 3.8

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# ARCHITECTURAL AND LANDSCAPE RISK FACTORS ASSOCIATED WITH BIRD–GLASS COLLISIONS IN AN URBAN ENVIRONMENT

DANIEL KLEM JR.,[1,5] CHRISTOPHER J. FARMER,[2] NICOLE DELACRETAZ,[3] YIGAL GELB,[3,4] AND PETER G. SAENGER[1]

ABSTRACT.—We studied building characteristics and landscape context to predict risk of migratory birds being killed by colliding with sheet glass on Manhattan Island, New York City, New York, USA. Trained volunteers monitored 73 discrete building facades daily from the Upper East Side to the southern tip of the Island during autumn 2006 and spring 2007 bird migratory periods using a consistent and scientifically valid search protocol. We recorded 475 bird strikes in autumn 2006 and 74 in spring 2007 of which 82 and 85%, respectively, were fatal. Most building and context variables exerted moderate influence on risk of death by colliding with glass. We recommend a suite of building characteristics that building designers can use to reduce risk of collisions by minimizing the proportion of glass to other building materials in new construction. We suggest that reduction of reflective panes may offer increased protection for birds. Several context variables can reduce risk of death at glass by reducing ground cover, including changes in height of vegetation, and eliminating shrubs and trees from areas in front of buildings. We estimated 1.3 bird fatalities per ha per year; this rate extrapolates to ~34 million annual glass victims in urban areas of North America north of Mexico during the fall and spring migratory periods. Clear and reflective sheet glass poses a universal hazard for birds, specifically for passage migrants in New York City, but also representative and comparable to growing urban areas worldwide. *Received 21 May 2008. Accepted 14 August 2008.*

Growing evidence supports the interpretation that, except for habitat destruction, collisions with clear and reflective sheet glass cause the deaths of more birds than any other human-related avian mortality factor (Klem 1989, 1990b, 2006; Erickson et al. 2001; Manville 2005, 2008). The deaths of 1 billion birds annually from collisions with glass in the United States (U.S.) alone is likely conservative; the worldwide toll is expected to be in the billions (Klem 1990b, 2006; Dunn 1993). Comparable estimates of annual U.S. bird deaths based on extrapolations from other human-related sources include: 120 million from hunting, 60 million from vehicular collisions, 400,000 at wind turbines, and potentially hundreds of millions by domesticated cats (AOU 1975; Banks 1979; Klem 1990b, 1991, 2006; Coleman et al. 1997; Erickson et al. 2001; Manville 2005, 2008). Birds generally act as if sheet glass and plastic in the form of windows and noise barriers are invisible to them. Lethal casualties result from head trauma after birds leave a perch from as little as 1 m away in an attempt to reach habitat seen through or reflected in clear and tinted panes (Klem 1990a, Klem et al. 2004, Veltri and Klem 2005). There is no window size, building structure, time of day, season of year, or set of weather conditions during which birds elude the lethal hazards of glass in urban, suburban, or rural environments (Klem 1989).

We assessed multiple risk factors associated with migratory bird deaths at glass in an urban landscape where increased strike rates have been previously recorded at windows reflecting nearby vegetation (Gelb and Delacretaz 2006). We identified characteristics of building design and landscape context that may explain collision rate at a site, and tested the hypothesis these variables influence the risk of window strikes by migratory birds. Our results are highly relevant to conservationists and regulatory agencies interested in identifying buildings that pose a potential lethal hazard to migrants on passage, and to architects, landscape planners, and other building professionals willing to incorporate these find-

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ings into their designs of human-built structures and environments to protect birds.

## METHODS

We and 30 trained volunteers affiliated with New York City Audubon collected data for this study by monitoring 73 discrete sites (i.e., building façades) from the Upper East Side to the southern tip of Manhattan Island, New York City, New York, USA. Each site was considered an independent sampling unit. It consisted of one surface of an entire building or a section of a building having a similar structure, and intercepted birds flying in a direction different from those intercepted by other façades of the building. Each sampling unit (i.e., façade) possessed a uniform appearance to the human eye and consisted of the same composition of glass and non-glass structure, and associated vegetation. All Upper East Side sites ($n$ = 7) were selected for study at the Metropolitan Museum of Art. All southern sites ($n$ = 18) were within the World Financial Center. We selected 48 sites from lower midtown (from 20th to 30th streets and from the Hudson River to the East River) to monitor bird–glass strikes within a uniform urban area. Lower midtown sites were selected to ensure as uniform distribution as possible of sampling units and these included combinations of no vegetation, 1–50% vegetation, 51–100% vegetation, no glass, 1–50% glass, and 51–100% glass. Tape and wheel rules were used to measure distances and heights. Distance of vegetation was measured from base of façade to closest branch, leaf, or blade of grass. Height of trees was measured using height of adjacent building. One of us (ND) estimated the percentage of vegetation and glass by eye while facing the middle of each site from the street curb to reduce any observer related variation in measurement error.

Each of nine combinations of categorical features was identified and systematically represented in the lower midtown area. The lower midtown location was also identified as characteristic of the greater New York City urban area, having sites with structural characteristics that included residential and commercial buildings at heights of four stories or less. We used the relatively uniform structure of the lower midtown area and the number of recorded mortalities discovered during the fall and spring migratory periods to estimate annual glass mortalities per area of urban habitat. All sites in all locations were grouped into four carcass and injured-bird search routes. A strike was recorded when a volunteer found a dead or injured bird in front of a glass or an opaque wall at the base of a façade with the search area extending to the gutter of the street. Added attention was given to inspecting bushes and planters when they were present. This methodology provided a conservative estimate of strike frequency, as it did not account for removal of carcasses by scavengers and street sweepers, injured birds that died outside the search area, or post-strike movements of survivors. Routes were walked slowly from 0700 to 1000 hrs, when previous monitoring revealed glass collision victims were found most often. Search routes were completed within 0.5 to 2 hrs. Dead birds were salvaged and donated to authorized researchers (with appropriate State and Federal scientific collection permits) for additional study, and injured birds were taken to local animal care centers for treatment.

We monitored each building façade daily for 58 days (i.e., 9 Sep–5 Nov) in autumn 2006 and 56 days (i.e., 2 Apr–27 May) in spring 2007 to detect window strikes resulting in bird injury or mortality. We divided variables considered to be potential predictors of strike events into two groups: (1) building design and (2) landscape context (Table 1). Building design variables consisted of construction features. Context variables characterized the area immediately in front of a façade. We measured variables defining each façade, and our sample size for the analysis was the number of façades. We measured nocturnal light levels between 0200 and 0500 hrs using a Mannix digital light meter, model DLM-1337.

We used Cox proportional hazards regression (Cox 1972, Riggs and Pollock 1992, SPSS 2006) to test for associations between variables in each group and the probability that a façade would experience a glass strike. Cox proportional hazards regression is applicable to any situation in which the response variable is the time to a discrete event. We screened variables for multicollinearity prior to analysis. We included the covariate with the strongest association with glass strikes for

TABLE 1. Variables measured at building façades in New York City, New York, USA.

| Variable | Variable type | Data code | Definition | *n* |
|---|---|---|---|---|
| Building design | | | | |
| Building height | Categorical | 1 | 1–4 stories | 18 |
| | | 2 | 5–10 stories | 29 |
| | | 3 | >10 stories | 26 |
| Glass type | Categorical | 1 | None | 11 |
| | | 2 | Reflective | 32 |
| | | 3 | Transparent | 26 |
| | | 4 | Reflective and transparent | 4 |
| Glass-non-glass ratio | Categorical | 1 | 0 | 11 |
| | | 2 | 1–50% | 19 |
| | | 3 | 51–100% | 43 |
| Night lighting 5 | Continuous | variable | Illumination (lux) 5 m from façade | 65 |
| Night lighting 10 | Continuous | variable | Illumination (lux) 10 m from façade | 65 |
| Size | Continuous | variable | Length of façade (m) | 73 |
| Vegetation reflected in glass | Categorical | 1 | None | 25 |
| | | 2 | 1–50% | 26 |
| | | 3 | 51–100% | 22 |
| Landscape context | | | | |
| Access | Categorical | 1 | Public | 69 |
| | | 2 | Private | 4 |
| Facing area | Categorical | 1 | Open (>18 m) | 38 |
| | | 2 | Restricted (≤18 m) | 35 |
| Facing habitat | Categorical | 1 | Vegetated ground cover at base of façade | 28 |
| | | 2 | Non-vegetated ground cover at base of façade | 45 |
| Ground cover distance | Continuous | variable | Distance from façade to nearest ground cover (m) | 73 |
| Ground cover height | Continuous | variable | Height of ground cover (m) | 73 |
| Location | Categorical | 1 | Upper east side | 7 |
| | | 2 | Lower midtown | 48 |
| | | 3 | Southern | 18 |
| Shrub distance | Continuous | variable | Distance from façade to nearest shrubs (m) | 73 |
| Shrub height | Continuous | variable | Height of shrubs (m) | 73 |
| Tree distance | Continuous | variable | Distance from façade to nearest trees (m) | 73 |
| Tree height | Continuous | variable | Height of trees (m) | 73 |

each pair of variables with $r < -0.5$ or $>0.5$ in further analyses and eliminated the other collinear variables. Cases (i.e., façades) in which no strike event occurred during the study were included in the analysis as censored observations. We arcsine transformed variables measured as proportions (% glass, % vegetation reflected) to normalize their distributions (Zar 1999). We derived separate models for each group using forward and backward stepping algorithms based on likelihood ratios (SPSS 2006). We used Akaike's Information Criterion (AIC), corrected for small sample sizes ($AIC_c$) to select final models, and model averaging with re-scaled parameter estimates to derive risk ratios in cases where >1 model had a $\Delta AIC_c \leq 2.0$ (Burnham and Anderson 2002).

We retained variables in proportional hazards models that had *P* values for their coefficients ≤0.15 and calculated risk ratios for those variables. We accepted a 15% level of significance because we believed it was sufficient to indicate the importance of variables in affecting the probability of glass strikes (Johnson 1999). Risk ratios estimate change in the relative risk of an event for an incremental change in the magnitude of a predictor variable (Riggs and Pollock 1992). The risk ratio for a given variable represents the independent contribution to risk of an event made by a covariate, regardless of the dimensions of the variable. Risk ratios are useful for estimating the contribution to risk of continuous and categorical variables, and we included both types of variable in our analysis. We measured continuous variables on differing scales (i.e., some were proportions whereas others were linear measures in meters), and standardized risk ratios for these variables for a 10% change in magnitude to allow direct comparisons among variables. We considered a variable to be a significant predictor of window strikes if the 90% confidence interval for the risk ratio did not include 1.0. Risk ratios <0.5 or >2.0 generally indicate large effects of covariates on risk of an event.

Risk ratios represent the independent contribution of each covariate to risk of an event, and we used relative influence (RI) values (i.e., sum of log-transformed risk ratios) to compare the influence of the groups of variables on risk (Farmer et al. 2006). We calculated an RI for model averaged estimates of effect size to minimize the influence of covariates occurring only in a single model for a given variable group.

## RESULTS

We recorded 475 and 74 glass strikes in autumn 2006 and spring 2007, respectively. Of these, 390 (82%) in autumn and 62 (85%) in spring were fatal. The number of strikes recorded at sites with no glass was 7 (1.5%) in autumn and 2 (2.7%) in spring. There were 50 and 25 known species casualties in autumn 2006 and spring 2007, respectively. The 10 species recorded most often as strike victims (in decreasing frequency) were: Dark-eyed Junco (*Junco hyemalis*), White-throated Sparrow (*Zonotrichia albicollis*), Ruby-crowned Kinglet (*Regulus calendula*), Golden-crowned Kinglet (*R. satrapa*), Hermit Thrush (*Catharus guttatus*), Common Yellowthroat (*Geothlypis trichas*), Northern Parula (*Parula americana*), Blackpoll Warbler (*Dendroica striata*), Ovenbird (*Seiurus aurocapilla*), and Swainson's Thrush (*Catharus ustulatus*) for autumn 2006, and Ovenbird, Black-and-white Warbler (*Mniotilta varia*), Rock Pigeon (*Columba livia*), Common Yellowthroat, Northern Waterthrush (*Seiurus noveboracensis*), Canada Warbler (*Wilsonia canadensis*), White-throated Sparrow, Ruby-crowned Kinglet, Gray Catbird (*Dumetella carolinensis*), and Blackburnian Warbler (*Dendroica fusca*) for spring 2007.

Window strikes occurred at 41 of 73 (56%) façades in autumn 2006 and 20 of 73 (27%) façades in spring 2007. Mean time to a window strike from the beginning of the study was 37.4 days (SE = 2.6) overall, and 21.4 days (SE = 2.6) within the subset of façades at which strikes occurred in autumn 2006. Mean time to a window strike was 52.0 days (SE = 2.1) overall, and 28.3 days (SE = 4.1) within the subset of façades at which strikes occurred in spring 2007. Overall, context variables (RI = 2.6 autumn, 4.8 spring) exerted a slightly stronger influence on risk of window strikes than building variables (RI = 1.9 autumn, 0.4 spring).

*Building Variables.*—Five building variables were included in proportional hazards models after screening for multicollinearity and eliminating variables with no significant association with the risk of glass strikes. Model selection using $AIC_c$ suggested that two autumn models (i.e., façade size, % glass, and glass type vs. glass type and % glass) were nearly equally likely given the data (Table 2). Significant model averaged estimates of effect size were found for the proportion of the façade that was window glass (i.e., % glass) with a 10% increase in this variable causing a 19% increase in risk (Table 3). The autumn model averaged risk ratio for reflective glass type was large (219% increase in risk), but not significant. The 90% confidence interval for reflective glass type nearly excluded 1.0, indicating there was an increase in risk, but our parameter estimate was imprecise.

Three models had $\Delta AIC_c \leq 2.0$ (Table 2), and were used in the calculation of model averaged parameter estimates for spring. The proportion of the façade that was window glass (% glass) was a significant predictor of risk with a 10% increase in this variable causing a 32% increase in risk of a window strike (Table 3). Façade size and night lighting each appeared to exert weak influences on risk. No building variables were found that significantly reduced the risk of window strikes.

*Context Variables.*—Eight context variables

TABLE 2. Model selection for building variables. Models indicated by bold type are equally likely based on $AIC_c$ values.

| Model | $AIC_c$ | $\Delta$ $AIC_c$ | *w* | $\chi^2$ | Model *P* |
|---|---|---|---|---|---|
| Autumn | | | | | |
| FS[a], GP[b], GT[c], NL[d] | 307.16 | 2.71 | 0.132 | 26.46 | 0.000 |
| **FS, GP, GT** | 305.16 | 0.71 | 0.358 | 26.43 | 0.000 |
| **GP, GT** | 304.45 | 0 | 0.510 | 24.68 | 0.000 |
| Spring | | | | | |
| GP, GT, NL, FS | 162.73 | 3.78 | 0.068 | 12.28 | 0.056 |
| **GP, GT, FS** | 160.90 | 1.96 | 0.169 | 11.22 | 0.011 |
| **GP, FS** | 159.68 | 0.73 | 0.313 | 10.42 | 0.005 |
| **GP** | 158.95 | 0 | 0.450 | 9.37 | 0.002 |

[a] Façade size.
[b] Percent glass.
[c] Glass type.
[d] Night lighting 5.

were included in proportional hazards models (Table 4). Model selection using $AIC_c$ suggested two autumn models (i.e., facing area, distance to ground cover, ground cover height, location, and tree height vs. facing area, ground cover height, location, and tree height) were likely given the data (Table 4). Model averaged estimates of effect size from the two models indicated that facing area, height of ground cover, and tree height significantly influenced risk of window strikes. Restricted facing areas (e.g., a short distance to the nearest building in front of a façade) reduced risk of window strikes 69%, whereas 10% increases in the height of ground cover and tree height increased risk of a strike by 13 and 30%, respectively (Table 5). Location and distance to ground cover exerted non-significant influences on risk of a glass strike.

Two models had $\Delta AIC_c \leq 2.0$ for spring (Table 4) and were used in calculation of model averaged parameter estimates. Restricted facing areas strongly (549%) increased risk of spring window strikes and a 10% increase in tree height moderately (22%) increased risk. Distance from façades to tree cover and height of ground cover affected the risk of window strikes non-significantly (Table 5).

We recorded 284 lethal strikes (1.1 fatalities/ha) within the 266-ha generalized urban lower midtown sampling location during autumn 2006. We recorded 47 lethal strikes (0.2 fatalities/ha) for the same area during spring 2007. We estimated 1.3 fatalities/ha of urban

TABLE 3. Model averaged estimates of effect size derived from Cox proportional hazards regression on building variables.

| Covariate | $\beta$[a] | SE | RR[b] | 90% CI | Predictor of risk |
|---|---|---|---|---|---|
| Autumn | | | | | |
| Façade size | 0.003 | 0.004 | 1.08 | 0.92–1.26 | NS[c] |
| Glass percent | 0.019 | 0.009 | 1.19 | 1.04–1.36 | Significant |
| Glass type (none) | −0.160 | 0.662 | 0.85 | 0.29–2.53 | NS |
| Glass type (reflective) | 1.160 | 0.738 | 3.19 | 0.95–10.74 | NS |
| Glass type (transparent) | 0.322 | 0.783 | 1.38 | 0.38–5.00 | NS |
| Spring | | | | | |
| Façade size | 0.004 | 0.052 | 1.11 | 0.13–7.76 | NS |
| Glass percent | 0.030 | 0.007 | 1.32 | 1.19–1.44 | Significant |
| Night lighting 5 | 0.002 | 0.019 | 1.04 | 0.45–2.25 | NS |

[a] Regression coefficients indicate strength and direction of relations between hazard functions and covariates. All regression coefficients retained in the model are reported.
[b] We standardized risk ratios (RR) and 90% confidence intervals (CI) of the continuous covariates (façade size, percent glass) for a 10% increase.
[c] Non-significant at $\alpha = 0.10$.

TABLE 4. Model selection for context variables. Models indicated by bold type are equally likely based on $AIC_c$ values.

| Model | $AIC_c$ | $\Delta\ AIC_c$ | *w* | $\chi^2$ | Model *P* |
|---|---|---|---|---|---|
| Autumn | | | | | |
| FA[a], GD[b], GH[c], LO[d], SD[e], SH[f], TD[g], TH[h] | 298.03 | 9.26 | 0.006 | 43.770 | 0.000 |
| FA, GD, GH, LO, SD, TD, TH | 295.53 | 6.75 | 0.022 | 43.732 | 0.000 |
| FA, GD, GH, LO, TD, TH | 293.08 | 4.31 | 0.076 | 43.172 | 0.000 |
| **FA, GD, GH, LO, TH** | 290.75 | 1.98 | 0.243 | 43.096 | 0.000 |
| **FA, GH, LO, TH** | 288.77 | 0 | 0.653 | 43.070 | 0.000 |
| Spring | | | | | |
| FA, GD, GH, LO, SD, SH, TD, TH | 159.53 | 9.79 | 0.004 | 27.80 | 0.001 |
| FA, GD, GH, SD, SH, TD, TH | 157.28 | 7.54 | 0.011 | 27.23 | 0.000 |
| FA, GD, GH, SD, TD, TH | 154.87 | 5.13 | 0.038 | 27.21 | 0.000 |
| FA, GD, GH, TD, TH | 152.52 | 2.78 | 0.121 | 26.15 | 0.000 |
| **FA, GH, TD, TH** | 150.47 | 0.73 | 0.338 | 25.05 | 0.000 |
| **FA, TD, TH** | 149.74 | 0 | 0.488 | 23.56 | 0.000 |

[a] Facing area.
[b] Ground cover distance.
[c] Ground cover height.
[d] Location.
[e] Shrub distance.
[f] Shrub height.
[g] Tree distance.
[h] Tree height.

area annually after combining these measures of attrition for autumn and spring.

## DISCUSSION

Most building and context variables exerted moderate influences on risk of glass strikes. The proportion of windows reflecting vegetation (i.e., % vegetation) was measured in the field, but we did not include it in the proportional hazards regressions, because it integrates building (i.e., % glass and glass type) and context (i.e., facing area, type, distance, and height of vegetation) variables, which made it difficult to interpret. It proved to be a significant predictor of glass strikes ($RR_{10}$ = 1.26, 90% CI = 1.14–1.39) when we included percent of reflected vegetation in an exploratory model. We interpret these findings as an

TABLE 5. Model averaged estimates of effect size derived from Cox proportional hazards regression on context variables.

| Covariate | $\beta$[a] | SE | RR[b] | 90% CI | Predictor of risk |
|---|---|---|---|---|---|
| Autumn | | | | | |
| Facing area | −1.177 | 0.493 | 0.31 | 0.14–0.69 | Significant |
| Ground cover distance | 0.005 | 0.025 | 1.02 | 0.89–1.14 | NS[c] |
| Ground cover height | 2.433 | 1.352 | 1.13 | 1.01–1.26 | Significant |
| Location (lower midtown) | −0.698 | 0.587 | 0.50 | 0.19–1.30 | NS |
| Location (southern Manhattan) | 0.339 | 0.611 | 1.40 | 0.51–3.83 | NS |
| Tree height | 0.097 | 0.030 | 1.30 | 1.14–1.48 | Significant |
| Spring | | | | | |
| Facing area | 1.857 | 0.650 | 6.49 | 2.23–18.89 | Significant |
| Ground cover height | 1.979 | 1.464 | 1.10 | 0.98–1.25 | NS |
| Tree distance | −0.055 | 0.036 | 0.70 | 0.48–1.03 | NS |
| Tree height | 0.076 | 0.028 | 1.22 | 1.08–1.39 | Significant |

[a] Regression coefficients indicate strength and direction of relations between hazard functions and covariates. All regression coefficients retained in the model are reported.
[b] We standardized risk ratios (RR) and 90% confidence intervals (CI) of the continuous covariates (ground cover distance, ground cover height, tree height) for a 10% increase.
[c] Non-significant at $\alpha$ = 0.10.

indication that building designers can reduce the risk of bird–glass strikes by reducing the proportion of glass to other building materials in any new construction. The type of glass affected the autumn model significantly, although no individual category of glass had a significant effect. The high-magnitude risk ratios for reflective glass suggest this type of glass strongly increases risk of strikes. However, confidence intervals with 1.0 near the lower confidence limits coupled with the large risk ratios are an indication the analysis lacked power to accurately estimate effect size for this variable.

Context variables had a slightly stronger relative influence than building variables, and the analysis indicates that several context variables under the control of builders can be manipulated to reduce the risk of glass strikes. We found that increasing the height of ground cover and tree cover adjacent to new and existing buildings increases the risk of strikes by 13 and 30%, respectively, for each 10% increase in height. Our risk ratios are scaled for any 10% change in a covariate indicating that 10% reductions of the heights of these types of cover will reduce the risk of strikes by the same amount. This supports a previous study documenting increased strikes at glass with reflected vegetation (Gelb and Delacretaz 2006). Eliminating vegetative ground cover from areas adjacent to buildings may also reduce risk, although the effect was non-significant in our analysis. Large reductions in risk (69%) in autumn can be achieved by restricting the area in front of façades, primarily by placing buildings close together. However, the large (549%) increase in risk associated with this context variable in spring contradicts this finding. This also suggests that migrating birds may behave differently in Manhattan in spring versus autumn, which would complicate efforts to manage strike risk using this context variable. Previous studies suggest that spacing between buildings may be of limited value since a lethal collision can occur when a bird strikes a glass surface after leaving a perch from as little as 1 m distant (Klem 1990b, Klem et al. 2004, Veltri and Klem 2005). The non-significant effect of location (indicating that lower midtown locations strongly reduced risk) in autumn regressions suggests that having tall buildings in the surrounding area increases risk of window strikes, presumably by restricting the availability of flight paths for birds.

Quantitative analyses of both building and context variables associated with the glass hazard for birds provide further support for recently published suggestions informing architects and other building industry professionals about how to mitigate or eliminate avian mortality at glass (Brown and Caputo 2007, City of Toronto Green Development Standard 2007). Our results confirm that sheet glass consisting of small windows to entire walls of buildings is a lethal hazard for birds. Searching for and monitoring potential hazardous sites will identify problem urban areas. Minimizing the use of large expanses of glass and nearby vegetation in the vicinity of clear and reflective panes will mitigate bird–glass collisions, and prevent injury and death to birds on passage during migratory periods. In this context, it is important to note that even variables that entered models non-significantly (i.e., confidence interval overlapping 1.0) exert some influence on risk of strikes, either directly or by conditioning the effect of significant predictors. Design changes by a builder on any or all of the variables identified (Tables 3, 5) will affect the risk of strikes; however, the strongest effect will be realized by altering the significant predictors.

Our systematic sampling of lower midtown provided an opportunity to estimate annual avian mortality at glass in a relatively uniform urban environment, typical of urban areas without skyscrapers, including single-story or two-story residences. The species recorded as collision casualties in the lower midtown study area are representative of the same or similar species on passage over a broad front, and expected to occur in similar urban environments throughout the continent (Lincoln and Peterson 1935, Able 1999). Using this sample and urban area data from Statistics Canada (2001) and U.S. Bureau of Census (2002), the annual bird kill at glass during migratory periods alone in the urban environment is estimated to be 5,676 for Manhattan, 3,163,633 for Canada, 31,159,228 for the United States, and 34,322,861 for North America north of Mexico. These estimates are likely conservative since they exclude buildings above four stories where large annual kills are known to occur at skyscrapers in urban centers similar to those in Chicago, Detroit, Minneapolis, New York, Toronto, and elsewhere (Klem 2006). The annual urban toll, at least for the U.S., seems reasonable given previous estimates of annual U.S. avian mortality at glass that ranges from 100 million to 1 billion, where most fatalities are thought to occur during the non-breeding season when large numbers of resident birds are attracted to feeders near windows (Klem 1990b, Klem 2006).

Of conservation interest were species on the U.S. Department of Interior (2002) list of Species of Management Concern or the National Audubon Society (2007) WatchList recorded as glass casualties: American Woodcock (*Scolopax minor*), Yellow-bellied Sapsucker (*Sphyrapicus varius*), Wood Thrush (*Hylocichla mustelina*), Chestnut-sided Warbler (*Dendroica pensylvanica*), Canada Warbler, and Baltimore Oriole (*Icterus galbula*). The hazard that clear and reflective sheet glass poses to birds is expected to increase as current urban areas increase, and human structures elsewhere are constructed in avian breeding and non-breeding areas and across migratory routes worldwide.

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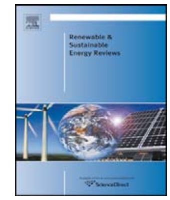

# Passive building energy savings: A review of building envelope components

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ABSTRACT

A significant portion of the total primary energy is consumed by today's buildings in developed countries. In many of these buildings, the energy consumption can be significantly reduced by adopting energy efficiency strategies. Due to environmental concerns and the high cost of energy in recent years there has been a renewed interest in building energy efficiency. This article strives to make an exhaustive technical review of the building envelope components and respective improvements from an energy efficiency perspective. Different types of energy efficient walls such as Trombe walls, ventilated walls, and glazed walls are discussed. Performance of different fenestration technologies including aerogel, vacuum glazing and frames are presented. Advances in energy efficient roofs including the contemporary green roofs, photovoltaic roofs, radiant-transmittive barrier and evaporative roof cooling systems are discussed. Various types of thermal insulation materials are enumerated along with selection criteria of these materials. The effects of thermal mass and phase change material on building cooling/heating loads and peak loads are discussed. Application of thermal mass as an energy saving method is more effective in places where the outside ambient air temperature differences between the days and nights are high. Air tightness and infiltration of building envelopes are discussed as they play a crucial role in the energy consumption of a building. Energy efficiency approaches sometimes might not require additional capital investment. For example, a holistic energy efficient building design approach can reduce the size of mechanical systems compensating the additional cost of energy efficiency features.

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**Nomenclature**

| | |
|---|---|
| AAC | Autoclaved aerated concrete |
| ACH | Air changes per hour |
| APS | Arizona public service |
| ASHRAE | American society of heating, refrigerating and air-conditioning engineers |
| ASTM | American society for testing and materials |
| BIPV | Building integrated photovoltaics |
| BUR | Built-up roof |
| C | Dimensionless constant |
| CFCs | Chlorofluoro carbons |
| $d$ | Gap thickness of the crack |
| DL | Daylighting |
| EC | Electrochromics |
| EPDM | Ethylene propylene diene monomer |
| EPS | Extruded polystyrene |
| ESP-r | Environmental systems performance-research |
| FRP | Fiber-reinforced plastic |
| HCFCs | Hydrochlorofluorocarbons |
| HOE | Holographic optical elements |
| HPI | High performance insulation |
| HTF | Heat transfer fluid |
| HVAC | Heating, ventilation and air conditioning |
| IECC | International energy conservation code |
| IR | Infrared |
| ISO | The International Standards Organization |
| L | Breadth of the crack |
| LASRS | Lightweight aluminum standing seam roofing systems |
| LEED | Leadership in energy and environmental design |
| LWC | Lightweight concrete |
| PCES | Phase change energy solutions |
| PCM | Phase change material |
| PIR | Polyisocyanurate |
| Q | Flow rate |
| RCC | Reinforced cement concrete |
| SC | Solar gain control |
| SCE | Solar collection envelope |
| SPD film | Suspended particle devices film |
| SR | Solar reflectance |
| TPO | Thermoplastic polyolefin |
| U | Thermal transmittance (in W/m$^2$ K) |
| UK | United Kingdom |
| US | United States of America |
| VR | Vaulted roof |
| WGBC | World green building council |
| $z$ | Length in the direction of flow |
| $\rho$ | Density |
| $\mu$ | Dynamic viscosity |
| $\Gamma$ | Energy transmittance |
| $\alpha, \beta$ | Constants |
| $\Delta P$ | Pressure difference |

## 1. Introduction

A significant portion of the energy is consumed by today's buildings in developed countries. For example, about 39% of the total US primary energy is consumed by buildings today [1], this fact emphasizes on the imperative need for energy savings in buildings. Both governments and scientific communities across the world have identified the potential and need for energy efficiency in the buildings, and initiated significant efforts in this direction. As of date, the WGBC (world green building council) has involved 82 nations all across the globe in taking up green building initiatives to some degree. LEED (Leadership in Energy and Environmental Design), an internationally recognized green building certification system, also identifies energy efficiency as an important attribute of green buildings.

**Table 1**
Code standard *U*-values (in W/m$^2$ K) for UK buildings.

| Envelope element | 1995 Standard *U*-values (W/m$^2$ K) | 2000 Standard *U*-values (W/m$^2$ K) | Percentage reduction in *U*-value (%) |
|---|---|---|---|
| Walls | 0.45 | 0.35 | 22 |
| Roofs | 0.25 | 0.16 | 36 |
| Floors | 0.45 | 0.25 | 44 |
| Windows | 3.3 | 2.2 | 33 |

Source: John et al. [6].

The buildings we find today are expected to achieve both energy efficient and environmental-friendly design. This idea of sustainable buildings encompasses various issues regarding energy, water, land and material conservation, together with environmental pollution and the quality of indoor and outdoor environments. A technical review on the recent developments in various building envelope components and their effects on the energy efficiency of a building is, therefore, highly relevant given the present context.

Building energy efficiency can be improved by implementing either active or passive energy efficient strategies. Improvements to heating, ventilation and air conditioning (HVAC) systems, electrical lighting, etc. can be categorized as active strategies, whereas, improvements to building envelope elements can be classified under passive strategies. Recent years have seen a renewed interest in environmental-friendly passive building energy efficiency strategies. They are being envisioned as a viable solution to the problems of energy crisis and environmental pollution.

A building envelope is what separates the indoor and outdoor environments of a building. It is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor conditions. Various components such as walls, fenestration, roof, foundation, thermal insulation, thermal mass, external shading devices etc. make up this important part of any building. Several researchers around the world carried out studies on improvements in the building envelope and their impact on building energy usage. Energy savings of 31.4% and peak load savings of 36.8% from the base case were recorded for high-rise apartments in the hot and humid climate of Hong Kong by implementing passive energy efficient strategies. The strategies include adding extruded polystyrene (EPS) thermal insulation in walls, white washing external walls, reflective coated glass window glazings, 1.5 m overhangs and wing wall to all windows [2]. In a different study, the thermal and heat transfer performance of a building envelope in subtropical climatic conditions of Hong Kong was studied using the DOE-2 building energy simulation tool. An energy effective building envelope design saved as much as 35% and 47% of total and peak cooling demands respectively [3]. In Greece, thermal insulation (in walls, roof and floor) and low infiltration strategies reduced energy consumption by 20–40% and 20% respectively. According to the same study, external shadings (e.g. awnings) and light-colored roof and external walls reduced the space cooling load by 30% and 2–4%, respectively [4]. Several numerical studies were also carried out on building envelopes and individual building envelope components. A detailed model of transient heat transfer through a typical building envelope developed by Price et al. [5] takes into account the convection and thermal radiation heat exchange at the interior and exterior surfaces of the building.

Over the years, code requirements on building envelopes have improved significantly, and continue to increase in performance. Table 1 shows how building envelope standards in the UK have changed over time. With each revision, the building envelope standards were upgraded substantially, emphasizing the growing need for energy conservation. In the United States, although different states implement different code standards, they are all derivatives from various versions of American society of heating refrigeration and air-conditioning engineers (ASHRAE) and International Energy Conservation Code (IECC) standards. The latest version of ASHRAE standard is ASHRAE 90.1-2007 and the IECC standard is IECC 2009.

Advanced and sustainable materials research for building envelope applications has seen significant progress in recent years. Fiber-reinforced plastic (FRP) is one such advanced composite material that can be used in wall and roof applications [7]. Sustainable earth material such as unfired clay bricks, a straw–clay mixture and straw bales were investigated for use in new or upgrading historical earth wall constructions [8]. These earth wall constructions can comply with the UK building regulations for thermal transmittance of less than 0.35 W/m$^2$ K.

A proper architectural design of a building envelope can significantly lower the energy usage through daylighting, reduced HVAC loads, etc. Innovations such as the self-shading envelopes are being explored by researchers. A nomogram simulation of a solar collection envelope (SCE) was discussed by using a computer modeling tool called SustArc [9]. The SCE concept is used to generate self-shading envelopes. In efficient self-shading envelope designs, the summer sun is blocked while the winter sun is permitted.

The most important building envelope components and their latest developments are discussed in the following sections.

## 2. Walls

Walls are a predominant fraction of a building envelope and are expected to provide thermal and acoustic comfort within a building, without compromising the aesthetics of the building. The thermal resistance (*R*-value) of the wall is crucial as it influences the building energy consumption heavily, especially, in high rise buildings where the ratio between wall and total envelope area is high. The market available center-of-cavity *R*-values and clear wall *R*-values consider the effect of thermal insulation. However, the influence of framing factor and interface connections is not taken into consideration [10].

Walls with thermal insulation have a higher chance of surface condensation when the relative humidity of ambient air is greater than 80%, provided the convective and radiative heat transfer coefficients of the exterior wall are small. This problem is more severe during winter months and in colder climatic regions with higher humidity levels [11]. This moisture condensation on building exterior walls promotes undesirable microbial growth which might reduce the wall life and lead to other undesirable conditions in the building. Conventionally, based on the materials used in construction, walls can be classified as wood-based walls, metal-based walls and masonry-based walls. There are other types of advanced building wall designs that are applied to improve the energy efficiency and comfort levels in buildings. The following sections describe such advanced wall technologies.

### 2.1. Passive solar walls

Typically used in cold climates, the walls that trap and transmit the solar energy efficiently into the building are called passive solar walls. This type of walls were first developed by E.S. Morse in the 19th century and later redesigned by Trombe et al. In these walls, typically, a 12-inch-thick concrete wall is used as a south (for geographical northern hemisphere) façade to absorb solar radiation. A glazing is used as an outer covering of the wall to provide the greenhouse effect. Several developments resulted from the basic designs of classical Trombe wall and composite Trombe–Michell wall [12–17]. One such Trombe wall system design proposed for cold climatic conditions has a steel panel backed with polystyrene

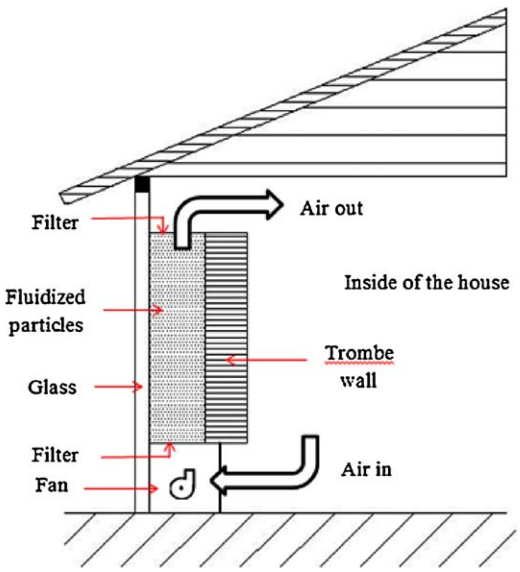


**Fig. 1.** A cross-sectional view of fluidized Trombe wall system with part details. Source: Tunç and Uysal [19].

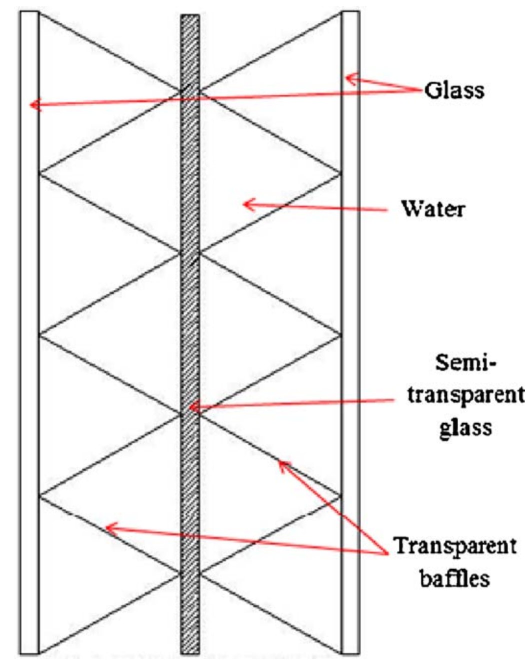


**Fig. 2.** A cross-sectional view of Transwall system with part details. Source: Nayak [20].

insulation mounted on the south façade. This design improved the operating efficiency of the classical Trombe wall by 56% [15]. A comparative study was conducted on four different kinds of solar wall configurations—unventilated solar wall, Trombe wall, insulated Trombe wall and composite solar wall—using numerical simulations. All of these walls, except the unventilated solar wall, transfer heat to the indoors both by conduction through wall and convection through circulating air. The unventilated solar wall transfers heat exclusively through conduction. A more convection-based type (controllable) of solar wall such as composite solar wall or insulated Trombe wall is preferable in regions with shorter heating seasons in order to avoid overheating in cooling season. Whereas a more conduction-based type (uncontrollable) of solar wall such as Trombe wall or unventilated solar wall is preferable in regions with longer heating seasons. However, the problem of overheating in summer can be prevented through the use of solar shields [14]. Jie et al. [17] have proposed an innovative design of PV integrated Trombe wall. In this design, PV cells are affixed on the back of the transparent glass cover of a normal Trombe wall. Both the heat rejected by the PV cells and the heat absorbed by the thermal mass of Trombe wall are used for space heating. A theoretical analysis on a Trombe wall with fin-type structured outer wall surface design suppresses the convective and infrared (IR) radiation heat losses from the wall's outer face to the glass cover thereby encouraging the conduction through the wall along with convective and radiative heat exchange to the inside of the room [16]. Phase change material (PCM) based Trombe walls have been reviewed [18]. Experimental results suggest that PCM Trombe walls were thinner and also performed better than concrete walls. A novel concept of fluidized Trombe wall system (as shown in Fig. 1) where the gap between the Trombe wall and the glass cover is fluidized with highly absorbing, low-density particles is introduced [19]. The solar energy absorbed by these highly absorptive particles is transferred to the indoors through fan-circulated air. A filter at the top of the air channel checks the fluidized particles from entering the indoor space. The overall efficiency of this design is higher compared to a classical Trombe wall design as the air (heat transfer fluid (HTF)) is in direct contact with the fluidized particles.

A Transwall (as shown in Fig. 2) is a transparent modular wall that provides both heating and illumination of the dwelling space. These walls are comprised of water enclosed between two parallel glass panes supported in a metal frame. A semi-transparent glass absorbing plate is at the center of the parallel glass panes. The incident solar radiation is partially absorbed by the water and semi-transparent glass plate, the rest of the transmitted radiation causes both heating and illumination that are required by the indoors [20].

### 2.2. Lightweight concrete (LWC) walls

Lightweight concrete (LWC) refers to any concrete produced with a density of less than 2000 kg/m$^3$. For structural purposes, the LWC density often ranges between 1600 and 2000 kg/m$^3$ along with a strength grade of 15 MPa. Whereas for thermal insulation purposes the density is often less than 1450 kg/m$^3$ along with strength grade as low as 0.5 MPa. The thermal resistance of light weight concrete can be improved by mixing with light weight aggregates. These aggregates can come from natural material (such as pumice, diatomite, expanded clay or expanded shale, etc.), processed by-products (such as foamed slag, sintered pulverized fuel ash) or unprocessed materials. The low-conductivity aggregates such as polystyrene beads, vermiculite and leca have been focus of research in recent years [21]. Autoclaved aerated concrete (AAC) is a type of LWC produced by introducing aluminum powder to generate miniscule air bubbles. It has superior thermal resistance than other types of LWC. AAC is first introduced in the early 20th century in Europe, and it is gaining popularity as exterior and interior wall material as an alternative to clay bricks in recent years in developing countries. The density of AAC ranges between 600 and 800 kg/m$^3$. All kinds of LWC walls are particularly useful in countries where concrete construction is predominant and the use of insulation in walls is not a common practice. Also, they can be constructed faster using less skilled labor.

### 2.3. Ventilated or double skin walls

An air gap between two layers of masonry wall braced with metal ties constitutes a ventilated or double skin wall. They are also called cavity walls. There are two basic kinds of ventilated walls, one with forced ventilation in the cavity, and the other with natural ventilation (stack effect). Most commonly, ventilated walls are used to enhance the passive cooling of buildings. Ciampi et al. [22] developed a mathematical model to evaluate the energy performance of a ventilated wall. They validated this model for 6 different ventilated wall designs. Although, energy savings for all the wall designs increase with the increase in width of the air gap, however, further increase over 0.15 m yielded only diminishing returns. A typical summer cooling energy savings of 40% can be achieved with a carefully designed ventilated wall. However, poor construction quality can introduce thermal bridge issues. Also, the parameters such as the thermal resistance of the exterior wall and relative roughness of the slabs delimiting the air duct are important.

### 2.4. Walls with latent heat storage

The phase change material (PCM) is incorporated in light weight wall structures to enhance the thermal storage capacity. PCM material is impregnated commonly in gypsum or concrete walls. Porous material such as plasterboard has better PCM impregnation potential than pumice concrete blocks. The thermal heat storage in PCM based walls depends on the amount (weight %) of PCM material impregnated in the wall material. The microencapsulation of PCM material in wall construction material has allowed this PCM weight ratio to about 30% in gypsum. Recent years have seen the advent of composite materials that can encapsulate PCM up to 60% by weight. Athienitis et al. [23] compared PCM based and non-PCM based gypsum board for inside wall lining and concluded that the PCM based wall lining lowered the maximum room temperature by 4 °C and reduces the heating demand during night. In a separate study, experimental results on PCM based composite wall boards showed a decrease in maximum room temperature by 4.2 °C [24].

## 3. Fenestration (windows and doors)

Fenestration refers to openings in a building envelope that are primarily windows and doors. The fenestration plays a vital role in providing thermal comfort and optimum illumination levels in a building. They are also important from an architectural standpoint in adding aesthetics to the building design. In recent years, there have been significant advances in glazing technologies. These technologies include solar control glasses, insulating glass units, low emissivity (low-e) coatings, evacuated glazings, aerogels and gas cavity fills along with improvements in frame and spacer designs [25]. A simulation study was carried out on 10 different glazing types applied to five different climatic zones in India [26]. It was observed that the annual energy savings by a window is dependent on not just the thermal conductivity (*U*-value) and the solar heat gain coefficient (SHGC or *g*-value) of the window but also on its orientation, climatic conditions and building parameters such as insulation level, floor area, etc.

For passive solar heating applications, windows with low U-value and high total solar energy transmittance ($\Gamma$) are preferred. A tradeoff should be made between *U*-value and solar transmission as most likely the measures to lower *U*-value shall lower the solar transmission [25]. In daylighting applications, spectrally selective low-e coatings allow the visible light of the solar spectrum and block the other wavelengths that are generally responsible for solar heat gains. These coatings are placed on the inside surface of the outermost pane, as most absorbed solar energy will be dissipated to the ambient air [25]. Low-e coatings are of two types: hard coating and soft coating. The hard coating is a tin oxide based coating whereas the soft coating is usually a thin layer of silver surrounded by dielectric protective layers. Typically, soft silver-based coatings have a lower solar transmittance and higher infrared reflectance compared to hard tin oxide-based coatings [27]. The visible transmittance of a low-e tin oxide-based glazing is increased by antireflection treatment with silicon dioxide ($SiO_2$). The measured percentage increase of integrated visible transmittance was 9.8% and a transmittance value of 0.915 was achieved [27]. This permits the usage of antireflection treated low-e glazing in the construction of triple glazing unit windows which has desirable *U*-value while not decreasing the visibility.

### 3.1. Types of glazing materials and technologies

State-of-the-art glazing materials and technologies that are aimed at providing high performance insulation (HPI) or solar gain control (SC) or daylighting (DL) solutions or a combination are presented in this section.

#### 3.1.1. Aerogel glazing

Aerogels are a category of open celled mesoporous solids with a volume porosity of greater than 50%. They have a density in the range of 1–150 kg/m$^3$, and are typically 90–99.8% air by volume. They can be formed from a variety of materials, including silica, alumina, lanthanide and transition metal oxides, metal chalcogenides, organic and inorganic polymers and carbon. Aerogel glazing entered the contemporary glazing market in the year 2006 and is, essentially, a granular aerogel encapsulated between polycarbonate construction panels that weigh less than 20% of the equivalent glass unit and have 200 times more impact strength. Light transmission and *U*-value of aerogel panels are a function of panel thickness. Their high performance, low density and outstanding light diffusing properties make them an appropriate choice for roof-light applications [28].

#### 3.1.2. Vacuum glazing

Vacuum space is created between two glass panes to eliminate the conductive and convective heat transfers between the glass panes reducing the center-of-glass *U*-value to as low as 1 W/m$^2$ K. Most often, low-e coating is applied on one or both of the glass panes to reduce the re-radiation into the indoor space [29]. Although, the technology faces some challenges in maintaining vacuum for longer periods, it is still a widely used energy efficient glazing option [28]. An exhaustive study is presented on the processes and the costs involved in the fabrication of vacuum glazing [30]. Also a comparison between the vacuum and argon filled double glazing is discussed. Heat transfer through evacuated triple glazing, a prospective glazing technology, was investigated by using analytical thermal network modeling and numerical finite element modeling [31]. The findings suggested that a triple vacuum glazing with a center-of-glazing thermal transmittance of less than 0.2 W/m$^2$ K is achievable.

#### 3.1.3. Switchable reflective glazing

Switchable reflective glazing is essentially a variable tint glazing and is typically suitable for cooling load dominant buildings with large solar gain [29]. In some types of switchable reflective glazing, the optical properties change as a function of the incident solar radiation, either by applying a low DC voltage (electrochromics (EC)) or by using hydrogen (gasochromics) to change from bleached to colored state. In others, light guiding elements such as switchable reflective light shelves reflect solar radiation [28]. A life cycle energy analysis performed on EC windows, operating in Greece, have shown an energy reduction of 54% which corresponding to 6388 MJ, compared to a standard window during a life of 25 years [32]. The payback period was found to be about 9 years and the total energy cost savings ranged from 228 to 569 €/m$^2$ for 10 and 25 years of EC window operation respectively. Currently, there are cost, warranty, switching time, glare and color rendering issues thwarting the marketability of this glazing technology.

*3.1.4. Suspended particle devices (SPD) film*

An SPD film is laminated between two glass panes. The SPD film has light absorbing particles that are randomly aligned in their normal state forming an opaque barrier. When voltage is applied, the particles align perpendicular to the plane of the glazing creating a transparent glass. The switching time (~1 s) is faster than EC glazing. This technology suffers from drawbacks such as radiant temperature, glare, color rendering, clearness and lifetime [28].

*3.1.5. Holographic optical elements*

Holographic optical elements (HOE) are light guiding elements comprising a holographic film sandwiched between two glass panes. The incident solar radiation is redirected, at a predefined angle through diffraction at the holographic film layer, usually onto the ceiling of the building interior. This can be used as a possible daylighting application. It suffers from some setbacks such as glare effects, light dispersion, milky clearness, limited exposure range of azimuth and zenith angles, etc. This technology is not yet commercialized [28].

*3.2. Frames*

The edge components (frame and spacer) of advanced fenestrations should minimize thermal bridging and infiltration losses. The effect of various combinations of frames and spacers on the *U*-value of different types of windows is described by Robinson and Hutchins [25]. Also, these edge effects are more pronounced in case of smaller size windows. The emphasis of low conductance frames was reiterated by Gustavsen et al. [33] in their review on low conductance window frames.

## 4. Roofs

Roofs are a critical part of the building envelopes that are highly susceptible to solar radiation and other environmental changes, thereby, influencing the indoor comfort conditions for the occupants. Roofs account for large amounts of heat gain/loss, especially, in buildings with large roof area such as sports complexes, auditoriums, exhibition halls etc. In accordance with the UK building regulations, the upper limits of *U*-value for flat roofs in 1965, 1976 and 1985 were 1.42 W/m$^2$ K, 0.6 W/m$^2$ K and 0.35 W/m$^2$ K, respectively. Currently, 0.25 W/m$^2$ K or less is required for all new buildings in the UK [34]. This reduction in the *U*-value over the years emphasizes the significance of thermal performance of roofs in the effort to increase the overall thermal performance of buildings.

Some passive cooling techniques could be implemented in tropical climates as result of modification in roof architecture. These include a compact cellular roof layout with minimum solar exposure, domed and vaulted roofs, naturally or mechanically ventilated roofs, micro ventilated roofs, high roofs and double roofs. Other methods such as white-washed external roof surfaces to reduce solar absorptivity, roofs covered with vegetation to provide humidity and shade, and usage of high thermal capacity materials such as concrete to minimize peak load demand are also gaining popularity. Roof shading is one way of reducing the impact of solar radiation on the roof surface. Economical roof shading is usually achieved with local material such as terracotta tiles, hay, date palm branches, inverted earthen pots, etc. which can usually contribute to a 6 °C drop in the indoor temperature [35]. Roof coatings are another way to mitigate the impact of solar radiation on the roof surface. High solar reflectance and high emissivity are the respective daytime and nighttime factors that govern the selection of a roof coating. Aluminum-pigmented coatings are less desirable because of their low infrared emittance. A cool coating can reduce a white concrete roof's surface temperature by 4 °C during a hot summer day and by 2 °C during night [35]. Most often, compound roofing systems are used to bring about the desired roof characteristics depending on the climatic conditions of the building location. A wide variety of roofing systems has emerged, and several of these are discussed in the following section.

*4.1. Types of roofs*

Roofs can be classified into different categories based on the type of construction. The following sections present some of the commonly used roofing structures along with recent developments.

*4.1.1. Masonry roofs*

In the developing countries of South Asia and the Middle East, masonry houses with reinforced cement concrete (RCC) roofs are popular owing to their pest (termite) resistance, natural calamity (cyclones) resistance, availability and cost effectiveness of concrete ingredients [36]. During tropical summers, they tend to exhibit unfavorable thermal characteristics such as higher soffit temperature and longer heat retaining capacity that affect the indoor air comfort conditions and increase energy costs. The indoor temperatures exceed 40 °C due to high roof temperatures of about 65 °C [35]. Higher soffit temperatures make them emit long wavelength infrared radiation towards the occupants. Even worse is that it might continue into the night due to the heat capacity of the slab. Also, the absorbed heat may lead to cracks in the supporting structure mainly made up of brick work or block work. This problem of high roof temperatures can be mitigated by employing roof shading, cool roof coatings or compound roof systems. A compound roof system developed with a combination of radiation reflectors and thermal insulation demonstrated substantial lowering of the heat conducted through a concrete roof [37]. An insulated concrete roof system with an antisolar coating proved successful in the tropical climatic conditions of Pakistan [38]. By lowering the roof temperature using this system, it was observed that the roof heat gain in summer was reduced by 45 kWh/day for a roof area of 208 m$^2$. Also, the overall heat transfer coefficient of the roof is reduced from 3.3 W/m$^2$ K to 0.54 W/m$^2$ K.

*4.1.2. Lightweight roofs*

Lightweight aluminum standing seam roofing systems (LASRS) are popularly used on commercial and government buildings as they are economical. However, they are wind sensitive due to weak seam-clip connection and also have bad thermal characteristics. Two easy ways to improve thermal characteristics of these roofs are by adding thermal insulation and using light colored roof paint. It was determined that the lighter colored surfaces such as white, off-white, brown and green yielded 9.3%, 8.8%, 2.5% and 1.3% reduction in cooling loads compared to an black-painted LASRS surface [39]. Recent investigations have revealed that the LASRS with glass fiber insulation does not suit well for hot and humid climates due to the interstitial condensation in the glass fiber layer. Alternative thermal insulation materials such as polyurethane, polystyrene or a combination of these have been evaluated [39]. These roofing systems, modeled and tested on an indoor stadium with a large roof surface area of 51 m × 41 m, indicated that roof structure with polyurethane insulation and white painted top surface performed better and saved 53.8% of the peak cooling load compared to a dark painted roof with glass wool insulation [39]. This can be attributed to the low thermal conductivity and thermal diffusivity of the polyurethane material and higher reflectivity of light colored roof surface.

#### 4.1.3. Ventilated and micro-ventilated roofs

The ventilated roof systems are essentially two slabs delimiting a duct through which air flows. This air gap/air flow diminishes the heat transfer across the roof into the building. Ventilated roofs can be either a passive type, with stack effect driving the air flow, or an active type, with fan induced ventilation. They are more popular in hot climatic conditions and are particularly useful in moderate height and wide roof area buildings. Depending on the size of the duct, the flow through it is either laminar or turbulent. A detailed energy analysis conducted on ventilated roof buildings confirmed that an energy savings of 30%, during Italian summer, can be achieved when compared to non-ventilated roof buildings [40]. During cold winters, it is advisable to close the air duct using suitable dampers from an energy savings standpoint. These dampers favor only a very small ventilation to drain off any possible condensate in the duct.

#### 4.1.4. Vaulted and domed roofs

Vaulted and domed roofs are quite popular in the vernacular architecture of the Middle East where the climatic conditions are hot and arid. Tang et al. [41] performed detailed finite element modeling of both vaulted roof (VR) and flat roof to compare their thermal performance in various climatic conditions. The half rim angle of a VR should be greater than 50° for it to show favorable influence on the indoor thermal conditions. South–north orientation of VR is more advantageous than east–west orientation. Also, they are only suitable for hot and dry climates, due to the presence of larger beam component of the solar radiation which is effectively reflected by the curved roof surface, and not so much for hot and humid climates [41]. Although VRs absorb more heat during the daytime than flat roofs, they also dissipate more heat through natural convection and re-radiation. Also, during night times, typical desert climate experiences colder ambient temperatures causing the VRs to dissipate heat even faster. High thermal stratification occurs inside VR buildings, with almost 75% of the stratification taking place in the volume under the vault, keeping the lower part of the building space cool. The hot air can be exhausted near the top of the gable walls of vaults [41].

#### 4.1.5. Solar-reflective/cool roofs

Solar-reflective roofs or cool roofs are high solar reflectance and high infrared emittance roofs. They maintain lower roof surface temperature and inhibit the heat conduction into the building. Two surface properties that affect the thermal performance of these roof surfaces are solar reflectance (SR) (reflectivity or albedo) and infrared emittance (or emissivity). Conventional roofing materials have a SR of 0.05–0.25. Reflective roof coatings can increase the SR to more than 0.60. Most roofing materials have an infrared emittance of 0.85 or higher, with the exception of metals, which have a low infrared emittance of about 0.25. Therefore, even though metals are very reflective (i.e. SR greater than 0.60), bare metal roofs and metallic roof coatings tend to get hot since they cannot emit the absorbed heat effectively as radiation. Special roof coatings can raise the infrared emittance of bare metal roofs [42]. As shown in some cases in Table 2, by increasing SR or infrared emittance, the roof surface temperature can be lowered. A white elastomeric coating or aluminum coating can raise the SR value more than 0.50. Additionally, the SR increases with coating thickness for some products [42]. To find the influence of highly reflective roofs on cooling and peak load variations, six different types of buildings were retrofitted with high reflectance white coatings or white PVC single-ply membrane at three different geographical sites in California (USA) [43]. It was concluded that the daily peak temperature of the roof surface for all the buildings was lowered by 33–42 K. The tests performed on these single-storey commercial/institutional buildings proved that high reflective roofs are economical for these buildings achieving cooling load savings of 5–40% and the peak demand savings of 5–10%.

#### 4.1.6. Green roofs

A building roof that is either fully or partly covered with a layer of vegetation is called a green roof. It is a layered composite system consisting of a waterproofing membrane, growing medium and the vegetation layer itself. Often, green roofs also include a root barrier layer, drainage layer and, where the climate demands, an irrigation system. There are two types of green roofs: intensive and extensive, the former has a deeper substrate layer and allows to cultivate deep rooting plants such as shrubs and trees; while the latter with thinner substrate layer allows to grow low level planting such as lawn or sedum. Extensive type is more commonly used as it can be retrofitted easily on existing roofs without modifications to the roof structure and also requires minimum maintenance. They have been proven to be fairly successful in cold climates, but needs more research on substrate material in hot and dry climates. The green roofs not only reflect the solar radiation, but also act as an extra thermal insulation layer. They are only meant to improve thermal protection of a building and should not replace the roof insulation layer. The typical additional load associated with an extensive green roof is about 120–150 kg/m$^2$ [45]. This is in the acceptable range of most buildings. A green roof system incurs higher annual savings when installed on a poorly insulated roof rather than a well-insulated roof.

The moisture content in growing media of the green roof influences its insulating properties. A 100 mm increase in the thickness of dry clay soil led to an increase in resistance by 0.4 m$^2$K/W, whereas for 40% moisture clay soil the increase was only 0.063 m$^2$K/W [46]. The wetter the medium, the poorer the insulating behavior compared to the dry growing media. The equivalent albedo of green roofs is about 0.7–0.85 as against an albedo of 0.1–0.2 for bitumen/tar/gravel roof [34]. Therefore, green roofs reflect solar radiation more efficiently than most conventional roofs. The building energy savings and the retrofit potential of green roofs in UK have been evaluated [62]. The field measurements carried out on low-rise commercial building, in the tropical climatic conditions of Singapore, reported that green roofs helped reduce the thermal reradiation effect experienced with bare roofs [47]. Average heat gain (summer) and heat loss (winter) reductions of 70–90% and 10–30%, respectively, were measured using green roof systems in Toronto, Canada [48]. The performance of green roofs on office buildings in Athens (Greece) is simulated and validated [49]. It is observed through simulations using the DOE-2 computer code that for a turf-type extensive green roof system installed on a non-insulated roof yielded 10.5% annual savings compared to only 0.6% annual savings when installed on an insulated roof [46]. The same conclusions are mathematically validated for Greek climatic conditions [50]. A thermal simulation package ESP-r (Environmental Systems Performance-research) was used to evaluate the performance of a green roof on a multi-storey residential building in Madrid (Spain). The building energy reduction is found to be maximum for the floor immediately below the roof surface and the savings were negligible/none for more than three floors below the roof [51].

Fig. 3 enumerates the various phenomena involved in the energy balance of the solar radiation received by a dry green roof, a wet green roof, and a traditional roof. Although wet soil green roofs disadvantageous as they are poor thermal insulators, they are advantageous in hot and dry climates where evapotranspiration is high. The wet green roofs have almost double the amount of evapotranspiration compared to dry green roofs making them actually remove heat from the building acting as a passive cooler [52].

**Table 2**
Solar reflectance and infrared emittance properties of typical roof types along with temperature rise [44].

| Roof surface type | Solar reflectance | Infrared emittance | Roof surface temperature rise (°C) |
|---|---|---|---|
| Ethylene propylene diene monomer (EPDM)–black | 0.06 | 0.86 | 46.1 |
| EPDM–white | 0.69 | 0.87 | 13.9 |
| Thermoplastic polyolefin (TPO)–white | 0.83 | 0.92 | 6.11 |
| Bitumen–smooth surface | 0.06 | 0.86 | 46.1 |
| Bitumen–white granules | 0.26 | 0.92 | 35 |
| Built-up roof (BUR)–dark gravel | 0.12 | 0.90 | 42.2 |
| BUR–light gravel | 0.34 | 0.90 | 31.7 |
| Asphalt shingles–generic black granules | 0.05 | 0.91 | 45.6 |
| Asphalt shingles–generic white granules | 0.25 | 0.91 | 35.6 |
| Shingles–white elastomeric coating | 0.71 | 0.91 | 12.2 |
| Shingles–aluminum coating | 0.54 | 0.42 | 28.3 |
| Steel–new, bare, galvanized | 0.61 | 0.04 | 30.6 |
| Aluminum | 0.61 | 0.25 | 26.7 |
| Siliconized polyester–white | 0.59 | 0.85 | 20.6 |

### *4.1.7. Photovoltaic roofs*

There have been significant efforts in recent years in integrating photovoltaics (PV) into building envelope. Especially, in countries where land-use is an important constraint, building integrated PV (BIPV) offer an effective solution by the use of building surface area while facilitating energy production and building envelope weather protection. PV roof tiles replace roofing material and are installed directly on to the roof structure. Ceramic tiles or fiber-cement roof slates have crystalline silicon solar cells glued directly on them. Another type of roof-integrated system has a PV element (glass-glass laminate) positioned in a plastic supporting tray anchored to the roof. Due to low cost and physical flexibility there has been growing interest in thin film PV for BIPV applications. Other types of PV roofs include sandwich PV roofing which offers multi-functionality such as electricity generation and thermal insulation [53].

Photovoltaic module based roof systems are still widely installed on sloped or flat roofs. They are either fixed directly on a weather-proof membrane with the help of aluminum framing system with drain trays or retrofit on top of the existing tiles. The generally guaranteed life span of these structures is around 30 years. An average retrofit cost of such system is around 7400 €/kW$_p$ as per the year 2003 prices [53]. The bulk of this cost is attributed to the price of PV modules. The cost of PV has gone down substantially since 2003, which would mean a lower price of these systems.

### *4.1.8. Thermal roof insulation systems*

The thermal insulation for roofs has been of growing importance lately, because on an average as much as 60% of the thermal energy leakage occurs through the roofs. Roof insulation has the potential for saving both cooling and heating loads. The transmittive barrier is a term often used to refer thermal insulation. When accompanied by a reflective surface (viz. an aluminum foil backing), it is referred to as radiant-transmittive barrier (as shown in Fig. 4) as it can also reflect infrared radiation. Polystyrene, fiberglass, rock-wool/mineral-wool are commonly used as roof insulation in the arid climates of Middle-East and Asia. Polystyrene or polyurethane insulation layers have the capability of reducing the load by more than 50% when compared to an identical building roof without insulation [35].

Laboratory experiments have been carried out on different configurations of roofing systems fabricated from five different kinds of insulating materials – polyurethane, polystyrene, polyethylene, sand and rubber along with two different reflector material – aluminum 1100-H14 and galvanized steel sheets [37]. Substantial reduction of heat flux through the roof, as high as up to 88%, is recorded for a combination of flat aluminum 1100 reflector and polyurethane insulator type concrete roof. The general results suggest that aluminum 1100-H14 is a better reflector than galvanized steel. Polyurethane and polystyrene performed better than other insulating materials. The geometry of the reflector seemed to have negligible effect unless there is forced convection [37]. A

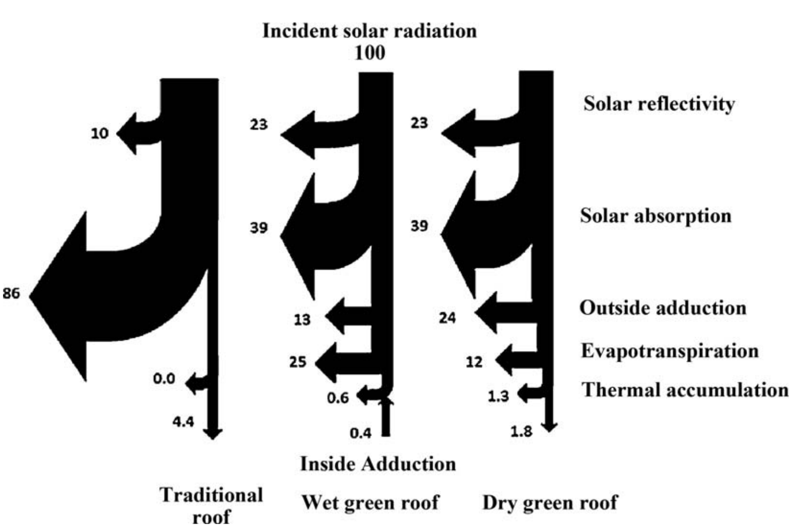


**Fig. 3.** Comparison of the energy exchanges of the dry or wet green roof with a traditional roof, summer season.
Source: Lazzarin et al. [52].

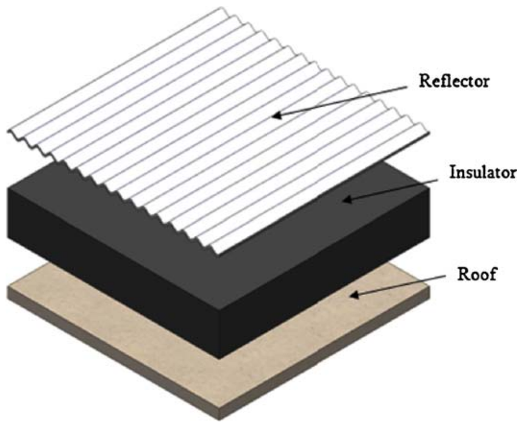


**Fig. 4.** Radiant-transmittive barrier.
Source: Alvarado et al. [37].

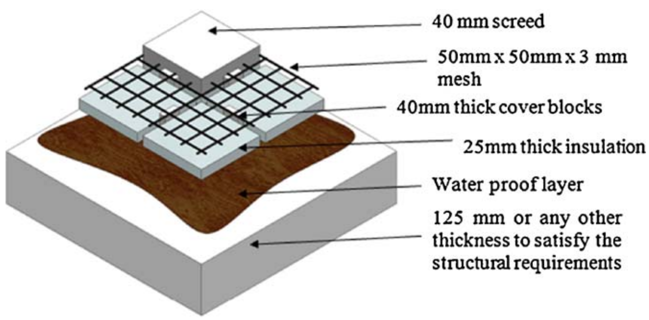


**Fig. 5.** Roof insulation system.
Source: Halwatura and Jayasinghe [36].

roof insulation system (as shown in Fig. 5) was tested on an occupied building in the tropical climate of Sri Lanka. The insulation used was expanded cellular polyethylene (thermal conductivity – 0.034 W/m$^2$ K). It was observed that an insulation thickness of 25 mm resulted in a soffit temperature reduction of at least 10 °C [36].

### 4.2. Evaporative roof cooling

In evaporative roof cooling, latent heat of evaporation is used to cool a building roof. There are different types of evaporative cooling methods. The techniques that are appropriate for tropical climates are roof ponds and wetted burlap bag covers. A roof pond is a shallow pool of water over a flat roof top with fixed side thermal insulations and a movable top thermal insulation. In summer, the top movable insulation covers the pond during daytime protecting it from solar radiation and exposes it to the environment during the night for nocturnal cooling of the water. In winters, the process happens vice versa, i.e. closed pond during the night and exposed pond during the day. The use of roof pond can lower the room temperature by about 20 °C in summer [35]. Wetted burlap bags are water soaked jute bags that are laid on roof tops to provide evaporative cooling, especially in regions with hot and arid weather. Although the roof temperature can be lowered by as much as 15 °C [35], these methods suffer from non-availability of water. Skytherm or evapo-reflective methods are more preferable in such climatic conditions [37]. A proposed evapo-reflective roof system (as shown in Fig. 6) consists of high thermal capacity rock bed in water over the concrete roof ceiling, a reflective aluminum sheet that encloses on the top and an air gap between the water surface and the aluminum reflector. A simulated comparison suggests that

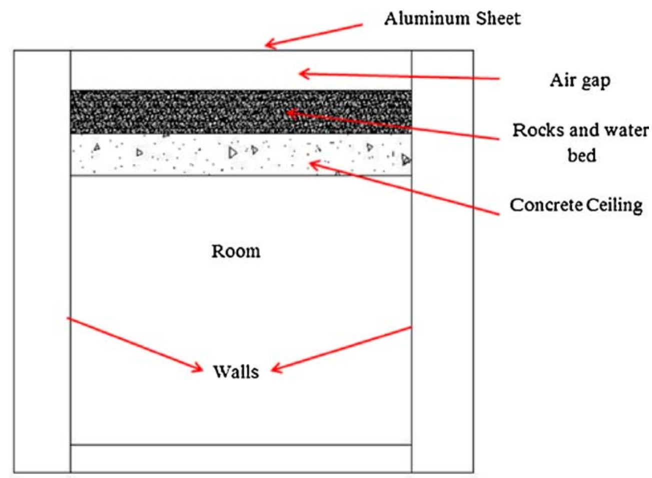


**Fig. 6.** Evapo-reflective roof cooling system.
Source: Ben Cheikh and Bouchair [54].

this evapo-reflective roof can reduce the indoor temperature by up to 8 °C in comparison to a bare concrete roof [54].

## 5. Thermal insulation, thermal mass and phase change materials

### 5.1. Thermal Insulation

Thermal insulation is a material or combination of materials, that, when properly applied, retard the rate of heat flow by conduction, convection, and radiation. It retards heat flow into or out of a building due to its high thermal resistance. The proper use of thermal insulation in buildings reduces not only the energy usage but also downsizes the HVAC system during design. A simple and effective way to improve the energy efficiency of a building is by improving the thermal insulation of the envelope. The thickness of insulation in building has increased since the early 1970s, almost doubling in northern Europe [55]. The best performance of thermal insulation is achieved by placing it closest to the surface of heat entry; i.e. in space heating load dominant regions, insulation should be placed close to the inner surface of the building envelope while in cooling load dominant regions it should be closer to the outer surface. Typically, the thickness of the insulation material in a 50 cm thick wall is around 25–30 mm depending on the building codes and regulations across various countries. An economic model to determine the optimum insulation thickness for external walls of a building for various locations in Turkey was developed [56]. Seasonal load savings were estimated using the model.

#### 5.1.1. Selection of insulation

The thermal conductivity and thermal inertia are practically the most important factors that affect the selection. The increase in temperature and moisture content of the thermal insulation increases its thermal conductivity, thereby degrading its performance. In fact, studies have shown that water in the form of vapor or liquid has a detrimental effect on the material characteristics of slag-rock wool fibers and fiberglass [57]. Environmental and health impacts are also important factors in selecting an appropriate insulation. The chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) gradually emitted over the life cycle of some foam type insulation materials such as extruded polystyrene (EPS) and polyisocyanurate (PIR) prove detrimental to the environment due to their large ozone depletion and global warming potentials. Insulating foam which contains isocyanates acts as a powerful irritant on eyes and skin. Often times, glass-fiber batt type insulation

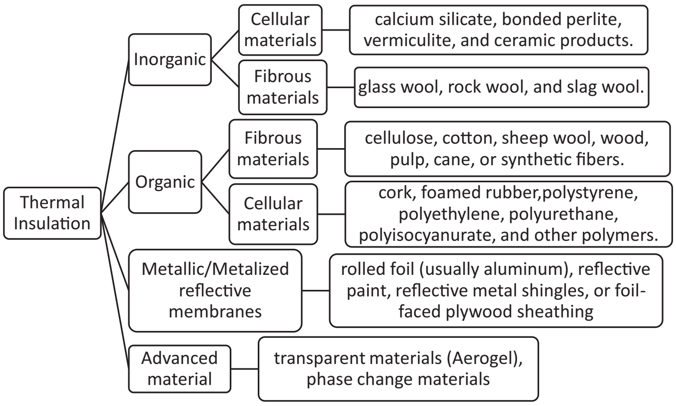


**Fig. 7.** Different types of thermal insulation.

material is known to cause health related problems, especially respiratory ailments, to the personnel handling it. Flammability is also an important factor in material selection. Rigorous tests check flare spread, fuel contribution, and smoke development rates to classify the flammability of the insulators accordingly. For example, the mixture of flame/glow-retardant chemicals with cellulose (an inherently flammable material) diminishes the fire propagation ability [58]. However, the addition of flame-retardants reduces the thermal resistance of the insulator thus diminishing its performance. Benefit to cost ratio is another important factor that is generally considered in the selection of insulation.

*5.1.2. Types of insulation*

The thermal insulation is available in different physical forms such as

1. Mineral fiber blankets: batts and rolls (fiberglass and rock wool).
2. Loose fill that can be blown-in (fiberglass, rock wool),
3. Poured-in, or mixed with concrete (cellulose, perlite, vermiculite).
4. Rigid boards (polystyrene, polyurethane, polyisocyanurate, and fiberglass).
5. Foamed or sprayed in-place (polyurethane and polyisocyanurate).
6. Boards or blocks (perlite and vermiculite).
7. Insulated concrete blocks and insulated concrete form.
8. Reflective materials (aluminum foil, ceramic coatings).

The types of insulation can be classified into 4 categories and respective subcategories depending on their material type as shown in Fig. 7 [55,59].

*5.1.3. Vacuum insulation panels*

Vacuum insulation panels are high performance thermal insulators made up of evacuated foil-encapsulated porous material. The selection of core material that can maintain vacuum is a challenge. Fumed silica ($SiO_x$) is one such material that suits the requirements of core material. Pressed boards made out of fumed silica has a low conductivity (close to 0.003 W/m K at 50 mbar) and has a conductivity of 0.020 W/m K at ambient pressure in dry conditions, half the thermal conductivity of traditional insulation materials [60].

*5.1.4. Structurally insulated panels (SIPs)*

Structurally insulated panels (SIPs) are pre-fabricated composite building elements used as walls, roofs, ceilings and floors. SIPs consist of insulation sandwiched between two structural boards. The commonly used insulation materials in SIPs are expanded polystyrene foam and polyurethane foam. In some cases, straw bales are also used as sustainable insulation material. The SIPs are manufactured in factories and shipped to job site allowing quicker installation, a major advantage of SIPs.

*5.2. Thermal mass*

Thermal mass refers to the high heat capacity materials that can absorb heat, store it and release it later. They include building components such as walls, partitions, ceilings, floors and furniture of a building that can store thermal energy. It helps in the regulation of indoor temperature by absorbing and progressively releasing the heat gained through both external and internal means. This leads to delaying/reducing the peak indoor loads and decreasing the mean radiant temperature [61,62]. For thermal storage to be effective, the diurnal ambient temperature variation should exceed 10 K. The thermal mass optimization is effected by the thermo-physical properties of the building material, building orientation, thermal insulation, ventilation, auxiliary cooling systems and occupancy patterns. This passive building energy efficiency technique is more effective to buildings such as offices that are unoccupied during the night when the thermal mass can be cooled with nighttime ventilation [62]. The effects of thermal mass and night ventilation on building cooling load are mathematically modeled [63]. In a case study on a 27,000 $ft^2$ commercial building in northern New York, energy savings of 18–20% (12.2–16.0 $kBtu/ft^2$) were achieved through addition of thermal mass. Reduction in both peak heating and cooling loads led to the downsizing of the HVAC system, offsetting the capital investment spent on thermal mass addition [64]. In a study, six different envelope configurations were compared through computational simulations. It was concluded that the position and distribution of thermal mass in the building envelope does not influence energy savings for high rise buildings in cold climates [65].

*5.3. Phase change materials (PCM)*

Phase change materials store and release heat to reduce the cooling and heating loads of a building. They basically function as a thermal mass and accomplish that by liquefying as they absorb heat, preventing the heat from reaching the conditioned space and releasing the heat when the outside temperature decreases (typically at night). A recent experimental work carried out by Arizona Public Service (APS) in collaboration with Phase Change Energy Solutions (PCES) Inc. with a new class of organic-based PCM (BioPCM) showed maximum energy savings of about 30%, a maximum peak load shift of about 60 min, and a maximum cost savings of about 30% over conventional non-PCM base-case. Also, unlike other organic based PCMs which are highly flammable, the BioPCM used in this case is less flammable and safer to use [66]. Feldman et al. [67] used differential calorimetry technique to determine the transition temperatures and latent heats of transition of fatty acids (capric, lauric, palmitic and stearic) and their binary mixtures, which are all attractive candidates for latent heat thermal storage. The PCM absorption capacity of 10 different building envelope materials was presented [68]. The PCM used in this case was a mixture of 50% butyl stearate and 48% palmitic acid.

## 6. Infiltration and airtightness

The movement of air into the conditioned space of a building through cracks, leaks, or other building envelope openings is referred as infiltration, and out of the building is called exfiltration. Infiltration affects the air conditioning load, temperature and moisture levels of indoor air in buildings. Also, when infiltrated air encounters colder regions of the building envelope, water vapor condenses which is not desirable due to various reasons such as promotion of mold and mildew growth, etc. [69]. Caulking/sealing of air leakage cracks and penetrations can improve the energy efficiency of a building by minimizing infiltration.

Unlike infiltration which depends on the pressures across the building envelope, airtightness of a building is independent of these naturally induced pressures. That is why it is an important parameter in building stock characterization, modeling assumptions or construction quality control. The measure of both infiltration and airtightness of a building are important from energy and indoor air quality (pollutant and moisture transports) standpoints.

### 6.1. Factors affecting infiltration

Infiltration is driven by a pressure difference across the building envelope caused due to temperature difference between indoor and outdoor air (stack effect), wind movement and operation of mechanical ventilation equipment and vented combustion devices. The rate of infiltration is affected by climatic factors, building surroundings, building age and building construction characteristics. During indoor heating, air tends to infiltrate the building through the leaks low in the building envelope and exfiltrate from the leaks high in the building envelope. The airflow patterns are reversed during indoor cooling. Ignoring the internal airflow resistance, the stack pressure difference is around 0.02 Pa per meter of building height and degree Celsius of indoor–outdoor temperature difference. Generally, lower wind speeds (2.5 m/s or less) generate an exterior wind pressure of 1 or 2 Pa; whereas higher wind speeds (10 m/s or more) can generate pressure of 25 Pa or more [70]. The operation of mechanical equipment, ventilation systems, local exhaust fans, and vented combustion appliances causes a net flow of air into the building or out of the building, thereby causing a respective raise or fall of the interior building pressure.

### 6.2. Mathematical formulation of infiltration

Generally, the power laws of the form $\Delta P = \alpha Q^{\beta}$ establish a relation between pressure drop ($\Delta P$) and volume flow rate ($Q$) in flow through cracks. Other laws, such as the square law (where $\Delta P = \alpha Q^2$) are also applicable to some types of leakage or crack geometries and pressure differences where fully developed turbulent flow is encountered. Here '$\alpha$' is a constant dependent on effective leakage area of the crack. In a different study, experiments on pressurization testing of windows resulted in quadratic law of the form: $\Delta P = AQ + BQ^2$. The coefficients $A = 12\,\mu z/Ld^3$ and $B = \rho C/2d^2L^2$ in this equation are independent of the flow rate. This law described experimental data better than the power law for window pressurization test [71]. Although the quadratic form addresses a wide range of laminar and turbulent flow rates, the equation inherently assumes a fully developed flow through leaks and cracks. However, this fully developed flow assumption is not valid as flow through the cracks is mostly developing, and also the transient pressure difference across the building envelope in real situation worsens the likelihood of a fully developed flow. A power law of the flow equation has been proven to better represent the infiltration across a building envelope [72]. ASHRAE crack method [73] and empirical equations derived from air tightness test results by Persily [74] for air leakages and infiltration appear to endorse the use of the power law form.

### 6.3. Pollutant infiltration

Buildings are ventilated by three means, namely: mechanical ventilation (induced by fans, blowers etc.), natural ventilation through fenestration (due to wind and buoyancy force) and infiltration through cracks and leaks. In mechanically ventilated buildings, the effectiveness of the filters influences the penetration of ambient particles. While in naturally ventilated buildings, particle penetration approaches unity because of the air exchange openings are large. In infiltration governed air change, particle penetration depends on geometry of air leakage path, pressure difference that drives the flow and particle transport properties. Although filters and other cleaning equipment minimize the pollutant levels in buildings, different particles and reactive gases enter through infiltration. Diesel soot, constituents of photochemical smog, industrial particulate emissions, aerosols, airborne pollen, spores and microbial volatile organic compounds from molds in building envelope are some examples of such urban pollutants [75]. Higher particle concentrations in the indoor air lead to adverse effects on human health. These concentrations depend primarily on the degree of penetration of these particles through the building envelope [76].

Rectangular/regular geometry surrogates of the real infiltration paths were developed using seven commonly-used building materials: aluminum, brick, concrete, plywood, redwood lumber, pine lumber and strand board. The crack heights were selected to be 0.25 and 1 mm to closely represent those in a real building. The length of the crack in direction of airflow was 4.3 and 9.9 mm for aluminum cracks and 4.5 mm for other materials. Also, the pressure difference across the crack was maintained similar to that of a normal building envelope 4 or 10 Pa. Particle penetration is almost 100% for particles of diameter 0.02–7 $\mu$m when the crack height is $\geq$1 mm. It is almost 95% for particles of diameter 0.1–1 $\mu$m when the crack height is $\geq$0.25 mm, assuming the pressure difference is at least 4 Pa. It was experimentally proven that the surface roughness and irregular crack geometries has a bearing on the particle penetration [76].

### 6.4. Infiltration and air tightness case studies

Persily et al. [69], collected air leakage data from over 70,000 U.S. homes. The average air leakage of these homes was about 20 air changes per hour at 50 Pa pressure difference, although conventional new houses constructed since 1993 seem to have an average value of 10 air changes per hour. Energy efficiency construction programs have reportedly reduced this value to 5 air changes per hour (ACH) for new houses. Also, against the popular belief in the U.S. that commercial and institutional buildings are relatively airtight, it was proven that they are more conducive to increased leakage than conventional new houses in the U.S. The U.S. commercial and institutional building data also proves that taller commercial/institutional buildings are tighter than shorter ones and, so did the buildings in colder climates than in warmer climates. It appears that the type of construction practices in taller buildings lend themselves more to airtight envelopes. The general residential building data obtained in USA suggests that 2 air changes per hour at 50 Pa could be considered a very tight house. A value of 5 air changes per hour could be considered moderately tight, while 10 air changes per hour could be considered typical and 20 air changes per hour can be classified leaky [74]. The data from 139 commercial and institutional buildings analyzed by Persily [74] have shown that taller buildings are more airtight than shorter buildings. The more careful design and construction to meet the structural demands of tall buildings may have yielded to their better air-tightness.

Experimental studies have been conducted to measure the infiltration on 20 residential buildings in Greece, a representative of Mediterranean/southern European type of climate [70]. These naturally ventilated building envelopes (with more than one exposed façade) are classified into three categories based on their air tightness and infiltration under natural conditions. This classification complies with the standard EN ISO 13790 that defines three categories of building air tightness levels: high, medium and low. The air tightness measured from a blower door test (at 50 Pa pressure difference) should be less than 4 ACH or infiltration rate measured from tracer gas decay should be less than 0.5 ACH to be classified as 'high' level of envelope tightness. Similarly, a 'low' level of envelope tightness indicates 10 ACH (or higher) or infiltration rate of 1.5 ACH (or higher). A 'medium' level of envelope tightness designates 4–10 ACH or infiltration rate of 0.8 ACH.

## 7. Building simulation software/programs

The building energy modeling codes can be used to estimate the energy performance of a building envelope, energy used in the building, HVAC sizing, estimate lighting requirements, economic feasibility estimates for building energy efficiency components, comparison of a building performance with a code standard building, etc. These codes can be used by building designers as guiding tools to develop an optimal energy efficient building. The modeling tools can also be used to predict a cost effective energy efficiency retrofit to an existing building. Several building energy modeling codes have been developed by different groups over the years. The accuracy of the building energy simulations heavily depends on the user input data such as building geometry and orientation, construction details, geographic location, mechanical equipment, type of building (residential or commercial), etc.

Crawley et al. [77] performed an up-to-date comparison of the features and capabilities of 20 major building energy simulation codes. The codes include BLAST, BSim,DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES/VES, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. The capabilities of these codes to model building envelope, daylighting and infiltration in buildings are also discussed. Antinucci et al. [62] identified 128 models with building energy simulation capabilities. Of those programs 54 can evaluate the variation in indoor air temperature, 45 can also consider the impact of thermal mass and shading, 48 tools include daylighting subroutines, whereas only 23 programs can simulate natural ventilation strategies. Most of these programs are compiled for architects and engineers, although some of them can be useful to technicians, builders and researchers. The majority of these programs can be used for simulation of residential and small-size commercial buildings, while only 47 of them have some capability of simulating large-size commercial buildings.

Apart from above mentioned software, there are certain specific computer programs that deal with simulation of the performance characteristics of certain envelope components. Programs such as Window, VISION4, FRAME4, FRAMEPlus, FENSIZE, Frame Simulator, RESFEN, SPACER etc. are used to simulate thermal performance characteristics of fenestration. GLASTRUCT and FENSTRUCT are used to simulate the structural performance of fenestration. Fenspec and Catalogue are multi-vendor databases for windows/fenestration products that can be searched for options that meet a designer's physical and performance criteria.

AWNSHADE, LESO-Shade, ParaSol, ShadowFX, Solar-2, Solarch, Sun Chart, SunCast, Sundi and SunPath are some shading/solar design tools that assist in analyzing the qualitative aspect of solar design (such as building appearance, lighting, glare) rather than quantitative energy issues.

CONTAM is a multi-zone indoor air quality and air flow analysis program that helps determine infiltration, exfiltration, room-to-room air flows, induced pressure differences due to indoor and outdoor temperature difference, wind movement and mechanical means, contaminant concentrations, occupant exposure patterns, etc. [78].

## 8. Building envelope diagnostics

Building envelopes, like any other components of the building, should receive regular and thorough inspection. The inspection techniques may vary from simple visual inspection through binoculars to sophisticated IR thermography.

### 8.1. Infrared thermography

The thermal infrared (IR) imaging is a handy diagnostic tool used for detecting building envelope defects. IR inspections are useful in detecting building energy problems such as heat losses, missing or damaged thermal insulation in walls and roofs, thermal bridges, air leakage and moisture sources. It is non-destructive and non-contact in operation and can be used to easily inspect remote regions of the envelope. The accuracy of the leakage measurement is dependent on various factors such as emissivity of the measured surface, air particles, ambient temperature, wind speed and distance from the target [79]. Most non-metallic surfaces such as paint, wood and plastics have high emissivity values greater than 0.8. For clean, well-polished, shiny metal surfaces, the emissivity is typically between 0.05 and 0.2, though oxide layer impurities can increase the emissivity values. Generally, a high emissivity surface (such as paper stickers, water soluble black paint, electrician's tape) can be affixed on a low emissivity surface (less than 0.5) while executing the measurement. A vivid description of emissivity measurement technique and the details of error corrections are described [80]. Atmospheric particles between the source and the lens of the IR camera cause transmission attenuation of IR radiation and the ambient air temperature affects the temperature of the IR radiation sensing equipment. IR equipment, usually have an internal compensation system that will correct these variations. Wind speed of 5 m/s or higher can influence the measurements due to convective heat losses. The distance of the target and the angle of vision influence the resolution and quality of the IR image. Farther distances and higher oblique angles of vision can lead to poor resolution and quality of the picture [79].

### 8.2. Fenestration diagnostics

Portable spectrometer or solar transmission meter is used to measure the emissivity of fenestration glazing. A portable handheld spectrometer is a surface-contact tool that uses an infrared emitter and detector to estimate the aggregate normal reflectance of a multi-pane glazing assembly. It is more convenient to use than solar transmission meter. The use of solar transmission meter on a fixed (non-opening) fenestration is impractical because it requires measuring irradiance with and without the glazing in the irradiance path. Neither of these devices can differentiate a low-e pane from a non-low-e pane nor can they determine the thickness of inter-pane gap. A handheld laser thickness gauge is used for such measurements [81].

### 8.3. Infiltration and airtightness diagnostics

Tracer gas measurements are used to calculate infiltration rates in buildings. The tracer gas released in the buildings is usually nitrous oxide ($N_2O$) whose concentration decays as it mixes with the indoor air. The $N_2O$ concentration is traced to determine the infiltration rate in air changes per hour (ACH or $h^{-1}$). ASTM standard E741 details various tracer gas methods applicable to single zone buildings.

The airtightness of a building is measured by blower door test or fan pressurization test. The blower door test is generally used for low rise residential buildings and is carried out at various induced pressures (generally at 50 Pa). ASTM standard E1827 describes the blower door test that employs an orifice approach to measure air flow rate. In commercial buildings, fan pressurization test, which is analogous to blower door test, is conducted to determine airtightness. The fan pressurization test method is

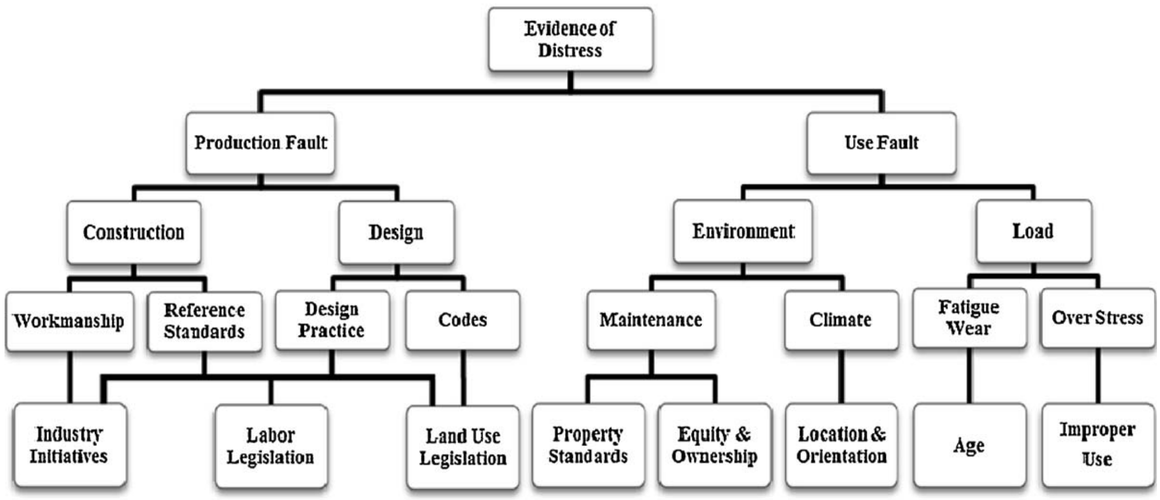


**Fig. 8.** Fault tree tool.

Source: Genge [83].

described comprehensively by ASTM standard E779. EN ISO 13829 also elucidates the fan pressurization test procedure in detail [82]. Elevated pressure differences in the range of 10 to 75 Pa are created between the interior and exterior of a building using a fan or a blower to override any weather factors influencing the pressure difference. The airtightness is calculated from the airflow rates required to maintain these induced pressure differences.

### 8.4. Envelope moisture diagnostics

The areas of moisture anomalies in building envelopes are identified using in situ moisture measurement procedures. Surface scanning dielectric meters and penetrating conductance meters are used to quantify the presence of moisture in non-conductive porous building material. Since both these devices are electrical based, they are susceptible to presence of static electricity and conductive materials. Of these, surface scanning techniques are advantageous because they do not damage the envelope surface and can be used on large surfaces. On the other hand, the penetrating conductance technique damages the envelope surface due to insertion of probes. The penetration method is often used after the surface scanning method to get accurate measurements.

## 9. Building envelope maintenance

Since building envelopes separate the indoor and outdoor environments, they are subjected to environmental effects of temperature, humidity, air movement, rain, snow, solar radiation and various other natural factors. It is important to carry out building envelope maintenance to ensure quality living/working/industrial environments and to avoid premature failure of the building structure. There are two types of building envelope maintenance—'Routine' maintenance involves regularly scheduled inspections, repairs or replacement of building envelope components and 'Response' maintenance involves emergency or immediate maintenance where failed components are repaired or replaced. Generally, building envelope repair and replacement costs contribute 20–30% of the overall building repair and maintenance life cycle costs [83]. The building envelope repair calls are the most frequent of all building repair calls, especially in high-rise structures and extreme climates [84]. Investment on annual maintenance audits and professional review of the general performance of building envelope components can prevent premature and costly failures.

One of the commonly encountered building envelope maintenance issues is water run-off damage. Whenever water runs down over building envelope components, it can leave behind contaminants that react with or adhere to the surface of the exposed envelope components, thus causing a temporary or permanent damage to the building envelope [84]. Building envelopes also need to be designed and protected from two wind storm effects: windborne debris and fluctuating pressures. This is an important consideration in hurricane/tropical cyclone/typhoon prone areas. A review of the wind storm effects on building envelopes conclude that the fenestration of high rise buildings are most affected due to the hurricane winds [85]. Some of the building codes and standards concerning the windborne debris and fluctuating pressures impact on the building envelope are also discussed in this review.

Commonly, considerable effort may be spent on examining, categorizing and documenting the symptoms of fault (distress) rather than the fault itself. For instance water leaks, efflorescence, spalled brick, etc., are often classified as fault when they actually are the symptoms of fault (distress). The fault tree tool that is useful in inspecting the building envelope performance is shown in Fig. 8. This tool helps the investigator identify the fault(s) causing the distress rather than the distress (symptom of fault). The fault tree is divided into two main divisions—the left branch is concerned with faults encountered during the creation of a building while the right branch is concerned with faults encountered during the operation of a building. Any identified building envelope distress may be related to one or more faults shown in the fault tree. Once those faults are identified, the necessary repair or replacement action can be initiated depending on the operational, financial and technical constraints to minimize or eradicate the distress [83].

## 10. Conclusion

This article reviewed various building envelope components from an energy efficiency and savings perspective. Improvements to building envelope elements are generally referred as passive energy efficiency strategies. Passive energy efficiency strategies are highly sensitive to meteorological factors and, therefore, require a broader understanding of the climatic factors by a designer. For example, application of thermal mass as an energy saving method is more effective in places where the atmospheric air temperature differences between the days and nights are high. Building energy modeling computer codes play an important role in choosing the best energy efficiency options for a given location. In order to ensure proper operation of the designed envelope, building envelope commissioning is essential. Periodic energy auditing of the building envelopes and maintenance are important to achieve the best energy performance and extended life for a building envelope.

Currently, while some of these advances in envelope component technologies are easy and cost effective to adopt, others still remain in the research and development phase for future applicability. Several studies have been performed to find the economic feasibility of various building energy efficiency strategies [86–88]. Cost-benefit analysis of some of these energy efficiency strategies for a cooling dominated desert climate is presented by Sadineni et al. [89]. Energy efficiency approaches sometimes might not require additional capital investment. For example, a holistic energy efficient building design approach can reduce the size of mechanical systems compensating the additional cost of energy efficiency features. Government incentives and rebates in many parts of the world are promoting the market penetration and social awareness of these technologies.

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# Bird-Friendly Building Design

Vassar's Bridge for Laboratory Sciences, shown here under construction in October 2015. The building is scheduled to open in January 2016. Cover rendering and photos courtesy of Ennead Architects

Exterior glass detail

Glass detail, showing frit pattern

**Cover rendering and photo this page:** The new Bridge for Laboratory Sciences building at Vassar College, designed by Richard Olcott/Ennead Architects, redefines the identity of the sciences on the College's historic campus and provides technologically advanced facilities for students, faculty, and researchers.

Fundamental to the building's design is its seamless integration with the natural landscape, scale, and campus aesthetic of the College. In this natural wooded setting, the need for strategies to reduce bird collisions with the building was apparent. In response, the building was designed to comply with LEED Pilot Credit 55: Bird Collision Deterrence.

Ennead managing partner Guy Maxwell is a nationally recognized champion of bird-friendly design and has led Ennead's innovative approach to make the building's glazing safer for birds, employing patterned glass, screens and sunshades, and Ornilux glass, a specialty glass product that uses a UV coating visible to birds but not humans.

By framing and showcasing views of the landscape, the building celebrates and connects students with the surrounding environment, while the overall development of the precinct repurposes an underutilized sector of campus.

# Table of Contents



The area of glass on a façade is the strongest predictor of threat to birds. There are also other reasons to limit glass. Skidmore Owings Merril's Bronx, New York, Emergency Call Center is a handsome example of creative design with restricted glass, for a building intended to be both secure and blast-resistant. Photo by Chris Sheppard, ABC

For updates and new information, see **collisions.abcbirds.org**



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# Executive Summary

A bird, probably a dove, hit the window of an Indiana home hard enough to leave this ghostly image on the glass. Photo by David Fancher

Collision with glass claims the lives of hundreds of millions of birds each year in the United States. It is second only to domestic cats as a source of mortality linked directly to human action. Birds that have successfully flown thousands of miles on migration can die in seconds on a pane of glass; impacts kill fledglings before they can truly fly. Because glass is dangerous for strong, healthy, breeding adults, as well as sick or young birds, it can have a particularly serious impact on populations.

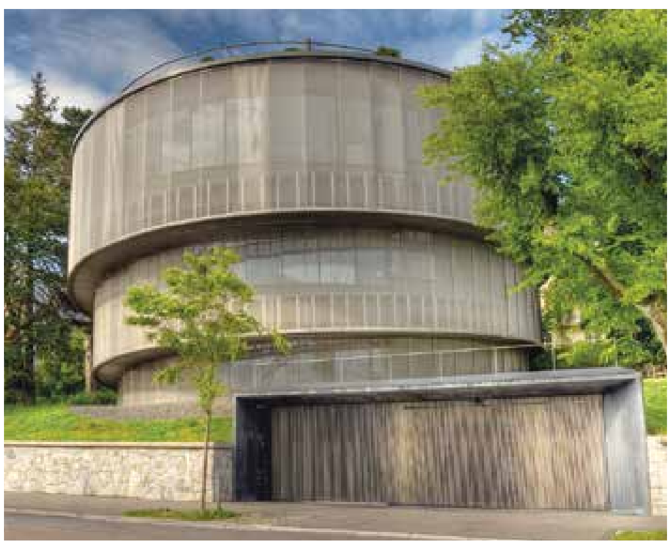
Bird kills occur at buildings across the United States and around the world. We know most about mortality patterns in cities, because that is where most monitoring takes place, but virtually any building with glass poses a threat wherever it is. The dead birds documented by monitoring programs or provided to museums constitute merely a fraction of the birds actually killed. The magnitude of this problem can be discouraging, but there are already effective solutions and an increasing commercial commitment to developing new solutions, if people can be convinced to adopt them.

That artificial lighting at night plays a significant part in mortality from glass is widely accepted, but often misunderstood. The majority of collisions with buildings take place during daylight. There are many well-documented instances of bright lights at night disorienting large numbers of birds—usually night-migrating passerines but also seabirds—some of which may circle in the light, sometimes until dawn. Nocturnal mortality associated with circulation events is caused by collision with guy wires and other structures. Such events were described starting in the late 19th century at lighthouses, and later at the Washington Monument, Statue of Liberty, and Empire State Building, which were the only brightly lit structures in their areas. Today, such events occur mostly at offshore drilling platforms and communication towers. These situations have in common bright light surrounded by darkness, and their frequency has decreased in cities as areas of darkness around bright structures have also become lit. However, there are strong indications that birds are still being disoriented by urban lights and that lights are linked to mortality, even though mortality patterns have changed.

Advances in glass technology and production since the mid-twentieth century have made it possible to construct skyscrapers with all-glass walls, homes with huge picture windows, and miles of transparent noise-barriers on highways. There has been a general increase in the amount of glass used in construction—and the amount of glass on a building is the best predictor of


Newhouse III, designed by Polshek Partnership Architects, is part of Syracuse University's S.I. Newhouse School of Public Communications. This building incorporates an undulating, fritted glass façade with the words of the first amendment etched in letters six feet high along the base. Photo by Christine Sheppard, ABC the number of birds it will kill. However, while glass is important for bringing light into buildings, a façade with over 30-40% glass dramatically increases energy use for heating and cooling. Bird-friendly design is becoming recognized as part of sustainable design, required increasingly by legislation across North America.

New construction can incorporate from the beginning bird-friendly design strategies that are cost neutral. There are many ways to reduce mortality from existing buildings, with more solutions being developed all the time. Because the science is constantly evolving, and because we will always wish for more information than we have, the temptation is to postpone action in the hope that a panacea is just around the corner. But we can't wait to act. We have the tools and the strategies to make a difference now. Architects, designers, city planners, and legislators are key to solving this problem. They not only have access to the latest building construction materials and concepts; they are also thought leaders and trend setters in the way we build our communities and prioritize building design issues.

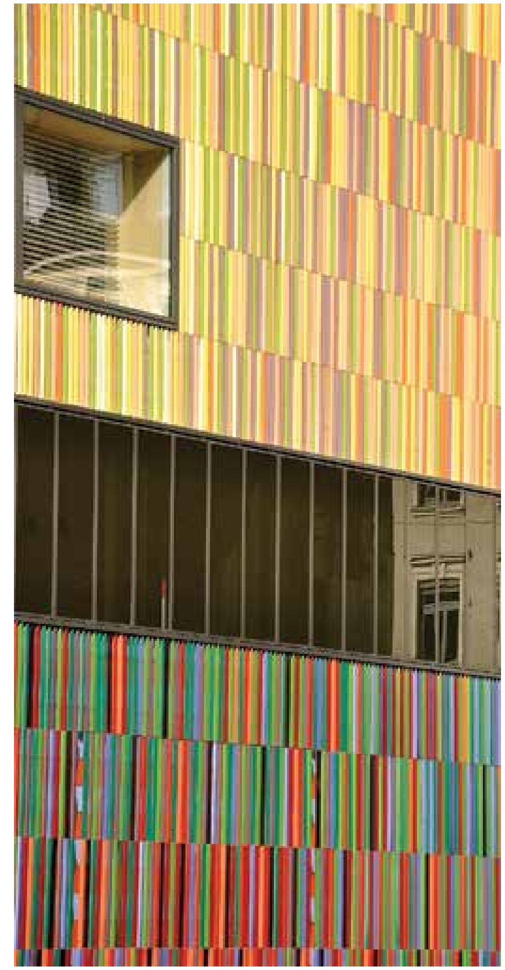


The steel mesh enveloping Zurich's Cocoon in Switzerland, designed by Camenzind Evolution, Ltd, provides privacy, reduces heating and cooling costs, and protects birds, but still permits occupants to see out. Photo by Anton Volgger

This publication aims to provide planners, architects, and designers, bird advocates, and local, municipal, and federal authorities, as well as the general public, with a clear understanding of the nature and magnitude of the threat glass poses to birds. Since the first edition, in 2011, there has been increased awareness of collisions, evidenced by new ordinances and guidelines for bird-friendly construction, new materials to retrofit existing buildings, and promotion by the glass industry of bird-friendly materials.

This edition includes an updated review of the underlying science, examples of solutions that can be applied to both new construction and existing buildings, and an explanation of what information is still needed. We hope it will spur individuals, businesses, communities, scientists, and governments to address this issue and make their buildings safer for birds. Constructing bird-friendly buildings and eliminating the worst existing threats require only imaginative design, effective retrofits, and recognition that birds have intrinsic and cultural as well as economic and ecological value to humanity.

American Bird Conservancy's Collisions Program works at the national level to reduce bird mortality by coordinating with organizations and governments, developing educational programs and tools, evaluating and developing solutions, creating centralized resources, and generating awareness.



The façade of Sauerbruch Hutton's Brandhorst Museum is a brilliant example of mixing glass and non-glass materials. Photo by Tony Brady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## Why Birds Matter

For many people, birds and nature have intrinsic worth. Birds have been important to humans throughout history, often symbolizing cultural values such as peace, freedom, and fidelity. In addition to the pleasure they can bring to people, we depend on them for critical ecological functions. Birds consume vast quantities of insects and control rodent populations, reducing damage to crops and forests and helping limit the transmission of diseases such as West Nile virus, dengue fever, and malaria. Birds play a vital role in regenerating habitats by pollinating plants and dispersing seeds. Birds are also a direct economic resource. According to the U.S. Fish and Wildlife Service, bird watching is one of the fastest growing leisure activities in North America, an over $40 billion industry accounting for many jobs.

## The Legal Landscape

At the start of the 20th century, following the extinction of the Passenger Pigeon and the near extinction of other bird species due to unregulated hunting, laws were passed to protect bird populations. Among them was the Migratory Bird Treaty Act (MBTA), which made it illegal to kill a migratory bird without a permit. The scope of this law, which is still in effect today, extends beyond hunting, such that anyone causing the death of a migratory bird, even if unintentionally, can be prosecuted if that death is deemed to have been foreseeable. At present, the scope of the MBTA is under challenge in federal court and it is impossible to say whether it will ever be used to curb glass collisions. However, courts in Canada have ruled that building owners are responsible for mortality caused by glass.

Violations of the MBTA can result in fines of up to $500 per incident and up to six months in prison. The Bald and Golden Eagle Protection Act (originally the Bald Eagle Protection Act of 1940), the Endangered Species Act (1973), and the Wild Bird Conservation Act (1992) provide further protections for birds that may apply to building collisions. Recent legislation, primarily at the city and state levels, has addressed the problem of mortality from building collisions and light pollution. Starting with Toronto, Canada, in 2009 and San Francisco, California, in 2010 an increasing number of states and municipalities have passed laws mandating bird-friendly design, while other authorities have passed voluntary measures.

## Glass: The Invisible Threat

Glass is invisible to both birds and humans. Humans learn to see glass through a combination of experience and visual cues like mullions and even dirt, but birds are unable to use these signals. Most birds' first encounters with glass are fatal when they collide with it at full flight speed. Aspects of bird vision contribute to the problem. Whereas humans have eyes in the front of their heads and good depth perception, most birds' eyes are placed at the sides of their heads. Birds thus have little depth perception beyond the range of their bills but extensive fields of view to the side and behind. They judge their flight speed by the passing of objects to their sides, so their focus in flight is not necessarily ahead. Besides simply using designs with less glass, we can protect birds by using screens, shutters, and details that partly obscure glass while still providing a view, or by using two-dimensional patterns that birds perceive as actual barriers. However, birds have poor contrast sensitivity compared to humans: shapes at a distance merge into a blur at closer range for birds. This means that most signals that make glass safe for birds will probably be readily visible to people.

Reflections on home windows are a significant source of bird mortality. The partially opened vertical blinds here may break up the reflection enough to reduce the hazard to birds. Photo by Christine Sheppard, ABC

Birds may try to reach vegetation seen through two or more glass walls or windows; the single decal here is not enough to solve the problem, but two or three could do the trick. Photo by Christine Sheppard, ABC

(Opposite) The White-throated Sparrow is the most frequent victim of collisions reported by urban monitoring programs. Photo by Robert Royse

## Lighting: Exacerbating the Threat

Most birds, with obvious exceptions, are active by day, with eyes best adapted for daylight sight. However, many bird species migrate by night, allowing them to use daylight hours for feeding. We still don't know everything about how night-flying birds navigate. We do know that birds probably have two special senses that allow them to determine location and direction using the Earth's magnetic field. One of these, located in the eye, may allow birds to "see" magnetic lines in the presence of dim blue light. Star maps, landmarks, and other mechanisms are also involved.

Artificial night lighting seemingly disrupts orientation mechanisms evolved to work with dimmer, natural light sources and can cause birds to deviate from their flight paths. The problem is compounded for birds flying in mist or cloud, which can cause them to fly lower and closer to artificial light sources, depriving them of celestial and magnetic cues. As birds fly near light sources, they may become disoriented and eventually land in the built environment.

Light at night can disorient birds, and the problem is not restricted to tall buildings. This scene of Las Vegas by night depicts a threat to any bird migrating nearby at night. Photo by BrendelSignature, Wikipedia

The majority of collisions with buildings actually take place by day. As birds seek food to fuel their next migratory flight, they face a maze of structures, and many, unable to distinguish between habitat and reflections, hit glass. The amount of light emitted by a building is a strong predictor of the number of collisions it will cause, more so than building height. Patterns of light intensity across a nocturnal landscape may influence the pattern of birds landing in that landscape at the end of migration stages. Thus, reducing light trespass from all levels of buildings and their surroundings is an important part of a strategy to reduce collisions with glass. There is some recent evidence that electromagnetic radiation outside the visible spectrum may also disorient birds.

## Birds and the Built Environment

Humans first began using glass in Egypt around 3500 BCE. Glass blowing, invented by the Romans in the early first century CE, greatly increased the ways glass could be used, including the first crude glass windows. The 17th century saw the development of the float process, enabling production of large sheets of glass. This technology became more sophisticated, eventually making glass windows available on a large scale by the 1960s. In the 1980s, development of new production and construction technologies culminated in today's glass skyscrapers and increasing use of glass in all types of construction.

Sprawling land-use patterns and intensified urbanization degrade the quality and quantity of bird habitat across the globe. Cities and towns encroach on riverbanks and shorelines. Suburbs, farms, and recreation areas increasingly infringe upon wetlands and woodlands. Some bird species simply abandon disturbed habitat. For resident species that can tolerate disturbance, glass is a constant threat, as these birds are seldom far from human structures. Migrating birds are often forced to land in trees lining our sidewalks, city parks, waterfront business districts, and other urban green patches that have replaced their traditional stopover sites.

The amount of glass in a building is the strongest predictor of how dangerous it is to birds. However, even small areas of glass can be lethal. While bird kills at homes are estimated at one to 10 birds per home per year, the large number of homes multiplies that loss to millions of birds per year in the United States, representing over 46% of the total problem. Other factors can increase or decrease a building's impact, including the density and species composition of local bird populations; local geography; the type, location, and extent of landscaping and nearby habitat; prevailing wind and weather; and patterns of migration through the area. All must be considered when planning bird-friendly buildings.

## Impact of Collisions on Bird Populations

About 25% of species are now on the U.S. Watch List of birds of conservation concern (abcbirds.org/birds/watchlist/), and even many common species are in decline. Habitat destruction or alteration of both breeding and wintering grounds remains the most serious man-made problem, but collisions with buildings are second only to domestic cats as direct fatality threats. Nearly one-third of the bird species found in the United States—more than 258 species, from hummingbirds to falcons—are documented as victims of collisions. Unlike natural hazards that predominantly kill weaker individuals, collisions kill all categories of birds, including some of the strongest, healthiest birds that would otherwise survive to produce offspring. Without action, the cumulative effect of these deaths will result in significant population declines. Most of the mortality is avoidable. This document is one piece of a strategy to keep building collisions from increasing and, ultimately, to reduce them.

## Bird Collisions and Sustainable Architecture

In recent decades, advances in glass technology and production have made it possible to construct tall buildings with all-glass walls, and we have seen a general increase in the amount of glass used in all types of construction. This is manifest in an increase in picture windows in private homes, glass balconies and railings, bus shelters, and gazebos. New applications for glass are being developed all the time. Unfortunately, as the amount of glass increases, so does the incidence of bird collisions.

The Cape May campus of Atlantic Cape Community College inherited a building with large areas of glass that did not have coatings or film to control temperature and glare—and there were many collisions. The addition of Collidescape has eliminated the threat to birds while reducing heating and cooling costs. Photo by Lisa Apel-Gendron



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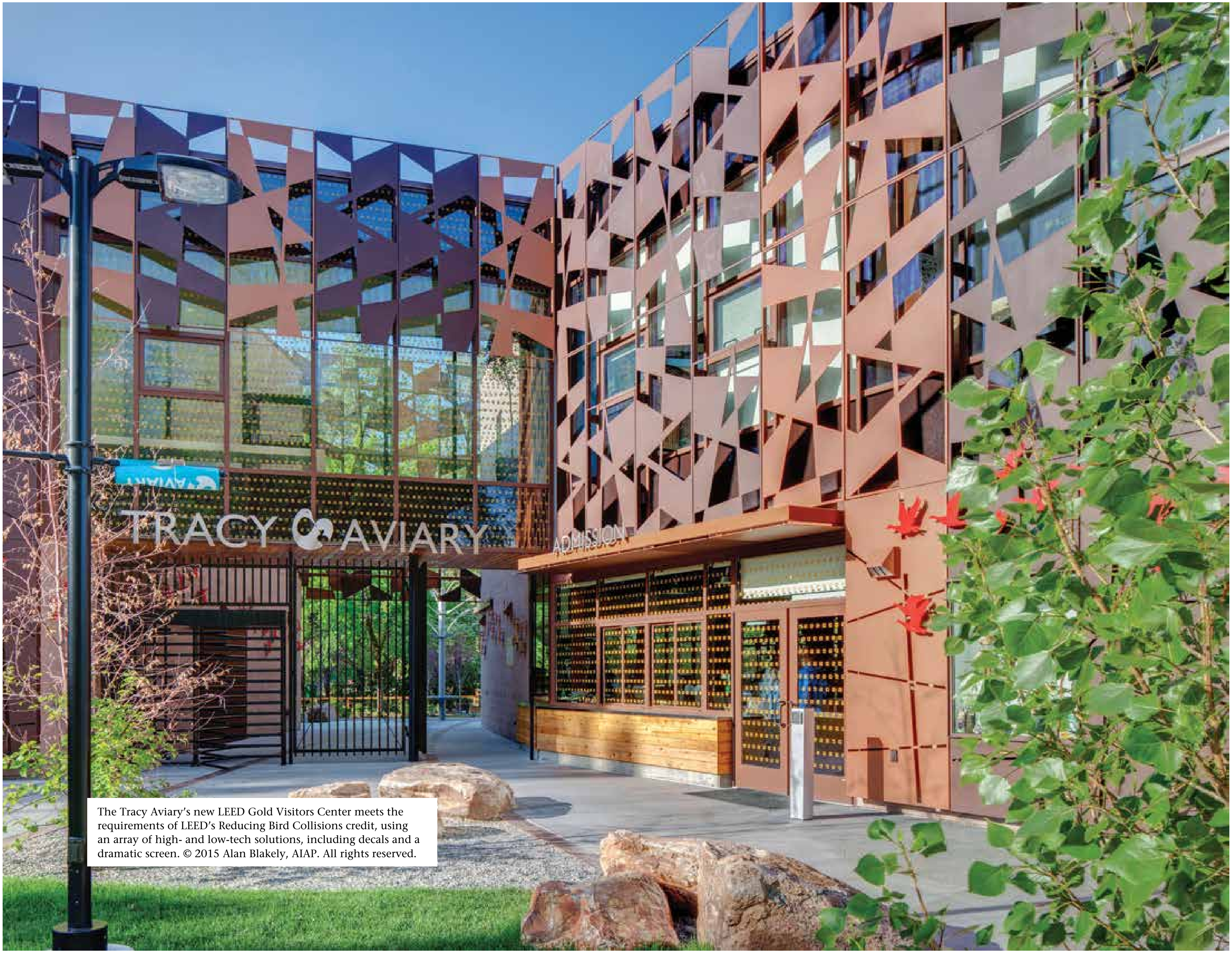


The Tracy Aviary's new LEED Gold Visitors Center meets the requirements of LEED's Reducing Bird Collisions credit, using an array of high- and low-tech solutions, including decals and a dramatic screen. © 2015 Alan Blakely, AIAP. All rights reserved.

In recent decades, growing concern for the environment has stimulated the creation of "green" standards and rating systems for development. The best known is the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design, or LEED. While the USGBC concurred that sustainable buildings should not kill birds, it was initially difficult to create recommendations within the LEED credit system. The solution was based on a technique called "tunnel testing," a non-lethal method using live birds that permits a relative threat score to be assigned to patterned glass and other materials. (The section on Research in Chapter 6 reviews the work underlying the assignment of threat scores.)

On October 14, 2011, USGBC added Pilot Credit 55: Bird Collision Deterrence to its Pilot Credit Library. The credit was drafted by American Bird Conservancy (ABC), members of the Bird-Safe Glass Foundation, and the USGBC Site Subcommittee. Building developers that wish to earn this credit must quantify the threat level to birds posed by various materials and design details. These threat factors are used to calculate an index, or weighted average, representing the building's façade; that index must be below a standard value to earn the credit. The index is intended to provide wide latitude in creating designs that meet the criteria. The credit also requires adopting interior and exterior lighting plans and post-construction monitoring.

Pilot Credit 55 has been the most widely used credit in the pilot library. A revised version of the credit, posted in the fall of 2015, expands its availability to all LEED rating systems except "neighborhoods."

ABC is a registered provider of the American Institute of Architects (AIA) Continuing Education System, offering classes on bird-friendly design and LEED Pilot Credit 55 in face-to-face and webinar formats. Contact Christine Sheppard, csheppard@abcbirds.org, for more information.

## Defining What's Good for Birds

It is increasingly common to see the term "bird-friendly" used in a variety of situations to demonstrate that a particular product, building, legislation, etc., is not harmful to birds. All too often, however, this term is unaccompanied by a clear definition and lacks a sound scientific foundation to underpin its use. Ultimately, defining "bird-friendly" is a subjective task. Is bird-friendliness a continuum, and if so, where does friendly become unfriendly? Is "bird-friendly" the same as "bird-safe?" How does the definition change from use to use, situation to situation? It is impossible to know exactly how many birds a particular building will kill before it is built, and so, realistically, we cannot declare a building to be bird-friendly before it has been carefully monitored for several years.

There are factors that can help us predict whether a building will be particularly harmful to birds or generally benign, and we can accordingly define simple "bird-friendly building standards" that, if followed, significantly reduce potential hazard to birds. That said, a 75% reduction of mortality at a structure that kills 400 birds a year means that structure will still kill 100 birds a year. Because window kills affect reproductively active adult birds, the cumulative effect of saving some birds is amplified by their reproductive output. Because a 100% reduction in mortality may be difficult to achieve, ABC takes the position that it is better to take reasonable available actions immediately than to put off taking action until a perfect solution is possible or to take no action at all.

Hariri Pontarini Architects with Robbie/Young + Wright Architects used botanical imagery in 3M laminates to depict the plants that produce many of the compounds used by students at the University of Waterloo School of Pharmacy, Canada. Photo by Christine Sheppard, ABC



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# Problem: Glass


The glass in this Washington, D.C., atrium poses a double hazard, drawing birds to plants inside as well as reflecting sky above. Photo by Christine Sheppard, ABC

## Properties of Glass

Glass, as a structural material, can range in appearance from transparent to mirrored to opaque. Its surface can completely reflect light or let virtually 100% of light pass through. A particular piece of glass will change appearance depending on environmental factors, including position relative to the sun, the difference between exterior and interior light levels, what may be reflected, and the angle at which it is viewed. Combinations of these factors can cause glass to look like a mirror or a dark passageway, or be completely invisible. Humans do not actually "see" clear glass, but are cued by context such as mullions, dirt, or window frames. Birds, however, do not perceive right angles and other architectural signals as indicators of obstacles or artificial environments: they take what they see literally. While local birds may become familiar with individual pieces of glass, they do not ever grasp the concept "glass."

The glass-walled towers of the Time Warner Center in New York City appear to birds as just another piece of the sky. Photo by Christine Sheppard, ABC

## Reflection

Under the right conditions, even transparent glass on buildings can form a mirror, reflecting sky, clouds, or nearby habitat attractive to birds. When birds try to fly to the reflected habitat, they hit the glass. Reflected vegetation is the most dangerous, but birds also attempt to fly past reflected buildings or through reflected passageways, with fatal results.

## Transparency

Birds strike transparent windows as they attempt to access potential perches, plants, food or water sources, or other lures seen through the glass, whether inside or outside. Large planted atria are frequent problems, as are glass balcony railings and "skywalks" joining buildings. The increasing trend toward glass used in landscapes, as walls around roof gardens, as handrails or walkway dividers and even gazebos is dangerous because birds perceive an unobstructed route through them to habitat beyond.

## Black Hole or Passage Effect

Birds often fly through small gaps, such as spaces between leaves or branches, into nest cavities, or through other small openings that they encounter. In some light, the space behind glass can appear black, creating the appearance of just such a cavity or "passage" with unobstructed access through which birds try to fly.

Transparent handrails are a dangerous trend for birds, especially when they front vegetation. Photo by Christine Sheppard, ABC

Large facing panes of glass can appear to be a clear pathway. Photo by Christine Sheppard, ABC

The same glass can appear transparent or highly reflective, depending on weather or time of day.

Photos by Christine Sheppard, ABC

## Factors Affecting Rates of Bird Collisions for a Particular Building

Every site and every building can be characterized as a unique combination of risk factors for collisions. Some of these, particularly aspects of a building's design, are very building-specific. Many problem design features can be readily improved, or, in new construction, avoided. Others of these—for example, a building's location relative to migration stopover sites, regional ecology, and geography—are difficult if not impossible to modify.

### Building Design

People like glass and it has become a popular building material. All-glass buildings have become more and more common as glass has become a low-cost material for construction. Glass causes virtually all bird collisions with buildings. Studies based on monitoring data have shown a direct relationship between the amount of glass on a building and the number of collisions at that site—the more glass, the more bird deaths.

Mirrored glass is often used intentionally to make a building "blend" into a vegetated area by reflecting its surroundings, making those buildings especially deadly to birds. However, all-glass buildings are coming increasingly into question. According to groups like the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the International Code Council, when there is more than 30-40% glass on a façade, heating and cooling costs begin to increase.

### Building Size

Glass skyscrapers, because of their height and visibility, are often the main focus of collision documentation, and they do account for more collisions per building than smaller structures. However, because there are many more homes and low-rise buildings, the latter account for more total mortality. A study published by scientists at the Smithsonian in 2014 estimated 508,000 annual bird deaths for high-rises, 339 million for low-rises, and 253 million for homes. More collisions probably occur at glass on lower floors, where most bird activity takes place, but when monitors have had access to setbacks and roofs, they have consistently found at least some carcasses, indicating that glass at any level can be a threat.

### Orientation and Siting

Because migrating birds are frequent collision victims, it is often assumed that more collisions will occur on north- and south-facing façades. However, most building collisions take place during the day, and building orientation in relation to compass direction has not been implicated as a factor. Siting of buildings with respect to surrounding habitat and landscaping has more

Birds flying from a meadow on the left are channeled toward the glass doors of this building by a rocky outcrop to the right of the path. Photo by Christine Sheppard, ABC

Mirrored glass is dangerous at all times of day, whether it reflects vegetation, sky, or simply open space through which a bird might try to fly. Photo by Christine Sheppard, ABC

Plantings on setbacks and rooftops can attract birds to glass they might otherwise avoid. Chris Sheppard, ABC

implications. Physical features like walkways that provide an open flight path through vegetated landscape, or obstacles like outcrops of rock or berms, can channel birds toward or away from glass and should be considered early in the design phase. Movement patterns of birds within surrounding habitat may cause unanticipated collisions. Birds often fly between landscape features, for example, between two stands of trees, and may be at risk from structures along their route.

Glass that reflects shrubs and trees causes more collisions than glass that reflects pavement or grass. Studies that measured vegetation within only 15 to 50 feet of a façade have led to the misconception that plantings beyond a certain distance don't influence collisions, but vegetation at much greater distances can easily be visible in reflections. Vegetation around buildings will bring more birds into the vicinity of the building; the reflection of that vegetation brings more birds into the glass. Taller trees and shrubs correlate with more collisions. It should be kept in mind that vegetation on slopes near a building will reflect in windows above ground level. Studies using bird feeders (Klem *et al.* 1991) have shown that fatal collisions result when birds fly toward glass from more than a few feet away.

## Time of Day

Collisions tend to happen most when birds are most active. Many studies have documented that although collisions peak during the early morning, they can happen at almost any time of day. Most monitoring programs have focused on early morning before cleaning crews have swept sidewalks because of the increased likelihood of finding birds and because it is easier to obtain volunteer searchers in the pre-work hours.

## Green Roofs and Walls

Green roofs bring elements attractive to birds to higher levels, but often they are built in close proximity to glass. However, recent work shows that well-designed green roofs can become functional ecosystems, providing food and even nest sites for birds. Siting of green roofs, as well as green walls and rooftop gardens, should therefore be carefully considered, and glass adjacent to these features should have protection for birds.

Green roofs and walls can provide food and other resources to birds, but they can also attract birds to glass that they might not otherwise encounter. Emilio Ambasz's ACROS building in Fukuoka, Japan, is an interesting example. Photo by Kenta Mobuchi

This atrium has more plants than anywhere nearby on surrounding streets, making the glass deadly for birds seeking food or shelter in this area. Photo by Christine Sheppard, ABC


Solutions: Glass

It is possible to design buildings that can reasonably be expected to kill few or no birds. Numerous examples already exist, not necessarily designed with birds in mind but simply to be functional and attractive. These buildings may have many windows, but their screens, latticework, louvers, and other devices outside, or patterns integrated into the glass, warn birds before they collide. Finding glass treatments that can eliminate or greatly reduce bird mortality, while minimally obscuring the glass itself, has been the goal of several researchers, including Martin Rössler, Daniel Klem, and Christine Sheppard. Their work, discussed in more detail in the Science chapter, has focused primarily on the spacing, length, width, opacity, color, and orientation of elements marked on glass, and has shown that patterns covering as little as 5% of the total glass surface can deter most strikes under experimental conditions. They have shown that as a general rule, most songbirds will not attempt to fly through horizontal spaces less than 2 inches high or through vertical spaces 4 inches wide or less. We refer to this as the 2 x 4 rule, and it is clearly related to the size and shape of birds in flight. (See chart on page 47).

Designing a new structure to be bird-friendly does not require restricting the imagination or adding to the cost of construction. Architects around the globe have created fascinating and important structures that incorporate little or no dangerous glass. In some cases, inspiration has been borne out of functional needs, such as shading in hot climates; in others, from aesthetics. Being bird-friendly usually has been incidental. Now, however, buildings are being designed with birds in mind, and materials designed for this purpose are multiplying. Until recently, retrofitting existing buildings has been more difficult and costly than it is today. However, new materials are appearing and costs can be controlled by targeting problem areas rather than entire buildings.

Bird-friendly materials and design features often overlap in function with materials to control heat and light, security measures, and decorative design details. Bird-friendly building-design strategies also fall into three general categories, although all three could be combined in a single structure. These are:

1. Using minimal glass (Bronx Call Center, U.S. Mission to the United Nations)
2. Placing glass behind some type of screening (de Young Museum, Cooper Union)
3. Using glass with inherent properties that reduce collisions (Brooklyn Botanic Garden Visitors Center; Student Center at Ryerson University, Toronto; and Cathedral of Christ the Light)

## Netting, Screens, Grilles, Shutters, Exterior Shades

There are many ways to combine the benefits of glass with bird-friendly design by incorporating elements that preclude collisions while providing light and views. Some architects have designed decorative façades that wrap entire structures. Decorative grilles are also part of many architectural traditions. Exterior, motorized solar screens and shades are effective at controlling heat and light, increase security, and can be adjusted to maximize view or bird and sun protection at different times. Netting, grilles, and shutters are common elements that can make glass safe for birds on buildings of any scale. They can be used in retrofit or be an integral part of an original design and can significantly reduce bird mortality.

(Opposite) The external glass screen on the GSA Regional Field Office in Houston, Texas, designed by Page Southerland Page, helps control heat but also reduces the likelihood of collisions. Photo by Timothy Hursley

The Brooklyn Botanic Garden's Visitors Center, designed by Weiss/Manfredi, was intended to be bird-friendly from its inception—a challenge, as it makes extensive use of glass. Photo @ Alber Vecerka, ESTO

Glass walls and doors at the Brooklyn Botanic Garden's Visitors Center include a custom fritting pattern that meets bird-friendly criteria. Monitoring for collisions after the building opened indicates that the design was successful. Photo by Christine Sheppard, ABC

Overhangs block viewing of glass from some angles, but do not necessarily eliminate reflections. Photo by Christine Sheppard, ABC

Reflections in this angled façade can be seen clearly over a long distance, and birds can approach the glass from any angle. Photo by Christine Sheppard, ABC

Before the current age of unopenable windows, screens protected birds in addition to serving their primary purpose of keeping bugs out. Screens are still among the most cost-effective methods for protecting birds, and, if insects are not an issue, nearly invisible netting can often be installed. Screens and netting should be installed at some remove from the window so that the impact of a strike does not carry birds into the glass. Several companies sell screens that can be attached with suction cups or eye hooks for small areas of glass. Others specialize in much larger installations. (Find sources at collisions.abcbirds.org).

## Awnings and Overhangs

Overhangs have been frequently recommended to reduce collisions. However, there are many situations in which overhangs do not eliminate reflections and only block glass from the view of birds flying above. They are thus of limited effectiveness as a general strategy. Overhangs work best when glass is shadowed from all sides. Functional elements such as balconies and balustrades can block the view of glass, protecting birds while providing an amenity for residents.

## Angled Glass

In a study (Klem et al., 2004) comparing bird collisions with vertical panes of glass to those tilted 20 or 40 degrees, the angled glass resulted in less mortality. Klem speculated that this was because the glass reflected the ground, not vegetation. Using angled glass has become a common recommendation as a bird-friendly feature. However, while angled glass may be useful in special circumstances, the birds in the study were flying parallel to the ground from nearby feeders, hitting the glass at acute angles, with less force than a perpendicular strike. In most situations, however, birds may approach glass from any angle.

## Patterns on Glass

Ceramic dots, other types of "frits," and other materials can be screened, printed, or otherwise applied to glass surfaces. This is often done to reduce the transmission of light and heat and can also provide design detail. In some cases, frit patterns are hardly visible, but when designed according to the 2 x 4 rule (see p. 47), patterns on glass can also prevent bird strikes. Patterns on the outside surface of glass deter collisions most effectively because they are always visible, even with strong reflections. This type of design, useful primarily for new construction, is currently more common in Europe and

A custom frit pattern was designed by Ennead Architects for Vassar College's Bridge for Laboratory Sciences building. Elements of the pattern occur on two separate surfaces, increasing visibility to birds in flight, who will see a constantly changing pattern that may appear to move. Photo by Christine Sheppard, ABC

Frit patterns behind highly reflective glass may not always be visible. However, in buildings like Skidmore Owings Merril's Cathedral of Christ the Light, the frit pattern is always visible and the pattern should appear as a virtual barrier, deterring birds from flying into it. Photo by Christine Sheppard, ABC


While some internal fritted glass patterns can be overcome by reflections, Frank Gehry's IAC headquarters in Manhattan is so dense that the glass appears opaque. Photo by Christine Sheppard, ABC

Ornilux Mikado's pattern reflects UV wavelengths. The spiderweb effect is visible only from very limited viewing angles. Photo courtesy of Arnold Glass

Asia, but is being offered by an increasing number of manufacturers in the United States. New technologies allowing printing of ceramic inks on the outside surface of glass may greatly increase options for bird-friendly design in the U.S.

More commonly, frit is applied to an internal surface of insulated glass units. This type of design may not be visible if the amount of light reflected by the frit is insufficient to overcome reflections on the outside surface of the glass or if frit is applied as dots below the visual threshold of birds. Some internal frits may only help break up reflections when viewed from some angles and in certain light conditions. However, with the right combination of surface reflectivity and frit application, a pattern on an inside surface can still be effective. The headquarters of the internet company IAC in New York City, designed by Frank Gehry, is composed entirely of fritted glass, most of high density and always visible. No collision mortalities have been reported at this building after two years of monitoring by New York City Audubon. FXFOWLE's Jacob Javits Center, also in Manhattan, reduced collisions by as much as 90% with a renovation that eliminated some dangerous glass and replaced other glass with a visible frit pattern. Another example of a visible internal frit pattern is seen in Skidmore Owings Merril's Cathedral of Christ the Light in Oakland, California.

## UV Patterned Glass

Songbirds, gulls, parrots, and other birds can see into the ultraviolet (UV) spectrum of light, a range largely invisible to humans (see page 41). Other bird types, including raptors, kingfishers, hummingbirds, and pigeons, are less sensitive to UV. Ultraviolet reflective and/or absorbing patterns "invisible to humans but visible to birds" are frequently suggested as the optimal solution for many bird collision problems, but few such products are available commercially as of 2015. Progress in development of bird-friendly UV glass has been slow, but with legislation in multiple locations mandating bird-friendly design, glass manufacturers and distributors, as well as window-film manufacturers, are taking an active role in developing new solutions for this application. Research indicates that UV patterns need strong contrast to be effective, especially in the early morning and late afternoon, when UV in sunlight is at low levels. However, UV patterns may be ineffective for many species that have been reported as victims of collisions with glass, including hummingbirds, flycatchers, American Woodcock, and woodpeckers.

## Opaque and Translucent Glass

Opaque, etched, stained, or frosted glass and glass block are excellent options to reduce or eliminate collisions, and many attractive architectural applications exist. They can be used in retrofits but are more commonly used in new construction. Frosted glass is created by acid etching or sandblasting transparent glass. Frosted areas are translucent, but various finishes are available with differing levels of light transmission. An entire surface can be frosted, or frosted patterns can be applied. Patterns should conform to the 2 x 4 rule described on page 47. For retrofits, glass also can be frosted by sandblasting on site. Stained glass is typically seen in relatively small areas but can be extremely attractive and is not conducive to collisions. Glass block is versatile, can be used as a design detail or primary construction material, and is also unlikely to cause collisions. Another promising material is photovoltaic glass, which has been used in stained-glass windows and highway noise barriers. This solution is especially interesting, because

The Wexford Science and Technology Building in Philadelphia, designed by Zimmer, Gunsul, Frasca, uses translucent glass to provide light without glare, making it safe for birds. Photo courtesy of Walker Glass transparent highway noise barriers can cause collisions, and such barriers are beginning to be installed in the United States.

## Window Films

Most patterned window films were initially intended for use inside structures as design elements or for privacy. Now, outside surface applications intended to reduce bird collisions are coming onto the market, and some have proved highly effective and popular. The oldest such product creates an opaque white surface on the outside of glass that still permits viewing from the inside. Patterns can be printed on this material, although images of trees and other habitat are not recommended.

A film with a pattern of narrow, horizontal stripes has eliminated collisions at the Philadelphia Zoo Bear Country exhibit for over five years (see photo opposite) and has been similarly successful in other installations when applied to outside surfaces of glass. In these cases, the response has been positive. Another option is to apply vinyl patterns like window film but with the transparent backing removed.

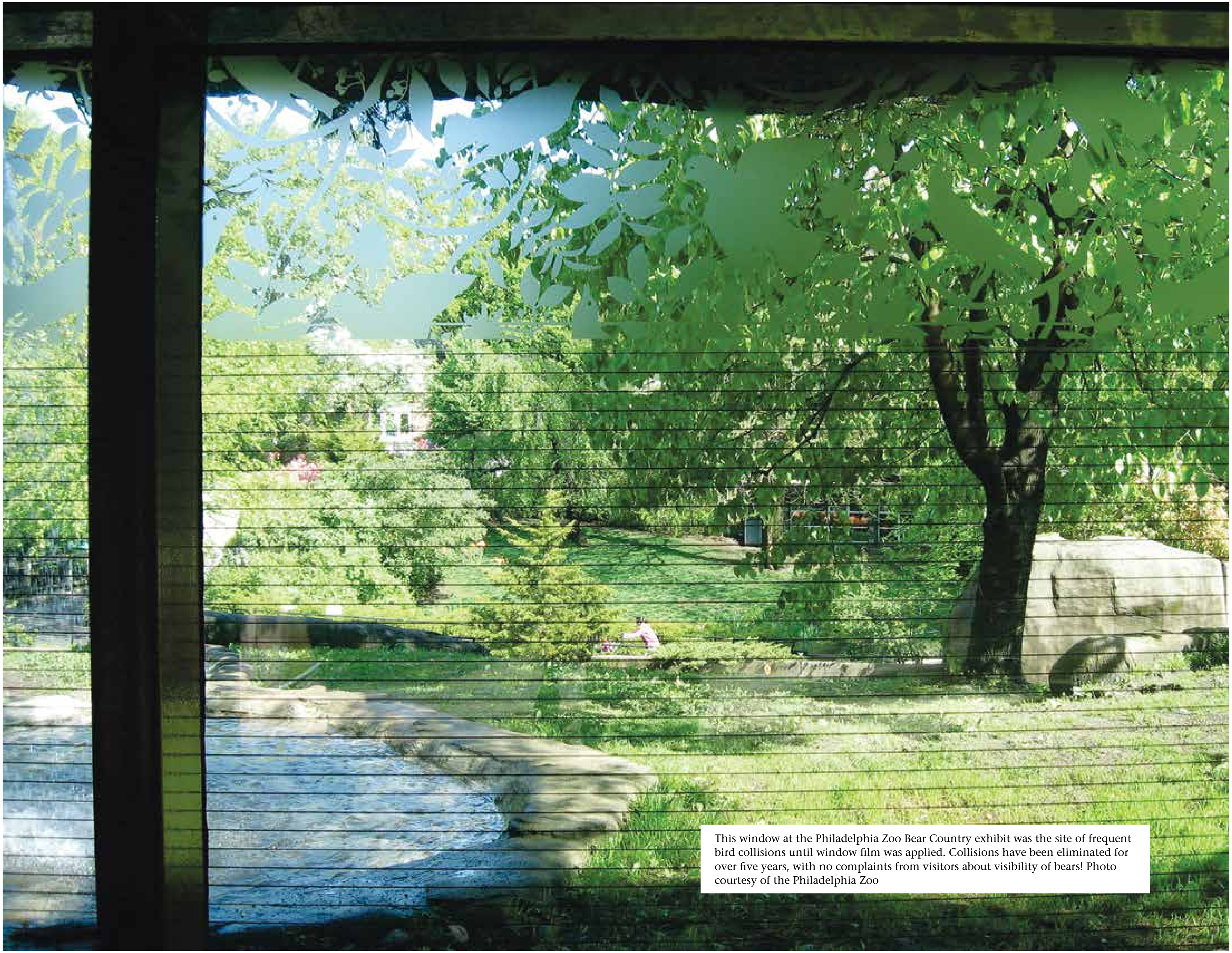
## Solutions Applied to Interior Glass

Light colored shades have been recommended as a way to deter collisions. However, when visible, they do not effectively reduce reflections, and reflections may make them completely invisible. Closed blinds have the same problems, but if visible and partly open, they can produce the appearance of a 2 x 4 pattern. If an exterior solution is not possible and tape or sticky notes are applied to the inside of windows, be sure to check the windows several times a day to ensure that these materials are visible.

## Decals and Tape

Decals are probably the most familiar solution to bird collisions, but their effectiveness is widely misunderstood. Birds do not recognize decals as

A Zen Wind Curtain is an inexpensive but extremely effective way to deter collisions. Lengths of parachute cord or similar materials are strung vertically, every four inches, in front of problem glass, creating both a visual and a physical barrier. Photo by Glenn Phillips, ABC



This window at the Philadelphia Zoo Bear Country exhibit was the site of frequent bird collisions until window film was applied. Collisions have been eliminated for over five years, with no complaints from visitors about visibility of bears! Photo courtesy of the Philadelphia Zoo

## ABC BirdTape

ABC, with support from the Rusinow Family Foundation, has produced ABC BirdTape to make home windows safer for birds. This easy-to-apply tape lets birds see glass while letting you see out, is easily applied, and lasts up to four years. For more information, visit abcbirdtape.org

Photos by Dariusz Zdziebkowski, ABC

silhouettes of falcons, spiderwebs, or other natural objects, but simply as obstacles that they may try to fly around. Decals can be very effective if applied following the 2 x 4 rule on the outside of glass, but in general, they must be replaced frequently, at least annually. Tape is generally more cost effective and quicker to apply, but most household tapes don't stand up well to the elements. Tape intended to last for several years on the outside of windows has become commercially available and is effective when applied following the 2 x 4 guide.

The Consilium Towers, a mirror-glass complex in Toronto, once killed thousands of birds each year. After being taken to court, its owners retrofitted the lower 60 feet of glass with a Feather Friendly dot pattern that has greatly reduced bird mortality.

Reflected in this glass is Michael Mesure, the founder of Toronto's Fatal Light Awareness Program. Photos by Christine Sheppard, ABC

### Temporary Solutions

In some circumstances, especially for homes and small buildings, quick, low-cost, temporary solutions, such as making patterns on glass with paint, stickers, or even post-its, can be very effective in the short term. Even a modest effort can reduce collisions. Such measures can be applied when needed and are most effective following the 2 x 4 rule. (For more information, see ABC's flyer "You Can Save Birds from Flying into Windows" and other sources at collisions.abcbirds.org).

ABC BirdTape was effective at the Forest Beach Migratory Reserve in Wisconsin (left), and also performed well in tunnel tests conducted in Austria. Photo by Christine Sheppard, ABC

# REMEDIATION CASE STUDY: Javits Center

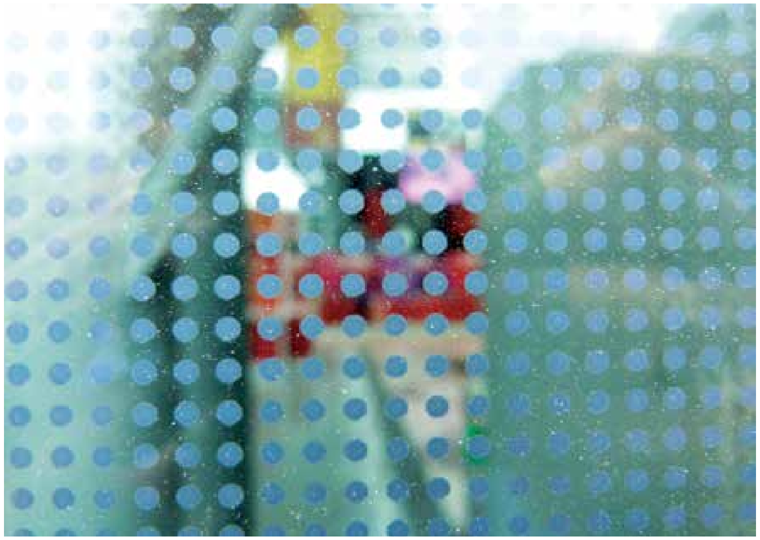
In 2009, the New York City Audubon Society identified the Jacob K. Javits Convention Center as having one of the highest bird-collision mortality rates in New York City.

A major renovation and expansion, designed by the bird-friendly architectural firm of FXFOWLE, was completed in 2014. Some especially deadly glass at street level was replaced with opaque panels. Large panes of clear fritted glass with varying surface characteristics were brought to the site and compared to find the right combination for birds and people.

A 6.75-acre green roof, with adjacent translucent glass, crowns the building and is already providing resources for birds.

Best of all, collisions at the now much larger site have been reduced by 90%.

From a distance, the Javits Center looks like a potential threat to birds.



At close range, a visible pattern of frit dots breaks up reflections, making the glass safe for birds.
Photos by Glenn Phillips, ABC

# Light: Problems and Solutions

Fixtures such as these reduce light pollution, saving energy and money and reducing negative impacts on birds. Photo by Dariusz Zdziebkowski, ABC

Birds evolved complex complementary systems for orientation and vision long before humans developed artificial light. We still have much more to learn, but recent science has begun to clarify how artificial light poses a threat to birds, especially nocturnal migrants. Although most glass collisions take place during daylight hours, artificial lighting at night plays a role in the number and distribution of collisions across the built environment. Unfortunately, the details of how birds respond to night lighting are less well understood than has been commonly believed.

Many collision victims, especially songbirds, are ordinarily active by day and have eyes specialized for color vision and bright light. But although they migrate at night, these birds have poor night vision. Instead, they have magnetic senses that allow them to navigate using the Earth's magnetic field. One of these is located in the retina and requires dim blue natural light to function. Red wavelengths found in most artificial light have been shown to disrupt that magnetic sense. Studies in Germany and Russia have documented birds flying through beams of light and diverting from their course anywhere from a few degrees to a full circle. Areas with significant light pollution may be completely disorienting to birds.

Birds are attracted to relative brightness, and by day often orient toward the sun. If a songbird flies into a home, darkening the room and opening a bright window is the best way to release it. Birds are thought to be attracted to artificial light at night, but we don't know what light level at what distance is sufficient to cause attraction or other behavioral impacts. Gauthreaux and Belser, discussing impacts of night lighting on birds, speculated that in fact, birds affected by night lighting may simply be on course to pass over the lights, not necessarily attracted from a distance. Marquenie and Van de Laar, studying birds and lights on a drilling rig in the North Sea, estimated that when all the lights on the platform were lit, they affected birds up to 3 to 5 kilometers away, causing many to circle the platform.

The science is inconclusive: Lights may only impact birds as they end a migratory stage and come down close to the built environment, or lights may divert birds that would ordinarily pass by. Bad weather can cause birds to fly lower and closer to lights, while also eliminating any visual cues. The interactions that produce correlations between building light emissions and collisions may take place at relatively close range. Once birds come close to a light source, the electromagnetic radiation actively interferes with their magnetic orientation mechanism.

Overly lit buildings waste electricity and increase greenhouse gas emissions and air pollution levels. They also pose a threat to birds. Photo by Matthew Haines

Houston skyline at night. Photo by Jeff Woodman

## Examples of Acceptable/Unacceptable Lighting Fixtures


Reprinted courtesy of DarkSkySociety.org

Some combination of attraction and disorientation may result in larger numbers of birds in the vicinity of brighter buildings and thus, by day, in more collisions. Interestingly, there seem to be no reports of lights attracting or disorienting migrants as they take off on a new migratory stage.

There has been a tendency to associate collision events with very tall structures, though published reports clearly document impact from light at all levels. Early reports of this phenomenon came from lighthouses. Contemporary reports of light-associated circling events are common at oceanic drilling rigs, and disoriented birds have been reported at night skiing sites. A study in Toronto, using the number of lighted windows on a series of buildings as an index of emitted light, found that the amount of light emitted, not the height of the building, was the best predictor of bird mortality.

### Solutions

Poorly designed or improperly installed outdoor fixtures add over $1 billion to electrical costs in the United States every year, according to the International Dark Skies Association. Recent studies estimate that over two-thirds of the world's population can no longer see the Milky Way, just one of the nighttime wonders that connect people with nature. Glare from poorly shielded outdoor light fixtures decreases visibility and can create dangerous conditions, especially for older people, and recent studies suggest that long-term exposure to night lighting can increase the risk of breast cancer, depression, diabetes, obesity, and sleep disorders. Together, the ecological, financial, and cultural impacts of excessive building lighting are compelling reasons to reduce and refine light usage.

Reducing exterior building and site lighting has proven effective at reducing mortality of night migrants at individual buildings, but achieving overall reduction in collisions will require applying those principles on a wider scale. At the same time, these measures reduce building energy costs and decrease air and light pollution. Efficient design of lighting systems plus operational strategies to reduce light trespass or “spill light” from buildings while maximizing useful light are both important strategies. In addition, an increasing body of evidence shows that red light and white light (which contains red wavelengths) particularly confuse birds, while green and blue light may have far less impact.

Light pollution is largely a result of inefficient exterior lighting, and improving lighting design usually produces savings greater than the cost of changes. For example, globe fixtures permit little control of light, which shines in all directions, resulting in a loss of as much as 50% of energy, as well as poor illumination. Cut-off shields can reduce lighting loss and permit use of lower powered bulbs. Most “vanity lighting” is unnecessary. However, when it is used, down-lighting causes less trespass than up-lighting. Where light is needed for safety and security, reducing the amount of light trespass outside of the needed areas can help by eliminating shadows. Spotlights and searchlights should not be used during bird migration. Communities that have implemented programs to reduce light pollution have not found an increase in crime.

Using automatic controls, including timers, photo-sensors, and infrared and motion detectors, is far more effective than relying on employees turning off lights. These devices generally pay for themselves in energy savings in less than a year. Workspace lighting should be installed where needed, rather than in large areas. In areas where indoor lights will be on at night, minimize perimeter lighting and/or draw shades after dark.

Switching to daytime cleaning of office buildings is a simple way to reduce lighting while also reducing costs.

## Lights Out Programs

Despite the complexity of reducing bird collisions with glass, there is one simple way to decrease mortality: turn lights off. Across the United States and Canada, “Lights Out” programs at the municipal and state levels encourage building owners and occupants to turn out lights visible from outside during spring and fall migration. The first of these, Lights Out Chicago, was started in 1995, followed by Toronto in 1997. The programs themselves are diverse. Some are directed by environmental groups, others by government departments, and still others by partnerships of organizations. Participation in most, such as Houston’s, is voluntary. Minnesota mandates turning off lights in state-owned and leased buildings.

Many jurisdictions have monitoring components. Monitoring programs can provide important information in addition to quantifying collision levels and documenting solutions. Ideally, lights-out programs would be in effect year-round and be applied widely, saving birds and energy costs and reducing emissions of greenhouse gases. ABC stands ready to help develop new programs and to support and expand existing programs.

Powerful beams of light, even in a landscape of urban light pollution, can entrap migrating birds, seen here circling in the beams of the 9/11 Memorial Tribute in Light in New York City. Because birds may circle for hours, monitors watch all night, and the light beams are temporarily turned off to release large accumulations of birds. Photo by Jason Napolitano

# Solutions: Policy

## Legislation

Changing human behavior is generally a slow process, even when the change is uncontroversial. Legislation can be a powerful tool for modifying behavior. Conservation legislation has created reserves, reduced pollution, and protected threatened species and ecosystems. Policies that promote bird-friendly design and reduction of light pollution have recently proliferated across the United States and Canada, following the early examples of Toronto and San Francisco. They vary considerably in scope and detail, often reflecting local politics. (A real-time database of ordinances and other instruments mandating or promoting bird-friendly action, including links to source language, can be found at collisions.abcbirds.org).

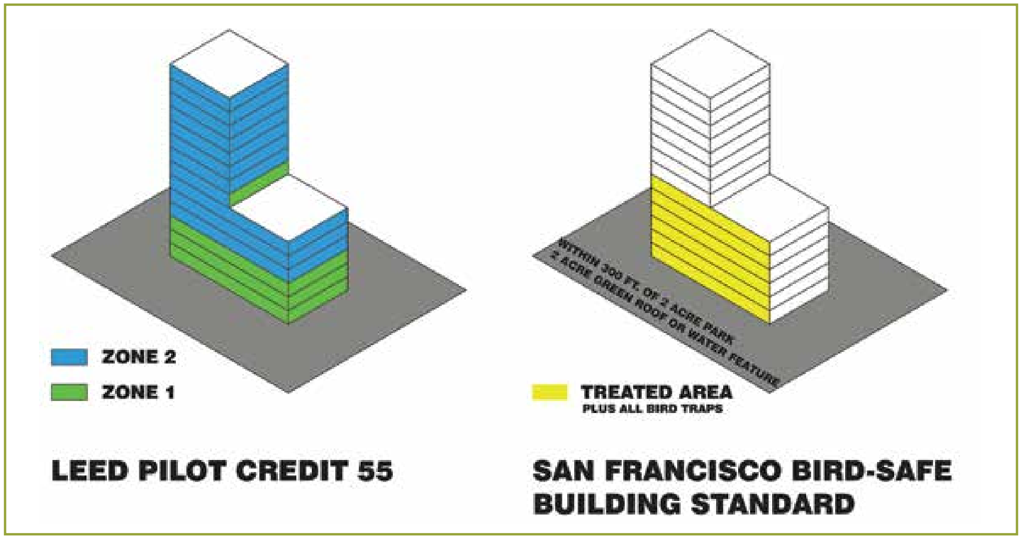
An early challenge in creating effective legislation was the lack of objective measures that architects could use to accomplish their task. For example, a common recommendation, to "increase visual noise," because it was unquantified and undefined, made it difficult for architects and planners to know whether a particular design complied with requirements. Material testing (see p. 45) has made it possible to assign relative threat factors to various building façade materials and to use those scores to create quantitative guidelines and mandates.

The illustration to the right broadly compares San Francisco's Bird-safe Building Standard with LEED Pilot Credit 55, both based on the use of materials with quantified threat levels. San Francisco's standard applies generally to new construction and is restricted to façades within 300 feet of a two-acre park or pond. The LEED credit is intentionally very flexible. It applies to all building facades and allows for restricted amounts of high-threat glass, or larger amounts of bird-friendly glass. Because birds are found throughout the built environment, ABC prefers the LEED model. (ABC's model legislation can be found on page 35.)

Bird lovers across the country are proposing bird-friendly design ordinances at both local and state levels. ABC is ready to actively support such efforts. Both mandatory and voluntary instruments can be effective. Voluntary guidelines are easier to modify if they prove to have unintended consequences and can lead to a mandate, but can also be ignored. Generally ABC recommends mandatory guidelines, beginning with a small subset of buildings and expanding as community support increases and resistance decreases.

Incorporating bird-friendly design issues into local sustainability policies is another way to drive change. An interesting example of this is the Fairfax County, Virginia, proffer system. New construction projects are required to address a series of sustainability issues, including potential bird mortality, and either to describe

The design of the Grange Insurance Audubon Center in Columbus, Ohio, includes many panels of glass, fitted with the silhouettes of species of birds in flight. Photo by Christine Sheppard, ABC




courtesy of Deborah Laurel

(Opposite) United States Capitol, Washington, D.C. Photo by stock.xchng

For its new Visitors Center in Sempach, opened in May 2015, the Swiss Ornithological Institute designed a mandala from bird silhouettes (below) that was applied on the inside of all glass using digital printing. The design provides 40-50% coverage and generates much discussion among visitors, an achievement second only to preventing bird collisions.

Photos by Hans Schmid

how these will be addressed by the project or explain why such action is not possible.

## Priorities for Policy Directives

ABC generally recommends against attempting to map locations where bird-friendly design is required because birds can be found in almost every environment, even in seemingly inhospitable ones. However, there may be occasions when it is necessary to compromise on the scope of legislation. In such cases, it must be recognized that proximity to undeveloped land, agricultural areas, parks, and water often correspond to increased bird populations and therefore increased risk of collisions. In addition, areas located in between landscape features desirable to birds may also pose higher risks. For example, in New York City some evidence suggests that birds approach Central Park from due south during spring migration, creating a greater risk zone directly south of the park. Also, building features such as green roofs should be considered when determining greater risk zones for policy purposes.

## Sustainability Rating Programs

Another driver of bird-friendly policies consists of sustainability rating programs like the Green Building Council's LEED program, Green Globes, Living Building Challenge, and others. There is general agreement that sustainable buildings should not kill birds. This tenet appears with differing levels of robustness in different systems, with the most specific being the LEED program, which grants Pilot Credit 55: Bird Collision Deterrence. The credit is calculated using a weighted average of the relative threat rating of each material on a building's façade. The credit has attracted a lot of attention, with many projects applying for it. The new Vassar Bridge for Laboratory Sciences on the cover of this publication was one of the first to be designed with the credit in mind and to earn the credit.

Because a number of glass-walled buildings have been awarded LEED certification at the highest level, at one point there was concern that sustainable design was not compatible with bird-friendly design. This was ironic, as in addition to providing natural light, glass on sustainable buildings is intended to link people inside with the natural world outside. However, according to both ASHRAE and ICC, costs for heating and cooling increase when total glass surface exceeds 30-40% of the total building envelope, depending on climate. This is more than sufficient for providing light and views when glass placement is considered thoughtfully. This is a great place to start the design of a bird-friendly structure.


The façade of the WÜRTH Building in Switzerland is mostly glass, laminated with a fabric that is black on the inside but aluminium-coated outside. The inner surface delivers good visibility, and the fabric provides shade and interesting visual effects outside. Preliminary studies by the Swiss Ornithological Institute suggest that the materials used in this building may also deter bird collisions. Photo by Hans Schmid

# Model Ordinance for Bird-Friendly Construction

[ORDINANCE Name]  Sponsored by:
[list names ]

WHEREAS, birds provide valuable and important ecological services,

WHEREAS, [location] has recorded [ ] species of resident and migratory bird species,

WHEREAS, birding is a hobby enjoyed by 64 million Americans and generates more than $40 billion a year in economic activity in the United States,

WHEREAS, as many as one billion birds may be killed by collisions with windows every year in the United States,

WHEREAS, reducing light pollution has been shown to reduce bird deaths from collisions with windows,

WHEREAS, new buildings can be designed to reduce bird deaths from collisions without additional cost,

WHEREAS, there exist strategies to mitigate collisions on existing buildings,

WHEREAS, more than 30% glass on a façade usually increases costs for heating and cooling

WHEREAS, bird-friendly practices often go hand-in-hand with energy efficiency improvements,

And WHEREAS [any additions specific to the particular location]

NOW, THEREFORE, BE IT ORDAINED, by [acting agency] [title of legislation and other necessary language]

(a) In this section the term "Leadership in Energy and Environmental Design (LEED)" means a green building rating system promulgated by the United States Green Building Council (USGBC) that provides specific principles and practices, some mandatory but the majority discretionary, that may be applied during the design, construction, and operation phases, which enable the building to be awarded points from reaching present standards of environmental efficiency so that it may achieve LEED certification from the USGBC as a "green" building.

b) [acting agency] does hereby order [acting department] to take the steps necessary to assure that all newly constructed buildings and all buildings scheduled for capital improvement are designed, built, and operated in accordance with the standards and requirements of the LEED Green Building Rating System Pilot Credit 55: Bird Collision Deterrence.

(c) The USGBC releases revised versions of the LEED Green Building Rating System on a regular basis; and [acting department] shall refer to the most current version of the LEED when beginning a new building construction permit project or renovation.

(d) New construction and major renovation projects shall incorporate bird-friendly building materials and design features, including, but not limited to, those recommended by the American Bird Conservancy publication *Bird-Friendly Building Design*.

(e) [acting department] shall make existing buildings bird-friendly where practicable.

The Studio Gang's Aqua Tower in Chicago was designed with birds in mind. Strategies included fritted glass and balcony balustrades. Photo by Tim Bloomquist

# The Science of Bird Collisions

Hundreds of species of birds are killed by collisions. These birds were collected by monitors with FLAP in Toronto, Canada. Photo by Kenneth Herdy

## Magnitude of Collision Deaths

The number of birds killed by collisions with glass every year is astronomical. Quantifying mortality levels and impacts on populations has been difficult, however. Until recently, local mortality studies—despite producing valuable information—aimed more at documenting mortality than quantifying it, and did not follow rigorous protocols. Loss *et al.* (2012) created methodology and techniques of analysis to determine the magnitude of anthropogenic mortality, using existing data sets. The authors comprehensively acquired published and unpublished data sets on collisions with buildings (Loss *et al.*, 2013). Data sets were filtered using a variety of criteria to ensure that they could be used in single analyses. Loss *et al.* (2014b) have also comprehensively described how to collect meaningful data on collisions.

The authors calculated the median annual mortality at homes at 253 million, or 2.1 birds per structure. Urban residences without feeders account for 33% of this mortality cumulatively, as there are more such residences, even though residences with feeders produce more collisions individually. Rural residences without feeders account for 31% of residential mortality, followed by urban residences with feeders (19%) and rural residences with feeders (17%). Median mortality at low-rise buildings (4 to 11 stories), calculated from two data sets, was averaged as 339 million, or 21.7 birds per building. High-rises, although collectively causing the least mortality (508,000), individually had the highest median rate of 24.3 bird collisions per building. Combining all building classes produces an estimate of 365 and 988 (median 599) million birds killed annually in the United States.

Machtans, *et al.* (2013) estimated that about 25 million (ranging from 16 to 42 million) birds are killed by colliding with windows in Canada annually, with 90% of building-related mortalities caused by houses, slightly less than 10% by low-rise buildings, and approximately 1% by tall buildings. In both cases, the total mortality caused by houses is a function of their large number compared to the two other classes of buildings.

Previously, Dunn (1993) surveyed 5,500 people who fed birds at their homes and recorded window collisions. She derived an estimate of 0.65-7.7 bird deaths per home per year for North America. Klem (1990) estimated that each building in the United States kills one to 10 birds per year. Using 1986 U.S. census data, he combined numbers of homes, schools, and commercial buildings for a maximum total of 97,563,626 buildings, producing an estimate of 100 million to one billion birds killed annually.

Klem *et al.* (2009a) used data from New York City Audubon's monitoring of 73 Manhattan building façades to estimate 0.5 collision deaths per acre per year in urban environments, for a total of about 34 million migratory birds annually colliding with city buildings in the

This Barn Swallow illustrates the type of acrobatic flying that may keep swallows from being frequent collision victims. If birds do identify glass as a barrier at close range, perhaps by sound or air movements, most species may be unable to react fast enough to avoid striking the surface. Photo by Keith Ringland

A sample of collision victims from Baltimore. Photo by Daniel J. Lebbin, ABC

Sharp-shinned Hawk. Photo by Ted Ardley

United States. However, there could be major differences in collision patterns in cities across the United States, and these numbers should be confirmed using data from additional locations.

In *The American Bird Conservancy Guide to Bird Conservation* (Lebbin *et al.*, 2010) the authors state "…we have reached a point in history when the impacts of human activities are so profound and far-reaching that from now on, it will always be impossible to untangle the completely natural declines from those that are partially or completely anthropogenic. From a conservation standpoint, it is largely irrelevant, anyway. Any human-caused stress that we can alleviate from a declining species can potentially benefit its population, and we should take action to lessen that stress if we can." This is abundantly true for bird mortality from glass because there are actions that many, if not most, individuals can take themselves, directly, to reduce the toll taken by existing glass.

## Patterns of Mortality

It is difficult to get a complete and accurate picture of avian mortality from collisions with glass. Collision deaths can occur at any time of day or year. Monitoring programs focus on cities, and even intensive monitoring programs cover only a portion of a city, usually visiting the ground level of a given site at most once a day and often only during migration seasons. Many city buildings have stepped roof setbacks that are inaccessible to monitoring teams. Some studies have focused on reports from homeowners on backyard birds (Klem, 1989; Dunn, 1993) or on mortality of migrants in an urban environment (Gelb and Delacretaz, 2009; Klem *et al.*, 2009a; Newton, 1999). Others have analyzed collision victims produced by single, large-magnitude incidents (Sealy, 1985) or that have become part of museum collections (Snyder, 1946; Blem *et al.*, 1998; Codoner, 1995). There is general support for the fact that birds killed in collisions are not distinguished by age, sex, size, or health (for example: Blem and Willis, 1998; Codoner, 1995; Fink and French, 1971; Hager *et al.*, 2008; Klem, 1989), but the majority of work has focused on data taken during migratory periods, primarily east of the Mississippi River.

## Species at Risk

Snyder (1946), examining window collision fatalities at the Royal Ontario Museum, noted that the majority were migrants and "tunnel flyers"—species that frequently fly through small spaces in dense, understory habitat. Conversely, resident species well adapted to and common in urban areas, such as the House Sparrow and European Starling, are not prominent on lists of fatalities, possibly because individuals surviving their first collision may teach offspring to avoid windows.

It is well known that zoo birds in exhibits with glass walls can and do learn about specific pieces of glass, but birds do not learn about glass as a general concept.

Dr. Daniel Klem maintains running totals of the number of species reported in collision events in countries around the world. (This information can be found at http://tinyurl.com/ob3nc4s). In 2015, the site identifies 868 species globally, with 274 from the United States. The intensity of monitoring and reporting programs varies widely from country to country, however.

Hager *et al.* (2008) compared the number of species and individual birds killed at buildings at Augustana College in Illinois with the density and diversity of bird species in the surrounding area. The authors concluded that the



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total window area, the habitat immediately adjacent to windows, and behavioral differences among species were the best predictors of mortality patterns, rather than the mere size and composition of the local bird population. Kahle *et al*. (2015) reached similar conclusions in an analysis of five years of data at the California Academy of Sciences, also finding that migrants do not make up the preponderance of birds killed and that males are overrepresented relative to their abundance in habitats adjacent to the museum. Dunn (1993), analyzing winter data from homes with bird feeders, found that the frequency distribution of birds at the feeders closely paralleled the distribution of species killed by nearby windows. Dunn found few collisions on windows of less than one square meter, and an increase in collisions with an increase in window size.

Species such as the White-throated Sparrow, Ovenbird, and Common Yellowthroat appear consistently on top 10 lists from urban areas. It is possible that these species respond more readily to light and thus are more likely to end migratory stages in the built environment, but this needs to be confirmed. Additionally, Loss *et al*. (2013) noted that Golden-winged Warbler, Painted Bunting, Canada Warbler, Wood Thrush), Kentucky Warbler, and Worm-eating Warbler—species identified as birds of conservation concern—were also disproportionately represented in building kills. Hager (2009) noted that window-strike mortality was reported for 45% of raptor species found frequently in urban areas of the United States and was the leading source of mortality for Sharp-shinned Hawks, Cooper's Hawks, Merlins, and Peregrine Falcons. Because most data on glass collisions are from the eastern half of the United States, these lists are presumably biased toward species occurring in that range.

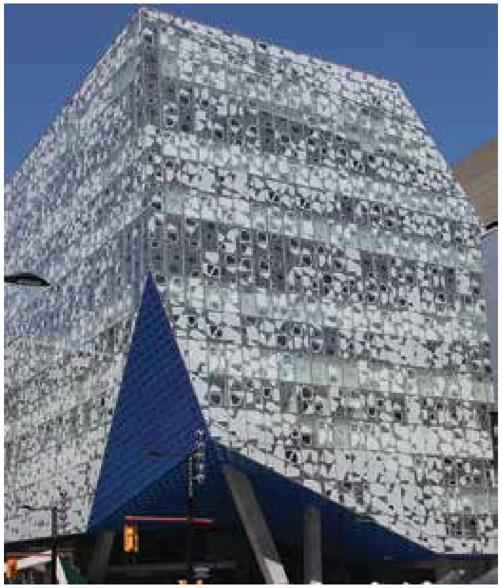
Common Yellowthroat. Photo by Owen Deutsch

# Characteristics of Buildings

## Amount of Glass

From a study of multiple buildings in Manhattan, Klem *et al*. (2009a) concluded that both the proportion and absolute amount of glass on a building façade best predict mortality rates, calculating that every increase of 10% in the expanse of glass correlates to a 19% increase in bird mortality in spring and 32% in fall. How well these equations predict mortality in other cities remains to be tested. Collins and Horn (2008), studying collisions at Millikin University in Illinois, concluded that total glass area and the presence/absence of large expanses of glass predicted mortality level. Hager *et al*. (2008, 2014) came to the same conclusion, as did Dunn (1993) and Kahle *et al*. (2015). However, the "patchiness" of glass across a façade—how many pieces, their size, how they are separated, etc. (another way of saying "visual noise")—has not yet been explored in detail but could be important.


The façade of the New York Times building, by FXFOWLE and Renzo Piano, is composed of ceramic rods, spaced to let occupants see out while minimizing the extent of exposed glass—good for controlling heat and light, and safe for birds. Photo by Christine Sheppard, ABC



Snohetta's Student Learning Centre at Ryerson University is one of the first constructed under Toronto's design law. Photo by Rick Ligthelm

## Time of Day

Most monitoring programs focus on early morning hours to document mortality during migration, often starting monitoring routes at dawn, before sidewalks are cleared. This can, however, lead to the misperception that night-flying migrants are crashing into lighted buildings at night, or only in early morning, whereas in fact most collisions take place during the day. It should be noted that "dawn" is a time that varies among species (Thomas *et al.* (2002), with some bird species active before humans start to see light in the sky.

Hager and Craig (2014), in a study of resident population collisions in northwestern Illinois between June and early August, found that 66% of birds died between sunrise and 4:00 p.m., with no collisions between 4:00 p.m. and sunset. Delacretaz and Gelb (2006) found collisions from early morning until mid-afternoon, but with a peak during morning hours. This finding is confirmed by monitoring programs like that of Pennsylvania Audubon, where routes were followed three times in succession early each day, with birds found at each pass (Keith Russell, pers. comm.) and where people living or working in buildings report window strikes through afternoon hours (Olson, pers. comm).

## Local Landscape

Gelb and Delacretaz (2006, 2009) evaluated data from collision mortality at Manhattan building façades. They found that sites where glass reflected extensive vegetation were associated with more collisions than glass reflecting little or no vegetation. Of the 10 buildings responsible for the most collisions, four were "low-rise." Klem (2009) measured variables in the space immediately associated with building façades in Manhattan as risk factors for collisions. Both increased height of trees and increased height of vegetation increased the risk of collisions in fall. Ten percent increases in tree height and the height of vegetation corresponded to 30% and 13% increases in collisions in fall. In spring, only tree height had a significant influence, with a 10% increase corresponding to a 22% increase in collisions. Confusingly, increasing "facing area," defined as the distance to the nearest structure, corresponded strongly with increased collisions in spring and with reduced collisions in fall. Presumably, vegetation increases risk both by attracting more birds to an area and by being reflected in glass.

Bayne *et al.* (2012) confirmed that the risk of bird–window collisions varies according to location (urban versus rural, home versus apartment, with or without feeders, and age of neighborhood). They used online surveys and determined that rural residences had more collisions than urban ones and residences with feeders had almost twice as many collisions as those without feeders. For urban dwellings, incidence of collisions increased with age of neighborhood, associated with presence of mature trees. Frequency of collisions varied seasonally: 24% in fall, 35% summer, 25% spring, 16% winter. Mortality patterns were similar: 26% fall, 31% summer, 26% spring, 17% winter. Forty-eight species were reported.

Hager *et al.* (2013) noted that estimates of bird-collision mortality often postulate a relatively constant range of collisions at all buildings (for example, Klem, 1990). However, they suggested that each building in a landscape has its own mortality "signature," based not only on characteristics of the structure but also on the distribution of resources throughout the local landscape, including land cover, habitat type, water, and pavement. Their protocol selected buildings at random and has recently been expanded to multiple other sites across North America.

## Avian Vision and Collisions

Bird species like falcons are famous for their acute vision, but taking a "bird's-eye view" is much more complicated than it sounds. To start with, where human color vision relies on three types of sensors, birds have four, plus an array of color filters that together allow birds to discriminate between many more colors than people (Varela *et al.* 1993) (see figure this page).

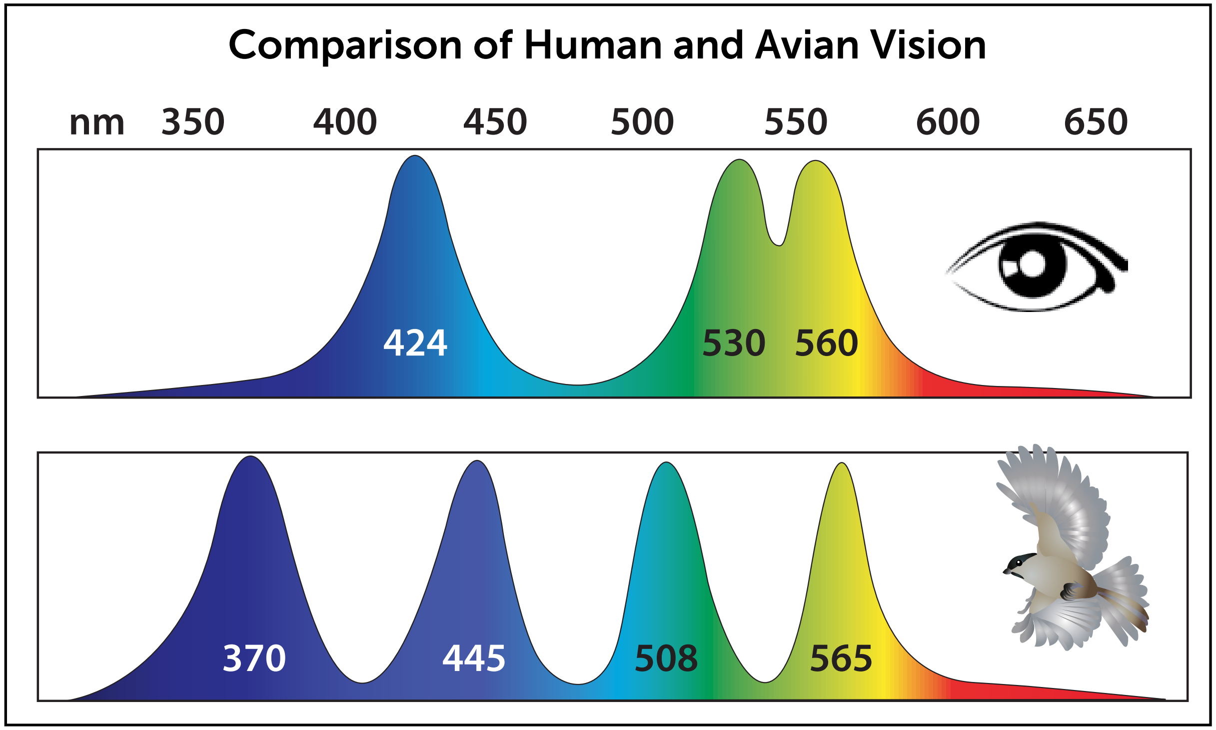
There is also variation in vision among different groups of birds. While some birds see only into the violet range of light, many birds, including most passerines (Ödeen and Håstad, 2003, 2013) see into the ultraviolet spectrum (UVS species).

Ultraviolet can be a component of any color (Cuthill *et al.* 2000). Whereas humans see red, yellow, or red + yellow, birds may see red + yellow, but also red + ultraviolet, yellow + ultraviolet, and red + yellow + ultraviolet—colors for which we have no names. Every object absorbs, reflects, and transmits ultraviolet light along with the other wavelengths in the visible spectrum. UV patterns on glass are often cited as desirable solutions to collisions—visible to birds but not to humans. However, aside from manufacturing complexities, many bird taxa that collide frequently with glass, including raptors, pigeons, woodpeckers, and hummingbirds, may not be able to perceive UV patterns (Håstad and Ödeen, 2014). Additionally, birds are often active in early morning, when UV light levels are low.

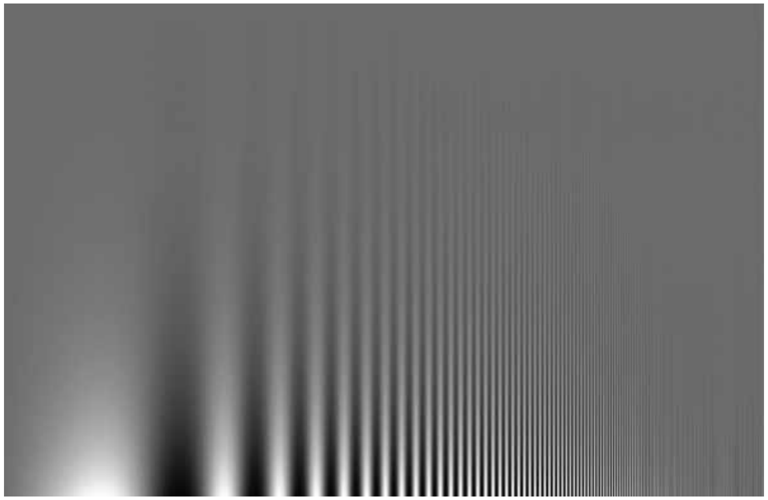
Humans and other primates have relatively flat faces, with eyes close together. The overlap of visual fields means that humans have good depth perception and a tendency to focus on what is ahead. Most birds have eyes at the sides of their heads, giving them excellent peripheral vision but poor depth perception, often limited to the length of their beaks, presumably to judge potential food items. They may be much less intent on what is in front of them (Martin 2011, 2012) but able to watch for potential predators to the side or behind them. Many species' most acute vision is to the side. Without much 3D vision, birds use a mechanism called "visual flow fields" to judge their speed and rate of progress in flight by the passage of environmental features to their sides (Bhagavatula *et al.* 2011). Collisions with glass may be partly a result of birds expecting open air ahead, combined with relatively poor forward vision.

Birds process images faster than humans; where we see continuous motion in a movie, birds would see flickering images (D'Eath, 1998; Greenwood *et al.* 2004; Evans *et al.* 2006). This speed helps many birds maneuver quickly in

Painted Bunting. Photo by Ted Ardley




Based on artwork by Sheri Williamson



Contrast sensitivity is a measure of the limit of visibility for low-contrast patterns. Each person's contrast sensitivity can be measured by the extent to which he or she can see the bars that form an arch in this photograph. The exact location of the peak of the curve varies with one's distance from the image; the area within the arch is larger when one is closer. For a given distance, the area under the arch is smaller for birds. Image courtesy of Izumi Ozawa, Berkeley Neuroscience Laboratory

response to unexpected obstacles as they fly through complex habitats. In one respect however—spatial contrast sensitivity—human vision outperforms avian (Ghim and Hodos, 2006). Contrast sensitivity is "the ability of the observer to discriminate between adjacent stimuli on the basis of their differences in relative luminosity (contrast) rather than their absolute luminances." Birds' lack of contrast sensitivity may be an impediment to creating signals to prevent collisions that are effective for birds but not visually intrusive to humans.

## Avian Orientation and the Earth's Magnetic Field

In the 1960s, it was discovered that migrating birds possess the ability to orient themselves using cues from the sun, polarized light, stars, the Earth's magnetic field, visual landmarks, and possibly even odors to find their way. Exactly how this works—and it likely varies among species—is still being investigated. (For a comprehensive review of the mechanisms involved in avian orientation, see Wiltschko and Wiltschko, 2009).

The Earth's magnetic field can provide both directional and positional information. It appears that night-flying migrants, and perhaps all bird species, have magnetic field-detecting structures in the retina of the eye that depend on light for function and provide compass orientation. This magnetic sense is wavelength-dependent. Experiments have shown that the compass is disrupted by long wavelength light but requires low-intensity short wavelength light (Wiltschko *et al.* 2007). This research has taken place only in laboratories, and it is important to determine how it translates to the real world.

In addition, anthropogenic electronic noise, found throughout urban environments, has recently been shown to disrupt magnetic compass orientation in European Robins at very low intensities (Engels *et al.* 2014). This finding may have serious implications for strategies aimed at reducing collisions by reducing artificial night lighting alone and should be a priority for additional work.

A second magnetic mechanism, providing birds with positional information, has been postulated, but its details have not been determined. (For a review of magnetoreception and its use in avian migration, see Mouritsen, 2015.)

## Birds and Light Pollution

The earliest reports of mass avian mortality caused by lights were from lighthouses, but this source of mortality essentially disappeared when steady-burning lights were replaced by rotating beams (Jones and Francis, 2003). Flashing or interrupted beams apparently allowed birds to continue to navigate, which has also been found more recently at cell towers with strobe lighting (Gehring *et al.* 2009). The emphasis on tall structures by Lights Out programs ignores the fact that light from many sources, from urban sprawl to parking lots, can affect bird behavior and potentially strand birds in the built environment (Gauthreaux and Belser, 2006). Evans-Ogden (2002) showed that light emission levels of 16 buildings, ranging in height from 8 to 72 floors and indexed by the number of lighted windows observed at night, correlated directly with bird mortality, and that the amount of light emitted by a structure was a better predictor of mortality level than building height, although height was a factor. Parkins *et al.* (2015) made similar findings.

Mass collision events of migrants associated with light and often with fog or storms have been frequently reported (Weir, 1976; Avery *et al.* 1977; Avery *et al.* 1978; Crawford, 1981a, 1981b; Gauthreaux and Belser, 2006; Newton, 2007). But these are no longer the predominant sources of mortality, possibly because the night landscape has changed radically since early reports of mass collision events at tall structures like the Washington Monument and Statue of Liberty. These and other structures were once beacons in areas of relative darkness, but are now surrounded by square miles of light pollution. While collisions at structures like cell towers continue to take place at night, the majority of collisions with buildings now take place during the day. (Hager, 2014; Kahle *et al.*, 2015; Olson, pers. comm.)

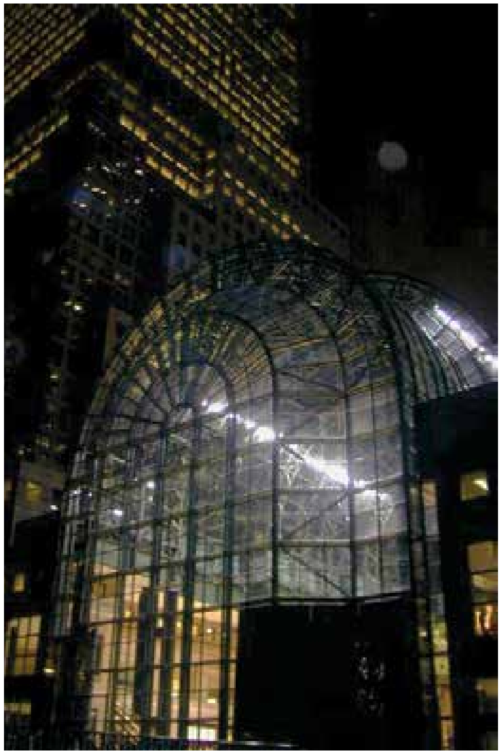
Patterns of light intensity seem to play a role in the distribution of collisions in the built environment, however. Birds may land in patterns dictated by the pattern of light intensity in an area, so the brightest buildings are the most likely to cause collisions early in the day. As birds move through the landscape seeking food, patterns related to distribution of vegetation appear. Studies using radar to map movement of birds through the built environment are starting to appear, but we need information at the level of species and individuals to truly understand how light is impacting birds.

It is often said that birds are attracted to lights at night (Gauthreaux and Belser, 2006; Poot *et al.* 2008). However, we do not have direct evidence that birds are, in fact, attracted to lights; they may simply *respond* to lights they encounter. Gauthreaux and Belser quote Verheijen as suggesting that "capture" might be a better word for birds' response to night lighting. While "capture" does seem appropriate to describe the phenomenon of birds circling drilling platforms, or in the lights of the 9/11 Memorial's Tribute in Light in Manhattan, "disorientation" is a term that covers more of the spectrum of behaviors seen when birds interact with light at night. Gauthreaux and Belser (2006), reporting unpublished data, stated that "exposure to a light field causes alteration of a straight flight path (for example hovering, slowing down, shifting direction, or circling)," and this has been reported by other authors.

Larkin and Frase (1988, in Gauthreaux and Belser, 2006) used portable tracking radar to record flight paths of birds near a broadcast tower in Michigan. Birds showed a range of response, from circling to arcs to linear flight. Haupt and Schillemeit (2011) described the paths of 213 birds flying through up-lighting from several different outdoor lighting schemes. Only 7.5% showed no change in behavior, while the remainder deviated from their courses by varying degrees, from minimal course deviation through circling. It is not known whether response differences are species related.

Bolshakov *et al.* (2010) developed the Optical-Electronic Device to study nocturnal migration behaviors of songbirds. Inspired by the more limited techniques of moon watching and watching birds cross ceilometer light beams, the device uses searchlights to illuminate birds from the ground, while a recording unit documents the birds' movements. With this technique, they can study 1) ground- and airspeed; 2) compensation for wind drift on the basis of direct measurements of headings and track directions of individual birds; 3) wing-beat pattern and its variation depending on

Swainson's Thrush. Photo by Owen Deutsch



The glass walls of this atrium, coupled with nighttime illumination, create an extreme collision hazard for birds. Photo courtesy of New York City Audubon

Canada Warbler. Photo by Ted Ardley

wind direction and velocity. In some cases, species can be identified. Bolshakov *et al.* (2013) examined the effects of wind conditions on numbers of birds aloft and flight trajectories of birds crossing the light beam from the apparatus. They determined that numbers of birds do differ with wind strength, but that birds may be attracted to the light beam under calm conditions. They also found that the light beam disturbs straight flight trajectories, especially in calm wind conditions. Regression models suggest that the probability of curved flight trajectories is greater for small birds, especially when there is little or no moon.

Bulyuk *et al.* (2014) used the same device to compare behaviors of night-migrating passerines under natural nocturnal illumination (at the Courish Spit of the Baltic Sea) with birds passing through an urban light environment (inside the city limits of St. Petersburg, Russia). Songbirds were distinguished as either small passerines or thrushes. The illuminated background caused a decrease in image quality. The shape of flight tracks was compared for the two groups, and a larger proportion of small songbirds changed flight path while crossing the light. This could be explained by flight type or flight speed. The proportion of songbirds changing flight trajectory in the lighted condition was much smaller than under the dark condition.

To understand exactly how light affects birds and what actions must be taken to reduce those effects, we need to know much more. For example, at what range (horizontal and vertical) and under what conditions do birds feel disruption from light, and of what intensity and wavelength composition? How do these factors change their behavior? Does night lighting have any effect on birds departing at the beginning of migratory stages? Do we ever actually see birds changing course to move toward a bright light source?

## Light Color and Avian Orientation

Starting in the 1940s, ceilometers—powerful beams of light used to measure the height of cloud cover—came into use and were associated with significant bird kills. Filtering out long (red) wavelengths and using the blue/green range greatly reduced mortality, although we don't know whether the intensities of these two colors of lights were equal. Later, replacement of fixed-beam ceilometers with rotating beams essentially eliminated the impact on migrating birds (Laskey, 1960). A complex series of laboratory studies in the 1990s demonstrated that birds required light in order to sense the Earth's magnetic field. Birds could orient correctly under monochromatic blue or green light, but longer wavelengths (yellow and red) caused disorientation (Rappli *et al.,* 2000; Wiltschko *et al.,*1993, 2003, 2007). Wiltschko *et al.* (2007) showed that above intensity thresholds that decrease from green to UV, birds showed disorientation. Disorientation occurs at light levels that are still relatively low, equivalent to less than half an hour before sunrise under clear sky.

Poot *et al.* (2008) demonstrated that migrating birds exposed to various colored lights in the field responded the same way as they do in the laboratory. Birds responded strongly to white and red lights and appeared disoriented by them, especially under overcast skies. Green light provoked less response and minimal disorientation; blue light attracted few birds and did not disorient those that it did attract. Birds were not attracted to infrared light. Evans *et al.* (2007) also tested different light colors but did not see aggregation under red light. However, they subsequently determined that the intensity of red light used was less than for other wavelengths, and when they repeated the trial with higher intensity red, they did see aggregation (Evans, pers. comm. 2011).



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Scientists working in the Gulf of Mexico (Russell, 2005), the North Atlantic (Wiese *et al.* 2001), and the North Sea (Poot *et al.* 2008) report that bright lights of oceanic drilling rigs induce circling behavior and mortality in birds at night. Working on a rig in the North Sea, Marquenie *et al.* (2013), estimated that birds were affected up to five kilometers away. Replacing about half the lights with new bulbs emitting minimal red light reduced circling behavior by about 50%. The authors speculate that completely re-lamping the platform would reduce bird aggregation by 90%. Gehring *et al.* (2009) demonstrated that mortality at communication towers was greatly reduced if strobe lighting was used as opposed to steady-burning white, or especially red lights. At the 9/11 Memorial Tribute in Light in Manhattan, when birds aggregate and circle in the beams, monitors turn the lights out briefly, releasing the birds (Elbin, 2015, pers. comm.). Regular, short intervals of darkness, or replacement of steady-burning warning lights with intermittent lights, are excellent options for protecting birds, and manipulating light color also has promise, although additional field trials for colored lights are needed.

## Research: Deterring Collisions

Systematic efforts to identify signals that can be used to make glass visible to birds began with the work of Dr. Daniel Klem in 1989. Testing glass panes in the field and using a dichotomous choice protocol in an aviary, Klem (1990) demonstrated that popular devices like "diving falcon" silhouettes were effective only if they were applied densely, spaced two to four inches apart. Owl decoys, blinking holiday lights, and pictures of vertebrate eyes were among items found to be ineffective. Grid and stripe patterns made from white material, one inch wide, were tested at different spacing intervals. Only three were effective: a 3 x 4-inch grid; vertical stripes spaced four inches apart; and horizontal

Glass panes are being tested at the Powdermill Tunnel, as seen from the outside. Photo by Christine Sheppard, ABC

Susan Elbin tests a bird in the tunnel at the Carnegie Museum's Powdermill Banding Station in southwestern Pennsylvania. Photo by Christine Sheppard, ABC

The tunnel: an apparatus for safely testing effectiveness of materials and designs for deterring bird collisions. Photo by Christine Sheppard, ABC

A bird's-eye view of glass in the tunnel. Photo by Christine Sheppard, ABC stripes spaced about an inch apart across the entire surface. (A summary of Klem's results can be found at collisions.abcbirds.org).

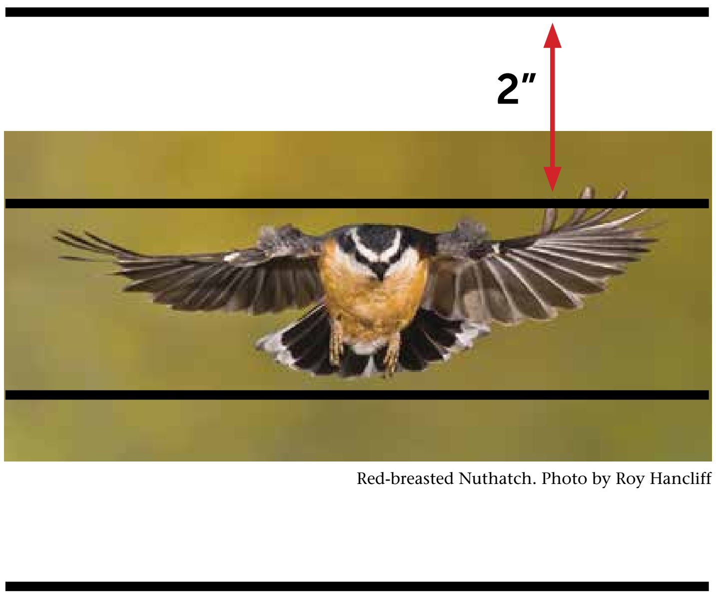
Building on Klem's findings, Rössler developed a testing program in Austria starting in 2004 and continuing to the present (Rössler and Zuna-Kratky, 2004; Rössler, 2005; Rössler, *et al.,* 2007; Rössler and Laube, 2008; Rössler, 2010; Rössler, 2012; Rössler, 2013). The banding center at the Hohenau Ringelsdorf Biological Station outside Vienna, Austria, offered a large sampling of birds for each test, in some instances permitting comparisons of a particular pattern under differing intensities of lighting. This program has focused primarily on geometric patterns, evaluating the impact of spacing, orientation, and dimensions. Birds are placed in a "tunnel," where they can view two pieces of glass: one unmodified (the control) and the other with the pattern to be tested. Birds fly down the tunnel and are scored according to whether they try to exit through the control or the patterned glass. A mist net keeps the bird from hitting the glass, and it is then released. The project focuses not only on finding patterns effective for deterring collisions, but also on effective patterns that cover a minimal part of the glass surface. To date, some patterns that cover only 5% of the glass have been found to be highly effective. (A summary of Rössler's results can be found at collisions.abcbirds.org).

The tunnel at Powdermill, showing the framework where the background will be mounted. Photo by Christine Sheppard, ABC

Building on Rössler's work, ABC collaborated with the Wildlife Conservation Society, New York City Audubon, and the Carnegie Museum to construct a tunnel at Powdermill Nature Reserve's banding station, primarily to test commercially available materials. Results from the first season showed that making an entire surface UV-reflective was not an effective way to deter birds. With UV materials, contrast seems to be important. Glass fritted in patterns conforming to the 2 x 4 rule, however, scored well as deterrents. (A summary of results from Powdermill can be found at collisions.abcbirds.org).

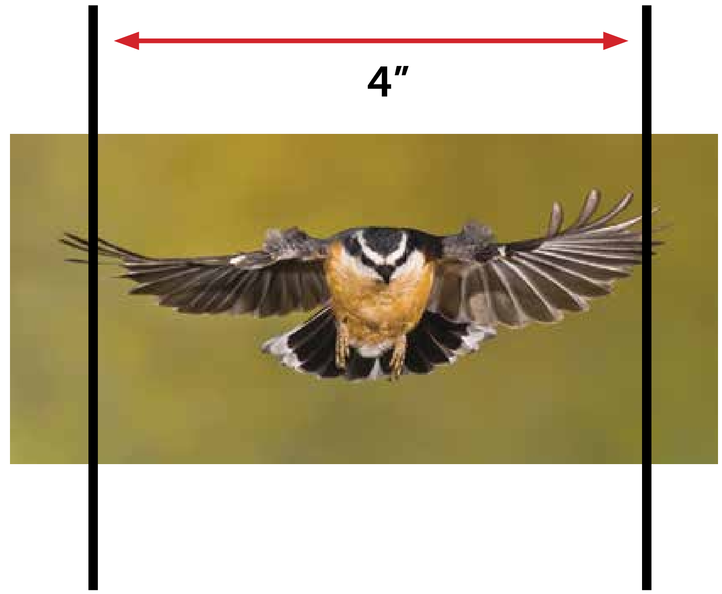
Most clear glass made in the United States transmits about 96% and reflects about 4% of light falling perpendicular to the outside surface. The amount of light reflected increases at sharper angles: clear glass reflects about 50% of incident light at angles over 70 degrees. Light on the inside of the glass is also partly reflected and partly transmitted. The relative intensities of light transmitted from the inside and reflected from the outside surfaces of glass combined with the viewing angle determine whether the glass appears transparent or mirrors the surrounding environment. Patterns on the inside surfaces of glass and objects inside the glass may not always be visible. These changeable optical properties support the argument that patterns applied to the outer surface of glass are more effective than patterns applied to the inner surface. Efforts have been made to model freestanding glass, glass installed on a building, and reflections on glass in some trials. (The testing protocol for freestanding glass, developed at Hohenau, and the testing protocols used at Powdermill can be found at collisions.abcbirds.org).

Horizontal lines with a maximum spacing of 2 inches




Red-breasted Nuthatch. Photo by Roy Hancliff

Vertical lines with a maximum spacing of 4 inches




## The 2 x 4 Rule

Research on songbirds, the most numerous victims of collisions, has shown that horizontal lines must be two or fewer inches apart to deter the majority of birds. Vertical spaces must be four or fewer inches apart. This difference presumably has to do with the shape of a flying bird. (Narrower spacing is required to deter collisions by hummingbirds.) Schiffner *et al.* (2014) showed that budgies have a very precise understanding of their own physical dimensions. Trained to fly in a tunnel, the birds were then challenged to pass through ever narrowing gaps. They were able to assess the width of the gaps relative to their body size and adjust their flight behavior accordingly. It seems likely that this is a general avian trait, useful for navigating complex environments at flight speed. Bhagavatula *et al.* (2011) used the same tunnel setup to investigate how optical flow cues guide flight. It appears that birds balance the speeds of images perceived by both eyes, in this case, images to the birds' sides. This reinforces the suggestion of Martin (2011) that humans experience the world as something ahead of them, while for birds in flight, what is ahead of them is not necessarily their primary focus.

# Evaluating Collision Problems—A Toolkit for Building Owners

American Woodcock are often victims of collisions. This bird hit a window in Washington, D.C., in March, 2011, and was recovered by ABC's Jason Berry. Photo by Dariusz Zdziebkowski, ABC

Often, only part of a building is responsible for causing most of the collisions. Evaluation and documentation can help in the development of a program of remediation targeting that area. Remediation can be almost as effective as modifying the entire building, as well as less expensive. Documentation of patterns of mortality and environmental features that may be contributing to collisions is essential. Operations personnel are often good sources of information for commercial buildings, as they may come across bird carcasses while performing regular maintenance activities. People who work near windows are often aware of birds hitting them.

Regular monitoring not only produces data on the magnitude and patterns of mortality, but also provides a baseline for demonstrating improvement. The best monitoring programs feature consistent effort, careful documentation of collision locations, and accurate identification of victims. Effective monitoring should document at least 18 months of collisions before mitigation is attempted, unless collision rates are especially high. (Resources for monitoring, from simple to sophisticated, can be found at collisions.abcbirds.org).

## Solutions

Many factors come into play in selecting how to make glass safe for birds. The table below compares common solutions according to their effectiveness, appearance, relative cost, ease of application, longevity, and required maintenance. Effective patterns on the exterior surface of glass will combat reflection, transparency, and passage effect. Within the 2 x 4 guidelines, however, considerable variation is possible when devising bird-friendly patterns. We recommend that lines be at least ¼-inch wide, but it is not necessary that they be only vertical or horizontal. Contrast between pattern and background is important, however, and designers should be aware that the background—building interior, sky, vegetation—may change in appearance throughout the day.

This security grille creates a pattern that will deter birds from flying to reflections. Photo by Christine Sheppard, ABC

### COMPARISON OF RETROFIT OPTIONS

| Material | Effectiveness | Cost | Application | Appearance | Longevity | Upkeep |
|---|---|---|---|---|---|---|
| Seasonal, temporary solutions | ***** | $ | * | * | na | na |
| Netting | ***** | $$ | ** | *** | **** | *** |
| Window film | ***** | $$$ | **** | ***** | *** | **** |
| Screens | ***** | $$ | *** | **** | ***** | **** |
| Shutters | ***** | $$$ | *** | **** | ***** | **** |
| Grilles | ***** | $$$ | **** | ***** | ***** | **** |
| Replace glass | ***** | $$$$$ | ***** | ***** | ***** | **** |
| **5 stars/dollars =** | **highly effective** | **expensive** | **easy** | **attractive** | **long-lasting** | **minimal** |

The following questions can guide the evaluation and documentation process by helping to identify features likely to cause collisions and other important factors.

## Seasonal Timing

Do collisions happen mostly during migration or fledging periods, in winter, or year round? If collisions happen only during a short time period, it may be possible to apply inexpensive, temporary solutions during that time and remove them for the rest of the year. Some birds will attack their own reflections, especially in spring. This is not a true collision. Territorial males, especially American Robins and Northern Cardinals, perceive their reflection as a rival male. They are unlikely to injure themselves, and temporarily blocking reflections in the offending window (and those nearby) from the outside should resolve the problem. Taping up paper and smearing a soap paste can both be effective.

Fog increases the danger of light both by causing birds to fly lower and by refracting light so it is visible over a larger area. Photo by Christine Sheppard, ABC

## Weather

Do collisions coincide with particular weather conditions, such as foggy or overcast days? Such collisions may be light-related, in which case an email notification system, asking building personnel to turn off lights when bad weather is forecast, is advisable.

## Diurnal Timing

Do collisions happen at a particular time of day? The appearance of glass can change significantly with different light levels, direct or indirect illumination, and sun angles. It may be possible to simply use shades or shutters during critical times.

Lower-floor windows are thought to be more dangerous to birds because they are more likely to reflect vegetation. Photo by Christine Sheppard, ABC

## Location

Are there particular windows, groups of windows, or building façades that account for most collisions? If so, it may be cost effective to modify only those sections of glass. Is glass located where birds fly between roosting or nesting and feeding sites? Are there areas where plants can be seen through glass—for example, an atrium, courtyard, or glass building connectors?

Are there architectural or landscaping features that tend to direct birds toward glass? Such features might include a wall or rock outcropping or a pathway bordered by dense vegetation. Solutions include using a screen or trellis to divert flight paths. Are there fruit trees, berry bushes, or other plants near windows that are likely to attract birds closer to glass? These windows should be a high priority for remediation. The glass itself can be modified, but it may also be possible to use live or inanimate landscaping elements to block the view between food sources and windows.

## Local Bird Populations

What types of birds are usually found in an area? Local bird groups or volunteers may be able to help characterize local and transitory bird populations, as well as the most likely routes for birds making short flights around the area. The American Birding Association, *Bird Watchers Digest*, Audubon chapters, and Birding.com are good places to start finding such resources. Universities, colleges, and museums may also be helpful.

## Post-Mitigation Monitoring

Monitoring efforts should continue for at least 18 months after mitigation efforts are made, and for at least two peak collision seasons (often the fall in urban areas, but spring and summer may also be peak seasons in more rural locations). Collision rates vary along with local bird populations, so a year of high population and high collisions may be followed by a year of low populations and low collisions, regardless of the effectiveness of any mitigation.

Use of glass with a highly effective horizontal frit pattern, together with sunshades, earned this retrofitted building on the SUNY Brockport campus the LEED "collision deterrence" credit. Photo by Paul Tankel

This Ovenbird survived a collision and was recovered alive during a Lights Out monitoring effort in Baltimore, Maryland. Photo by Daniel J. Lebbin, ABC

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A dramatic use of glass block characterizes the Hecht Warehouse in Washington, D.C., designed by Abbott and Merkt. Photo by Sandra Cohen-Rose/Colin Rose

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The World Trade Center of New Orleans, designed by Edward Durrell Stone, uses a simple bird-friendly strategy; almost all windows have exterior shutters. Photo by Christine Sheppard, ABC

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For the Langley Academy in Berkshire, U.K., Foster + Partners used louvers to control light and ventilation, also making the building safe for birds. Photo by Chris Phippen Ofis

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The Institut Arabe du Monde in Paris, France, provides light to the building interior without using glass. Photo by Joseph Radko, Jr.

**American Bird Conservancy** is the Western Hemisphere's bird conservation specialist—the only organization with a single and steadfast commitment to achieving conservation results for native birds and their habitats throughout the Americas. With a focus on efficiency and working in partnership, we take on the toughest problems facing birds today, innovating and building on sound science to halt extinctions, protect habitats, eliminate threats, and build capacity for bird conservation.

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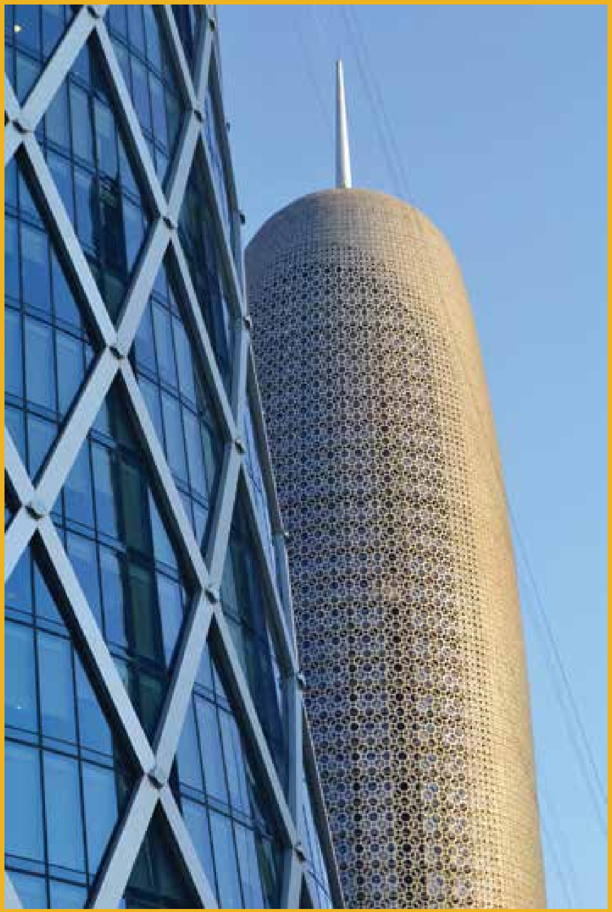
The Orange Cube, a commercial and cultural complex, was designed by Jacob + McFarlane Architects as part of redevelopment of the harbor in Lyons, France. The external skin virtually eliminates threats to birds while permitting natural illumination of the interior and sightlines for those inside. Photo © Nicolas Borel

# American Bird Conservancy's Bird-Friendly Building Standard

The U.S. Green Building Council's LEED Pilot Credit 55 represents the best current understanding of what constitutes a bird-friendly building. Briefly, a bird-friendly building is one where:

- At least 90% of the material in the exposed façade from ground level to 40 feet (the primary bird collision zone) has a threat score of 30 or less, derived from controlled experiments.
- At least 60% of material in the exposed façade above the collision zone meets the above standard.
- All glass surrounding atria or courtyards meets the above standard.
- There are no "see through" passageways or corners.
- Outside lighting is appropriately shielded and directed to minimize attraction to night migrating or nocturnal birds.
- Interior lighting is turned off at night if not in use and designed to minimize light escaping through windows during night operation.
- Landscaping is designed without features known to increase collisions.
- Actual bird mortality is monitored and compensated for (for example, in the form of habitat preserved or created elsewhere, mortality from other sources reduced, etc.).



The Burj Qatar, designed by Jean Nouvel, was named Best Tall Building Worldwide in 2012. The façade, created with multi-layered screens, expresses local culture while providing protection from high temperatures and sand. Photo by Marc Desbordes

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David Chipperfield's expansion of the Anchorage Museum has a surface of mirror glass, made bird-friendly by a frit pattern that conforms with 2 x 4 recommendations. Museum staff confirm that while collisions do occur in the area, the museum sees few, if any. Photo by Larry Vincent

COLLISION COURSE: Scientists struggle to make windows safer for birds
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# COLLISION COURSE

## Scientists struggle to make windows safer for birds

By Susan Milius

Ornithologist Christine Sheppard, frowning as if she's lost something, squints into the darkness of a 30-foot-long contraption. It looks like a stretch-limo version of a garden shed, but one end sports high-tech glass available only from an industrial R&D lab. From a hole at the other end dangles a child's pajama leg.

What Sheppard has lost is a song sparrow. She is using the tunnel contraption to test whether birds will fly into the piece of glass at the end. Since birds often don't see glass and fly right into it, Sheppard hopes to test whether stripes or other markings on the glass can warn birds away from a fatal impact. The pajama leg provides a soft chute to slip a sparrow or other bird into at the dark end of the tunnel. The bird flies toward the light-filled windows at the other end, and at the last instant a hair-fine net in front of the glass prevents a collision.

This setup, at Powdermill Avian Research Center in Rector, Pa., is one of three in the United States testing ways to prevent birds from flying into glass. According to one oft-quoted estimate, window crashes account for up to a billion bird deaths a year in the United States alone.

Creating no-crash glass has turned out to be much trickier than it sounds. The researcher behind the first U.S. glass-testing setup for birds, ornithologist

BUILDING: LABSAS/ISTOCKPHOTO; BIRDS: BLACKRED/ISTOCKPHOTO





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Daniel Klem Jr., has been working on the issue for about four decades. His is a tale of the perils of applied science, from "aha" moments to entrenched public resistance and commercial disinterest. Basic research on bird vision has flourished, shedding light on what birds can and can't see, but translating neuroscience into safer window designs and getting them adopted is not so easy.

Ironically, the green building movement of recent years has made landscapes even more dangerous, Sheppard says. Efforts to shave energy costs by letting in more natural light have meant more glass for birds to collide with. But now she's working with architects and glass companies in ways that may at last hatch a market for bird-safe products. Tests show that opaque stripes or dots on windows can reduce bird kills, if people are only willing to use them.

But both Sheppard and Klem have been searching for the Holy Grail of bird safety: windows with patterns that birds can see but that are invisible to people. It is not an exact science. So far this morning at Sheppard's tunnel, one test subject darted out an uncapped observation hole instead of completing the test flight. A crow just walked down the tunnel. The lost song sparrow has caused a temporary halt in tunnel operations. The bird is free to fly through the open door, but it's lingering inside in the cozy darkness. Sheppard grabs a long-handled net and is preparing to clamber into the tunnel herself when — whoop! — the sparrow flies.

## Population unknown

It's hard to find a good number for just how many birds die in window collisions. Klem is the source of the numbers stating that U.S. windows kill 100 million to 1 billion birds a year. "I blatantly and openly tell you they're estimates," he says.

Klem's numbers are based on his 1990 estimates of the number of birds a typical building kills annually (between one and 10) and the number of buildings in the United States (based on 1986 data). Now Scott Loss of Oklahoma State University in Stillwater and colleagues are creating a new estimate using data on per-building mortality rates from 23 studies.

**100 million**
**to**
**1 billion**

Estimated number of birds killed by glass collisions annually in the United States

Whatever the new estimate is, there will be debate over what it means for total bird populations. Many species of North American birds are declining in numbers, but they also face degraded habitat, pollutants, invasive species, wind turbines and other hazards. The scale of the hazard windows pose won't be clear without comparable studies of local populations, Loss and colleagues argued in 2012 in *Frontiers in Ecology and the Environment.*

For ornithologists and bird lovers, though, buildings that kill wildlife are disturbing regardless of total population impact. Architect Anne Lewis leads City Wildlife project volunteers who get up before dawn to walk through downtown Washington, D.C., documenting birds that have crashed against glass. Sometimes she picks up stunned birds, placing them in paper bags to rest before being released in leafy parks far from dangerous glass. "Sometimes they die in your hand," she says. "It makes a believer out of you."

## Bird safety basics

Witnessing bird collisions made a believer out of Daniel Klem while he was still a graduate student. One day in 1974, he sat down on a bench in front of the mirrored-glass chemistry building at Southern Illinois University Carbondale. "It only took about 20 minutes," he remembers. A mourning dove thumped against an upper story of the building so hard that feathers scattered, and the bird dropped to die on the ground.

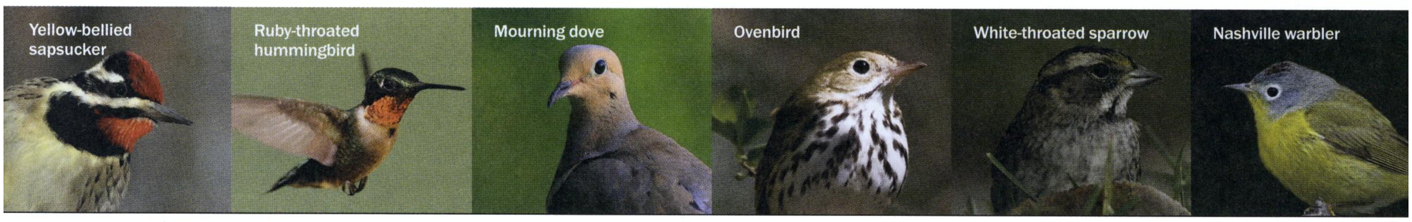
At the time, no one knew why birds fly into glass. A 1931 scientific report on yellow-billed cuckoo crashes treated the deceased as "rare, self-destroying incompetents," says Klem, now at Muhlenberg College in Allentown, Pa. As the building boom after World War II fed demand for picture windows and glass walls, accounts of birds crashing into windows surged. So did speculations on the cause. Perhaps the birds just didn't understand glass. Or their eyes were bad. Or sun glare, mist or smoke temporarily blinded them. One report even suggested the birds were drunk on fermented fruit.

Klem began to set up experiments. He propped panes of clear and mirrored glass against tree trunks at the edge of the woods on his adviser's property, and he built a 12-foot Masonite tunnel, the first ever for testing windows. Birds flew toward a pane of clear glass as readily as through an empty window frame, showing no sign they could tell glass from air.

"It's the glass, stupid," is Klem's sloganized conclusion. Birds just don't see clear glass as an obstacle. Reflections may even lure them toward what appear to be trees, grass or other shelter that actually lie behind them.

To see how people might warn birds away from glass, Klem began testing bird-deterrence markings in his tunnel. He compared a plain pane with glass adorned with something: stripes, silhouettes of predators or even blinking lights.

**Below are a few U.S. bird species often found dead after flying into glass, according to surveys by wildlife groups in Washington, D.C., and Chicago.**




FROM LEFT: STEVENRUSSELLSMITHPHOTOS/SHUTTERSTOCK; STEVE BYLAND/SHUTTERSTOCK; STEVE BRIGMAN/SHUTTERSTOCK; WILLIAMSHERMAN/ISTOCKPHOTO; PAULREEVESPHOTOGRAPHY/SHUTTERSTOCK; GERALD MARELLA/SHUTTERSTOCK





58107

**Daniel Klem (left) has been trying for decades to convince people to use simple bird-safe methods like the decoratively coated glass behind him. Christine Sheppard (right) tests birds' reactions to new kinds of glass in her testing tunnel.**

(A lone predator decal is useless.)

His results helped establish what's now known as the two-by-four rule. Most birds won't fly through a space less than 4 inches wide between vertical stripes or 2 inches high between horizontal stripes.

This finding has had conspicuously little impact on offices, homes, airports, bus shelters and the rest of the increasingly glassy world. The failure has little to do with the birds or the experiments. "People told me time and time again, 'You know, Dan, you go mucking around with the way people look through their windows, and you're going to lose,'" he says. Any pattern obscuring a view means counterintuitive marketing for anything but bathrooms.

Then came a *Nature* paper in 1978 from prominent ecologist Thomas Eisner of Cornell and a colleague reporting evidence that homing pigeons react to real-world ultraviolet light. "From the very instant I read about it, I was excited," Klem says. "I was beside myself, thinking this could be the Holy Grail."

People can't see the very short wavelengths, from 100 to 400 nanometers, that make up ultraviolet light, but it turns out that pigeons and many more birds can. In theory, window patterns that show up only in UV could warn birds of a no-fly zone while giving humans a clear view.

But after the initial thrill, Klem says, "I realized there wasn't any way for me to test this." He contacted glass companies, people who might know product developers, people who might know people, searching for a material that reflects UV wavelengths but not others. He found a lot of UV absorbers, but no useful UV-only reflectors. He refers to this period as a "time when I was in this frustration — which was most of the '80s and the '90s."

Eventually a chemist who developed window films for cars happened to hear a radio interview with Klem, and as a side project devised a UV film that reduced bird crashes. The chemist's company deemed the project financially untenable, though, and yet another attempt to finance it has fallen through within the last year. A few other companies are now testing and even marketing UV-reflecting products such as decals and glass.

As for testing the effectiveness of such products, Klem argues that tunnels are "informative but not completely reliable," because they are not very accurate mimics of windows in actual buildings. Instead, he mounts glass to be tested and clear glass for comparison in frames, shuffling positioning to counteract quirks of lighting or location. He scores effectiveness by comparing numbers of carcasses or smudges on each pane. He omits nets, he says, because they can be visible from some angles and in some lighting, distorting results.

He's far from the only scientist to sacrifice animals in a study. "It's a part of the work that I grimace at," he says. He tells his students that when extraterrestrial scientists finally reach Earth, it's only fair that he volunteer as their specimen. But unless he can trust that his results are realistic, he says, he runs the risk of "sanctioning something that is continuing to kill animals."

For decades, mainstream ornithology wasn't exactly ignited by Klem's interest in window glass, and a 2003 magazine profile called him "the Rodney Dangerfield of ornithology." As far as a widespread awareness of collision hazards that fuels a broad resolve to change windows, "we're still quibbling," he says. "I'm an educational failure."

## Bird's-eye view

While Klem struggled with window treatments, basic research on avian vision flourished, with ever more precise analyses of eye structure, nerve responses and which genes turn on when. These scientists haven't been talking to people like Klem who work on practical problems, says Graham Martin of the University of Birmingham in England.

And if they were to talk, it's not clear what they could say except that

**Reflections not only cause collisions but also affect behavior. This cardinal crashed repeatedly, though not fatally, into a window, defending its territory from a reflection.**

CLOCKWISE FROM TOP LEFT: BILL UHRICH/HAWK MOUNTAIN; S. MILIUS; JOHN SCHERR





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designing a UV pattern to warn a bird about glass could be difficult.

For one thing, most birds' eyes are on the sides of their heads. "Birds have got this fantastically comprehensive visual field," Martin says, "but the best vision for most birds is actually out sideways."

In some big birds, such as eagles, bustards and the two vulture species Martin reported on in *Ibis* in 2012, a gap between the left and right visual fields creates a blind spot to the upper front. "As soon as they start to look down, they're effectively flying blind," Martin says.

This gap means these birds may not see an obstacle ahead, nor would they see warning patterns ahead. "They're flying with the assumption — that has been a pretty good one for the last God knows how many millions of years — that there won't be anything sticking up in the way," Martin says.

Songbirds, which are more often killed by windows than are the big scavengers and birds of prey that Martin studies, do not have this big frontal blind spot. But even for them, "forward vision is not so good," Martin says. Birds, like people, typically get their sharpest view in the center of the eye's field of view. For side-eyed birds, that's to the side. Martin predicts that patterns to the front probably need to be extra bold for birds to notice them.

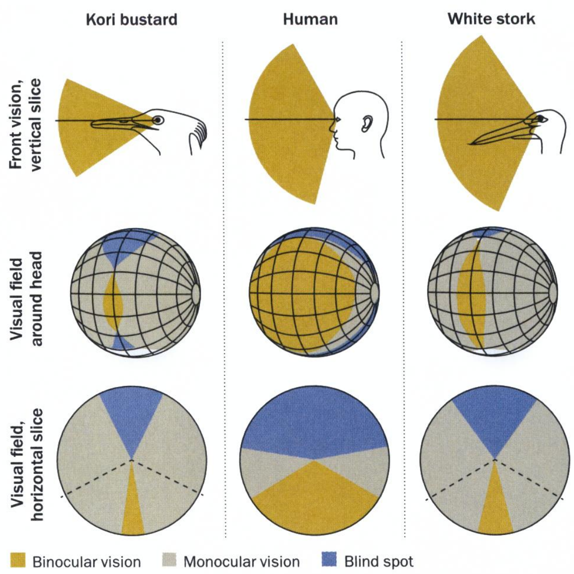
Another problem in creating bird-visible patterns is that birds are not as sensitive to contrast as people are. For a typical bird to pick out a grayscale pattern, the contrast between grays has to be about 10 times greater than it would for a human observer, says Almut Kelber of Lund University in Sweden.

There are other problems specific to developing UV-reflecting patterns. Even one of the commonly repeated examples of birds seeing UV signals in nature may not be true, Kelber and her colleagues argued in May in the *Journal of Experimental Biology*. A 1995 paper had proposed that birds of prey track voles in Finland by catching the UV glimmer of their urine dribbled across the landscape. Kelber found that lenses and fluids in the eyes of kestrels filter out much of the UV. And in any case, the voles Kelber's team tested didn't pee in ultraviolet. This doesn't mean that other birds have trouble seeing in UV. But Kelber cautions against generalizing about bird vision based on the small number of species that have been tested.

What's more, perceiving ultraviolet patterns while in motion "might be impossible for birds," says Daniel Osorio, a color vision expert at the University of Sussex in England. The part of the bird's midbrain that analyzes motion receives information from cells in the eye that aren't sensitive to ultraviolet, current evidence suggests.

Neither Osorio nor Martin is optimistic about UV-reflecting patterns after attending a symposium on birds and glass at a September meeting of European ornithologists. Birds may not sensitive enough to UV to detect a warning pattern on an actual window, researchers suggested at the meeting.

**Visual fields of birds and humans**




**Where birds see** With eyes on the sides of their heads, birds have a different field of view than humans. Africa's Kori bustards have a narrower vertical range of binocular vision than people or storks. If a bustard looks 25 degrees down, it has a blind spot to its front. The middle row shows areas of each vision type surrounding each animal's head, facing the center of the yellow binocular zone. The bottom row shows a slice through the equator of those spheres, showing humans' large rear blind spot compared with birds.

G.R. MARTIN, ADAPTED BY S. EGTS

## Bird-safe by law

In some places, regulations are beginning to encourage or require more bird-safe architecture. Minnesota mandates that buildings that receive state funds include certain bird-safety features in plans for environmental friendliness. Since 2011, buildings in San Francisco's bird-rich areas near parks or water must meet avian safety requirements, and Oakland, Calif., this year added a layer to its building permit process requiring feasible improvements in protective measures for birds.

Toronto has been a center of activity for bird-safe buildings, with pioneering regulations, and this year an unusual lawsuit. A major property company, Cadillac Fairview, ended up in court because the massive glass facades on its Yonge Corporate Centre were killing birds.

The company was acquitted this year after, the decision noted, installing window-taming treatments that cost about $100,000. The judge stated that emissions of reflected light from windows causing bird crashes should be considered violations of Canada's environmental laws.
*— Susan Milius*





58109

**Bird-safe can be beautiful, advocates say. Chicago's Aqua Tower (left) has textured (or fritted) glass and balconies limiting birds' view of windows. Other strategies include UV-reflecting patterns (Ornilux glass, top right) and window shades (bottom right).**

CLOCKWISE FROM TOP LEFT: CHICAGOGEEK/FLICKR; ECOMBETZ/WIKIMEDIA COMMONS; SALI SASAKI/FLICKR

## Build it

Experiments on birds won't do any good if there's no market for the results, though. So Sheppard is taking her case to architects and glass manufacturers. Her testing tunnel results are now what some companies rely upon to rate the safety of new kinds of glass for birds.

For the first two decades of Sheppard's ornithology career, she didn't bother with experiments since she had an obviously successful device: soap.

When she finished her Ph.D. and went to work for the Wildlife Conservation Society's Bronx Zoo, the staff routinely smeared soap on any expanses of glass surrounding a new bird on exhibit. The newcomer would avoid the solid-looking windows. Once it learned its way around, the staff would wash off the soap.

Then the zoo planned to build a new Center for Global Conservation and turned to Sheppard for advice on keeping the building from becoming a bird killer. The moment she found an Internet reference to a nonlethal contraption in Austria for testing glass, she decided to build one.

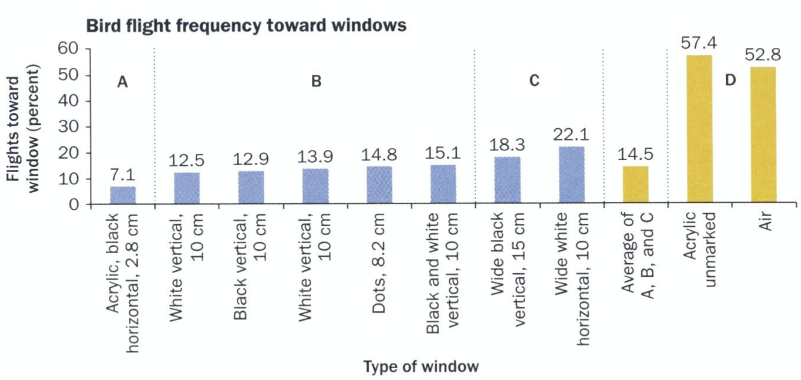
She now has one testing tunnel at Pennsylvania's Powdermill Nature Reserve and a new one at the Bronx Zoo. She also has what may be the only job in the world devoted to making buildings safe for birds, at the American Bird Conservancy. She has made trade-offs in experimental design different from those in Klem's work. Sheppard's controlled flights in tunnels give results from a large number of test birds of known species, without harming any. But the birds fly from a dark tunnel toward a light-filled window, which isn't what usually happens in real life. "I'm not trying to be realistic," she says. "I'm testing patterns."

Opaque dots and stripes covering as little as 5 percent of glass surface can prevent 90 percent of collisions, she says (see sidebar, facing page). What architects dream about, though, are patterns invisible to humans, and those are harder to develop. Ornilux, made by Arnold Glas in Germany, carries subtle, irregular crisscross bands that reflect UV. This glass tested as bird-visible in Sheppard's Powdermill tunnel. For Klem, the protection worked only if there was less light behind the window than in front of it, he and a colleague report in the June *Wilson Journal of Ornithology*. Though Sheppard and Klem emphasize different elements of experimental design, both acknowledge that lighting and other conditions vary in real life. "Architects need to take our results, along with what we know about reflections, and make informed decisions," Sheppard says.

In another of Sheppard's tests, panes with tiny white dots on the glass surface didn't seem to alert birds to an obstacle. Birds were almost as likely to veer toward a panel as away from it. Increasing the density of the dots — which made more of the glass opaque — helped. It looked like a simple case of covering more surface area.

But then Sheppard tested glass panes

**Glass houses** Researchers in Austria tested nearly 800 bird flights toward windows covered with stripes, dots or no marks (listed below with distance between markings). The results are grouped from most bird-safe (A) to least (C). Acrylic panes, or Plexiglas, containing thin black horizontal filaments were the top performer. In other tests (D), birds were at least as likely to fly toward unmarked acrylic as toward an empty window frame. SOURCE: M. RÖSSLER *ET AL*/*BOKU VIENNA* 2009





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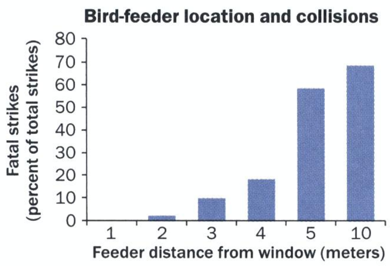



**Feeding bird deaths** Bird feeders can draw birds toward windows, but are less deadly if placed within a meter of glass. Birds may be drawn to the feeder instead of windows and are not flying as fast if they hit a window while flying away. SOURCE: D. KLEM *ET AL/WILSON BULLETIN* 2004

## Bird safety dos and don'ts

Even small panes of glass can trick a bird into a fatal crash, and some products sold for bird safety may not work, warns Christine Sheppard of the American Bird Conservancy. Here are some solutions that Sheppard recommends:

**Recommended**

- **Window screens** reduce bird collisions by reducing reflections and providing a softer surface.
- **Washable tempura paints** can provide a simple warning and can be changed seasonally as decoration.
- **Shutters or exterior shades** can be closed when no one is looking out a window or during high-risk seasons for collisions, such as spring and fall migration.
- **Stripes or dots on the outside of glass** can break up reflections. Ideally, vertical lines should be spaced no more than 4 inches apart, horizontal lines no more than 2 inches apart.
- **Fritted glass**, which has a rough surface, reduces reflections and collisions as long as the fritting is on the outside surface.

**Not recommended or problematic**

- **A single predator decal** such as a hawk silhouette is not recognizable to birds as a dangerous predator. Arranging multiple decals could deter birds by reducing a window's transparent area, but decal shape does not matter.
- **Light-colored blinds or shades** inside windows may be better than nothing, but depending on the lighting, birds can still see deceptive reflections.
- **Overhangs or awnings** can block a window from sight for birds above but can leave birds with views of reflected plants and sky.
- **Glass slanted** at least 20 degrees from the vertical reduced deaths in tests near feeders, but Sheppard says this may work only when birds fly parallel to the ground.

with eighth-inch-wide lines instead of dots. Glass marked with either vertical or horizontal lines scored much better than the dotted panels — even though the lines covered about the same small fraction of the surface. "It became very clear it's not simply the coverage," Sheppard says. Within certain limits, stripes appear to be more effective for their size than dots as practical warning signs on buildings.

To get any of these solutions in place, "you have to get to the architects," Sheppard says. She helped the Green Building Council develop a way to calculate a building's lethality to birds. In 2011 they began a pilot program to add a collision-deterrence credit to the LEED program, or Leadership in Energy & Environmental Design, which certifies buildings as environmentally responsible. To get the credit, architects have to minimize clear panes, and their see-through acreage can expand in proportion to how well the glass performs in Sheppard's tunnel test.

One spring day at the Powdermill bird-banding station, a pane with a UV pattern (Sheppard can't say more about the proprietary material) sits in the testing slot beside regular glass. At this time of year, the bird-banding crew starts at 5 a.m. six days a week, trooping through shrubbery every half hour to check the nets that capture birds to be banded and tested. Birds hang in dark clots of tangled threads. In dozens of quick miracles, banders unsnarl them and fit each bird into its own beige cloth bag. To keep their hands free, the banders clip each bag to a cord around their necks, creating broad necklaces that occasionally twitch.

Thus dressed, the crew strides back to a snug room. Hands slide into anonymous beige bags and emerge with delicate creatures, the technicians working with the intensity of a surgical team to measure birds as quickly as possible.

Sheppard and technician Matthew Webb, hovering on the edges of the controlled rush, accept a bag and step across the station's yard to the glass-testing tunnel. Webb pulls out a yellow warbler, brilliant as a daffodil and only somewhat bigger. Webb squints at the numbers on its leg band, reads them into the video recorder and slips his handful of bird into the tunnel. Seen from outside, there's just a man with one arm down a pajama leg.

The actual test is so fast, just two or three seconds, that it's almost anticlimactic. Webb, watching the small screen of the video recorder aimed into the tunnel, suddenly pronounces "indirect right," and it's over. The warbler has swerved and ended up on the right, flying away from the UV-treated glass. Sheppard opens a large door, and in seconds a yellow dot of warbler blurs off toward the shrubs.

Across the yard, windows in the banding station carry fleets of translucent tape, with admirable two-by-four spacing. They shouldn't be a menace to the warblers, sparrows, kinglets, wrens, flycatchers and literally hundreds of other travelers darting through the woods. But after starting to think about glass, it's hard to stop. Just down the road in the town of Donegal, more windows loom in the houses, the Dairy Queen, the turnpike tollbooths. So many windows, and still so few stripes. ■

### Explore more:

- See the American Bird Conservancy's report, "Bird-friendly building design," at bit.ly/SNbirdsglass





58111

# YOU CAN SAVE BIRDS FROM FLYING INTO WINDOWS!

Christine Sheppard, ABC

**Millions of birds die every year flying into windows, because they can't tell reflections from trees, plants and sky. *Most of those windows are on houses.***

Never had a bird hit your window? Perhaps you have been lucky—so far. More likely, you haven't been around to see or hear it when it happened, and the bird has either flown off to die elsewhere or been scavenged by a neighborhood cat, raccoon, or crow. But the odds are that sooner or later, your windows will kill a bird.

Wood Thrush killed after colliding with a window. Photo: Mike Parr, ABC

This Barn Swallow dove through the small space shown at top flight speed—over 30 miles per hour! Photo: Keith Ringland

Horizontal stripes spaced two inches apart are an effective way to keep birds from hitting your windows. Photo: Christine Sheppard, ABC

Not all windows are equally hazardous. Check to see which of your windows are most reflective, and closest to areas where you see birds when they are active. **Collisions happen more frequently during spring and fall migration periods or when resident birds fledge young or leave territories to seek food in winter.**

**Even small windows can be dangerous**, as many birds fly into small spaces such as tree cavities or between branches.

Even small windows can pose a threat to birds. Photo: Christine Sheppard, ABC

**Research has identified solutions** to alert birds to windows. The easiest of these involve applying visible markings to the outside of windows in patterns that the birds can see while requiring minimal glass coverage to keep your view unobscured. Although we don't yet have all the answers, we know that most birds will avoid windows with vertical stripes spaced four inches apart or less, or horizontal stripes spaced two inches or less apart. Stripes should be at least ¼" wide and light colors are generally more visible. More complicated or irregular patterns will also work as long as they follow the general spacing guidelines specified above.

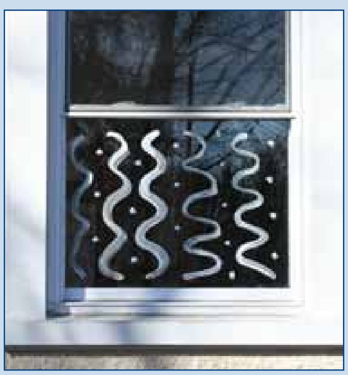
On the other side of this page, we provide information on some of the products you can use to help prevent birds from crashing into your windows and where to find them.

**For more information contact:**
Dr. Christine Sheppard, ABC Bird Collisions Campaign Manager, csheppard@abcbirds.org

Photo: Christine Sheppard, ABC.

**Here are some quick and affordable ways to protect birds from your windows. These should be applied to the outside of the glass to break up reflections.**

Window tape patterns are easy to apply and provide an effective deterrent against bird strikes. Shown is ABC Bird Tape. Photo: Dariusz Zdziebkowski, ABC.



Tempera paint is a washable, long-lasting, and non-toxic solution to preventing bird/window collisions. Photo: Christine Sheppard, ABC.

Window netting provides a see-through screen that will cut down on bird strikes. Photo: John Pace, BirdMaster Bird Control Systems

1. Apply Tempera paint (available at most art supply and craft stores) free-hand with brush or sponge, or use a stencil. Tempera is long-lasting, even in rain, and non-toxic, but comes right off with a damp rag or sponge. Find stencils at **www.michaels.com, www.amazon.com,** or download stencils for free at **www.spraypaintstencils.com**.

2. Use tape to create patterns. Any opaque tape can work, but translucent ABC BirdTape transmits light and is made to last outdoors (**www.abcbirdtape.org**).

3. Most window films designed for external use are not patterned and will not deter birds. However, interior window films come in many colors and styles, and can be applied on the outside of windows to prevent collisions (see **www.thesunshieldpros.us/WindowFilm/decorative_film.html**). CollidEscape, designed for external use, is see-through from the inside, opaque from the outside (**www.collidescape.org**).

4. If you don't want to alter the glass itself, you can stretch lightweight netting, screen, or other material over the window. The netting must be several inches in front of the window, so birds don't hit the glass after hitting the net. Several companies, (**www.birdscreen.com**, **www.birdsavers.com**) sell screens or other barriers that can be attached with suction cups or eye hooks (also see **www.birdbgone.com, www.nixalite.com,** or **www.birdmaster.com**).

5. What about prefabricated decals? Birds see decals shaped like raptors as obstacles but not as predators. To be effective, any type of decal must be spaced as described above, more closely than recommended by most manufacturers (**www.windowdressingetc.com, www.windowalert.com, www.duncraft.com**). Or make your own! Arti Stick Window Color paints come in 18 colors and are marketed for children. Drawings on sheets of plastic become translucent as they dry, and can be peeled off and applied to windows (visit **www.dickblick.com**).

For more information, contact:

AMERICAN BIRD CONSERVANCY

P.O. Box 249, 4249 Loudoun Avenue
The Plains, VA 20198
www.abcbirds.org • info@abcbirds.org
540-253-5780 • 888-247-3624

**RESOLUTION No.** 37122 As Amended

Implement a comprehensive update to the City of Portland's Green Building Policy to reflect advances in green building knowledge and practices (Resolution)

WHEREAS, conventional development and construction practices deplete natural resources and cause air and water pollution, solid waste, deforestation, toxic wastes, health hazards, climate change, and other negative consequences; and

WHEREAS, buildings account for more than one-third of the nation's energy use, 30 percent of greenhouse gas emissions and waste output; and

WHEREAS, the increasing urgency of climate change, rising energy prices and a fragile economy pose serious threats to Portland's ability to thrive, now and in the future; and

WHEREAS, green building complements existing policies related to development and natural resource conservation including solid waste, recycling, and composting policies, sustainable procurement policies, the Stormwater Management Manual, 1 Percent for Green Streets, the Climate Action Plan, the Portland Plan, the Transportation Systems Plan, the Economic Development Strategy, and Metro 2040 Framework Plan; and

WHEREAS, sustainable development practices present a major economic development opportunity for Portland and Oregon; and

WHEREAS, preserving historic buildings, structures and materials is a key aspect of sustainability; and

WHEREAS, the City of Portland recognizes its responsibility to implement, continue, and promote building practices that protect human health and the quality of the air, water, and other natural resources; reduce construction practices that negatively impact native fish, vegetation, wildlife, and other ecosystems; and minimize human impact on local and worldwide ecosystems; and

WHEREAS, the United States Green Building Council has, in a national collaborative process, created the Leadership in Energy and Environmental Design (LEED) green building certification program that recognizes best-in-class building strategies and practices; and

WHEREAS, Earth Advantage is a green building certification standard and rating system for the design, construction, and operation of high-performance small commercial and multifamily buildings developed and maintained by Earth Advantage Institute; and

WHEREAS, Living Building Challenge is a green building certification program that is a pathway for regenerative design and includes imperatives in seven performance areas: site, water, energy, health, materials, equity, and beauty; and

WHEREAS, Salmon-Safe provides guidance for public agency land managers, site developers, and designers interested in developing and operating sites that demonstrate environmental stewardship by minimizing watershed impacts; and

WHEREAS, in 1999 the City Council accepted the Green Building Options Study and Green Building Initiative to develop an inter-bureau effort to implement green building standards for all City design, construction, operation, and maintenance practices; and

WHEREAS, in 2001, Resolution 35956 established the City's Green Building Policy to require all new City facilities to register and certify at the LEED Certified level and incorporate green building strategies into tenant improvement and operation and maintenance practices; and

WHEREAS, in 2005, Resolution 35956 revised the City's Green Building Policy to raise the certification level of new City facilities to LEED Gold, require ecoroof coverage on new and replacement roofs, and define inter-bureau efforts to support community-wide green building practices; and

WHEREAS, in 2009, Resolution 36700 revised the City's Green Building Policy to clarify and enhance its content to support implementation and project management; and

WHEREAS, in 2013, Resolution 37034 directed exploration of opportunities to advance bird-friendly building design and management practices into City plans, policies and programs, including the Green Building Policy for City-owned facilities; and

WHEREAS, the City of Portland has designed and/or constructed eleven LEED-registered projects and numerous green remodel, tenant improvement, ecoroof, and public infrastructure projects; and

WHEREAS, the City of Portland seeks to improve understanding and compliance with this Policy, retain its leadership in green building policy implementation, and respond to advances in the green building industry.

**POLICY**

NOW, THEREFORE, BE IT RESOLVED, that the City of Portland Green Building Policy is adopted with the attached Exhibits and Appendices; and

BE IT FURTHER RESOLVED that the City of Portland shall finance and staff its green building projects at a level suitable to meet the policy requirements; and

BE IT FURTHER RESOLVED that the appendices of this Resolution may be updated by the Bureau of Planning and Sustainability with consent of affected bureaus and offices; and

BE IT FURTHER RESOLVED that this resolution is binding City policy and supersedes the prior Green Building Policy (2001), 2005 update adopted by Resolution 35956, and 2009 update adopted by Resolution 36700.

Adopted by the Council: APR 22 2015

Mayor Charlie Hales

Prepared by: Alisa Kane

Date Prepared: March 21, 2015

Mary Hull Caballero
Auditor of the City of Portland

By Susan Parsons

Deputy

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Agenda No.
**RESOLUTION NO.** 37122 As Amended

Title

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|---|
| Implement a comprehensive update to the City ~~of Portland~~'s Green Building Policy to reflect advances in green building knowledge and practices (Resolution) |

| | |
|---|---|
| **INTRODUCED BY**<br>Commissioner/Auditor:<br>**Mayor Hales** | CLERK USE: DATE FILED APR 17 2015 |
| **COMMISSIONER APPROVAL** | Mary Hull Caballero<br>Auditor of the City of Portland |
| Mayor—Finance and Administration - Hales | |
| Position 1/Utilities - Fritz | |
| Position 2/Works - Fish | By: ______________________<br>Deputy |
| Position 3/Affairs - Saltzman | |
| Position 4/Safety - Novick | **ACTION TAKEN:** |
| **BUREAU APPROVAL** | |
| Bureau: BPS<br>Bureau Head: Susan Anderson<br>× Susan Anderson | |
| Prepared by: Alisa Kane<br>Date Prepared: 2/13/15 | |
| Impact Statement<br>Completed ☒ Amends Budget ☐ | |
| Portland Policy Document<br>If "Yes" requires City Policy paragraph stated in document.<br>Yes ☒ No ☐ | |
| **City Auditor Office Approval:**<br>required for Code Ordinances | |
| **City Attorney Approval:**<br>required for contract, code. easement, franchise, charter, Comp Plan | |
| **Council Meeting Date April 22, 2015** | |

| **AGENDA** |
|---|
| **TIME CERTAIN** ☒<br>**Start time: 9:30 a.m.**<br><br>**Total amount of time needed: 20 min**<br>**(for presentation, testimony and discussion)** |
| **CONSENT** ☐ |
| **REGULAR** ☐<br>**Total amount of time needed: ______**<br>**(for presentation, testimony and discussion)** |

| FOUR-FIFTHS AGENDA | COMMISSIONERS VOTED AS FOLLOWS: | YEAS | NAYS |
|---|---|---|---|
| 1. Fritz | 1. Fritz | ✓ | |
| 2. Fish | 2. Fish | ✓ | |
| 3. Saltzman | 3. Saltzman | ✓ | |
| 4. Novick | 4. Novick | ✓ | |
| Hales | Hales | ✓ | |

## Exhibit A: Green Building Policy for City-owned Facilities

### Background

Building construction, remodeling, and operation are major contributors to carbon emissions, air and water pollution, deforestation and other environmental and human health hazards. Green building practices provide design and construction strategies that mitigate these harmful consequences and conserve natural resources, improve efficiency and protect human health. Improving the performance of buildings, infrastructure and sites benefits the City and its residents. Green building saves the City money through increased operational efficiencies, supports local economic development, and strengthens established goals related to reducing carbon emissions and improving livability.

Decisions the City makes today about the design and construction of its buildings will impact the physical, environmental and social health of the community for many years to come. By using green building practices in the construction and operation of its own facilities, the City serves as a model for all development in Portland. This policy is expected to yield long-term savings by efficiently managing energy, water, waste and stormwater, and improving the health, comfort and productivity of building occupants.

### Policy intent

The City of Portland will incorporate green building practices into the design, construction, remodeling and operation of all City-owned facilities. The intent of these practices is to provide environmental benefits, create local jobs, improve occupant health, enhance employee productivity and generate lifecycle financial savings for the City and its community partners.

### Policy definitions, requirements and application

All City-owned projects will follow the policy requirements according to type of use, size and budget.

**City-owned projects** include work spaces and structures that the City designs, builds, owns, operates, maintains, or supports through loans, grants, and/or other financial benefit.

**Occupied spaces** are used predominantly for permanent offices, workspaces or recreation, and are heated and/or cooled for occupant comfort. Projects in occupied spaces will comply with Section 1.1. or 1.2 (relevant to their project budget and/or size) and Sections 2 through 6.

**Unoccupied spaces** include warehouses, parking garages, storage areas, maintenance areas and pump stations. Projects in unoccupied spaces will comply with Section 1.3 and Sections 2 through 6.

**Total construction budget** is the cost to achieve the project scope of work as defined in the contract documents, drawings and specifications. It includes trade permits and the 1.5 percent state requirement for solar. This cost is most often determined by a professional cost estimator or engineer.

**Section 1: Environmental performance requirements for new construction and major renovations**

**1.1 All new, <u>occupied</u> City-owned buildings over 20,000 square feet and/or with a total construction budget over $5 million will:**

A. Register and certify for the US Green Building Council's Leadership in Energy and Environmental Design (LEED) Building Design and Construction (BD+C) at the Gold level **and/or** achieve Living Building Challenge status.

B. Achieve 15 percent energy savings beyond the applicable Oregon Energy Efficiency Specialty Code.

C. Incorporate on-site renewable energy systems **and** meet the State of Oregon's 1.5 percent for Green Technology requirement.

D. Earn or meet LEED's advanced energy metering credit requirements to support ongoing energy monitoring and commissioning.

E. Earn or meet LEED's enhanced commissioning credits requirements.

F. Use native and/or non-invasive drought-tolerant plants, and use no potable water for irrigation, except for the first two years to establish plantings, or in cases of drought.

G. Select WaterSense-labeled products for all eligible fixtures to reduce total potable water use by at least 20 percent over the building's estimated baseline.

H. Cover the entire roof, minus skylights, mechanical systems, and fire and access routes, with an ecoroof. Exemptions to this requirement must be approved by the Commissioner-in-Charge of the bureau or office after completing the compliance check-sheet in Appendix A. Bureaus and offices are encouraged to consult with the Bureau of Environmental Services for technical assistance.

I. Incorporate stormwater management and related watershed enhancement strategies that support Salmon Safe certification during construction and after project completion.

J. Incorporate measures to reduce bird strikes and fatal light attraction, including treatment of exterior glass and glazed surfaces, lighting design, best management practices and other applicable measures as specified in Appendix B.

K. Provide or lease no more than the minimum auto parking required by code. In extraordinary circumstances, with written approval from the Bureau of Transportation, and with commitment to implement an approved Transportation Demand Management (TDM) Plan, additional on-site auto parking above code minimum may be provided. Additional auto parking shall be limited to the minimum shown in a parking demand analysis approved by the Bureau of Transportation. Extraordinary circumstances may include: visitors or employees arriving or departing a site when there is no transit service within ¼ mile of the site and there is insufficient on-street parking within ¼ mile of the site to meet projected demand. City fleet vehicle parking is exempt from this requirement.

L. Price auto parking for employees and visitors consistent with parking prices within one-quarter mile of the site.

M. Provide covered and secure bicycle parking for employees and visitors at an amount equal to the 25% mode share target in the City's Climate Action Plan unless and until replaced by mode share targets in the 2015 Transportation System Plan.

N. Pre-wire charging stations at the time of building and parking lot construction for City-owned electric vehicles where financially feasible and where vehicles will be parked on-site after the project is complete.

O. Follow construction waste prevention guidelines in Section 3.

P. Follow space allocation standards and space planning guidelines in Appendix C.

**1.2 All new, occupied City-owned buildings under 20,000 square feet and/or with a total construction budget under $5 million will:**

A. Register and certify for the US Green Building Council's Leadership in Energy and Environmental Design (LEED) Building Design and Construction (BD+C) at the Gold level **and/or** pursue Earth Advantage Commercial certification at the Gold level, **and/or** design, build and operate to achieve Living Building Challenge status.

B. Achieve 5 percent energy savings beyond the applicable Oregon Energy Efficiency Specialty Code.

C. Incorporate onsite renewable energy systems and/or meet the State of Oregon's 1.5 percent for Green Technology requirement.

D. Earn or meet LEED's commissioning credit requirements.

E. Use native and/or non-invasive drought-tolerant plants and use no potable water for irrigation, except for the first two years to establish plantings, or in cases of drought.

F. Select WaterSense-labeled products for all eligible fixtures to reduce potable water use.

G. Cover the entire roof, minus skylights, mechanical systems, and fire and access routes, with an ecoroof. Exemptions to this requirement must be approved by the Commissioner-in-Charge of the bureau or office after completing the compliance check-sheet in Appendix A. Bureaus and offices are encouraged to consult with the Bureau of Environmental Services for technical assistance.

H. Incorporate stormwater management and related watershed enhancement strategies that support Salmon Safe certification during construction and after project completion.

I. Incorporate measures to reduce bird strikes and fatal light attraction, including treatment of exterior glass and glazed surfaces, lighting design, best management practices, and other applicable measures as specified in Appendix B.

J. Provide or lease no more than the minimum auto parking required by code. In extraordinary circumstances, with written approval from the Bureau of Transportation, and with commitment to implement an approved Transportation Demand Management

(TDM) Plan, additional on-site auto parking above code minimum may be provided. Additional auto parking shall be limited to the minimum shown in a parking demand analysis approved by the Bureau of Transportation. Extraordinary circumstances may include: visitors or employees arriving or departing a site when there is no transit service within ¼ mile of the site and there is insufficient on-street parking within ¼ mile of the site to meet projected demand. City fleet vehicle parking is exempt from this requirement.

K. Price auto parking for employees and visitors consistent with parking prices within one-quarter mile of the site.

L. Provide covered and secure bicycle parking for employees and visitors at an amount equal to the 25% mode share target in the City's Climate Action Plan unless and until replaced by mode share targets in the 2015 Transportation System Plan.

M. Pre-wire charging stations at the time of building and parking lot construction for City-owned electric vehicles where financially feasible and where vehicles will be parked on-site after the project is complete.

N. Follow construction waste prevention guidelines in Section 3.

O. Follow space allocation standards and space planning guidelines in Appendix C.

**1.3 All new, <u>unoccupied</u> City-owned structures and facilities will:**

A. Select ENERGY STAR-labeled lighting and equipment to reduce energy use.

B. Incorporate on-site renewable energy systems and/or meet the State of Oregon's 1.5 percent for Green Technology requirement.

C. Use native and/or non-invasive drought-tolerant plants and use no potable water for irrigation, except for the first two years to establish plantings, or in cases of drought.

D. Select WaterSense-labeled products for all eligible fixtures to reduce potable water use.

E. Cover the entire roof, minus skylights, mechanical systems, and fire and access routes, with an ecoroof. Exemptions to this requirement must be approved by the Commissioner-in-Charge of the bureau or office after reviewing the compliance check-sheet in Appendix A. Bureaus and offices are encouraged to consult with the Bureau of Environmental Services for technical assistance.

F. Incorporate stormwater management and related watershed enhancement strategies that support Salmon Safe certification during construction and after project completion.

G. Incorporate measures to reduce bird strikes and fatal light attraction, including treatment of exterior glass and glazed surfaces, lighting design, best management practices, and other applicable measures as specified in Appendix B.

H. Provide or lease no more than the minimum auto parking required by code. In extraordinary circumstances, with written approval from the Bureau of Transportation, and with commitment to implement an approved Transportation Demand Management

(TDM) Plan, additional on-site auto parking above code minimum may be provided. Additional auto parking shall be limited to the minimum shown in a parking demand analysis approved by the Bureau of Transportation. Extraordinary circumstances may include: visitors or employees arriving or departing a site when there is no transit service within ¼ mile of the site and there is insufficient on-street parking within ¼ mile of the site to meet projected demand. City fleet vehicle parking is exempt from this requirement.

I. Price auto parking for employees and visitors consistent with parking prices within one-quarter mile of the site.

J. Provide covered and secure bicycle parking for employees and visitors at an amount equal to the 25% mode share target in the City's Climate Action Plan unless and until replaced by mode share targets in the 2015 Transportation System Plan.

K. Pre-wire charging stations at the time of building and parking lot construction for City-owned electric vehicles where financially feasible and where vehicles will be parked on-site after the project is complete.

L. Follow construction waste prevention guidelines in Section 3.

**Section 2: Environmental performance requirements for existing buildings, tenant improvements and leased spaces.**

2.1 All interior improvements to occupied, City-owned, City-leased, or leased out spaces will use the Bureau of Planning and Sustainability's guide to creating high-performance workspaces, or "Green TI Guide" **and/or** register and certify for LEED for Interior Design and Construction (ID+C) at the Silver level.

2.2 All occupied, City-owned existing buildings will register and certify for LEED for Building Operations and Maintenance (O+M) certification at the Silver level.

2.3 All bureaus and offices will use the most current version of LEED O+M to guide product and service specifications, and operations and maintenance best practices. Bureaus and offices will reference the standards or criteria in LEED O+M that support achievements in meeting related City sustainability policies and initiatives, such as sustainable procurement, energy and water efficiency, toxics use reduction, and waste reduction.

2.4 Bureaus and offices will implement Salmon-Safe recommendations, as they are developed, with the intent to become Salmon-Safe certified.

2.5 Roof replacements on all City-owned spaces will include an ecoroof to cover the entire roof, minus skylights, mechanical systems, and fire and access routes. Exemptions to this requirement must be approved by the Commissioner-in-Charge of the bureau or office after completing the compliance check-sheet in Appendix A. Bureaus and offices are encouraged to consult with the Bureau of Environmental Services for technical assistance.

2.6 Program staff and building managers will explore options to reduce hazards to birds when planning retrofits to existing City-owned buildings and facilities with practical and cost-effective solutions.

2.7 City bureaus and offices that lease out spaces in non-City owned buildings will give preference to locating in third-party certified green buildings.

2.8 Follow construction waste prevention guidelines in Section 3.

**Section 3: Construction waste prevention, preservation, restoration, salvage, reuse and recycling**

3.1 To meet the City's 85 percent waste diversion goal, all construction and tenant improvement projects will employ the following waste management hierarchy throughout each project:

A. Salvage and Reuse. Materials suitable for reuse will be reused on-site, transferred, sold, or donated in accordance with City Code 5.36.

B. Recycle.
1. Where project site space allows, projects will have separated, single stream recycling for metal, unpainted scrap drywall, wood, cardboard, land-clearing debris and inert materials (asphalt, brick, concrete). Recycling containers or designated areas should be clearly labeled to indicate acceptable materials.
2. Where project site space does not allow for separated, single stream recycling, applicable construction debris recyclables will be comingled for recycling. Comingled materials must be delivered to a Metro-authorized material recovery facility (MRF) for processing prior to disposal.

C. Landfill or Hazardous Waste Disposal. Construction waste not suitable for reuse or recycling will be landfilled or disposed of as hazardous waste according to applicable laws.

3.2 City projects considering full or partial demolition will use the following hierarchy of salvage and reuse strategies. Bureaus and offices will determine which strategy to use based on the volume and quality of the reusable and salvageable materials available from the project. Bureaus and offices are encouraged to consult with the Bureau of Planning and Sustainability for technical assistance.

A. Preservation or Relocation. As applicable, determine if it is cost-effective to adapt and preserve or relocate a structure in lieu of demolition.

B. Full Deconstruction. Fully disassemble the building for the purposes of maximizing the reuse potential of both structural and non-structural materials.

C. Hybrid Deconstruction. Combine the use of heavy machinery and manual labor for deconstruction, with the goal of maximizing the reuse and recycling potential of materials.

D. Non-Structural Salvage. Reclaim reusable non-structural components such as appliances, doors, windows, and finish materials. Follow traditional demolition practices after non-structural salvage is complete.

**Section 4: Historic buildings and structures**

4.1 Exterior changes to City-owned historic buildings and structures will follow City regulations for properties that are designated historic or conservation landmarks, in historic or conservation districts, or listed in Portland's Historic Resource Inventory.

4.2 For projects involving City-owned buildings over 50 years old not designated as historic or conservation resources, and that include removal, demolition, improvement, or alteration, the Historic Landmarks Commission should be consulted. The Portland Historic Landmarks Commission may be consulted via a discussion with Bureau of Development Services staff or at a regularly-scheduled Landmarks Commission meeting.

4.3 Interior changes to City-owned historic buildings and structures are not regulated by historic review. However, impact of alterations to potentially character-defining historic features and materials will be considered, and the Landmarks Commission should be consulted for advice on minimizing adverse impacts. The Portland Historic Landmarks Commission may be consulted via a discussion with Bureau of Development Services staff or at a regularly-scheduled Landmarks Commission meeting.

**Section 5: Training, financing, technical assistance, reporting and policy updates**

5.1 The Bureau of Planning and Sustainability, with assistance from Procurement Services and other bureaus and offices, will identify green building training opportunities for project managers, operations and maintenance staff. All appropriate project managers, maintenance and operations staff will pursue green building training.

5.2 The City will pursue federal, state or local incentives to facilitate the implementation of the Green Building Policy when appropriate.

5.3 Project managers will seek technical assistance and resources from bureaus and offices with expertise in corresponding areas.

5.4 The Bureau of Planning and Sustainability will provide assistance to help all City bureaus and offices meet the requirements of this policy.

5.5 The Bureau of Planning and Sustainability will convene bureaus and offices to create and maintain a Citywide Policy Implementation Guide.

5.6 The Bureau of Planning and Sustainability will track policy implementation annually and will update the Green Building Policy every four years or as needed. Progress updates will be included in Sustainable City Government reports.

5.7 The Office of Management and Finance's Facilities Services will convene bureaus to share operations and maintenance best practices that support implementation of this policy.

## Section 6: Exemptions

6.1 Each bureau and office is responsible for incorporating this Green Building Policy into its projects, capital improvements, operations and maintenance, purchasing practices, and staff training. Projects that cannot meet the policy requirements due to size, function, or building and zoning regulations may request exemptions from the bureau or office's Commissioner-In-Charge, but will incorporate green building measures to the maximum extent possible.

## Appendix A — Ecoroof Information and Exemption Checksheet

### Background

Ecoroofs are living, breathing, vegetated roof systems that provide a sustainable alternative to conventional roofing. They are part of a growing worldwide effort to promote sustainable development and reduce the negative impacts from buildings on air, water, energy and the earth. Ecoroofs are used extensively in other countries, especially in Europe. Even though they are a relatively new approach to roofing in the U.S., they are catching on. Green Roofs for Healthy Cities estimates that in 2012 alone, more than 20 million square feet of ecoroof were constructed in the U.S. As of August 2014, there are 436 ecoroofs in Portland covering nearly one million square feet of rooftop and managing close to 23 million gallons of stormwater per year.

### Benefits

Ecoroofs provide a variety of environmental and human health benefits including:

- Reducing stormwater runoff peak flow and alleviating local stream flooding.
- Reducing impacts on aging and undersized sewer infrastructure.
- Reducing stormwater runoff temperature and pollutant loads.
- Extending the life of a roof to 40 years versus 20 years.
- Helping to cool urban areas.
- Insulating buildings and saving energy and money.
- Capturing and holding carbon and improving air quality.
- Providing habitat for insects and birds.
- Providing area for greenspaces, therapeutic gardens and roof top agriculture.
- Incorporating aesthetic features, art and nature.
- Creating new jobs and supporting local industry.
- Qualifying for LEED credits.
- Qualifying for stormwater fee discount.
- Qualifying for Portland Floor Area Ratio (FAR) bonus.

### Stormwater Management Manual Compliance

The Stormwater Management Manual (SWMM) requires new development to retain stormwater on-site as much as possible. An ecoroof is considered an impervious surface reduction approach. For new construction, an ecoroof that covers the entire structure means the project meets the SWMM and no further stormwater facility sizing calculations or other design considerations are needed.

### Costs and Benefits

When comparing the cost of an ecoroof to the cost of a conventional roof or an ENERGY STAR roof, you must determine the cost of the "green" portion of the roof. This portion includes a drainage layer, growing media and vegetation. Ecoroofs can cost more initially, but they can save money over the life of the roof. A cost/benefit analysis conducted by ECONorthwest for the Bureau of Environmental Service concluded that an ecoroof on a publically-owned structure begins to save money immediately. At year 20, the cost of the ecoroof breaks even. The Cost/Benefit Report is viewable at https://www.portlandoregon.gov/bes/article/261053.

Another study, conducted by ARUP for the United States General Accounting Office, found ecoroofs pay back in 6.2 years. The study is available at http://www.gsa.gov/portal/mediaId/158783/fileName/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.action.

Sometimes a building will require structural upgrades to be able to hold the added weight of an ecoroof. The structural upgrade may not be prohibitively expensive. For example, a new, five-story wood frame apartment building in the Pearl District was redesigned to have an ecoroof with an added structural cost of only $1.60 per square foot of roof area.

**Structural Capacity**
For re-roofing existing facilities, the range of structural improvements have varied widely. For example, no structural upgrades were required for the Portland Building ecoroof. Other existing buildings may require extensive structural upgrades, resulting in a prohibitively expensive ecoroof. You most likely will have to hire a qualified professional to get structural information about a building. This expertise is often required for seismic and other permit-related issues.

The Office of Management and Finance (OMF) prepared a report on several buildings evaluated for ecoroofs. View the document at http://www.portlandoregon.gov/bes/index.cfm?&a=287490

**Maintenance**
All roofs require maintenance. Ecoroofs need to be checked for trees and excess weeds in early summer. Depending on the design and plant material, an ecoroof may require irrigation for the first few years as the vegetation gets established. Proper design and operation of an ecoroof can minimize weeds. A maintenance plan will describe the routine maintenance that is needed to keep the ecoroof in excellent condition.

**Design**
It is best to design a new building that can hold the additional weight of an ecoroof. Even if an alternate roofing material is used initially, design and construct the building to hold an ecoroof since a building can easily be retrofitted with an ecoroof in the future.

If the facility has formal historic designation, then the Historic Landmarks Commission and/or design review may be required. Working on a designated historic building does not preclude using an ecoroof. If it is not desirable to see the ecoroof on an historic building, then it can be designed with low-growing vegetation that will not be visible from ground level.

**Red Cinder Design**
The Bureau of Environmental Services (BES) developed a design for a low-cost, low-maintenance ecoroof that requires little or no irrigation. This design uses red cinder rock as mulch to retain moisture in the soil during hot summer months and to suppress weed growth. Three of BES' pump stations have a red cinder ecoroof. These roofs have never been irrigated, and minimal weed pulling is the only maintenance that has been done. The design guidelines are online at https://www.portlandoregon.gov/bes/article/464519.

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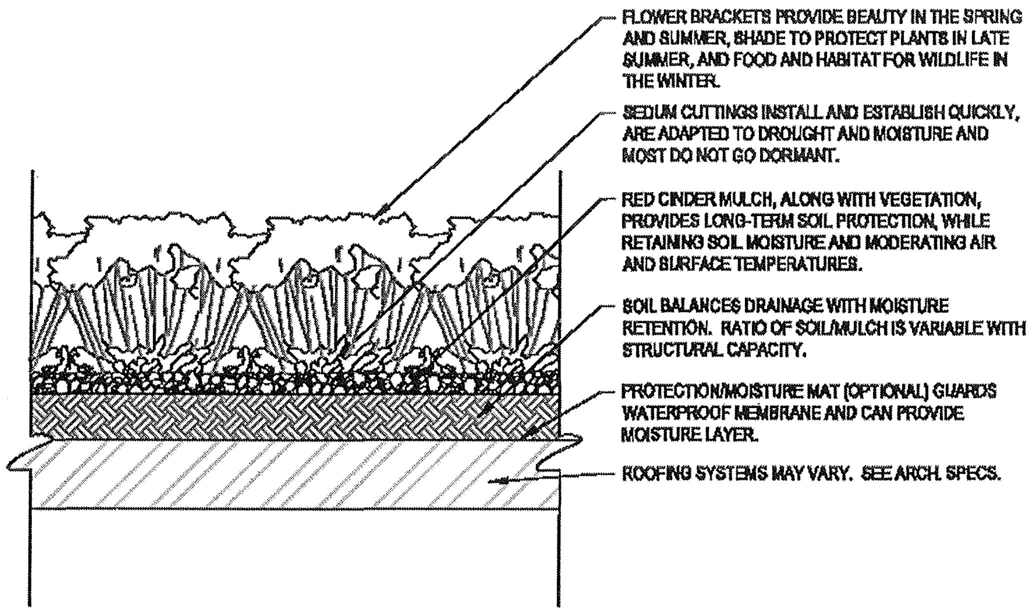


*Typical Cross Section of BES Red Cinder Ecoroof*

**Technical Assistance**

Many resources related to ecoroofs exist. Check the BES ecoroof web page at www.portlandoregon.gov/ecoroof for technical information and manuals, instructional videos, links to local and national research programs, websites, educational tools, and events. BES staff is available to help with your ecoroof project. Contact Amy Chomowicz at 3-5323, or amy.chomowicz@portlandoregon.gov.

**Ecoroof Exemption Checksheet**
The project manager must complete and sign this checksheet before designs are finalized to meet the intent of Green Building Policy. Please send a copy of this form to: BES Sustainable Stormwater Program 106/1000.

Project Name: ______________________________

Site Address: ______________________________

Project Manager name/title (City bureau/office): ______________________________

Project architect of record (firm): ______________________________

**Section I. Project Elements**

Building type (e.g. commercial, industrial, warehouse, pump station, residential)

Building area: ______________________

Ecoroof area: ______________________

Roof slope: ______________________

Is the ecoroof visible from the street? Yes ___ No ___

Are you using the red cinder design? Yes ___ No ___

Brief description of the project and/or the ecoroof:

______________________________________________________________

______________________________________________________________

For existing structures

Can the existing structure hold additional weight? If yes, how much? ____________

If the building needs to be upgraded to hold additional weight, what is the cost of the upgrade?

______________________________________________________________

**Section II.**
Please complete the following section to determine if your project is exempt from having an ecoroof.

New construction:
- ☐ Project roof is less than 500 sf
- ☐ The project is single family residential, or, if multi-family, has fewer than 4 units
- ☐ The roof slope is greater than a 5 x 12 pitch (22 degrees)

For existing structures:

- ☐ Project roof is less than 500 sf
- ☐ The project is single family residential, or, if multi-family, has fewer than 4 units
- ☐ The roof slope is more than a 5 x 12 pitch (22 degrees)
- ☐ The existing structure cannot hold additional weight, and/or the cost of structural upgrades is excessive

If one or more boxes in Section II are checked, then the project is encouraged, but not required, to have an ecoroof. If requesting an exemption, have the bureau or office director and Commissioner in Charge sign here:

Signatures:

| | |
|---|---|
| ______________________ | ______________________ |
| Bureau/Office Director | Date |
| ______________________ | ______________________ |
| Commissioner in Charge | Date |

## Appendix B — Bird-friendly Building Design and Management Practices Checksheet

**Background**
Portland sits on the Pacific Flyway, a major north-south flight route extending from Alaska to South America. The City is home or a critical stopping point for more than 200 species of birds. Many of these bird species are in decline due to multiple risk factors. Structural hazards are a primary threat to both resident and migratory birds, ranked second as a mortality factor after habitat destruction. It is estimated that between about 500 million to 900 million birds die each year from window strikes in the United States alone. The Audubon Society of Portland has conducted studies documenting that bird collisions kill a diverse array of bird species in the city, including species in decline.

In 2003 the U.S. Fish and Wildlife Service selected the City of Portland as a pilot project city for the Urban Conservation Treaty for Migratory Birds Program, which included a focus on reducing hazards to migratory birds. Portland has since developed a Bird Agenda that recommends mitigation efforts, including bird-friendly building guidelines. In partnership with Audubon, the U.S. Fish and Wildlife Service and the American Bird Conservancy, the City has sponsored the development of Resource Guide for Bird-Friendly Building Design for Portland. The Resource Guide includes extensive recommendations to reduce the risk of bird mortality from collisions with buildings and fatal light attraction. It also notes that there are opportunities to increase energy efficiency and help meet LEED certification requirements by incorporating bird-friendly design approaches. And the Resource Guide provides information about other cities, including Chicago, San Francisco, Toronto and New York, which have adopted regulatory and/or voluntary bird-friendly building guidelines and Lights Out programs.

In October 2013 the City Council adopted Resolution 37034 directing City bureaus and offices to explore opportunities to integrate Bird-Friendly Building Design into the City policies, plans, and programs, including updates to Portland's Comprehensive Plan, Central City Plan, and the City's Green Building Policy.

**Goals of the policy include:**

1. Reduce bird collisions with buildings and other structures, and avoid construction-related impacts on nesting birds.

2. Carry out City Council direction to advance bird-friendly building design and building management practices through City plans and policies, including the Green Building Policy (Resolution 37034, October 2, 2013).

3. Demonstrate leadership and join other progressive cities in adopting bird-friendly design guidelines.

4. Apply the principles and tools of the Resource Guide for Bird-friendly Building Design, Portland Oregon, First Edition, July 2012, and Guidance: Avoiding Impacts on Nesting Birds during Construction and Revegetation Projects, Version 2 October 2010, to City sponsored projects.

5. Build awareness of bird collision risks and options to reduce them, as well as ways to avoid liability under the Migratory Bird Treaty Act.

6. Support market development for bird-friendly building and lighting materials.

The Bird-Friendly Building Design Checksheet is intended to:

- Reflect accepted tools and practices to reduce risks of bird collision.
- Be clear and simple to implement.
- Be relevant and applicable to the project scale, design, location and feature-specific hazards.
- Provide opportunities to meet multiple project-related requirements and design/performance objectives (e.g., energy efficiency).
- Support other City goals.

The project manager and project architect of record must complete and sign this checksheet to meet the intent of Green Building Policy. Completed checksheets must be retained in the project file.

Project name: ______________________________

Site address: ______________________________

Project manager name/City bureau/office: ______________________________

Project architect of record (firm): ______________________________

**Applicability**
Please complete sections I and II below to determine if the bird-friendly building design measures outlined in the remainder of the checksheet are required for your project.

**I. Project scale and key project elements**. (check all that apply)

- ☐ The project includes one or more structures with a footprint of more than 500 square feet
- ☐ The project includes one or more monopole structure
- ☐ The project includes one or more wind energy facilities

**NOTE: If NO boxes in section I are checked, the measures outlined in this appendix are encouraged but are not required to meet the policy. You may sign the checksheet at the end of Appendix B.**

II. **LEED Pilot Credit 55.** Projects qualifying for the LEED Pilot Credit 55: Bird Collision Deterrence meet the policy.

**If this project will qualify for LEED Pilot Credit 55, please check the box below and sign the checksheet at the end of Appendix B with LEED Pilot Credit 55 documentation.**

- ☐ This project is being designed to qualify for the LEED Pilot Credit 55, Bird Collision Deterrence.

**Bird-friendly Building Design and Management Practices – Checksheet**

**Required measures**

A. **Window Treatments** (check at least one box as instructed below)
This section applies to projects with at least 10 percent exterior glass, sky-bridges or atriums with exterior glazing, or glass railings.

To reduce reflectivity and make exterior glass visible to birds, apply at least one of the following treatments to at least 90 percent of new windows or other exterior glass i) between the ground and 60 feet above the ground, and ii) for one story above a vegetated roof. This section is not required for single family residential homes. For non-single family residential projects with less than 50 percent exterior glass this section applies only to exterior glass on the ground floor and to the first story above a vegetated roof.

**If project does not meet these criteria write NA here ___**

- ☐ Non reflective, opaque or translucent glass
- ☐ Glass that reflects ultraviolet light (which birds can see), such as Ornilux.
- ☐ Glass that has photovoltaic cells embedded, such as IQ Glass or Voltalux.
- ☐ Application of patterns (e.g., dots, stripes, images, abstract patterns) to exterior (first outside facing) glass surfaces. Patterns may be etched, fritted or in films. Spaces between pattern elements must be no more than two inches horizontally and four inches vertically, or both, i.e. patterns must conform to the "two by four" rule.
- ☐ External screens, decorative grills, screens, netting, louvers, shutters or exterior shades placed as close to the outside glass surfaces as possible, with openings that meet the "two by four" rule.

B. **Reducing Light Attractants** (all measures apply unless not applicable — check each box or write NA on the box)

- ☐ Minimize exterior lighting.
- ☐ No up-lighting or light beams.
- ☐ Install full cut off, shielded, or directional lighting to minimize light spillage, glare, or light trespass.
- ☐ Install time switch control devices, occupancy sensors, or non-emergency interior lights that can be programmed to turn off during non-work hours or otherwise designated hours.

C. **Use best available science to select light intensity, color, and flash frequencies that reduce bird hazard if complying with federal aviation safety requirements.**
If applicable, describe: ________________________________________

**Additions or exterior alterations to existing development**, may comply with section A. or B. above by retrofitting existing windows or light fixtures if to do so will more effectively reduce hazards to birds. If retrofit is selected, describe proposal and rationale here:

D. **Additional measures** (check the box on each line or write NA on the box)

- ☐ Mirrored glass, exterior mirrors or mirroring materials are not allowed in building or landscape design.
- ☐ Minimize the number and co-locate rooftop antennas and other rooftop structures.
- ☐ Wind generators must appear solid when in motion.
- ☐ Tower structures must not include guy wires.
- ☐ Bird attractants (exterior/interior landscaped areas, vegetated roofs, water features) may not be placed where they could be reflected in, or be viewed through, exterior glass unless the glass incorporates bird-friendly treatments (see Section A above).

E. **Avoid adversely affecting nesting birds** (required per federal Migratory Bird Treaty Act) (check the box)

- ☐ Schedule timing construction-related activities (e.g., vegetation removal, site preparation, demolition) and other steps as suggested in the BES Terrestrial Ecology Enhancement Strategy Guidance.

Description (optional):

---

**Best Management Practices** (optional and encouraged – check all that apply)
The following BMPs are intended to promote bird safety through construction practices and building operation/site and management.

- ☐ Extinguish nighttime non-security architectural illumination treatments during the spring (February 15 to May 31) and fall (August 15 to November 30) bird migration periods.
- ☐ Distribute educational materials on bird-friendly practices to building managers and occupants.
- ☐ Install interior blinds, shades or other window coverings in windows with clear glass on the ground floor, visible from the exterior, as part of the construction project contract, lease agreement or CC&Rs.
- ☐ Install exterior screens on windows that open in residential projects.
- ☐ Request employees to turn off task lighting at work stations and draw office window coverings at end of the day.
- ☐ Schedule maintenance activities to occur during the day, or conclude before 11 p.m. if possible, and avoid maintenance activities that could cause disturbance during nesting seasons.

**Authorized Signatures for Appendix B - Bird-friendly Building Design and Management Practices Checksheet**

The signed and dated checksheet must be kept on record in the project file.

**Project manager**

____________________________________________________
Print name and City bureau/office

____________________________________________________
Project manager signature date

**Project architect of record**

____________________________________________________
Print name and firm

____________________________________________________
Project manager signature date

## Appendix C — Space Allocation Standards and Space Planning Guidelines

### Space Allocation Standards

Space Allocation Standards are a tool to assist the City in making better decisions about effective and efficient planning of their office needs. These guidelines support the implementation of green building strategies used by third-party certifications such as LEED and Earth Advantage. These standards aim to use space more efficiently – saving costs, reducing energy and allowing for material reuse. The standards also promote indoor environmental health by improving ventilation and retaining access to views and daylight. These standards are designed to help develop a flexible work environment that is able to respond to change, meet the needs of employees and the public, enhance communication, and improve efficiency and productivity.

There is supportable evidence that the implementation of proposed space allocation standards, based on industry best practices for both private and government organizations, can provide the City sufficient office space for the next five years in City-owned buildings.

The proposed allocation standards do not change in size from the existing standards, but further definition is provided to assist in consistent implementation. In addition, guidelines for space planning are also provided.

| Workstation type | Dimensions | Total square footage | Notes |
|---|---|---|---|
| Private Office – Director | 20x12 | 240 sf | |
| Private Office – Manager | 10x12 | 120 sf | |
| Open Workstation – Standard | 8x8 | 64 sf | |
| Open Workstation – Large | 8x10 | 80 sf | For supervisors and managers |
| Open Workstation – Small | 6x6 | 36 sf | Configured for inspectors, interns, and other "fly-in" uses |
| Conference Room – Director (dedicated) | Varies | Greater than 240 sf | |
| X-Large Conference (shared) | 28-40 person | Varies | |
| Large Conference Room | 20-24 person | Greater than 240 sf | |
| Medium Conference Room | 12-16 person | 240 sf | |
| Small Conference Room | 4-6 person | 120 sf | |

The space allocation workspace standards should be considered a maximum space allowance.

## Space Planning Guidelines

### General

- Limit full height walls; provide open flexible areas for efficiency.
- Private offices, Storage, Copy Rooms, Lactation Rooms, Equipment Rooms, Training Rooms, Interview Rooms, and other rooms with full-height walls are located in the building center or core.
- Modular sizes allow future flexibility – private offices and conference/support spaces are interchangeable over time.
- **Lunchroom/Breakroom** – provide one lunchroom for each floor of office space.
- **Lactation Room** – provide one lactation room for each Bureau and or one for every two floors (preferably for each floor of office space).
- **Copy Room(s)** – provide enclosed ventilated room in the building core on each office floor.
- **Special Program Requirements** – consider best location; group similar functions as possible (Locker Rooms, Showers, Exercise Rooms); full-height walls are located in the building center or core.

### Private Offices

- Director Office – located at building core; dedicated Bureau Conference Room – located adjacent to Director Office at building core.
- Manager Office - located at the building core; private office provided for managers who are responsible for work of a sensitive nature on a daily basis including personnel, legal and other confidential issues.

### Open Office Areas

- When possible, locate filing/equipment adjacent to building core.
- Standard open office workstation design is based on 8'x8' module.
- 8'x8' module can accommodate a number of different workstation layouts for both focused individual workspaces and open collaborative workspace.
- 8'x8' modules can be arranged in groups of 4, 6, and 8 for best circulation.
- Workstation groups are planned so that views to the exterior are possible from main circulation aisles for all; secondary circulation is 90 degrees to the exterior walls.
- Open office workstations are located in open areas with access to exterior windows.
- Workstations must be planned to allow 3' minimum circulation space along the exterior window walls.
- Panel heights to be no higher than 54". If higher panels are needed, consider sections above 54" to be transparent/translucent.

## Implementation

Office of Management and Finance Facilities Services is tasked with overseeing the implementation of a Space Master Plan. It is their responsibility to attempt to achieve a balance between agency program needs, and efficient effective design solutions. Further, it is their responsibility to promote equity between bureaus in the utilization and quality of space.

Standards do not entitle employees to specific workstation sizes but rather it is a method for determining the overall requirements of a group and for determining how the space should be allocated. Actual individual workspace allocations are based on functional space requirements, the priorities of the organization and the total space within the budget which is available.

## Exceptions

These proposed Office Space Standards are guidelines, and it is recognized that there will be exceptions, and that there will be specific program requirements which are not addressed in the standards.

To request exceptions from the Space Allocation Standards, the organization should document the requirements for space in excess of the standard using specific Bureau mission requirements. Benchmarking with other organizations performing similar functions to ensure the allocation of space requested is encouraged.

Requests for exceptions should first be reviewed and approved by the affected Manager or Director, and then should be submitted in writing to Facilities Services. Facilities Services will review the request in light of the overall City Space Master Plan.

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*Review*

# Landscape, Legal, and Biodiversity Threats that Windows Pose to Birds: A Review of an Important Conservation Issue

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**Abstract:** Windows in human residential and commercial structures in urban, suburban, and rural landscapes contribute to the deaths of billions of birds worldwide. International treaties, federal, provincial, state, and municipal laws exist to reduce human-associated avian mortality, but are most often not enforced for bird kills resulting from window strikes. As an additive, compared to a compensatory mortality factor, window collisions pose threats to the sustainability and overall population health of common as well as species of special concern. Several solutions to address the window hazard for birds exist, but the most innovative and promising need encouragement and support to market, manufacture, and implement.

**Keywords:** bird-window collisions; collision prevention; building and landscape architecture; conservation

## 1. Introduction

Clear and reflective windows in human structures of all sizes in urban, suburban, and rural settings are unintentionally killing vast numbers of birds the world over [1–3]. The annual toll of bird deaths from striking windows range from 100 million to 1 billion (latest quantitative estimate based on available data is 365–988 million) in the United States (U.S.), from 16 to 42 million in Canada [4–7]. Forty years of detailed observation and experimentation reveal that birds behave as if sheet glass and plastic are invisible to them [4,8,9]. Birds strike clear panes while attempting to reach habitat seen through corridors (linkways) or where windows join in the corner or are oriented one behind the other to create an illusion of a passageway through a dwelling. In addition, for installed clear, as well as tinted, panes light levels are most often lower inside a room than outside, which creates a reflection of the facing habitat and sky that deceives a flying bird who attempts to reach it. Birds kill themselves flying into windows of all sizes, buildings of different shapes and sizes, throughout the day and seasons of the year, and during all types of weather conditions. Fatal strikes are possible wherever birds and windows coexist.

For their aesthetic, recreation, and scientific value and utility birds are admired and studied by people everywhere. Because windows are a lethal threat to birds and are a result of human construction, we must accept the responsibility to protect this exquisitely useful natural resource for future generations. Clearly, the dead and dying resulting from bird-window collisions are unwanted and unintended. However, no reasonable person would likely argue for a windowless world to protect birds, and I have never advocated for using less glass in human residential or commercial buildings. What I have strongly and consistently advocated for is making all sheet glass and plastic exposed to the environment safe for birds. The short-term means of doing so requires the retrofitting of existing windows; the long-term solution is bird-safe sheet glass and plastic specifically manufactured for remodeling and new construction. Relying on encouraging people to voluntarily implement short and long-term measures to protect birds from windows is a monumental struggle with only limited success. Iconic historic federal bird protection laws and recent legislation at local, state, and provincial levels have addressed protecting birds from windows; these acts in turn have effectively incited action among building professionals and conservationists to make windows safe for birds. At least one law firm dedicated to environmental protection in Canada has brought suit against building managers who have a long standing record of overseeing buildings at which birds have been consistently killed, year after year, fatalities that are foreseeable and preventable given current knowledge and the availability of practical solutions. Universally changing building codes to require the use of bird safe glass and plastic will ensure the future protection of wild bird life in the human built environment. Like other measures enacted to ensure a healthier environment for all life, such as prohibiting the use of the pesticide DDT in North America or substituting unleaded for leaded gasoline, requiring bird safe windows will not prove to be cost prohibitive given their value for saving countless innocent bird lives that in turn provide utilitarian and aesthetic services to humans. What follows is a brief review of the landscape, legal, and avian biodiversity threats that windows pose to birds and how to effectively address them.

## 2. Discussion

Because birds behave as if windows are invisible to them the best predictor of what species are killed, at what location, in what numbers, depends on the density of individuals in the immediate vicinity of the lethal hazard. Various landscape features can influence the density of birds near windows, such as location of a dwelling, the amount of glass exposed to the environment, the immediate and surrounding vegetation, the presence of water as an attractant, and artificial lighting conditions.

All species may be potentially vulnerable to window strikes, but past and current studies clearly reveal that not all species have been documented as window strike casualties [6–12]. Ruffed grouse (*Bonasa umbellus*, American woodcock (*Scolopax minor*), *Accipiter* hawks, hummingbirds, *Catharus* and *Hylocichla* thrushes, and ovenbird (*Seiurus aurocapilla*) are suspected to be deceived by clear and reflective panes more often because of their habits of swiftly flying through restricted passageways through dense vegetation [8,9,13,14]. Tropical hermit hummingbirds (*Phaethornis* spp.) are thought to be especially susceptible to window collisions because of their habit of traplining [15]. Predators and their pursued prey often become collision victims when raptors hunt near windows [8,9,16,17]; collisions occur when predator is engage in a concentrated chase following prey performing erratic evasive flights, frequently but not exclusively at feeding stations near windows. American robin (*Turdus migratorius*) and cedar waxwing (*Bombycilla cedrorum*) are suspected to be more vulnerable to flying into windows after becoming intoxicated on fermented fruits [8,9,18]; accounts indicate that birds behave similar to humans when under the influence of alcohol and as such those that "drink" and fly are apt to be more vulnerable than those that do not. Addressing differential species vulnerability to windows, recent detailed studies have found North American and Neotropical migrants, those flying long distances or at night, to be killed more often than diurnal migrants or non-migratory residents [6,7,10–12]. Those species known to occur in large numbers around buildings, especially in urban areas, such as rock pigeon (*Columba livia*), European starling (*Sturnus vulgaris*), and house sparrow (*Passer domesticus*) are known collision casualties [3,8], but at most study sites they have been recorded infrequently or not at all as window fatalities [6–12]. This seeming immunity to windows is likely the result of their behavior flying to perches such as sills and ivy or other vegetation that are near glass surfaces where, like feeders close to windows, if they strike the glass they do so with a force below which is needed to injure or kill themselves, but enough to learn to avoid the space thereafter [3,19]. Resident northern cardinals (*Cardinalis cardinalis*) may similarly gain protection when discovering their reflected image and responding to it as a rival in their territory [3,8,11,12]. Hager and his colleagues reported little or no support for bird density near windows explaining the species and number of fatal strikes at the buildings they studied [11,12]. Their measure of density included counting the number of birds within 50 or less meters from the windows they monitored, but density is a meaningful explanation of the number of strikes if measured within 10 or less meters of a window surface, a vulnerable contact zone, where individuals of any species can be deceived attempting to reach habitat seen behind clear or reflected in mirrored panes. Although clear and reflective glass may be invisible to birds, the results of recent experiments reveal that alterations to the outside surface of windows, even with clear external films, offer enough visual cues to reduce the risk of a strike by 59% or more [20,21].

If birds are a welcome addition around human dwellings, it is imperative to transform windows into barriers that birds will see and avoid rather than modifying landscape features to reduce their presence.

The vertebrate eye, and among them, the bird eye even with its astounding abilities, in many ways greater than human vision is most likely not capable of seeing clear and reflective windows. I interpret what we know about avian vision and behavior to conclude that clear and reflective sheet glass is an indiscriminate killer, taking the fittest as well as the less fit members of species populations. Notwithstanding claims that window collisions represent a compensatory mortality factor for bird populations in general [10,22,23], the inability of any individual of a species to see clear and reflective glass as a barrier to be avoided is reasonable justification to believe all individuals of a population are potentially vulnerable. Therefore, I interpret avian mortality resulting from collisions with clear and reflective windows to be an addition to the more expected compensatory factors of disease, predation, starvation, adverse weather, and others. The consequence of this type of attrition is that it is potentially damaging to the health of the abundant as well as species of conservation concern.

We have the means to protect birds by using retrofit methods on existing windows, and a growing number of novel panes prepared for remodeling and new construction. Most preventive techniques currently available are unacceptable to most homeowners and building managers because of aesthetics, practical application, and cost. Nevertheless, an increasing number of preventive methods are finding acceptance because of more effective education which in turn incites volunteerism or through the threat of legal action for inaction.

### *2.1. Landscape*

Windows the size of a few centimeters (cm) like those in garage doors to those covering and making up entire walls of multi-story buildings are known to kill birds. But just as the density of individual birds in the vicinity of windows increases the chance of a fatal strike, the more glass surface the greater probability of providing an illusion resulting in a strike [7,8]. Attractants such as immediate and surrounding vegetation that guide birds to the vicinity of windows, water containers, baths, or impoundments, and bird feeders contribute to increasing fatalities because of greater numbers of individuals in the immediate vicinity of the hazard [6,7,12,24–26].

Hager and his colleagues [12] found bird kills at windows in an urban environment were related positively to window area and negatively to development. They reported that season of the year, development, and distance to vegetation best explained the number of birds killed at windows. They concluded that patchy environmental resources and the amount of window area create special variation in window mortality in an urban setting; finding that more birds are killed when attracted to vegetation that offers cover and food near buildings with greater glass facades.

The types of human dwellings account for a disproportionate amount of mortality [6,7]. Both Canadian and U.S. studies attribute most annual avian morality at windows occurred in residences (1–3 stories), in low-rise buildings (4–11 stories), and at high-rise buildings (equal or greater than 12 stories); 44% at residences, 56% at low-rises, and <1% at high rises. The amount of mortality at each building type is the consequence of relative representation in the environment; larger more dramatic kills occur at high rise urban skyscrapers, but these multi-story structures are few compared to large numbers of single residence dwellings and low rise commercial buildings.

### *2.2. Legal*

At the federal level in the U.S. the International Migratory Bird Treaty Act (MBTA) of 1918 and the Endangered Species Act (ESA) of 1973, as respectively amended, potentially can be powerful tools to protect birds from windows. Although unintentionally killing a single individual wild bird is theoretically cause for legal action under the MBTA, it seems unreasonable to enforce when every human dwelling containing windows are likely violators. Moreover, given the original purpose of the MBTA to protect over exploitation of birds from the millinery trade, some legal professionals believe that using the MBTA to protect birds from windows may limit rather than enhance environmental protection in general. The ESA is restricted to listed endangered species such as the plain pigeon (*Patagionenas inorata*) and Kirtland's warbler (*Setophaga kirtlandii*) that are known window victims. The results of recent studies have supported and reinforced the potential risk windows pose to species of conservation concern in North America, and by inference worldwide [6,7]. The U.S. General

Services Administration (GSA) is mandated to use sustainable designs in new federal construction, and in so doing plan to incorporate bird-safe features in their structures. An introduced U.S. House of Representative bill titled Federal Bird-Safe Building Act would require all new federal buildings to be built bird-safe remains under consideration. In Canada, the Species at Risk Act and the Ontario Environmental Protection Act have been used in the courts to protect birds from windows. Among a few others, bird-safe window practices have been implemented in the cities of Minneapolis, Oakland, and Toronto. In Toronto, the non-profit environmental law firm Ecojustice brought suit against the building managers Cadillac Fairview under their Species at Risk Act and the provincial law Ontario Environmental Protection Act. The outcome of the case is interpreted as an environmental success because the courts established reflected light radiation to be responsible for creating an illusion that takes the lives of protected birds. The judge dismissed the case against Cadillac Fairview because they showed due diligence in retrofitting their offending windows with external film to mitigate continued bird casualties. The environmental victory is interpreted from the expectation that other building managers will institute bird-safe practices to prevent their properties from being the target of future litigation. Clearly, the use of the legal system is a far more powerful means of stimulating action to protect birds from windows than relying on the voluntary efforts of the many constituencies involved in this important conservation issue for birds and people; among them are the building professionals that include glass manufacturers, architects, developers, building managers, landscape designers, and the conservation community that include government law enforcement, research scientists, and the legion of conservation advocate organizations. Over the long term, to stimulate the creation of new products to retrofit existing buildings and produce novel panes for remodeling and new construction, the introduction, enactment, and enforcement of federal legislation requiring windows be made safe for birds is an ambitious, worthy, and justified goal to protect this useful and valuable natural resource.

### *2.3. Biodiversity*

A survey of North American museums and select individuals has documented 267 (28%) of the 947 species occurring in the continental U.S. and Canada to be window casualties [27]. From additional systematic surveys and contacting select knowledgeable individuals, my records document 868 (9%) of the approximately 10,000 bird species known to be window strike casualties worldwide [3,28]. Window strike victims of conservation concern appearing on the National Audubon Society 2007 WatchList for the U.S. are 6 (9%) of the 67 species on their Red List, 24 (26%) of 94 species on their Yellow List [3]. Red List species are declining rapidly and are of global conservation concern. Yellow List species are declining but at a slower rate and are of national conservation concern. In addition, those species on formal lists of conservation concern, Loss and his colleagues [7] found the following species with declining populations to be especially vulnerable to windows in the U.S.: golden-winged warbler (*Vermivora chrysoptera*), painted bunting (*Passerina ciris*), Canada warbler (*Cardellina canadensis*), wood thrush (*Hylocichla mustelina*), Kentucky warbler (*Geothlypis formosa*), and worm-eating warbler (*Helmitheros vermivorum*).

To my knowledge the only bird species currently known to be adversely affected by window strike mortality at the population level is the swift parrot (*Lathamus discolor*) of Australia, a world threatened species; in 2006 Raymond Brereton (personal communication), Manager of the Swift Parrot

Recovery Program for Parks and Wildlife Service of the State of Tasmania, stated that 1.5% of the 1000 breeding pair population annually succumbing to window collisions [1–3,29]. Documented window casualties and their respective international conservation designations included the following: Critically Endangered—Townsend's shearwater (*Puffinus auricularis*), yellow-crested cockatoo (*Cacatua suphurea*); Endangered—swift parrot and eastern bristlebird (*Dasyornis brachypterus*); Vulnerable—Gould's petrel (*Pterodroma leucoptera*), cape gannet (*Morus capensis*), superb parrot (*Polytelis swainsonii*), cerulean warbler (*Setophaga cerulea*), marsh grassbird (*Megalurus pryeri*); Near Threatened—northern bobwhite (*Colinus virginianus*), copper pheasant (*Syrmaticus soemmerringii*), oriental darter (*Anhinga melanogaster*), black rail (*Laterallus jamaicensis*), bush thick-knee (*Burhinus grallarius*), plain pigeon, whistling green-pigeon (*Treron formosae*), New Zealand pigeon (*Hemiphaga novaseelandiae*), red-headed woodpecker (*Melanerpes erthrocephalus*), olive-sided flycatcher (*Contopus cooperi*), Bell's vireo (*Vireo bellii*), flame robin (*Petroica phoenicea*), diamond firetail (*Stagonopleura guttata*), golden-winged warbler, Kirtland's warbler, Brewer's sparrow (*Spizella breweri*), and painted bunting [3]. Historically conservationist have reminded all who will listen that the time to save a species is when it is abundant, not when it is on the brink of extinction or experiencing troubling declines as all currently designated species of special concern are doing. Given the indiscriminate killing of individuals at all levels of health in species populations, windows adding to natural compensatory attrition can potentially place common as well as species of concern at risk. The biodiversity of the planet is irreparably harmed when a species becomes extinct; the loss or threat of loss of birds as integral parts in the world ecosystems and as useful indicators of environmental health would be devastating. The scale of avian loss from window collisions makes addressing this human-associated mortality factor imperative; to be responsible stewards of the earth humans ideally must eliminate and minimally mitigate the killing of birds at the windows we install in our dwellings, residential and commercial structures that are increasing exponentially over the entire globe as humans increase and eventually spread across every avian breeding and non-breeding areas, and migratory routes.

### *2.4. Prevention*

Architecturally designing the surface of buildings to make their glass more visible to birds is fundamental to reducing bird-window collision mortalities, and the American Bird Conservancy (ABC) has offered several examples to encourage bird-friendly building design [30]. Bird-friendly building guidelines addressing building location, landscaping, lighting, and bird-window collision prevention have been prepared for the state of Minnesota, cities of Calgary, New York, and Toronto [31–34], which have in turn stimulated briefer but meaningful recommendations for, among others, Baltimore, Chicago, and San Francisco. A structural design that has proven to protect birds by deflecting the force with which the bird strikes the pane is angling windows inward by 20 to 40 degrees; the greater the angle the greater the protection [19]. At those sites where feeders are used to attract birds, placing the feeder within less than one meter protects visitors by limiting the ability of a bird to build up enough momentum to injure or kill itself hitting a nearby window [19]. A number of alternatives are available to retrofit existing windows to protect birds, but most require tolerating some limited interference looking out a treated pane from inside a dwelling. Tapes, strings, netting, and conventional window screening are effective for residential homes. In addition to these options, one-way external films successfully have been used on residential and commercial buildings. These methods and other background information on the general threats windows pose to birds are available at Acopian Bird Savers, ABC, Chicago Ornithological Society, CollidEscape, and Fatal Light Awareness Program (FLAP) websites [35–40].

Few sheet glass products are currently available specifically to prevent bird-window collisions for remodeling and new construction. Those that have been effective also limit viewing, but for those committed to protecting innocent potential victims the obstructed view is acceptable. Line and dot patterns that uniformly cover the entire pane and are applied in the form of ceramic frit or etching to surface #1 (facing outside environment) of a single or multi-pane window are most effective; they are less effective if applied to inner surfaces [20,21]. To completely eliminate collisions the dot and line patterns must be separated at most by 5 cm if oriented in horizontal rows, or 10 cm if oriented in vertical columns [4].

I have repeatedly described the most elegant solution to be one that transforms windows into barriers that birds see and humans do not. This method uses ultraviolet (UV) signals in the form of adjacent and contrasting UV-reflecting and UV-absorbing elements separated by the same 5 and 10 cm pattern elements visible to humans. One German glass manufacturer has produced and sold a supposedly bird-safe pane using UV signals but reliable experimental testing of their windows revealed that they are ineffective, even more hazardous to birds than conventional glass. The interpretation of the inability of these panes to alert birds to their presence is that the UV signal is too weak (7%–22%) over the too narrow UV wavelength (300–400 nanometers) range, reaching above 20% UV-reflection only at 397 nm [21]. In comparison, previous studies found external films with UV-reflecting components of 20%–40% over 300–400 nm to effectively deter bird-window collisions [20,21]. Remarkably, although known for some time, no external film company has produced a product for retrofitting offending windows, nor has any glass manufacturer produced an effective bird-safe window using UV signals. A federal government mandate coupled with effective enforcement requiring bird safe windows in all human built structures would stimulate product development and expedite bird protection.

## 3. Conclusions

Bird-window collisions and the extravagant toll they exact on birds is still an underappreciated human-associated avian mortality factor. For a topic that is an extremely important conservation issue for birds and people, educating the general public and through them stimulating those who can enact effective means to mitigate, or ideally eliminate, these unwanted and unintended deaths is still an essentially unfulfilled need, even a desperate one for those of us who have worked so hard for so long to protect birds from a preventable senseless death. From the first modern reports and annual estimates of the carnage birds experience at windows, speculating 3–5 million annual deaths in the U.S. to a more objective assessment of 1 billion a year, the topic continues to receive periodic but brief attention in broadcast media and popular and professional publications [4–7,41,42]. One dramatic example of the scale of attrition exacted by windows is that if one accepts the lowest contemporary estimate of 100 million annual kills at glass in the U.S. you need 333 Exxon Valdez oil spills each year to match the level of this tragedy. Yet the 100,000 to 300,000 marine birds estimated to be killed by the 1989 Exxon Valdez oil spill in Alaska is still, along with the more recent Gulf oil spill, cited by various media as an example of a world-class environmental disaster while the exponentially higher toll from window strikes is relatively ignored. Arguably windows also play a role in the toll that domestic cats exact on birds, estimated to be the greatest human-associated source of attrition on wild birds in the U.S. and Canada [43–45]. But what cats take is connected and confounded in that unknown numbers of birds preyed upon by cats were first victims of window strikes, having been injured or killed outright. Studies have documented that cats among other predators and scavengers regularly patrol the areas below and in the vicinity of windows to capture the dead and dying [16,19]. Moreover, windows are invisible to birds and therefore birds are at risk whenever they confront clear and reflective panes, and almost certainly there are exponentially far more windows present and passively threatening birds in the environment than there are cats to do so. Detailed continuous monitoring of a single home revealed one out of two strikes results in an outright fatality, half of those that strike fly away with some trauma and injury [46]. Those that survive often appear debilitated and likely succumb to their injuries or predators that find them relatively easy prey. The dead and surviving suffer head trauma, resulting in blood in the brain, and thought to be the cause of death or debilitation; injured and initially surviving birds that were monitored after striking a window and then captured and cared for exhibited increased paralysis over time that eventually ended their life [46,47]. Moreover, detailed monitoring of field experiments have revealed the minimally one out of four bird strikes leave no evidence of a collision, such as a feather, feather or body imprint, blood or other fluid on the window surface [20]. Consequently, the number of deaths may be even far greater than our most objective and sophisticated methods permit us to determine.

Irrespective of the potential species population effects, preventing the deaths of innocent victims that have no voice and no ability to prevent killing themselves because of an attractive realistic illusion created by humans is justified for ethical and legal reasons. Ethically we humans should require that the environment we build causes no unintended harm to what we judge to be other valuable and useful life. Legally, there are international treaties and national acts, and a growing number of regional and local laws and other legislation specifically written to protect the killing of protected birds. To prevent bird-window collisions and all their consequences, windows in the form of sheet glass and plastic must be transformed into barriers that diverse bird species will see and avoid. Notwithstanding skeptics [48,49], the most elegant solution, using UV signals that birds see and we humans do not has been shown to be an effective prevention method [20,21]. External films with effective prevention are not being manufactured because those with the know-how will not commit to production because they cannot factor in unconventional consumer interest into their business plan to determine if it merits their investment. Glass manufacturers currently seem technically incapable of offering a strong enough UV signal to produce an effective bird-safe pane for remodeling and new construction. Both these building industry constituents must be convinced to commit to producing bird-safe products to ensure we humans will be able to save more bird lives from windows.

**Acknowledgments**

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## Conflicts of Interest

The author declares no conflict of interest.

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# Hidden Markov models for estimating animal mortality from anthropogenic hazards

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*Abstract.* Carcass searches are a common method for studying the risk of anthropogenic hazards to wildlife, including nontarget poisoning and collisions with anthropogenic structures. Typically, numbers of carcasses found must be corrected for scavenging rates and imperfect detection. Parameters for these processes (scavenging and detection) are often estimated using carcass distribution trials in which researchers place carcasses in the field at known times and locations. In this manuscript I develop a variety of estimators based on multi-event or hidden Markov models for use under different experimental conditions. I apply the estimators to two case studies of avian mortality, one from pesticide exposure and another at wind turbines. The proposed framework for mortality estimation points to a unified framework for estimation of scavenging rates and searcher efficiency in a single trial and also allows estimation based only on accidental kills, obviating the need for carcass distribution trials. Results of the case studies show wide variation in the performance of different estimators, but even wider confidence intervals around estimates of the numbers of animals killed, which are the direct result of small sample size in the carcass distribution trials employed. These results also highlight the importance of a well-formed hypothesis about the temporal nature of mortality at the focal hazard under study.

*Key words: anthropogenic hazards; avian mortality; carbofuran; carcass searches; competing risks; granular insecticide; hidden Markov models; scavenging; searcher efficiency; wind turbine.*

## INTRODUCTION

Carcass searches have been used to study many sources of anthropogenic mortality to wildlife, including pesticide poisoning of nontarget species (Finley 1965, Mineau 1988, Fleischli et al. 2004) and collisions with anthropogenic objects such as windows (Klem 1989), transmission wires (Bevanger 1998), automobiles (Gerow et al. 2010), wind turbines (Kuvlesky et al. 2007), and communications towers (Longcore et al. 2012). Regardless of the cause of mortality (hereafter "focal hazard"), the use of carcass counts to estimate the number of animals killed is complicated due to difficulty in detecting carcasses and because scavengers may remove many carcasses before discovery (Mineau and Collins 1988, Smallwood 2007, Prosser et al. 2008). Thus quantification of mortality rates at focal hazards using carcass counts requires estimates of both carcass scavenging rates and carcass detection probabilities (Loss et al. 2012).

Carcass distribution trials, in which carcasses are placed in the field at known times and locations are a common method for estimating scavenging rates and detection probabilities (Rosene and Lay 1963, Balcomb 1986). To estimate scavenging rates, researchers typically place surrogate carcasses at known locations in proximity to the focal hazard under study (Balcomb 1986, Linz et al. 1997). These surrogate carcasses are then monitored by personnel who know their locations in order to determine scavenger removal rates. To estimate searcher efficiency, the design is similar, but the success of naïve searchers is estimated by sending them out to look for carcasses (Tobin and Dolbeer 1990, Rivera-Milán et al. 2004).

Methods used for analysis of data from carcass distribution trials vary widely and depend upon the objective of the experiment. To estimate detection probabilities, researchers typically use binomial proportions (Tobin and Dolbeer 1990, Gerow et al. 2010), although distance sampling (Rivera-Milán et al. 2004) and multinomial methods to correct for reporting rates (Ward et al. 2006) have also been used. To estimate persistence, researchers typically use survival analysis (Balcomb 1986, Linz et al. 1997, Prosser et al. 2008) or known-fate mark–recapture methods (Ward et al. 2006). In at least one case, researchers have estimated the joint probability of discovery and persistence (Madrigal et al. 1996). In rare cases, the same experiment is used to estimate both scavenging rates and searcher efficiency (Smallwood 2007), although analysis typically focuses on estimating one or the other parameter in isolation. However, given appropriate analytical methods, it would be sensible to estimate both parameters simultaneously. Ideally, estimation of scavenging rates and detection probabilities could be done using only accidental kills at the focal hazard, obviating the need for carcass distribution trials.

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In this paper I develop a series of estimators for the number of animals killed at a focal hazard, when carcasses are subject to both scavenging and imperfect detection. I illustrate the use of the estimators through reanalysis of avian mortality data from two case studies, the first resulting from pesticide exposure, and the second due to collisions with wind turbines. Throughout, I distinguish the estimation of detection and scavenging probabilities from the task of using these estimated probabilities to extrapolate the actual numbers of animals killed at focal hazards. My primary focus is on the latter and I show that the inferential problem associated with this extrapolation is similar to other problems arising from imperfect detection in animal demography, including avian point count sampling (Nichols et al. 2009), occupancy modeling (MacKenzie et al. 2006), and abundance estimation from mark–recapture studies (Williams et al. 2002). The framework I present shows that the parameter estimation problem falls within the domain of hidden Markov models (MacDonald and Zucchini 1997, Gimenez et al. 2012) for which statistical software is available. This statistical framework allows scavenging and searcher efficiency to be estimated simultaneously from a unified analysis of a single trial under a variety of experimental conditions. With some generalization, this method can be applied using only accidental kills at a focal hazard, obviating the need for carcass trials. It also provides a rigorous foundation for estimating the numbers of animals killed based on carcass counts and estimates of scavenging and discovery rates, regardless of whether the latter are derived from carcass distribution trials or from accidental kills.

## Methods

### *A general statistical model*

In the general case, carcasses are scavenged continuously, whereas observer searches take place episodically, usually with mean search interval greater than one day. This can be accommodated using a multi-event framework (Pradel 2005) with two transition matrices, one for the scavenging process, $\mathbf{S}_t$, and one for the discovery process, $\mathbf{D}_t$, where the subscript $t$ indicates that the rates within each matrix are assumed to change with time:

$$\mathbf{S}_t = \begin{bmatrix} q_{rt} & p_{rt} & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and

$$\mathbf{D}_t = \begin{bmatrix} q_{dt} & 0 & p_{dt} \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

In these matrices, $p_{rt}$ is the probability of removal (subscript r) by scavengers on day $t$, given that the carcass was present at the start of day $t$ and $q_{rt} = 1 - p_{rt}$. Similarly, $p_{dt}$ is the probability (given search) of discovery by searchers (subscript d) on day $t$ and $q_{dt} = 1 - p_{dt}$. The product $\mathbf{A}_t^{(i,j)}$ forms the basis for a general probability model for the fates of carcasses:

$$\mathbf{A}_t^{(i,j)} = \left(\prod_{t=i}^{j} \mathbf{S}_t\right)\mathbf{D}_j = \begin{bmatrix} q_{dj}\prod_{t=i}^{j} q_{rt} & 1 - \prod_{t=i}^{j} q_{rt} & p_{dj}\prod_{t=i}^{j} q_{rt} \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}. \quad (1)$$

Here, $\mathbf{A}_t^{(i,j)}$ describes transitions of carcasses among three states over the time between two searches (day $i$ through day $j$, where day $i$ is the day following the previous search and day $j$ is the day of the subsequent search). The three states (respectively, in row/column order) are: (1) neither scavenged nor detected; (2) scavenged; and (3) detected.

Thus, for example, the probability of detection (column 3), given that a carcass is neither scavenged nor detected (row 1) is $p_{dj}\prod_{t=i}^{j} q_{rt}$.

Eq. 1 also forms the basis for a likelihood function for carcass trials:

$$l(p_{rt}, p_{dt} \mid \mathbf{J} = [j_1, j_2, j_3, \ldots, j_n]) \propto \mathbf{V}_1\left[\prod_{k=1}^{n} \mathbf{A}_t^{(j_{k-1}+1, j_k)}\right]\mathbf{V}'_m. \quad (2)$$

In Eq. 2, $j_0 = 0$ is the day carcasses are placed in the environment, $\mathbf{J}$ is a vector giving the days on which carcass searches are performed, $n$ is the total number of carcass searches performed, and $\mathbf{V}_m$ is a unitary row vector with all entries zero except a 1 in column $m$, indicating the observed state of the carcass. The full time-specific likelihood will have non-identifiable parameters ($p_{rt}$, and possibly $p_{dt}$ depending on actual carcass discoveries and search schedules). However, with suitable constraints (e.g., logit-linear trends in scavenging probability or both parameters) the identifiability issues can be easily solved.

This framework is easily extended to a case in which only accidental kills are used for inference, obviating the need for carcass trials. Consider the case of two observers assigned to survey a given focal hazard. Their visits may be at irregular intervals, but they must survey at least twice (ideally more), always together, and in such a way that they do not reveal discovered carcasses to each other. During each visit, each observer independently records the species and location of any carcass detected *and then leaves the carcass in place*. At subsequent visits, each observer records whether or not a carcass known to him or her has been scavenged and searches for new carcasses. Under this model, a carcass in the field could be in one of five states: (1) neither scavenged nor detected; (2) detected by observer 1 and not observer 2, (and unscavenged); (3) detected by observer 2 and not observer 1, (and unscavenged); (4) detected by both observer 1 and observer 2, (and unscavenged); (5) scavenged.



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Analysis of this survey design is identical to that just described (with similar parameter identifiability issues), but with the following matrices substituted for $\mathbf{S}_t$ and $\mathbf{D}_t$:

$$\mathbf{S}_t = \begin{bmatrix} q_{rt} & 0 & 0 & 0 & p_{rt} \\ 0 & q_{rt} & 0 & 0 & p_{rt} \\ 0 & 0 & q_{rt} & 0 & p_{rt} \\ 0 & 0 & 0 & q_{rt} & p_{rt} \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

and

$$\mathbf{D}_t = \begin{bmatrix} q_{dt1}q_{dt2} & p_{dt1}q_{dt2} & q_{dt1}p_{dt2} & p_{dt1}p_{dt2} & 0 \\ 0 & q_{dt2} & 0 & p_{dt2} & 0 \\ 0 & 0 & q_{dt1} & p_{dt1} & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

In this $\mathbf{D}_t$ matrix, $p_{dt1}$ is the probability that a carcass is detected by observer 1 on day $t$, given that he or she looks; $p_{dt2}$ is the probability that a carcass is detected by observer 2 on day $t$, given that he or she looks; $q_{dt1}$ and $q_{dt2}$ are the respective complements. Once detected, carcasses can transition among states of knowledge by the opposing observers and into the scavenged state. When only accidental kills are used, state 1 is an unobservable state. Thus entry into a probability model is possible only via states 2–4, and for estimation purposes, row/column 1 could be omitted. However, as will be shown, it is useful to retain the unobservable state for extrapolating the numbers of animals killed.

*Estimators for the numbers of animals killed*

Typically, the purpose for estimating $p_{rt}$ and $p_{dt}$ (or $p_{dt1}$ and $p_{dt2}$) is to extrapolate from the number of accidental kills found ($N_f$) to the number of animals actually killed. Whether or not detection and scavenging rates are estimated in a carcass distribution trial or using only accidental kills, the problem of extrapolation to the numbers of animals killed ($N_k$) is similar, and based upon the Horvitz-Thompson (Horvitz and Thompson 1952) estimator:

$$N_k = \frac{N_f}{p_f}. \quad (3)$$

In Eq. 3, $p_f$ is the probability that a carcass, killed at the focal hazard, is ultimately found under a given search protocol. The matrices previously formulated are the basis for the development of estimators for $p_f$.

It should be obvious, but also worth stating, that the form for the estimator for $p_f$ will depend primarily upon the conditions under which accidental mortality occurs, not the conditions under which a carcass trial takes place. One important consideration is whether or not mortality at the focal hazard is ongoing during monitoring (as would be the case with most focal hazards such as wind turbines, power lines, and roads), or whether mortality can be assumed to be the result of a single event, such as a pesticide application on a known date. Because the latter situation is simpler, I begin with it.

*Sudden-event mortality*

In the most general case (considered here), parameters $p_{rt}$ and $p_{dt}$ are assumed to vary with time and the intervals between carcasses searches are of variable duration. In this case, an estimator for $p_f$ is

$$p_f = \mathbf{V}_1\left(\prod_{k=1}^{n}\mathbf{A}_t^{(j_{k-1}+1,j_k)}\right)\mathbf{V'}_3$$
$$= p_{dj_1}\prod_{t=1}^{j_1} q_{rt} + \sum_{k=2}^{n} p_{dj_k}\prod_{t=j_{k-1}+1}^{j_k} q_{rt}\prod_{m=1}^{k-1} q_{dj_m}\prod_{u=j_{m-1}+1}^{j_m} q_{ru}. \quad (4)$$

In plain English, Eq. 4 states that the probability that a carcass is found is the probability that it begins in state 1 (neither scavenged nor detected) and ends in state 3 (detected) over the course of monitoring.

Eq. 4 can be simplified when conditions allow. When $p_{rt}$ and $p_{dt}$ are constant ($p_{rt} = p_r$ and $p_{dt} = p_d$, for all $t$), then, letting $d_k = j_k - j_{k-1}$ represent the number of days separating search $j_{k-1}$ and search $j_k$,

$$\mathbf{S} = \begin{bmatrix} q_r & p_r & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{D} = \begin{bmatrix} q_d & 0 & p_d \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and

$$\mathbf{A}^{(j_{k-1}+1,j_k)} = \mathbf{A}^{(d_k)} = \mathbf{S}^{d_k}\mathbf{D} = \begin{bmatrix} q_d q_r^{d_k} & 1-q_r^{d_k} & p_d q_r^{d_k} \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

Eq. 4 becomes

$$p_f = \mathbf{V}_1\left(\prod_{k=1}^{n}(\mathbf{S}^{d_k}\mathbf{D})\right)\mathbf{V'}_3 = q_r^{d_1}p_d + p_d\sum_{k=2}^{n} q_r^{d_k} q_d \prod_{m=1}^{k-1} q_r^{d_m}. \quad (5)$$

In Eq. 5, $d_1$ is the amount of time between the mortality event and the first search. This formulation gives rise to a different definition of the search schedule as a vector giving the numbers of days separating sequential searches ($\mathbf{J} = [d_1, d_2, d_3, \ldots, d_n]$). When a monitoring schedule with fixed period ($\bar{d}$) between searches is used, the expression for $p_f$ further simplifies to

$$p_f = q_r^{\bar{d}} p_d \sum_{k=1}^{n} (q_r^{\bar{d}} q_d)^{k-1} = q_r^{\bar{d}} p_d \frac{1-(q_r^{\bar{d}} q_d)^n}{1-q_r^{\bar{d}} q_d}. \quad (6)$$

Finally, as the number of searches gets large, then $\lim_{n\to\infty}(q_r^{\bar{d}} q_d)^n = 0$, and

$$p_f = \frac{q_r^{\bar{d}} p_d}{1-q_r^{\bar{d}} q_d}. \quad (7)$$

An alternative derivation of Eq. 7 highlights the central role of the transition matrices in development of the estimators. When $d_k = \bar{d}$ for all $k$, and $p_r$ and $p_d$ are constant, then the asymptotic behavior of $\mathbf{A}^{(\bar{d})}$ is given by the product of the fundamental matrix, $\mathbf{N}$, and the matrix of absorption probabilities, $\mathbf{R}$ (Kemmeny and Snell 1960). In this case, $\mathbf{N} = (1 - q_r^{\bar{d}} q_d)^{-1}$, $\mathbf{R} = [1 - q_r^{\bar{d}}, q_r^{\bar{d}} p_d]$, and the product $\mathbf{NR} = [(1 - q_r^{\bar{d}})/(1 - q_r^{\bar{d}} q_d), (q_r^{\bar{d}} p_d)/(1 - q_r^{\bar{d}} q_d)] = [1 - p_f, p_f]$, as per Eq. 7. In practice, empirical estimates of mortality at focal hazards often assume constant rates of scavenging and detection probability and use the mean interval between searches to characterize search effort. Thus either Eq. 6 or Eq. 7 would be appropriate for such conditions, depending upon the duration of the experiment.

A major limitation to the estimators for $p_f$ just presented is that they require all carcasses to share the same exposure to both scavenging and discovery. In the case of acute pesticide poisoning on a known date followed by carcass searches, this requirement may be met (at least approximately) if all mortality occurs immediately after the pesticide application. This was one of the cases considered by Mineau and Collins (1988) and a sample analysis using the above estimators (Eqs. 5–7) is presented below in the carbofuran case study. However, with many focal hazards, mortality is distributed more evenly over the period of monitoring. Estimators for such cases are developed in the following section.

### *Ongoing mortality*

When carcasses enter the environment during the course of the study, a reasonable approach (suggested by Shoenfeld 2004) is to assume a constant hazard and estimate the daily rate at which carcasses enter the environment ($\lambda$) and then multiply by the total length of the experiment, in days ($T$), $N_k = \lambda T$, where $T = \sum_{k=1}^{n} d_k$. The transition matrix approach may also be used to estimate $\lambda$, although several potential complications must be considered. First, unless a sweep of the area searched is performed prior to the onset of monitoring, then the carcasses found must be considered a mixture of those that were already present prior to the first search (hereafter $N_{f0}$) and those that entered the area searched during the experiment (hereafter $N_{fe}$). When a sweep is performed I assume that the sweep occurs on day $t = j_0 = 0$ and all carcasses in the environment are removed. Thus the first search interval ($d_1$) gives the time between the sweep and the first search subsequent to the sweep. Conversely, if no sweep is performed, then day $t = j_1 = 0$ is the day of the first search and all carcasses discovered are counted.

A general expression for $N_{f0}$ is

$$N_{f0} = \lambda \left( \sum_{t=-\infty}^{0} \prod_{u=t}^{0} q_{rt} \right) \left( p_{d0} + q_{d0} \mathbf{V}_1 \left( \prod_{k=1}^{n} \mathbf{A}_t^{(j_{k-1}+1, j_k)} \right) \mathbf{V'}_3 \right). \tag{8}$$

In Eq. 8, $t = u = 0$ corresponds to the day of the first search. A general expression for $N_{fe}$ is

$$N_{fe} = \lambda \left[ \sum_{k=1}^{n-1} \sum_{h=j_{k-1}+1}^{j_k} \left( \mathbf{V}_1 \left[ \mathbf{A}_t^{(h, j_k)} \prod_{m=k+1}^{n} \mathbf{A}_t^{(j_{m-1}+1, j_m)} \right] \mathbf{V'}_3 \right) + \sum_{h=j_{n-1}+1}^{j_n} \left( \mathbf{V}_1 \mathbf{A}_t^{(h, j_n)} \mathbf{V'}_3 \right) \right]. \tag{9}$$

These formulas are of the form $N_{f0} = \lambda g_{f0}$ and $N_{fe} = \lambda g_{fe}$, where $g_f$ is the expected probability that an arbitrary carcass will be discovered during monitoring; $g_{f0}$ is the expected probability that an arbitrary carcass, killed prior to the onset of monitoring, will be discovered during monitoring; and $g_{fe}$ is the expected probability that an arbitrary carcass, killed between the first and last search, will be discovered during monitoring. Letting $N_f = N_{f0} + N_{fe}$ and $g_f = g_{f0} + g_{fe}$, the expected daily rate at which carcasses enter the area searched is $\lambda = N_f/g_f$ and the expected number of animals killed is $N_k = (N_f/g_f)T$. Therefore, the probability that an arbitrary carcass killed between the first and last searches will be discovered is

$$p_f = \frac{g_f}{T} = \frac{g_{f0} + g_{fe}}{T}. \tag{10}$$

Simpler formulae (Eqs. 11–16 in Table 1) are available when scavenging and discovery rates are constant and when searches occur according to a fixed period (see Table 1 and Appendix).

These estimators apply when $p_d$ and $p_r$ are estimated from carcass distribution trials. Similar estimators can be derived for cases in which scavenging and detection rates are estimated from accidental kills. The most general case is simply Eq. 4 with the time-specific matrices and state vectors for the double observer model substituted. As before, an asymptotic estimator for $p_f$ under a periodic monitoring schedule with constant detection and scavenging rates can be derived from the matrix $\mathbf{A}^{(j_{k-1}, j_k)}$, with discovered states (2, 3, and 4) made absorbing. The two pertinent matrices are again $\mathbf{N}$ and $\mathbf{R}$, which, for a fixed period between searches ($\bar{d}$), are given by

$$\mathbf{N} = \frac{1}{1 - q_r^{\bar{d}} q_d 1 q_{d2}}$$

and

$$\mathbf{R} = [\, q_r^{\bar{d}} p_{d1} q_{d2} \quad q_r^{\bar{d}} p_{d2} q_{d1} \quad q_r^{\bar{d}} p_{d1} p_{d2} \quad 1 - q_r^{\bar{d}} \,].$$

Thus, $p_f$ is the sum of the probabilities of ending in any of states 2, 3, or 4:

$$p_f = \frac{q_r^{\bar{d}} p_{d1} q_{d2} + q_r^{\bar{d}} p_{d2} q_{d1} + q_r^{\bar{d}} p_{d1} p_{d2}}{1 - q_{d1} q_{d2} q_r^{\bar{d}}} = \frac{(1 - q_{d1} q_{d2}) q_r^{\bar{d}}}{1 - q_{d1} q_{d2} q_r^{\bar{d}}}. \tag{17}$$

Like Eq. 7, Eq. 17 depends on the assumption that all carcasses share the same search schedule and exposure

TABLE 1. Formulae for ongoing mortality estimators.

| Eq. | Searches | Duration | Expected number of carcasses found |
|---|---|---|---|
| 11 | variable | n/a | $N_{f0} = \lambda\left(\frac{q_r}{1-q_r}\right)\left[p_d + q_d\mathbf{V}_1\left(\prod_{k=1}^{n}\mathbf{A}^{(d_k)}\right)\mathbf{V}_3'\right]$ |
| 12 | periodic | n/a | $N_{f0} = \lambda p_d\left(\frac{q_r}{1-q_r}\right)\left(\frac{1-(q_d q_r^{\bar{d}})^{n+1}}{1-q_d q_r^{d}}\right)$ |
| 13 | periodic | long | $N_{f0} = \lambda p_d\left(\frac{q_r}{1-q_r}\right)\left(\frac{1}{1-q_d q_r^{\bar{d}}}\right)$ |
| 14 | variable | n/a | $N_{fe} = \lambda\sum_{k=1}^{n-1}\sum_{h=1}^{d_k}\left[\mathbf{V}_1\left(\mathbf{A}^{(h)}\prod_{m=k+1}^{n}\mathbf{A}^{(d_m)}\right)\mathbf{V}_3'\right] + \lambda\sum_{h=1}^{d_n}\left(\mathbf{V}_1\mathbf{A}^{(h)}\mathbf{V}_3'\right)$ |
| 15 | periodic | n/a | $N_{fe} = \lambda p_d\frac{q_r(1-q_r^{\bar{d}})}{(1-q_r)(1-q_d q_r^{\bar{d}})}\left[n - q_d q_r^{\bar{d}}\left(\frac{1-(q_d q_r^{\bar{d}})^n}{1-q_d q_r^{\bar{d}}}\right)\right]$ |
| 16 | periodic | long | $N_{fe} = \lambda p_d\frac{q_r(1-q_r^{\bar{d}})}{(1-q_r)(1-q_d q_r^{\bar{d}})}\left(n - \frac{q_d q_r^{\bar{d}}}{1-q_d q_r^{\bar{d}}}\right)$ |

*Notes:* Terms are $\lambda$, daily mortality rate at the anthropogenic hazard; $N_k$, number of animals killed at the hazard between the first and last search; $N_{f0}$, expected number of carcasses found that were already in the environment prior to the first search; $N_{fe}$, expected number of carcasses found that were killed between the first and last search; $q_r$, the daily probability that a carcass is *not* removed by scavengers; $p_d$, per search probability that a carcass is discovered; $q_d = 1 - p_d$; $n$ is the number of carcass searches; $k$ is an index for carcass searches; $m$ is an index for carcass searches subsequent to the $k$th search; $h$ is an index for days within an interval between searches; $\bar{d}$ is a fixed period between searches; $\mathbf{V}$ is a row vector; $\mathbf{A}$ is a matrix of carcass transitions. The abbreviation n/a means not applicable (the equation does not depend upon the duration of monitoring).

to scavenging and discovery. Thus Eq. 17 would not be appropriate for a case in which carcasses are continually entering the environment, which is typical of many focal hazards, including power lines, wind turbines, and windows. For this case, defining $q_d = q_{d1}q_{d2}$ and substituting into the equations in Table 1 should give accurate estimates for $g_f$ and $p_f$ (note that the same reasoning could be applied to derive Eq. 17 from Eq. 7 without the use of **N** and **R** presented previously).

To be useful, these estimates of $p_f$ (and hence $N_k$) require estimates of their associated standard errors. If the likelihood in Eq. 2 were used, a finite difference approximation to the covariance matrix (of $p_d$ and $p_r$) would be available as a byproduct of estimation and could be used to obtain a delta-method approximation to the variance of $p_f$. When $p_r$ and $p_d$ are estimated in separate carcass distribution trials, they may be assumed to be independent and the covariance matrix can be approximated by a diagonal matrix formed from the sampling variances for the two parameters. An alternative method, employed below, is to use a parametric bootstrap procedure that mimics the experimental conditions under which $p_r$ and $p_d$ were originally estimated.

As a final methodological point, the estimators for $p_f$ described previously apply only to areas actually searched for carcasses. However, it may often be the case that only a subset of anthropogenic hazards (e.g., turbines) is monitored and/or a limited area surrounding each focal hazard is searched. When the appropriate proportion is known (proportion of hazards searched, proportion of carcasses expected in the search area), correcting the estimate is straightforward using the Horvitz-Thompson (1952) estimator (notation below adapted from Huso 2011). An example when sampling is unequal among hazards is as follows:

$$N_k = \frac{1}{\pi}\sum_z \frac{1}{\pi_{az}}\frac{N_{fz}}{p_f}. \qquad (18)$$

In Eq. 18, $N_{fz}$ is the number of animals found at a given hazard (indexed by $z$), $\pi$ is the proportion of hazards sampled, and $\pi_{az}$ is the proportion of total carcasses at a given hazard expected to be within the area searched. Finally, when subsets of focal hazards differ in their estimates of $p_f$, which could be due to different rates of scavenging or detection, or different search schedules, then Eq. 18 can be further generalized. In a very general case, let $N_{fz}$ represent the number of carcasses found at turbine $z$ and assume that all carcasses have a different fitted probability of being found (say $p_{fzc}$, indicating the probability that the $c$th carcass at turbine $z$ is found). Then the expression $N_{fz}/p_f$ can be replaced by

$$\sum_{c=1}^{N_{fz}}\frac{1}{p_{fzc}}.$$

*Case study 1. Granular carbofuran poisoning*

As part of the pesticide registration process (40 CFR §158.630, *available online*)[2] the U.S. Environmental Protection Agency (EPA) can request that field studies

[2] http://www.gpo.gov/fdsys/pkg/CFR-2012-title40-vol25/pdf/CFR-2012-title40-vol25-sec158-630.pdf

TABLE 2. Data from granular carbofuran study summarized in U.S. EPA (1987).

| Parameter | Value |
|---|---|
| $p_r$ | 0.23 |
| $p_d$ | 0.6 |
| $T$ | 45 days |
| $n$ | 26 |
| **J** | [1,1,1,1,1,1,3,1,1,1,1,1,3,1,1,1,1,1,3,1,1,1,1,5,8,3] |
| $\bar{d}$ | 1.7 days |
| $N_f$ | 92 |

*Notes:* The length of the experiment is given by $T$. When $p_r$ and $p_d$ are constant, **J** is more conveniently defined as a vector of days between subsequent searches.

be conducted by chemical registrants to assess the potential for adverse effects on wildlife as a result of anticipated use patterns. U.S. EPA (2012) guidelines for conducting such studies require estimates of carcass removal rates by scavengers and estimates of searcher efficiency and provide an equation for adjusting carcass counts to estimate total mortality. The component of that equation giving the probability that a carcass is found is equivalent to $p_f = 1/q_r p_d$. The resulting estimate of $N_k$ is further adjusted to account for avian density and the area searched (U.S. EPA 2012).

One such study was carried out by Booth et al. (1986) and summarized by U.S. EPA (1987) to assess the effects of two formulations of granular carbofuran on birds using Iowa and Illinois cornfields. Summary data for the Illinois study are presented in Table 2. Below I reanalyze the carbofuran data using the U.S. EPA (2012) estimator and compare the results to those obtained using estimators developed in this manuscript. Because carbofuran granules can persist for days or weeks on the soil surface, I also assumed that mortality might be distributed more evenly and I applied the ongoing mortality estimators (Table 1) under the assumption that a sweep had been performed (i.e., no carcasses were in the environment prior to the pesticide application). For this study, no information was provided by U.S. EPA (1987) on standard errors for $p_r$ and $p_d$. Thus to illustrate the influence of sample size on mortality extrapolation, I used parametric bootstrap sampling to generate standard errors under a range of sample sizes, assuming that both parameters were estimated using a single trial lasting one week, with a fixed number of carcasses monitored daily.

*Case study 2. Mortality at the Mountaineer Wind Energy Center*

The Mountaineer Wind Energy Center (Excelon Corporation), in Tucker and Prescott Counties, West Virginia, USA came online in December 2002. From 4 April through 11 November 2003, post-construction mortality was monitored at 44 wind turbines and two meteorology towers (Kerns and Kerlinger 2004). Carcass removal rates and searcher efficiency were studied in a carcass distribution trial using 30 carcasses. During the course of monitoring, 69 bird fatalities were discovered, of which 33 were attributed to collision with a power substation, not the wind turbines, leaving 36 fatalities attributed to collision with turbines. Shoenfeld (2004) developed two mortality estimators (one assuming probabilistic search schedule and one assuming periodic search) for the Mountaineer study, which were applied by Kerns and Kerlinger (2004) to calculate an estimated 178 birds killed. Parameters for the Mountaineer case study are presented in Table 3.

Below I reanalyze the data presented by Kerns and Kerlinger (2004), comparing the resulting estimates from the Shoenfeld (2004) estimators to those obtained using the estimators developed in this manuscript. Because no mention of a sweep was made in the report, I assumed none had been performed. Also, while the authors cite the use of the Shoenfeld (2004) estimator, they do not specifically mention which version they use. Thus I applied both Shoenfeld estimators to the data in Table 3 to compare against the ongoing mortality estimators developed here. Finally I ran the analyses with two different search intervals. For this study, the actual search schedule for each turbine was not reported. Therefore, to fit the variable search schedule estimator, I estimated an approximate search schedule by taking the first date of each of the 22 rounds of searches reported by Kerns and Kerlinger (2004). To fit the estimators with mean search interval, I first took the

TABLE 3. Data from Mountaineer Wind Energy Center from 2003 Annual Report.

| Parameter | Value | Notes |
|---|---|---|
| $p_r$ | 0.1493 | Average persistence time of 30 carcasses was 6.7 days. |
| $p_d$ | 0.2759 | Of 30 distributed carcasses, one was scavenged before searchers began looking. |
| $T$ | 221 days | Monitoring began on 4 April 2003 and ended on 11 November 2003. |
| $n$ | 21 | 22 rounds of searches were performed and no sweep was mentioned, resulting in 21 intervals between searches. |
| **J** | see Table 2 *Notes* | **J** = [13,7,13,10,6,9,21,36,24,7,7,7,6,8,7,7,7,7,7,8,7], based on first day of each round (dates of actual visits to each turbine not reported). |
| $\bar{d}$ | 7 | The intended search interval was 7 days, but the realized search interval (based on **J** above) was 10.5 days. |
| $N_f$ | 36 | Of 69 total fatalities discovered, 33 were attributed to collisions with a power substation. |
| $N_k$ | 178 | Corrected fatality rate as reported by the authors using the Shoenfeld estimator (version of Shoenfeld estimator used was not specified). |

TABLE 4. Estimated numbers of birds killed based on reanalysis of carbofuran data.

| Estimator | $\hat{p}_f$ | $\hat{N}_k$ |
|---|---|---|
| U.S. EPA | 0.464 | 198 |
| Sudden-event variable schedule (Eq. 5) | 0.671 | 137 |
| Sudden-event periodic schedule, short experiment (Eq. 6) | 0.516 | 178 |
| Sudden-event periodic schedule, long experiment (Eq. 7) | 0.516 | 178 |
| Ongoing mortality, variable schedule (Eq. 14) | 0.563 | 163 |
| Ongoing mortality, periodic schedule, short (Eq. 15) | 0.624 | 148 |
| Ongoing mortality, periodic schedule, long (Eq. 16) | 0.624 | 148 |

average search interval of the approximate schedule as described above (10.67 days) and I also fit the data using a mean search interval of 7 days, as intended in the design of the study. Standard errors were estimated using parametric bootstrap.

Computer programs in R (R Development Core Team 2008) and MATLAB (MathWorks 2012) for the estimators and analyses performed in this paper are available in the Supplement.

## RESULTS AND DISCUSSION

### *Case study 1. Granular carbofuran poisoning*

Values for $\hat{p}_f$ ranged from 0.464 to 0.671 and $\hat{N}_k$ ranged from 137 to 198 (Table 4). The sudden-event variable search estimator (Eq. 5) produced the largest values for $\hat{p}_f$, and hence the smallest $\hat{N}_k$, whereas the U.S. EPA (2012) estimator produced the smallest estimate of $\hat{p}_f$, and hence the largest $\hat{N}_k$. Estimates from the ongoing mortality estimators using mean search interval were identical, regardless of whether the experiment was assumed to be long or not (Table 4). Similarly, estimates from the sudden-event estimators were also identical to each other, regardless of whether the experiment was assumed to be long or not. Thus the duration of this experiment (45 days) was more than sufficient for the estimators to converge on their asymptotic expectation. Bootstrap standard errors decreased with hypothetical sample size used for a carcass distribution trial, suggesting that large sample sizes may be needed for carcass distribution trials to produce precise estimates of the numbers of animals killed (Fig. 1).

### *Case study 2. Mortality at the Mountaineer wind project*

Results of the reanalysis are presented in Table 5. Using the reported parameters, I was unable to re-derive the estimated 178 birds killed using the Shoenfeld estimator (possibly due to variation in search schedule among turbines). However, the re-derived estimate using the Shoenfeld probabilistic estimator with $\bar{d} = 7$ came very close (Table 5). For $\bar{d} = 7$, the ongoing mortality estimators (Eqs. 11–16) produced similar estimates to the Shoenfeld probabilistic estimator (172 vs. 175 birds killed), all of which were larger than the estimate produced by the Shoenfeld periodic estimator (Table 5). For $\bar{d} = 10.67$, the ongoing mortality estimators for uniform search schedules also produced estimates similar to the Shoenfeld probabilistic estimator and larger than the Shoenfeld periodic estimator (Table 5). Thus, the Shoenfeld estimator for periodic search appears to be particularly negatively biased. These negative biases in the Shoenfeld estimators agree with the analyses of Huso (2011). Note that the estimator based on the empirical search schedule **J** provided the largest $\hat{N}_k$ and, more generally, substitution of the average search interval will result in a small negative bias in $\hat{N}_k$ compared to those based on the actual search schedule. Finally, note that the values of $\hat{\lambda}$ suggest a daily mortality rate (at all 44 turbines combined) of just over 1 bird per day, although the confidence limits around daily mortality estimates were quite large, as were the confidence limits around $\hat{N}_k$ (Table 5). The large confidence limits result, in part, from the small sample size (30 carcasses) used for the carcass distribution trial, which resulted in large sampling variation in $\hat{p}_r$ and $\hat{p}_d$ under parametric bootstrap sampling.

### *Parameter estimation and software*

A major advantage of the multi-event approach outlined here is that it provides a unified method for estimating the parameters ($p_r$, $p_d$) required for all of the estimators for $N_k$ described herein, using a single carcass

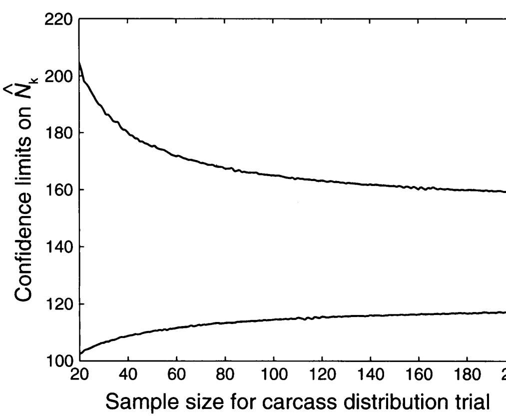


FIG. 1. Hypothetical bootstrap-estimated 95% confidence limits around estimated mortality (using the Horvitz-Thompson [1952] estimator) due to granular carbofuran poisoning ($\hat{N}_k$ = 137), using the sudden-event mortality estimator for variable search schedule and assuming a one-week carcass distribution trial.



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Table 5. Estimated numbers of birds killed based on reanalysis of the Mountaineer Wind Project data (confidence limits based on 100 000 replicate bootstrap samples).

| Estimator | $\bar{d} \approx 10.67$ days | | $\bar{d} \approx 7$ days | |
|---|---|---|---|---|
| | $\hat{N}_k$ (95% CI) | $\hat{\lambda}$ (95% CI) | $\hat{N}_k$ (95% CI) | $\hat{\lambda}$ (95% CI) |
| Shoenfeld probabilistic | 244 (134–584) | n/a | 172 (98–399) | n/a |
| Shoenfeld periodic | 222 (118–560) | n/a | 157 (86–377) | n/a |
| Ongoing (Eqs. 11 and 14) | 254 (133–635) | 1.13 (0.60–2.8) | 175 (94–430) | 0.78 (0.42–1.9) |
| Ongoing (Eqs. 12 and 15) | 246 (124–609) | 1.10 (0.56–2.7) | 175 (94–425) | 0.78 (0.42–1.9) |
| Ongoing (Eqs. 13 and 16) | 246 (124–607) | 1.10 (0.56–2.7) | 175 (95–426) | 0.78 (0.42–1.9) |

*Note:* Entries of "n/a" indicate not applicable.

distribution trial. Nevertheless, the estimators for $p_f$ (and hence $N_k$) are consistent with the simple methods often used for analysis of carcass distribution trials, based on simple binomial proportions (as illustrated in the case studies). Thus, when the assumption of constant parameters is sufficient and placed carcasses are monitored daily, then $\hat{p}_d = n_f/n_p$, where $n_f$ is the number of placed carcasses found and $n_p$ is the number of carcasses placed. Similarly, $\hat{p}_r = n_r/n_e$, where $n_r$ is the number of placed carcasses removed by scavengers and $n_e$ is the total number of days that placed carcasses were exposed to scavenging (Mayfield 1965). Estimated sampling variances for these binomial estimates are $\hat{p}_d$ $(1 - \hat{p}_d)/n_p$ and $\hat{p}_r$ $(1 - \hat{p}_r)/n_e$, respectively.

Heisey and Fuller (1985) provided scalar likelihood functions and the computer program MICROMORT that also allow estimation of $p_d$ and $p_r$ simultaneously, when these parameters are assumed constant. When monitoring is not daily, the models described herein are hidden Markov models (MacDonald and Zucchini 1997, Gimenez et al. 2012). When probabilities are constant, standard nest survival software (e.g., Dinsmore et al. 2002, Shaffer 2004) can be combined with simple binomial proportions (in this case of carcasses that are scavenged vs. carcasses discovered in a carcass distribution trial) to obtain estimates of $p_d$ and $p_r$ (Heisey and Fuller 1985, Etterson and Stanley 2008). Alternatively, Etterson and Stanley (2008) generalized the models of Etterson et al. (2007*a*, *b*) to provide likelihood functions for the parameters within the matrices **S** and **D**.

The generalized model for variable search schedule described by Eq. 2 is a mixture of two binomial processes and could be analyzed using standard tag recovery models (e.g., White and Burnham 1999), with $q_{rt}$ serving as the survival probability and $p_{dt}$ serving as the recovery rate, provided that carcasses are removed from the experiment upon discovery by searchers. This would allow such models to be analyzed in program MARK (White and Burnham 1999) with great flexibility in hierarchical specification of model parameters. Recently, Choquet et al. (2009) described general software (E-SURGE) for estimating parameters of multi-event mark–recapture models that could be used to fit all the models described in this manuscript, including the double observer model, to experimental data. E-SURGE will also allow covariates to different probabilities to be modeled and probably offers the most general method for parameter estimation for the models described herein.

*Relationship to other estimators*

The Shoenfeld (2004) estimators introduced here have been used to estimate numbers of animals killed in encounters with at least three types of focal hazards, including vehicle collisions (Gerow et al. 2010), window strikes (Bracey 2011), and wind turbines (Baerwald and Barclay 2009, Huso 2011). Shoenfeld's estimator for probabilistic search is $N_k = N_f((pT_r + T_s)/pT)$, where $p$ is the probability of carcass detection given that the carcass has not been scavenged, $T_r$ is the mean time to carcass removal, and $T_s$ is the mean time between searches (identical to $\bar{d}$). This is a special case of Eq. 7 under a very restrictive set of conditions. To see this, assume that $T_r$ and $T_s$ are derived from geometric distributions with parameters $p_r$ and $p_s$, respectively. Then $N_k = N_f(pp_s + p_r)/pp_s$. When searches are performed every day, then $p_s = 1$ and the conditional probability of detection given that a carcass is not scavenged is $p = p_d q_r$. Substituting these into the discrete Shoenfeld (2004) formula for $N_k$ yields $N_k = N_f((p_d q_r + p_r)/p_d q_r)$, which gives an estimate for $p_f$ equivalent to Eq. 7 when $\bar{d} = 1$. Thus the Shoenfeld (2004) probabilistic estimator requires the following three assumptions: (1) that carcass searches occur daily, (2) that $p_r$ and $p_d$ are constant, and (3) that carcasses are left in the environment until they are either discovered or scavenged.

The estimators presented here are closely related to the estimator published by Huso (2011), where the scavenging process in these estimators is a discrete-time (geometric) version of the exponential scavenging process she assumed. Therefore, performance of these estimators should be similar to that of the Huso (2011) estimator. Nevertheless there are some differences. The Huso (2011) estimator can accommodate temporal heterogeneity in scavenging through the use of alternative survival distributions, whereas covariate analysis using functions of the time index ($t$) would be required for the estimators presented here.

*Assumptions underlying the mortality estimators ($N_k$)*

Two common simplifying assumptions in mortality extrapolation include the assumption that scavenging rates and detection probabilities are approximately constant (Shoenfeld 2004, Huso 2011; but see Smallwood 2007), and that search effort is adequately characterized by the mean interval between searches. However, scavenging rates ($p_r$) are known to vary among sites (Tobin and Dolbeer 1990, DeVault et al. 2003, Bracey 2011) and over time (Smallwood 2007). Similarly, detection probabilities may vary with habitat or size of a carcass (Smallwood 2007). Several of the estimators provided here relax the assumption of constant detection and scavenging, including Eq. 4 for sudden-event mortality and Eq. 8 for ongoing mortality. The assumption of fixed periodic intervals between searches is relaxed by Eqs. 4, 5, 8, 9, 11, and 14. When the underlying rates ($p_d$ and $p_r$) depend upon covariates that do not vary with time, the inverse logit transformation can be used within the likelihood (Eq. 2) for parameter estimation and subsequent substitution into the mortality extrapolators.

Another common assumption underlying the use of carcass distribution trials is that placed carcasses have the same scavenging rates and discovery probabilities as accidental kills. However, there are many reasons why human-distributed carcasses might experience different rates of scavenging and discovery than carcasses resulting from accidents at a focal hazard (Smallwood 2007). Experimentally placed carcasses might be more or less detectable than accidental kills, depending on the effort made in hiding carcasses. Scavenging rates might differ due to pre-processing of carcasses (decomposition prior to freezing for preservation, for example) or anthropogenic marks used for carcass identification (Smallwood 2007). One potential solution is to make all inference from accidental kills at the focal hazard, obviating the need for a carcass distribution trial. I have provided theory and equations for such a case using two observers (e.g., Eq. 17).

Although I have shown that it is theoretically possible to accurately estimate scavenging and discovery rates using only carcasses from accidental kills, simulations (M. A. Etterson, *unpublished data*) suggest that a large number of animals killed may be required to obtain a sufficient number of carcasses detected by both observers to allow precise estimation of $p_f$. Thus, this estimator may be more useful for focal hazards that tend to produce concentrated mortality events, such as poisonings, rather than those that result in relatively low daily mortality spread over long periods, such as wind turbines. Also, while theoretically feasible, it may be empirically difficult for two observers to simultaneously search for carcasses at a site without revealing their discoveries to each other. This limitation could be overcome if observers search, for example, on alternate days, and the problem is analytically tractable with the transition matrix approach outlined herein, but the transition matrices and asymptotic solutions are different than those presented here. Finally, the algorithm explored here used a double observer method (Nichols et al. 2000), but removal (Farnsworth et al. 2002) and time of detection methods (Alldredge et al. 2007) might also work under some circumstances. Note also that distance sampling has already been applied to the study of carcass detection (Rivera-Milán et al. 2004).

Another assumption underlying many mortality estimators, including those presented here, is that no carcasses of animals killed at the focal hazard, other than those scavenged, are unavailable for discovery. Decomposition (when the search interval is long), human removal without reporting (for example by curious passersby in a public location), and plowing (Erickson et al. 2003) are examples whereby carcasses would be made unavailable for discovery. Violations of this assumption in a carcass distribution trial can be handled by redefining the scavenging rate to include all processes by which carcasses are made unavailable before they are discovered. However, doing so may create complications for analysis of scavenging rates in the presence of covariates if different covariates exert differing (or no) influences on actual scavenging vs. decomposition or removal by non-reporting people. Attempts to then use such data from a carcass distribution trial to extrapolate the number of animals killed would rest on an implicit assumption that the same confounding factors apply to accidental kills.

With accidental kills, when a subset of animals is mortally wounded by the focal hazard, but subsequently dies elsewhere (often referred to as crippling bias; Smallwood 2007), which is known to occur with window strikes (Dunn 1993), wind turbines (Smallwood 2007), road kill (Gerow et al. 2010), and pesticide poisoning (Mineau 2005), this subset of animals is generally unavailable for discovery. Similarly, carcasses of animals killed by collision with vehicles may be obliterated by subsequent collisions or may be transported outside of any reasonable search radius. When some carcasses are unavailable for discovery, the effect on all of the estimators presented here would be to introduce a negative bias in $\hat{N}_k$.

A final assumption worth mention here is that all carcasses found died due to the focal hazard. In most cases, verification of the focal hazard as the cause of mortality will prove difficult. However, several authors have demonstrated the ability to do so in an ecotoxicological context, for example by testing for cholinesterase inhibition (Mineau and Collins 1988, Elliott et al. 2008) or by looking for specific contaminants in the gastrointestinal tract (Fleischli et al. 2004, Elliott et al. 2008). Conditions under which alternative sources of mortality might be of concern for studying collision mortality include cases in which multiple hazards occur sufficiently close to each other that the cause of mortality cannot be confidently assigned to a single source. In such circumstances, one possible course of action would be to estimate parameters for the joint hazard and compare to similar sites at which only one or the other hazard occurs, but this course would carry with it many strong assumptions about similarities between sites.

*Limitations and conclusions*

As pointed out by Huso (2011), the Horvitz-Thompson (1952) estimator may be biased due to Jensen's inequality (Jensen 1906) when the parameter $p_f$ is estimated rather than known a priori. Although the sudden-event estimators (Eqs. 4–7) and the ongoing mortality estimators (Table 1; Eqs. 11–16) are unbiased when $p_f$ is known (computer programs for verification are included in the Supplement), they are positively biased when $p_f$ is estimated. Some suggestion as to the magnitude of the positive bias is provided in the standard error algorithms, which also provide bootstrap estimates of $E(\hat{N}_k)$. For the Mountaineer data, the bias may be about −10%.

An important limitation to all of the estimators presented here is that they make simple assumptions about the temporal distribution of mortality at a focal hazard (e.g., that they are concentrated on a single date, as in the carbofuran example, or that they are distributed evenly over time, as in the wind turbine example). In reality, mortality at focal hazards is likely to be episodic, either due to the nature of the hazard itself or due to the way in which animals interact with it. For example, pesticide-induced mortality would spike in response to an application and then subside as the chemical decays in the environment, but might spike again in response to a subsequent application. Further, while I have made a simplifying assumption of immediate mortality following such an application, in reality, granular insecticides may continue to kill birds over a period of days (or potentially much longer; Elliott et al. 2008). Similarly, collision mortality may be elevated at peaks of migratory activity (and even within these periods, still heterogeneous due to variable weather conditions), but lower (and possibly absent; Hager et al. 2008) during other times. Thus a well-formulated hypothesis about the temporal distribution of mortality at focal hazards is necessary for the development and use of these and other estimators for the number of animals killed.

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## Supplemental Material

### Appendix

Derivation of the estimators for ongoing mortality presented in Table 1 from the matrix forms presented in Eqs. 8 and 9 (*Ecological Archives* A023-092-A1).

### Supplement

R and MATLAB code for mortality estimators (*Ecological Archives* A023-092-S1).



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Conservation Biology

Conservation Practice and Policy

# Optimism and Challenge for Science-Based Conservation of Migratory Species in and out of U.S. National Parks

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**Abstract:** *Public agencies sometimes seek outside guidance when capacity to achieve their mission is limited. Through a cooperative agreement and collaborations with the U.S. National Park Service (NPS), we developed recommendations for a conservation program for migratory species. Although NPS manages ~36 million hectares of land and water in 401 units, there is no centralized program to conserve wild animals reliant on NPS units that also migrate hundreds to thousands of kilometers beyond parks. Migrations are imperiled by habitat destruction, unsustainable harvest, climate change, and other impediments. A successful program to counter these challenges requires public support, national and international outreach, and flourishing migrant populations. We recommended two initial steps. First, in the short term, launch or build on a suite of projects for high-profile migratory species that can serve as proof to demonstrate the centrality of NPS units to conservation at different scales. Second, over the longer term, build new capacity to conserve migratory species. Capacity building will entail increasing the limited knowledge among park staff about how and where species or populations migrate, conditions that enable migration, and identifying species' needs and resolving them both within and beyond parks. Building capacity will also require ensuring that park superintendents and staff at all levels support conservation beyond statutory borders. Until additional diverse stakeholders and a broader American public realize what can be lost and do more to protect it and engage more with*

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*land management agencies to implement actions that facilitate conservation, long distance migrations are increasingly likely to become phenomena of the past.*

**Keywords:** conservation, migration, national parks, planning capacity

Optimismo y Retos para la Conservación Científicamente Basada de Especies Migratorias Dentro y Fuera de Parques Nacionales de E.U.A.

**Resumen:** *Las agencias públicas a veces buscan ayuda externa cuando la capacidad de cumplir su misión es limitada. A través de un acuerdo cooperativo y colaboraciones con el Servicio de Parques Nacionales de E.U.A. (SPN), desarrollamos recomendaciones para un programa de conservación para especies migratorias. Aunque el SPN maneja ~36 millones de hectáreas de suelo y agua en 401 unidades, no hay un programa centralizado para conservar a la fauna silvestre que depende de unidades del SPN y que también migran a cientos y miles de kilómetros de distancia más allá de los parques. Las migraciones están en peligro por la destrucción del hábitat, la cosecha no sustentable, el cambio climático y otros impedimentos. Un programa exitoso para contrarrestar estos retos requiere de apoyo público, alcance nacional e internacional y poblaciones migrantes florecientes. Recomendamos dos pasos iniciales. Primero, a corto plazo, lanzar o crear una serie de proyectos para especies migratorias de alto perfil que pueden servir como prueba para demostrar la centralidad de las unidades del SPN para la conservación en diferentes escalas. Segundo, a largo plazo, crear una capacidad nueva para conservar a las especies migratorias. La capacidad de creación involucrará incrementar el conocimiento limitado entre los empleados de los parques sobre cómo y dónde las especies o las poblaciones migran, las condiciones que permiten la migración y la identificación de las necesidades de las especies y la resolución de esto tanto dentro como fuera de los parques. La capacidad de creación también requerirá asegurar que los superintendentes y empleados del parque en todos los niveles apoyen la conservación más allá de los límites legales. Hasta que varias partes interesadas y la mayoría del público americano no se den cuenta de lo que se puede perder y hacer más para protegerlo y se involucren más con agencias del manejo de suelo para implementar acciones que faciliten la conservación, las migraciones a larga distancia probablemente se vuelvan un fenómeno del pasado.*

**Palabras Clave:** capacidad de planeación, conservación, migración, parques nacionales

## Introduction

When public agencies lack sufficient scientific expertise to solve problems, they sometimes seek advice from outside parties who can contribute expertise and new or innovative approaches to complex issues. Examples include U.S. state agencies asking NGOs to help map rare species, U.S. agencies asking the National Academy of Sciences to conduct scientific and economic analyses of predator control (Orians et al. 1997), and appeals for assistance from all levels of government to universities. However, when requests concern conservation, actions beyond ecological science often are necessary.

In 2008, the U.S. National Park Service (NPS) sought help while developing an action plan to conserve aerial, marine, and terrestrial populations of migrating wildlife. They requested a collaboration "to provide the NPS with a long term approach to dealing with many of the issues facing migratory species ... and an approach to assessing the number of species and critical habitat and linkages for species that spend short and long periods of time within the boundaries of our parks." We agreed to this request in part because more than 100 years ago parks were admonished for establishing boundaries that failed to provide sufficient space for the needs of migrating animals (Hague 1893) and, more recently, for not doing more to accommodate members of species that move beyond NPS statutory boundaries (Berger 2003).

Although migration is an ecological process central to maintaining biological diversity, addressing NPS's request required us to consider attitudes and behaviors of individuals, society, and agencies. Our purpose in sharing our experience is to illustrate opportunities and limitations of conservation approaches. The questions, challenges, and potential solutions we present are relevant to many agencies other than NPS in which natural resource managers must grapple with extensive movements and migration of wild animals (henceforth, wildlife).

## National Parks and an Operational Definition of Migration

The NPS has over 400 units including internationally known parks such as Grand Canyon (Arizona) and Yellowstone (Wyoming, Montana, and Idaho). Collectively, NPS manages about ~36 million hectares of public lands and water for natural values. The NPS mission is "to conserve the scenery and the natural and historic objects and the wildlife therein and to ... leave them unimpaired for the enjoyment of future generations" (NPS Organic

Act 1916). Leaving the parks unimpaired is difficult because park boundaries do not move but animals do. Such dissonance leads to possible conflicts beyond protected area boundaries that involve wild species and human safety or economies.

Defining migration as the seasonal movement of the same individuals between two areas is generally accurate for species such as humpback whale (*Megaptera novaeangliae*), Arctic Tern (*Sterna paradisaea*), and Yellow Warbler (*Setophaga petechia*), and this definition is well understood by the public (Wilcove 2008). Biological complexity, however, dictates a different definition for some species (Dingle & Drake 2007). Monarch butterflies (*Danaus plexippus*) complete their northward migration across several generations (Brower 1995). Most anadromous Pacific salmon (Oncorhynchus *spp.*) migrate across freshwater, estuarine, and oceanic habitats (e.g., Gende et al. 2002). The females of numerous bat species migrate over long distances, whereas males remain behind (Medellin et al. 2009). Such diversity leads to an operational definition of migration: the cyclic movement of individuals or populations of animals across different ecosystems between seasonal ranges.

**Table 1. Central challenges to conserve migration in and beyond U.S. National Park Service units illustrated by different levels of sample questions that need to be answered.**

| *Challenges* | *Sample questions* |
|---|---|
| Philosophical | What should be conserved: migration phenomena or abundance; all, or some, migrations; existing migrations or active restoration of those lost; distinct migrations or the most common ones? |
| Migratory baselines | Which data are critical to conservation (e.g., historic routes)? Which NPS units are central to conserving migrations? What are the ecological risks (e.g., disease, parasites)? |
| Ecological knowledge | What questions are relevant (e.g., why do animals migrate and how variable are migrations)? Given climate uncertainty, how should conservation move forth? |
| Social knowledge | How will partners be involved? Who are the stakeholders? What are attitudes within and beyond NPS units? What roles do partners play? |

## Need for a Migratory Species Initiative

The phenomenon of wildlife migration to and from U.S. national parks has not been central to management policies despite current recognition that migrations are disappearing (Berger 2004; Harris et al. 2009). Interest in migratory species has however existed for some 125 years. In 1883, an American Ornithologists' Union committee investigated migratory patterns of birds, largely because many of them were perceived to be in decline. In 1979, the Convention on Migratory Species, under the auspices of the United Nations Environmental Program, recognized the importance of migrations across air, land, and water and facilitated initiatives aimed at protection. The Neotropical Migratory Bird Conservation Act of 2000, administered by the U.S. Department of the Interior, now provides grants to domestic and international partners for the conservation of Neotropical migrants that breed in Canada and the United States and winter in Latin America. Scientists working in NPS units have come to realize most parks are not sufficiently large to maintain viable migratory populations of many species (Newmark 1995; National Park System Advisory Board [NPSAB] 2012). Nevertheless, progress to enhance protection for migrants beyond NPS units has been limited.

Science informs park policies and operations, and managers use scientific information to reach decisions. Public perception, however, is also a strong modulator of wildlife policies (NPSAB 2012). Wildlife watching is a major public activity, and it offers some of the best opportunities to connect the public with nature. Migratory species, including at least 300 species of Neotropical migrant birds, comprise a large proportion of the wildlife that visitors to national parks see. In coastal parks such as Everglades (Florida) and Point Reyes (California), seasonal migrations are a primary draw for visitors. In NPS units, including the Channel Islands (California), Point Reyes, and Glacier Bay (Alaska), annual whale migrations are key attractions. Each year, several million visitors to Yellowstone National Park observe North American bison (*Bison bison*), pronghorn (*Antilocapra americana*), and elk (*Cervus elaphus*)—ungulates that historically migrated to lower elevations outside the park during winter. The public invests time and money in viewing species in residence or during migration events, yet perhaps they do not appreciate the large area over which conservation action is necessary to ensure that such opportunities for watching animals in parks persist.

## Challenges

The challenges of conserving migratory species that use national parks—and the reasons they are typically not emphasized in management plans—are complex and involve philosophical, ecological, and social questions (Table 1). In the absence of answers to such questions, most of which will require much work, conservation gains will be limited.

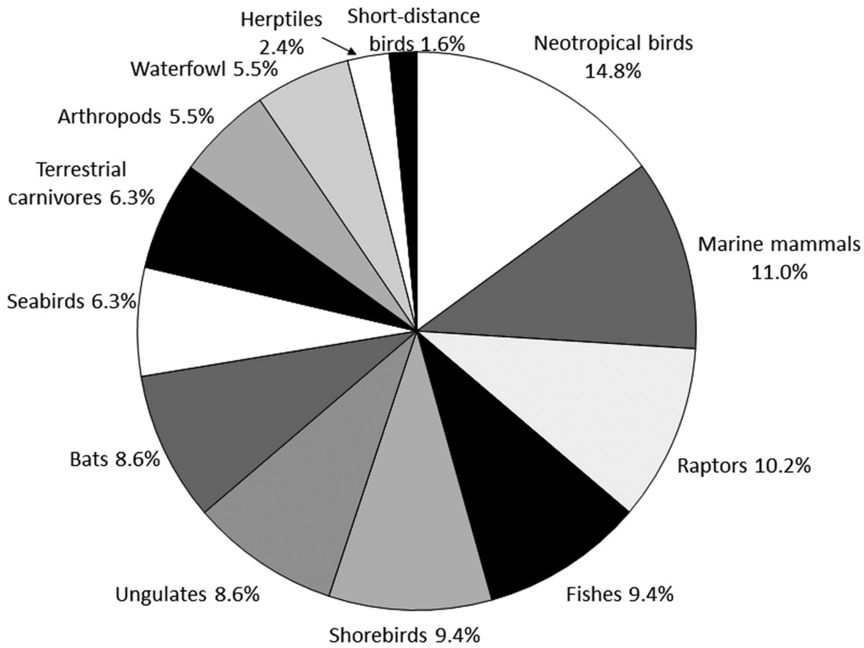


*Figure 1. Taxonomic classes of migratory species dependent on one or more U.S. national park units. Classes based on responses by National Park Service (NPS) personnel (*n *= 125) to the following request: "Please list the common names of species or groups of species (Neotropical birds, etc.) whose migration is completely dependent on the NPS unit you represent, e.g., migration could not occur without this site."*

Bison are a striking example of the challenge of conserving even well-known species that move beyond a protected-area boundary. The last free-roaming populations of bison in the United States were centered in the Montana–Yellowstone region when, in 1872, Yellowstone was designated the nation's first national park. Twenty years later, when most land was still not privately owned or populated, it was already clear that even parks the size of Yellowstone (8983 $km^2$) were insufficient to accommodate migrations, and naturalists argued for an adjustment of park boundaries (Hague 1893; Hornaday 1913; Supporting Information). Today, bison are largely restricted by humans to the park and, due to concerns about brucellosis (a bacterial disease that affects reproduction in wildlife and livestock), economic damage to private lands, and human safety, herded back or shot if they venture beyond park borders (Plumb et al. 2009). Parks such as Badlands and Wind Cave (both in South Dakota) have built fences around areas with bison to prevent their roaming. Conservation of migrations of these and many other taxa either in or beyond national parks has never been addressed systematically.

Some aspects of the ecology of migratory species remain poorly understood. For instance, there is a deficit in knowledge of interactions among migratory species and diseases such as avian influenza, whirling disease, and sylvatic plague, which affect birds, fishes, and mammals, respectively. Diseases carried by migrants affect species that occur in parks and humans (Karesh & Cook 2005). Corridors that may facilitate migration among park units may also increase disease risks to animals or humans in parks (Hess 1996).

## Building an NPS Migratory Species Initiative

Given our goal of suggesting how NPS might construct a conservation program, the Wildlife Conservation Society (WCS), led by K.E., surveyed NPS personnel to examine their knowledge of migrations and threats to them. Understanding the state of knowledge, even informally, could aid in planning a set of actions. If, for instance, much was known about migrants per se and associated threats, priority-setting exercises to address a range of mitigation measures might commence. We recruited participants in the voluntary survey through NPS administrative memoranda and internal NPS Web pages. We received responses from 125 personnel based at 154 parks, including parks within all 32 ecoregions that are part of a long-term NPS monitoring program (Vital Signs) (Fancy et al. 2009). Eighty-one percent of respondents identified themselves as biologists and 19% identified themselves as administrators. Percentages below may sum to >100% because some response categories were not mutually exclusive.

Respondents listed diverse migrant species that use the NPS units where they were based (Fig. 1) and identified migratory routes that extend beyond the boundaries of those units. Respondents also indicated that habitat loss (49%) and climate change (25%) outside of NPS boundaries may threaten viability of migratory species that use the NPS units where they were based (Fig. 2). Roads (59% of respondents) and recreation (52%) were perceived as the greatest threats to migratory species within the parks where the respondents were based. There was a nearly 4-fold difference in the perceived threat of climate change



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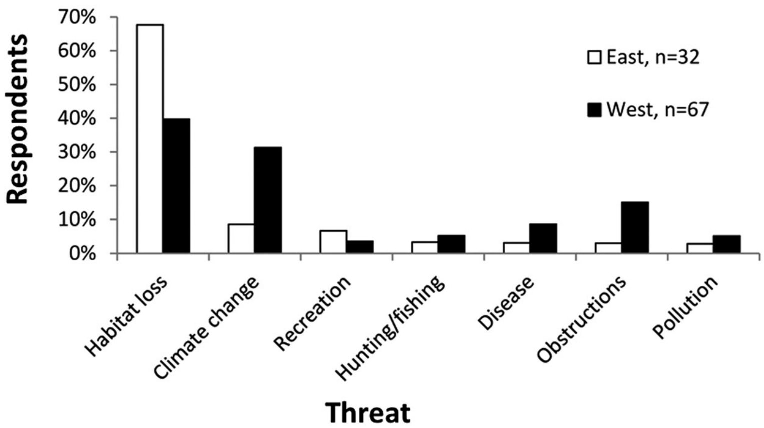


*Figure 2. Percentage of respondents identifying 1 of 7 threats as the greatest threat to migratory species. Ninety-nine NPS employees in the eastern (east of 101°W) and western (west of 101°W) United States were asked to "Rank the most important threats to migratory wildlife that use your NPS unit (from 1 to 7, with 1 being the most important)." Threats are listed on the x-axis from the greatest (habitat loss) to least threat (pollution).*

to migratory wildlife among responders from NPS units in the western United States (i.e., west of 101°) (31%) versus those from the eastern United States (8%). A greater percentage of respondents from the eastern (68%) than from the western (40%) United States indicated that habitat loss was the greatest threat to migratory wildlife in their units (Fig. 2). Nearly 80% of survey respondents were aware of current research aimed at identifying specific migratory pathways. In response to the question, "Are there any efforts currently underway to protect migration corridors/pathways inside or outside the NPS unit you represent?" a much smaller percentage (24%) listed examples.

When asked to share information they thought was pertinent to conservation of migratory species by the NPS, 67% of respondents noted a lack of coordinated measures to conserve migratory species within and outside park boundaries. Examples of such statements included, "We cannot protect most migratory species with our actions within our individual units. The protection must be across boundaries, region-wide, and we must expect that some migration patterns will change with climate and habitat change," and "Not enough is being done now to coordinate with neighboring state and county agencies to protect migration corridors for terrestrial (plant and animal) species, now and in the face of climate change." Other respondents pointed to the diversity of threats to migratory wildlife, from dams and fish harvest outside NPS units to absence of protection of stopover sites for birds.

Beyond NPS units, no clear infrastructure exists to facilitate migration, although the 1916 National Park Service Organic Act arguably established the necessary policy and legal mandate for doing so (Keiter 2010). Internally, recognition to cooperate beyond boundaries for the protection of migratory species is formally recognized (Management Policies 2006), and this recognition provides for NPS cooperation, including the spending of appropriated funds, outside park boundaries (Consolidated Natural Resources Act [CNRA] 2008). Moreover, clear precedence exists for NPS participation in public and private partnerships (e.g., Rivers, Trails, and Conservation Assistance Program; Wild and Scenic Rivers; Trails and Rails; National Natural Landmarks Program; and Heritage Partner Programs). In recent years, migration has been addressed through collaboration between NPS and partners. For example, in 2008 the first U.S. wildlife migration corridor was established by the U.S. Forest Service in cooperation with Grand Teton National Park in Wyoming, U.S. Fish and Wildlife Service (USFWS), Bureau of Land Management (BLM), and private landowners (Berger 2004; Berger et al. 2006). In September 2011, a partnership among Olympic National Park (Washington), Bureau of Reclamation, Lower Elwha Klallam Tribe, local and state governments, and public interest groups directed the largest dam removal in U.S. history (the 33-m Elwha dam) to restore migratory salmon populations (http://www.nps.gov/olym/nature science/elwha-ecosystem-restoration.htm). In February 2012, agreements were reached among numerous agencies and private landowners to amend the Interagency Bison Management Plan and allow bison to migrate north from Yellowstone National Park and access 30,000 additional hectares of winter habitat (http://fwp.mt.gov/news/publicNotices/decisio Notices/pn_0555.html).

### Short-Term Demonstration Projects and Feasibility of Protecting Migrations

To build on these recent partnerships and develop a migratory species initiative, we identified an opportunity for NPS and partner organizations to implement a small number of projects to improve management of migratory species or fill information gaps. Besides yielding rapid results, these pilot projects may provide transferable lessons for a more comprehensive effort and build credibility for a migratory species initiative within and outside the NPS. We proffer two examples of partnerships and a case in which a migration was protected.

The NPS and USFWS cooperated to conserve Kittlitz's Murrelet (*Brachyramphus brevirostris*), a small, rare seabird that occurs only in parts of Alaska and Russia (Day et al. 1999). About 10–30% of the world's population occurs within and adjacent to Glacier Bay, Kenai Fjords, and Wrangell-St. Elias National Parks during summer (USFWS 2005). Nearly nothing is known about the species during its 8-month (September–April) nonbreeding season (Day et al. 1999). The murrelet's movements typify high-latitude migrants that breed in Alaska's coastal parks during the summer: they arrive in early May, are most abundant in July (Kissling et al. 2011), and depart by late autumn. Anecdotal information suggests individuals migrate along the Alaska Peninsula during autumn and overwinter along the ice margins in the Bering Sea, but specific habitat, staging areas, and migratory timing and routes are virtually unknown.

Understanding migrations and winter habitat is relevant to conservation of Kittlitz's Murrelet because core populations of the species, including populations within or adjacent to U.S. national parks (van Pelt & Piatt 2003; USFWS 2005; Kissling et al. 2007), have declined. The USFWS is considering whether to propose listing the species under the Endangered Species Act. The collaboration between NPS and USFWS aims to identify factors limiting population growth by quantifying overwinter survival with the first mark-recapture effort for this species. The USFWS has deployed several satellite tags on murrelets in and near national parks that will help document migratory routes and, potentially, overwintering areas. Such information is fundamental to address threats, including those to migration routes with end points in the Bering and Chukchi Seas, where resource extraction and shipping activity are increasing.

The second pilot project was initiated in 2011 at our recommendation. The WCS, NPS, and private landowners are collaborating to deploy geolocators (small, lightweight receptors attached to an animal that logs its movements until data are downloaded after an animal is recaptured) on grassland birds. Receptors are fitted to birds in their breeding grounds and record the birds' locations, which include those along their migration routes. As a group, grassland birds have exhibited the most precipitous decline among North American birds (NABCI 2009). Declining species include Sprague's Pipit (*Anthus spragueii*), Chestnut-collared Longspur (*Calcarius ornatus*), and McCown's Longspur (*Rhynchophanes mccownii*), each of which breeds in the northern Great Plains and migrates south to wintering grounds across northern Mexico and the southwestern United States (NABCI 2009). Understanding migratory movements will help the NPS clarify the extent to which the species use their units within the Great Plains and help identify where conservation intervention is most needed. As in the murrelet example, NPS and partners have facilitated assessment of habitats beyond their boundaries as a first step for developing conservation plans.

Path of the Pronghorn, an NPS collaboration, has already resulted in unprecedented protection of a migratory species (Cohn 2010; Hannibal 2011). Pronghorn are the longest-distance terrestrial mammal migrant in the conterminous United States, and parks are too small to encompass their seasonal movements (Berger 2004). From their summer habitat in Grand Teton National Park, 300 to 400 pronghorn migrate through an invariant 2 km wide, 70 km long path to winter grounds far south of the park; one-way movements reach up to 350 km (Berger et al. 2006). Efforts to formally protect the migration corridor beyond Grand Teton culminated in a 2008 amendment to the Bridger-Teton National Forest Plan. That amendment was driven by multiple meetings among agency staff and stakeholders, and nearly 20,000 responses were received during the public comment period before its adoption. Media coverage at local, national, and international levels, coupled with public support, open commentary, and most critically local officials' attention beyond their statutory jurisdiction, resulted in the pathway's protection (Hannibal 2011).

### Components of a Long-Term NPS Migratory Species Initiative

We suggested to NPS that a long-term migratory species initiative by NPS could include four components: data compilation (including research), capacity building, outreach and education, and habitat conservation and restoration. We recommended four data-compilation actions. First, identify all species that are seasonal residents in or that pass through NPS administrative units. The compilation could be hosted and maintained by the existing NPS Inventory and Monitoring Program. Second, identify habitats of migrants. Collect information on ecosystems in NPS units that provide resources for migratory species, distributions of those species, and the extent to which such ecosystems can sustain migrants without extensive management outside parks. Third, establish a basis to identify threats to migratory species inside and outside park ecosystems. Although NPS recognized formally its intention to conserve migrants across boundaries (Management Policies 2006), a stronger focus on such an effort would enable a basis for NPS to identify threats that affect migrants, from habitat loss and fragmentation to climate change (Jenni & Kery 2003; Both et al. 2006). Fourth, set priorities. Using information on migrants, threats, and habitats, prioritize migratory species and decide on next steps for engagement. Such an exercise would force decisions (Table 1) about allocation of conservation interventions among taxonomic groups and species, ecological scales and processes, and NPS units.

Building internal and external capacity is requisite for any new initiative in any organization. Although our survey demonstrated much was unknown about migrations within parks and threats to migrations, we did not address whether park biologists and managers understand why migration affects viability. Regardless, it will be critical to maintain or develop capacity at higher administrative levels because without local, regional, and national support for a migration program within NPS, little will be achieved. It is also critical to identify external stakeholders after a suite of priority migratory species or interventions are determined. Stakeholders might include state wildlife agencies, federal agencies (e.g., BLM, U.S. Forest Service, USFWS, and Department of Defense), indigenous landholders, international partner agencies (e.g., Trilateral Committee of Wildlife and Ecosystem Conservation and Management), private landowners, and nongovernmental partners.

High-priority outreach and education actions include convening workshops to identify and develop projects with collaborators, synthesis of results and insights across the NPS and its partners, and development of educational materials. The NPS has ready and able partners in another agency within Department of the Interior, the USFWS, for which migratory species already are a priority (http://www.fws.gov/info/pocketguide/fundamentals.html) and in state wildlife agencies, many of which are transitioning from an emphasis on hunting and fishing to conservation of diverse species as identified in state wildlife action plans (www.wildlifeactionplan.org). Many of these state plans identify migratory species among species of greatest conservation need and outline strategies and actions to conserve habitats for migratory species. Finally, with an annual average of ~281 million visitors to NPS units (2008–2012) (NPS 2013), an enormous opportunity exists not only to educate the public on migrations, but also to foster development of a sense of stewardship for migratory species.

The single most important component of an NPS migratory species initiative is conservation of habitats for migratory species. We identified three actions that could be taken. First, encourage functional (not statutory) expansion of park boundaries through voluntary cooperation and develop management agreements with adjacent landowners. The fragmented system of national parks is not sufficient to maintain migratory species or processes. Establishing cooperative management action, placing lands or waters under conservation easement or lease, and working with land trusts to establish new conservation areas through fee acquisition or easement are effective and probably more feasible than expanding parks' administrative boundaries for conserving habitats of migratory species near parks.

Second, link conservation efforts for migrants with other conservation objectives. Efficiently selecting sites for conservation requires that multiple goals be pursued. For example, conservation of migration corridors might also provide habitat for rare species and contribute to their conservation (Moilanen et al. 2009). Increasing connectivity among conservation areas—one approach to address effects of climate change—may also benefit migratory species because in the absence of connected landscapes populations are more susceptible to local extirpation (Hilty et al. 2006).

Third, improve ecological management of existing park lands and waters. Sometimes migration can be maintained simply by changing management practices to assure connectivity of lands or stopover sites. For example, impediments to migration of some species can be reduced by removing dams or by temporarily closing, eliminating, or building wildlife crossings under or over migration barriers such as roads.

## Finding Support for Conserving Migratory Species

Literally and symbolically, NPS lands have been among those at a historic core of wildlife protection in the United States. Yellowstone, the world's first national park, is touted internationally as an exemplar for building cooperation across landscapes to conserve some migrants (Hannibal 2011). Approaches of possible partners beyond the boundaries of formal parks also offer cause for optimism. In 2007 the Western Governors' Association unanimously passed Resolution 07–01, which asserted, "... protecting wildlife migration corridors and crucial wildlife habitat in the West ... " will be a driving goal, a strategy created in part because of effective outreach that touted migrations at state gubernatorial levels (Hannibal 2011). More recently, the USFWS has facilitated landscape conservation cooperatives (i.e., collaborations among nongovernmental organizations, universities, states, federal governments, and Native American tribal groups) that further private–federal partnerships with a tacit goal of protecting migrations (Austen 2011). Local initiatives from around the world (such as Path of the Pronghorn) also serve as models of success, and with acceptance from the local populace these may be more effective than top-down approaches to assure long-term conservation of migrants (Schaller 2012).

The action plan we presented in response to NPS's request to formulate a strategy to better conserve migrations built initially on natural science while recognizing success will not be achieved unless internal capacity is strong at high levels of NPS. All new plans require funding and, often, subtle if not dramatic changes in operations. Because funding always seems limited, real progress can stem from only a few sources. The public is the critical source because the public's voice is central in shaping policy. The NPS units attract as many visitors annually as do professional American baseball, basketball, and football games combined. If the public becomes a strong advocate for decisive action to conserve migratory wildlife, then our recommended program may have a greater probability of being developed and implemented.

It is worthwhile to ask what has changed within NPS with respect to conservation of migratory species during the period since the request for our assistance. As outlined above, the NPS has not only participated in projects such as Partners in Flight, but also adopted pilot projects beyond their statutory boundaries on migratory marine and grassland birds to explore possibilities on how to better protect migrants. Additionally, NPS hosted workshops on migration to which NPS superintendents were invited and that some attended, and NPS built a Web site with facts about migration. Most notable perhaps was a 2-year planning effort of an independent committee of non-NPS scientists that suggested how NPS might address future science in parks. Among the committee's recommendations was that NPS work with stakeholders to enhance connectivity and to facilitate migrations beyond park boundaries (NPSAB 2012).

Conservation in the United States has changed from protection of scenic landscapes and monumental features within static parks (Runte 2010) to maintaining species and ecosystem resilience within dynamic landscapes. Change in institutions is slower than changes in understanding within the scientific community, but we believe the NPS has the potential to work productively with stakeholders to develop coordinated cross-boundary initiatives to conserve migratory species.

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## Supporting Information

A preliminary survey of migration knowledge among National Park Service Units is available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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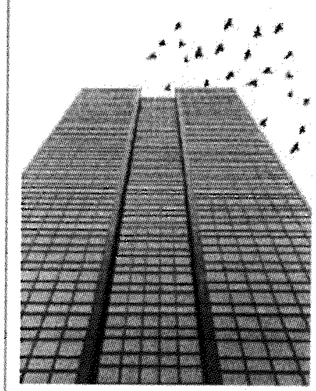
# Collision Course | Zoology | Science News

**Scientists struggle to make windows safer for birds**

By Susan Milius

Web edition: September 5, 2013
Print edition: September 21, 2013; Vol.184 #6 (p. 20)

Ornithologist Christine Sheppard, frowning as if she's lost something, squints into the darkness of a 30-foot-long contraption. It looks like a stretch-limo version of a garden shed, but one end sports high-tech glass available only from an industrial R&D lab. From a hole at the other end dangles a child's pajama leg.



Credit: Building: labsas/iStockphoto; Birds: Blackred/iStockphoto

What Sheppard has lost is a song sparrow. She is using the tunnel contraption to test whether birds will fly into the piece of glass at the end. Since birds often don't see glass and fly right into it, Sheppard hopes to test whether stripes or other markings on the glass can warn birds away from a fatal impact. The pajama leg provides a soft chute to slip a sparrow or other bird into at the dark end of the tunnel. The bird flies toward the light-filled windows at the other end, and at the last instant a hair-fine net in front of the glass prevents a collision.

This setup, at Powdermill Avian Research Center in Rector, Pa., is one of three in the United States testing ways to prevent birds from flying into glass. According to one oft-quoted estimate, window crashes account for up to a billion bird deaths a year in the United States alone.

Creating no-crash glass has turned out to be much trickier than it sounds. The researcher behind the first U.S. glass-testing setup for birds, ornithologist Daniel Klem Jr., has been working on the issue for about four decades. His is a tale of the perils of applied science, from "aha" moments to entrenched public resistance and commercial disinterest. Basic research on bird vision has flourished, shedding light on what birds can and can't see, but translating neuroscience into safer window designs and getting them adopted is not so easy.

Ironically, the green building movement of recent years has made landscapes even more dangerous, Sheppard says. Efforts to shave energy costs by letting in more natural light have meant more glass for birds to collide with. But now she's working with architects and glass companies in ways that may at last hatch a market for bird-safe products. Tests show that opaque stripes or dots on windows can reduce bird kills, if people are only willing to use them.

But both Sheppard and Klem have been searching for the Holy Grail of bird safety: windows with patterns that birds can see but that are invisible to people. It is not an exact science. So far this morning at Sheppard's tunnel, one test subject darted out an uncapped observation hole instead of completing the test flight. A crow just walked down the tunnel. The lost song sparrow has caused a temporary halt in tunnel operations. The bird is free to fly through the open door, but it's lingering inside in the cozy darkness. Sheppard grabs a long-handled net and is preparing to clamber into the tunnel herself when — whoop! — the sparrow flies.

View larger image | Above are a few U.S. bird species often found dead after flying into glass, according to surveys by wildlife groups in Washington, D.C., and Chicago.

Credit: Top row, from left: StevenRussellSmithPhotos/Shutterstock; Steve Byland/Shutterstock; Steve Brigman/Shutterstock; Bottom row, from left: WilliamSherman/iStockphoto; PaulReevesPhotography/Shutterstock; Gerald Marella/Shutterstock

**Population unknown**

It's hard to find a good number for just how many birds die in window collisions. Klem is the source of the numbers stating that U.S. windows kill 100 million to 1 billion birds a year. "I blatantly and openly tell you they're estimates," he says.

Klem's numbers are based on his 1990 estimates of the number of birds a typical building kills annually (between one and 10) and the number of buildings in the United States (based on 1986 data). Now Scott Loss of Oklahoma State University in Stillwater and colleagues are creating a new estimate using data on per-building mortality rates from 23 studies.

Whatever the new estimate is, there will be debate over what it means for total bird populations. Many species of North American birds are declining in numbers, but they also face degraded habitat, pollutants, invasive species, wind turbines and other hazards. The scale of the hazard windows pose won't be clear without comparable studies of local populations, Loss and colleagues argued in 2012 in *Frontiers in Ecology and the Environment*.

For ornithologists and bird lovers, though, buildings that kill wildlife are disturbing regardless of total population impact. Architect Anne Lewis leads City Wildlife project volunteers who get up before dawn to walk through downtown Washington, D.C., documenting birds that have crashed against glass. Sometimes she picks up stunned birds, placing them in paper bags to rest before being released in leafy parks far from dangerous glass. "Sometimes they die in your hand," she says. "It makes a believer out of you."

Daniel Klem (left) has been trying for decades to convince people to use simple bird-safe methods like the decoratively coated glass behind him. Christine Sheppard (right) tests birds' reactions to new kinds of glass in her testing tunnel.

Credit: From left: Bill Uhrich/Hawk Mountain; S. Milius

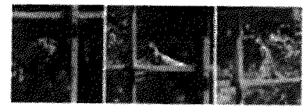
**Bird safety basics**

Witnessing bird collisions made a believer out of Daniel Klem while he was still a graduate student. One day in 1974, he sat down on a bench in front of the mirrored-glass chemistry building at Southern Illinois University Carbondale. "It only took about 20 minutes," he remembers. A mourning dove thumped against an upper story of the building so hard that feathers scattered, and the bird dropped to die on the ground.

At the time, no one knew why birds fly into glass. A 1931 scientific report on yellow-billed cuckoo crashes treated the deceased as "rare, self-destroying incompetents," says Klem, now at Muhlenberg College in Allentown, Pa. As the building boom after World War II fed demand for picture windows and glass walls, accounts of birds crashing into windows surged. So did speculations on the cause. Perhaps the birds just didn't understand glass. Or their eyes were bad. Or sun glare, mist or smoke temporarily blinded them. One report even suggested the birds were drunk on fermented fruit.

Klem began to set up experiments. He propped panes of clear and mirrored glass against tree trunks at the edge of the woods on his adviser's property, and he built a 12-foot Masonite tunnel, the first ever for testing windows. Birds flew toward a pane of clear glass as readily as through an empty window frame, showing no sign they could tell glass from air.

"It's the glass, stupid," is Klem's sloganized conclusion. Birds just don't see clear glass as an obstacle. Reflections may even lure them toward what appear to be trees, grass or other shelter that actually lie behind them.



Reflections not only cause collisions but also affect behavior. This cardinal crashed repeatedly, though not fatally, into a window, defending its territory from a reflection.

Credit: John Scherr

To see how people might warn birds away from glass, Klem began testing bird-deterrence markings in his tunnel. He compared a plain pane with glass adorned with something: stripes, silhouettes of predators or even blinking lights. (A lone predator decal is useless.)

His results helped establish what's now known as the two-by-four rule. Most birds won't fly through a space less than 4 inches wide between vertical stripes or 2 inches high between horizontal stripes.

This finding has had conspicuously little impact on offices, homes, airports, bus shelters and the rest of the increasingly glassy world. The failure has little to do with the birds or the experiments. "People told me time and time again, 'You know, Dan, you go mucking around with the way people look through their windows, and you're going to lose,' " he says. Any pattern obscuring a view means counterintuitive marketing for anything but bathrooms.

Then came a *Nature* paper in 1978 from prominent ecologist Thomas Eisner of Cornell and a colleague reporting evidence that homing pigeons react to real-world ultraviolet light. "From the very instant I read about it, I was excited," Klem says. "I was beside myself, thinking this could be the Holy Grail."

People can't see the very short wavelengths, from 100 to 400 nanometers, that make up ultraviolet light, but it turns out that pigeons and many more birds can. In theory, window patterns that show up only in UV could warn birds of a no-fly zone while giving humans a clear view.

But after the initial thrill, Klem says, "I realized there wasn't any way for me to test this." He contacted glass companies, people who might know product developers, people who might know people, searching for a material that reflects UV wavelengths but not others. He found a lot of UV absorbers, but no useful UV-only reflectors. He refers to this period as a "time when I was in this frustration — which was most of the '80s and the '90s."

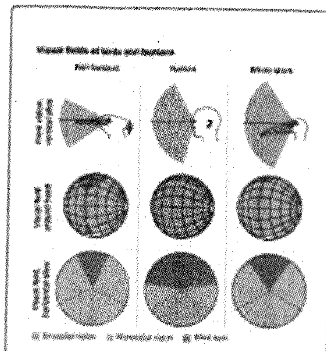
Eventually a chemist who developed window films for cars happened to hear a radio interview with Klem, and as a side project devised a UV film that reduced bird crashes. The chemist's company deemed the project financially untenable, though, and yet another attempt to finance it has fallen through within the last year. A few other companies are now testing and even marketing UV-reflecting products such as decals and glass.

As for testing the effectiveness of such products, Klem argues that tunnels are "informative but not completely reliable," because they are not very accurate mimics of windows in actual buildings. Instead, he mounts glass to be tested and clear glass for comparison in frames, shuffling positioning to counteract quirks of lighting or location. He scores effectiveness by comparing numbers of carcasses or smudges on each pane. He omits nets, he says, because they can be visible from some angles and in some lighting, distorting results.

He's far from the only scientist to sacrifice animals in a study. "It's a part of the work that I grimace at," he says.

He tells his students that when extraterrestrial scientists finally reach Earth, it's only fair that he volunteer as their specimen. But unless he can trust that his results are realistic, he says, he runs the risk of "sanctioning something that is continuing to kill animals."

For decades, mainstream ornithology wasn't exactly ignited by Klem's interest in window glass, and a 2003 magazine profile called him "the Rodney Dangerfield of ornithology." As far as a widespread awareness of collision hazards that fuels a broad resolve to change windows, "we're still quibbling," he says. "I'm an educational failure."



Where birds see

View larger image | With eyes on the sides of their heads, birds have a different field of view than humans. Africa's Kori bustards have a narrower vertical range of binocular vision than people or storks. If a bustard looks 25 degrees down, it has a blind spot to its front. The middle row shows areas of each vision type surrounding each animal's head, facing the center of the yellow binocular zone. The bottom row shows a slice through the equator of those spheres, showing humans' large rear blind spot compared with birds.

Credit: Modified from G.R. Martin; adapted by S. Egts.

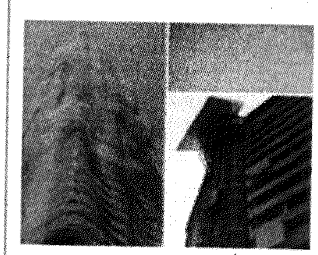
**Bird's-eye view**

While Klem struggled with window treatments, basic research on avian vision flourished, with ever more precise analyses of eye structure, nerve responses and which genes turn on when. These scientists haven't been talking to people like Klem who work on practical problems, says Graham Martin of the University of Birmingham in England.

And if they were to talk, it's not clear what they could say except that designing a UV pattern to warn a bird about glass could be difficult.

For one thing, most birds' eyes are on the sides of their heads. "Birds have got this fantastically comprehensive visual field," Martin says, "but the best vision for most birds is actually out sideways."

In some big birds, such as eagles, bustards and the two vulture species Martin reported on in *Ibis* in 2012, a gap between the left and right visual fields creates a blind spot to the upper front. "As soon as they start to look down, they're effectively flying blind," Martin says.



View larger image | Bird-safe can be beautiful, advocates say. Chicago's Aqua Tower (left) has textured (or fritted) glass and balconies limiting birds' view of windows. Other strategies include UV-reflecting patterns (Ornilux glass, top right) and window shades (bottom right).

Credit: Clockwise from top left: Chicagogeek/Flickr; Ecombetz/Wikimedia Commons; Sali Sasaki/Flickr

This gap means these birds may not see an obstacle ahead, nor would they see warning patterns ahead. "They're flying with the assumption — that has been a pretty good one for the last God knows how many millions of years — that there won't be anything sticking up in the way," Martin says.

Songbirds, which are more often killed by windows than are the big scavengers and birds of prey that Martin studies, do not have this big frontal blind spot. But even for them, "forward vision is not so good," Martin says. Birds, like people, typically get their sharpest view in the center of the eye's field of view. For side-eyed birds, that's to the side. Martin predicts that patterns to the front probably need to be extra bold for birds to notice them.

Another problem in creating bird-visible patterns is that birds are not as sensitive to contrast as people are. For a typical bird to pick out a grayscale pattern, the contrast between grays has to be about 10 times greater than it would for a human observer, says Almut Kelber of Lund University in Sweden.

There are other problems specific to developing UV-reflecting patterns. Even one of the commonly repeated examples of birds seeing UV signals in nature may not be true, Kelber and her



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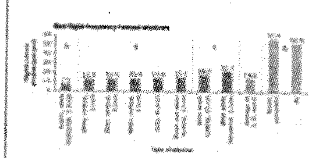
colleagues argued in May in the *Journal of Experimental Biology*. A 1995 paper had proposed that birds of prey track voles in Finland by catching the UV glimmer of their urine dribbled across the landscape. Kelber found that lenses and fluids in the eyes of kestrels filter out much of the UV. And in any case, the voles Kelber's team tested didn't pee in ultraviolet. This doesn't mean that other birds have trouble seeing in UV. But Kelber cautions against generalizing about bird vision based on the small number of species that have been tested.



Glass houses

View larger image | Researchers in Austria tested nearly 800 bird flights toward windows covered with stripes, dots or no marks (listed above with distance between markings). The results are grouped from most bird-safe (A) to least (C). Acrylic panes, or Plexiglas, containing thin black horizontal filaments were the top performer. In other tests (D), birds were at least as likely to fly toward unmarked acrylic as toward an empty window frame.

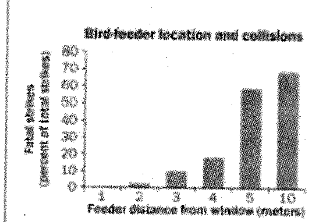
Credit: Source: M. Rössler et al/Boku Vienna 2009

What's more, perceiving ultraviolet patterns while in motion "might be impossible for birds," says Daniel Osorio, a color vision expert at the University of Sussex in England. The part of the bird's midbrain that analyzes motion receives information from cells in the eye that aren't sensitive to ultraviolet, current evidence suggests.

Neither Osorio nor Martin is optimistic about UV-reflecting patterns after attending a symposium on birds and glass at a September meeting of European ornithologists. Birds may not sensitive enough to UV to detect a warning pattern on an actual window, researchers suggested at the meeting.

**Build it**

Experiments on birds won't do any good if there's no market for the results, though. So Sheppard is taking her case to architects and glass manufacturers. Her testing tunnel results are now what some companies rely upon to rate the safety of new kinds of glass for birds.




Feeding bird deaths

Bird feeders can draw birds toward windows, but are less deadly if placed within a meter of glass. Birds may be drawn to the feeder instead of windows and are not flying as fast if they hit a window while flying away.

Credit: D. Klem et al/Wilson Bulletin 2004

For the first two decades of Sheppard's ornithology career, she didn't bother with experiments since she had an obviously successful device: soap.

When she finished her Ph.D. and went to work for the Wildlife Conservation Society's Bronx Zoo, the staff routinely smeared soap on any expanses of glass surrounding a new bird on exhibit. The newcomer would avoid the solid-looking windows. Once it learned its way around, the staff would wash off the soap.

Then the zoo planned to build a new Center for Global Conservation and turned to Sheppard for advice on keeping the building from becoming a bird killer. The moment she found an Internet reference to a nonlethal contraption in Austria for testing glass, she decided to build one.

She now has one testing tunnel at Pennsylvania's Powdermill Nature Reserve and a new one at the Bronx Zoo. She also has what may be the only job in the world devoted to making buildings safe for birds, at the American Bird Conservancy. She has made trade-offs in experimental design different from those in Klem's work. Sheppard's controlled flights in tunnels give results from a large number of test birds of known species, without harming any. But the birds fly from a dark tunnel toward a light-filled window, which isn't what usually happens in real life. "I'm not trying to be realistic," she says. "I'm testing patterns."

Opaque dots and stripes covering as little as 5 percent of glass surface can prevent 90 percent of collisions, she says (see sidebar). What architects dream about, though, are patterns invisible to humans, and those are harder to develop. Ornilux, made by Arnold Glas in Germany, carries subtle, irregular crisscross bands that reflect UV. This glass tested as bird-visible in Sheppard's Powdermill tunnel. For Klem, the protection worked only if there was less light behind the window than in front of it, he and a colleague report in the June *Wilson Journal of Ornithology*. Though Sheppard and Klem emphasize different elements of experimental design, both acknowledge that lighting and other conditions vary in real life. "Architects need to take our results, along with what we know about reflections, and make informed decisions," Sheppard says.

In another of Sheppard's tests, panes with tiny white dots on the glass surface didn't seem to alert birds to an obstacle. Birds were almost as likely to veer toward a panel as away from it. Increasing the density of the dots — which made more of the glass opaque — helped. It looked like a simple case of covering more surface area.

But then Sheppard tested glass panes with eighth-inch-wide lines instead of dots. Glass marked with either vertical or horizontal lines scored much better than the dotted panels — even though the lines covered about the same small fraction of the surface. "It became very clear it's not simply the coverage," Sheppard says. Within certain limits, stripes appear to be more effective for their size than dots as practical warning signs on buildings.

To get any of these solutions in place, "you have to get to the architects," Sheppard says. She helped the Green Building Council develop a way to calculate a building's lethality to birds. In 2011 they began a pilot program to add a collision-deterrence credit to the LEED program, or Leadership in Energy & Environmental Design, which certifies buildings as environmentally responsible. To get the credit, architects have to minimize clear panes, and their see-through acreage can expand in proportion to how well the glass performs in Sheppard's tunnel test.

One spring day at the Powdermill bird-banding station, a pane with a UV pattern (Sheppard can't say more about the proprietary material) sits in the testing slot beside regular glass. At this time of year, the bird-banding crew starts at 5 a.m. six days a week, trooping through shrubbery every half hour to check the nets that capture birds to be banded and tested. Birds hang in dark clots of tangled threads. In dozens of quick miracles, banders unsnarl them and fit each bird into its own beige cloth bag. To keep their hands free, the banders clip each bag to a cord around their necks, creating broad necklaces that occasionally twitch.

Thus dressed, the crew strides back to a snug room. Hands slide into anonymous beige bags and emerge with delicate creatures, the technicians working with the intensity of a surgical team to measure birds as quickly as possible.

Sheppard and technician Matthew Webb, hovering on the edges of the controlled rush, accept a bag and step across the station's yard to the glass-testing tunnel. Webb pulls out a yellow warbler, brilliant as a daffodil and only somewhat bigger. Webb squints at the numbers on its leg band, reads them into the video recorder and slips his handful of bird into the tunnel. Seen from outside, there's just a man with one arm down a pajama leg.

The actual test is so fast, just two or three seconds, that it's almost anticlimactic. Webb, watching the small screen of the video recorder aimed into the tunnel, suddenly pronounces "indirect right," and it's over. The warbler has swerved and ended up on the right, flying away from the UV-treated glass. Sheppard opens a large door, and in seconds a yellow dot of warbler blurs off toward the shrubs.

Across the yard, windows in the banding station carry fleets of translucent tape, with admirable two-by-four spacing. They shouldn't be a menace to the warblers, sparrows, kinglets, wrens, flycatchers and literally hundreds of other travelers darting through the woods. But after starting to think about glass, it's hard to stop. Just down the road in the town of Donegal, more windows loom in the houses, the Dairy Queen, the turnpike tollbooths. So many windows, and still so few stripes.

### Bird-safe by law

In some places, regulations are beginning to encourage or require more bird-safe architecture. Minnesota mandates that buildings that receive state funds include certain bird-safety features in plans for environmental friendliness. Since 2011, buildings in San Francisco's bird-rich areas near parks or water must meet avian safety requirements, and Oakland, Calif., this year added a layer to its building permit process requiring feasible improvements in protective measures for birds.

Toronto has been a center of activity for bird-safe buildings, with pioneering regulations, and this year an unusual lawsuit. A major property company, Cadillac Fairview, ended up in court because the massive glass facades on its Yonge Corporate Centre were killing birds.

The company was acquitted this year after, the decision noted, installing window-taming treatments that cost about $100,000. The judge stated that emissions of reflected light from windows causing bird crashes should be considered violations of Canada's environmental laws. — *Susan Milius*

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### Bird safety dos and don'ts

Even small panes of glass can trick a bird into a fatal crash, and some products sold for bird safety may not work, warns Christine Sheppard of the American Bird Conservancy. Here are some solutions that Sheppard recommends:

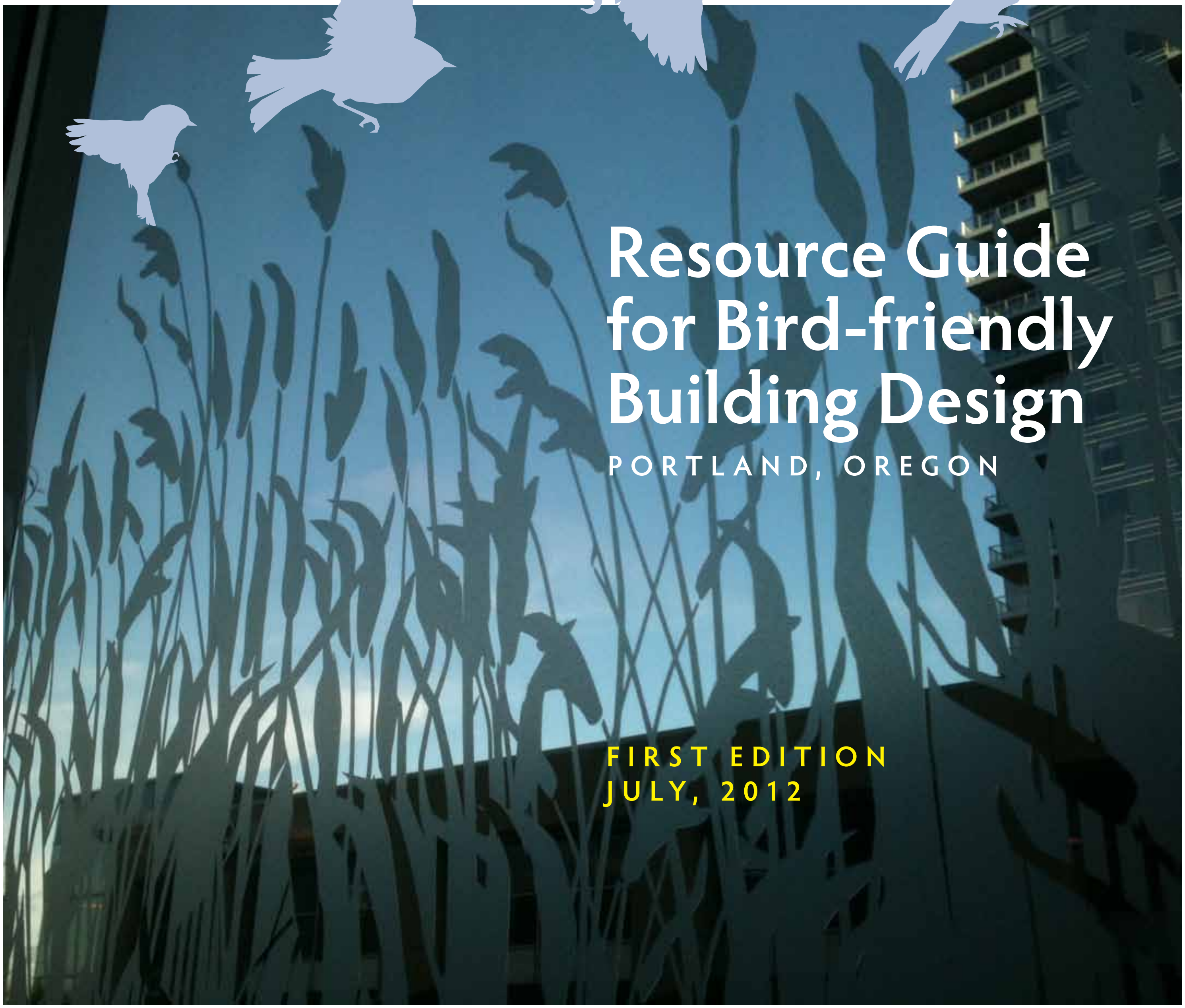
**Recommended**

- **Window screens** reduce bird collisions by reducing reflections and providing a softer surface.
- **Washable tempura paints** can provide a simple warning and can be changed seasonally as decoration.
- **Shutters or exterior shades** can be closed when no one is looking out a window or during high-risk seasons for collisions, such as spring and fall migration.
- **Stripes or dots on the outside of glass** can break up reflections. Ideally, vertical lines should be spaced no more than 4 inches apart, horizontal lines no more than 2 inches apart.
- **Fritted glass,** which has a rough surface, reduces reflections and collisions as long as the fritting is on the outside surface.

**Not recommended or problematic**

- **A single predator decal** such as a hawk silhouette is not recognizable to birds as a dangerous predator. Arranging multiple decals could deter birds by reducing a window's transparent area, but decal shape does not matter.
- **Light-colored blinds or shades** inside windows may be better than nothing, but depending on the lighting, birds can still see deceptive reflections.
- **Overhangs or awnings** can block a window from sight for birds above but can leave birds with views of reflected plants and sky.

- **Glass slanted** at least 20 degrees from the vertical reduced deaths in tests near feeders, but Sheppard says this may work only when birds fly parallel to the ground.



# Resource Guide for Bird-friendly Building Design

PORTLAND, OREGON

FIRST EDITION
JULY, 2012

Audubon Society of Portland
Founded in 1902

AMERICAN BIRD CONSERVANCY

Together Green
act today, shape tomorrow

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Right: Orange-crowned Warbler, a collision victim at the Atwater in South Waterfront. Photo: Mary Coolidge

Cover photo: Window films for branding and privacy, like this one designed by Heidi McBride and Megan Geer, can be beautiful, functional, and provide bird-friendly visual markers on windows. Photo: Mary Coolidge

# Executive Summary

*"Participation in the Urban Conservation Treaty for Migratory Birds demonstrates [Portland's] long term commitment to the protection and conservation of migratory birds. The program instills a sense of stewardship and responsibility…to ensure that [birds] remain an important element in the urban landscape."* – USFWS Portland Urban Conservation Treaty, 2003

In 2003, Mayor Vera Katz and City Commissioners pledged Portland's ongoing stewardship to our bird populations when we entered into the U.S. Fish and Wildlife Service (USFWS) Urban Conservation Treaty for Migratory Birds. In 2011, Portland Received a Challenge grant from the USFWS to develop local, voluntary Bird-friendly Building Guidelines.

Portland is a city characterized by its parks and natural areas, its bridge-nesting peregrines, its ecoroofs and naturescapes. Portlanders famously converge by the thousands on the Chapman Elementary School hill in September to witness the nightly spectacle of Vaux's Swifts taking to their chimney roost, and hundreds of homeowners have enrolled in the Backyard Habitat Certification Program to attract wildlife and improve their backyards' contribution to habitat connectivity through the city. We rely on birds to pollinate our plants, control our pests, disperse our seeds, generate recreation and tourism dollars, and capture our imaginations.

The Portland region hosts a remarkable 209 species of birds – everything from the Great Blue Heron to the Rufous Hummingbird. Some birds are year-round residents, well-adapted to city life. Some are just passing through, using the Pacific Flyway as they migrate northward or southward. Still others come for the winter, taking advantage of our mild Willamette Valley climate. They all contribute to Portland's identity as a green city.

Yet, birds face heightened hazards in the city, where they encounter deceptive and ubiquitous window glass, which they don't perceive as a barrier. Collision threats are exacerbated by unshielded overnight lighting, which draws migratory birds into urban areas at night, increasing their exposure to glass during the day. Research beginning in the late 1970's shows that window collisions are one of the top sources of mortality for birds, ranked second only to habitat destruction in terms of impact. Today, collisions are estimated to account for the death of up to 1 billion birds annually in the US alone. At a time when 1 in 4 bird species are showing precipitous population declines, anthropogenic threats to our bird populations with achievable, if incremental, solutions demand our attention. Surveys coordinated by Audubon Society of Portland have evaluated window collisions since fall 2009. While these surveys represent a small sampling effort, the data indicates that window glass undoubtedly poses a hazard to our urban bird populations. Downtown surveys catalogued a diverse array of native warblers, hummingbirds, flycatchers, and sparrows that fatally collided with buildings, 36 species to date.

Though most survey programs around the country focus primarily on commercial high-rises, window collisions are known to occur at both large and small buildings and residences. Mortality patterns are much more easily tracked in commercial districts, which results in amassing of more data about mortality patterns at high-rises than at homes. However, given the number of small commercial and residential buildings across the country, these structures represent a significant source of mortality. Challenges to surveying this type of development make it difficult to accurately quantify the true magnitude of strike mortality. However, Audubon Society of Portland has a unique source of valuable information about window strikes at homes and small buildings: collision intakes and phone calls received by the Wildlife Care Center increase our tracking capacity beyond targeted monitoring programs. What is clear is that all building types, large and small, residential and

**Window collisions are one of the top sources of mortality for birds, ranked second only to habitat destruction in terms of impact. Today, collisions are estimated to account for the death of up to one billion birds annually in the US alone.**

41 Cooper Square in New York City, by Morphosis Architects, features a skin of perforated steel panels fronting a glass/aluminum window wall. The panels reduce heat gain in summer and add insulation in winter while also making the building safer for birds. Photo: Christine Sheppard, ABC

commercial, can pose a collision hazard where unmarked glass is used, and represent an opportunity for improved design.

Bird-Friendly Building Guidelines are an essential component of a comprehensive urban sustainability strategy. Cities such as San Francisco, New York, Toronto, Chicago and the state of Minnesota have already adopted Bird-Friendly Building Guidelines, some regulatory, some voluntary. Integrating Bird-friendly Building Guidelines into Portland's sustainability planning efforts will compliment other adopted strategies including: the Climate Change Action Plan; the Watershed Management Plan, the Urban Forest Action Plan, Grey to Green, Ecodistricts Initiative, and the Portland Bird Agenda.

In recent years, vast improvement in the energy-efficiency of glass has led to proliferation of glass curtain walls in architecture. Research into collision rates has shown the percentage of unmarked glass on a building to be the strongest predictor of bird mortality. And yet, there are already myriad examples of innovative designs which incorporate bird-friendliness into buildings, whether intentionally or incidentally, and many of these can help achieve multiple building objectives. Simply by understanding and avoiding collision hazards in building design, incorporating visual markers into the most predictably hazardous parts of a building, and identifying architectural approaches that elegantly layer bird-friendliness with energy conservation or other objectives, architects can begin to mold their designs toward bird-friendliness while remaining cost-neutral. For example, thoughtfully designed fritted windows can reduce solar heat gain, provide privacy, allow for light entry, and mark windows for birds. Audubon's voluntary Lights Out Portland program dovetails well with the city's Climate Action Plan goal of achieving 80% carbon reduction by 2050.

Evolution of the US Green Building Council's LEED standards to include a Bird Collision Deterrent Pilot Credit (Pilot Credit 55, introduced October 14, 2011) is strong evidence that leaders in the green building movement are committed to ensuring that green buildings are also safe for birds (see Appendix V). Great strides have been made in recent years to bring ecosystem-level considerations into play, with this new BCD Pilot Credit as well as the Light Pollution Reduction Pilot Credit 7, which predates it.

**Simply by understanding and avoiding collision hazards in building design, incorporating visual markers into the most predictably hazardous parts of a building, and identifying architectural approaches that elegantly layer bird-friendliness with energy conservation, architects can begin to mold their designs toward bird-friendliness while remaining cost-neutral.**

This resource guide is a customization of American Bird Conservancy's Bird-Friendly Building Design template, which was based on guidelines first developed by NYC Audubon Society. It aims to provide Portland architects, planners, designers, local authorities, and homeowners with a clear understanding of the nature and magnitude of the threat posed by unmarked glass to birds. Given Portland's projected growth by more than 100,000 households in the next 25 years, the development of this guide is well-timed to provide a resource for both the construction of new buildings and retrofits and remodels of existing buildings. Increased awareness among innovative designers about bird-friendly design options will yield thoughtful design of bird-friendly buildings that artfully achieve ecological, energetic, and aesthetic goals.

This edition includes an appendix on the science behind available solutions, examples of how these solutions can be applied to both new construction and existing buildings, and an explanation of the kind of information still needed. We hope it will spur imaginative incorporation of trend-setting bird-friendly designs into our local built landscape, and help illustrate the synergistic benefits that can weave together bird-friendliness with energy efficiency, aesthetics, branding, privacy, and other innovative design objectives.

# Table of Contents



Willow Flycatcher
Photo: Jim Cruce

# A Quick Look at Bird-friendly Building Design Recommendations

Cedar Waxwing
Photo: Jim Cruce

## Treat High Risk Zones:

- Glass on first 40' of a building
- Glass on first floor adjacent to an ecoroof or rooftop garden
- Windows at corners, on skybridges and in atria
- Freestanding glass around courtyards, ecoroofs, patios, and balconies

*See page 13 for more information.*

## Window Treatment Options for High Risk Zones:

- Exterior frits, sandblasting, translucence, etching or screenprinting
- Exterior branding on glass for retail
- Exterior window films
- Exterior shades or shutters
- Glass block
- Exterior netting or screens
- Exterior framework, grilles, or trellises
- Awnings, overhangs, and deeply-recessed windows
- Louvers

*See page 17 for more information.*

## Tips for Achieving Cost-effectiveness in New Construction and Retrofits:

- Have bird-friendly building design in mind from the start of project design.
- Plan to work within your project budget using bird-friendly design principles and materials—may or may not result in design modifications.
- Look for economies—unit costs go down as amount of materials increases.
- Seek opportunities to meet multiple project goals using bird-friendly design approaches (e.g. window treatments that provide privacy or branding or meet energy-reduction goals).

## Lighting:

- Shield all outdoor lighting (full cut-off above 90 degrees)
- Properly design all outdoor lighting to be directed to minimize light spill
- Eliminate up-directed architectural vanity lighting
- Minimize down-directed architectural vanity lighting
- Design interior lights to minimize light spill
- Install or design for motion sensor lighting
- Design all non-exempt interior and exterior lighting to be off overnight (minimum: midnight to 6 am)
- Participate in Audubon's Lights Out Portland program

*See page 32 for more information.*

## Other:

- Monitor bird mortality
- Distribute materials about birds and window collisons
- Report window collisions to Portland Audubon 503.292.6855

Song Sparrow
Photo: Jim Cruce

# Introduction

## Birds Matter

Birds have been important to humans throughout history, often used to symbolize cultural values such as peace, freedom, and fidelity.

In addition to the pleasure they can bring to people, we depend on them for critical ecological functions. Birds consume vast quantities of insects, and control rodent populations, reducing damage to crops and forests, and helping limit the transmission of diseases such as West Nile virus, dengue fever, and malaria. Birds play a vital role in regenerating habitats by pollinating plants and dispersing seeds.

Birds are also a vast economic resource. A 2009 USFWS study showed that bird watching is one of the fastest growing leisure activities in North America, and a multi-billion-dollar industry.

The 55,000 square foot mural on the mausoleum overlooking Oaks Bottom Wildlife Refuge features local birds. Photo: Bob Sallinger

## The Legal Landscape

At the start of the 20th Century, following the extinction of the Passenger Pigeon and the near-extinction of other bird species due to unregulated hunting, laws were passed to protect bird populations. Among them was the Migratory Bird Treaty Act (MBTA), which made it illegal to kill a migratory bird. The scope of this law extends beyond hunting, such that anyone causing the death of a migratory bird, even if unintentionally, can be prosecuted if that death was foreseeable. This may include bird deaths due to collisions with glass, though there have yet to be any prosecutions in the United States for such incidents. Violations of the MBTA can result in fines of up to $1,500 per incident and up to six months in prison.

The Bald and Golden Eagle Protection Act (originally the Bald Eagle Protection Act of 1940), the Endangered Species Act (1973), and the Wild Bird Conservation Act (1992) provide further protections for birds that may be relevant to building collisions.

Recent legislation, primarily at the city and state level, has addressed the problem of mortality from building collisions and light pollution. Cook County, Illinois, San Francisco, California, Toronto, Canada, and the State of Minnesota have all passed laws or ordinances aimed at reducing bird kills, while other authorities have pushed for voluntary measures.

The International Dark Sky Association, an environmental organization whose mission is “to preserve and protect the nighttime environment” now actively supports legislation designed to restore the dark by curbing light emissions. Portland has joined 21 other North American Cities in establishing a voluntary Lights Out program.

## Glass: The Invisible Threat

Glass can be invisible to both birds and humans. Humans learn to see glass through a combination of experience (many of us have



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# Introduction

The Varied Thrush is a common victim of window collisions in the Portland area. Photo: R. Michael Liskay

Warblers, such as this Yellow Warbler, are often killed by window collisions as they migrate. Photo: Eric Liskay

**Most birds' first encounter with glass is fatal when they collide with it at full speed.**

walked into a glass door or seen somebody do so), visual cues and context, but birds are unable to use these signals. Most birds' first encounter with glass is fatal when they collide with it at full speed.

No one knows exactly how many birds are killed by glass – the problem exists on too great a scale and many mortalities go undetected – but estimates range from 100 million to one billion birds each year in the United States. Despite the enormity of the problem, however, solutions are available that can reduce bird mortality while retaining the advantages of glass as a construction material, without sacrificing architectural standards.

## Lighting: Exacerbating the Threat

Bird collisions with glass are greatly exacerbated by artificial light. Light escaping from building interiors or from exterior fixtures can attract birds, particularly during migration on foggy nights or when the cloud base is low. Strong beams of light can cause birds to circle in confusion and collide with structures, each other, or even the ground. Others may simply land in lighted areas and must then navigate an urban environment rife with other dangers, including glass. *(This is discussed further in the Problem: Lighting section, page 29)*

## Birds and the Built Environment

Human population growth exerts real consequences on our wildlife populations in the form of habitat loss. Sprawling land use patterns and poorly planned and designed urbanization degrade both the quantity and quality of available habitat. The rate of sprawl in the US nearly quadrupled between 1954 and 2000. The tendency to build along waterways and shorelines means not only habitat depletion, but erection of potentially hazardous buildings along historic migratory pathways and in traditional stopover areas.

Great advancements in glass engineering have seen the evolution of buildings from relatively solid, blocky buildings to relatively transparent structures. The advent of mass-produced sheet glass in the early 1900's and the invention of float glass in the 1950's allowed mass production of flat glass for modern windows. In the 1980's, development of new production and construction technologies culminated in today's glass skyscrapers.

The amount of unmarked glass in a building is considered the strongest predictor of how dangerous it is to birds. However, even small areas of glass can be lethal. While bird kills at residential homes are estimated at one to ten birds per home per year, the large number of homes multiplies that loss to millions of birds per year in the United States.

Other factors can affect a building's potential impact, including the density and species composition of local bird populations, local geography, the location, and extent of landscaping and nearby habitat, weather, and patterns of migration through the area. All these factors will be considered in this document.

## Impact of Collisions on Bird Populations

About 25% of species are now on the US Watchlist of Birds of Conservation Concern (http://library.fws.gov/pubs/mbd_watchlist.pdf). Forty years of Christmas Bird Count data indicate that even many common species are in decline (http://stateofthebirds.audubon.org/cbid/). Habitat destruction or alteration on both breeding and wintering grounds remains the most serious man-made problem, but collisions with buildings represent the largest known fatality threat. Nearly one third of the bird species found in the United States, over 258 species, are documented as victims of collisions. Over 78 species have been catalogued in Portland in 4 seasons of tracking collisions (2009-2011).

Unlike natural sources of mortality that predominantly kill weaker individuals, collisions kill some of the strongest, healthiest birds that would otherwise survive to produce offspring. This is both unsustainable and avoidable. Anthropogenic sources of mortality—like collision hazards—are both avoidable and mitigable: ***the goal of the Resource Guide for Bird-friendly Building Design is to provide avenues for incremental improvement in hazard reduction.***

## The Impact of Trends in Modern Architecture

In recent decades, advances in glass technology and production have made it possible to construct buildings with all-glass curtain walls, and we have seen a significant increase in the amount of glass used in construction. Unfortunately, as the amount of glass increases, so does the incidence of bird collisions.

New trends in green development can potentially help reduce risk to birds in the built environment. The Green Building Council's (GBC) Leadership in Energy and Environmental Design, or LEED has recently begun to include language addressing the threat of glass to birds.

Their *Resource Guide*, starting with the 2009 edition, calls attention to parts of existing LEED credits that can be applied to reduce negative impacts on birds. Reducing light pollution, reducing disturbance to natural landscapes, and reducing energy use can all benefit birds. On October 14, 2011, GBC added Credit 55: Bird Collision Deterrence, to their Pilot Credit Library (http://www.usgbc.org/ShowFile.aspx?DocumentID=10402). Drafted by ABC, members of the Bird-safe Glass Foundation, and the GBC Site Subcommittee, the credit is open to both new construction and existing buildings.

Various materials have been evaluated to rate their threat level to birds. These threat factors are used to calculate an index representing the building's façade, and that index must stay below a standard value to earn the credit. The credit also requires adopting interior and exterior lighting plans as well as post-construction monitoring. Appendix I reviews the work underlying the assignment of threat factors.

Reflections of the sky and clouds on glass towers pose a danger to birds flying above treeline. Photo: Mary Coolidge

**Unlike natural sources of mortality that predominantly kill weaker individuals, collisions kill some of the strongest, healthiest birds that would otherwise survive to produce offspring. This is both unsustainable and avoidable.**

# Introduction

The area of glass on a façade is the strongest predictor of threat to birds. The façade of Sauerbruch Hutton's Brandhorst Museum in Munich is a brilliant example of the creative use of non-glass materials. Photo: Tony Brady

Audubon Society of Portland has worked with ABC to become a registered provider of AIA Continuing Education on bird-friendly design and LEED Pilot Credit 55. Contact Audubon Society of Portland for more information: www.audubonportland.org.

## Defining "Bird-friendly"

It is increasingly common to see the term "bird-friendly" used to demonstrate that a product, building, or legislation is not harmful to birds. However, this term lacks a clear definition and sound scientific foundation to underpin its use.

It is impossible to know exactly how many birds a building will kill before it is built, and so realistically, we cannot declare a building to be bird-friendly before it has been carefully monitored for several years. However, there are several factors that can help us predict whether a building will be harmful to birds or generally benign, and we can accordingly define simple "bird-smart standards" that, if followed, will ensure that a prospective building poses a minimal potential hazard to birds.

Boris Pena's Public Health Office building in Mallorca, Spain, sports a galvanized, electro-fused steel façade which deflects bird strikes. Photo: Boris Pena



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# ABC's Bird-friendly Building Standard

## A bird-friendly building is one where:

- At least 90% of exposed façade material from ground level to 40 feet (the primary bird collision zone) has been demonstrated in controlled experiments[1] to deter 70% or more of bird collisions.
- At least 60% of exposed façade material above the collisions zone meets the above standard.
- There are no transparent passageways, corners, atria or courtyards that can trap birds.
- Outside lighting is appropriately shielded and directed to minimize attraction to night-migrating songbirds.[2]
- Interior lighting is turned off at night or designed to minimize light escaping through windows
- Landscaping is designed to keep birds away from the building's façade.[3]
- Actual bird mortality is monitored and compensated for (e.g., in the form of habitat preserved or created elsewhere, mortality from other sources reduced, etc.).

1. See the section Research: Deterring Bird Collisions in Appendix I for information on these controlled studies.
2. See the section Solutions: Lighting Design on page 34
3. See Landscaping and Vegetation, Appendix I on page 43

Red-tailed Hawk in downtown Portland. Photo: Bob Sallinger

The Hotel Puerta America in Mexico City was designed by Jean Nouvel, and features external shades. This is a flexible strategy for sun control, as well as preventing collisions; shades can be lowered selectively when and where needed. Photo: Ramon Duran

The large, unmarked panes of glass in this building reflect sky and trees. The building's proximity to the Willamette River and its greenroof with adjacent unmarked glass make it a potential collision hazard. Photo: Mary Coolidge

# Problem: Glass

## The Ever-changing Properties of Glass

Glass can appear very differently depending on a number of factors, including: the angle at which it is viewed; the difference between exterior and interior light levels; seasons; weather; and time of day. Combinations of these factors can cause glass to look like a mirror or dark passageway, or to be completely invisible. Humans do not actually “see” glass, but are cued by context such as window frames, roofs or doors. Birds, however, do not perceive architectural signals as indicators of obstacles or artificial environments.

## Reflectivity

Viewed from outside, transparent glass on buildings is often highly reflective – even under Portland’s often overcast skies. Almost every type of architectural glass, under the right conditions, reflects the sky, clouds, or nearby habitat familiar and attractive to birds. When birds try to fly to the reflected habitat, they hit the glass. Reflected vegetation is the most dangerous, but birds also attempt to fly past reflected buildings or through reflected passageways.

## Transparency

Birds strike transparent windows as they attempt to access potential perches, plants, food or water sources, and other lures seen through the glass. Glass skywalks joining buildings, glass walls around planted atria, windows meeting at building corners, and exterior glass handrails or walkway dividers are dangerous because birds perceive an unobstructed route to the other side.

## Passage Effect

Birds often fly through small gaps, such as spaces between leaves or branches, nest cavities, or other small openings. In some light, glass can appear black, creating the appearance of just such a cavity or “passage” through which birds try to fly.

The glass-walled towers of the Time-Warner Center in New York City appear to birds as just another piece of the sky. Photo: Christine Sheppard, ABC

**Humans do not actually “see” glass, but are cued by context such as window frames, roofs or doors. Birds, however, do not perceive architectural signals as indicators of obstacles or artificial environments.**

Transparent handrails are a dangerous trend for birds, especially when they are in front of vegetation. Photo: Mary Coolidge

The mirrored windows at Lewis and Clark were highly reflective on gray days as well sunny days. Photo: Mary Coolidge

## Factors Affecting Collisions Rates for a Particular Building

Every site and every building can be characterized as a unique combination of risk factors for collisions. Some, particularly aspects of a building's design, are very structure-specific. Many hazardous design features can be readily countered, or, in new construction, avoided. Others, like a building's location and siting, relate to migration routes, regional ecology, and geography – factors that are difficult if not impossible to modify.

## Overall Design

The relative threat posed by a particular building depends substantially on the amount of exposed glass, the type of glass used, and the presence of "design traps". Klem (2009) in a study based on data from Manhattan, found that a 10% increase in the area of reflective and transparent glass on a building façade correlated with a 19% increase in the number of fatal collisions in spring and a 32% increase in fall.

## Type of Glass

The type of glass used in a building is a significant component of its danger to birds. Mirrored glass is often used to make a building "blend" into an area by reflecting its surroundings, which makes those buildings especially deadly to birds. Mirrored glass is reflective at all times of day, and birds mistake reflections of sky, trees, and other habitat features for reality. Non-mirrored glass can appear highly reflective or transparent, depending on time of day, weather, angle of view, and other variables. Tinted glass may reduce collisions, but only slightly. Low-reflection glass may be less hazardous in some situations but can create a "passage effect" – appearing as a dark void that could be flown through (see page 13).

## Building Size

Unmarked glass on buildings of all sizes, residential and commercial alike, can pose a significant hazard to birds. Still, as building size increases, so usually does the amount of glass, making larger buildings a greater single threat. It is generally accepted that the lower stories of any type of building are the most dangerous because they reflect trees and other landscape features, which themselves are attractive to birds, and therefore the first 40' of a building should utilize bird-friendly features. However, monitoring programs which have access to setbacks and roofs of tall buildings have documented window collisions. Voluntary, internal reporting programs in Portland have documented collisions up to the 19th and 21st stories.

## Orientation and Siting

Building orientation in relation to compass direction has not been implicated as a factor in collisions, but siting of a building with respect to surrounding habitat and landscaping can be an issue, especially if glass is positioned so that it reflects vegetation. Physical features such as outcrops or pathways that provide an open flight path through the landscape can channel birds towards or away from glass and should be considered early in the design phase.

## Design Traps

Windowed courtyards can be death traps for birds, especially if they are heavily planted. Birds are attracted into such places, and then try to leave by flying directly towards reflections on the walls. Glass skywalks and outdoor handrails, and building corners where glass walls or windows are perpendicular are dangerous because birds can see through them to sky or habitat on the other side.

## Reflected Vegetation

Glass that reflects shrubs and trees causes more collisions than glass that reflects pavement or grass (Gelb and Delecretaz, 2006).

**Local Retrofit: Window Screen Installation at Lewis and Clark Law School.** A multistory bank of mirrored windows (top photo) made the LRC building disappear into adjacent Tryon Creek State Park, and was the site of up to 50 documented collisions per season (spring/fall). Since the installation of screens (bottom photo), no fatalities have yet been documented at the LRC building (as of the date of this publication). Photos: Mary Coolidge



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Planted, open courtyards lure birds then prove dangerous when they encounter reflections of vegetation on surrounding windows. Photo: Mary Coolidge

Studies have only quantified vegetation within 15 – 50 feet of a façade, but reflections can be visible at much greater distances. Vegetation around buildings will bring more birds into the vicinity of the building; the reflection of that vegetation brings more birds into the glass. Taller trees and shrubs correlate with more collisions. It should be kept in mind that vegetation on slopes near a building will reflect in windows above ground level. Studies with bird feeders (Klem *et al.*, 1991) have shown that fatal collisions result when birds fly towards glass from more than a few feet away.

## Green Roofs, Gardens and Walls

Recent work shows that well designed green roofs and roof gardens can become functional ecosystems, providing food and nest sites for birds.  However, green roofs bring habitat elements attractive to birds to higher levels, often near unmarked glass. Glass treatment around green roofs, green walls and rooftop gardens should be considered with features that prioritze protection for birds. Under the new LEED Bird Collision Deterrent Credit, glass on the first floor adjacent to a green roof is Zone 1, or high risk, and must meet a more stringent standard for bird-safety.

Unmarked glass adjacent to ecoroofs can be hazardous to birds that are attracted to available habitat. Photo by Tom Liptan

## Windows Take their Toll on KGW-Audubon Raptor Cam Fledglings

Since 2007, people from around the world have tuned in to watch a pair of Red-tailed Hawks that have nested and raised young on a downtown Portland fire escape. The KGW-Audubon Raptor Cam has provided an intimate view into the lives of these urban hawks. One of the sad realities illuminated by Raptor Cam is the hazard posed by windows to young birds as they begin to explore the world around them. Of the eleven nestlings that have fledged from the Raptor Cam nest between 2007 and 2011, four have suffered serious collisions with windows. Fortunately three were able to be returned to the wild after treatment. Most birds are not so lucky...

## Portland's Bridge-nesting Peregrines

The first Peregrine Falcon to fledge off Portland's Fremont Bridge collided with a window on East Burnside within a week of taking her first flight. She spent a month in captivity recovering from internal injuries before being released back to the wild. Window strikes have remained a significant cause of injury for both resident and migratory peregrine populations in Portland.

# Solution: Glass

Numerous examples of bird-friendly buildings exist, which were primarily designed to be functional and attractive, and incidentally pair well with bird-friendly objectives. These buildings may have screens, latticework, grilles, or other visual noise either outside the glass or integrated into the glass that helps to reduce collisions.

Identifying glass treatments that eliminate or greatly reduce bird mortality while minimally obscuring the glass itself has been the goal of several researchers, including Martin Rössler, Dan Klem, and Christine Sheppard. Their research, discussed in detail in Appendix I, has focused primarily on the spacing, width, and orientation of lines marked on glass, and has shown that patterns covering as little as 5% of the total glass surface can deter 90% of strikes under experimental conditions. Most birds will not attempt to fly through horizontal spaces less than 2" high, nor through vertical spaces 4" wide or less. This concept has become known as the 2" x 4" Rule.

Research on human vision shows a striking ability to complete partial images in order to compensate for missing visual information. This linking of visual fragments and filling-in by our brains means it is possible to design patterns on windows that alert birds to a barrier while minimally impacting views out.

Designing a new structure to be bird friendly can be imaginative, innovative, sustainable and cost-neutral. Architects around the globe have created fascinating structures that incorporate little or no unmarked glass. Inspiration has been born out of functional needs, such as shading in many climatic zones, and/or aesthetics; being bird-friendly was often secondary or incidental. Retrofitting existing buildings can often be done by targeting areas where strikes are known to occur, rather than entire buildings.

## Local Victories

Bird-friendly considerations are just beginning to gain traction in the Portland area. An exterior screening project at Lewis and Clark Law School *(pictured on page 15)* demonstrates a local commitment

View of fritted window pattern (above) at the OHSU Center for Health and Healing demonstrate how frit patterns can be designed to afford views out (Photo at left is a close-up). Frits can synergistically reduce solar heat gain, afford privacy, and provide visual cues to approaching birds. No collisions have been documented at this building in four seasons of monitoring. Photo: Mary Coolidge

Most birds will not attempt to fly through horizontal spaces less than 2" high, nor through vertical spaces 4" wide or less. This concept has become known as the **2" x 4" Rule**.

**There are many ways to combine the benefits of glass with bird-safe or bird-friendly design by incorporating elements that minimize collisions without obscuring vision.**

to reduce collisions at a problematic bank of windows on the south side of the Legal Research Center. Prototype screens will be incrementally installed campus-wide due to the true scope of the hazard. The Port of Vancouver has also recently undertaken to retrofit problem windows at its Administrative Offices, and has researched alternatives, evaluating effectiveness, affordability and aesthetics. Port staff also developed a memorandum on window collisions for tenants to help prevent and address window strikes. The University of Portland recently committed to designing all new buildings to comply with bird-friendly goals and standards.

### Facades, netting, screens, grilles, shutters, exterior shades

There are many ways to combine the benefits of glass with bird-friendly design by incorporating elements that minimize collisions without obscuring vision. Some architects have designed decorative facades that wrap entire structures. Recessed windows can functionally reduce the amount of visible glass and thus the threat to birds. Netting, screens, grilles, shutters and exterior shades are commonly used elements that can make glass safe for birds. They can be used in retrofits or be an integral part of an original design, and can significantly reduce bird mortality.

Screens once protected birds in addition to their primary purpose of keeping bugs out. Screens and nets are still among the most cost-effective methods for protecting birds. Netting can often be installed so as to be nearly invisible, but must be installed several inches in front of the window, so impact does not carry birds into the glass.

Decorative grilles are also part of many architectural traditions, as are shutters and exterior shades, which have an additional advantage – they can be closed during high-risk seasons for birds, such as migration and fledging (see Appendix II).

Functional elements such as balconies and balustrades can act like a façade, protecting birds while providing an amenity for residents.


The façade of the New York Times building, by FX Fowle and Renzo Piano, is composed of ceramic rods, spaced to let occupants see out, while minimizing the extent of exposed glass. Photo: Christine Sheppard, ABC

External shades on Renzo Piano's California Academy of Sciences in San Francisco are lowered during migration seasons to eliminate collisions. Photo: Mo Flannery



Upper left: If designed densely enough, window films for branding and street activity can pair marketing with bird-friendliness. Photo: Mary Coolidge

Upper right: An exterior trellis on the new Edith Green Wendell Wyatt Federal building will shade the west aspect of the building, and may prove to be bird-friendly. Framework on the south and east aspects of the building does not meet the 2" x 4" rule, but will likely provide some visual cues to approaching birds. Photo: Mary Coolidge

Lower right: Etching patterns on glass at the Bird House at the National Zoo has worked to greatly reduce collision incidents. Photo: Bob Sallinger

Lower left: Fritted bike-themed design work on Whole Foods windows create interest and branding while helping to interrupt reflections. Fritting would be more effective on the outside of the window. Photo: Mary Coolidge

# Solution: Glass

Some approaches that have been described as bird-friendly solutions in recent years need more critical consideration. Awnings, overhangs, tinting, UV patterns, and angled glass are not foolproof solutions, but must be carefully designed in order to be effective at eliminating reflections and reducing strike hazards.

## Awnings and Overhangs

Overhangs may reduce collisions. However, they do not eliminate reflections, and only block glass from the view of birds flying above, and thus are of limited effectiveness.

## UV Patterned Glass

Birds can see into the ultraviolet (UV) spectrum of light, a range largely invisible to humans *(see page 36)*. UV-reflective and/or absorbing patterns (transparent to humans but visible to birds) are frequently suggested as a solution for many bird collision problems. Progress in the search for bird-friendly UV glass has been slow due to the inherent technical complexities. Ornilux Mikado by Arnold Glass has been rated for use in LEED Pilot Credit 55 and is now available in the United States *(photo page 47)*. The cost for this product has already dropped 20% since early 2011. With the introduction of LEED Pilot Credit 55, development of Bird-friendly Building Guidelines in multiple cities, and increased awareness, demand will drive product development and availability.

## Angled Glass

In a study (Klem et al., 2004) comparing bird collisions with vertical panes of glass to those tilted 20 degrees or 40 degrees, the angled glass resulted in fewer mortalities. While angled glass may be useful in special circumstances, the birds in the study were flying parallel to the ground from nearby feeders. However, birds approach glass from many angles. Therefore, angled glass is not considered a reliable strategy. The New York Times printing plant, pictured below, clearly illustrates angled glass reflecting nearby vegetation.

## Tinting

Some colors and densities of tinted glass may reduce collisions, but these have not been sufficiently tested to determine the density necessary to achieve deterrence. Collisions have been documented on BirdSafe surveys at various Portland buildings with blue, green, and dark tints.

Overhangs block viewing of glass from some angles, but do not necessarily eliminate all reflections. Photo: Christine Sheppard, ABC

The angle on the New York Times printing plant facade is not sufficient to eliminate deceptive reflections of nearby vegetation. Photo: Christine Sheppard, ABC

Tinted windows at the State Building readily reflect vegetation. More testing on colors and density is needed. Photo: Mary Coolidge

Deeply recessed windows, such as these on Stephen Holl's Simmons Hall at MIT, can block viewing of glass from oblique angles. Photo: Dan Hill



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Translucent glass panels on the Kunsthaus Bregenz in Austria, designed by Atelier Peter Zumthor, provide light and air to the building interior without dangerous reflections.
Photo : William Heltz

The glass facade of SUVA Haus in Basel, Switzerland, renovated by Herzog and de Meuron, is screen-printed on the outside with the name of the building owner. Photo: Miguel Marqués Ferrer

## Patterns on Glass: Meeting Multiple Objectives

Patterns are often applied to glass to reduce the transmission of light and heat or to provide screening or branding. When designed according to the 2 x 4 rule, *(see page 17)* patterns on glass can also prevent bird strikes. External patterns on glass deter collisions effectively because they interrupt glass reflections. Ceramic dots or 'frits' and other materials can be screened, printed, or otherwise applied to the glass surface. This design element, useful primarily for new construction, is more common in Europe and Asia, but is increasingly available in the United States.

Patterns applied to an internal surface of double-paned windows may not be visible if the amount of light reflected from the frit is insufficient to overcome reflections on the glass' outside surface. Some internal frits may only help break up reflections when viewed from some angles and in certain light conditions. This is particularly true for large windows, but also depends on the density of the frit pattern. The internet company IAC's headquarters building in New York City, designed by Frank Gehry, is composed entirely of fritted glass, most of high density *(page 23)*. No collision mortalities have been reported at this building after two years of monitoring by Project Safe Flight. Current research is testing the relative effectiveness of different frit densities, configurations, and colors.

## Opaque and Translucent Glass

Opaque, etched, stained, frosted glass, and glass block are excellent options to reduce or eliminate collisions, and many attractive architectural applications exist. They can be used in both retrofits and new construction.

Frosted glass is created by acid etching or sandblasting transparent glass. Frosted areas are translucent, but different finishes are available with different levels of light transmission. An entire surface can be frosted, or frosted patterns can be applied. Patterns should conform to the 2 x 4 rule described on page 17. For retrofits, glass can also be frosted by sandblasting on site.

The Studio Gang's Aqua Tower in Chicago was designed with birds in mind. Strategies include fritted glass and balcony balustrades. Photo: Tim Bloomquist



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Galeo, part of a complex designed by Atelier Christian de Portzamparc in Issy les Moulineaux, France, has an external skin of printed glass scales which help to reduce reflections. Photo: Sipane

Renzo Piano's Hermes Building in Tokyo has a façade of glass block. Photo: Mariano Colantoni

The dramatic City Hall of Alphen aan den Rijn in the Netherlands, designed by Erick van Egeraat Associated Architects, features a façade of etched glass. Photo: Dik Naagtegal

External frit, as seen here on the Lile Museum of Fine Arts, by Ibos and Vitart, is more effective at breaking up reflections than patterns on the inside of the glass. Photo: G. Fessy


While some internal fritted glass patterns can be overcome by reflections, Frank Gehry's IAC Headquarters in Manhattan is so dense that the glass appears opaque. Photo: Christine Sheppard



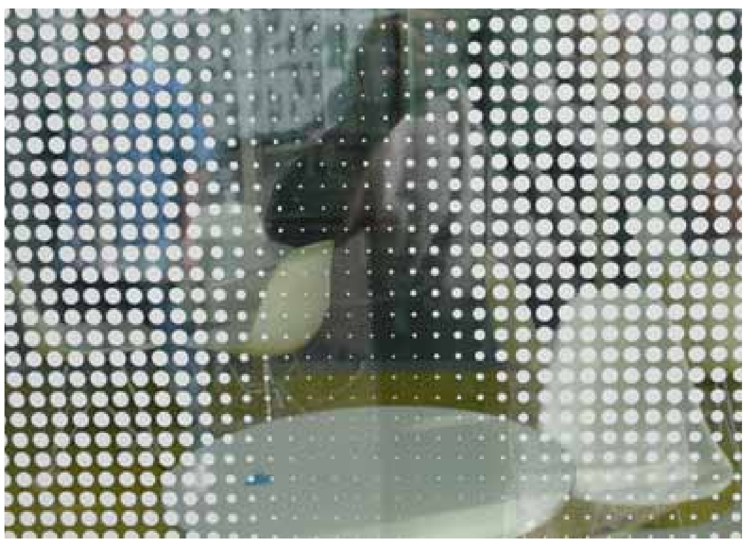
58200

# Solution: Glass

**Patterns are often applied to glass to reduce the transmission of heat or to provide screening or branding. When designed according to the 2" x 4" rule, patterns on glass can also prevent bird strikes.**

Dense stripes of internal frit on University Hospital's Twinsburg Health Center in Cleveland, by Westlake, Reed, Leskosky will overcome virtually all reflections. Photo: Christine Sheppard, ABC

Privacy film on Mirabella windows preserves light entry and views out while marking the window for birds. Such film is more effective if applied to the exterior. Photo: Mary Coolidge



A detail of a pattern printed on glass at the Cottbus Media Centre in Germany. Photo: Evan Chakroff

Visual markers on the balcony glass at the Eliot Tower provide some privacy and decrease strike hazards. Photo: Mary Coolidge



58201

The window at the Philadephia Zoo's Bear Country exhibit was the site of frequent bird collisions until this window film was applied. Collisions have been eliminated without obscuring views out. Photo: Philadephia Zoo.

Fritted glass photo panels on the Gibbs Street Pedestrian Bridge elevator in South Waterfront are part of a public art project made possible by the Regional Arts & Culture Council and the Portland Bureau of Transportation through the City's Percent for Art Program. Artist Anna Valentina Murch made the photographs of water, which were printed onto the glass panels by Peters Studios, thus marking the windows for birds. Photo by Jeanne Galick.

# Solution: Glass

Photo : Dariusz Zdziebkowski

The American Bird Conservancy, with support from the Rusinow Family Foundation, has produced ABC BirdTape to make home windows safer for birds. This easy-to-apply tape lets birds see glass while letting you see out, is easily applied, and lasts up to four years. For more information, visit www.ABCBirdTape.org

## Window Films

Currently, most patterned window films are intended for interior use as design elements or for privacy, but this is beginning to change. 3M™ Scotchcal™ Perforated Window Graphic Film, also known as CollidEscape, is a well-known external solution. It covers the entire surface of a window, appears opaque from the outside, and permits a view out from inside. Interior films, when applied correctly, have held up well in external applications, but this solution has not yet been tested over decades. A film with horizontal stripes has been effective at the Philadelphia Zoo's Bear Country exhibit (see photo on right) and the response of people has been positive.

## Internal Shades, Blinds, and Curtains

Light colored shades do not effectively reduce reflections and are not visible from acute angles. Blinds have the same limitations, but when visible and partly open, can help to break up reflections.

Tape decals (Window Alert shown here) placed following the 2 x 4 rule can be effective at deterring collisions. Photo: Christine Sheppard, ABC

## Temporary Solutions

In some circumstances, especially for homes and small buildings, quick, low-cost, DIY solutions such as applications of tape or paint can be very effective. Such measures can be applied to problem windows and are most effective following the 2 x 4" rule. For more information, see Portland Audubon's Tips for Reducing Strikes at Home and a Birds and Windows Brochure at www.audubonportland.org/issues/metro/bsafe/tips.

## Decals

Decals are probably the most popularized solution to collisions, but their effectiveness is dependant on density of application. Birds do not recognize raptor decals as predators, but simply as obstacles to try to fly around.

Decals are most effective if applied following the 2" x 4" rule, but even a few may reduce collisions.

Reflections on home windows are a significant source of bird mortality. Partially opened vertical blinds may break up reflections enough to reduce the hazard to birds. Photo: Christine Sheppard, ABC



58203

## Residential and Small Building Collisions and Treatments

Though Bird-friendly Building Guidelines developed to date primarily address strike hazards, data, and solutions at the larger commercial scale, strikes can occur as readily at small-scale commercial and residential developments where unmarked glass is used. Research at large commercial buildings is far more common simply because of scope, access, and logistical limitations. High-rises in commercial districts tend to be geographically clustered and accessible to volunteers via sidewalk rights-of-way, thus lending themselves well to targeted observation, and resulting in a predominance of data from commercial districts.

Some research has endeavored to focus on residential construction. Dunn (1993) estimated that between 0.65 and 7.7 bird deaths per residential home occur every year in North America (described in Appendix 1: The Science of Bird Collisions). Therefore, though it may be tempting to implicate high-rise buildings in the majority of collisions, homes do contribute significantly to sources of collision risk and their distribution across the landscape in urban, exurban, and rural areas makes their cumulative impact undeniable. San Francisco's new Bird Safe Building Standards require residential buildings with "substantial glass façade" (those with a greater than 50% glass façade area) to incorporate glazing treatments such that 95% of all unbroken glass expanses 24 square feet or larger are treated.

Single and two-story homes occur largely within the highest risk zone of collisions, that is: within 40 feet of the ground. Homes often have vegetation near to and reflected in windows. Vegetation, bird-feeders, and birdbaths attract birds into yards, where they face deceptive reflections. Even small windows pose a hazard, because birds are accustomed to flying into small gaps in vegetation. Though the scale and budgets of residential and small commercial development may indeed call for unique, cost-effective approaches, the same principles of hazard-reduction apply. Architects and designers can mitigate hazardous features (such windows meeting

Silhouettes placed every 12 inches on the exterior of this residential window are spaced too far apart to reliably eliminate all strikes, but will likely reduce strike incidence.

Designwork on TriMet bus shelters has been shown to help to reduce vandalism and also marks the freestanding glass for birds. Photo: Mary Coolidge

# Solution: Glass

## When designing homes and small buildings with glass:

- Treat all glass on home or building, especially glass which meets at corners or allows view through another pane of glass to the outside
- Treat all freestanding glass around courtyards, patios, and balconies

## Window design/ treatment options:

- Exterior screens
- Exterior framework, grilles, trellises or louvers; shades or shutters
- Awnings, overhangs, and deeply-recessed windows
- Glass: Exterior frits, sandblasting, translucence, UV patterns, glass block or screenprinting
- Consider exterior branding on glass for retail locations
- Exterior window films

at corners, unmarked glass expanses, glass balcony walls, or garden walls) by marking windows (with divided light panes, stained glass, UV patterns or frit patterns) or using exterior screening (screens, shades, or trellises) to reduce predictable collision threats. There is no single prescriptive one-size-fits all approach to designing bird-friendly buildings; solutions will be unique and innovative responses to a variety of variables and objectives. The exploration and development of more residentially-geared solutions will be addressed in updates of this document as they become available.

As reported in Appendix 1: the Science of Bird Collisions, Audubon's Wildlife Care Center (WCC) brought in 590 window strikes of 86 species in 2009, 2010, and 2011 combined, the majority from residential properties. Catalogued phone call reports tallied nearly 100 public reports per year during this same period, primarily from residential buildings in the Portland area, underscoring the vital importance of addressing both residential hazards and commercial-scale hazards.

Top left: Diamond leaded glass present on old English style houses in Portland adheres to the 2"x4" rule and effectively marks windows for birds.

Top right: Stained glass like this Frank Lloyd Wright reproduction by local designer Lisa Peterson can add aesthetic interest while effectively marking a window for birds.

Middle left: Close up of fritted glass residential entry provides privacy, reduces solar heat gain on this southern exposure, and still affords views in and out.

Middle right: Povey Brothers Glass Company produced extraordinary art glass in Portland at the turn of the century, and their windows are both beautiful and bird-friendly!

Bottom left: Ribbed glass used in a residential window retrofit provides privacy and effectively eliminates reflections.

Bottom Right: Window screens are still one of the most cost effective ways to reduce strike hazards while keeping insects out of building and home interiors.



58205

## Small-scale Retrofits to Prevent Window Strikes:

- Position bird feeders within 3 feet or more than 30 feet away from windows. At very close distance, birds have less momentum if they strike the window.
- Apply decals to the outside of the window, more densely than packaging suggests. Some decals will help reduce collision risk, but the best practice is still to adhere to the 2" x 4" rule. Available at Audubon's Nature Store, Backyard Bird Shops, and online.
- Apply tape horizontally, spaced ~2 inches apart to outside of window (www.abcbirdtape.org).
- Apply string, cord, mylar tape, raptor sillhouettes or other moving deterrents to the outside of the window (www.birdsavers.com/).
- Affix screen or mesh netting several inches in front of a window to cushion impact (www.birdbgone.com, www.birdscreen.com).
- Apply window film to the outside of a window (www.lfdcollidescape.com, www.thesunshieldpros.us).
- Participate in Lights Out Portland! Turn outside lights off and close drapes from August 25 through November 15 and March 15 through June 7 (migration season) to minimize the luring of migrants into cities.

There are many quick, easy, and cost-effective ways to deter collisions on a short term basis. Here, tape stripes, stenciled, and free hand patterns in tempera paint on home windows. Photo: Christine Sheppard, ABC

Waterproof, washable markers can be used in imaginative, fun, and cost-effective ways to deter collisions. This peacock window design offered a family-friendly activity and produced a beautiful image while marking the window for birds! Photo: Mary Coolidge

The view out of a window with horizontal tape spaced every 2 inches looks much like a view through miniblinds. Photos: Mary Coolidge



58206

When birds encounter beams of light, especially in inclement weather, they tend to circle in the illuminated zone, appearing disoriented and unwilling or unable to leave. In this photo, each white speck is a bird trapped in the beams of light forming the *9/11 Tribute in Light* in New York City. Volunteers watch during the night and the lights are turned off briefly if large numbers of entrapped birds are observed.

Photo: Jason Napolitano

# Problem: Lighting

Artificial light is increasingly recognized as a hazard for humans as well as wildlife. Rich and Longcore (2006) have gathered comprehensive reviews of the impact of "ecological light pollution" on the feeding, migrating and reproductive cycles of vertebrates, insects, and even plants.

## Beacon Effect and Urban Glow

Light at night, especially during bad weather, creates conditions that are particularly hazardous for night-migrating birds which rely on celestial cues to navigate. Typically flying at altitudes over 500 feet, migrants often descend to lower altitudes during inclement weather, where they may encounter artificial light from buildings. Water vapor in fog or mist refracts light, forming an illuminated halo around light sources and can lead to catastrophic mortality events (see Appendix II).

## Fatal Light Attraction

There is clear evidence that birds are attracted to and entrapped by light (Rich and Longcore, 2006; Poot et al., 2008; Gauthreaux and Belser, 2006). When birds encounter beams of light, especially in inclement weather, they tend to circle in the illuminated zone. This has been documented recently at the *9/11 Memorial in Lights*, where lights must be turned off intermittently when large numbers of birds become caught in the beams.

Significant mortality of migrating birds has been reported at oil platforms in the North Sea and the Gulf of Mexico. Van de Laar (2007) tested the impact on birds of lighting on an off-shore platform. When lights were switched on, birds were immediately attracted to the platform in significant numbers. Birds dispersed when lights were switched off. Once trapped, birds may collide with structures or fall to the ground from exhaustion, where they are at risk from predators.

While mass mortalities at very tall illuminated structures (such as skyscrapers) during fog or other inclement weather have received the most attention, mortality has also been associated with ground-level lighting during clear weather. Once birds land in lit areas overnight, they are at increased risk from colliding with nearby structures as they begin to forage for food in the vicinity the following day.

In addition to killing birds, overly-lit buildings waste electricity, and increase greenhouse gas emissions and air pollution levels. Poorly- designed or improperly-installed outdoor fixtures add over one billion dollars to electrical costs in the United States every year, according to the International Dark Sky Association. Recent studies estimate that over two thirds of the world's population can no longer see the Milky Way, just one of the nighttime wonders that connect people with nature. Together, the ecological, financial, and cultural impacts of excessive lighting are compelling reasons to reduce and refine light usage.

Unshielded lights in Elizabeth Caruthers Park in South Waterfront would benefit from full cutoff shielding to reduce contribution to ecological light pollution. Photo: Mary Coolidge

**Light pollution has been shown to impact the Circadian rhythm of birds, fish, wildlife, and plants as well as humans.**



58208

# Problem: Lighting

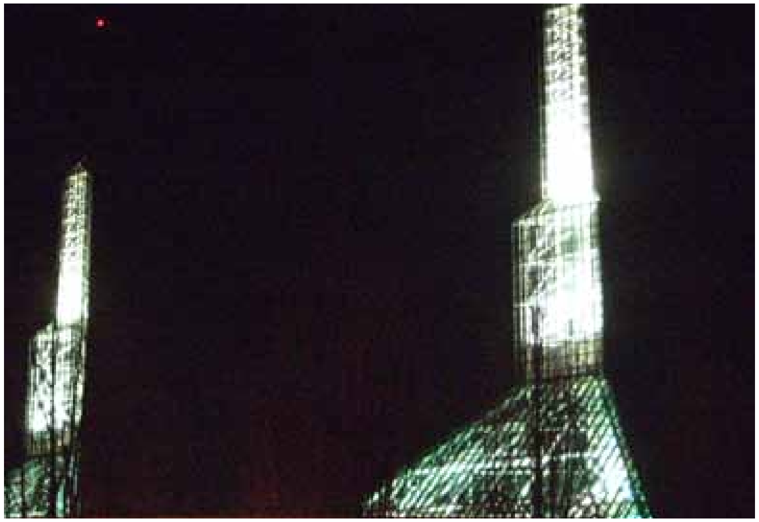
**Overly lit buildings waste electricity, increase greenhouse gas emissions and air and light pollution levels as well as pose a threat to birds.**

Floodlight at the base of the OHSU tram tower. Photo: Mary Coolidge

Unshielded, upward-directed floodlights at the base of the OHSU Tram Tower contribute directly to Portland's skyglow; existing fixtures which light the tram from above could instead be utilized as the primary lighting system. Photo: Mary Coolidge


Light spill is apparent from this stairwell in the Pearl District, and could be minimized by exterior shielding. Photo: Mary Coolidge

The height of the Wells Fargo Tower, coupled with its corner floodlights, make this building a potential collision hazard for migrants. Dimming or extinguishing exterior and rooftop lighting during migration season can help reduce collision hazards. Photo: Mary Coolidge



The iconic spires of the Oregon Convention Center feature unshielded light fixtures, rendering the spires visible for miles; though controversial, dimming or extinguishing these lights during migration season could reduce a potential collision hazard. Photo: Mary Coolidge

Though newer acorn-style light fixtures in South Waterfront have incorporated some shielding design, full cut-off improvements to the design of these fixtures would reduce contribution to light pollution. Photo: Mary Coolidge



58210

# Solution: Lighting Design

**Poorly-designed or improperly-installed outdoor fixtures add over one billion dollars to electrical costs in the United States every year, according to the International Dark Sky Association.**

Reducing exterior building and site lighting can:

- reduce mortality of night migrants
- reduce building energy costs
- decrease air pollution and
- decrease light pollution.

Efficient design of lighting systems and operational strategies to reduce light “trespass” from buildings are both important strategies. In addition, an increasing body of evidence shows that red lights and white light (which contains red wavelengths) particularly attract and confuse birds, while green and blue light have less impact.

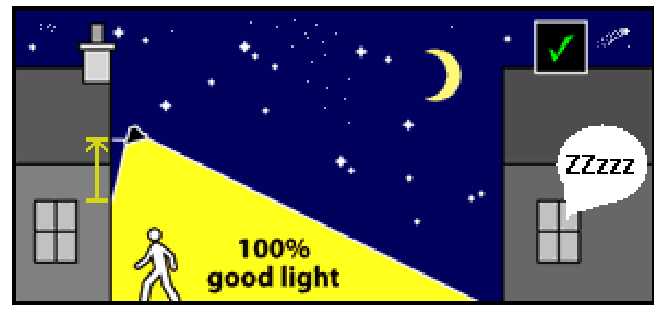
Light pollution is largely a result of inefficient exterior lighting, and improving lighting design usually produces savings greater than the cost of changes. For example, globe fixtures permit little control of light, which shines in all directions, resulting in a loss of as much as 50% of energy, as well as poor illumination. Cut-off shields can reduce lighting loss and permit use of lower wattage bulbs, resulting in lower costs.

Most “vanity lighting” is unnecessary. At minimum, building features should be illuminated using down-lighting rather than up-lighting. Spotlights and searchlights should not be used during bird migration.

Using automatic controls (timers, photo-sensors, and infrared and motion detectors) is more effective than reliance on people to turn off lights. These devices generally pay for themselves in energy savings in less than a year. The Center for Climate and Energy Solutions (www.c2es.org) Lighting Efficiency page cites that “some estimates suggest that occupancy sensors can reduce energy use by 45 percent, while other estimates are as high as 90 percent.” Energy Trust of Oregon provides incentives to help offset up-front costs.

Workspace lighting should be installed where needed, rather than lighting large areas. In areas where indoor lights will be on at night, minimize perimeter lighting and/or draw shades after dark.

BADLY AIMED 500W HALOGEN FLOODLIGHT



WELL AIMED 100W FLOODLIGHT

Switching to daytime cleaning is a simple way to reduce lighting while also reducing costs.

## Safety Concerns

Safety is a primary concern when designing exterior building lighting systems. Unshielded lighting that causes glare is problematic because it saturates rod cells in the eye (responsible for night-vision) and causes pupils to dilate, which reduces the amount of light that enters the eye. The result is temporary night-blindness, which may actually compromise a person’s safety. Constant lighting can also allow intruders and prowlers to remain concealed in predictable shadows, which underscores the importance of well-shielded motion sensor lighting instead of constant-burning lights that produce a dazzling glare.

The Federal Bureau of Investigation's 2009 crime statistics actually indicate that over half of residential burglary crimes are known to have occurred during daylight hours, and less than 30% are known nighttime burglaries. In 2000, the Chicago Alley Lighting Project worked to increase both the number of alley streetlights and the wattage of bulbs (from 90 watt to 250 watt), with the goal of decreasing crime and increasing Chicagoans' sense of safety. Data analysis of pre- and post-installation of these alley lights revealed an increase of 21% in reported offenses occurring at night. Read more here: http://www.icjia.state.il.us/public/pdf/ResearchReports/Chicago%20Alley%20Lighting%20Project.pdf. Communities that have implemented programs to reduce light pollution have not found an increase in crime.

The International Dark Sky Association advocates for putting light where it is needed, during the time period it will be used, and at the levels that enhance visibility. Outdoor lighting directed usefully at the ground reduces dazzling glare, allows for use of lower wattage bulbs, and saves money, electricity, and birds.

## Lights Out Programs

Birds evolved complex systems for navigation long before humans developed artificial light. Recent science has just begun to clarify how artificial light poses a threat to nocturnal migrants. Despite the complexity of this issue, there is one simple way to reduce mortality: turn lights off.

Across the United States and Canada, "Lights Out" programs encourage building owners and occupants to turn out lights visible from outside, at least during spring and fall migration. The first of these, Lights Out Chicago, began in 1995, followed by Toronto in 1997. There are over twenty programs as of mid-2011.

The programs themselves are diverse. They may be directed by environmental groups, by government departments, or by partnerships of organizations. Participation in some, such as Houston's, is voluntary. Minnesota mandates turning off lights

Portland's light-pollution is visible in this satellite image of North America. Photo courtesy of NASA.

Shielded lights, such as those shown above, cut down on light pollution and are much safer for birds. Photo: Susan Harder

Cut-off shields can reduce lighting loss and permit use of lower wattage bulbs, resulting in lower costs. Shielded light fixtures are widely available in many different styles. Top photo: Susan Harder; bottom photo: Dariusz Zdziebkowski, ABC

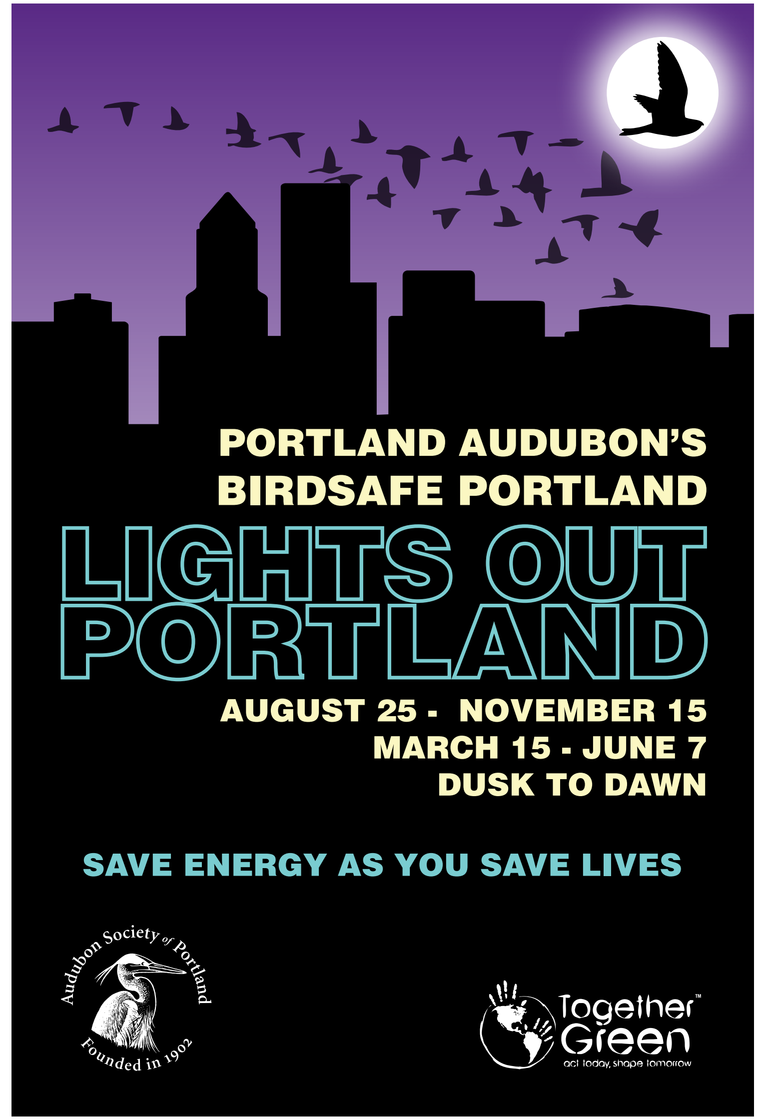
**Lights Out map legend**

- **Red:** state ordinance
- **Yellow:** cities in state-wide programs
- **Turquoise:** program in development
- **Blue:** local programs

in state-owned and -leased buildings, while Michigan's governor proclaims Lights Out dates annually. Many jurisdictions have a monitoring component or work with local rehabilitation centers. Monitoring programs provide important information in addition to quantifying collision levels and documenting solutions. Toronto, for example, determined that short buildings emitting more light can be more dangerous to birds than tall building emitting less light.

### Lights Out Portland

Coordinated by Audubon Society of Portland, Lights Out Portland asks buildings to turn off all unnecessary lighting from dusk to dawn between August 25th and November 15th (fall migration) and between March 15th and June 7th (spring migration). Lights Out provides for 3 levels of participation (silver, gold, platinum), affording some flexibility in the degree of participation. Visit www.audubonportland.org/issues/metro/birdsafe/lo for more information on enrollment, Energy Trust of Oregon incentives, and participating buildings.




Enrollment in Lights Out Portland is voluntary, seasonal and is a way to achieve multiple financial, environmental, and social benefits.

## Houston skyline during Lights Out

Inset: Typical Houston skyline
Photos: Jeff Woodman



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Hundreds of species of birds are killed by collisions. These birds were collected by monitors with FLAP in Toronto, Canada. Photo: Kenneth Herdy

# Appendix 1: The Science of Bird Collisions

## Magnitude of Collision Deaths

The number of birds killed by collisions with glass every year is astronomical. Klem (1990) estimated conservatively that each building in the United States kills one to ten birds per year. Using 1986 United States Census data, he combined numbers of homes, schools, and commercial buildings for a maximum total of 97,563,626 buildings. Dunn (1993) surveyed 5,500 homes with birdfeeders and recorded window collisions. She estimated 0.65 – 7.7 bird deaths per home per year for North America, supporting Klem's calculation. Therefore, given the number of homes across the landscape, they are considered a significant source of mortality.  Attention cannot be solely focused on large buildings and highrises.

The number of buildings in the United States has increased significantly since 1986. Commercial buildings generally kill more than ten birds per year, as would be expected since they have large expanses of glass (Hager *et al.*, 2008; O'Connell, 2001). Thus, one billion annual fatalities is likely to be closer to reality, and possibly even too low.

Klem *et al.*, (2009a) used data from New York City Audubon's monitoring of seventy-three Manhattan building facades to estimate 0.5 collision deaths per acre per year in urban environments, for a total of about 34 million migratory birds annually colliding with city buildings in the United States.

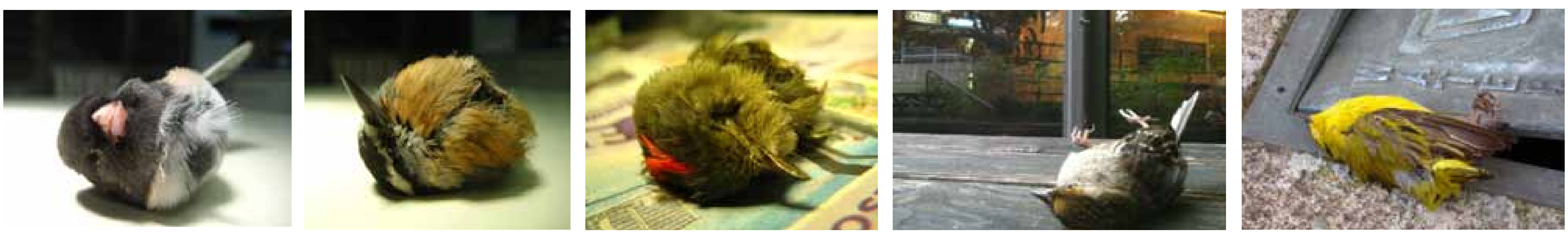
## Patterns of Mortality

It is difficult to get a complete and accurate picture of avian mortality from collisions with glass. Collision deaths can occur at any time. Even intensive monitoring programs only cover a small sampling of buildings, are restricted to public rights of way, and often only occur during migration seasons.

Many city buildings have stepped roof setbacks that are inaccessible to monitoring teams. Recognizing these limitations to detection, some papers have focused on reports from homeowners on backyard birds (Klem, 1989; Dunn, 1993) or on mortality of migrants in an urban environment (Gelb and Delacretaz, 2009; Klem *et al.*, 2009a, Newton, 1999). Others have analyzed collision victims from single, catastrophic incidents (Sealy, 1985) or that have become part of museum collections (Snyder, 1946; Blem et al., 1998; Codoner, 1995).

There is general support for the fact that birds killed in collisions are not distinguished by age, sex, size, or health (for example: Blem and Willis, 1998; Codoner, 1995; Fink and French, 1971; Hager et al., 2008; Klem, 1989). Interestingly, species well adapted to and common in urban areas, such as the American Crow, House Sparrow and European Starling, are not prominent on lists of fatalities, and there is evidence that resident birds are less likely to die from collisions than migratory birds.

**Given the sheer number of residential homes across the landscape, and their tendency to attract birds and reflect vegetation, these buildings are considered a significant source of window collision mortality.**



A few collision victims documented by Portland Audubon's BirdSafe survey. Photos: Mary Coolidge

# Appendix 1: The Science of Bird Collisions

BirdSafe Portland surveys found glass collisions were fatal for at least 36 native bird species (below):

- Anna's Hummingbird
- Black-capped Chickadee
- Bewick's Wren
- Black-throated Gray Warbler
- Cedar Waxwing
- Cooper's Hawk
- Common Yellowthroat
- Dark-eyed Junco
- Fox Sparrow
- Golden-crowned Kinglet
- Golden-crowned Sparrow
- Hammond's Flycatcher
- Hairy Woodpecker
- Hermit Thrush
- Lesser Goldfinch
- Lincoln's Sparrow
- MacGillivray's Warbler
- Mourning Dove
- Orange-crowned Warbler
- Pileated Woodpecker
- Pacific-slope Flycatcher
- Red-breasted Nuthatch
- Red-breasted Sapsucker
- Rufous Hummingbird
- Savannah Sparrow
- Song Sparrow
- Spotted Towhee
- Swainson's Thrush
- Townsend's Warbler
- Varied Thrush
- Warbling Vireo
- Western Tanager
- White-crowned Sparrow
- Willow Flycatcher
- Wilson's Warbler
- Yellow Warbler

Collision mortality appears to be a density-independent phenomenon. Hager *et al.* (2008) compared the number of species and individual birds killed at buildings at Augustana College in Illinois with the density and diversity of bird species in the surrounding area. The authors concluded that total window area, habitat immediately adjacent to windows, and behavioral differences among species were the best predictors of mortality patterns, rather than simply the size and composition of the local bird population.

From a Manhattan study of buildings, Klem *et al* (2009a) concluded that the expanse of glass on a building facade is the factor most predictive of mortality rates, calculating that every increase of 10% in the expanse of glass correlates to a 19% increase in bird mortality in spring, 32% in fall.

Collins and Horn (2008) studied collisions at Millikin University in Illinois, concluding that total glass area and the presence/absence of large expanses of glass predicted mortality level. Hager et al (2008) came to the same conclusion. Gelb and Delacretaz's (2009) work in New York City indicated that collisions are more likely to occur on windows that reflect vegetation.

Dr. Daniel Klem maintains species lists from collision events in countries around the world. This information can be found at: www.muhlenberg.edu/main/academics/biology/faculty/klem/aco/Country%20list.htm#World

He notes 859 species globally, with 258 from the United States. The intensity of monitoring and reporting programs varies widely from country to country, however. Hager (2009) noted that window strike mortality was reported for 45% of raptor species found frequently in urban areas of the United States, and represented the leading source of mortality for Sharp-shinned Hawks, Cooper's Hawks, Merlins, and Peregrine Falcons. See Portland's Urban Raptors and Collisions on page 16.

## BirdSafe Portland Surveys

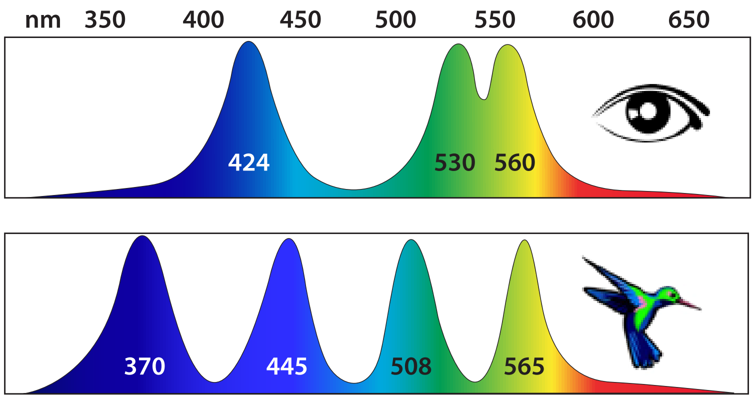
Window collision surveys are being conducted in numerous eastern and mid-western cities, but have been initiated in few west coast cities. San Francisco adopted Standards for Bird-Safe Buildings (July 2011). They have yet to conduct collision surveys, though they do identify monitoring as a goal in their standards, and coast-wide surveys at multiple cities along the Pacific Flyway would provide valuable information about which of our migrants are most at risk of colliding with windows.

In an effort to estimate the magnitude of collisions in the Portland area, Audubon Society of Portland has coordinated BirdSafe Portland surveys seasonally since fall 2009 (pilot season). Surveys have continued through fall 2011. During spring and fall migration, trained volunteers surveyed twenty-one buildings at dawn looking for evidence of strikes. Following low detection rates during the pilot season, building owners and managers, maintenance people, and tenants in each target building were solicited for collision reports. Detection rates increased as a result of increased reporting from areas outside of the right-of-way (courtyards, balconies, terraces, ecoroofs, etc). BirdSafe surveys catalogued up to 62 collisions per season on survey, and a cumulative total of 35 native species were detected. A list of these species can be found in far-left column.

While residential surveys using volunteers are virtually impossible due to private property limitations and staggering scope, much residential data can be gleaned from the Audubon Wildlife Care Center (WCC). As reported in the Residential and Small Building Collisions and Treatments section on page 26, Audubon's WCC brought in 590 window strikes of 86 native species in 2009, 2010, and 2011 combined, primarily from residential properties.

Additionally, Audubon catalogues about 100 calls per year reporting window strikes, most of which come from small buildings and residences.

## Comparison of Human and Avian Vision




While human color vision relies on three types of sensors, birds have four and many birds can see into the ultraviolet spectrum. Illustration based on artwork by Sheri Williamson

## Avian Vision and Collisions

Taking a "bird's-eye view" is much more complicated than it sounds. While human color vision relies on three types of sensors, birds have four. An array of color filters also allows them to see many more colors than people see (Varela *et al.*, 1993) (see chart below). Many birds, including most passerines (Ödeen and Håstad, 2003) also see into the ultraviolet spectrum. Ultraviolet can be a component of any color (Cuthill *et al.*, 2000). Where humans see red, yellow, or red + yellow, birds may see red + yellow, but also red + ultraviolet, yellow + ultraviolet, and red + yellow + ultraviolet. They can also see polarized light (Muheim *et al.*, 2006, 2011), and they process images faster than humans; where we see continuous motion in a movie, birds see flickering images (D'Eath, 1998; Greenwood *et al.*, 2004; Evans *et al.*, 2006). Birds also have two receptors that permit them to sense the earth's magnetic field, which they use for navigation (Wiltschko *et al.*, 2006).

## Avian Orientation and the Earth's Magnetic Field

Thirty years ago, it was discovered that birds orient themselves relative to the Earth's magnetic field and locate themselves relative to their destination. They appear to use cues from the sun, polarized light, stars, the Earth's magnetic field, visual landmarks, and even odors to find their way. Exactly how this works is still being investigated, but there have been interesting discoveries that also shed light on light-related hazards to migrating birds.

Lines of magnetism between the north and south poles have gradients in three dimensions. Cells in three compartments of birds' upper beaks, or maxillae, contain the iron compounds maghemite and magnetite which probably allow birds to detect their "map" (Davila, 2003; Fleissner *et al.*, 2003, 2007). Other magnetism-detecting structures are found in the retina of the eye, and depend on light for activity. Light excites receptor molecules, setting off a chain reaction. The chain in cells that respond to blue wavelengths includes molecules that react to magnetism, producing magnetic directional cues as well as color signals. For a comprehensive review of the mechanisms involved in avian orientation, see Wiltschko and Wiltschko, 2009.

## Birds and Light Pollution

The earliest reports of mass avian mortality caused by lights were from lighthouses, a source of mortality which essentially disappeared when steady-burning lights were replaced by rotating beams (Jones and Francis, 2003). Flashing beams apparently allow birds to continue to navigate. While mass collision events at tall buildings and towers have received most attention (Weir, 1976; Avery *et al.*, 1977; Avery *et al.*, 1978; Crawford, 1981a, 1981b; Newton, 2007), light from many sources, from urban sprawl to parking lots, can affect bird behavior and cause bird mortality (Gochfeld, 1973). Gochfeld (in Rich and Longcore, 2006) noted that bird hunters throughout the world have used lights to disorient and net birds on cloudy nights. In a review of the effects of artificial light on

House Finch  Photo: Mike Houck

Anna's Hummingbird
Photo:R. Michael Liskay

Window strikes represent the leading source of mortality for urban Sharp-shinned Hawks (above), Cooper's Hawks, Merlins, and Peregrine Falcons.
Photo: Jim Cruce

migrating birds, Gauthreaux and Belser (2006) report the use of car headlights to attract birds at night on safari.

Evans-Ogden (2002) showed that light emission levels of sixteen buildings ranging in height from eight to 72 floors correlated directly with bird mortality, and that the amount of light emitted by a structure was a better predictor of mortality level than building height, although height was a factor. Wiltschko *et al* (2007) showed that above intensity thresholds that decrease from green to UV, birds showed disorientation. Disorientation occurs at light levels that are relatively low, equivalent to less than half an hour before sunrise under clear sky. It is thus likely that light pollution causes continual, widespread, low-level mortality that collectively is a significant problem.

The mechanisms involved in both attraction to and disorientation by light are poorly understood and may differ for different light sources (see Gauthreaux and Belser (2006) and Herbert (1970) for reviews.) Haupt and Schillemeit described the paths of 213 birds flying through beams uplighting from several different outdoor lighting schemes. Only 7.5% showed no change in behavior. Migrating birds are severely impacted, while resident species may show little or no effect. It is not known whether this is a result of physiological differences or simply familiarity with local habitat.

Steady-burning red and white lights are most dangerous to birds. Photo: Mike Parr, ABC

### Light Color and Avian Orientation

In the 1940s, ceilometers came into use to measure the height of cloud cover and were thought to be associated with significant bird kills. Filtering out long (red) wavelengths and using the blue/ultraviolet range greatly reduced mortality. Later, replacement of fixed beam ceilometers with rotating beams essentially eliminated impact on migrating birds (Laskey, 1960).

A series of laboratory studies in the 1990s demonstrated that birds required light in order to sense the Earth's magnetic field. Birds could orient correctly under monochromatic blue or green light, but longer wavelengths (yellow and red) caused disorientation (Rappli et al., 2000; Wiltschko *et al.*, 1993, 2003, 2007). It was demonstrated that the magnetic receptor cells on the eye's retina are inside the type of cone cell responsible for processing blue and green light, but disorientation seems to involve a lack of directional information.

Poot *et al.* (2008) demonstrated that migrating birds exposed to different colored lights in the field respond the same way they do in the laboratory. Birds were strongly attracted to white and red light, and appeared disoriented by them, especially under overcast skies. Green light was less attractive and minimally disorienting; blue light attracted few birds and did not disorient those that it did attract (but see Evans *et al.*, 2007). Birds were not attracted to infrared light. This work was the basis for development of the Phillips "Clear Sky" bulb, which produces white light with minimal red wavelengths (Marquenie et al., 2008) and is now in use in Europe on oil rigs and at some electrical plants. According to Van de Laar et al. (2007), tests with this bulb on an oil platform during the 2007 fall migration produced a 50 – 90% reduction in birds

Fog increases the danger of light both by causing birds to fly lower and by refracting light so it is visible over a larger area. Photo: Christine Sheppard, ABC

circling and landing. Recently, Gehring et al. (2009) demonstrated that mortality at communication towers was greatly reduced if strobe lighting replaced steady-burning white, or especially, red lights. Replacement of steady-burning warning lights with intermittent lights is an excellent option for protecting birds, and possibly manipulating light color.

## Weather Impact on Collisions

Weather has a significant and complex relationship with avian migration (Richardson, 1978), and large-scale, mass mortality of migratory birds at tall, lighted structures (including communication towers) has often correlated with fog or rain (Avery et al., 1977; Crawford, 1981b; Newton, 2007). The conjunction of bad weather and lighted structures during migration is a serious threat, presumably because visual cues for orientation are not available. However, not all collision events take place in bad weather. For example, in a report of mortality at a communications tower in North Dakota (Avery *et al.*, 1977), the weather was overcast, usually with drizzle, on four of the five nights with the largest mortality. However, on the fifth occasion, the weather was clear.

## Landscaping and Vegetation

Gelb and Delacretaz (2006, 2009) evaluated data from collision mortality at Manhattan buildings. They found that sites where glass reflected extensive vegetation were associated with more collisions than glass reflecting little or no vegetation. Of the ten buildings

Lower floor windows are thought to be more dangerous to birds because they are more likely to reflect vegetation. Photo: Christine Sheppard, ABC

**Birds are strongly attracted to white and red light, and appeared disoriented by them, especially under overcast skies. Replacement of steady-burning warning lights with intermittent lights is a viable option for protecting birds, and possibly manipulating light color.**

This security grille creates a pattern that will deter birds from flying to reflections. Photo: Christine Sheppard, ABC

responsible for the most collisions, four were "low-rise." Klem (2009) measured variables in the space immediately associated with building facades in Manhattan as risk factors for collisions.

Both increased height of trees and increased height of vegetation increased the risk of collisions in fall. Ten percent increases in tree height and the height of vegetation corresponded to 30% and 13% increases in collisions in fall. In spring, only tree height had a significant influence, with a 10% increase corresponding to a 22% increase in collisions. Presumably, vegetation increases risk both by attracting more birds to an area, and by being reflected in glass.

### Research: Deterring Collisions

Systematic efforts to identify signals that make glass visible to birds began with the work of Klem in 1989. Testing glass panes in the field and using a dichotomous choice protocol in an aviary, Klem (1990) demonstrated that popular devices like "diving falcon" silhouettes were only effective if they were applied densely, spaced two to four inches apart. Owl decoys, blinking holiday lights, and pictures of vertebrate eyes were among items found to be ineffective.

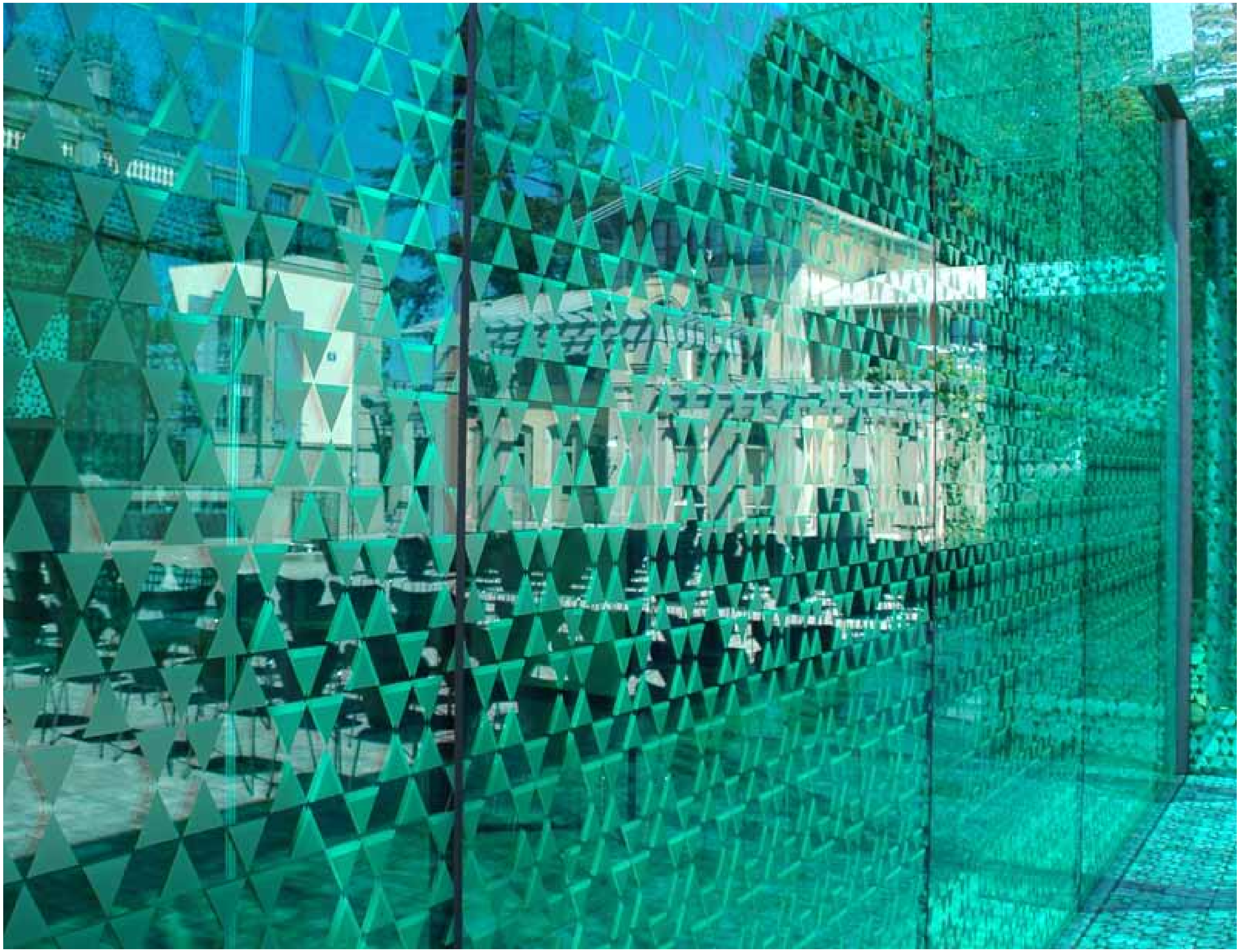
White grid and stripe patterns made from one inch wide material were tested at various spacing intervals. Only three were effective: a 3x4 inch grid, vertical stripes spaced four inches apart, and horizontal stripes spaced about an inch apart across the entire surface.

In further testing using the same protocols, Klem (2009) confirmed the effectiveness of 3MTMScotchcalTM Perforated Window Graphic Film (also known as CollidEscape), WindowAlert® decals, if spaced at the two- to four-inch rule, as above, and externally applied ceramic dots or "frits," (0.1 inch dots spaced 0.1 inches apart). Window films applied to the outside surface that rendered glass opaque or translucent were also effective. The most effective deterrents in this study were stripes of highly reflective 40% UV film (D. Klem, pers. comm., March 2011) alternating with high UV absorbing stripes.

Building on Klem's findings, Rössler developed a testing program in Austria starting in 2004 (Rössler and Zuna-Kratky, 2004; Rössler, 2005; Rössler, et al., 2007; Rössler and Laube, 2008; Rössler, 2009). Working at the banding center at the Hohenau Ringelsdorf Biological Station outside Vienna, Austria made possible a large

Patterns on the outside of glass, such as that shown above, are more effective than patterns on an inside surface. Photo: Hans Schmid

A pattern of narrow horizontal stripes has proven to be highly effective at deterring bird collisions, while covering only about 7% of the surface of the glass. Photo: Hans Schmid



This glass facade of a modern addition to the Reitberg Museum in Zürich, Germany, was designed by Grazioli and Krischanitz. It features a surface pattern formed of green enamel triangles, beautiful and also bird-friendly. Photo: Hans Schmidt

This Barn Swallow flying sideways through a barn door perfectly illustrates the 2" x 4" rule.
Photo: Keith Ringland

**Glass fritted in patterns conforming to the 2" x 4" rule scored well as deterrents.**



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sampling of birds for each test and permitted comparisons of a particular pattern under different intensities of lighting. This program has focused primarily on geometric patterns, evaluating the impact of different spacing, orientation, and dimensions. Birds are placed in a "tunnel," where they can view two pieces of glass: one unmodified, (the control) and the other with the pattern to be tested. Birds fly down the tunnel and are scored according to whether they try to exit through the control or the pattern. A mist net prevents the bird from hitting the glass and it is then released. The project focuses not only on finding patterns effective for deterring collisions, but also on effective patterns that cover a minimal part of the glass surface. To date, some patterns have been found to be highly effective while covering only 5% of the glass.

Building on Rössler's work, ABC has collaborated with the Wildlife Conservation Society and the Carnegie Museum to construct a tunnel at Carnegie's Powdermill Banding Station, primarily to test commercially available materials. This project has been supported by the Association of Zoos and Aquarium's Conservation Endowment Fund, the Colcom Foundation, and New York City Audubon. Results from the first season showed that an entirely UV-reflective surface was not effective at detering birds. UV materials seem to rely on contrast for effectiveness. Glass fritted in patterns conforming to the 2" x 4" rule scored well as deterrents.

Most clear glass made in the United States transmits about 96% of light falling perpendicular to the outside surface, and reflects about 4%. The amount of light reflected increases at sharper angles – clear glass reflects about 50% of incident light at angles over 70 degrees. Light on the inside of the glass is also partly reflected and partly transmitted. The relative intensities of light transmitted from the inside and reflected from the outside surfaces of glass, as well as the viewing angle, determine if the glass appears transparent or mirrors the surrounding environment.

ABC's Chris Sheppard testing a bird in the tunnel at the Carnegie Museum's Powdermill Banding Station in southwestern Pennsylvania. Photo: Susan Elbin, 2011

The tunnel – an apparatus for safely testing effectiveness of different materials and designs for deterring bird collisions. Photo: Christine Sheppard, ABC

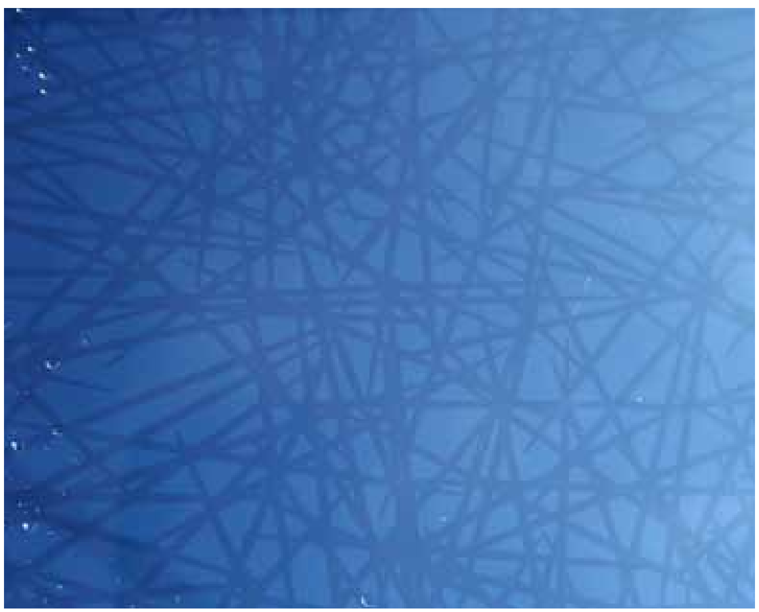
A bird's eye view of glass in the tunnel. Photo: Christine Sheppard, ABC

Patterns on the inside surfaces of glass and objects inside the glass may not always be visible. These optical properties emphasize the superiority of patterns applied to the outer surface of glass over patterns applied to the inner surface.

The majority of the work described here uses protocols that approximate a situation with free-standing glass – birds can see through glass to the environment on the other side, patterns tested are between the bird and the glass and patterns are primarily back-lit. While this is useful and relevant, it does not adequately model most glass installed in buildings. New protocols test materials whose effectiveness depends on the glass being primarily front-lit. This includes UV patterns and frit patterns on the inside surfaces of insulated glass. Window treatments and product testing are ongoing and data will continue to be shared as it becomes available.

A dense internal frit pattern on the glass of the Bike and Roll building, near Union Station in Washington D.C., makes it look almost opaque. Photo: Christine Sheppard, ABC

A panel of fritted glass, ready for testing. Photo: Christine Sheppard, ABC



Ornilux Mikado's pattern reflects UV wavelengths. The spiderweb effect is only visible to humans from very limited viewing angles. Photo: Arnold Glass

Patterns with more contrast and distinct spaces, such as the one shown on the left, are much more effective than repeating, all-over patterns like the one shown above. Photo: Christine Sheppard, ABC



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Bird collisions with buildings occur year-round, but peak during the migration periods in spring and especially in fall.

# Appendix II: Bird Migration

Portland sits along the Pacific Flyway, a primary north-south migration route on the West Coast of North America. Migrants generally follow natural geographical features such as valleys, shorelines, and mountain passes that concentrate migrants & may also provide them with clues to navigation. These features are known as leading lines. Portland's 209 species of birds are made up of both resident and migratory species. Our fall migration stretches from August 25 – November 15, and spring migration lasts from March 15 – June 7.

While bird collisions occur year-round, they peak during migration periods in spring and especially in fall when millions of adults and juvenile birds travel between breeding and wintering grounds, perhaps as far as Alaska and South America. Migration is a complex phenomenon, and hazards can vary depending on migration distances, immediate weather conditions, availability of food, and human-made obstacles encountered along the way.

Many species' migratory patterns alternate flight with stopovers to replenish their energy stores. Night-flying migrants, including many songbirds, generally take off within a few hours of sunset and land sometime between midnight and dawn (Kerlinger, 2009). Once birds land, they may remain for several days, feeding and waiting for appropriate weather to continue.

During that time, they travel around the local area, in search of good feeding sites. Almost anywhere they stop, they risk hitting glass. Like other cities, Portland's collision monitoring program involves searching near dawn for birds that have been killed or injured during the night *(see page 40)* for details on BirdSafe Portland surveys). Programs that monitor during the day continue to find birds that have collided with windows (Gelb and Delecretaz, 2009; Olson, pers. Comm.; Russell, pers. Comm.; Hager, 2008). These diurnal collisions are widespread, and represent the greatest number of bird deaths and the greatest threat to birds.

Birds moving between wintering grounds (usually to the south) and breeding grounds travel along the Pacific Flyway, a broad migration route that brings them through Oregon. Illustration courtesy of USFWS

**Portland sits along the Pacific Flyway, a primary north-south migration route on the West Coast of North America. The Portland area regularly hosts 209 species of birds, a diversity composed of both resident and migratory species.**



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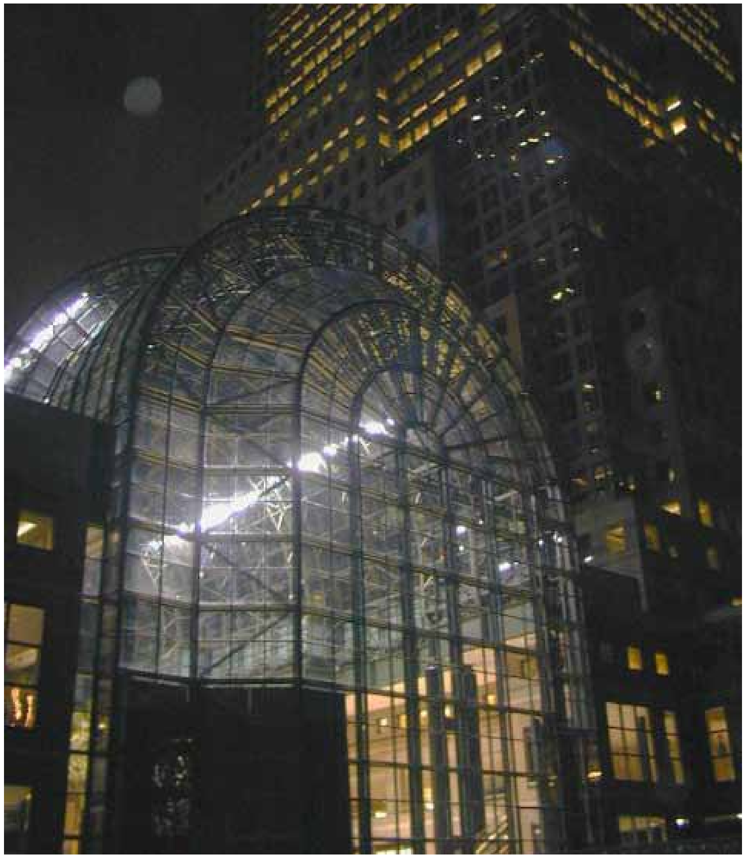
# Appendix II: Bird Migration

**Night-migrating songbirds, already imperiled by habitat loss, are at double the risk, threatened both by illuminated buildings at night and by glass reflections during the day.**



The glass walls of this atrium, coupled with night-time illumination, create an extreme collision hazard for birds. Photo: NYC Audubon

Migrating Vaux's swifts roosting at Chapman Elementary School is a well-known phenomenon in Portland, with thousands of people gathering each September to see their nightly convergence down the chimney. Photo: Vern di Pietro

### Diurnal Migrants

Daytime migration routes often follow land forms such as rivers, mountain ranges and coastlines. Birds tend to be concentrated along these routes or "flyways." Some songbird species such as American Robin, Horned Lark, and Rufous Hummingbird migrate during the day. Diurnal migrant flight altitudes are generally lower than those of nocturnal migrants, putting them at greater risk of collisions with tall buildings.

### Nocturnal Migrants

Many songbirds migrate at night to avoid predators, to take advantage of cooler temperatures and less turbulent air, and in order to forage during daylight hours. Songbirds may fly as many as 200 miles in a night, and stop to rest and feed for one to three days, but these patterns are strongly impacted by weather, especially wind and temperature. Birds may delay departure, waiting for good weather. They generally fly at an altitude of about

2,000 feet, but may descend or curtail flight altogether if they encounter a cold front, rain, or fog. There can be a thousand-fold difference in the number of birds aloft from one night to the next. Concentrations of birds may develop in "staging areas", where birds prepare to cross large barriers such as the Great Lakes or Gulf of Mexico.

Night-migrating songbirds, already imperiled by habitat loss, are at double the risk, threatened both by illuminated buildings at night *(see Appendix I)* and by glass reflections during the day.

Millions are at risk as they ascend and descend, flying through or stopping in or near populated areas. City buildings are unseen obstacles by night and pose confusing reflections by day.

After landing, nocturnal migrants make short, low flights near dawn, searching for feeding areas and encountering glass in cities, suburbs and exurbs. When weather conditions cause night-fliers to descend into the range of lighted structures, catastrophic collision events can occur around tall buildings. Urban sprawl is creating large areas lit all night that may be causing less obvious, more dispersed bird mortality.

## Local Movements

Glass collisions by migrating songbirds are by far the best known, but mortality of other groups of birds is not insignificant. Fatalities from collisions have been reported for 19 of 42 raptor species in both urban and non-urban environments. Collisions are the leading known cause of death for four raptor species in cities, including the Peregrine Falcon. Breeding birds encounter glass as they search for nest sites or food, patrol territories or home ranges, flee predators or pursue prey. Mortality increases as inexperienced fledglings leave the nest and begin to fly on their own.

Breeding birds encounter glass as they search for nest sites or food, patrol territories or home ranges, flee predators or pursue prey. Mortality increases as inexperienced fledglings leave the nest and begin to fly on their own.

The mirrored glass of this office building reflects nature so perfectly that it is easy to see how birds mistake reflection for reality. Photo: Christine Sheppard, ABC

Reflections of "urban canyons" between tall buildings can also deceive birds that attempt to fly through perceived passageways. Photo: Christine Sheppard, ABC

Swainson's Thrushes are common collision victims in Portland. Photo: Mary Coolidge

A volunteer with BirdSafe Portland picks up a Wilson's Warbler that had collided with the plate glass. Wilson's Warblers migrate through Portland and have been recorded in local collision surveys. Photo: Mary Coolidge

# Appendix III: Evaluating Collision Problems – A Toolkit

Often, only part of a building is responsible for causing most of the collisions. Evaluation and documentation can help develop a program of remediation targeting that area. This can be almost as effective as modifying the entire building, as well as being less expensive.

Documentation of patterns of mortality and environmental features that may be contributing to collisions is essential. Operations personnel are often good sources of information as they may come across bird carcasses while performing regular maintenance activities. People who work near windows are often aware of birds hitting them. Regular monitoring documents mortality patterns and provides a baseline for demonstrating improvement. This monitoring is an internal effort by the building owner or manager, tenants, and staff. The data collected is a resource for internal use and evaluation. The following questions can help guide the evaluation and documentation process by identifying features likely to cause collisions.


External shades, as shown here on the Batson Building in Sacramento, California, designed by Sym Van der Ryn, are a simple and flexible strategy for reducing bird collisions, as well as controlling heat and light. Photo: MechoShade

Often, only part of a building is responsible for causing most of the collisions.

## Seasonal Timing

**Are collisions happening mostly during migration or fledging periods, in winter, or year round?** If collisions happen only during a short time period, it may be possible to apply inexpensive, temporary solutions during that time and remove them for the rest of the year.

Some birds will attack their own reflections, especially in spring. This is not a true collision. Territorial males, especially American Robins and Cardinals, perceive their reflection as a rival male. They are unlikely to injure themselves, but temporarily blocking the offending window from the outside should resolve the problem.

## Diurnal Timing

**Are collisions happening at a particular time of day?** The appearance of glass can change significantly with different light levels, direct or indirect illumination, and sun angles. It may be possible to simply use shades or shutters during critical times *(see Appendix II)*.

## Weather

**Do collisions coincide with particular weather conditions, such as foggy or overcast days?** Such collisions may be light-related. It may be possible to create an email notification system, asking building personnel to turn off lights when bad weather is forecast.

## Location

**Are there particular windows, groups of windows or building facades that account for most collisions?** There are often particular windows or aspects of a building that account for most collisions; it may be cost-effective to modify only these problematic sections of glass.

The American Goldfinch is a common resident in the Portland area. Photo: Jim Cruce

## Vegetation

**Is landscaping contributing to collisions?** If so, landscaping may be more easily addressed and less costly to fix than glass modification or replacement. If there is an area where plants are visible through glass, moving plants away from windows may help to resolve a collision issue. If there is a clear pathway bordered by vegetation that directs birds toward windows, a trellis to shield the glass, reduce reflections, and divert flight paths may be considered. If fruit trees or berry bushes are attracting birds near to a glassy area, here again, a trellis or a screen may be less expensive than retrofits to the glass itself.

There may also be secondary factors contributing to collisions that are more easily addressed and less costly fixes than glass modification or replacement.

## Evaluating Retrofit Options

In some cases, a collision problem on a building may be deemed sufficient to warrant a retrofit. When determining which material to use in retrofitting the area, there are many factors to consider. Seasonal, temporary solutions may be appropriate for on an interim basis to quickly address the collision issue while evaluating a long-term solution. Temporary solutions may include ABC Bird Tape *(see page 26)*, mylar tape, tempera paint, decals, or any of a myriad imaginative ways to create relatively effective, low cost, and easy to apply visual noise on a window.

Any retrofit approach may be evaluated by a number of factors, including: effectiveness, cost, ease of application or implementation, longevity, ease of maintenance, and potential to improve the energy performance of the building. Specific evaluation of approaches will vary widely based on details of product selection, but a general overview follows.

**Netting:** Fine mesh can be an effective, relatively low-cost, seasonal solution. This type of approach was used at the FBI's 10-story LEED Platinum office building in Chicago, where collisions were a concern. Netting requires installation prior to each spring and fall migration, but has little impact on the building's aesthetics.
**Window Films:** Films are available for use on the exterior surface of a window, where they are most effective. They can be quite effective and are easy to apply to small areas, and can carry an energy benefit, but some may decrease light entry and have a visible impact on window appearance, both from inside and outside.

**Exterior Screens:** Screens can effectively reduce visible reflections, provide insulation from strike impact, reduce solar heat gain, and are one of the less costly approaches to a retrofit. Screens installed at Lewis and Clark Law School have been very effective at reducing strike incidence, and seasonal removability makes them more acceptable to building occupants.

**Shutters** are a very effective strike deterrent, provide an energy efficiency benefit, may be aesthetically pleasing, and have reliable longevity. They can be useful for reducing seasonal strikes. Replacing glass with fritting or UV patterned glass is likely to be the most expensive retrofit option, but is one of the more attractive options, can increase the energy efficiency of the window, and requires no added maintenance.

**Reglazing glass** in place is an option for introducing visual noise while preserving the existing windows, and requires no additional product maintenance. Etching and sandblasting can create branding on retail glazing or can provide built-in privacy for other conditions.

**Trellises** that act as a green screen can be easily installed as a retrofit, can provide a shading or privacy benefit, are aesthetically pleasing, and can be a relatively low-cost fix. Careful plant selection can help offset potential maintenance demand.



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## Research

Research on songbirds, the most numerous victims of collisions, has shown that horizontal spaces must be 2” or narrower, to deter the majority of birds. Vertical spaces must be 4” or narrower. This difference presumably has to do with the shape of a flying bird with outstretched wings. Within these guidelines, however, considerable variation is possible when devising bird-friendly patterns. We recommend that lines be at least ¼” wide, but it is not necessary that they be only vertical or horizontal. Contrast between pattern and background is important, however, be aware that the background – building interior, sky, vegetation – may change in appearance throughout the day. Effective patterns on the exterior surface of glass will combat reflection, transparency and passage effect. In the case of handrails or other applications viewed from both sides, patterns should be applied to both surfaces if birds can approach from either side.

The white stripes on this glass wall are an easy way to make a very dangerous area safe for birds. Photo: Hans Schmid

**Research on songbirds, the most numerous victims of collisions, has shown that horizontal spaces must be 2" or narrower, to deter the majority of birds. Vertical spaces must be 4" or narrower.**

While patterns on the exterior surface of glass are most effective, blinds and curtains can help disrupt reflections. Partially open blinds, like those seen here, are most effective. Photo: Christine Sheppard, ABC

Patterns achieved with film or by etching glass can be beautiful as well as very effective in preventing bird collisions. Photo: Bob Sallinger



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Peregrine Falcon and nest on the Interstate Bridge. Photo: Bob Sallinger

# Appendix IV: Legislation

In recent years, efforts to standardize bird-friendly approaches have resulted in voluntary guidelines and/or legislation in a number of cities and states across the United States and Toronto. Cook County, Illinois, was the first to pass bird-friendly construction legislation, sponsored by then-assemblyman Mike Quigley. In 2006, Toronto, Canada, proposed a Green Development Standard, initially a set of voluntary guidelines to promote sustainable site and building design, including guidelines for bird-friendly construction. Development Guidelines became mandatory on January 1, 2011, but the process of translating guidelines into blueprints is still underway. San Francisco adopted Standards for Bird-safe Buildings in September, 2011.

### Listed below are some examples of current and pending ordinances at levels from federal to municipal.

**Federal (proposed):** Illinois Congressman Mike Quigley (D-IL) introduced the Federal Bird-Safe Buildings Act of 2011 (HR 1643), which calls for each public building constructed, acquired, or altered by the General Services Administration (GSA) to incorporate, to the maximum extent possible, bird-safe building materials and design features. The legislation would require GSA to take similar actions on existing buildings, where practicable. Importantly, the bill has been deemed cost-neutral by the Congressional Budget Office. See http://thomas.loc.gov/cgi-bin/query/z?c112:H.R.1643.IH: Congressional Budget Office estimates are a matter of public record and can be found at http://www.cbo.gov/cost-estimates/

**State: Minnesota (enacted):** Chapter 101, Article 2, Section 54: Between March 15 and May 31, and between August 15 and October 31 each year, occupants of state-owned or state-leased buildings must attempt to reduce dangers posed to migrating birds by turning off building lights between midnight and dawn, to the extent turning off lights is compatible with the normal use of the buildings. The commissioner of administration may adopt policies to implement this requirement. See www.revisor.leg.state.mn.us/laws/?id=101&doctype=Chapter&year=2009&type=0

**State: Minnesota (enacted; regulations pending):** Beginning on July 1, 2010, all Minnesota State bonded projects – new and substantially renovated –that have not already started the schematic design phase on August 1, 2009 will be required to meet the Minnesota Sustainable Building 2030 (SB 2030) energy standards. See www.mn2030.umn.edu/

**State: New York (pending):** Bill S04204/A6342-A, the Bird-friendly Buildings Act, requires the use of bird-friendly building materials and design features in buildings. See http://assembly.state.ny.us/leg/?bn=S04204&term=2011

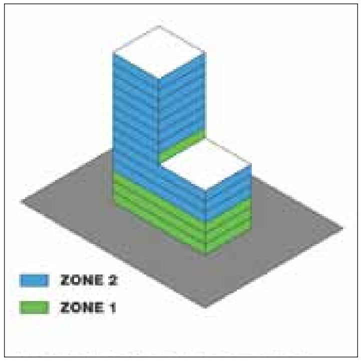
**City: San Francisco (enacted):** The city's Planning Department has developed the first set of objective standards in the nation, defining areas where the regulations are mandated and others where they are recommended, plus including criteria for ensuring that designs will be effective for protecting birds. See www.sf-planning.org/index.aspx?page=2506

**City: Toronto:** On October 27, 2009, the Toronto City Council passed a motion making parts of the Toronto Green Standard mandatory. The standard, which had previously been voluntary, applies to all new construction in the city, and incorporates specific Bird-Friendly Development Guidelines, designed to eliminate bird collisions with buildings both at night and in the daytime.Beginning January 31, 2010, all new, proposed low-rise, non-residential, and mid- to high-rise residential and industrial, commercial, and institutional development will be required under Tier 1 of the Standard, which applies to all residential apartment buildings and non-residential buildings that are four stories tall or higher. See www.toronto.ca/planning/environment/greendevelopment.htm

**Voluntary Bird-friendly Building Guidelines:** These guidelines, available in several jurisdictions, offer voluntary best practices resource guides for architects, developers, building managers, engineers, and the general public for the design and retrofitting of bird-friendly homes and buildings. Examples of guidelines include: New York City (www.nycaudubon.org/our-publications/bird-safe-buildings-guidelines); Minnesota (http://mn.audubon.org/guide-urban-bird-conservation/bird-building-collisions); and Chicago (www.birdsandbuildings.org/docs/ChicagoBirdSafeDesignGuide.pdf).

**These legislative efforts promote bird-friendly design and the reduction of light pollution.**

# Appendix V: LEED Pilot Credits Addressing Ecosystem-level Considerations




Zone 1 includes the first 3 floors above ground level and the first floor above a green roof. Zone 2 includes all façade area above the 3rd floor. Zone 1 is considered twice as dangerous as Zone 2.

## Pilot Credit 55: Bird Collision Deterrence

On October 14, 2011, The US Green Building Council introduced a pilot credit with the explicit intent of "reduc[ing] bird injury and mortality from in-flight collisions with buildings." The establishment of the Bird Collision Deterrence (BCD) credit demonstrates the USGBC's commitment to expanding the standards of its green building program to include ecosystem-level considerations in its rating system. Since collisions can occur due to a combination of factors, the credit addresses unmarked window glass as well as both interior and exterior lighting. The credit is available to both new construction and existing buildings.

For new construction, the building must comply with a building façade option, an interior lighting option, an exterior lighting option, and develop a 3-year post-construction monitoring plan.

## Building Façade Requirement

Develop a façade design strategy to make the building visible as a physical barrier, and eliminate reflections. The BCD Pilot credit helps to direct architects and designers to window materials that have been tested & rated for their visibility to birds. Strategies for creating visual noise can include opacity, translucence, fritting, UV-patterns, exterior films, louvers, screening, netting, and shutters. A summary of Material Threat Factors allows a designer to calculate the overall Bird Collision Threat Rating (BCTR) for the building, which must score no higher than 15. All glazed corners or fly-through conditions (closely placed unmarked glass) must have a Threat Factor equal to or below 25. If all the materials used in the façade have a Threat Factor of <15, the project may submit a materials list in lieu of a BCTR calculation.

### For more on BCD and BCTR Calculation:

An example of a proposed BCD project and its accompanying BCTR Calculation is available on page 10 of the LEED Pilot Credit Library materials http://www.usgbc.org/ShowFile.aspx?DocumentID=10402

### Sampling of Material Threat Factor ratings:

- Opaque material, 0
- Exterior adhesive film, 2
- Interior patterned film 2" horiz. or 4" vert., 15
- Exterior louvers 2" horiz. or 4" vert., 5
- Glass Block 8" x 8" x 4", textured, 10
- Exterior white dot frit, 15
- Operable shutters, 10
- UV-patterned glass, 25

The building is first separated into two risk zones: Zone 1 (high risk) and Zone 2 (low risk). Zone 1 includes the first 3 floors above ground level and the first floor above a green roof. Zone 2 includes all façade area above the 3rd floor. Zone 1 is considered twice as dangerous as Zone 2.

For each zone, calculate the BCTR according to the formula:

1. [((Material Type 1 Threat Factor) x (Material Type Area)) + ((Material Type 2 Threat Factor) x (Material Type Area))…] / [Total Façade Zone Area = Façade Zone BCTR.

2. Then determine the total building Bird Collision Threat Rating by performing the following calculation with BCTRs for Zone 1 and Zone 2:
   [((Zone 1 BCTR) x 2) + (Zone 2 BCTR)] / 3 = Total Building BCTR

#### Lighting Requirement

In addition to a façade treatment and monitoring, the credit requires that overnight lighting be responsibly designed to minimize light spill from both interior spaces and exterior fixtures.



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The new bird-safety credit addresses the hazard of light pollution by requiring properly-shielded fixtures, as well as establishment of manual or automatic shutoff programs from midnight to 6 am (safety lighting is exempted). The credit is synergistic with other LEED-spirited goals: it minimizes waste of electricity (and money!), helps to reduce carbon emissions, minimizes impacts to wildlife, and preserves our age-old cultural heritage of star-gazing.

#### Post-Construction Monitoring Plan

Submit a copy of the 3-year post-construction monitoring plan to routinely monitor for collision-prevention effectiveness. Include methods to identify and document strike locations, the number, date, and time of collisions, as well as the feature that may be contributing to collisions. The plan should include a process for correcting problem areas if any are discovered. Monitoring is not intended to be punitive, but rather, intended to provide data on the effectiveness of different design approaches.

### Existing Building Operation & Maintenance

#### Lighting

For both interior and exterior lighting, the building must provide necessary reports, drawings, and descriptions of light fixtures, lighting systems, and operations as above to demonstrate compliance.

#### Post-Construction Monitoring Plan

Implement a 3-year façade monitoring Plan in NC, CS, Schools, Retail, Healthcare above. If a collision area is identified, consider a temporary or permanent retrofit. Implement interim retrofits within 120 days, and permanent retrofits within 2 years.

### LEED Pilot Credit 7: Light Pollution Reduction

The US Green Building Council has rewritten the Light Pollution Reduction credit to make it easier to understand, more flexible for designers, and more applicable to different sources of light pollution. The Credit explicitly intends to "increase night sky access, improve nighttime visibility, and reduce development impacts on wildlife environments by reducing uplight (skyglow) and light trespass (glare)." The establishment of the Light Pollution Reduction credit is just one of the ways that the USGBC is demonstrating its commitment to include ecosystem-level considerations in its rating system.

For both the uplight and light trespass requirements, an optional path allows teams to demonstrate compliance by selecting luminaires with an appropriate BUG rating and placing them appropriately. No point-by-point calculation is required. The calculation path is simplified and requires calculations for fewer locations. Many projects can achieve the credit by simply complying with ASHRAE 90.1–2010 and selecting luminaires with an appropriate BUG rating.

The term *lighting boundary* has been introduced to indicate the nearest property line adjacent to the project site (modified in some cases). Light trespass requirements relate to the lighting boundary, rather than the LEED site boundary. Skyglow/Uplight requirements are still met based on all non-exempt exterior luminaires located within the LEED site boundary.

The credit is available for pilot testing in New Construction, Core & Shell, Schools, Retail, Healthcare, and EBOM.

**Full text of the LEED Pilot Credit 55 language:** http://www.usgbc.org/ShowFile.aspx?DocumentID=10402

**Summary of Material Threat Factors:** https://www.usgbc.org/ShowFile.aspx?DocumentID=10397

**Full text of the LEED Pilot Credit 7 language:** http://www.usgbc.org/ShowFile.aspx?DocumentID=8219

**Bird-friendly practices often go hand-in-hand with energy efficiency improvements**

Rufous Hummingbird. Photo: Jim Cruce

# Appendix VI: Cost Effectiveness – Considerations and Case Studies

**Despite tremendous gains in the energy efficiency of glass, it is still far less energy efficient than solid walls, and is, in fact, the least energy efficient façade material available.**

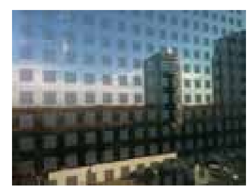
There are many approaches to designing a bird-friendly building. By far, the best way to realize cost-effectiveness is to incorporate bird-friendly design considerations into the initial concept, rather than addressing them as an afterthought. Capitalizing on potential opportunities to match bird-friendly approaches with other building objectives is an elegant approach that many designers have taken. There are numerous examples throughout this document of buildings that have achieved bird-friendliness while meeting other primary objectives. These may include energy efficiency, pure aesthetics, creation of privacy, or incorporation of branding into the building envelope. Case studies can begin to illustrate what the relative cost is for window treatment, but cost estimates are best formulated on a project-by-project basis, in light of other objectives in the building design, identifying where energy efficiency can be improved, and whether other objectives such as privacy or branding can be met.

Despite tremendous gains in the energy efficiency of glass, it is still far less energy efficient than solid walls, and is, in fact, the least energy efficient façade material available. An energy analysis by the University of Leeds, UK, indicated that energy efficiency decreases when window area exceeds 30% of an exterior wall. This is because R-values for a solid, insulated wall can be 5 to 30 times higher than glass. Scaling back on the percentage of glass as a building material is the best design strategy to maximize energy efficiency while reducing risk to birds. A recent article in *Environmental Building News*:19:7 entitled "Rethinking the All-glass Building" weighed the benefits of the all-glass building against the energetic and environmental operating costs, and concluded that an "overuse" of vision glass results in high energetic penalty. This is supported by research at the Pacific Northwest National Laboratory showing that high window-to-wall ratios (WWR) increase energy use in every climate zones studied (M. Rosenberg, pers. comm.). In San Francisco, a slight decrease in energy use occurred up to a 20% WWR, above which an energy penalty resulted. Where glass is used, adding patterns to glass (fritting or silk-screening) lowers the window's Solar Heat Gain Coefficient, which is a measure of the amount of solar heat transmitted. Long-term building costs are impacted by both the upfront costs of materials and installation, as well as the ongoing costs of operating a building over time.

The Federal Bird Safe Buildings Act of 2011 (HR 1643) proposes that all federal buildings constructed, acquired, or altered by the General Services Administration should incorporate bird safe materials and design features where practicable. A Congressional Budget Office analysis deemed the bill to be cost-neutral. In fact, many designers who have designed bird-friendly buildings have asserted that they do not see a significant increase in cost if these design approaches come into consideration from the start.

### Case Study: Prendergast Laurel

Prendergast Laurel architects performed a cost analysis for a 12,625 square foot library, comparing the costs of conventional insulated glass to fritted or UV-patterned glass. For 3,084 square feet of glass, the total window cost (labor and materials) rose from $428,000 to $447,260 when upgrading all 3,084 square feet of façade glass to UV or fritted glass. The cost increase was $19,260, on an $11,350,000 building, which represents a 0.18% overall cost increase. Overall building costs increased by less than 1/2 a percent in this analysis.



Patterned glass at OHSU. Photo: Mary Coolidge

### Case Study: OHSU Center for Health and Healing

The new OHSU Center for Health and Healing in South Waterfront, designed by GBD Architects, uses vision glass on 40% of the building's skin, amounting to a total 78,105 square feet of glass façade. Of the total 78,105 square feet of glass skin, 9,092 square feet is fritted, or 12% of the vision glass. The skin of the building represented a cost of $10,443,794 of a total $145 million project cost, which represents 7.2% of total project cost. The net



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cost on the upgrade to fritted glass (a 50% upcharge to the cost of glass) on this building amounted to $45,460 in total, or a 0.03% increase in project cost for fritting, a treatment which in various places helped to create a sense of enclosure in the space, provided solar protection and glare control, and animated the façade as seen from a distance.

### Retrofit Case Study: Lewis and Clark Law School

Mirrored windows on the Lewis and Clark Law School Legal Research Center have long been the site of fatal bird collisions. Students at the school developed a monitoring program to document fatalities, and when it was determined that hawk silhouettes were not effectively deterring collisions, the Law School administration hired Hennebery Eddy Architects to develop several retrofit test solutions. Test products included fixed exterior window screens, electronic roll-down window screens, and exterior window film. The approved project budget was $88,000, but ultimately, removable exterior screens designed by Steve Kem were installed on the LRC building for a fraction of the estimated cost, and have successfully reduced the collision hazard *(see page 15)*.

Madrid's Vallecas 51, designed by Somos Arquitectos, uses open-celled polycarbonate panels – a sustainable and recyclable skin that presents no threat to birds. Photo: Victor Tropchenko

### Retrofit Case Study: Port of Vancouver

Highly reflective windows at the administrative building at the Port of Vancouver (PoV) have been the site of historic window collisions. PoV has initiated a pilot installation of roll-up solar shades to provide seasonal screening on 6 windows. Manufactured by Portland-based Suntek Solar Shades, the screens were supplied and installed by Integrity Window Coverings of Vancouver, WA, and cost $260 each, installed. Screens will be tested for effectiveness and acceptability by PoV staff, and will be coupled with a vegetation screening strategy. PoV also acts as a landlord to various industrial tenants, including two tenants who are undertaking new construction. Bird-Friendly Building flyers, produced by PoV, as well as additional resource materials have been provided to tenants to encourage consideration of bird-friendly design

Six reflective windows on the Port of Vancouver administrative building are slated for a pilot installation of roll-up solar shades, which will serve the dual purpose of softening incoming light and reducing strike hazards.
Top photo shows window with shades up and bottom shows the window with the shades down. Photo PoV.

Issues of cost prompted Hariri Pontarini Architects, in a joint venture with Robbie/Young + Wright Architects, to revise a planned glass and limestone façade on the School of Pharmacy building at the University of Waterloo, Canada. The new design incorporates watercolors of medicinal plants as photo murals. Photo: Anne H. Cheung



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Stunned Yellow Warbler after striking a window. Photo: Kate MacFarlane


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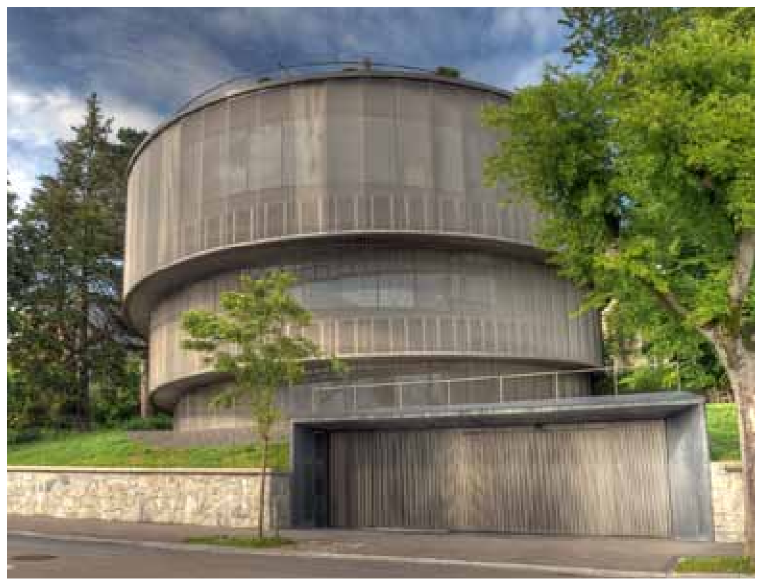

The steel mesh enveloping Zurich's Cocoon in Switzerland, designed by Camenzind Evolution Ltd, provides privacy and protects birds, but still permits occupants to see out. Photo: Anton Volgger



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A 2009 USFWS study showed that bird watching is one of the fastest growing leisure activities in North America, and a multi-billion-dollar industry. Photo: Mike Houck


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The IIT Student Center in Chicago uses faceted glass, Panelite panels and a dot matrix pattern (above) in its facade. These elements create visual noise which is perceptible to birds.

The U.S. Census Complex in Suitland, Maryland, designed by Skidmore, Owings, Merrill, features a brise soleil that shades the curtain wall. Wavy vertical fins of marine-grade, white oak reduce sun glare while eliminating glass reflections. Photo: Esther Langan


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Great Blue Heron, designated as Portland's official city bird. Photo: Jim Cruce

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Snow and Canada Geese above Sauvie Island. Photo: Mike Houck



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This Mourning Dove fatally hit a window hard enough to leave this ghostly image on the glass. Implementing bird-friendly design solutions can alleviate these types of collisions.

Photo: Jeanne Donaldson

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TECH TALK

# THE ROLE OF REFLECTIVITY IN GLASS SELECTION

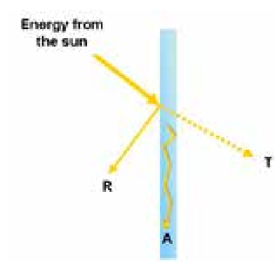
# THE ROLE OF REFLECTIVITY IN GLASS SELECTION

This Tech Talk provides information to help understand the role reflectivity plays when selecting glass for a building façade.

## introduction

**WHAT IS REFLECTIVITY?**

The solar spectrum encompasses all energy coming from the sun and is made of three components; visible, infrared and ultraviolet. Visible is light you see when looking at the sun, infrared is the heat you feel on your skin and ultraviolet fades fabrics and deteriorates plastic. When these three components hit glass on a building they are reflected from the surface (R), transmitted through the glass (T) or absorbed into the glass (A).




As building facades become more complex it is increasingly necessary to understand not only what the sun brings through a building façade, but also what happens to light reflected from its surface. Reflectivity, as it will be discussed in this Tech Talk, is the visible portion of the sun's energy being reflected from the glass on the exterior of a building.

**REFLECTIVITY AND CODES**

Today, codes limiting exterior reflectance of glass products on buildings are intended to minimize hindrances caused by sunlight. For example, a driver's visibility may be impaired if excess sunlight is reflected from a building into their car. In some cities, this has resulted in implementation of codes limiting reflectivity near specific roadways. The codes are intended to minimize the chance of reflected sunlight impairing driver visibility.

Although deterring obstacles caused by sunlight is necessary, the complexity of reflectivity goes well beyond referencing an exterior reflectance percentage limit. A building code written with terminology such as *"glass to have no greater than XX% reflectivity" or "glass shall have a maximum exterior visible reflectivity of XX%"* falls short because it doesn't take into account all characteristics of reflectivity.

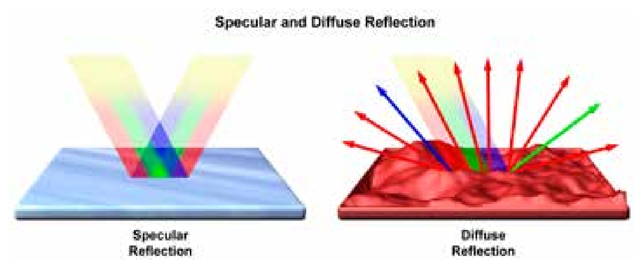
Utilizing a single percentage value in an attempt to control sunlight also needlessly restricts the use of some very energy efficient glass products.

Within a glass product's exterior reflectance value a portion of the reflectance is specular and a portion is diffuse. The specular reflection is much more likely to be a disturbance than the diffuse reflection. Therefore, a single exterior reflectance value is not an accurate predictor for the likelihood of issues to occur. A building code limiting the amount of specular reflectivity would provide a more realistic way to address concerns.

**SPECULAR VERSUS DIFFUSE REFLECTION**

Specular reflection occurs when the sun's light is directly reflected so the angle of incidence equals the angle of reflection. Since the sun's rays are reflected together, there is less opportunity to reduce reflectivity concerns.

Diffuse reflection occurs when the sun's light is re-directed in multiple directions after hitting a surface. This scattering reduces the amount of light reflecting in a single direction so the potential interference the reflected sunlight is reduced.




Selecting glass to reduce specular and increase diffuse reflection will appear less mirrored and will be more likely to reduce hindrances caused by reflected sunlight.

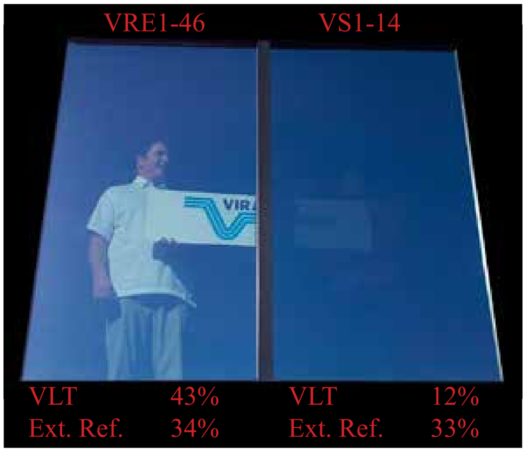
## glass product characteristics

Glass products are typically selected to meet both aesthetic and solar requirements. Reflectivity is often one of many glass features reviewed. Optimal glass selection happens when all features are reviewed simultaneously rather than utilizing a single characteristic to drive glass selection. The all encompassing approach provides the most favorable balance between reflectivity, light transmittance and solar control. It also allows for the use of a wider variety of energy efficient glass products than just selecting glass based on its exterior reflectance value.

**COATINGS**

Coatings are thin layers of metal applied to glass to improve solar performance. Each coating has unique solar performance as well as light transmittance and exterior reflectivity.

When selecting a coating it is important to consider its visible light transmittance (VLT) along with its exterior reflectivity. Two products with similar color and exterior reflectivity may appear dissimilar due to a difference in VLT. For instance VS1-14 and VRE1-46 both have a silver reflective appearance but VRE1-46 has more than three times the light transmittance for VS1-14. This VLT difference is enough for the products to have a different appearance.




While visual appearance may be different, when two coatings have a similar exterior reflectance, the specular reflection is similar so the potential for difficulties caused by reflected sunlight is also similar.

**TINTED GLASS**

Adding a tinted substrate to a glass make-up is similar to coatings in that it reduces the overall exterior reflectivity and improves the solar performance but does not increase the portion of reflectivity that is diffused.

To decrease specular reflectivity the diffuse reflection needs to be increased by silk-screening, adding translucent film or a translucent interlayer to the glass.

**SILK-SCREENED AND TRANSLUCENT GLASS**

To increase the diffuse portion of the exterior reflectance, a silk-screen pattern can be added to the glass. A silk-screen pattern applied to the second surface, prior to applying a coating, will decrease specular and increase diffuse reflection. A translucent pvb interlayer also provides opportunity to diffuse reflected light.

## building design

**CURVED FACADES**

When sunlight hits a curved façade the reflection becomes even more complex because the curve shifts the reflectivity angles. Concave facades have the potential to concentrate reflected light to a single area creating a hot spot. Convex facades have the potential to scatter light. This can make it difficult to determine how the sun's rays will reflect after they hit the façade and can create unpredicted reflectance.

Modeling the reflectivity of a curved façade during design is the best way to understand how the sunlight will interact with the glass and building façade.

**EXTERIOR ELEMENTS**

Balconies, canopies, sun shades and fins all alter reflection. If a balcony shadows a portion of the façade, the amount of light reaching the façade is reduced so the amount of light available to be reflected is reduced. In cases like this, even if the reflectivity of the glass is higher, the potential for the glass to reflect sunlight is less of a concern due to the sun being blocked from the glass by the balconies.

**SURROUNDING ENVIRONMENT**

Another item to consider is the environment around the project. If a building is constructed in an open field with few buildings or trees nearby, the reflection will always be the sky. The appearance of a building in this setting will be greatly affected by the weather conditions but nothing else.

This example shows one building at two times of the day and illustrates how different the reflectivity appears based on sky conditions.

*77 CityPoint, Waltham, MA*
*VRE1-38 and VRE3-38 Insulating*

Likewise, a building in the city which is surrounded by other buildings and structures can be much less affected by changing sky conditions.

**CONCLUSION**

When selecting glass products for a project located in an area where sunlight is a concern or where the building geometry may affect reflectance angles, it is important to carefully review the glazing options. Consider options such as tinted glass to reduce reflectivity, a silk-screen to diffuse the reflectance or possibly a combination of both tinting and silk-screening.

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SAN FRANCISCO
PLANNING
DEPARTMENT

# Standards for
# Bird-Safe Buildings

SAN FRANCISCO PLANNING DEPARTMENT | Adopted July 14, 2011

# Adopted July 14, 2011

By the San Francisco Planning Commission

SAN FRANCISCO
PLANNING
DEPARTMENT

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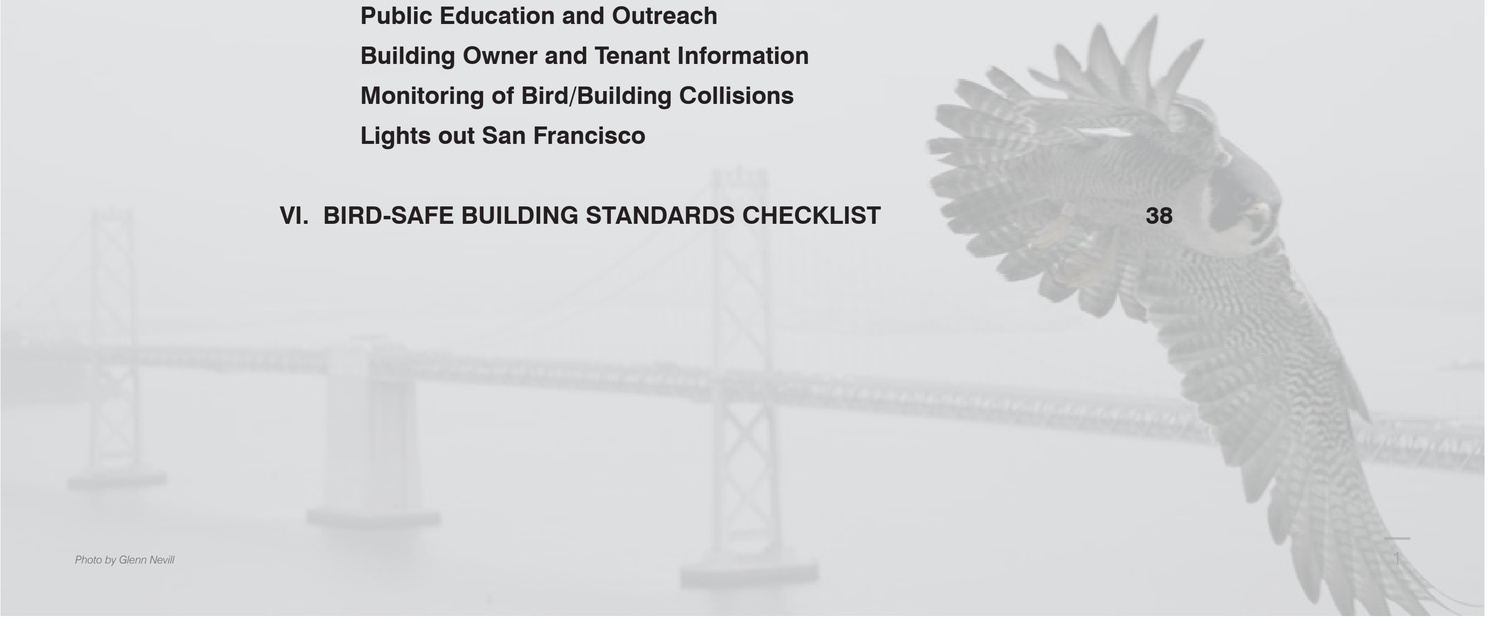

Photo by Glenn Nevill

# PREFACE: Purpose of the Standards

Photo by Robert Lewis

Varied Thrush

Photo by Robert Lewis

Anna's Hummingbird

*"The wide variety of native birds that thrive in urban areas underscores the importance of these artificial habitats to the survival of many bird populations. Creating greenspace in urban environments, landscaping with native plants in backyards and parks, adopting architecture and lighting systems that reduce collisions, and keeping pets indoors will provide the greatest benefit to breeding birds and migrants seeking safe places to rest and find food during their spectacular journeys."*

- 2009 State of The Birds Report by the United States Government US Department of Interior

Pigeons and sparrows are readily visible in San Francisco. These ubiquitous city birds are not shy about sharing our urban spaces. But the casual observer may be shocked to learn that our City's birds are much more diverse. There are about 400 species of birds in San Francisco; remarkably, this is nearly half the species in all North America (*Kay 2009*). For those who look, the shyer species are just around the corner. This is due in part to the diverse habitats of the Bay Area and its position on the coastal migration path, the Pacific Flyway. Some birds are well-adapted to urban life, and they may remain here as year-round "residents." Others are migratory, passing through the City southward in autumn en route to their winter feeding grounds, then returning northward in spring to establish territories in summer breeding grounds.

There are special problems posed for birds living in or flying through cities. Over 30 years of research has documented that buildings and windows are the top killer of wild birds in North America (*Banks 1979; Ogden 1996; Hager et al. 2008; Klem 2009; Gelb and Delacretaz 2009*). Structure collision fatalities may account for between 100 million and 1 billion birds killed annually in North America (*United States Fish and Wildlife Service 2002; Klem 2009*). According to the leading expert, Dr. Daniel Klem Jr., this toll strikes indiscriminately culling some of the healthiest of the species. "From a population standpoint, it's a bleeding that doesn't get replaced," he stated, estimating that between one and five percent of the total migratory population die in window crashes annually (*Klem, 2009*). Many of these are endangered or threatened species whose populations are already declining due to habitat loss, toxin loads, and other severe environmental pressures.

Juvenile residents and migrants of all ages — those least familiar with the urban setting — face the greatest risk of injury or death from the hazards of the city environment. Collision hazards include vehicles, bridges, transmission towers, power lines, and turbines, but the majority of avian deaths and injuries occur from impacts with building components such as transparent or reflective glass. Night-time lighting also interferes with avian migrations. Scientists have determined that bird mortality caused by collisions with structures is "biologically significant" for certain species (*Longcore et al. 2005*). In other words, building collisions are a threat of sufficient magnitude to affect the viability of bird populations, leading to local, regional, and national declines. Night-migrating songbirds—already imperiled by habitat loss and other environmental stressors—are at double the risk, threatened both by illuminated buildings when they fly at night and by daytime glass collisions as they seek food and shelter.

While species that are plentiful may not be threatened by structure collisions, many species that are threatened or endangered show up on building collision lists (*Ogden 1996 and references therein*).

Strategies that improve the urban design quality or sustainability of the built environment may help to make a more bird-safe city. For example, San Francisco has a long-standing policy prohibiting installation of mirrored glass, to meet aesthetic goals. This policy also benefits birds, which mistake reflections for real space and don't perceive the glass as a deadly barrier. The launch of the Golden Gate Audubon Society, Pacific Gas and Electric Company, and Department of the Environment's voluntary Lights Out San Francisco program in 2008 links smart energy policy with bird preservation strategies.

Occasionally policy goals may conflict, and we must balance the benefits and costs of one policy against the other. For instance, gains in energy and resource conservation provided by wind generators could also have negative environmental impacts if installations of those wind farms increase mortality among flying animals.

*Photo courtesy New York Audubon's "Bird-Safe Guidelines"*

A Red-Tailed Hawk may see its reflection as a territorial rival to be driven away, resulting in a collision.

## WHAT THIS DOCUMENT DOES

Annual kills at high-risk structures are foreseeable and avoidable and merit protection (*Klem, 2009*). This publication serves as the Planning Commission's policy document for Section 139 of the Planning Code, "*Standards for Bird-Safe Buildings*." The controls described within aim to identify high-risk features in an urban setting and regulate these situations to the best of current scientific understanding. In areas where the risks are less well known, the Department does not propose to apply controls but instead recommends project sponsors use the checklist contained in this document as an educational tool to increase their understanding of potential dangers. Qualifications for achieving recognition as a Bird-Safe building are included in the document to acknowledge building owners who voluntarily take measures to help keep birds safe above and beyond the requirements. At this time, the Planning Department also urges local researchers to further explore the issue and for citizens to get involved in local monitoring efforts.



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# I. The Issue: Birds, Buildings, People and Cities

## Changing Nature of North America and Building Design

The consequences of our population growth are well-known: sprawling development across the country compounds habitat loss and disrupts vital ecological functions. The rate of sprawl in the United States almost quadrupled between 1954 and 2000. An area of undeveloped land about the size of Connecticut is converted to urbanized landscapes annually in the United States (*U.S. Department of Agriculture 1997*). This loss of habitat exerts great pressures on our wildlife.

Less well-known to the general public are the effects of our specific development forms on wildlife. Buildings and birds have coexisted since people first sought shelter. Early blocky buildings posed little threat to birds as the building elements were quite visibly solid. The advent of mass produced sheet glass in 1902 greatly increased the potential for transparency. The innovation of steel frame buildings with glass curtain walls resulted in transparent high-rise buildings.

After the Second World War, these steel and glass buildings were widely used and became the iconic 20th Century American building. Today, planners and urban dwellers increasingly demand building transparency to achieve street activation and pedestrian interest. As glass surface area increases so do the number of bird collisions. After World War II birdwatchers began documenting major bird-building, single-event collisions that resulted in the deaths of hundreds of birds. The first recorded event occurred on September 10, 1948 when more than 200 birds of 30 species were killed upon collision with the Empire State Building (*McAdams 2003)*. Similar events have occurred every decade with notable events killing 10,000 to 50,000 birds at a strike (*Bower 2000*). In 2011, the New York Times reported, that "After 5,000 red-winged blackbirds fell from the sky in Arkansas on New Year's Eve, many Americans awakened to a reality that had not necessarily been on their radar: many birds die as a result of collisions with buildings" (*Kaufman 2011).* These single-event strikes are often tied to inclement weather, night migration, and brightly lit structures.

ABOVE: The proposed new Transbay Terminal presents a transparent façade with enticing vegetation visible both inside the building and on the roof. The façade is currently planned to include fritted glass.


ABOVE: Many historic buildings such as the old Transbay Terminal present a solid appearance.



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Photo courtesy of Lundberg Design

ABOVE: The City's new bus shelters designed by Lundberg Design use a subtle frit pattern to indicate the barrier. This design, called "SF Fog," is effective in alerting both people and birds to the glass. INSETS show how the frit pattern is more dense at the bottom and dissipates like the City's fog at the top.

While single-event collisions are dramatic, the bulk of bird deaths result from the cumulative effects of a lone, confused bird mistaking glass for a safe flight path. The lone bird strike occurs over and over with conservative estimates calculating that each building kills 10 birds per year on average in the United States (*Klem 1990*). Poorly designed buildings kill hundreds per year (*Hager et al. 2008*). Current research finds that earlier estimates of up to 1 billion bird deaths per year due to building collisions were conservative (*Klem et al. 2009 and references therein*).

New trends in green architecture can either increase or decrease the risk for birds. Green design that facilitates bird safety includes: the avoidance of light pollution, reduced disturbance to natural landscapes and biological systems, and lowered energy use. Green design can also be hard on birds. Green buildings surrounded by lush landscaping may attract more birds. Window reflections of adjacent greenery lure birds to false trees. Green atria inside buildings too may call birds to an inaccessible haven only to have their journey harshly interrupted mid-flight. In 2011, the Chicago Tribune reported that birds were crashing into the FBI's Chicago office, a Platinum LEED Building, at a clip of 10 birds a day during migration (*DeVore 2011*).

Green building design can go hand-in-hand with bird-safe design. The Green Building Council rating system, LEED, challenges designers to assess the impact of building and site development on wildlife, and incorporate measures to reduce threats. Buildings may be certified as silver, gold, or platinum according to the number of credits achieved. A LEED a bird-friendly pilot may be developed as early as summer 2011, for testing and eventual inclusion into the main LEED structure. There is still room for improvement. In the future, green design should thoroughly consider the impact of design on wild flora and fauna.

BELOW: The California Academy of Sciences showcases many green design features including a green roof set within a lush, green landscape that is a natural respite for birds migrating through the city. Because its use of glass could also pose a collision risk, researchers at the Academy are studying the effects of the building on birds and testing various methods of improving bird safety, including the use of external screens, as shown on page 29.

http://slowmuse.files.wordpress.com/2008/10/cas1.jpg

# The Basics: Birds and Buildings

## BIRDS AND GLASS

Glass is everywhere and is one of the least recognized, but most serious, threats to birds; one that is increasing as humans continue to build within bird habitats across the planet. Clear glass is invisible to birds and to humans, but both can learn to recognize and avoid it. Unfortunately, most birds' first encounter with glass is fatal. They collide at full speed when they try to fly to sky, plants, or other objects seen through glass or reflected on its surface. Death is frequently not instantaneous, and may occur as a result of internal hemorrhage days after impact, far away from the original collision site, making monitoring the problem even more difficult. The two primary hazards of glass for birds are reflectivity and transparency.

### REFLECTIVITY

Viewed from outside buildings, transparent glass often appears highly reflective. Almost every type of architectural glass under the right conditions reflects the sky, clouds, or nearby trees and vegetation. Glass which reflects the environment presents birds with the appearance of safe routes, shelter, and possibly food ahead. When birds try to fly to the reflected habitat, they hit the glass. Reflected vegetation is the most dangerous, but birds may also attempt to fly past reflected buildings or through reflected passageways.

### TRANSPARENCY

During daylight hours, birds strike transparent windows as they attempt to access potential perches, plants, food or water sources and other lures seen through the glass. "Design traps" such as glass "skywalks" joining buildings, glass walls around planted atria and windows installed perpendicularly on building corners are dangerous because birds perceive an unobstructed route to the other side.

http://www.princeton.edu/pr/pictures/l-r/princeton_modern/


Photo by AnMarie Rodgers

TOP: Clouds and neighboring trees reflect in the glass curtain wall of Sherrerd Hall on the Princeton campus making it difficult for birds to distinguish real from reflection.

BOTTOM: A Market Street building with a transparent corner may lead birds to think the tree is reachable by flying through the glass.

## GLAZING CHARACTERISTICS

Reflective and transparent glass each present hazards to birds (*Gelb and Delacretaz 2009*).

### REFLECTIVITY

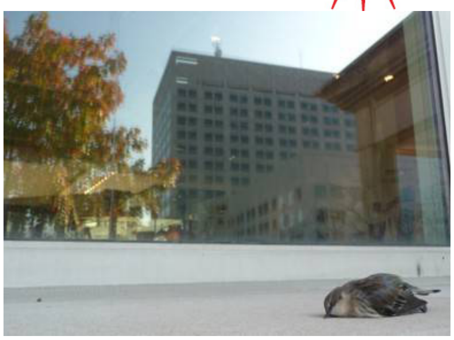


*Image courtesy of Lightsoutindy.org*

*Photos Courtesy NY Audubon*

### TRANSPARENCY

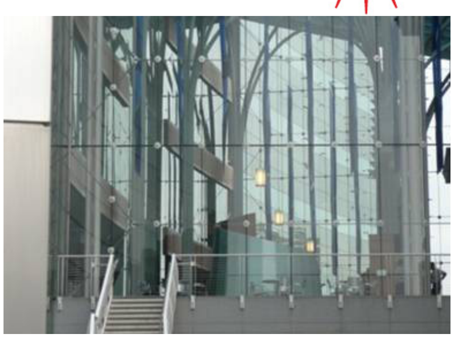
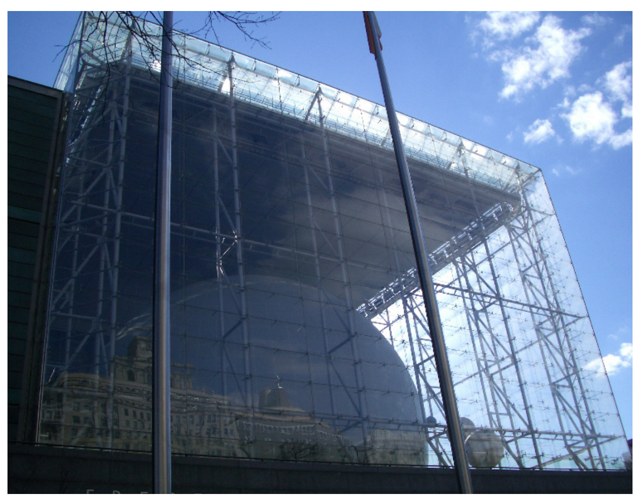


*Image courtesy of Lightsoutindy.org*



TOP: Reflections: A bird looking for a perch may mistake the reflected tree for an actual tree.

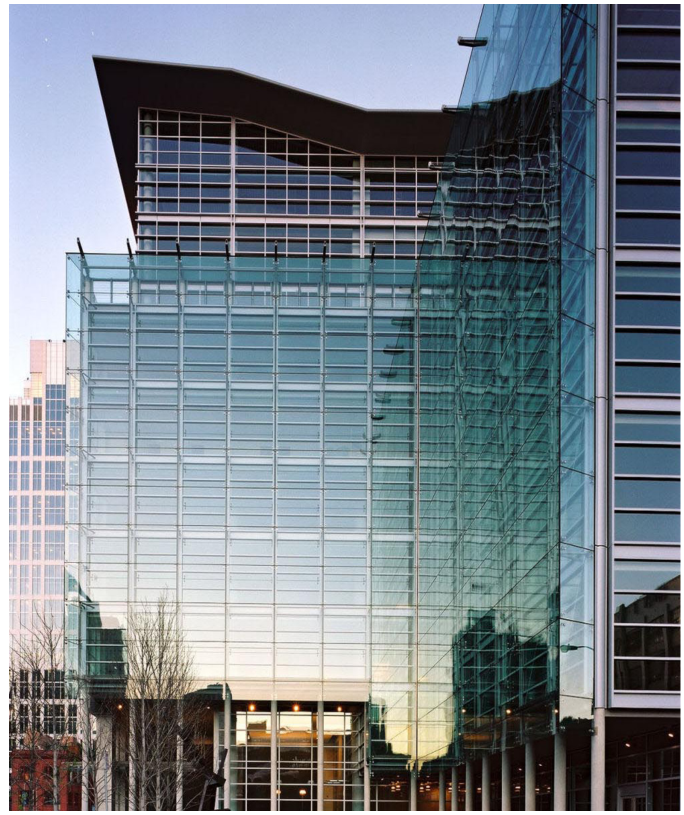
BOTTOM: Transparent glass can be mistaken for a clear flight path.

## GLASS RELATIVE TO BUILDING HEIGHT AND MASSING

Typically, as building size increases, so does the amount of glass, making larger buildings more of a threat. Lower stories of buildings are the most dangerous because windows here are at or below canopy height and are more likely to reflect trees and other landscape features that attract birds. This makes a long, low building more of a hazard than a tall one of equal interior square-footage. However, as monitoring programs access setbacks and roofs of tall buildings, they are finding that birds also collide with buildings at the higher floors. This is an area where more information is needed.

## AMOUNT OF GLASS

Glass causes virtually all bird collisions with buildings. It's logical that as the amount of glazing increases on a building the threat also increases. A study in New York (*Klem et al, 2009*) found a 10% increase in the area of reflective and transparent glass on a building façade correlated with a 19-32% increase in the number of fatal collisions, in spring and fall, when visiting migrants are present.



TOP: SoMa's Foundry Square presents a full façade of highly reflective glass. While all glass can be reflective, glass manufacturers label glass with standards "reflectivity" ratings.

## REDUCING KNOWN BIRD TRAPS

*Photo Courtesy NY Audubon*

Windowed courtyards and open-topped atria can be hazardous, especially if they are heavily planted. Birds fly down into such places, and then try to leave by flying directly towards reflections on the walls. Glass skywalks, handrails and building corners where glass walls or windows are perpendicular are dangerous because birds can see through them to sky or habitat on the other side.

ABOVE LEFT: This café on Market Street uses a glass wind barrier lined with attractive flowers that may entice birds.

ABOVE RIGHT: This glass walkway allows for a clear sightline though the passage. Without treatment to the glazing, this can create a hazards for birds.

## CLEAR FLIGHT PATHS

Birds have evolved to fly through tree canopies at speed. This ability to navigate tight places is a benefit in most natural settings but may be a liability in the built environment. Early attempts to ward off bird collisions with glass panes included the unsuccessful attempts at placing falcon stickers in the middle of each pane. As the acrobatic bird below demonstrates and as current research has shown, collisions are most effectively reduced when flight paths are eliminated by the breaking of glass swaths to less than either 4" vertically or 2" horizontally (*Sheppard 2010*).

Hand Print Rule: Small birds may try to fly through any spaces that are about the size of a handprint.

http://zuzutop.com/2009/07/a-job-for-superswallow/

Exceptional Acrobats: Some birds such as the barn swallow pictured here can easily fly through spaces that are more narrow. This bird is traveling at 35 mph through a 2-inch seam.

We don't know exactly what birds see when they look at glass but we do know that the amount of glass in a building is the strongest predictor of how dangerous it is to birds. Other factors can increase or decrease a building's impact, including the density and species composition of local bird populations, the type, location and extent of landscaping and nearby habitat, prevailing wind and weather, and patterns of migration through the area. All must be considered when planning bird-friendly environments. Commercial buildings with large expanses of glass can kill large numbers of birds, estimated at 35 million per year in the US (*Hager et al 2008*). With bird kills estimated at 1-10 per building per year, the large number of buildings multiplies out to a national estimate of as much as a billion birds per year (*Klem et al 2009; Klem 1990, 2009*). As we'll discuss, certain particularly hazardous combinations can result in hundreds of deaths per year for a single building.

*Photo by Hendrik Dacquin*

BOTTOM A fatal bird-strike leaves behind a print of the bird's plumage as evidence of the force of the impact.

## BIRDS AND LIGHTING

### LIGHT

While recent research suggests that nighttime collisions may be more limited in scope than previously thought (*Gelb and Delacretaz 2009 and references therein*), at night artificial light degrades the quality of migratory corridors and adds new dangers to an already perilous journey. These conditions can be exacerbated by unfavorable weather and San Francisco fog, limiting birds' ability to see navigational markers like the stars and moon. Flood lights on tall buildings or intense uplights emit light fields that entrap birds reluctant to fly from a lit area into a dark one. This type of lighting has resulted in mass mortalities of birds (*Ogden 1996 and references therein*).

Lights disrupt birds' orientation. Birds may cluster around such lights circling upward, increasing the likelihood of collisions with the structure or each other. Importantly, vital energy stores are consumed in nonproductive flight. The combination of fog and light doubly affects birds' navigation and orientation. (*Ogden 2006*)

Besides reducing adverse impacts on migrating birds, there are significant economic and human health incentives for curbing excessive building illumination. In June 2009, the American Medical Association declared light pollution a human health threat and developed a policy in support of control of light pollution.

Overly-lit buildings waste tremendous amounts of electricity, increasing greenhouse gas emissions and air pollution levels, and of course, wasting money. Researchers estimate that the United States alone wastes over one billion dollars in electrical costs annually because poorly designed or improperly installed outdoor fixtures allow much of the light to go up to the sky. "Light pollution" has negative aesthetic and cultural impacts. Recent studies estimate that over two-thirds of the world's population can no longer see the Milky Way, a source of mystery and imagination for star-gazers. Together, the ecological, financial, and aesthetic/cultural impacts of excessive building lighting serve as compelling motivation to reduce and refine light usage (*Scriber 2008*).

Light at night, especially during bad weather, creates conditions that are particularly hazardous to night migrating birds. Typically flying at heights over 500 feet, migrants often descend to lower altitudes during inclement weather, where they may encounter artificial light from buildings. Water vapor in very humid air, fog or mist refracts light, greatly increasing the illuminated area around light sources. Birds circle in the illuminated zone, appearing disoriented and unwilling or unable to leave (*Ogden 2006*). They are likely to succumb to lethal collision or fall to the ground from exhaustion, where they are at risk from predators. While mass mortalities at very tall illuminated structures such as skyscrapers have received the most attention, mortality is also associated with ground level lighting and with inclement weather.

BELOW: Hazards can combine in downtown San Francisco. In this photo beacon lighting, light spillage, and fog mix.

*Photo by AnMarie Rodgers*



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While we typically think of birds as early risers, during migration season many species will travel at night. White lights, red lights, skyglow, brightly lit buildings and interiors can distort normal flight routes (*Poot et al. 2008*). The risks vary by species. Songbirds, in particular, seem to be guided by light and therefore appear more susceptible to collisions with lit structures. Migrant songbirds have been documented by multiple sources to suffer single night mortalities of hundreds of birds at a single location (*Ogden 1996 and references therein*).

*Image courtesy Lights Out SF*

ABOVE: Lighting and Navigation: Birds migrate by reading light from the moon and stars, as well as by geomagnetic signals radiated from earth. Cumulative light spillage from cities can create a glow that is bright enough to obscure the starlight needed for navigation.

LEFT: Beacon Effect: Individual structures may be lit in a manner that draws birds like a moth to a flame. Beacon structures can draw birds towards land that may offer little shelter or food or towards collisions with glass. Once at the structure, birds may be hesitant to leave the lit area causing them to circle the structure until exhausted. (*Ogden 1996*)

RIGHT: Skyglow can be increased during periods of inclement weather. Current research indicates that red lights in particular may disrupt geomagnetic tracking. Red lights required for airline safety would be permitted (above image). Decorative red lighting, such as on the building below in New York, would be discouraged.

*Image courtesy Lights Out SF*

*Image courtesy NY Audubon*

Map courtesy of Texas Parks and Wildlife Department.

## OTHER CAUSES OF COLLISIONS:

### LOCATION: MACRO-SETTING

San Francisco is on the Oceanic Route of the Pacific Flyway. During migration, birds tend to follow rivers and the coastline. In this way migrants funnel southward together in the fall and disperse northward in the spring.

### VISITING BIRDS

Migrating birds are unfamiliar with the City and may be exhausted from their flight. Instances of collisions rise during the migratory seasons as birds travel to lower elevations to feed, rest, and use light to recalibrate their navigation. (*Hager et al. 2008*).

LEFT: Millions of birds – more than 350 species – follow the Pacific Flyway. Of the two primary routes, the Oceanic Route passes through the Bay Area. Spring migration occurs between February through May, and fall migration begins in August and lasts through November. During this time, collisions with buildings can increase notably.

Photos by Eddie Bartley.

LEFT: According to the Golden Gate Audubon Society, over 250 species migrate through San Francisco Bay, many of them small songbirds such as warblers, thrushes, tanagers and sparrows that migrate at night and may be more susceptible to collisions with structures when descending for feeding and resting because of unfamiliar territory and confusing signals from the urban environment. Bird photos from left to right are Anna's Hummingbird, Yellow Warbler, and Lazuli Bunting.

## LOCATION: MICRO-SETTING

How a building meets adjacent landscape features can be critical in determining the risk to birds. Buildings with large windows located adjacent to extensive vegetation present great hazards. In suburban areas, buildings with these features have been documented to kill 30 birds per year (*Klem 1990; and O'Connell 2001*). This combination may be even more lethal in urban areas. Studies of Manhattan structures with large swaths of glazing adjacent to large open spaces have recorded well over 100 collisions per year (*Gelb and Delacretaz 2009*).

## BUILDING FEATURES

Well-articulated buildings orient people as well as birds, directing flow of traffic, creating enticing rest areas and adding aesthetic appeal.

RIGHT: Although located in a park setting, the De Young Museum minimizes hazards due to its low amount of glazing and perforated copper façade.

## WEATHER CONDITIONS

Inclement weather can obscure obstacles and exacerbate skyglow conditions (*Ogden 1996 and references therein*).

*http://izismile.com/2009/09/30/beautiful_pictures_of_san_francisco_covered_with_fog_10_pics_1_video.html*



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## Implications for San Francisco

Three decades of researching bird/building collisions has yielded both many answers and posed new questions. The high number of North American bird deaths and the ecological importance of birds demonstrate that the problem exists on a national level, but it is natural to wonder if the dense nature of San Francisco presents the same compelling pressure for a local response. The short answer is yes—San Francisco has both an important population of birds and a potentially injurious built environment for them. As discussed previously, San Francisco is both home to many birds and is on a major migratory pathway. Locally, there are incidents of celebrated birds such, as the Peregrine Falcon, repeatedly losing their young due to collisions with downtown skyscrapers. With only a few studies currently underway in San Francisco and results not yet complete, anecdotally, local birders have monitored several buildings and have noted significant numbers of bird injuries and deaths (*Weeden, 2010*). San Francisco Animal Care and Control staff further reported collecting 938 wild birds over a two year period from May 2008 through June 2010, noting the majority of birds were found during the spring and fall migratory periods. The California Academy of Sciences in Golden Gate Park is spearheading their own research and bird-safe building methods, in a proactive effort to avoid bird fatalities at their facility. In lieu of large-scale local monitoring programs there are a great many studies of dense urban cities that we can further draw upon. These studies demonstrate that birds respond similarly to certain building and environmental features, regardless of geographic location.

### SPOTLIGHT ON A LOCAL CELEBRITY

The Peregrine Falcon population suffered a huge blow to their numbers due to the use of pesticides including DDT beginning in the 1950s. In 1970 the California Peregrine Falcon population was reduced to only two known breeding pairs. The Santa Cruz Predatory Bird Research Group (SCPBRG) participated in the reintroduction of the species and has monitored the Peregrine Falcons nesting in San Francisco and other sites.

Natural cliff dwellers, the species adapted to nesting in bridges and downtown high-rises. As the population increased, Peregrine Falcons were reported in the San Francisco financial district and in 1987 a nest box was placed near a commonly used perch on the PG&E Headquarters Building. In 2003, Peregrine Falcons nested in the downtown for the first time and have been a closely watched since. SCPBRG trained citizens to participate in a group called “Fledge Watch” to increase understanding of how young falcons fare in the city. In 2009, 76 people volunteered for 5 hour shifts monitoring the 36-58 day old Peregrines from sunrise to sunset in either San Jose or San Francisco. The public could also view the falcons from the downtown building nest via a webcam.

According to Glenn Stewart of SCPBRG, “while there have been building collision fatalities, the target nest success of Peregrine Falcons in San Francisco was 1.5 per nest and has been exceeded at 1.6 young fledged per nest.”

It appears that several weeks after fledging, urban Peregrine Falcons recognize glass as a barrier. In the first few weeks when the young are learning to fly they are most at risk for a collision. In other habitats, falcons face predators like eagles, owls, and when on the ground by bobcats, and coyotes. Like other birds, Peregrine Falcons see in the ultra violet (UV) range.

The architects and designers of the downtown environment did not consider bird building collision as a potential risk. In the future when buildings are being designed and upgraded, the latest information and options should be considered.

- Noreen Weeden, *Golden Gate Audubon Society*

*Photo by Glenn Nevill*

A native San Franciscan juvenile Peregrine Falcon (deceased offspring of “Dapper Dan” and “Diamond Lil”) perched on sill near reflective glass. All three fledged young from that year (2009) died as a result of building collisions. Two more fledglings died from collisions in 2011.



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## LESSONS FROM MAJOR CITIES

Academic researchers and bird-rescue organizations in Chicago, Toronto, and New York City have documented thousands of structure collisions and come to some interesting conclusions.

Perhaps the most established monitoring program of bird-building collisions in a dense city is NYC Audubon's Project Safe Flight in Manhattan. Project Safe Flight documented over 5,400 collisions between 1997-2008. A recent study (*Gelb, Delacretaz 2009*) analyzed this data to determine the critical contributing factors for the structures with the largest number of bird fatalities.

- The study looked at the 10 most deadly collision sites and found the combination of open space, vegetation, and large windows (greater than 1 meter x 2 meter) to be more predictive of death than building height.
- The frequency of collisions is highest along façades that have lush exterior vegetation and either reflective or transparent windows.
- The majority of the collisions occurred during the daytime and involved migrant species.
- High-rise buildings and night lighting presented less risk than windows adjacent to open spaces one hectare or greater in size.
- The majority of collisions are likely due to high-collision sites that feature glass opposite exterior vegetation.
- Urban mortalities may be higher than previously thought. Non-urban studies estimated that high-collision sites would have about 30 collisions per year. At the Manhattan collision sites examined in this study, well over 100 collisions were recorded per year.

The most dangerous building in this study was not a high-rise, but instead was a 6-story office building adjacent to densely vegetated open space.

Studies in Toronto and other eastern and Great Lakes cities have documented tens of thousands of bird fatalities attributable to building collisions. A 10-year study of bird-building collisions in downtown Toronto found over 21,000 dead and injured birds in the city's downtown core. A 25-year study by researchers from Chicago's Field Museum of Natural History documented a particularly problematic building in Chicago (McCormick Place Convention Center) with over 30,000 dead birds of 141 species. The lights at the McCormick Palace were left on at night until 2000. Anecdotal reports for this building cited an 80% decrease in the number of birds killed, by simply turning out building lights (*Kousky 2004*).

Other researchers have agreed that lights can cause a significant problem, but that turning off lights isn't the only answer *(Shephard, Klem 2011)*. As shown in the Manhattan study of ten buildings, daytime collisions were higher and occurred in areas with vegetation opposite glass. Toronto's approach to tackle this dual issue was to provide mandatory construction standards for daytime, while continuing to increase participation in their Lights Out program at night.


*Photos courtesy NY Audubon*

ABOVE: The windows of Morgan Mail Building in Manhattan are adjacent to green landscaped open spaces, making it the most dangerous for birds in a recent study.

RIGHT: Morgan Mail Building causality.

## Spotlight on San Francisco's Migrant Birds

Bird collisions with buildings occur year-round, but peak during the migration period in spring and especially in fall when millions of birds travel between breeding and wintering grounds. Migration is a complex phenomenon, and different species face different levels of hazards, depending on their migration strategy, immediate weather conditions, availability of food, and anthropogenic obstacles encountered en route.

Photo by Noreen Weeden

**Nocturnal migrants:** Many songbirds migrate at night, possibly to take advantage of cooler temperatures and less turbulent air, and because they need daylight to hunt insects for food. Generally, these birds migrate individually, not in flocks, flying spread out across most of their range. Migrants depart shortly after sundown. The number of birds in flight peaks before midnight, then drops. Songbirds may fly as many as 200 miles in a night, then stop to rest and feed for one to three days, but these patterns are strongly impacted by weather, especially wind and temperature. Birds may delay departure, waiting for good weather. They generally fly at an altitude of about 2,000 feet, but may descend or curtail flight altogether if they encounter a cold front, rain, or fog. There can be a thousand-fold difference in the number of birds aloft from one night to the next. Concentrations of birds may develop in 'staging areas' where birds prepare to cross large barriers such as the Great Lakes or Gulf of Mexico.

Photo by Eddie Bartley

**Diurnal migrants:** Daytime migrants include raptors, which take advantage of air currents to reduce the energy needed for flight. Other diurnal migrants, including shorebirds and water-birds, often fly in flocks and their stopover sites are less dispersed because of their dependence on bodies of water. This means that daytime migration routes often follow land forms such as rivers and mountain ranges, and birds tend to be concentrated along these routes or 'flyways'. Not all songbirds migrate at night—species such as robins, larks, kingbirds and others migrate during the day. Birds' daytime flight altitudes are generally lower than their nighttime counterparts.

Millions of birds, especially songbirds, are thus at risk, as they ascend and descend, flying through or stopping at or near populated areas. As city buildings grow in height, they become unseen obstacles by night and pose confusing reflections by day. Nocturnal migrants, after landing, make short, low flights near dawn, searching for feeding areas and running a gauntlet of glass in almost every habitat: in cities, suburbs and, increasingly, exurbs. When weather conditions cause night flyers to descend into the range of lighted structures, huge kills can occur around tall buildings. Urban sprawl is creating large areas lit all night that may be causing less obvious, more dispersed bird mortality.

- Christine Sheppard, *American Bird Conservancy*

### THE IMPORTANCE OF MACRO-LOCATION (ON MIGRATION PATH) VS. MICRO-LOCATION (WITHIN A PARK-LIKE SETTING) AS A RISK FACTOR

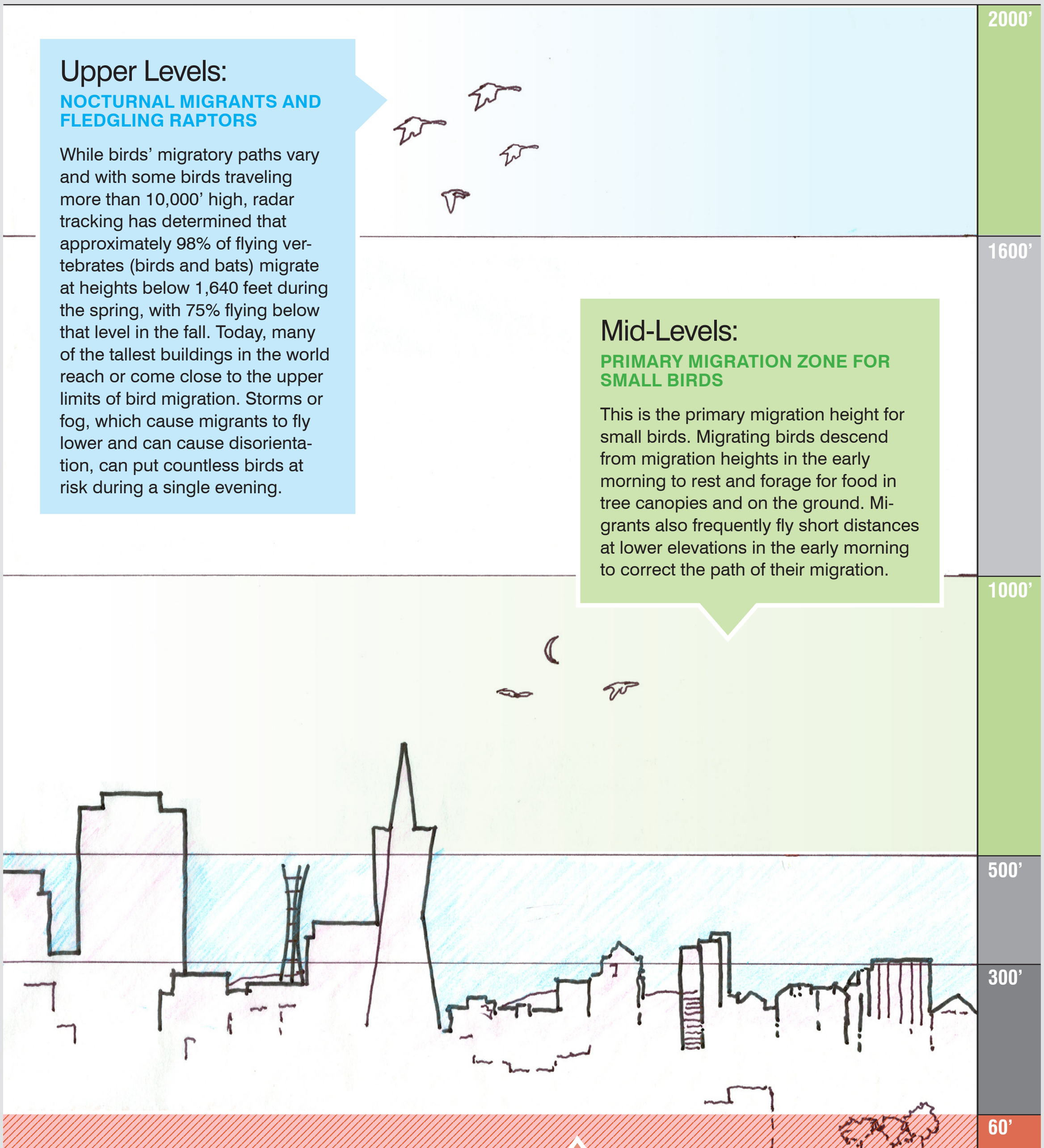
A study of collisions at suburban office parks in Virginia found a large mortality rate for migrant birds even though the office parks were not on a migratory route—suggesting that the combination of mirrored windows and vegetation was more of a collision risk to visiting birds (*O'Connell 2001*). This study also suggests that the location of the building relative to the flyway may be less important than other risk factors such as building design and siting relative to plantings and open space.

Photos by Eddie Bartley

By flying at night, migrants like the Orange-Crowned Warbler (NEAR RIGHT) and Western Tanager (ABOVE LEFT) minimize predation, and avoid overheating that could result from the energy expended to fly such long distances. This also enables them to feed during the day and refuel for the night.

Daytime migrants like this Cooper's Hawk (FAR RIGHT) and the Sharp-shinned Hawk (ABOVE RIGHT) depend on the heating earth for added lift. Riding rising air currents called thermals, these birds take advantage of this lift to rise to the top of one thermal, set their wings in the direction they want to travel and then coast to the next thermal.

## Spotlight on Building Height and Bird Migration




### Upper Levels:

**NOCTURNAL MIGRANTS AND FLEDGLING RAPTORS**

While birds' migratory paths vary and with some birds traveling more than 10,000' high, radar tracking has determined that approximately 98% of flying vertebrates (birds and bats) migrate at heights below 1,640 feet during the spring, with 75% flying below that level in the fall. Today, many of the tallest buildings in the world reach or come close to the upper limits of bird migration. Storms or fog, which cause migrants to fly lower and can cause disorientation, can put countless birds at risk during a single evening.

### Mid-Levels:

**PRIMARY MIGRATION ZONE FOR SMALL BIRDS**

This is the primary migration height for small birds. Migrating birds descend from migration heights in the early morning to rest and forage for food in tree canopies and on the ground. Migrants also frequently fly short distances at lower elevations in the early morning to correct the path of their migration.

### Bird Building Collision Zone:

**INCREASED COLLISIONS FOR LOCAL BIRDS AND MIGRANTS SEARCHING FOR FOOD AND SHELTER**

The most hazardous areas of all buildings, especially during the day and regardless of overall height, are the ground level and bottom few stories. Here, birds are most likely to fly into glazed façades that reflect surrounding vegetation, sky, and other attractive features.

# II. Bird-Safe Treatments

## A Survey of Treatments from Easy to Innovative

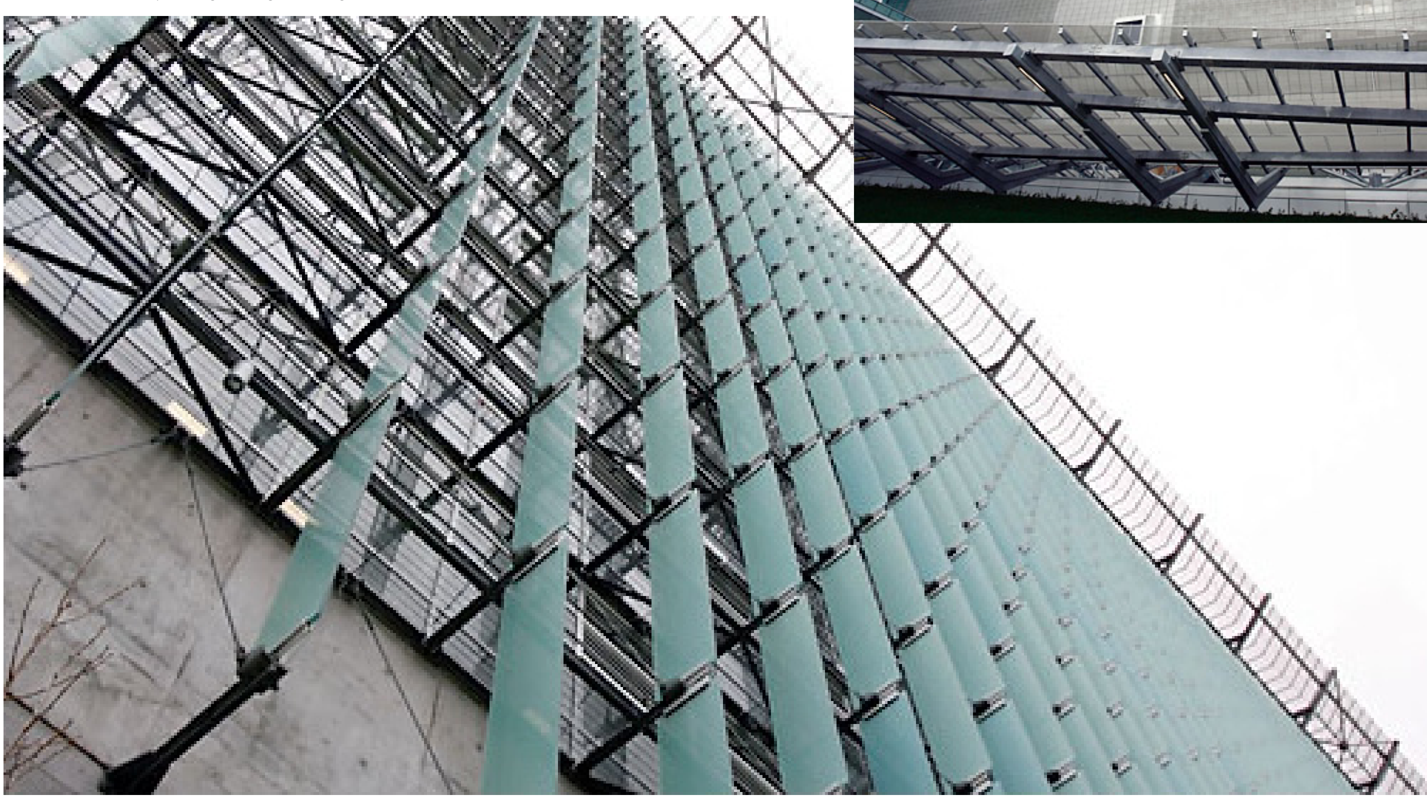
Effective bird-safe building treatments exist and have been employed on buildings of significant architectural stature. San Francisco has a local example of such treatments that has been recognized nationally. The new Federal Building is cited as an example of bird-safe building design in United States Representative Mike Quigley's (D-IL) pending bill,"Federal Bird-Safe Buildings Act of 2011" (*House Bill No. 1643*). This bill, if adopted, would require federal buildings to incorporate bird-safe design principals.

Bird-safe design options are limited only by the imagination. Safe buildings may have large expanses of glass but use screens, latticework, grilles and other devices, both functional and decorative, outside the glass or integrated into the glass. There are treatments for existing glass that will reduce mortality to zero. These treatments do provide a view from inside, though often presenting a level of opacity from the outside, a factor that can deter application of these solutions. Glass treatments that can eliminate or greatly reduce bird mortality, while only minimally obscuring the glass itself, are therefore highly desirable and encourage more 'bird-friendly' design.

RIGHT: The south façade sports perforated steel panels that filter sunlight and serve as thermal buffers but also may convince birds that the structure is solid.

BOTTOM: San Francisco's Federal Building's north façade boasts floor-to-ceiling glass buffered behind a grid of metal catwalks and opaque glass fins.

*Photos by Kurt Rodgers, SF Chronicle*
*http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2007/02/25/MNG2DOATDN1.DTL*



## GLASS AND FAÇADE TREATMENTS

Reduction of bird strikes with new buildings can be achieved with simple and cost-effective means. Creating a visual signal, or "visual noise barrier," that alerts the birds to the presence of glass objects can be achieved with relatively little additional cost. Fritting, the placement of ceramic lines or dots on glass, is one method of creating a visual noise barrier. People inside the building see through the pattern, which has little effect on the human-perceived transparency of the window. Fritting can also reduce air conditioning loads by lowering heat gain, while still allowing enough light transmission for day-lighting interior spaces. There is now a commercially available insulated glass with ultra-violet patterns that are designed to deter birds while largely being imperceptible to humans.

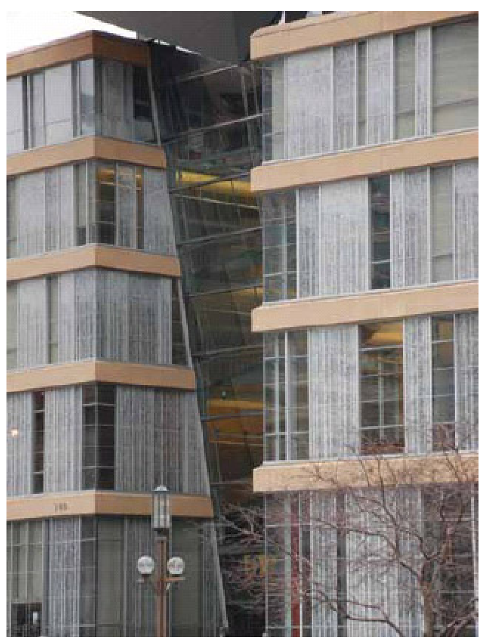
### FRITTED AND FROSTED GLASS

Ceramic dots, or frits, are applied between layers of insulated glass to reduce transmission of light. These can be applied in different colors and patterns and can commonly be seen on commercial buildings. At Swarthmore College, external, densely fritted glass was incorporated into the design of the Unified Science Center. Virtually no strikes have been reported at either site. Fritting is a commonly-used and inexpensive solution that is most successful when the frits are applied on the outside surface.

### ANGLED GLASS

While angled glass may be a useful strategy for smaller panes, it is generally not effective for large buildings. Birds approach glass from many angles, and can see glass from many perspectives. Generally, the desired angle for effective treatment is 20-40 degrees. These angles are difficult to maintain for large buildings, however, this strategy may work in low-scaled buildings with a limited amount of glass (*Ogden 1996 and references therein; and Klem et al. 2004*).

*Minnesota Bird-Safe Building Guidelines*



*Minnesota Bird-Safe Building Guidelines*

LEFT: Swarthmore College uses fritting on a large expanse of glass facing an open space.

RIGHT: The Minnesota Central Library's atrium features angled glass, a dramatic architectural feature that reduces reflections of habitat and sky from most angles. The likelihood of fatal collisions at this angle is lessened.

## ULTRA-VIOLET GLASS

The Bronx Zoo uses glass that reflects UV light—primarily visible to birds, but not to people (*Klem 2009*). This glass may be about 50% more expensive than typical glass but is comparable to energy-efficient glass (*Eisenberg 2010*).

TOP RIGHT: The Bronx Zoo from the NYTimes.

*http://www.nytimes.com/2010/08/29/business/29novel.html?ref=anne_eisenberg*

## FILM AND ART TREATMENT OF GLASS

Windows may be used as canvases to express building use through film and art. In certain instances, windows made bird-safe through an application of art may receive funding through San Francisco's One Percent for Public Art Program.

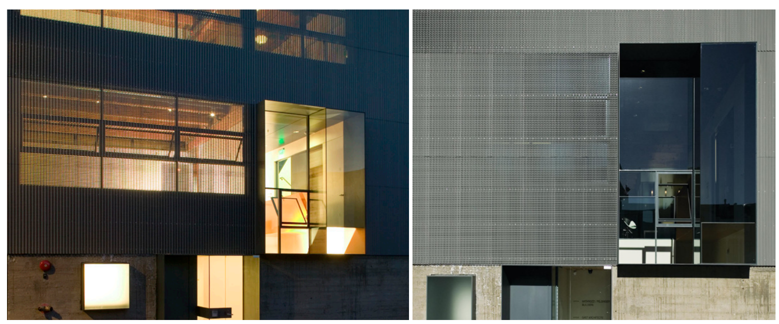
SECOND RIGHT: IIT Student Center, Chicago.

*NY Bird-Safe Design Guidelines*

## EXTERNAL SCREENS

External screens are both inexpensive and effective. Screens can be added to individual windows for small-scale projects or can become a façade element of larger developments. This time-tested approach precludes collisions without completely obscuring vision. Before non-operable windows, screens were more prevalent. At the other end of the spectrum are solutions that wrap entire structures with lightweight netting or screens. To be effective, the netting must be several inches in front of the window, so birds don't hit the glass after hitting the net.

THIRD RIGHT: The Matarozzi/Pelsinger Building in San Francisco is a LEED Gold building designed by Aidlin-Darling. It has screens over the majority of its façade that protect birds from impact and allow views out for users of the building (left nighttime/right daytime)

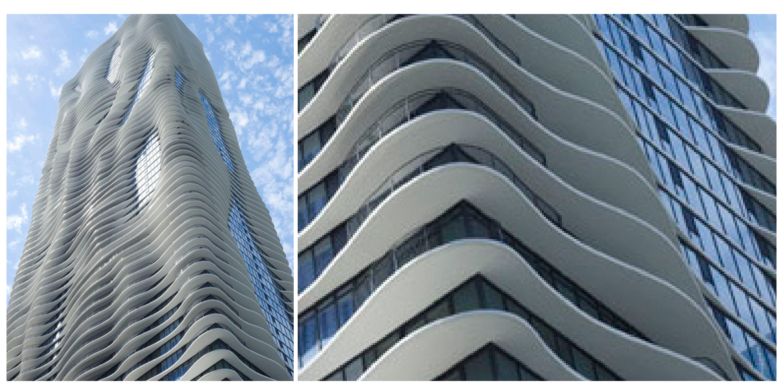


*Minnesota Bird-Safe Building Guidelines*

## ARCHITECTURAL FEATURES

Overhangs, louvers, and awnings can block the view of the glass from birds located above the feature but do not eliminate reflections. This approach should be combined with window treatments to achieve results.

BOTTOM RIGHT: The award winning Aqua Tower, Chicago, uses overhangs and other features that provide bird-safe design as well as energy efficiency.



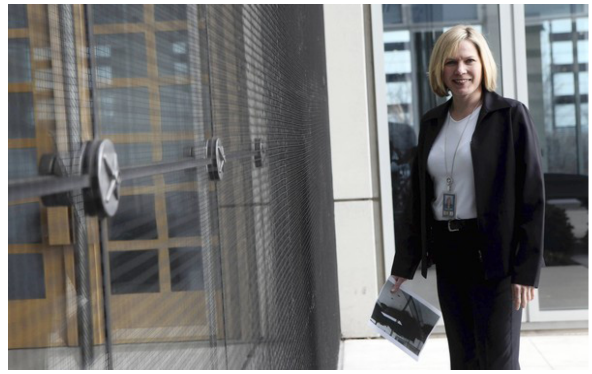
*Steve Hall/Studio Gang*

## NETTING

Netting has proven to be a versatile and effective option for bird-safe window treatment. Netting is stretched several inches over windows or entry ways to prevent birds from hitting the glass. Specifically designed netting is almost completely invisible and does not require invasive installation techniques. It can be used for new buildings, retrofits to existing buildings, replacement glass façades, and for preserving original features of historic buildings.

During the spring and fall migrations, agency staff at the FBI building in Chicago discovered at least 10 birds a day crashing into windows outside of their first floor, plant filled indoor atrium. Seasonal netting was installed and bird collision monitors noted a substantial reduction in bird strikes, without compromising the look of the building or the ability to see into or out of the lobby (*DeVore 2011*).

Netting has also been used successfully to treat historic buildings, where it's critical to maintain the original character of the building. Prestigious historic preservation awards have been earned for netting work on famous buildings such as the American Museum of Natural History and the US Department of Justice. Other historically significant structures with netting include New York Metropolitan Opera, Independence Hall, and even Alcatraz Prison.



*Heather Charles, Chicago Tribune*

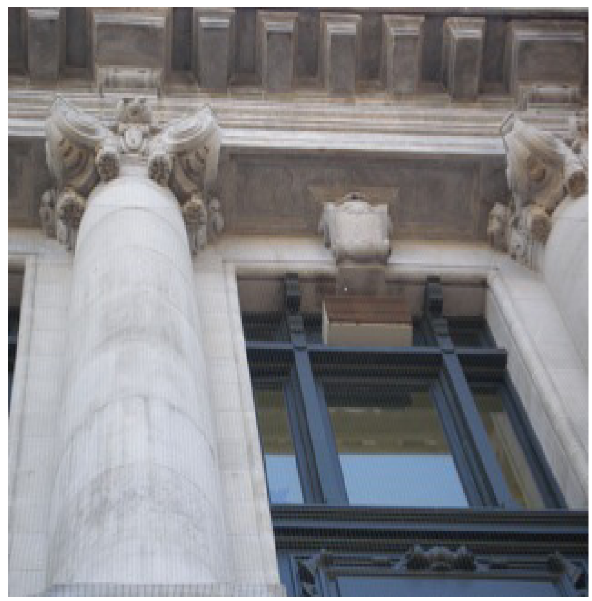


*Photo Courtesy of Birdmasters, Inc.*

*Photo Courtesy of Birdmasters, Inc.*

TOP RIGHT: Special agent Julia Meredith discovered so many dead and injured birds on the ground outside the Chicago offices of the FBI that she lobbied to have special bird-friendly netting installed on the building's first floor windows. She estimates that the nets have reduced the number of birds crashing into the windows by 90 percent.

CENTER RIGHT: A close-up view of the New York Public Library barely shows the marble toned and clear netting over the building.

BOTTOM RIGHT: The netting placed over the windows at the New York Public Library is virtually invisible and helps prevent both bird strikes and building deterioration from pest species.

## WIND GENERATORS

San Francisco has a policy to encourage the installation of on-site, renewable energy systems, such as small wind generators. Currently, there are two general types of wind generators available. One uses scoops or blades to spin on a vertical axis, shown at far left below. It is probable that birds would perceive this type as a solid barrier even when it's rotating.

The second design uses a propeller-like rotor to spin on a horizontal axis. This is a small-scale version of the most common generator used on large-scale wind farms throughout the world.

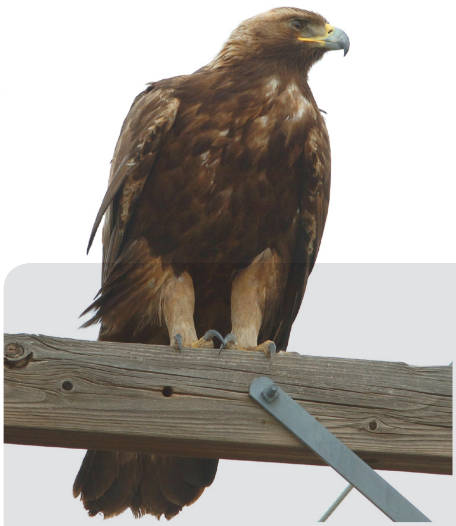
While it is unreasonable to believe that these small urban systems would cause the annihilation of birds such as the well-known disaster at Altamont, California (see discussion on adjacent page) a certain amount of caution is prudent in the absence of established scientific research. The Planning Department has exercised that caution by allowing a more widespread installation of vertical axis machines, and limiting locations of horizontal axis, open-bladed generators to areas that would seem to be less densely populated by birds, especially migrants and juveniles.

The only clear way at present to learn whether small urban wind generators will harm birds is to allow the installation of a few, and to monitor the interactions with animals, if any. For this reason, all approvals for wind generators have conditions that require monitoring and reporting of bird and bat strikes. These reporting protocols are in accord with recommendations made by the Mayor's Task Force on Urban Wind.

As of June 2011, none of the approved windmills have submitted monitoring information to the Planning Department.

LEFT: Horizontal axis and vertical access wind generators that do not present a solid appearance are discouraged, especially adjacent to water or open space larger than 2 acres.

ABOVE: Vertical axis wind generators may vary in appearance. Blades that present a solid appearance (such as the left image) are encouraged.



Golden Eagle photo by Eddie Bartley.

## Spotlight on the Altamont Windmills

Golden Eagles, named for the golden feathering at the nape of their necks, are majestic raptors that can be found throughout most of California and much of the northern hemisphere. California protects these magnificent raptors as both a species of special concern and a fully protected species, making it illegal to harm or kill them. Golden Eagles are protected under the Bald and Golden Eagle Protection Act. Golden Eagle are also protected under the Federal Migratory Bird Treaty Act, which forbids the killing (even unintentional killing) of any migratory bird.

Golden Eagles typically prefer open terrain, such as the rolling hills of eastern Alameda County. The open grasslands, scattered oaks, and bountiful prey make this area ideal habitat for Golden Eagles. Today, it supports the highest-known density of Golden Eagle nesting territories in the world.

**Conservation Issues**

Every year, an estimated 75 to 110 Golden Eagles are killed by the wind turbines in the Altamont Pass Wind Resource Area (APWRA). Some lose their wings, others are decapitated, and still others are cut in half. The lethal turbines have been reduced from 6,000 to less than 5,000 which are still arrayed across 50,000 acres of rolling hills in northeastern Alameda and southeastern Contra Costa counties. The APWRA, built in the 1980s, was one of the first wind energy sites in the U.S. At the time, no one knew how deadly the turbines could be for birds. Few would now deny, however, that Altamont Pass is probably the worst site ever chosen for a wind energy project. According to a 2004 California Energy Commission (CEC) report, as many as 380 Burrowing Owls (also a state-designated species of special concern), 300 Red-tailed Hawks, and 333 American Kestrels are killed every year. The most recent study by Dr. Shawn Smallwood, a member of the Altamont Scientific Review Committee estimates that approximately 7,600-9,300 birds are killed here each year. (*Smallwood 2010*)

In 2004, Golden Gate Audubon joined four other Bay Area Audubon chapters (Marin Audubon, Santa Clara Valley Audubon, Mt. Diablo Audubon, and Ohlone Audubon) and Center for Biological Diversity and Californians for Renewable Energy (CARE) in challenging the renewal permits for this facility. The Audubon/CARE CEQA lawsuit settled, with terms requiring the wind companies to reduce avian mortality by 50% within three years and to complete a comprehensive conservation plan to govern operations in the Altamont.

Reducing the kill entirely may not be possible as long as the wind turbines continue to operate at Altamont. However, significant progress can be made. The CEC estimates that wind operators could reduce bird deaths by as much as 50 percent within three years–the goal stated in the settlement agreement–and by up to 85 percent within six years–all without reducing energy output significantly at APWRA. These reductions could be achieved by removing turbines that are the most deadly to birds and shutting down the turbines during four winter months when winds are the least productive for wind energy, combined with some additional measures. Anecdotal data indicate there may not be a substantial improvement for Golden Eagles and there may actually be much higher mortality for bats.

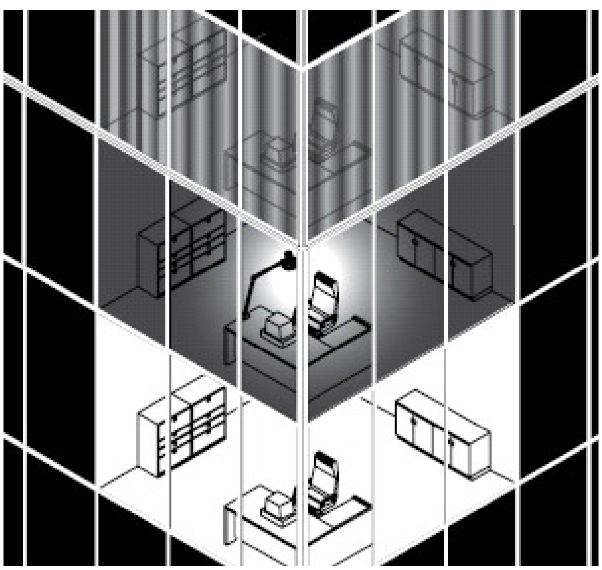
Golden Gate Audubon is working with Alameda County to ensure that the permits granted to the wind industry achieve reductions in bird mortality, in addition to other requirements that will help address the unacceptable bird kills at Altamont Pass over the long term. Pursuit of clean energy technology, when done correctly, can help reduce the risk of global warming and its impacts on wildlife.

*Written by the Golden Gate Audubon Society.*

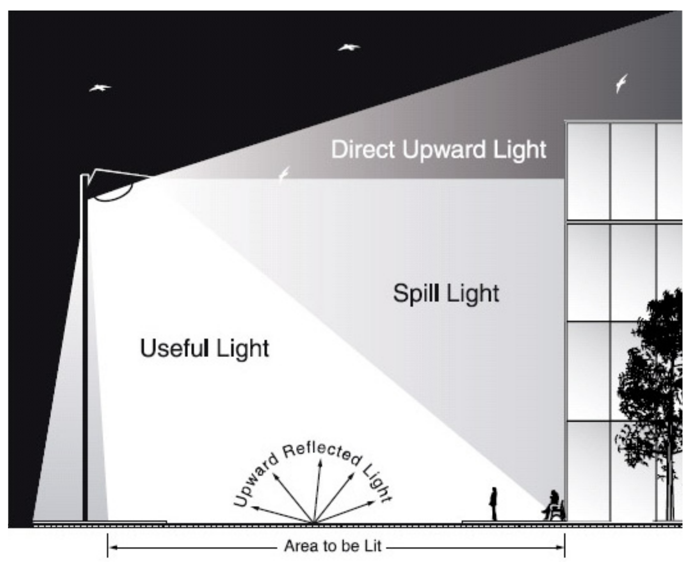
## LIGHTING TREATMENTS

While the ultimate cause of collisions are invisible surfaces, light pollution can increase risk. Night migrants depend on starlight for navigation, and brightly-lit buildings can draw them off course. Once within the aura of bright lights, they can become disoriented, and may collide with buildings, or may fly in circles around the light source, until they drop to the ground from exhaustion, having expended their limited energy reserves needed to complete their migration. Architects and building owners should collaborate to address the two key lighting issues: design and operation.

Eliminating unnecessary lighting is one of the easiest ways to reduce bird collisions, with the added advantage of saving energy and expense. As much as possible, lights should be controlled by motion sensors. Building operations can be managed to eliminate or reduce night lighting from activities near windows. Minimize perimeter and vanity lighting and consider filters or special bulbs to reduce red wavelengths where lighting is necessary. Strobe lighting is preferable to steady burning lights. Exterior light fixtures should be designed to minimize light escaping upwards. Motion detectors are thought to provide better security than steady burning lights, because lights turning on provide a signal, and because steady lights create predictable shadows.

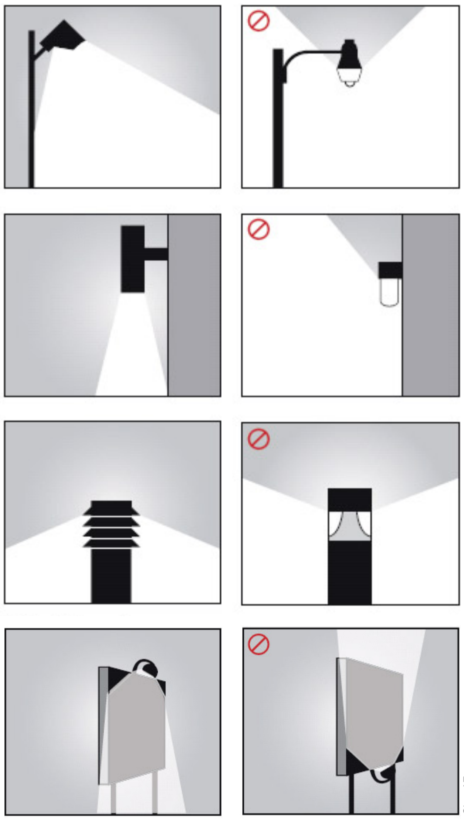

Minnesota Bird-Safe Building Guidelines

REDUCE: UNNECESSARY INTERIOR LIGHT



Minnesota Bird-Safe Building Guidelines

REDUCE: UNNECESSARY EXTERIOR LIGHT



City of Toronto

PREFERRED DISCOURAGED

The Tribute of Lights / Copyright (c) 2010 John de Guzman: http://johndeguzman.com

## LIGHTING DESIGN

The built environment should be designed to minimize light pollution including: light trespass, over-illumination, glare, light clutter, and skyglow while using bird-friendly lighting colors when possible (*Poot et al. 2008*).

- → **Avoid uplighting**
- → **Avoid light spillage**
- → **Use green and blue lights when possible**

## LIGHTING OPERATIONS

Unneeded interior and exterior lighting should be turned off from dusk to dawn during migrations: February 15 through May 31 and August 15 through November 30. Rooms where interior lighting is used at night should have window coverings that adequately block light transmission, and motion sensors or controls to extinguish lights in unoccupied spaces. Event searchlights are strongly discouraged during these times.

Several cities, including San Francisco, have launched citywide efforts to reduce unneeded lighting during migration. In addition to saving birds, these "Lights Out" programs save a considerable amount of energy and reduce pollution by reducing carbon dioxide emissions. The savings for a building can be significant. One participating municipal building in the Toronto Lights Out program reported annual energy reductions worth more than $200,000 in 2006.

Lights Out requires that building owners, managers, and tenants work together to ensure that all unnecessary lighting is turned off during Lights Out dates and times (during spring and fall migration February 15th through May 31st and August 15th through November 30th). Best practices for lighting include turning off unnecessary lights after dusk and leaving the lights off until dawn. If inside lights are needed, window coverings such as blinds or drapes should be closed.

LEFT: The white streaks are the time-exposed paths of birds attracted to, dazed by, and circling within the columns of light. Many succumbed to exhaustion and perished without completing their migration. Lights Out policies do not allow the use of searchlights during the Spring and Autumn migration periods for this reason.



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# III. Bird-Safe Requirements and Guidelines Across North America

When discussing human-caused threats to birds, the US Fish and Wildlife Service reports "that the incidental, accidental or unintentional take of migratory birds is not permitted by the Service and is a criminal violation of the Migratory Bird Treaty Act" but that the Service first attempts to work with industries and individuals who unintentionally cause bird death before pursuing criminal prosecution (*US Fish and Wildlife Service 2002*).

Several major cities are addressing the issue through local legislation.

- **Chicago:** In July of 2008, Cook County, Illinois, which includes Chicago, passed an ordinance requiring that all new buildings and major renovations incorporate design elements to reduce the likelihood of bird collisions. This ordinance established Chicago as the first major jurisdiction with a requirement for bird-safe elements. Other nearby local jurisdictions, such as Highland Park, are also following suit with new bird-safe architecture requirements.
- **Toronto:** This effort has evolved from voluntary ratings and incentive program to bird-friendly construction guidelines that became mandatory at the beginning of 2010. The bird-friendly guidelines were integrated into Toronto's local Green Development Standard, required for nearly all new construction. In addition, the City of Toronto offers an acknowledgement program that offers incentives to developers and building owners and managers who implement the Bird-Friendly Development Guidelines. Once a development has been verified by City staff as "bird-friendly", the City provides the owner with an original print by a local artist and the building may be marketed as "bird-friendly." A bird-friendly designation could give these buildings a competitive advantage by identifying these features to an increasingly environmentally concerned and aware marketplace. Toronto also has had great success with their Lights Out program which has been in effect since 2006. (See images on page 36.)
- **Minnesota:** As of 2009, the State of Minnesota requires that all state owned and leased buildings turn off their lights at night during migration. As of June, 2011, bird-safe building criteria are being developed for incorporation into the State of Minnesota Sustainable Building Guidelines.
- **Michigan:** Since 2006, the governor of Michigan has issued an annual proclamation, declaring "Safe Passage" dates during spring and fall migration, when buildings managers are asked to turn off lights at night.
- **Nationally:** In April 2011, Congressman Mike Quigley introduced a bill (*H.R. 1643*) into the U.S. Congress that, if passed, would mandate bird-friendly construction practices for federal buildings.

*NY Bird-Safe Building Guidelines*

# IV. San Francisco's Bird-Safe Requirements

It is clear from studies done throughout the U.S. and Canada that certain building and landscape configurations can be especially dangerous to birds. These sites present heightened risks for collisions and necessitate requirements, which are included in Section 139 of the Planning Code, Standards for Bird-Safe Buildings.

NY Bird-Safe Building Guidelines

The following bird-safe measures apply in San Francisco.

Structure and/or siting characteristics that present the greatest risk to birds are called "bird-hazards" and include:

1 Location-related hazards

2 Building feature-related hazards

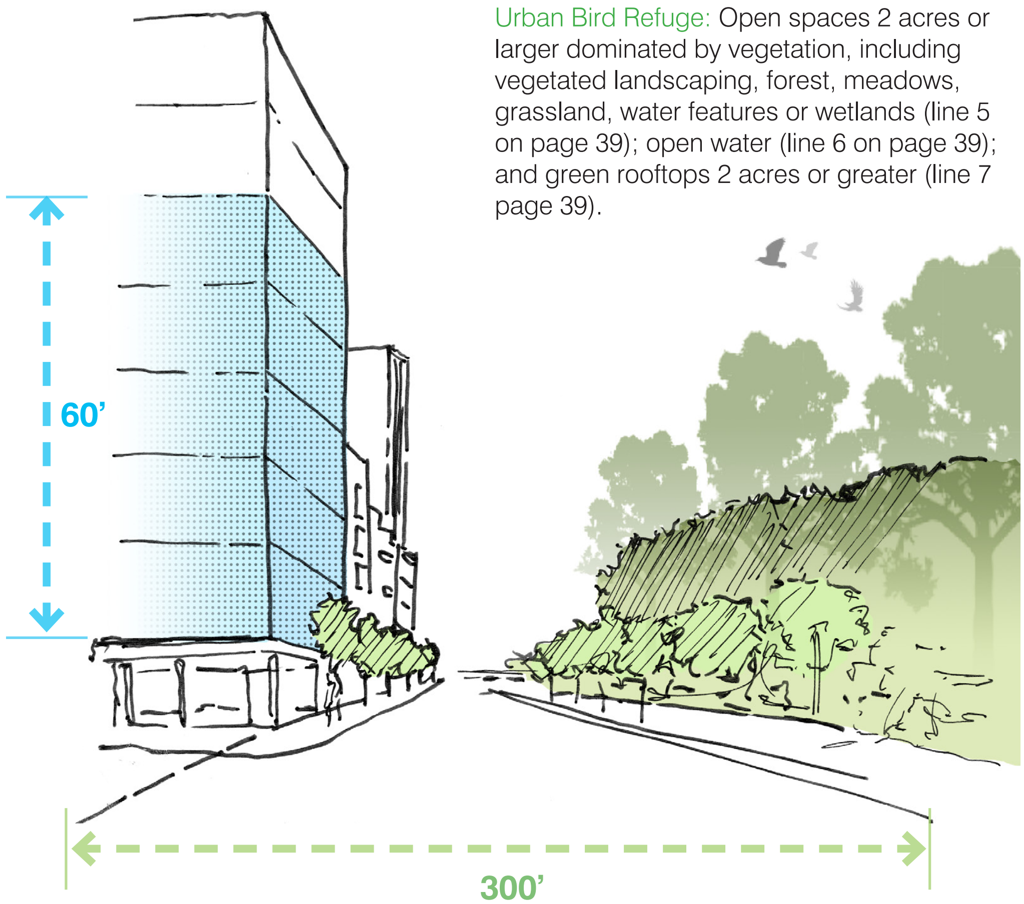
# 1 Requirements for Location-Related Hazards

## What is a "location-related" hazard?

Location-Related Hazard: Buildings located inside of, or within a clear flight path of less than 300 feet from an Urban Bird Refuge (defined below) require treatment when:

- New buildings are constructed;
- Additions are made to existing buildings (Note: only the new construction will require treatment); or
- Existing buildings replace 50% or more of the glazing within the "bird collision zone" on the façade(s) facing the Urban Bird Refuge.

Bird Collision Zone: The portion of buildings most likely to sustain bird strikes. This area begins at grade and extends upwards for 60 feet. This zone also applies to glass façades directly adjacent to large landscaped roofs (two acres or larger) and extending upward 60 feet from the level of the subject roof.




Urban Bird Refuge: Open spaces 2 acres or larger dominated by vegetation, including vegetated landscaping, forest, meadows, grassland, water features or wetlands (line 5 on page 39); open water (line 6 on page 39); and green rooftops 2 acres or greater (line 7 page 39).



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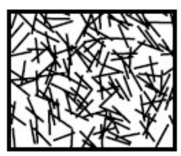
## What requirements apply to a “location-related” hazard?

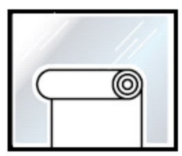
Treatment of Location-Related Hazards. Buildings located inside of or within a clear flight path from an Urban Bird Refuge shall implement the following applicable treatments for façades facing an Urban Bird Refuge.

- Façade Treatments: Bird-Safe Glazing Treatment is required such that the Bird Collision Zone consists of no more than 10% untreated glazing. Building owners are encouraged to concentrate permitted transparent glazing on the ground floor and lobby entrances to enhance visual interest for pedestrians.
- Lighting Design: Minimal lighting shall be used. Lighting shall be shielded. No uplighting shall be used. No event searchlights should be permitted for the property.
- Wind Generators: Sites must not feature horizontal access windmills or vertical access wind generators that do not appear solid.

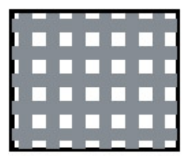
ABOVE: The California Academy of Sciences uses external screens 24 hours per day during spring and fall migration to reduce bird/building collisions.



Solution: Visual Noise



Solution: Use of plastic films, diachroic coatings and tints on facade



Solution: Screen / scrim / fritting



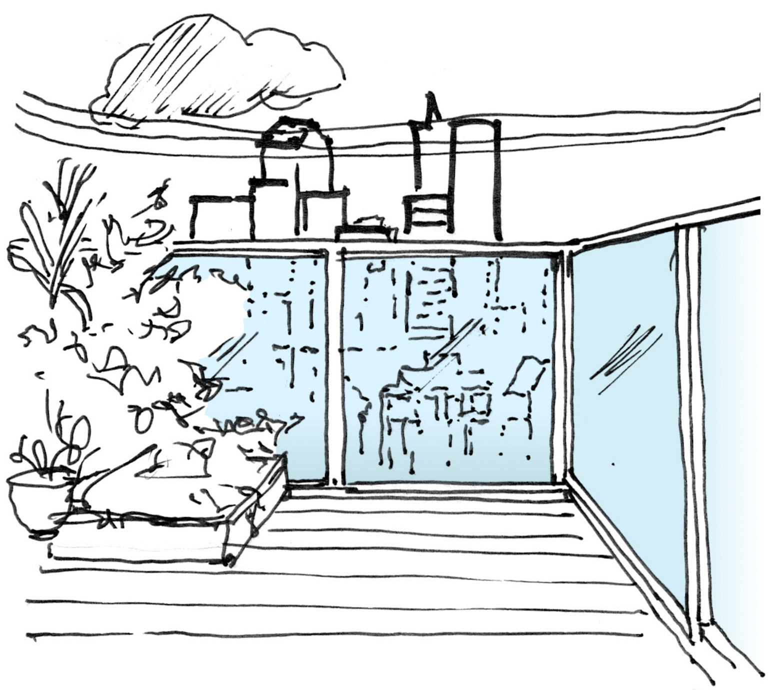
58280

# 2 Requirements for Feature-Related Hazards

## What is a "feature-related" hazard?

Building Feature-Related Hazard: Certain potential bird traps are hazardous enough to necessitate treatment, regardless of building location. A building-specific hazard is a feature that creates hazards for birds in flight unrelated to the location of the building. Building feature-related hazards include free- standing clear glass walls, skywalks, greenhouses on rooftops, and balconies that have unbroken glazed segments 24 square feet and larger in size. (See citywide bird-safe checklist, lines 19-22 on page 39). These features require treatment when:

- New buildings are constructed;
- Additions are made to existing buildings (Note: only the new construction will require treatment).



LEFT: These windows are an example of a feature-related hazard.



58281

## What requirements apply to a “featured-related” hazard?

Treatment of Feature-Related Hazards - Regardless of whether the site is located inside or adjacent to an Urban Bird Refuge, 100% of building feature-related hazards shall be treated.

Image courtesy of Lightsoutindy.org

LEFT: A transparent glass skywalk poses a “feature-related” hazard.

LEFT: This skywalk was intentionally treated with fritting by the Indiana Museum to avoid creating a “feature-related” hazard.

RIGHT: The fritting maintains transparency for pedestrians.

Images courtesy of Lightsoutindy.org

## The Details: Exceptions and Specifications

**Exceptions:** Certain exceptions apply to the afore-mentioned controls.

1) Treatment of Historic Buildings. Treatment of replacement glass façades for structures designated as City landmarks or within landmark districts pursuant to Article 10 of the Planning Code, or any building Category I-IV or Category V within a Conservation District pursuant to Article 11 of the Planning Code, shall conform to Secretary of Interior Standards for Rehabilitation of Historic Properties. Reversible treatment methods such as netting, glass films, grates, and screens are recommended. Netting or any other method demonstrated to protect historic buildings from pest species that meets the Specifications for Bird-Safe Glazing Treatment stated above may also be used to fulfill the requirement.

2) Exceptions for Treatment of Location-Related Hazards for Residential Buildings within R-Zoned Districts.

→ *Limited Glass Façade:* Residential buildings less than 45 feet in height within R-Districts that have an exposed façade comprised of less than 50% glass are exempt from new or replacement glazing treatments, but must comply with feature-related and wind generation requirements below.

→ *Substantial Glass Façade:* Residential buildings within R-Districts that are less than 45 feet in height but have a façade with a surface area of more than 50% glass, must provide glazing treatments for location-related hazards such that 95% of all large, unbroken glazed segments that are 24 square feet and larger in size are treated.

3) Other Waivers or Modifications by the Zoning Administrator. The Zoning Administrator may either waive requirements for Location-Related Hazards or Feature-Related Hazards or modify the requirements to allow equivalent Bird-Safe Glazing Treatments based upon the recommendation of a qualified biologist.

Photo courtesy NY Audubon

A New York volunteer examining a window casualty.

**Glazing Treatment Specifications:** Bird-safe glazing treatment may include fritting, netting, permanent stencils, frosted glass, exterior screens, physical grids placed on the exterior of glazing or UV patterns visible to birds. To qualify as Bird-Safe Glazing Treatment, vertical elements of the window patterns should be at least 1/4 inch wide at a minimum spacing of 4 inches, or have horizontal elements at least 1/8 inch wide at a maximum spacing of 2 inches (*Klem 2009.*)

# V. Recommended Actions and Bird-Safe Stewardship

## Public Education and Outreach Partnerships

The Planning Department will partner with the Golden Gate Audubon Society to conduct outreach on bird-safe building practices. Staff will work collaboratively to increase awareness of bird/building issues, and disseminate educational materials on design and treatment options. A public education effort will proactively increase awareness of the issues and strive to make bird safety practices a part of the construction lexicon within this highly urbanized area. Developers, architects, planners, property owners, businesses, city residents and youth groups are encouraged to contact the Department about educational programs. Curriculum will include education about the standards for bird-safe buildings and exploring citizen involvement of monitoring bird/building collisions as well as general advocacy for bird conservation.

*Photo courtesy Jessica Weinberg. http://www.jessicaweinberg.com/*

## Building Owner Bird-Safe Stewardship

Owners of new buildings and buildings proposing major renovations with a façade of greater than 50% glass are encouraged to evaluate their building against the Bird-Safe Building Checklist (pages 38-39) and provide future tenants with a copy of this document. Although requirements only apply to the most hazardous conditions, building owners and architects can become more aware of potential hazards and treatments. With the support of building owners who help educate future tenants, the people of San Francisco would become better educated about ways to enhance bird safety.

Building owners can help make their buildings safer by evaluating the risks of their buildings and retrofitting buildings with known hazards. Engaging in conservation measures outlined in this guide and granting access to collision monitoring groups help to address the issue and increase our understanding.

## Encouraged Treatments

The following treatments are encouraged to enhance bird safety, in addition to meeting requirements:

- → Expanding treatment outside of the Bird Collision Zone: bird-safe treatments on building façades above the minimum height requirements.
- → Other window treatments: latticework, grilles and other devices, both functional and decorative, outside the glass or integrated into the glass spacing requirements;
- → Placement of trees or tall shrubs: should be located directly adjacent to glazing (with 3 feet) to slow birds down on approach, or placed far enough away to avoid reflecting canopies in the glazing.



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## Building Tenant Education

Some of the most effective treatments for making buildings bird-safe are those that require the cooperation of building owners and tenants. For this reason, the City should continue to use and should expand a "carrot"-based system to widely encourage participation in bird-safe efforts. San Francisco's existing Lights Out for Birds Program seeks to educate residents and provide recognition of voluntary bird-safe measures. Since 2008, the City has urged building owners and managers to turn off unnecessary interior and exterior lights. Twenty-two of the City's forty-four tallest buildings have been asked to participate.

To raise bird-awareness of building occupants, building owners may supply tenants with copies of this booklet. Building occupants can help make buildings bird-safe through the following good practices:

- Interior plants should be moved so as not to be visible from the outside.
- Consider limiting nighttime building use by combining motion operated light sensor with daytime cleaning services. This combination will reduce light pollution and increase energy conservation.
- Where interior lighting is used at night, window coverings should be closed to block light transmission adequately.
- Consider seasonal migration needs. Unneeded interior and exterior lighting should be turned off from dusk to dawn from February 15 through May 31 AND August 15 through November 30.

*Photo by Robert Lewis*

Greater Scaup

*Photo by Robert Lewis*

Western Sandpiper



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## Bird/Building Collision Monitoring

Project Safe Flight in Manhattan has collected and documented over 4,000 dead and injured birds since 1997. In 2009 the Chicago Bird Collision monitors recovered more than 6,000 dead or injured migratory birds from more than 100 different species. In Toronto, Fatal Light Awareness Program (FLAP) volunteers patrol Toronto's downtown core in the early morning hours rescuing live birds and collecting the dead ones since 1993. In the summer of 2010, the Oregon Zoo funded a six-week sunrise study of Portland's newest and tallest buildings where volunteers collected dead and injured birds. Audubon Minnesota has collected over 3000 birds of 110 species from monitoring efforts between 2007-2011.

Aside from regular collection of injured or dead migratory birds throughout the City by San Francisco Animal Care and Control staff and bird group volunteers, the only large bird/building monitoring program currently being conducted by the California Academy of Sciences, read more on page 14 (*Flannery 2011)*. Additional regular monitoring of the hazard in San Francisco is needed to help in the evaluation of local conditions and refinement of appropriate controls. Collaborations between building owners and bird-research groups should be encouraged to help increase our understanding of San Francisco's unique conditions. With the publication of this document, the City calls for more local research to help achieve the goal of better characterizing the problem on a local level, as well as for testing of new bird-safe technologies that could be utilized along with those that are already available.

### CONTACT THE SAN FRANCISCO BIRD-STRIKE HOTLINE TO REPORT BIRD-STRIKES

Report injured birds found outside of buildings by emailing ***safebirds@goldengateaudubon.org*** or by calling **Golden Gate Audubon Society** at **(510) 843-6551** with the following information:

Date:

Time:

Address including cross streets:

Location details:

Species of bird, if known:

Male or female, if known:

Adult or juvenile bird, if known:

Condition of bird:

Did you see or hear the collision?
If so, please provide a description:

Weather:

Please email a photo of the bird and building, if possible. If the bird appears to be injured, call **San Francisco Animal Care and Control** at **(415) 554-9400** and record the date and time you called.

*Photo by Eddie Bartley*

A 2008 San Francisco pilot study discovered a Green Heron in the Downtown area. Further monitoring may reveal other unexpected neotropical migrants passing through the City's dense core.

## Lights Out for Birds San Francisco

The Golden Gate Audubon Society, Pacific Gas and Electric Company and the San Francisco Department of the Environment administer "Lights Out for Birds – San Francisco." This voluntary program helps building owners, managers and tenants save energy and money while protecting migratory birds. Lights Out for Birds asks participants to turn off building lights during the bird migration (February through May and August though November each year).

"Participants in the Lights Out for Birds program can save natural resources, money, and birds by turning off lighting after dusk each evening and leaving lights off until dawn," said Mike Lynes, Conservation Director for Golden Gate Audubon. "Over 250 species of birds migrate through San Francisco in the spring and fall, and many that migrate at night can become confused by the City's lights and collide with tall buildings and towers. The Lights Out for Birds program can reduce bird deaths while cutting energy costs and saving participants thousands of dollars each year."

The North American Bird Conservation Initiative—a joint effort of federal agencies and nonprofit conservation organizations—released the "2009 State of the Birds" in which it reported that the majority of migratory birds in North America are suffering significant population declines due to human-induced causes, including habitat loss and collisions. In addition to window treatments to reduce daytime collisions, effective Lights Out programs can help stem these population declines.

Participants in the Lights Out for Birds program also gain significant financial benefits. Building operators and tenants have reported significant savings on energy bills as a result of participation—one business in Toronto reported a savings of $200,000 in 2006. In 2010 Mayor Gavin Newsom announced energy efficient retrofit funding for 2,000 small to mid-sized businesses and 500 homes. By installing timers or motion detectors and turning off unnecessary lights, building owners and operators can significantly reduce their energy bill. Reduced energy consumption decreases overall greenhouse gas emissions, which is essential in the effort to combat climate change.

San Francisco was one of the first cities to implement a Lights Out program in 2008. Now over 21 cities in the US and Canada have a Lights Out program. Conservationists hope that the program extends to every major city in North America, to save birds, energy and money.

*Photos of 2008 Lights Out Toronto by Dick Hemingway via WWF-Canada.*

Toronto's established Lights Out Program creates a dramatic change in the skyline appearance. As San Francisco's program spreads we should be able to see seasonal changes as our skyline lights up in non-migratory months and dims down during migration.



58287

Building owners, managers and tenants interested in an energy evaluation and current rebates should contact the San Francisco Department of the Environment or a PG&E representative. For more information on how to participate in the program and to learn about local bird populations and how to help, contact the Golden Gate Audubon Society at (510) 843-6551.

### PARTICIPANTS IN SAN FRANCISCO LIGHTS OUT FOR BIRDS

101 California Street
Allsteel Inc.
Barker Pacific Group, Inc.
New Resource Bank
Pacific Gas and Electric Company
San Francisco Department of the Environment
Tishman Speyer

ABOVE: Rescued thrush resting safely in the hand of a Chicago Bird Collision Monitor volunteer.

*Photo: Willowbrook Wildlife Center*
*http://www.chicagoaudubon.org/imgcas/21-02/rescuedthrush.jpg)*

## Beyond Requirements: Voluntary Treatments and Acknowledgment

San Francisco building owners who implement Bird-Safe treatments are strongly encouraged to seek recognition under the City's new Bird-Safe Building Certification and Acknowledgement Program. Buildings which avoid creating hazards or implement bird-safe treatments as identified in this document would be acknowledged by the City and could be marketed as such. Three levels of certification will be offered:

**Bird-Safe Building**:
The building meets the minimum conditions for bird-safety. This level focuses on ensuring "bird-hazards" and "bird traps" are not created or are remedied with bird-safe treatments.

**Select Bird-Safe Building:**
The building meets all of the minimum requirements; commits to "lights out" practices during migratory seasons; reduces untreated glazing beyond the requirements; and commits to educating future building occupants.

**Sterling Bird-Safe Building:**
This is the highest level of Bird-Safe Building certification possible. The building meets all of the conditions of the other certification levels, plus the building reduces the amount of glass on the façade, avoids or treats additional hazards—beyond the requirements, and features year-round best management practices for lighting.

The program will be administered by the Planning Department. Buildings that qualify will be awarded plaques and public recognition through the City's website and outreach materials. To find out if your building qualifies for Bird-Safe Certification, fill out the attached Bird-Safe Building Checklist on pages 38-39 of this document and contact the Planning Department at (415) 558-6377.

# VI. Bird-Safe Building Checklist

**Use of this checklist:** This checklist serves three purposes: 1) assessing risk factors and determining risks which must be addressed by the requirements; 2) increasing awareness of risk factors that are de minimis and don't require treatment; and 3) evaluating buildings for certification as a bird-safe building.

1

REQUIREMENTS FOR THE MOST HAZARDOUS CONDITIONS: The conditions that warrant special concern in San Francisco are designated by red-shaded boxes. These red boxes indicate prohibited building conditions or conditions which are only permitted if the glazing is installed with bird-safe glazing treatments. If the project combines a glass façade with a high-risk location ("location-related hazard", line 5-7), glazing treatments will be required for the façade(s) such that the amount of untreated glazing is reduced to less than 10% for the façade facing the landscaping, forest, meadow, grassland, wetland, or water. If a project creates a new bird-trap or "feature-related hazard" (lines 19-22) or remodels an existing feature-related hazard, bird-safe treatment will be required.

2

INCREASING AWARENESS: Owners of buildings with a façade of greater than 50% glass (lines 9 -10) are strongly encouraged to evaluate the building against the checklist and to help provide future tenants with copies of this guide. Use this checklist to evaluate design strategies for building new structures and retrofitting existing buildings throughout the City. This checklist summarizes conditions that could contribute to bird mortality and will help to identify the potential risks. Interested neighborhood groups and trade associations are encouraged to contact the Department for suggestions on how to proactively increase awareness of the issue and make bird safety practices a part of the construction lexicon.

3

VOLUNTARY RATINGS: Project sponsors interested in submitting a project for "Bird-Safe Certification" may use this form. The Department will partner with local artists to produce appropriate artwork and/or plaques to acknowledge those who actively seek to reduce bird collisions on their property.  The ratings system will create tiers certification to recognize projects that meet minimum requirements as well as those projects that exceed the requirements.

**RISK ASSESSMENT LEGEND:**

**Potential Risk Factors:** These shade indicate factors that may present hazards to birds. Note: actual risks vary greatly depending upon building and site-specific variables.

**GRAY**: This shade indicates potential increased risk. NOTE: *The net assessment of total risk varies with the combination of building factors. While every building in San Francisco will present some element of risk to birds, only combinations with "red" boxes present a risk level necessitating bird-safe treatments.*

**RED:** This shade indicates prohibited conditions or conditions which are prohibited unless bird-safe treatment is applied.

**CERTIFICATION LEGEND:**

By checking all of the boxes for one (or more) of these colors on the Bird-Safe Building Checklist (page 39), a building owner is eligible to apply to the Planning Department for Bird-Safe Building Certification.

**Bird-Safe Building Certification and Acknowledgement:** Buildings which avoid creating hazards or which enhance bird safety with treatments identified as effective in this document would be acknowledged by the City and could be marketed as such. This document proposes three levels of certification by the City. Certification is determined by applying the checklist criteria.

**Yellow:**
**Bird-Safe Building**
The building meets the minimum conditions for bird-safety. This level focuses on ensuring "bird-hazards" and "bird traps" are not created or are remedied with bird-safe treatments.

**Green:**
**Select Bird-Safe Building**
The building meets all of the minimum requirements; commits to "lights out" practices during migratory seasons; reduces untreated glazing beyond the requirements; and commits to educating future building occupants.

**Blue:**
**Sterling Bird-Safe Building**
This is the highest level of Bird-Safe Building certification possible. The building meets all of the conditions of the other certification levels, plus the building reduces the amount of glass on the façade, avoids or treats additional hazards—beyond the requirements, and features year-round best management practices for lighting.

## BIRD-SAFE BUILDING CHECKLIST

**Using the key on the prior page, complete this checklist as a guide to help evaluate potential bird-hazards or eligibility for Bird-Safe Building Certification.**

| | | QUESTION | | YES | NO |
|---|---|---|---|---|---|
| **MACRO-SETTING** (PAGE 12, 16) | 1 | **Is the structure located within a major migratory route?** (All of San Francisco is on the Pacific Flyway) | | | |
| | 2 | **Is the location proximate to a migratory stopover destination?** (Within 1/4 mile from Golden Gate Park, Lake Merced or the Presidio) | | | |
| | 3 | **Is the structure location in a fog-prone area?** (Within 1/2 mile from the ocean or bay) | | | |
| **MICRO-SETTING (LOCATION-RELATED HAZARD)** (PAGES 13, 16, 28-29) | 4 | **Is the structure located such that large windows greater than 24 square feet will be opposite of, or will reflect interlocking tree canopies?** | | | |
| | 5 | **Is the structure inside of, or within a distance of 300 feet from an open space 2 acres or larger dominated by vegetation?** (Requires treatment of glazing, see page 28) | | | |
| | 6 | **Is the structure located on, or within 300 feet from water, water features, or wetlands?** (Requires treatment of glazing, see page 28) | | | |
| | 7 | **Does the structure feature an above ground or rooftop vegetated area two acres or greater in size?** (Requires treatment of glazing, see page 29) | | | |
| **GLAZING QUANTITY** (PAGE 8) | 8 | **Is the overall quantity of glazing as a percentage of façade:** (Risk increases with amount of glazing) | **Less than 10%?** | | |
| | | | **More than 50%?** (Residential Buildings in R-Districts must treat 95% of unbroken glazed segments 24 square feet or greater in size if within 300 feet of an Urban Bird Refuge.) | | |
| | 9 | **Will the glazing be replaced?** | **More than 50% glazing to be replaced on an existing bird hazard (including both feature-related hazards as described in lines 19-22 and location-related hazard as described in lines 4-7)?** (Requires treatment see pages 29 and 31.) | | |
| **GLAZING QUALITY** (PAGE 6, 7) | 10 | **Is the quality of the glass best described as:** | **Transparent** (If so, remove indoor bird-attractions visible from outside the windows.) | | |
| | 11 | | **Reflective** (If so, keep visible light reflectance low (between 10-20%) and consider what will reflect in the windows. Note: Some bird-safe glazing such as fritting and UV spectrum glass may have higher reflectivity that is visible to birds.) | | |
| | 12 | | **Mirrored or visible light reflectance exceeding 30%.** (Prohibited by Planning Code.) | | |
| **GLAZING TREATMENTS** (PAGE 18-21) | 13 | **Is the building's glass treated with bird-safe treatments such that the "collision zone" contains no more than 10% untreated glazing for identified "location-related hazards" (lines 4-7) and such that 100% of the glazing on "feature-related hazards" (lines 19-22) is treated?** | | | |
| | 14 | **Is the building's glass treated for required "bird hazards" (as described in line 13)** *and* **such that no more than 5% of the collision zone (lower 60') glazing is untreated but not for the entire building?** | | | |
| | 15 | **Is the building glazing treated (as described above in lines 14 and 15)** *and* **such that no more than 5% of the glazing on the exposed façade is left untreated?** | | | |
| **BUILDING FAÇADE GENERAL** (PAGE 8, 13) | 16 | **Is the building façade well-articulated (as opposed to flat in appearance)?** | | | |
| | 17 | **Is the building's fenestration broken with mullions or other treatments?** | | | |
| | 18 | **Does the building use unbroken glass at lower levels?** | | | |
| **BUILDING FEATURE-RELATED HAZARDS AND BIRD TRAPS** (PAGE 8, 30-31) | 19 | **Does the structure contain a "feature-related" hazard or potential "bird trap" such as:** | **Free standing clear-glass walls, greenhouse or other clear barriers on rooftops or balconies?** (Prohibited unless the glazing is treated with bird-safe applications.) | | |
| | 20 | | **Free standing clear-glass landscape feature or bus shelters?** (Prohibited unless the glazing is treated with bird-safe applications.) | | |
| | 21 | | **Glazed passageways or lobbies with clear sight lines through the building broken only by glazing?** | | |
| | 22 | | **Transparent building corners?** | | |
| **LIGHTING DESIGN** (PAGE 10, 25) | 23 | **Does the structure, signage or landscaping feature uplighting?** (Prohibited within 300 feet of an Urban Bird Refuge) | | | |
| | 24 | **Does the structure minimize light spillage and maximize light shielding?** | | | |
| | 25 | **Does the structure use interior "lights-out" motion sensors?** | | | |
| | 26 | **Is night lighting minimized to levels needed for security?** | | | |
| | 27 | **Does the structure use decorative red-colored lighting?** | | | |
| **LIGHTING OPERATIONS** (PAGE 12, 24-25) | 28 | **Will the building participate in San Francisco Lights Out during the migration seasons?** (February 15-May 31 and August 15- November 30th) To achieve "sterling" certification the building must participate in year-round best management practices for lighting. | | | |
| **OTHER BUILDING ELEMENTS** (PAGE 23) | 29 | **Does the structure feature rooftop antennae or guy wires?** | | | |
| | 30 | **Does the structure feature horizontal access wind generators or non-solid blades?** (Prohibited within 300 feet of an Urban Bird Refuge) | | | |
| **CONSENT** (PAGE 34) | 31 | **Does the building owner agree to distribute San Francisco's Bird-Safe Building Standards to future tenants?** | | | |

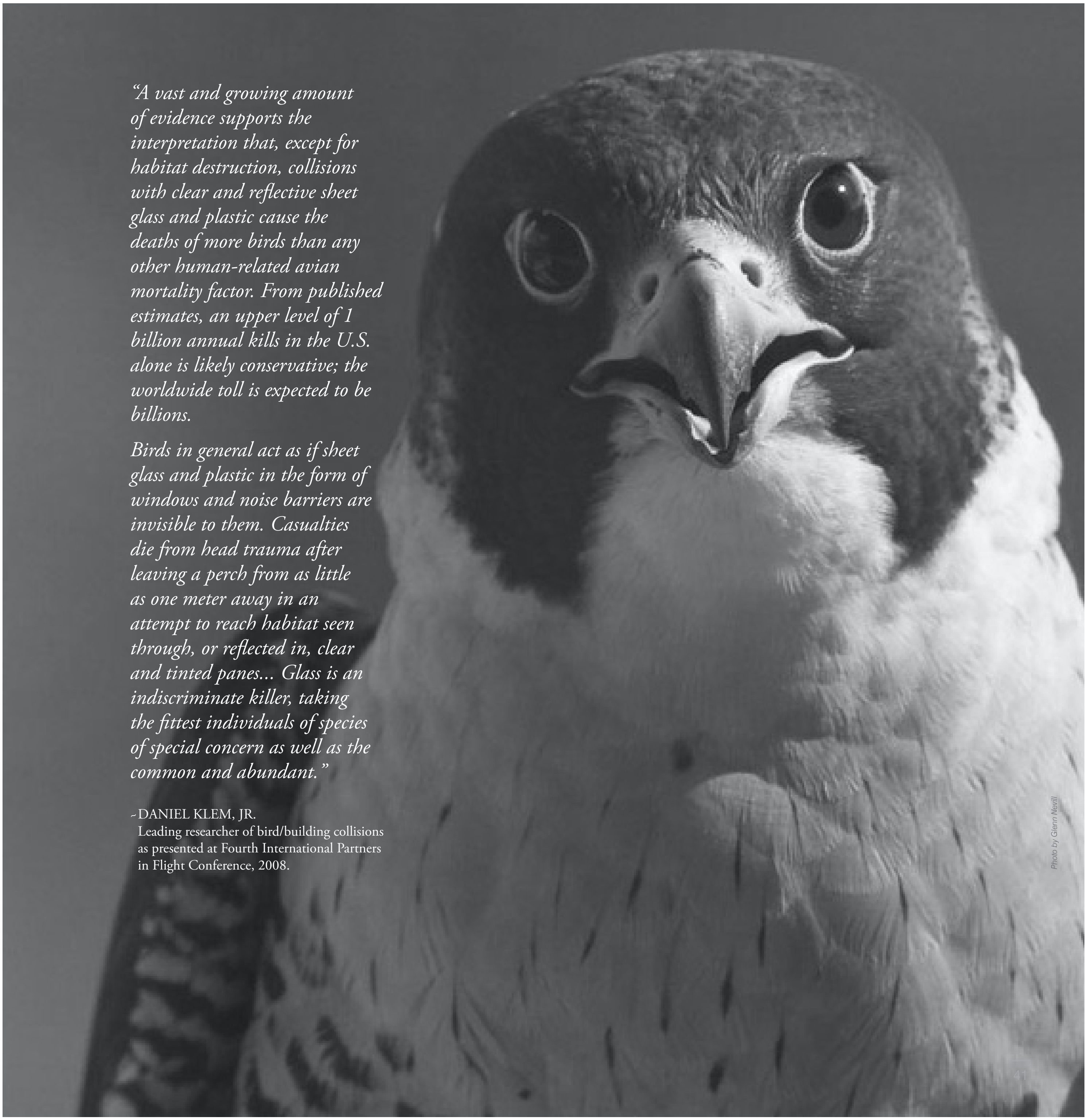
**Authorized Signature** X ______________________________ **Date:** ________________

From City of Toronto Green Development Standard: "Bird-Friendly Development Guidelines."

Some of the birds killed by building collisions and collected during one migration season in Toronto's Financial District.



58291



*"A vast and growing amount of evidence supports the interpretation that, except for habitat destruction, collisions with clear and reflective sheet glass and plastic cause the deaths of more birds than any other human-related avian mortality factor. From published estimates, an upper level of 1 billion annual kills in the U.S. alone is likely conservative; the worldwide toll is expected to be billions.*

*Birds in general act as if sheet glass and plastic in the form of windows and noise barriers are invisible to them. Casualties die from head trauma after leaving a perch from as little as one meter away in an attempt to reach habitat seen through, or reflected in, clear and tinted panes... Glass is an indiscriminate killer, taking the fittest individuals of species of special concern as well as the common and abundant."*

~DANIEL KLEM, JR.
Leading researcher of bird/building collisions as presented at Fourth International Partners in Flight Conference, 2008.

Photo by Glenn Nevill

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# How to manage the urban green to improve bird diversity and community structure

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ABSTRACT

Urbanization is a fundamental environmental change, today happening at accelerated speed worldwide. Despite the strong and permanent human impact, urban biodiversity has generally proved to be surprisingly high. Quantitative information on the effect of management actions on biodiversity is often lacking but is an indispensable basis for decisions by urban planners and managers. We therefore quantified key urban variables to predict changes in avian biodiversity when their urban habitat is modified. We analysed species richness, diversity (Simpson index) and community composition of 63 bird species with reference to major urban environmental gradients at 96 sampling points in three Swiss cities. Best explanatory models were selected from candidate models following information theory, and their respective predictions were averaged based on AICc-weights. Bird species richness and diversity are negatively affected by increasing fractions of sealed area or buildings, while increasing vegetation structures, in particular trees, show positive effects. Our models predict an increase from 13 species in the absence of trees to 20 species with 46% tree cover (+54%). Coniferous trees help to maximize bird species richness, with the models predicting an increase from 14 species at sites with only deciduous woody plants to 20 species (+43%) at places with equal representation of coniferous and deciduous plants. While the analysis of the Simpson index did not show any influence of the coniferous and broadleaf woody plants mixture, partial redundancy analysis revealed such an influence on bird community composition, highlighting the importance to consider several measures when analyzing biodiversity.



## 1. Introduction

Nowadays, the majority of the world's human population lives in cities. The fraction of these urban inhabitants is constantly growing on all continents and is expected to reach 70% by 2050 (United Nations, 2008). Furthermore, the urban environment has recently gained broad attention by an increasing number of ecologists. Although the urbanization process is wide-spread, high-impact environmental transformation (Grimm et al., 2008), many studies show that cities host a surprisingly high number of species and individuals (e.g. Sukopp, 1998; Marzluff, 2001; Palomino and Carrascal, 2006; Sattler et al., 2010a,b). Moderately urbanized areas often support higher species richness than rural zones (Blair, 1996; Blair and Launer, 1997). Species richness and species diversity are generally considered good indicators of the quality of nature and ecosystem health (Rapport, 1999). However, they have limitations and do not elucidate all aspects of the community dynamic: species richness does not consider the differences in species composition and diversity metrics have a limited comparability between points (Jost, 2006). Community analyses are used to explain changes in community composition (e.g. Moretti et al., 2006).

The importance to identify thresholds of particular habitat variables which, if exceeded or undercut would cause biodiversity to be maintained or even enhanced in the urban environment, has been highlighted by several studies (e.g. Marzluff and Ewing, 2001). Such predicted thresholds are important tools for convincing environmental managers and politicians of the effectiveness of specific measures. In addition, there is an increasing consensus that biodiversity is important for the quality of life of the people in general, and of urban inhabitants in particular. Sandström et al. (2006) claimed that perceived life quality of citizens might improve when the fraction of nature in urban areas increases. Natural areas and conservation practices in cities give the opportunity for citizens to directly experience nature (Miller, 2006), which is a crucial aspect for restoration in a world with a high urban population (Home et al., 2009a).

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Birds are often chosen as indicators of habitat quality. Their ecology is well known and species respond well to the availability of habitat structures (Clergeau et al., 1998; Evans et al., 2009). In cities, birds are widely considered as an optimal model group to study the ecological effect of urbanization (McDonnell and Hahs, 2008). Strong inter-specific differences in the response of birds to urbanization are known (Møller, 2009), thus, it is expected that increasing urban densification modifies both bird community compositions and structure. Nevertheless, abiotic conditions are similar between cities (Grimm et al., 2008) and thus avian communities are often comparable, independent from latitude (Clergeau et al., 2006; Evans et al., 2009). The following general patterns have been identified on how urbanization influences avian biodiversity: (1) bird species richness and diversity decrease along urbanization gradients ranging from moderately urbanized to densely built-up areas (Clergeau et al., 1998, 2006). (2) Avian abundance tends to increase along the same gradient (Clergeau et al., 1998; Palomino and Carrascal, 2006; Grimm et al., 2008), which reflects the overall dominance of few synantrophic species (omnivorous and ubiquitous) contributing to biotic homogenization (e.g. Clergeau et al., 2006; La Sorte and McKinney, 2007). (3) Specialist species (e.g. woodland and farmland species with narrow ecological requirements, often insect feeders and ground nesters) decrease with increasing urbanization (e.g. Clergeau et al., 1998; Fernández-Juricic, 2004; Devictor et al., 2007).

Several studies provide evidence that site-specific environmental factors (e.g. size of residential house properties) influence avian species occurrence in urban areas (e.g. McKinney, 2002; Sattler and Tobler, 2004; Evans et al., 2009), which suggests that already management decisions by inhabitants and property owners on the site scale can affect nesting and feeding habitats for urban birds (McKinney, 2002; Grimm et al., 2008). The following management actions have been devised with the aim of enhancing urban bird populations: (1) providing additional food resources (Gaston et al., 2007; Evans et al., 2009); (2) enhancing reproduction possibilities with nest boxes (Gaston et al., 2007); (3) increasing structural vegetation diversity (Böhning-Gaese, 1997; Chace and Walsh, 2004; Evans et al., 2009); (4) planting native rather than exotic woody plants (Chace and Walsh, 2004; Daniels and Kirkpatrick, 2006; Burghardt et al., 2009); (5) preserving woodland patches in urban developments (Croci et al., 2008); (6) increasing connectivity among green structures within and around cities (Marzluff and Ewing, 2001; Fernández-Juricic, 2004).

These studies usually indicate the direction of influence (positive/negative) of such management decisions on avian biodiversity, but in addition to this important information there is an urgent need for knowledge on the extent of effects of single factors (Kim and Byrne, 2006). Quantification of the respective influence of single factors on species numbers, diversity and composition facilitates the communication with policy makers, urban planners and builders (e.g. McDonnell and Hahs, 2008; Stagoll et al., 2010). In this way, closer collaboration between the different stakeholders is fostered which is urgently needed with increasing urbanization.

Therefore, in the present study, we calculated model predictions for human-influenced factors such as structural elements to sustain and possibly even enhance bird biodiversity despite increasing expansion and densification of cities. For the same goal of effective planning measures for avian biodiversity, we also analysed the influence of the composition of woody plants which are an important part of the urban green. In particular, we aim to answer the following questions: (A) Structural elements—Which are the most important urban elements that affect bird species richness (species number) and diversity (representing species richness and community evenness) and what are their effect sizes? Do we also find a pre-eminent influence of trees, as revealed by previous studies and, if yes, what is the predicted influence of this variable? (B1) Woody plant composition—Which composition of tree and bush species, with regard to foliage type (coniferous, broadleaf), origin (native, exotic) and woody plant species richness, maximize bird species richness and diversity? (B2) Woody plant composition and bird community—Which additional information is obtained by community analysis? How do different bird species react to changes in woody plant composition?

## 2. Materials and methods

### 2.1. Study sites and sampling design

We chose the three Swiss cities of Zurich, Lucerne (both North of the Alps) and Lugano (South of the Alps) as study areas (further details in Appendix S1a). With >73% of the population living in cities (Schuler et al., 2004), Switzerland provides plentiful opportunities to study the effect of small to medium sized cities in central Europe on avian biodiversity. The three cities consist of historical centres, residential areas, business quarters, public green areas, historical parks and cemeteries, and former industrial areas that have been developed for new apartments and office buildings. All three cities are characterized by a temperate climate (North: average January temperature 1 °C, July 17 °C; South: January 3 °C, July 20 °C) with a yearly precipitation of 1000 mm for Zurich, 1150 mm for Lucerne and 1600 mm for Lugano. Within each of the three cities 32 sampling points (total 96) were selected along a continuous urbanization gradient, which was measured as the fraction of sealed and built area in the 50 m radius around the sampling points. The selection of the individual sampling points followed a reasoned choice sampling strategy to cover the entire urbanization gradient (3–92% sealed and built area). We included a wide range of urban habitat types (private gardens, semi-public spaces of apartment buildings, public parks and courtyards of industrial buildings) at different developmental stages into the study (detailed locations in Germann et al., 2008). The mean distance of 388 m (±21 m SE) between sampling points inhibited spatial auto-correlation, which was confirmed using the Moran's Index (Legendre and Legendre, 1998; data not shown). A minimal distance of 250 m was kept between sampling points and the city fringe.

### 2.2. Bird survey

We used the point count method in the early morning to record birds at sampling points (Bibby et al., 2000) during the breeding season (April 15th–June 13th 2007). Each of the 96 points was visited six times, over the two months (mean interval between visits: 10.6 days, range 4–15 days). Considering that the time of day affects bird activity, which in turn affects detection probability, the order of sampling points during one morning tour was alternated between start (1 h before sunrise) and finish (at the latest 5 h after sunrise) of each tour. Each visit lasted 15 min to give a total of $6 \times 15 = 90$ min per sampling point (144 h overall). Presence of bird species was recorded visually and acoustically in a radius of 50 m, with the first 10 min of observations at the centre and the remaining 5 min checking areas hidden from the observer (e.g. behind buildings). When counting birds, we took special care that individuals were counted once only. We did not distinguish between breeders and other visitors as distinction is difficult, and over-flying birds were counted only when they were flying low and/or showed connection to the ground environment (i.e. searching for food). Species richness for each sampling point was defined as the total number of species detected during the six visits. Abundance for each species and sampling point was defined as the maximum number of individuals present in any of the six visits. We chose Simpson index as measure of species diversity. The Simpson index emphasizes the

**Table 1**
Continuous habitat variables according to the main study questions on structural elements (analysis A) and woody plant composition (analysis B).

| Variable | Mean (min–max) | Units | Definition |
|---|---|---|---|
| Analysis (A) structural elements | | | |
| *BUILDING* | 0.23 (0.00–0.65) | Relative coverage in radius 50 m | Buildings |
| *SEALED AREA* | 0.26 (0.00–0.78) | | Asphalted surfaces (roads, spots), diverse anthropogenic features (i.e. gazebos, statues, fountains) |
| *GRASS* | 0.30 (0.03–0.76) | | Short grass, long grass and native flowers |
| *BUSH* | 0.13 (0.00–0.36) | | Woody plants (<5 m high) |
| *TREE* | 0.13 (0.00–0.47) | | Woody plants (>5 m high) |
| Analysis (B) woody plant composition[a] | | | |
| *CONIFEROUS* | 0.05 (0.00–0.35) | Relative coverage in radius 50 m | Coniferous woody plants cover (trees and bushes) |
| *DECIDUOUS* | 0.21 (0.03–0.65) | | Deciduous woody plants cover (trees and bushes) |
| *EXOTIC* | 0.12 (0.00–0.33) | | Exotic woody plants cover (trees and bushes) |
| *NATIVE* | 0.14 (0.01–0.59) | | Native woody plants cover (trees and bushes) |
| *WOODY SPECIES RICHNESS* | 2.14 (1.00–4.54) | $n$ | Mean number of woody plants species |

[a] In analysis B1 the following ratios of the coverage were used: *CONIFEROUS/DECIDUOUS* (Mean, 0.25; Min 0.00; Max 2.91) and *EXOTIC/NATIVE* (1.95; 0.00; 13.93).

evenness of a community, being less sensitive to species richness. It is meaningful, very robust, widely used and allows comparisons with the results of other studies (Magurran, 2004):

$$\text{Simpson} = 1 - \sum_{i=1}^{n} p_i^2$$

where $n$ is the number of species observed at the sampling point and $p_i$ is the relative abundance of species $i$.

Bird community composition at the different sampling points was expressed by the abundance (see definition in the previous paragraph) of each species, obtaining a 'species by sites' matrix.

### 2.3. Habitat variables

According to the main research questions, ten habitat variables (Table 1) were recorded at or within a 50 m radius of the sampling points and were digitized using Geographic Information Systems (ArcGIS 9.2, ESRI Redlands, USA):

(A) Structural elements – Detailed structural habitat variables were expressed as relative area coverage (=fraction; 100% = 7854 m$^2$ for a single location).

(B1) Woody plant composition – We were especially interested in the influence of different types of woody plants (foliage, origin, species richness) on avian biodiversity. Opposed to analysis A, where we distinguished between trees and bushes based on an arbitrary height limit of 5 m, we renounced this distinction in analysis B and considered the type of the tree and bush continuum as 'woody plant composition'. Two habitat variables are expressed as ratios (*CONIFEROUS/DECIDUOUS* and *EXOTIC/NATIVE*) as (a), in this analysis, we were not interested in the absolute woody plant coverage which would have dominated the effect of composition and (b) to minimize the number of variables in the candidate models. We calculated mean species richness of woody plants (*WOODY SPECIES RICHNESS*), using the following formula:

$$\text{WSR} = \sum_{i=1}^{n} \text{SR}_i \frac{\text{area}_i}{\text{area}_{\text{TOT}}}$$

where $n$ is the number of different woody plants patches within a 50 m radius, $\text{SR}_i$ is the estimated number of woody plants species within patch $i$ (three categories: 1 species ($\text{SR}_i = 1$), 2–3 species (=2.5), ≥4 species (=5)), $\text{area}_i$ is the area of woody plants patch $i$ and $\text{area}_{\text{TOT}}$ is the total woody plants area within 50 m radius (sum of all $\text{area}_i$).

(B2) Woody plant composition and bird community – The analysis is based on the same variables as analysis B1, but *CONIFEROUS, DECIDUOUS*, *EXOTIC* and *NATIVE* are expressed as relative area coverage.

### 2.4. Statistical analysis

For the two study questions A and B1, we analysed the correlation of bird species richness and diversity with the habitat variables with linear mixed-effects models (Laird and Ware, 1982; Crawley, 2007), separating random effects (cities) from fixed effects (habitat variables). We found a normal distribution of the model residuals of both response variables (bird species richness and Simpson index) and thus used linear models.

We regressed species richness and Simpson index as a measure for species diversity on two different sets of explanatory variables corresponding to the two study questions (A and B1). All variables are continuous. Pair-wise correlation analysis showed that correlation coefficients $r$ were below 0.7 which was defined as the maximal accepted limit of correlation.

For each of the two analyses, we formulated a priori models including all possible combinations of the variables. A total of 32 pre-defined models were tested for the structural elements analysis (analysis A) and eight models for the woody plant composition analysis (analysis B1). All composition models related to analysis B1 contained the area fraction of woody plants as a co-variable to account for the total cover at each sampling point. We expected a curvilinear relation (optimum curve) for the variable *CONIFEROUS/DECIDUOUS* (ratio), so we included its quadratic function into the modeling for species richness and species diversity. For the variable *BUILDING* we only expected a curvilinear relationship for the response variable bird species richness, because moderately built areas can host building dwelling species that profit from artificial rocks without necessarily losing the species already present at sampling locations with less buildings. On the other hand, for species diversity we expected *BUILDING* to exhibit a linear effect, as the Simpson index might be negatively affected by newly dominant building dwelling species. Consequently, we included the quadratic function of *BUILDING* into the modeling for species richness but not for species composition.

Models were ranked according to the small-sample unbiased Akaike's Information Criterion (AICc). AICc weights and evidence ratios were calculated (Burnham and Anderson, 2002; Johnson and Omland, 2004). Models with evidence ratios <10 were defined as the most parsimonious set of models. These selected models were predicted individually for all of the independent variables varying between the minimum and maximum value of the data set, while the remainder were kept constant at their mean value. By bootstrapping (1000 repetitions), standard deviations were calculated for the predicted values. Predicted values were then averaged on the basis of their AICc weights (Burnham and Anderson, 2002). The explained variation of every model was calculated using the generalized form of $R^2$ for linear mixed effects models proposed by Xu (2003). All statistical calculations were carried out with the pro-

**Table 2**
Selected linear mixed-effects models (most parsimonious set of models with evidence ratio smaller than 10), relating species richness to five environmental variables (estimates and SD are indicated). (A) Structural elements analysis; (B1) Woody plant composition analysis.

| Model | Intercept | Tree | Bush | Grass | Sealed area | Building | Building$^2$ | Δ-AICc[a] | AICw[b] | ER[c] | $k$[d] | $R^{2}$[e] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (A) | | | | | | | | | | | | |
| 8 | 15.6 (1.0) | 16.3 (3.2) | | | −9.7 (2.4) | | | 0.0 | 45.0% | 1.0 | 5 | 41.3% |
| 17 | 14.6 (1.2) | 15.8 (3.2) | 6.4 (4.3) | | −8.8 (2.4) | | | 2.0 | 17.0% | 2.7 | 6 | 42.6% |
| 16 | 9.5 (1.0) | 12.7 (3.6) | 13.2 (4.2) | 7.6 (2.2) | | | | 2.8 | 11.3% | 4.0 | 6 | 42.0% |
| 21 | 17.7 (1.7) | 11.3 (4.0) | | | −9.7 (2.3) | −5.8 (8.6) | −3.2 (14.8) | 3.5 | 7.9% | 5.7 | 7 | 44.3% |
| 19 | 15.0 (1.5) | 15.5 (3.5) | | 1.5 (2.7) | −8.7 (3.0) | | | 4.0 | 6.2% | 7.3 | 6 | 41.5% |
| 26 | 12.4 (2.0) | 13.4 (3.6) | 9.5 (4.8) | 4.2 (3.0) | −5.6 (3.4) | | | 4.3 | 5.4% | 8.4 | 7 | 43.7% |

| Model | Intercept | Coniferous/deciduous | (Coniferous/deciduous)$^2$ | Exotic/native | Woody species richness | Δ-AICc[a] | AICw[b] | ER[c] | $k$[d] | $R^{2}$[e] |
|---|---|---|---|---|---|---|---|---|---|---|
| (B1) | | | | | | | | | | |
| 1 | 10.2 (0.8) | 6.0 (1.9) | −1.1 (0.8) | | | 0.0 | 61.6% | 1.0 | 6 | 16.1% |
| 4 | 10.7 (0.9) | 6.6 (1.9) | −1.3 (0.8) | −0.2 (0.1) | | 1.8 | 25.7% | 2.4 | 7 | 19.9% |
| 5 | 9.6 (1.2) | 6.3 (2.0) | −1.2 (0.8) | | 0.3 (0.5) | 3.9 | 8.6% | 7.2 | 7 | 16.3% |

[a] Difference compared to small-sample unbiased Akaike's Information Criterion of the best model.
[b] Model weight.
[c] Evidence ratio.
[d] Number of parameters.
[e] Adjusted $R^2$ (Xu, 2003).

gram R v2.6.0 (R Development Core Team, 2007) using library nlme (Pinheiro et al., 2008).

For the study question B2, partial Redundancy Analysis of bird community composition (pRDA; Legendre and Legendre, 1998) was performed using the CANOCO software (Microcomputer Power, Ithaca, NY, USA) and referring to Lepš and Šmilauer (2003). As a multivariate analysis of variance, pRDA tests the linear relationship between a response matrix (i.e. abundance of bird species by 96 sampling points) and the explanatory variables (i.e. five woody plant composition variables; Table 1), while controlling for co-variables (i.e. the three cities, alike to the linear mixed-effects models above). Monte Carlo permutation tests (999 permutations) were performed to assess the significance of the different canonical axes. Species that were observed only few times and/or only at one sampling point (singletons) can cause problems in the analysis, because their occurrence could be accidental and not due to environmental reasons. Therefore, only species observed at least 5 times and at more than one sampling point were included in the pRDA analysis (39 species).

## 3. Results

We recorded 4120 individuals of 63 species within a radius of 50 m from the 96 sampling points. Overall, we recorded an average of 15.2 species per sampling point (SD = 3.9; range = 7–25) with only small variation between the three cities (Appendix S1b). For species identity and frequencies per city see Appendix S2.

### 3.1. Structural elements

For bird species richness, six out of the initial 32 models were found by the evidence ratios as the most parsimonious set of models (Table 2A). The explanatory power of the selected models is very high with an average $R^2$ of 42.6% per selected model. The variable *TREE* is contained in all six selected models (sum of AICc weights = 92.7%) and shows the highest positive correlation with bird species richness. *SEALED AREA* (in five selected models; sum of weights = 81.4%) shows the highest negative correlation. *BUSH* and *GRASS* exhibit a moderately positive influence on bird species richness (each in three selected models; sum of weights = 33.7% and 22.9%, respectively) while *BUILDING* (linear and quadratic term) shows a negative correlation with bird species richness (in one selected model; weight = 7.9%).

For bird species diversity (Simpson index), nine out of the initial 32 models were defined as the most parsimonious set of models (Table 3A). With an averaged $R^2$ of 21.0%, their explanatory power is about half that of the models that explained species richness. Again, *TREE* is contained in eight of the nine selected models (sum of weights = 84.0%) and shows the highest positive correlation with species diversity. *BUILDING* shows a moderate negative correlation (in four selected models; sum of weights = 23.4%), *BUSH* has a moderate positive correlation (in three selected models; sum of weights = 25.4%), whereas there is hardly any correlation for *GRASS* and *SEALED AREA* (in two selected models each; sum of weights = 13.8% and 9.5%, respectively).

The averaged predictions of the selected models illustrate the outstanding and positive influence of *TREE* on both bird species richness and diversity (Fig. 1): a 20% increase of tree area results in an average of three additional bird species and an increase of Simpson index of about 0.24 (i.e. 24% increase in the probability that two randomly chosen birds belong to two different species). Considering their standard deviations (SD), species richness predictions are reasonably reliable along the entire tree gradient under study, whereas the predictions for species diversity become less reliable for tree coverage above 30% of the total area. The variables *BUSH* and *GRASS* have a moderate and similar positive effect on bird species richness and diversity (although considerably less important than variable *TREE*). The predictions for *SEALED AREA* (Fig. 1) yield a contrasting picture for species richness (negative influence) and for species diversity (no influence). A 40% increase of the sealed area causes a loss of three bird species, whereas predictions become less reliable when the fraction of sealed area is above 50%. In contrast to the influence of sealed area, species richness is not greatly influenced by the fraction of area covered by buildings, while a 25% increase in built area decreases the Simpson index by about 0.01. In this case, species diversity predictions become less reliable for buildings fraction above 40%.

### 3.2. Woody plant composition

For bird species richness, three models were defined as the most parsimonious set of models (Table 2B1). The explanatory power of these models, with the averaged $R^2$ of 17.4%, is lower than in the analysis of the structural elements. The variable *CONIFEROUS/DECIDUOUS* (including its quadratic term) occurs in all the three selected models (sum of weights = 95.9%) and reveals a curvilinear response of bird species richness. The variables

**Table 3**
Selected linear mixed-effects models (most parsimonious set of models with evidence ratio smaller than 10), relating species diversity to five environmental variables (estimates and SD are indicated). (A) Structural elements analysis; (B1) Woody plant composition analysis.

| Model | Intercept | Tree | Bush | Grass | Sealed area | Building | Δ-AICc[a] | AICw[b] | ER[c] | $k$[d] | $R^2$[e] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (A) | | | | | | | | | | | |
| 1 | 0.81 (0.01) | 0.28 (0.06) | | | | | 0.0 | 28.4% | 1.0 | 4 | 19.4% |
| 6 | 0.80 (0.02) | 0.26 (0.06) | 0.14 (0.08) | | | | 1.3 | 14.9% | 1.9 | 5 | 21.6% |
| 9 | 0.85 (0.03) | 0.20 (0.07) | | | | −0.11 (0.07) | 1.5 | 13.4% | 2.1 | 5 | 21.8% |
| 7 | 0.80 (0.02) | 0.23 (0.07) | | 0.05 (0.04) | | | 2.7 | 7.3% | 3.9 | 5 | 20.7% |
| 8 | 0.83(0.02) | 0.25 (0.06) | | | −0.05 (0.05) | | 2.9 | 6.6% | 4.3 | 5 | 20.4% |
| 16 | 0.78 (0.02) | 0.20 (0.07) | 0.16 (0.08) | 0.07 (0.04) | | | 3.0 | 6.5% | 4.4 | 6 | 23.7% |
| 18 | 0.83 (0.03) | 0.20 (0.07) | 0.11 (0.08) | | | −0.09 (0.07) | 3.9 | 4.0% | 7.1 | 6 | 23.0% |
| 5 | 0.90 (0.02) | | | | | −0.22 (0.05) | 4.5 | 3.0% | 9.3 | 4 | 15.7% |
| 21 | 0.86 (0.03) | 0.18 (0.08) | | | −0.05 (0.05) | −0.11 (0.07) | 4.5 | 2.9% | 9.7 | 6 | 22.7% |

| Model | Intercept | Coniferous/deciduous | (Coniferous/deciduous)$^2$ | Exotic/native | Woody species richness | Δ-AICc[a] | AICw[b] | ER[c] | $k$[d] | $R^2$[e] |
|---|---|---|---|---|---|---|---|---|---|---|
| (B) | | | | | | | | | | |
| 0 | 0.79 (0.02) | | | | | 0.0 | 71.3% | 1.0 | 4 | 0.0% |
| 2 | 0.80 (0.02) | | | 0.00 (0.00) | | 3.6 | 11.6% | 6.2 | 5 | 0.9% |
| 3 | 0.80 (0.02) | | | | −0.01 (0.01) | 3.9 | 10.3% | 6.9 | 5 | 0.6% |

[a] Difference compared to small-sample unbiased Akaike's Information Criterion of the best model.
[b] Model weight.
[c] Evidence ratio.
[d] Number of parameters.
[e] Adjusted $R^2$ (Xu, 2003).

*EXOTIC/NATIVE* and *WOODY SPECIES RICHNESS* (one model each; weight = 25.7% and 8.6%, respectively) do not exhibit a strong influence on bird species richness.

For bird species diversity, three models were defined as the most parsimonious set of models (Table 3B1). The explanatory power of these models is virtually inexistent with an averaged $R^2$ of 0.5%. The best model is the null model (AICc weight = 71.3%) indicating random distribution (only the control variable total woody plants cover was included). Consequently, none of the analysed variables (*CONIFEROUS/DECIDUOUS*, *EXOTIC/NATIVE* and *WOODY SPECIES RICHNESS*) affects species diversity.

The averaged predictions of the selected models (Fig. 2) on woody plant composition illustrate that only the variable *CONIFEROUS/DECIDUOUS* has a considerable (positive) influence on only bird species richness. This variable shows a quadratic curve that probably has not yet reached its optimum. If all woody plants are deciduous, bird species richness is expected to be at its minimum value of about 14 species (=intercept). If deciduous and coniferous woody plants reach the same coverage (1:1 ratio), six additional bird species are predicted to be present. Predictions become less reliable for ratios >1 and thus the prediction of the maximum is doubtful. It is questionable whether a higher fraction of area covered by coniferous species would still increase bird species numbers. Bird species diversity does not respond to any variable included in the composition analysis (Fig. 2).

### 3.3. Woody plant composition and bird community

The five habitat variables included in the pRDA analysis (Table 1) explained 15.1% of the total variance in bird community composition. Fig. 3 depicts the results with respect to the first two (and most important) canonical axis. The first axis alone explained 9.9% of the variance ($p \leq 0.001$). When moving along the first axis from left (low

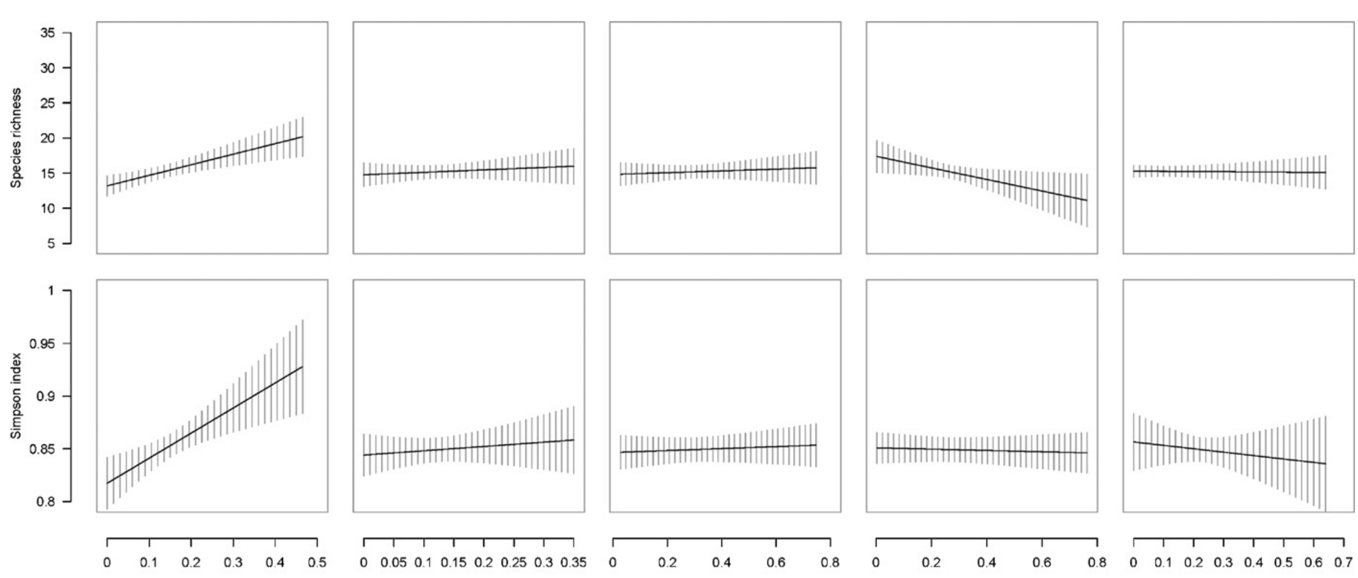


**Fig. 1.** Model averaged predictions (mean and SD) of bird species richness (above) and bird species diversity (below) on the basis of the most parsimonious set of models for structural elements analysis (A).

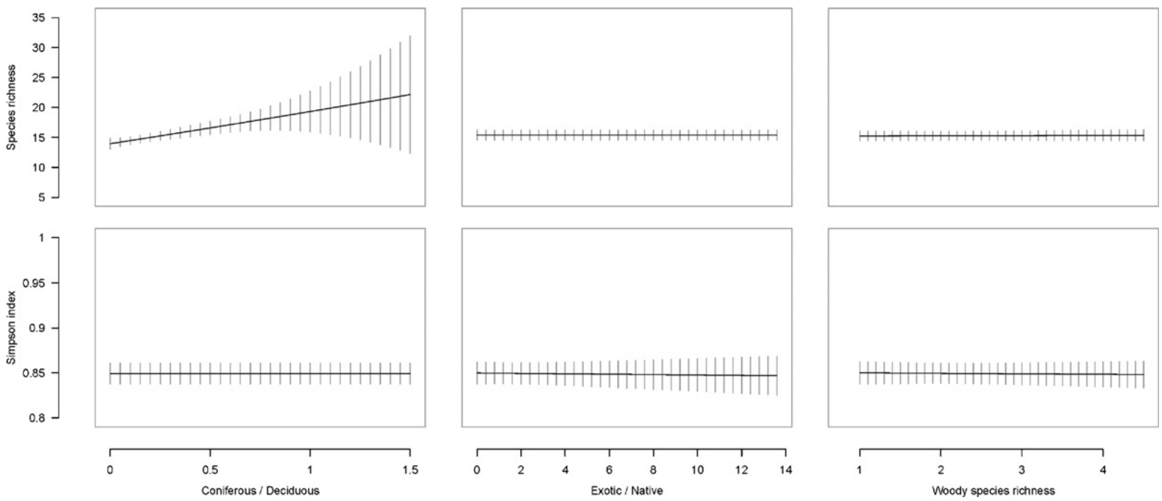


**Fig. 2.** Model averaged predictions (mean and SD) of bird species richness (above) and bird species diversity (below) on the basis of the most parsimonious set of models for woody plant composition analysis (B1).

fraction of woody plants) to right (high fraction) many bird species become more abundant; in particular, woody plants positively affected *Dendrocopos major*, *Columba palumbus*, *Fringilla coelebs* and *Cyanistes caerulus* as shown by the similar direction of the species arrows and the first axis. Only a few species are negatively correlated with woody plants (e.g. *Passer domesticus/hispaniolensis italiae*, *Streptopelia decaocto*, *Columba livia domestica* and *Apus apus*). The right hand side of the first axis represents a mixture of coniferous and broadleaf woody plants. The arrows of coniferous and broadleaf trees and bushes illustrate that these woody plant types, when dominant, potentially differentiate bird communities. Most species, however are placed in intermediate positions and do not show evident preference for either foliage type. Some species (e.g. *Regulus ignicapilla*, *Periparus ater*, *Turdus merula*, *Certhia brachydactyla*) prefer coniferous woody plants to

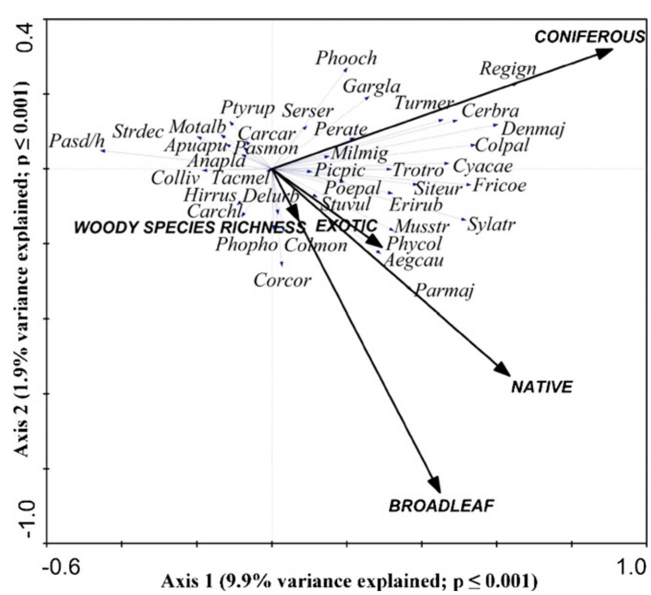


**Fig. 3.** Species community analysis by pRDA depicting 39 species (black arrows) in the environmental space of the first two canonical axis. The five explanatory variables are in bold and capital letters. Longer arrows illustrate a higher correlation of the species with one of the main axis and/or explanatory variables. Species names are composed by the first three letters of the genus and the first three letters of the species name, for species list see Appendix S2. Two pairs of ecologically equivalent species were summarized in species complexes (*Corvus corone* + *Corvus cornix* = *Corcor*; *Passer domesticus* + *Passer hispaniolensis italiae* = *Pasd/h*).

broadleaf ones. Exotic and native woody plants seem to have similar directions, but the different length of the arrows indicates that native woody plants correlate better with the first and the second canonical axes than the exotic ones (Fig. 3). However, hardly any species correlates with any of the two variables (with the exception of *Parus major* with native woody plants). In our study sites, the fraction of exotic and native woody plants as well as woody plant species richness do not influence urban bird communities.

## 4. Discussion and conclusions

Most studies on urban birds have considered the classical rural–urban gradient approach as proposed by McDonnell and Pickett (1990), which has generally revealed a negative impact of urbanization (i.e. increasing sealed area) on bird species richness and diversity (e.g. Clergeau et al., 1998; Palomino and Carrascal, 2006). Our study, focusing on gradients within cities, found that three species are lost when sealed area increases by 40%, confirming the general negative pattern of urbanization also on the intra-urban scale. The positive effects of increasing area coverage and of higher complexity of urban green structures on species richness and diversity on our comparatively small 50 m radius illustrates the strong effect of fine scale composition of urban green and they are similar to results obtained at larger scales (Lancaster and Rees, 1979; Clergeau et al., 2001).

### 4.1. Pre-eminent positive influence of trees

Our results suggest that the amount of trees is the most important habitat variable enhancing bird species richness and diversity in cities, confirming previous studies (Goldstein et al., 1986; Clergeau et al., 1998; Palomino and Carrascal, 2006; Sandström et al., 2006; Evans et al., 2009). We predict an increase from 13 bird species in the absence of trees to 20 species with 46% tree cover (+54%), keeping other model variables constant. The positive effect of trees outweighs the negative effect of sealed area and buildings, probably because trees open up the vertical dimension and thereby substantially increase both habitat dimensions and available niches. Therefore, increasing the fraction of tree cover in the urban matrix seems to be the most promising and efficient measure to enhance bird species richness and diversity.

While sealed area decreases overall bird species richness but not species diversity, an increasing building fraction has the opposite effect, i.e. leads to a reduction in bird diversity but not in richness. In highly urbanized areas, only few species (e.g. *Apus apus*, *Passer domesticus*, *Columba livia* f. *domestica*) profit from buildings as secondary rock habitats and from abundant food resources, and thus dominate the community (Clergeau et al., 2006; La Sorte and McKinney, 2007). Prior to our study and based on the intermediate disturbance hypothesis (Connell, 1978) and results of other studies and taxa (Blair, 1996; Marzluff, 2005; Tratalos et al., 2007; Lepczyk et al., 2008; Sanford et al., 2009), we had expected bird species richness to attain its maximum at an intermediate state of building density. However, our study reveals that buildings do not affect bird species richness, in that the loss of sensitive species is compensated by the appearance of generalist building dweller species (same species as above).

### 4.2. The influence of woody plant composition on urban avian diversity and species communities

We found that woody plant composition is important for bird richness reaching the maximum number of species with equal representation of coniferous and deciduous plants. At a ratio of 1:1 we predict the occurrence of 20 species although Fig. 2 suggests that more coniferous woody plants could enhance bird species richness even more (note increased SD, however). These results are confirmed by the community analysis, which shows that most species correlate with both coniferous and broadleaf woody plants indicating that the presence of both type of vegetation is favorable to many urban birds. While bird species relying on trees in general profit from the presence of either coniferous and deciduous trees, some specialist species will make use of the habitat only when their preferred foliage type covers a sufficient area. A balanced mixture of both habitat types thus maximizes the total number of species, as indicated by Palomino and Carrascal (2006). Our result contradicts Thompson et al. (1993) who found that bird species richness is highest in gardens with higher ratios of deciduous to coniferous trees. As indicated by the community analysis, the availability of coniferous and broadleaf woody plants does not only affect the presence/absence of species, but also their abundance: some species seem to prefer increased area coverage of coniferous trees, e.g. *Regulus ignicapilla*, *Periparus ater* and *Certhia brachydactyla*. Such changes in abundance of some species due to alterations in the foliage composition of woody plants may not be unraveled when using Simpson index only; the changes may be counterbalanced by abundance shifts of other species resulting in limited or no changes in Simpson index. Our results of the community analysis show that sometimes a constant Simpson index masks complex shifts in community composition.

With regard to the effect of native vs. exotic plants on urban birds, Donnelly and Marzluff (2004) in North America and Daniels and Kirkpatrick (2006) in Australia found a higher correlation of native bird species with native plants than with exotic plants. Again in Australia, White et al. (2005) found lower bird species richness and a modified community composition in areas dominated by exotic vegetation compared to areas where native vegetation prevails. In our fine-scaled study in Switzerland, we found no influence of exotic and native woody plants on neither bird species richness, nor species diversity, nor community composition. We neither found an influence of woody plant species richness on any avian biodiversity measure, which contradicts the results of Shwartz et al. (2008), who found a positive influence of the number of woody plant species on avian species richness in urban areas in Tel Aviv (Israel).

The lack of relationship between any of the woody plant characteristics and species diversity suggests that in areas with high tree fraction no single bird species reaches dominance and thereby greatly impacts Simpson index. Simpson index is mainly influenced by dominant species. Increasing built area, results in few species becoming dominant. This result is confirmed by the community analysis (Fig. 3): the first canonical axis describes a general gradient from areas with a high fraction (right) to areas with a low fraction of woody plants (left), where a limited number of species tends to dominate (e.g. *Passer domesticus/hispaniolensis italiae*, *Streptopelia decaocto*, *Columba livia domestica* and *Apus apus*; see also Appendix S2).

### 4.3. Conclusions and perspectives

Human requirements for more buildings and transport infrastructure put high pressure on urban green space (densification). While it seems illusive and may be even contra-productive to stop this process (with regard to general conservation efforts: when densification is stopped, urban sprawl is likely to increase) it should be a goal to plan and manage urban green in a way to compensate for the loss of green area as habitats for birds. Our results lead us to two quantitative recommendations for vegetation structures that positively influence avian biodiversity in cities:

(1) The conservation or re-planting of trees and large bushes optimizes vertical vegetation structure and is regarded as the most effective long-term measure to enhance both bird species richness and diversity. Our models predict a 54% increase from 13 bird species in the absence of trees to 20 species with 46% tree cover.
(2) A well-balanced mixture of coniferous and deciduous woody plants maximizes bird species richness. Our models predict a 43% increase from 14 bird species at places with the presence of only deciduous woody plants to 20 species at places with equal representation of coniferous and deciduous plants.

We want to stress that urban planning and management decisions are already effective at comparatively fine scales (<1 ha).

More than 60 bird species can breed in Swiss cities, which is approximately one third of all regularly breeding species of Switzerland. Nevertheless Red List species (11 species, Keller et al., 2001), priority species (9 species, Bollmann et al., 2002) and specialists are underrepresented among urban birds (Appendix S2). Thus, offering optimal habitats in cities cannot replace bird protection measures outside the city fringe (Miller, 2006). From a social science perspective, a recent study has shown the popularity of birds in the public (Home et al., 2009b). So, urban birds and their diversity represent a crucial element on how people can experience urban nature. Such experiences are essential for the individual well-being of city inhabitants (Fuller et al., 2007) and for political decisions regarding environmental conservation since personal experiences influence people's opinion (Turner et al., 2004; Dunn et al., 2006).

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.landurbplan.2011.02.033.

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List of Appendices

**Appendix S1**: Information about the three cities considered: a) information on location, geographical extent and human population; b) bird species richness in the three cities (total, mean, range).

| | Zurich | Lucerne | Lugano |
|---|---|---|---|
| a) | | | |
| Geographical coordinates | 47°22′N, 8°33′E | 47°03′N, 8°18′E | 46°00′N, 8°57′E |
| Area | 91.88 km² | 24.15 km² | 26.2 km² |
| Elevation | 408 m a.s.l. | 436 m a.s.l. | 273 m a.s.l. |
| Residents | 367’000 | 58’000 | 49'000 |
| b) | | | |
| Total bird species richness | 42 | 51 | 40 |
| Mean (SD) per sampling point | 14.0 (3.7) | 16.4 (4.4) | 15.1 (3.2) |
| Range | 9-25 | 9-25 | 7-21 |

**Appendix S2:** List of all bird species according to the three cities considered (n locations = 32 per city, total 96).

| Scientific Name | English Name | Species status [a] | Steadiness and dominance (%) [b] | | | |
|---|---|---|---|---|---|---|
| | | | Zurich | Lucerne | Lugano | Overall |
| *Accipiter nisus* | Eurasian Sparrowhawk | | 1 (0.1) | 1 (0.1) | 0 (0.0) | 2 (0.0) |
| *Acrocephalus scirpaceus* | Eurasian Reed Warbler | | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |
| *Aegithalos caudatus* | Long-tailed Tit | | 5 (0.9) | 14 (2.3) | 10 (1.9) | 29 (1.7) |
| *Anas platyrhynchos* | Mallard | | 1 (0.1) | 5 (0.8) | 0 (0.0) | 6 (0.3) |
| *Apus apus* | Common Swift | #, § | 28 (18.4) | 29 (12.2) | 25 (7.0) | 82 (12.4) |
| *Ardea cinerea* | Grey Heron | | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |
| *Buteo buteo* | Common Buzzard | | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |
| *Carduelis cannabina* | Common Linnet | | 0 (0.0) | 0 (0.0) | 1 (0.1) | 1 (0.0) |
| *Carduelis carduelis* | European Goldfinch | § | 15 (1.7) | 19 (2.5) | 25 (3.7) | 59 (2.7) |
| *Carduelis chloris* | European Greenfinch | § | 30 (4.6) | 26 (3.1) | 30 (4.5) | 86 (4.1) |
| *Certhia brachydactyla* | Short-toed Treecreeper | | 4 (0.3) | 5 (0.4) | 2 (0.1) | 11 (0.3) |
| *Coccothraustes coccothraustes* | Hawfinch | | 1 (0.1) | 0 (0.0) | 0 (0.0) | 1 (0.0) |
| *Coloeus monedula* | Western Jackdaw | VU, # | 1 (0.3) | 5 (0.7) | 0 (0.0) | 6 (0.3) |
| *Columba livia f. domestica* | Common Pigeon | | 12 (3.3) | 8 (1.8) | 22 (5.6) | 42 (3.6) |
| *Columba palumbus* | Common Wood Pigeon | | 3 (0.2) | 10 (1.0) | 0 (0.0) | 13 (0.4) |
| *Corvus cornix* | Hooded Crow | | 0 (0.0) | 0 (0.0) | 32 (6.9) | |
| *Corvus corone* | Carrion Crow | | 28 (4.9) | 28 (5.0) | 0 (0.0) | 88 (5.6) [c] |
| *Cyanistes caeruleus* | Eurasian Blue Tit | | 28 (3.9) | 26 (4.3) | 16 (1.4) | 70 (3.2) |
| *Delichon urbicum* | Common House Martin | § | 1 (0.1) | 0 (0.0) | 9 (2.4) | 10 (0.8) |
| *Dendrocopos major* | Great Spotted Woodpecker | | 7 (0.6) | 7 (0.6) | 2 (0.1) | 16 (0.4) |
| *Emberiza cirlus* | Cirl Bunting | VU, # | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |
| *Erithacus rubecula* | European Robin | | 12 (1.1) | 11 (0.9) | 14 (1.2) | 37 (1.1) |
| *Fringilla coelebs* | Common Chaffinch | | 26 (3.6) | 30 (4.8) | 28 (3.7) | 84 (4.1) |
| *Garrulus glandarius* | Eurasian Jay | | 3 (0.4) | 5 (0.5) | 0 (0.0) | 8 (0.3) |
| *Hippolais polyglotta* | Melodious Warbler | NT | 0 (0.0) | 0 (0.0) | 1 (0.1) | 1 (0.0) |
| *Hirundo rustica* | Barn Swallow | | 1 (0.2) | 1 (0.1) | 4 (0.4) | 6 (0.2) |
| *Jynx torquilla* | Eurasian Wryneck | VU, # | 0 (0.0) | 0 (0.0) | 1 (0.1) | 1 (0.0) |
| *Larus michahellis* | Yellow-legged Gull | NT | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |
| *Locustella naevia* | Common Grasshopper Warbler | VU, # | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |
| *Lophophanes cristatus* | European Crested Tit | | 0 (0.0) | 2 (0.2) | 0 (0.0) | 2 (0.1) |
| *Loxia curvirostra* | Red Crossbill | | 0 (0.0) | 0 (0.0) | 1 (0.1) | 1 (0.0) |
| *Mergus merganser* | Common Merganser | VU | 0 (0.0) | 2 (0.1) | 0 (0.0) | 2 (0.0) |
| *Milvus migrans* | Black Kite | | 2 (0.2) | 2 (0.2) | 0 (0.0) | 4 (0.1) |
| *Motacilla alba* | White Wagtail | | 7 (0.7) | 10 (1.0) | 11 (0.9) | 28 (0.9) |
| *Muscicapa striata* | Spotted Flycatcher | § | 7 (0.6) | 15 (1.5) | 10 (1.0) | 32 (1.0) |
| *Oenanthe oenanthe* | Northern Wheatear | | 0 (0.0) | 0 (0.0) | 1 (0.1) | 1 (0.0) |
| *Parus major* | Great Tit | | 29 (5.9) | 32 (6.4) | 24 (3.0) | 85 (5.1) |
| *Passer domesticus* | House Sparrow | § | 32 (24.1) | 29 (16.7) | 0 (0.0) | |
| *Passer hispaniolensis italiae* | Spanish Sparrow | § | 0 (0.0) | 0 (0.0) | 32 (29.4) | 93 (23.5) [c] |
| *Passer montanus* | Eurasian Tree Sparrow | | 1 (0.2) | 1 (0.1) | 2 (0.4) | 4 (0.2) |
| *Periparus ater* | Coal Tit | | 3 (0.2) | 6 (0.6) | 7 (0.7) | 16 (0.5) |
| *Phalacrocorax carbo* | Great Cormorant | | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |
| *Phoenicurus ochruros* | Black Redstart | | 19 (1.8) | 28 (3.3) | 14 (1.2) | 61 (2.1) |
| *Phoenicurus phoenicurus* | Common Redstart | NT, # | 2 (0.2) | 1 (0.1) | 18 (1.8) | 21 (0.7) |
| *Phylloscopus collybita* | Common Chiffchaff | | 5 (0.5) | 10 (0.9) | 2 (0.1) | 17 (0.5) |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Phylloscopus trochilus* | Willow Warbler | NT, # | 0 (0.0) | 0 (0.0) | 1 (0.1) | 1 (0.0) |
| *Pica pica* | Eurasian Magpie | | 19 (2.3) | 11 (1.4) | 0 (0.0) | 30 (1.2) |
| *Picus viridis* | European Green Woodpecker | | 1 (0.1) | 1 (0.1) | 2 (0.1) | 4 (0.1) |
| *Poecile palustris* | Marsh Tit | | 1 (0.1) | 3 (0.3) | 0 (0.0) | 4 (0.1) |
| *Ptyonoprogne rupestris* | Eurasian Crag Martin | | 0 (0.0) | 0 (0.0) | 2 (0.4) | 2 (0.1) |
| *Pyrrhula pyrrhula* | Eurasian Bullfinch | | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |
| *Regulus ignicapilla* | Common Firecrest | | 6 (0.6) | 15 (1.6) | 9 (0.8) | 30 (1.0) |
| *Regulus regulus* | Goldcrest | | 1 (0.2) | 0 (0.0) | 0 (0.0) | 1 (0.0) |
| *Saxicola rubetra* | Whinchat | NT, # | 0 (0.0) | 0 (0.0) | 1 (0.1) | 1 (0.0) |
| *Serinus serinus* | European Serin | § | 8 (0.6) | 15 (1.5) | 24 (2.7) | 47 (1.6) |
| *Sitta europaea* | Eurasian Nuthatch | | 8 (0.7) | 10 (1.0) | 7 (0.6) | 25 (0.8) |
| *Streptopelia decaocto* | Eurasian Collared Dove | § | 14 (1.9) | 5 (0.6) | 19 (2.7) | 38 (1.7) |
| *Sturnus vulgaris* | Common Starling | | 20 (3.4) | 19 (3.3) | 10 (1.4) | 49 (2.7) |
| *Sylvia atricapilla* | Eurasian Blackcap | | 21 (3.2) | 27 (3.3) | 28 (4.8) | 76 (3.8) |
| *Tachymarptis melba* | Alpine Swift | NT, # | 2 (0.4) | 2 (0.7) | 1 (0.1) | 5 (0.4) |
| *Troglodytes troglodytes* | Winter Wren | | 3 (0.4) | 5 (0.4) | 4 (0.4) | 12 (0.4) |
| *Turdus merula* | Common Blackbird | | 31 (7.1) | 32 (12.5) | 31 (8.1) | 94 (9.2) |
| *Turdus philomelos* | Song Thrush | | 0 (0.0) | 2 (0.1) | 0 (0.0) | 2 (0.0) |
| *Turdus viscivorus* | Mistle Thrush | | 0 (0.0) | 1 (0.1) | 0 (0.0) | 1 (0.0) |

[a] Conservation status according to the Red List of birds of Switzerland (Keller et al. 2001): VU = vulnerable, NT = near threatened; # = indicates whether a species was considered as a priority species for Switzerland (Bollmann et al. 2002); § identifies indicator species for urban habitats (Zbinden et al. 2005).
[b] Steadiness expresses the number of sampling points with the presence of the species. Dominance indicates the fraction (%) of individuals of a single species on the total individual number of birds.
[c] As *Passer hispaniolensis italiae and Corvus cornix* occupy the ecological niche of *P. domesticus* and *C. corone* in Lugano, we calculate the overall steadiness and dominance as if they were the same species.

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**RE: DRAFT OF BIRD-SAFE BUILDING STANDARDS DECEMBER 30, 2010**

Thank you for introducing building improvement regulations which are critically important to protect the stunning beauty and diversity of our American birds.

Glass has become one of our favorite building materials, but it is deadly for many birds. This fact has largely been overlooked by glass manufacturers, so glass remains an imperfect environmental product. Glass energy coatings have become commonplace in recent years. Manufacturers must be encouraged to manufacture new environmentally responsible glass products that <u>also</u> routinely add frit or ultra-violet wavelength coatings to make glass visible to birds.

Night lighting in urban and suburban America is all too often over-designed resulting in porches and parking lots bright enough to read a book. The energy expended is perhaps double what is necessary for safe passage. Lower footcandle levels as well as increased numbers of shielded fixtures could maintain safe <u>even</u> lighting that is less disruptive to our nocturnal wildlife and less wasteful. Positive growth is seen in migratory season “lights out” initiatives for urban office towers, however urban residential towers will require both glass treatment and lighting controlled by motion sensors.

The following comments refer to text and page location:

6. A dynamic of changing technologies for glass, structural systems, and mechanical systems (air-conditioning) has contributed to the increased bird mortality from glass collisions. Before air-conditioning, operable windows were typically fully screened. It is important to emphasize this dynamic since many people will automatically think “well, we’ve used glass for hundreds of years, so what’s the problem now?”

20. I’m attaching cost data for one of our projects, a case study of a branch library for The New York Public Library. Based on conversations with Wasau Windows and Arnold Glas regarding pricing for glass treated with frit or ultraviolet coating, at this time these products are priced at a 50% premium to conventional insulated glass. The case study illustrates how this factor would affect the overall cost of the building, assuming that all glass were treated. I am also sending a generic study provided by FXFowle’s project estimator. This study appears to document a building type such as a speculative office tower where the interior fit-out and finishes are omitted. I did not get clarification on the building type, but I’m sure Bruce Fowle would be happy to answer questions. Clearly, the current cost effects of fully treating speculative buildings of this type are high. This means that as focused treatment areas spur manufacturing innovation, then the cost should drop and allow for greater treated glass application and acceptance.

20. Our office designed a project with angled glass that has prompted repeated complaints from the director regarding bird strikes. Angling the glass does not change its fundamental qualities of refection and transparency. I suggest removing this from the text to prevent future public confusion.

21. A Public School and University program that used student art to create window decals & stencils would be fantastic!

21. External screens can also moderate glare and solar heat gain.  Always try to mention the up-side.

29. Equivalent glazing treatments should meet testing standards like other building materials.  I suggest noting that biologist recommendation and flight tunnel testing is required.

29. Glazing reflectivity measurements should follow industry standard terminology. I'm attaching PPG glass data that shows that "visible light reflectance" for clear uncoated glass is 15%.  Their Solarcool "mirrored" glass is 37%.  Based on the PPG chart, it looks like many energy coated choices are available that fall under 10% visible light reflectance, so perhaps this is a better place to set the bar.

29. I suggest setting footcandle levels for types of outdoor lighting, similar to LEED.  This will help guide designers.

33. Detailed maps of migratory stopover locations, dense urban context, and fog prone areas will need to be posted online.

33. An "appendix" with measurements or formulas for acceptable articulating modules will help people answer this question.  Otherwise it's too subjective.

33. Add "unbroken glass or butt-glazing at lower levels"

Thanks for the opportunity to comment on this important effort.

Deborah Laurel
Prendergast Laurel Architects
www.prendergast-laurel.com/

**Library Case Study: Conventional Insulated Glass**

| A | B | C | D | E | F | G | H | I | J | K1 | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Building Type** | **Site** | **Zoning** | **Area** | **# Flrs** | **Total Façade Area (S.F.)** | **Glass Window Area (SF)** | **Windows: Total Cost (Labor & Material)** | **Windows: Material Cost (60% of H)** | **Glass: Material Cost (15% of I)** | **Total Building Cost** | **Portion for Glass (J/K1)** |
| Public Library | Urban | Attached | 12,625 SF | 2 | 11,705 | 3084 | $428,000 | $256,800 | $38,520 | $11,350,000 | .34 % |
| | | | | | | | | | | | |

**Library Case Study: Glass with Frit or UV Coating**

| A | B | C | D | E | F | G | H2 | I2 | J2 | K2 | L |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Building Type** | **Site** | **Zoning** | **Area** | **# Flrs** | **Total Façade Area (S.F.)** | **Glass Window Area (SF)** | **Windows: Total Cost (Labor & Material)** | **Windows: Material Cost (60% of H2)** | **Glass: Material Cost (21.5% of I2)** | **Cost Increase (J x 1.5)** | **Increased Cost for Protected Glass (K2/K1)** |
| Public Library | Urban | Attached | 12,625 SF | 2 | 11,705 | 3084 | $447,260 | $268,356 | $57,780 | $19,260 | .18 % |

**TOSCANO CLEMENTS TAYLOR**

**RELATIVE COSTS OF USING ORNILUX GLASS, OR FRIT, IN NEW CONSTRUCTION**

| **BUILDING SIZE (GSF)** | **250,000 GSF** | **250,000 GSF** | **250,000 GSF** | **100,000 GSF** | **100,000 GSF** | **100,000 GSF** | **50,000 GSF** | **50,000 GSF** | **50,000 GSF** |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| PERCENTAGE OF GLAZING TO SOLID EXTERIOR WALL | 100.00% | 50.00% | 75.00% | 100.00% | 50.00% | 75.00% | 100.00% | 50.00% | 75.00% |
| | | | | | | | | | |
| COST OF GLAZING (Low E, double glazed units) | 14.00% | 7.00% | 10.50% | 16.00% | 8.00% | 12.00% | 18.00% | 9.00% | 13.50% |
| COST OF ALL OTHER BUILDING COMPONENTS AND SYSTEMS | 86.00% | 93.00% | 89.50% | 84.00% | 92.00% | 88.00% | 82.00% | 91.00% | 86.50% |
| TOTAL BUILDING COST | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| | | | | | | | | | |
| ADDITIONAL COST OF BIRD CONTROL GLAZING (FRIT OR ORNILUX) | 7.00% | 3.50% | 5.25% | 8.00% | 4.00% | 6.00% | 9.00% | 4.50% | 6.75% |

Notes:
Based on cost data at 4th Quarter 2010
Costs are for construction ony (excludes soft costs)
Costs are for buildings only - site costs are excluded

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12/01/2010

# PPG Monolithic Glass Comparisons

| Table of Performance Values[1] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Glass Thickness | | Transmittance[2] | | | Reflectance[2] | | (BTU/hr•ft²°F) NFRC U-Value[4] | | U-Value[5] EN 673 (W/m²*K) | Shading Coefficient[6] | Solar Heat Gain Coefficient[7] | Light to Solar Gain (LSG)[8] |
| Inches | mm | Ultra-violet % | Visible % | Total Solar Energy % | Visible Light % | Total Solar Energy % | Winter Night-time | Summer Day-time | | | | |
| **Uncoated** | | | | | | | | | | | | |
| ***STARPHIRE*® Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 88 | 91 | 90 | 8 | 8 | 1.03 | 0.93 | 5.78 | 1.04 | 0.90 | 1.01 |
| 1/4 | 6 | 87 | 91 | 89 | 8 | 8 | 1.02 | 0.93 | 5.75 | 1.03 | 0.90 | 1.01 |
| 5/16 | 8 | 86 | 91 | 88 | 8 | 8 | 1.01 | 0.91 | 5.68 | 1.02 | 0.89 | 1.02 |
| 3/8 | 10 | 85 | 91 | 87 | 8 | 8 | 1.00 | 0.91 | 5.63 | 1.02 | 0.89 | 1.02 |
| 1/2 | 12 | 83 | 90 | 86 | 8 | 8 | 0.98 | 0.89 | 5.53 | 1.01 | 0.88 | 1.03 |
| 5/8 | 16 | 81 | 90 | 84 | 8 | 8 | 0.97 | 0.88 | 5.43 | 1.00 | 0.87 | 1.03 |
| 3/4 | 19 | 80 | 90 | 83 | 8 | 7 | 0.95 | 0.86 | 5.34 | 0.99 | 0.86 | 1.04 |
| 1 | 25 | 77 | 89 | 80 | 8 | 7 | 0.92 | 0.84 | 5.16 | 0.97 | 0.84 | 1.06 |
| **CLEAR Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 69 | 89 | 79 | 9 | 7 | 1.03 | 0.93 | 5.78 | 0.96 | 0.83 | 1.07 |
| 1/4 | 6 | 66 | 89 | 77 | 9 | 7 | 1.02 | 0.93 | 5.75 | 0.94 | 0.81 | 1.09 |
| 5/16 | 8 | 61 | 88 | 72 | 8 | 7 | 1.01 | 0.91 | 5.68 | 0.90 | 0.78 | 1.12 |
| 3/8 | 10 | 58 | 87 | 69 | 8 | 7 | 1.00 | 0.91 | 5.63 | 0.88 | 0.76 | 1.14 |
| 1/2 | 12 | 53 | 85 | 64 | 8 | 6 | 0.98 | 0.89 | 5.53 | 0.84 | 0.72 | 1.18 |
| 5/8 | 16 | 48 | 84 | 59 | 8 | 6 | 0.97 | 0.88 | 5.43 | 0.80 | 0.69 | 1.22 |
| 3/4 | 19 | 46 | 83 | 55 | 8 | 6 | 0.95 | 0.86 | 5.34 | 0.77 | 0.67 | 1.24 |
| 1 | 25 | 40 | 80 | 48 | 8 | 6 | 0.92 | 0.84 | 5.16 | 0.72 | 0.62 | 1.29 |
| ***OPTIBLUE*® Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 44 | 64 | 64 | 6 | 6 | 1.02 | 0.93 | 5.75 | 0.84 | 0.72 | 0.89 |
| ***SOLEXIA*™ Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 35 | 80 | 52 | 8 | 6 | 1.03 | 0.93 | 5.78 | 0.75 | 0.64 | 1.24 |
| 1/4 | 6 | 31 | 77 | 47 | 8 | 6 | 1.02 | 0.93 | 5.75 | 0.71 | 0.61 | 1.26 |
| ***ATLANTICA*™ Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 20 | 71 | 39 | 7 | 5 | 1.03 | 0.93 | 5.78 | 0.65 | 0.56 | 1.27 |
| 1/4 | 6 | 16 | 67 | 34 | 7 | 5 | 1.02 | 0.93 | 5.75 | 0.61 | 0.52 | 1.29 |
| ***CARIBIA*® Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 28 | 71 | 37 | 7 | 5 | 1.03 | 0.93 | 5.78 | 0.63 | 0.54 | 1.32 |
| 1/4 | 6 | 24 | 68 | 32 | 7 | 5 | 1.02 | 0.93 | 5.75 | 0.60 | 0.51 | 1.33 |
| ***AZURIA*™ Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 46 | 72 | 36 | 7 | 5 | 1.03 | 0.93 | 5.78 | 0.62 | 0.54 | 1.33 |
| 1/4 | 6 | 42 | 68 | 32 | 7 | 5 | 1.02 | 0.93 | 5.75 | 0.59 | 0.51 | 1.34 |
| 5/16 | 8 | 35 | 61 | 26 | 6 | 5 | 1.01 | 0.91 | 5.68 | 0.55 | 0.47 | 1.30 |
| 3/8 | 10 | 31 | 57 | 23 | 6 | 5 | 1.00 | 0.91 | 5.63 | 0.53 | 0.45 | 1.26 |
| ***PACIFICA*™ Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 15 | 42 | 27 | 5 | 5 | 1.02 | 0.93 | 5.75 | 0.56 | 0.48 | 0.88 |
| ***SOLARBLUE*™ Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 31 | 56 | 47 | 6 | 5 | 1.02 | 0.93 | 5.75 | 0.71 | 0.61 | 0.92 |
| ***SOLARBRONZE*® Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 30 | 59 | 55 | 6 | 6 | 1.03 | 0.93 | 5.78 | 0.77 | 0.66 | 0.89 |
| 1/4 | 6 | 26 | 53 | 50 | 6 | 6 | 1.02 | 0.93 | 5.75 | 0.73 | 0.63 | 0.84 |
| 5/16 | 8 | 18 | 43 | 39 | 6 | 5 | 1.01 | 0.91 | 5.68 | 0.65 | 0.56 | 0.77 |
| 3/8 | 10 | 14 | 37 | 34 | 5 | 5 | 1.00 | 0.91 | 5.63 | 0.61 | 0.52 | 0.72 |
| 1/2 | 12 | 9 | 27 | 24 | 5 | 5 | 0.98 | 0.89 | 5.53 | 0.54 | 0.46 | 0.59 |
| ***SOLARGRAY*® Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 29 | 50 | 48 | 6 | 5 | 1.03 | 0.93 | 5.78 | 0.71 | 0.62 | 0.81 |
| 1/4 | 6 | 24 | 44 | 42 | 6 | 5 | 1.02 | 0.93 | 5.75 | 0.67 | 0.58 | 0.77 |
| 5/16 | 8 | 17 | 33 | 31 | 5 | 5 | 1.01 | 0.91 | 5.68 | 0.59 | 0.51 | 0.65 |
| 3/8 | 10 | 13 | 28 | 26 | 5 | 5 | 1.00 | 0.91 | 5.63 | 0.55 | 0.47 | 0.59 |
| 1/2 | 12 | 8 | 18 | 17 | 5 | 5 | 0.98 | 0.89 | 5.53 | 0.49 | 0.41 | 0.44 |
| ***OPTIGRAY*® 23 Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 8 | 23 | 19 | 5 | 5 | 1.02 | 0.93 | 5.75 | 0.50 | 0.42 | 0.55 |
| ***GRAYLITE*® Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 7 | 14 | 26 | 5 | 5 | 1.02 | 0.93 | 5.75 | 0.55 | 0.47 | 0.29 |

**Important glass design considerations and comprehensive technical information, including performance, thermal stress and wind load tools for all PPG glasses are available at www.ppgideascapes.com/glasstechnical. Monolithic Glass Data can also be found at www.ppgideascapes.com/glasstechnical or by calling 1-888-PPG-IDEA (1-888-774-4332).**

# PPG Monolithic Glass Comparisons

**Table of Performance Values*[1]**

| Glass Thickness | | Transmittance[2] | | | Reflectance[2] | | NFRC U-Value[4] (BTU/hr•ft²°F) | | U-Value[5] EN 673 (W/m²*K) | Shading Coefficient[6] | Solar Heat Gain Coefficient[7] | Light to Solar Gain (LSG)[8] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inches | mm | Ultra-violet % | Visible % | Total Solar Energy % | Visible Light % | Total Solar Energy % | Winter Night-time | Summer Day-time | | | | |
| **Coated** | | | | | | | | | | | | |
| ***VISTACOOL™ (2) AZURIA™* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 35 | 52 | 26 | 19 | 10 | 1.02 | 0.92 | 5.73 | 0.52 | 0.45 | 1.16 |
| 5/16 | 8 | 29 | 46 | 20 | 16 | 9 | 1.01 | 0.91 | 5.66 | 0.49 | 0.42 | 1.10 |
| ***VISTACOOL™ (2) CARIBIA®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 20 | 52 | 26 | 19 | 9 | 1.02 | 0.92 | 5.73 | 0.53 | 0.45 | 1.15 |
| 5/16 | 8 | 14 | 46 | 20 | 16 | 8 | 1.01 | 0.91 | 5.66 | 0.49 | 0.42 | 1.09 |
| ***VISTACOOL™ (2) PACIFICA™* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 12 | 32 | 22 | 10 | 7 | 1.02 | 0.93 | 5.75 | 0.51 | 0.44 | 0.74 |
| ***VISTACOOL™ (2) SOLARGRAY®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 20 | 34 | 35 | 11 | 8 | 1.02 | 0.92 | 5.73 | 0.60 | 0.52 | 0.65 |
| 5/16 | 8 | 14 | 26 | 26 | 8 | 7 | 1.01 | 0.91 | 5.66 | 0.54 | 0.46 | 0.55 |
| ***SOLARCOOL® (1) SOLEXIA™* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 9 | 30 | 23 | 37 | 30 | 1.03 | 0.93 | 5.75 | 0.43 | 0.37 | 0.80 |
| ***SOLARCOOL® (2) SOLEXIA™* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 9 | 30 | 23 | 23 | 12 | 1.03 | 0.93 | 5.78 | 0.50 | 0.43 | 0.69 |
| ***SOLARCOOL® (1) CARIBIA®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 7 | 26 | 14 | 36 | 30 | 1.03 | 0.93 | 5.75 | 0.36 | 0.31 | 0.83 |
| ***SOLARCOOL® (2) CARIBIA®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 7 | 26 | 14 | 19 | 9 | 1.03 | 0.93 | 5.78 | 0.44 | 0.38 | 0.68 |
| ***SOLARCOOL® (1) AZURIA™* Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 13 | 27 | 16 | 36 | 30 | 1.03 | 0.93 | 5.78 | 0.37 | 0.32 | 0.85 |
| 1/4 | 6 | 12 | 26 | 14 | 36 | 30 | 1.03 | 0.93 | 5.75 | 0.36 | 0.30 | 0.86 |
| ***SOLARCOOL® (2) AZURIA™* Glass** | | | | | | | | | | | | |
| 3/16 | 5 | 13 | 27 | 16 | 20 | 10 | 1.04 | 0.94 | 5.81 | 0.45 | 0.38 | 0.72 |
| 1/4 | 6 | 12 | 26 | 14 | 19 | 10 | 1.03 | 0.93 | 5.78 | 0.44 | 0.37 | 0.70 |
| ***SOLARCOOL® (1) PACIFICA™* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 4 | 16 | 13 | 36 | 30 | 1.02 | 0.93 | 5.75 | 0.35 | 0.30 | 0.53 |
| ***SOLARCOOL® (2) PACIFICA™* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 4 | 16 | 13 | 10 | 7 | 1.02 | 0.93 | 5.75 | 0.44 | 0.37 | 0.43 |
| ***SOLARCOOL® (1) SOLARBLUE™* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 9 | 21 | 24 | 36 | 30 | 1.02 | 0.93 | 5.75 | 0.44 | 0.38 | 0.57 |
| ***SOLARCOOL® (2) SOLARBLUE™* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 9 | 21 | 24 | 14 | 11 | 1.02 | 0.93 | 5.75 | 0.51 | 0.44 | 0.49 |
| ***SOLARCOOL® (1) SOLARBRONZE®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 7 | 21 | 27 | 36 | 30 | 1.03 | 0.93 | 5.75 | 0.46 | 0.40 | 0.52 |
| ***SOLARCOOL® (2) SOLARBRONZE®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 7 | 21 | 27 | 13 | 11 | 1.03 | 0.93 | 5.78 | 0.53 | 0.46 | 0.45 |
| ***SOLARCOOL® (1) SOLARGRAY®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 7 | 17 | 23 | 36 | 30 | 1.03 | 0.93 | 5.75 | 0.43 | 0.37 | 0.46 |
| ***SOLARCOOL® (2) SOLARGRAY®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | 7 | 17 | 23 | 11 | 9 | 1.03 | 0.93 | 5.78 | 0.51 | 0.43 | 0.40 |
| ***SOLARCOOL® (1) GRAYLITE®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | <1 | 3 | 4 | 36 | 30 | 1.03 | 0.93 | 5.75 | 0.29 | 0.24 | 0.14 |
| ***SOLARCOOL® (2) GRAYLITE®* Glass** | | | | | | | | | | | | |
| 1/4 | 6 | <1 | 3 | 4 | 5 | 4 | 1.03 | 0.93 | 5.78 | 0.39 | 0.33 | 0.10 |

* Performance data is based on representative samples of factory production. Actual values may vary slightly due to variations in the production process.

1. **Figures may vary due to manufacturing tolerances. All tabulated data is based on NFRC methodology using the LBNL's Window 5.2 software.**
2. Transmittance and reflectance values based on spectrophotometric measurements and energy distribution of solar radiation.
3. Solar infrared transmittance between 800 and 2150 nm (Parry Moon AM 2 irradiance).
4. **U-value** is the overall coefficient of heat transmittance or heat flow measured in BTU/hr. • ft² • °F. Lower U-values indicate better insulating performance. Winter nighttime U-values are calculated using an outdoor air temperature of 0°F (-17.8°C), indoor air temperature of of 70°F (21°C), outdoor air velocity of 15 mph (6.7 m/s), indoor air velocity of 0 mph (0 m/s) and a solar intensity of 0 BTU/hour/square foot (0 w/m²). Summer daytime U-values are calculated using an outdoor air temperature of 89°F (32°C), indoor air temperature of 75°F (24°C), outdoor air velocity of 7.5 mph (3.4 m/s), indoor air velocity of 0 mph (0 m/s), and a solar intensity of 248 BTU/hour/square foot (783 w/m²).
5. **European U-Value** is the overall coefficient of heat transmittance or heat flow measured in Watts/m² • °C, and is calculated using WinDat WIS version 3.0.1 software.
6. **Shading Coefficient** is the ratio of the total amount of solar energy that passes through a glass relative to 1/8-in. (3.0 mm) thick clear glass under the same design conditions. It includes both solar energy transmitted directly plus any absorbed solar energy re-radiated and converted. Lower shading coefficient values indicate better performance in reducing summer heat gain. Shading coefficients at outdoor air temperature of 89°F (32°C), outdoor air velocity of 7.5 mph (3.4 m/s), indoor air temperature of 75°F (24°C), indoor air velocity of 0 mph (0 m/s) and solar intensity of 248 BTU /hour/ square foot (783 w/m2).
7. **Solar Heat Gain Coefficient (SHGC)** represents the solar heat gain through the glass relative to the incident solar radiation. It is equal to 86% of the shading coefficient.
8. **Light to Solar Gain (LSG) ratio** is the ratio of visible light transmittance to solar heat gain coefficient.

One–inch insulating glass data and comparisons can be found at www.ppgideascapes.com or by calling the PPG Solutions Hotline at 1-888-774-4332.

For data on: *Solargreen®* Glass — see *Atlantica™* Glass
*Solex®* Glass — see *Solexia™* Glass
*Azurlite®* Glass — see *Azuria™* Glass



58311

# One-Inch Insulating Glass Unit Comparisons with PPG Glass

**Insulating Vision Unit Performance Comparisons** 1-inch (25mm) units with 1/2-inch (13mm) airspace and two 1/4-inch (6mm) lites; interior lite clear unless otherwise noted

| Glass Type — Outdoor Lite: Coating if Any (Surface) Glass + Indoor Lite: Coating if Any (Surface) Glass | Transmittance[2] Ultra-violet % | Transmittance[2] Visible % | Transmittance[2] Total Solar Energy % | Exterior Reflectance[2] Visible Light % | Exterior Reflectance[2] Total Solar Energy % | (BTU/hr•ft²°F) NFRC U-Value[3] Winter Night-time | (BTU/hr•ft²°F) NFRC U-Value[3] Summer Day-time | U-Value[4] EN 673 (W/m²*K) | Shading Coefficient[5] | Solar Heat Gain Coefficient[6] | Light to Solar Gain (LSG)[7] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Uncoated** | | | | | | | | | | | |
| Clear Glass + Clear | 50 | 79 | 61 | 15 | 12 | 0.47 | 0.50 | 2.81 | 0.81 | 0.70 | 1.13 |
| *STARPHIRE*® + *STARPHIRE* | 77 | 84 | 80 | 15 | 14 | 0.47 | 0.50 | 2.81 | 0.94 | 0.82 | 1.02 |
| *SOLEXIA*™ + Clear | 25 | 69 | 39 | 13 | 8 | 0.47 | 0.50 | 2.81 | 0.57 | 0.49 | 1.41 |
| *ATLANTICA*™ + Clear | 13 | 60 | 29 | 11 | 7 | 0.47 | 0.50 | 2.81 | 0.47 | 0.40 | 1.50 |
| *CARIBIA*® + Clear | 20 | 60 | 28 | 11 | 7 | 0.47 | 0.50 | 2.81 | 0.45 | 0.39 | 1.55 |
| *AZURIA*™ + Clear | 34 | 61 | 28 | 11 | 7 | 0.47 | 0.50 | 2.81 | 0.45 | 0.39 | 1.56 |
| *PACIFICA*™ + Clear | 12 | 38 | 23 | 7 | 6 | 0.47 | 0.50 | 2.81 | 0.41 | 0.35 | 1.07 |
| *SOLARBLUE*™ + Clear | 25 | 50 | 37 | 9 | 7 | 0.47 | 0.50 | 2.81 | 0.56 | 0.49 | 1.03 |
| *SOLARBRONZE*® + Clear | 21 | 47 | 39 | 8 | 7 | 0.47 | 0.50 | 2.81 | 0.59 | 0.51 | 0.93 |
| *SOLARGRAY*® + Clear | 20 | 40 | 33 | 7 | 7 | 0.47 | 0.50 | 2.81 | 0.53 | 0.45 | 0.88 |
| *OPTIGRAY*® 23 + Clear | 6 | 21 | 15 | 6 | 5 | 0.47 | 0.50 | 2.81 | 0.34 | 0.29 | 0.71 |
| *GRAYLITE*® + Clear | 6 | 12 | 19 | 5 | 5 | 0.47 | 0.50 | 2.81 | 0.39 | 0.34 | 0.36 |
| **Coated** | | | | | | | | | | | |
| ***SUNGATE*® 500 Low-E Glass** | | | | | | | | | | | |
| *SUNGATE* 500 (2) + Clear | 42 | 74 | 52 | 17 | 14 | 0.35 | 0.35 | 1.96 | 0.71 | 0.62 | 1.19 |
| *SOLEXIA* + *SUNGATE* 500 (3) Clear | 21 | 64 | 33 | 14 | 9 | 0.35 | 0.35 | 1.96 | 0.51 | 0.44 | 1.45 |
| *ATLANTICA* + *SUNGATE* 500 (3) Clear | 11 | 56 | 25 | 12 | 7 | 0.35 | 0.35 | 1.96 | 0.41 | 0.35 | 1.60 |
| *CARIBIA* + *SUNGATE* 500 (3) Clear | 17 | 56 | 24 | 12 | 7 | 0.35 | 0.35 | 1.96 | 0.40 | 0.34 | 1.65 |
| *AZURIA* + *SUNGATE* 500 (3) Clear | 29 | 57 | 24 | 12 | 7 | 0.35 | 0.35 | 1.96 | 0.40 | 0.34 | 1.66 |
| *PACIFICA* + *SUNGATE* 500 (3) Clear | 10 | 35 | 19 | 7 | 6 | 0.35 | 0.35 | 1.96 | 0.35 | 0.30 | 1.16 |
| *SOLARBLUE* + *SUNGATE* 500 (3) Clear | 21 | 46 | 32 | 10 | 9 | 0.35 | 0.35 | 1.96 | 0.51 | 0.44 | 1.06 |
| *SOLARBRONZE* + *SUNGATE* 500 (3) Clear | 18 | 44 | 33 | 9 | 9 | 0.35 | 0.35 | 1.96 | 0.53 | 0.46 | 0.96 |
| *SOLARGRAY* + *SUNGATE* 500 (3) Clear | 17 | 37 | 28 | 8 | 8 | 0.35 | 0.35 | 1.96 | 0.47 | 0.40 | 0.92 |
| *OPTIGRAY* 23 + *SUNGATE* 500 (3) Clear | 6 | 19 | 13 | 6 | 6 | 0.35 | 0.35 | 1.96 | 0.28 | 0.24 | 0.80 |
| *GRAYLITE* + *SUNGATE* 500 (3) Clear | 5 | 11 | 16 | 5 | 6 | 0.35 | 0.35 | 1.96 | 0.33 | 0.28 | 0.41 |
| ***SOLARBAN*® 60 Solar Control Low-E Glass** | | | | | | | | | | | |
| *SOLARBAN* 60 (2) *STARPHIRE* + *STARPHIRE* | 25 | 74 | 38 | 11 | 43 | 0.29 | 0.27 | 1.55 | 0.46 | 0.40 | 1.85 |
| *SOLARBAN* 60 (2) Clear + Clear | 19 | 70 | 33 | 11 | 29 | 0.29 | 0.27 | 1.55 | 0.44 | 0.38 | 1.85 |
| *SOLARBAN* 60 (2) *ATLANTICA* + Clear | 5 | 54 | 20 | 8 | 7 | 0.29 | 0.27 | 1.55 | 0.31 | 0.27 | 1.98 |
| *SOLARBAN* 60 (2) *AZURIA* + Clear | 13 | 54 | 21 | 8 | 7 | 0.29 | 0.27 | 1.55 | 0.32 | 0.28 | 1.93 |
| *SOLARBAN* 60 (2) *CARIBIA* + Clear | 8 | 54 | 20 | 8 | 4 | 0.29 | 0.27 | 1.55 | 0.31 | 0.27 | 1.99 |
| *SOLARBAN* 60 (2) *SOLEXIA* + Clear | 10 | 61 | 25 | 10 | 11 | 0.29 | 0.27 | 1.55 | 0.36 | 0.32 | 1.92 |
| *SOLARBAN* 60 (2) *PACIFICA* + Clear | 5 | 34 | 15 | 6 | 7 | 0.29 | 0.27 | 1.55 | 0.26 | 0.22 | 1.52 |
| *SOLARBAN* 60 (2) *SOLARBLUE* + Clear | 10 | 45 | 21 | 7 | 13 | 0.29 | 0.27 | 1.55 | 0.32 | 0.28 | 1.60 |
| *SOLARBAN* 60 (2) *SOLARBRONZE* + Clear | 8 | 42 | 20 | 7 | 16 | 0.29 | 0.27 | 1.55 | 0.31 | 0.27 | 1.56 |
| *SOLARBAN* 60 (2) *SOLARGRAY* + Clear | 8 | 35 | 17 | 6 | 12 | 0.29 | 0.27 | 1.55 | 0.28 | 0.24 | 1.47 |
| *SOLEXIA* + *SOLARBAN* 60 (3) Clear | 10 | 61 | 25 | 11 | 11 | 0.29 | 0.27 | 1.55 | 0.42 | 0.36 | 1.70 |
| *ATLANTICA* + *SOLARBAN* 60 (3) Clear | 5 | 53 | 20 | 9 | 7 | 0.29 | 0.27 | 1.55 | 0.35 | 0.30 | 1.78 |
| *CARIBIA* + *SOLARBAN* 60 (3) Clear | 8 | 54 | 20 | 9 | 7 | 0.29 | 0.27 | 1.55 | 0.35 | 0.31 | 1.74 |
| *AZURIA* + *SOLARBAN* 60 (3) Clear | 13 | 54 | 21 | 9 | 7 | 0.29 | 0.27 | 1.55 | 0.36 | 0.31 | 1.75 |
| *PACIFICA* + *SOLARBAN* 60 (3) Clear | 5 | 34 | 15 | 6 | 7 | 0.29 | 0.27 | 1.55 | 0.29 | 0.25 | 1.36 |
| *SOLARBLUE* + *SOLARBAN* 60 (3) Clear | 10 | 45 | 21 | 8 | 13 | 0.29 | 0.27 | 1.55 | 0.37 | 0.32 | 1.39 |
| *SOLARBRONZE* + *SOLARBAN* 60 (3) Clear | 8 | 42 | 20 | 7 | 17 | 0.29 | 0.27 | 1.55 | 0.36 | 0.31 | 1.36 |
| *SOLARGRAY* + *SOLARBAN* 60 (3) Clear | 8 | 35 | 17 | 7 | 13 | 0.29 | 0.27 | 1.55 | 0.32 | 0.28 | 1.26 |
| *OPTIGRAY* 23 + *SOLARBAN* 60 (3) Clear | 3 | 18 | 9 | 5 | 6 | 0.29 | 0.27 | 1.55 | 0.21 | 0.18 | 1.02 |
| *GRAYLITE* + *SOLARBAN* 60 (3) Clear | 2 | 11 | 7 | 5 | 10 | 0.29 | 0.27 | 1.55 | 0.20 | 0.17 | 0.64 |
| **SOLARBAN® 70XL Solar Control Low-E Glass †** | | | | | | | | | | | |
| *SOLARBAN* 70XL (2) + Clear | 6 | 64 | 25 | 12 | 52 | 0.28 | 0.26 | 1.50 | 0.32 | 0.27 | 2.37 |
| *SOLARBAN* 70XL (2) *SOLEXIA* + Clear | 3 | 54 | 19 | 10 | 12 | 0.28 | 0.26 | 1.50 | 0.29 | 0.25 | 2.18 |
| *SOLARBAN* 70XL (2) ATLANTICA + Clear | 2 | 48 | 16 | 9 | 8 | 0.28 | 0.26 | 1.50 | 0.26 | 0.23 | 2.07 |
| *SOLARBAN* 70XL (2) *CARIBIA* + Clear | 2 | 48 | 16 | 9 | 7 | 0.28 | 0.26 | 1.50 | 0.27 | 0.23 | 2.07 |
| *SOLARBAN* 70XL (2) *AZURIA* + Clear | 4 | 48 | 17 | 9 | 7 | 0.28 | 0.26 | 1.50 | 0.27 | 0.23 | 2.09 |
| *SOLARBAN* 70XL (2) *PACIFICA* + Clear | 1 | 30 | 11 | 6 | 7 | 0.28 | 0.26 | 1.50 | 0.21 | 0.18 | 1.63 |
| *SOLARBAN* 70XL (2) *SOLARBLUE* + Clear | 3 | 40 | 15 | 7 | 15 | 0.28 | 0.26 | 1.50 | 0.25 | 0.21 | 1.84 |
| *SOLARBAN* 70XL (2) *SOLARBRONZE* + Clear | 2 | 37 | 14 | 7 | 19 | 0.28 | 0.26 | 1.50 | 0.23 | 0.20 | 1.87 |
| *SOLARBAN* 70XL (2) *SOLARGRAY* + Clear | 2 | 31 | 12 | 7 | 15 | 0.28 | 0.26 | 1.50 | 0.22 | 0.19 | 1.65 |
| *SOLEXIA* + *SOLARBAN* 70XL (3) | 3 | 56 | 20 | 11 | 13 | 0.28 | 0.26 | 1.50 | 0.37 | 0.32 | 1.74 |
| *ATLANTICA* + *SOLARBAN* 70XL (3) | 2 | 49 | 17 | 10 | 8 | 0.28 | 0.26 | 1.50 | 0.32 | 0.28 | 1.74 |
| *CARIBIA* + *SOLARBAN* 70XL (3) | 2 | 49 | 17 | 9 | 8 | 0.28 | 0.26 | 1.50 | 0.32 | 0.28 | 1.75 |
| *AZURIA* + *SOLARBAN* 70XL (3) | 4 | 49 | 17 | 10 | 8 | 0.28 | 0.26 | 1.50 | 0.33 | 0.29 | 1.70 |
| *PACIFICA* + *SOLARBAN* 70XL (3) | 2 | 31 | 12 | 6 | 7 | 0.28 | 0.26 | 1.50 | 0.26 | 0.22 | 1.30 |
| *SOLARBLUE* + *SOLARBAN* 70XL (3) | 3 | 41 | 16 | 8 | 16 | 0.28 | 0.26 | 1.50 | 0.32 | 0.27 | 1.48 |
| *SOLARBRONZE* + *SOLARBAN* 70XL (3) | 3 | 38 | 15 | 8 | 20 | 0.28 | 0.26 | 1.50 | 0.30 | 0.26 | 1.48 |
| *SOLARGRAY* + *SOLARBAN* 70XL (3) | 2 | 32 | 13 | 7 | 15 | 0.28 | 0.26 | 1.50 | 0.27 | 0.24 | 1.34 |
| *OPTIGRAY* 23 + *SOLARBAN* 70XL (3) | 1 | 17 | 7 | 5 | 7 | 0.28 | 0.26 | 1.50 | 0.19 | 0.16 | 1.04 |
| *GRAYLITE* + *SOLARBAN* 70XL (3) | 1 | 10 | 5 | 5 | 11 | 0.28 | 0.26 | 1.50 | 0.16 | 0.14 | 0.71 |

# One-Inch Insulating Glass Unit Comparisons with PPG Glass

**Insulating Vision Unit Performance Comparisons** 1-inch (25mm) units with 1/2-inch (13mm) airspace and two 1/4-inch (6mm) lites; interior lite clear unless otherwise noted

| Glass Type — Outdoor Lite: Coating if Any (Surface) Glass + Indoor Lite: Coating if Any (Surface) Glass | Transmittance[2] Ultra-violet % | Transmittance[2] Visible % | Transmittance[2] Total Solar Energy % | Exterior Reflectance[2] Visible Light % | Exterior Reflectance[2] Total Solar Energy % | (BTU/hr•ft²°F) NFRC U-Value[3] Winter Night-time | (BTU/hr•ft²°F) NFRC U-Value[3] Summer Day-time | U-Value[4] EN 673 (W/m²*K) | Shading Coeffi-cient[5] | Solar Heat Gain Coeffi-cient[6] | Light to Solar Gain (LSG)[7] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Coated** | | | | | | | | | | | |
| ***SOLARBAN*® 80 Solar Control Low-E Glass** | | | | | | | | | | | |
| *SOLARBAN* 80 (2) Clear + Clear | 13 | 48 | 20 | 33 | 38 | 0.29 | 0.27 | 1.52 | 0.28 | 0.24 | 1.98 |
| *SOLARBAN* 80 (2) Clear + *OPTIBLUE*†† | 10 | 34 | 15 | 32 | 38 | 0.29 | 0.27 | 1.52 | 0.27 | 0.23 | 1.48 |
| *SOLARBAN* 80 (2) *OPTIBLUE* + Clear | 9 | 34 | 15 | 19 | 28 | 0.29 | 0.27 | 1.52 | 0.23 | 0.20 | 1.70 |
| *SOLARBAN* 80 (2) *OPTIBLUE* + *OPTIBLUE* | 7 | 25 | 11 | 19 | 28 | 0.29 | 0.27 | 1.52 | 0.23 | 0.20 | 1.23 |
| ***SOLARBAN*® z50 Solar Control Low-E Glass††** | | | | | | | | | | | |
| *SOLARBAN* z50 (2) *OPTIBLUE* + Clear | 14 | 51 | 26 | 8 | 23 | 0.29 | 0.27 | 1.55 | 0.36 | 0.31 | 1.64 |
| *SOLARBAN* z50 (2) *OPTIBLUE* + *OPTIBLUE* | 11 | 37 | 20 | 7 | 23 | 0.29 | 0.27 | 1.55 | 0.35 | 0.31 | 1.18 |
| *AZURIA* + *SOLARBAN* z50 (3) *OPTIBLUE* | 10 | 39 | 16 | 8 | 7 | 0.29 | 0.27 | 1.55 | 0.35 | 0.30 | 1.31 |
| *ATLANTICA* + *SOLARBAN* z50 (3) *OPTIBLUE* | 4 | 39 | 15 | 8 | 7 | 0.29 | 0.27 | 1.55 | 0.34 | 0.30 | 1.28 |
| *CARIBIA* +*SOLARBAN* z50 (3) *OPTIBLUE* | 6 | 39 | 15 | 8 | 7 | 0.29 | 0.27 | 1.55 | 0.34 | 0.30 | 1.29 |
| *SOLEXIA* + *SOLARBAN* z50 (3) *OPTIBLUE* | 8 | 44 | 19 | 10 | 11 | 0.29 | 0.27 | 1.55 | 0.41 | 0.35 | 1.26 |
| *PACIFICA* + *SOLARBAN* z50 (3) *OPTIBLUE* | 4 | 25 | 12 | 6 | 7 | 0.29 | 0.27 | 1.55 | 0.28 | 0.24 | 1.01 |
| *SOLARBLUE* + *SOLARBAN* z50 (3) *OPTIBLUE* | 8 | 32 | 17 | 7 | 13 | 0.29 | 0.27 | 1.55 | 0.36 | 0.31 | 1.03 |
| *SOLARBRONZE* + *SOLARBAN* z50 (3) *OPTIBLUE* | 7 | 30 | 16 | 7 | 17 | 0.29 | 0.27 | 1.55 | 0.35 | 0.31 | 0.98 |
| *SOLARGRAY* + *SOLARBAN* z50 (3) *OPTIBLUE* | 6 | 25 | 14 | 6 | 13 | 0.29 | 0.27 | 1.55 | 0.32 | 0.28 | 0.91 |
| ***SOLARBAN*® R100 Solar Control Low-E Glass** | | | | | | | | | | | |
| *SOLARBAN* R100 (2) + Clear | 12 | 42 | 19 | 32 | 41 | 0.29 | 0.27 | 1.55 | 0.27 | 0.23 | 1.79 |
| *SOLARBAN* R100 (2) *STARPHIRE* + *STARPHIRE* | 16 | 44 | 21 | 33 | 57 | 0.29 | 0.27 | 1.55 | 0.27 | 0.23 | 1.87 |
| *SOLARBAN* R100 (2) *AZURIA* + Clear | 8 | 32 | 12 | 21 | 11 | 0.29 | 0.27 | 1.55 | 0.22 | 0.19 | 1.66 |
| *SOLARBAN* R100 (2) *ATLANTICA* + Clear | 3 | 31 | 12 | 20 | 11 | 0.29 | 0.27 | 1.55 | 0.22 | 0.19 | 1.67 |
| *SOLARBAN* R100 (2) *CARIBIA* + Clear | 5 | 32 | 12 | 20 | 11 | 0.29 | 0.27 | 1.55 | 0.22 | 0.19 | 1.67 |
| *SOLARBAN* R100 (2) *SOLEXIA* + Clear | 6 | 36 | 15 | 25 | 17 | 0.29 | 0.27 | 1.55 | 0.24 | 0.21 | 1.72 |
| *SOLARBAN* R100 (2) *OPTIBLUE* + Clear | 8 | 30 | 14 | 19 | 31 | 0.29 | 0.27 | 1.55 | 0.23 | 0.20 | 1.50 |
| *SOLARBAN* R100 (2) *PACIFICA* + Clear | 3 | 20 | 9 | 11 | 9 | 0.29 | 0.27 | 1.55 | 0.19 | 0.16 | 1.24 |
| *SOLARBAN* R100 (2) *SOLARBLUE* + Clear | 6 | 26 | 12 | 15 | 17 | 0.29 | 0.27 | 1.55 | 0.22 | 0.19 | 1.40 |
| *SOLARBAN* R100 (2) *SOLARBRONZE* + Clear | 5 | 25 | 11 | 15 | 20 | 0.29 | 0.27 | 1.55 | 0.21 | 0.18 | 1.38 |
| *SOLARBAN* R100 (2) *SOLARGRAY* + Clear | 5 | 21 | 10 | 12 | 16 | 0.29 | 0.27 | 1.55 | 0.19 | 0.17 | 1.23 |
| ***VISTACOOL*™ Subtly Reflective Glass** | | | | | | | | | | | |
| *VISTACOOL* (2) *AZURIA* + Clear | 29 | 47 | 22 | 21 | 11 | 0.47 | 0.50 | 2.81 | 0.39 | 0.34 | 1.39 |
| *VISTACOOL* (2) *CARIBIA* + Clear | 16 | 47 | 22 | 21 | 10 | 0.47 | 0.50 | 2.81 | 0.39 | 0.34 | 1.38 |
| *VISTACOOL* (2) *PACIFICA* + Clear | 10 | 29 | 19 | 11 | 8 | 0.47 | 0.50 | 2.81 | 0.37 | 0.31 | 0.93 |
| *VISTACOOL* (2) *SOLARGRAY* + Clear | 17 | 31 | 28 | 17 | 9 | 0.47 | 0.50 | 2.81 | 0.47 | 0.40 | 0.77 |
| ***SOLARCOOL*® Reflective Glass** | | | | | | | | | | | |
| *SOLARCOOL* (1) *SOLEXIA* + Clear | 7 | 27 | 18 | 37 | 31 | 0.47 | 0.50 | 2.81 | 0.32 | 0.28 | 0.96 |
| *SOLARCOOL* (2) *SOLEXIA* + Clear | 7 | 27 | 19 | 24 | 12 | 0.48 | 0.50 | 2.82 | 0.36 | 0.31 | 0.87 |
| *SOLARCOOL* (1) *CARIBIA* + Clear | 6 | 23 | 12 | 37 | 30 | 0.47 | 0.50 | 2.81 | 0.25 | 0.22 | 1.05 |
| *SOLARCOOL* (2) *CARIBIA* + Clear | 6 | 24 | 12 | 19 | 9 | 0.48 | 0.50 | 2.82 | 0.30 | 0.25 | 0.94 |
| *SOLARCOOL* (1) *AZURIA* + Clear | 10 | 23 | 11 | 37 | 30 | 0.47 | 0.50 | 2.81 | 0.25 | 0.21 | 1.10 |
| *SOLARCOOL* (2) *AZURIA* + Clear | 10 | 24 | 12 | 20 | 10 | 0.48 | 0.50 | 2.82 | 0.29 | 0.25 | 0.95 |
| *SOLARCOOL* (1) *PACIFICA* + Clear | 4 | 14 | 10 | 36 | 30 | 0.47 | 0.50 | 2.81 | 0.24 | 0.21 | 0.69 |
| *SOLARCOOL* (2) *PACIFICA* + Clear | 4 | 15 | 11 | 10 | 7 | 0.47 | 0.50 | 2.81 | 0.29 | 0.25 | 0.59 |
| *SOLARCOOL* (1) *SOLARBLUE* + Clear | 7 | 19 | 19 | 37 | 31 | 0.47 | 0.50 | 2.81 | 0.33 | 0.28 | 0.67 |
| *SOLARCOOL* (2) *SOLARBLUE* + Clear | 7 | 20 | 19 | 15 | 11 | 0.47 | 0.50 | 2.81 | 0.37 | 0.32 | 0.61 |
| *SOLARCOOL* (1) *SOLARBRONZE* + Clear | 6 | 18 | 21 | 37 | 31 | 0.47 | 0.50 | 2.81 | 0.35 | 0.31 | 0.59 |
| *SOLARCOOL* (2) *SOLARBRONZE* + Clear | 6 | 19 | 21 | 14 | 12 | 0.48 | 0.50 | 2.82 | 0.40 | 0.34 | 0.55 |
| *SOLARCOOL* (1) *SOLARGRAY* + Clear | 6 | 15 | 17 | 37 | 30 | 0.47 | 0.50 | 2.81 | 0.32 | 0.27 | 0.57 |
| *SOLARCOOL* (2) *SOLARGRAY* + Clear | 6 | 16 | 18 | 11 | 10 | 0.48 | 0.50 | 2.82 | 0.36 | 0.31 | 0.50 |
| *SOLARCOOL* (1) *GRAYLITE* + Clear | <1 | 3 | 4 | 36 | 30 | 0.47 | 0.50 | 2.81 | 0.17 | 0.14 | 0.21 |
| *SOLARCOOL* (2) *GRAYLITE* + Clear | 1 | 3 | 4 | 5 | 4 | 0.48 | 0.50 | 2.82 | 0.22 | 0.19 | 0.17 |
| ***VISTACOOL*™ and *SOLARCOOL*® with *SUNGATE*® 500 Low-E (3)** | | | | | | | | | | | |
| *VISTACOOL* (2) *AZURIA* + *SUNGATE* 500 (3) Clear | 24 | 44 | 19 | 22 | 11 | 0.35 | 0.35 | 1.96 | 0.34 | 0.29 | 1.53 |
| *VISTACOOL* (2) *CARIBIA* + *SUNGATE* 500 (3) Clear | 14 | 44 | 19 | 22 | 11 | 0.35 | 0.35 | 1.96 | 0.34 | 0.29 | 1.51 |
| *VISTACOOL* (2) *PACIFICA* + *SUNGATE* 500 (3) Clear | 9 | 27 | 16 | 11 | 8 | 0.35 | 0.35 | 1.96 | 0.31 | 0.27 | 1.03 |
| *VISTACOOL* (2) *SOLARGRAY* + *SUNGATE* 500 (3) Clear | 14 | 29 | 23 | 12 | 10 | 0.35 | 0.35 | 1.96 | 0.41 | 0.35 | 0.83 |
| *SOLARCOOL* (2) *PACIFICA* + *SUNGATE* 500 (3) Clear | 3 | 14 | 9 | 10 | 7 | 0.35 | 0.35 | 1.96 | 0.23 | 0.20 | 0.70 |
| *SOLARCOOL* (2) *SOLEXIA* + *SUNGATE* 500 (3) Clear | 6 | 25 | 15 | 24 | 13 | 0.35 | 0.35 | 1.96 | 0.31 | 0.26 | 0.98 |
| *SOLARCOOL* (2) *CARIBIA* + *SUNGATE* 500 (3) Clear | 5 | 22 | 10 | 19 | 10 | 0.35 | 0.35 | 1.96 | 0.24 | 0.20 | 1.11 |
| *SOLARCOOL* (2) *AZURIA* + *SUNGATE* 500 (3) Clear | 8 | 22 | 10 | 20 | 10 | 0.35 | 0.35 | 1.96 | 0.23 | 0.20 | 1.11 |
| *SOLARCOOL* (2) *SOLARBLUE* + *SUNGATE* 500 (3) Clear | 6 | 18 | 15 | 15 | 12 | 0.35 | 0.35 | 1.96 | 0.32 | 0.27 | 0.67 |
| *SOLARCOOL* (2) *SOLARBRONZE* + *SUNGATE* 500 (3) Clear | 5 | 18 | 17 | 14 | 13 | 0.35 | 0.35 | 1.96 | 0.34 | 0.29 | 0.61 |
| *SOLARCOOL* (2) *SOLARGRAY* + *SUNGATE* 500 (3) Clear | 5 | 15 | 14 | 11 | 10 | 0.35 | 0.35 | 1.96 | 0.30 | 0.26 | 0.56 |
| *SOLARCOOL* (2) *GRAYLITE* + *SUNGATE* 500 (3) Clear | <1 | 3 | 3 | 5 | 5 | 0.35 | 0.35 | 1.96 | 0.16 | 0.14 | 0.21 |



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**Insulating Vision Unit Performance Comparisons** — 1-inch (25mm) units with 1/2-inch (13mm) airspace and two 1/4-inch (6mm) lites; interior lite clear unless otherwise noted

| Glass Type — Outdoor Lite: Coating if Any (Surface) Glass + Indoor Lite: Coating if Any (Surface) Glass | Transmittance[2] | | | Exterior Reflectance[2] | | NFRC U-Value[3] (BTU/hr•ft²°F) | | U-Value[4] EN 673 (W/m²*K) | Shading Coefficient[5] | Solar Heat Gain Coefficient[6] | Light to Solar Gain (LSG)[7] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ultra-violet % | Visible % | Total Solar Energy % | Visible Light % | Total Solar Energy % | Winter Night-time | Summer Day-time | | | | |
| **Coated** | | | | | | | | | | | |
| ***VISTACOOL***™ and ***SOLARCOOL***® with ***SOLARBAN***® 60 Solar Control Low-E (3) | | | | | | | | | | | |
| *VISTACOOL* (2) *AZURIA* + *SOLARBAN* 60 (3) Clear | 11 | 42 | 16 | 20 | 11 | 0.29 | 0.27 | 1.55 | 0.30 | 0.26 | 1.61 |
| *VISTACOOL* (2) *CARIBIA* + *SOLARBAN* 60 (3) Clear | 7 | 42 | 16 | 20 | 11 | 0.29 | 0.27 | 1.55 | 0.29 | 0.25 | 1.66 |
| *VISTACOOL* (2) *PACIFICA* + *SOLARBAN* 60 (3) Clear | 4 | 26 | 12 | 11 | 9 | 0.29 | 0.27 | 1.55 | 0.24 | 0.21 | 1.23 |
| *VISTACOOL* (2) *SOLARGRAY* +*SOLARBAN* 60 (3) Clear | 7 | 27 | 14 | 11 | 15 | 0.29 | 0.27 | 1.55 | 0.28 | 0.24 | 1.13 |
| *SOLARCOOL* (2) *PACIFICA* + *SOLARBAN* 60 (3) Clear | 2 | 13 | 6 | 10 | 8 | 0.29 | 0.27 | 1.55 | 0.17 | 0.15 | 0.89 |
| *SOLARCOOL* (2) *SOLEXIA* + *SOLARBAN* 60 (3) Clear | 3 | 24 | 10 | 24 | 15 | 0.29 | 0.27 | 1.55 | 0.22 | 0.19 | 1.26 |
| *SOLARCOOL* (2) *CARIBIA* + *SOLARBAN* 60 (3) Clear | 2 | 21 | 8 | 19 | 10 | 0.29 | 0.27 | 1.55 | 0.19 | 0.16 | 1.30 |
| *SOLARCOOL* (2) *AZURIA* + *SOLARBAN* 60 (3) Clear | 4 | 21 | 8 | 19 | 10 | 0.29 | 0.27 | 1.55 | 0.19 | 0.16 | 1.31 |
| *SOLARCOOL* (2) *SOLARBLUE* + *SOLARBAN* 60 (3) Clear | 3 | 17 | 9 | 14 | 15 | 0.29 | 0.27 | 1.55 | 0.21 | 0.18 | 0.97 |
| *SOLARCOOL* (2) *SOLARBRONZE* +*SOLARBAN* 60 (3) Clear | 3 | 17 | 9 | 14 | 18 | 0.29 | 0.27 | 1.55 | 0.21 | 0.18 | 0.92 |
| *SOLARCOOL* (2) *SOLARGRAY* + *SOLARBAN* 60 (3) Clear | 2 | 14 | 7 | 11 | 14 | 0.29 | 0.27 | 1.55 | 0.19 | 0.16 | 0.86 |
| *SOLARCOOL* (2) *GRAYLITE* + *SOLARBAN* 60 (3) Clear | <1 | 3 | 2 | 5 | 5 | 0.29 | 0.27 | 1.55 | 0.12 | 0.10 | 0.28 |
| ***VISTACOOL***™ and ***SOLARCOOL***® with ***SOLARBAN***® z50 Solar Control Low-E | | | | | | | | | | | |
| *VISTACOOL* (2) *AZURIA* + *SOLARBAN* z50 (3) *OPTIBLUE* | 9 | 30 | 12 | 20 | 11 | 0.29 | 0.27 | 1.55 | 0.29 | 0.25 | 1.20 |
| *VISTACOOL* (2) *CARIBIA* + *SOLARBAN* z50 (3) *OPTIBLUE* | 5 | 30 | 12 | 20 | 11 | 0.29 | 0.27 | 1.55 | 0.29 | 0.25 | 1.20 |
| *VISTACOOL* (2) *PACIFICA* + *SOLARBAN* z50 (3) *OPTIBLUE* | 4 | 19 | 9 | 11 | 9 | 0.29 | 0.27 | 1.55 | 0.24 | 0.21 | 0.91 |
| *VISTACOOL* (2) *SOLARGRAY* + *SOLARBAN* z50 (3) *OPTIBLUE* | 5 | 20 | 11 | 11 | 15 | 0.29 | 0.27 | 1.55 | 0.27 | 0.24 | 0.82 |
| *SOLARCOOL* (2) *PACIFICA* + *SOLARBAN* z50 (3) *OPTIBLUE* | 1 | 9 | 4 | 10 | 8 | 0.29 | 0.27 | 1.55 | 0.17 | 0.14 | 0.65 |
| *SOLARCOOL* (2) *SOLARBLUE* + *SOLARBAN* z50 (3) *OPTIBLUE* | 2 | 12 | 7 | 14 | 15 | 0.29 | 0.27 | 1.55 | 0.20 | 0.17 | 0.71 |
| *SOLARCOOL* (2) *GRAYLITE* + *SOLARBAN* z50 (3) *OPTIBLUE* | <1 | 2 | 1 | 5 | 5 | 0.29 | 0.27 | 1.55 | 0.12 | 0.10 | 0.20 |
| ***VISTACOOL***™ and ***SOLARCOOL***® with ***SOLARBAN***® 70XL Solar Control Low-E (3) † | | | | | | | | | | | |
| *VISTACOOL* (2) *AZURIA* + *SOLARBAN* 70XL (3) | 4 | 38 | 14 | 21 | 12 | 0.28 | 0.26 | 1.50 | 0.27 | 0.24 | 1.59 |
| *VISTACOOL* (2) *CARIBIA* +*SOLARBAN* 70XL (3) | 2 | 38 | 13 | 20 | 11 | 0.28 | 0.26 | 1.50 | 0.27 | 0.23 | 1.65 |
| *VISTACOOL* (2) *PACIFICA* + *SOLARBAN* 70XL (3) | 1 | 24 | 9 | 11 | 9 | 0.28 | 0.26 | 1.50 | 0.22 | 0.19 | 1.24 |
| *VISTACOOL* (2) *SOLARGRAY* + *SOLARBAN* 70XL (3) | 2 | 25 | 10 | 11 | 17 | 0.28 | 0.26 | 1.50 | 0.23 | 0.20 | 1.24 |
| *SOLARCOOL* (2) *SOLEXIA* + *SOLARBAN* 70XL (3) | 1 | 22 | 8 | 24 | 16 | 0.28 | 0.26 | 1.50 | 0.20 | 0.17 | 1.28 |
| *SOLARCOOL* (2) *CARIBIA* + *SOLARBAN* 70XL (3) | 1 | 19 | 6 | 19 | 10 | 0.28 | 0.26 | 1.50 | 0.18 | 0.15 | 1.27 |
| *SOLARCOOL* (2) *AZURIA* + *SOLARBAN* 70XL (3) | 1 | 19 | 7 | 19 | 10 | 0.28 | 0.26 | 1.50 | 0.18 | 0.15 | 1.27 |
| *SOLARCOOL* (2) *PACIFICA* + *SOLARBAN* 70XL (3) | 1 | 12 | 4 | 10 | 8 | 0.28 | 0.26 | 1.50 | 0.15 | 0.13 | 0.89 |
| *SOLARCOOL* (2) *SOLARBLUE* + *SOLARBAN* 70XL (3) | 1 | 16 | 6 | 14 | 16 | 0.28 | 0.26 | 1.50 | 0.18 | 0.15 | 1.03 |
| *SOLARCOOL* (2) *SOLARBRONZE* + *SOLARBAN* 70XL (3) | 1 | 15 | 6 | 14 | 19 | 0.28 | 0.26 | 1.50 | 0.17 | 0.15 | 1.01 |
| *SOLARCOOL* (2) *SOLARGRAY* + *SOLARBAN* 70XL (3) | 1 | 13 | 5 | 11 | 15 | 0.28 | 0.26 | 1.50 | 0.16 | 0.14 | 0.89 |
| *SOLARCOOL* (2) *GRAYLITE* + *SOLARBAN* 70XL (3) | < 1 | 3 | 1 | 5 | 5 | 0.28 | 0.26 | 1.50 | 0.11 | 0.09 | 0.27 |

† ***Solarban*** 70XL for annealed applications is applied to ***Starphire*** glass; heat treated applications will require either clear or ***Starphire*** glass depending on manufacturing process.

†† ***Optiblue*** is a unique substrate by PPG designed specifically for ***Solarban*** z50 glass. It can also be used for spandrel glass and as an interior lite for ***Solarban*** 80 glass.

1. **Performance data is based on representative samples of factory production. Actual values may vary due to the production process and manufacturing tolerances. All tabulated data is based on NFRC methodology using the LBNL Window 5.2 software. Variations from previously published data are due to minor changes in the LBNL Window 5.2 software versus Version 4.1.**
2. **Transmittance and Reflectance** values are based on spectrophotometric measurements and energy distribution of solar radiation.
3. **U-Value** is the overall coefficient of heat transmittance or heat flow measured in BTU/hr. • ft² • °F. Lower U-values indicate better insulating performance.
4. **European U-Value** is the overall coefficient of heat transmittance or heat flow measured in Watts/m²•°C, and is calculated using WinDat WIS version 3.0.1 software.
5. **Shading Coefficient** is the ratio of the total amount of solar energy that passes through a glass relative to 1/8-inch (3.0mm) thick clear glass under the same design conditions. It includes both solar energy transmitted directly plus any absorbed solar energy re-radiated and convected. Lower shading coefficient values indicate better performance in reducing solar heat gain. Note: Performance values were calculated using the LBNL Window 5.2 program using NFRC 100-2001 standard winter and summer design condition.
6. **Solar Heat Gain Coefficient (SHGC)** represents the solar heat gain through the glass relative to the incident solar radiation. It is equal to 86% of the shading coefficient.
7. **Light to Solar Gain (LSG) ratio** is the ratio of visible light transmittance to solar heat gain coefficient.

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# Analysis and modelling of window and glazing systems energy performance for a well insulated residential building

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Energy savings

A B S T R A C T

The energy performance of a window depends on its thermal transmittance, the glazing solar transmittance, and the air leakage due to the frame and installation airtightness.

In new installations air leakage represents a quite small term which is almost independent from the window and in particular from the glazing system selection.

The contributions of the two other terms to the building thermal balance are not independent to each other: the most effective thermal insulating glazing, as triple glazings, are generally characterized by low solar transmittance reducing solar gains. The thermal energy balance of the building is then affected not only in summer but also in winter, potentially increasing heating energy need.

This work evaluates the impact of different kinds of glazing systems (two double and two triple glazings), window size (from 16% to 41% of window to floor area ratio), orientation of the main windowed façade and internal gains on winter and summer energy need and peak loads of a well insulated residential building. The climatic data of four localities of central and southern Europe have been considered: Paris, Milan, Nice and Rome. A statistical analysis has been performed on the results in order to identify the most influencing parameters.



## 1. Introduction

As a consequence of the EPB Directive 2002/91/CE, many national legislations were adopted by the Member States introducing requirements imposed by law for energy saving for new and existing buildings, as for instance in Italy with the laws [1,2]. In many cases those requirements assumed the form of stronger insulation performance for all envelope building surfaces and in particular of maximum values for the thermal transmittance of the envelope components.

Italian legislation [3] acted also on the solar transmittance of glazings, intending to control the summer solar gains by giving maximum allowable solar transmittance values in absence of other solar control devices. However, solar gains can largely influence the thermal energy balance of building both in summer and winter season as emphasized by the methodology for the calculation of energy needs adopted by European Community Countries proposed by CEN standard EN ISO 13790:2007 [4].

Building designers should take into account that the most effective thermal insulating glazing systems, as the triple glazing windows, are also characterized by low solar transmittance. This could be useful to control solar gains during the summer season and to reduce cooling energy use, but in winter the reduction of solar gains can overcome the reduction of thermal losses and increase the energy needs.

Besides to solar transmittance, the size and the orientation of the windows could have a large effect on the energy use of buildings. The right design of a modern low energy building is then a careful trade-off among the properties of the different components, its collocation and its orientation. This is very important for the optimization of the solar gains.

The performances of glazing systems for different Italian climatic conditions and for different extensions of glazed area have been analyzed by the authors for office buildings [5,6]. In that case, computer simulations were performed in order to evaluate heating and cooling loads, with different window area extension, different glass types and different air flow ventilation; the simulated office building was proposed by IEA Task 27. Authors suggest to utilize

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**Nomenclature**

| | |
|---|---|
| $A$ | surface area [m$^2$] |
| CDD | equivalent cumulative degree-days [K d] |
| $F$ | view factor for radiation exchange |
| $g$ | glazing solar transmittance |
| $\phi$ | thermal power [W] |
| $h$ | heat exchange coefficient [W m$^{-2}$ K$^{-1}$] |
| $H$ | global irradiation [MJ/m$^2$] |
| HDD | heating degree-days [K d] |
| $I$ | global irradiance [W/m$^2$] |
| $R$ | adduction surface resistance [(m$^2$ K)/W] |
| $R^2$-adj | adjusted coefficient of determination |
| $T$ | absolute temperature [K] |
| $U$ | thermal transmittance [W m$^{-2}$ K$^{-1}$] |

*Greek symbols*

| | |
|---|---|
| $\varepsilon$ | emissivity |
| $\theta$ | temperature [°C] |
| $\sigma$ | Stefan–Boltzmann constant ($5.67 \times 10^{-8}$) [W m$^{-2}$ K$^{-4}$] |

*Subscripts*

| | |
|---|---|
| $C$ | in cooling operation |
| $e$ | relative to the external ambient |
| $f$ | relative to the floor area |
| $g$ | relative to the glazing |
| $H$ | in heating operation |
| $i$ | relative to the internal ambient (temperature) |
| int | relative to the internal ambient (gains) |
| $m$ | mean value between the air temperature and the sky fictive temperature |
| max | maximum value for the considered season |
| $r$ | relative to the IR radiation exchange |
| sol | solar (heat gain) |
| set | of set point |
| sky | relative to the sky vault |
| sol–air | equivalent sol–air |
| tr | transmission (heat transfer) |
| $W$ | relative to the window |
| *2dd* | two days moving average |

low-emission glasses and to optimize the percentage of the window area depending on the climatic zone in order to optimize the specific thermal need [kWh/(m$^2$ year)].

Karlsson and Roos [7] emphasized the importance of the solar transmitting properties and predicted that the use of low thermal transmittance and low emittance glazings can lead to a worse performance especially in heating dominated climates and for south orientations.

Rosencrantz et al. [8] showed that an anti reflective coating significantly increases the solar and daylight transmittances of low-emissive glazings. However they found that for northern climate and quite high window transmittances, differently than for the daylight factor improvement, the reduction of thermal losses obtained by low-emissive coatings prevails on the recovery of solar gains given by the anti-reflective coating.

Persson et al. [9], analyzed the influence of window size on the energy balance of low energy houses, calculating winter and summer energy use for different orientations of a terraced passive house with triple glazings windows in the climate conditions of Gothenburg (Sweden). As regards the building orientation they found analogous trends for the winter and summer energy use, but differently from the results of the present paper, they showed a certain improvement in winter performance when reducing the window area in south orientation. This could be due to the higher opaque envelope insulation and to the particular climatic condition of Gothenburg, with lower solar radiation and lower external temperatures and to the higher set point temperature, which enhance the relevance of the window thermal losses with respect to the opaque envelope losses and to the solar gains.

Poirazis et al. [10] analyzed the effect of glazing features and surface on a large office building, simulating the energy performance with different orientations, control strategies and internal layout for the climate of Gothenburg. Eskin and Turkmen [11] calculated the effects on energy performance of parameters like the climatic conditions, insulation, thermal capacity, aspect ratio, color, shading, window systems and area, ventilation rates and control strategies for a office building in four climates in Turkey. The effects of window size and type were considered mainly for their impact on the cooling energy and peak load.

Approaching the design of a large office building in Portugal by means of a sensitivity analysis, Almeida Ferreira Tavares and Oliveira Gomes Martins [12] found that triple glazing windows do not improve so much the energy performance in winter as they do in summer.

To similar conclusions came Carriere et al. [13] considering the energy retrofit and the conservation measures implementation for a large commercial building in Saskatoon (Canada).

Urbikain and Sala [14] compared different Window Energy Rating System (WERS) in order to obtain a WERS for two climatic zones in Spain, establishing a dependence law of the useful energy for the heating system of the building in terms of the total transmittance of the window, the frame thermal transmittance, the glazing solar transmittance and the infiltration rate.

The present work is aimed to evaluate the impact of different kinds of glazing systems (two double and two triple glazings), window size (considering a range from 16% to 41% of window to floor area ratio), orientation of the principal windowed wall and internal gains on the winter and summer energy use and peak loads of a well insulated residential building. The climatic data of four localities of central and southern Europe have been considered, Paris (Trappes), Milan, Nice and Rome.

The analysis has not been extended to the lighting use, which does not seem relevant for the considered residential destination for the quite large window area of all the simulated configurations, and to the impact on the internal thermal comfort of the higher radiant temperature allowed by the more insulated glazings.

## 2. The building

Starting from a quite simple example of a residential building, a set of simulations has been performed to evaluate the importance on the winter and summer energy need.

The considered building is an example of a well insulated solution with an average thermal transmittance of the opaque envelope around 0.17–0.18 W m$^{-2}$ K$^{-1}$) (Table 1). With a rectangular shape (internally 10.22 m long per 6.11 m wide), it develops on two storeys. The longer and south oriented side contains the main part of the window surface. Other 3.2 m$^2$ of transparent elements (the 3% on the floor area) are present only on the opposite side (north).

A constant ventilation by outside air of 0.3 air change per hour has been considered.

The study analyzes in the climatic and solar radiation conditions of Paris (for which the data of the near town of Trappes were considered), Milan, Nice and Rome, the effects of:

- four different kinds of glazing systems, two of which are double glazings and two are triple glazings, with the features indicated

**Table 1**
Composition of the opaque envelope.

| | Thickness m | Conductivity $W\,m^{-1}\,K^{-1}$ | Density $kg\,m^{-3}$ | Specific heat $J\,kg^{-1}\,K^{-1}$ |
|---|---|---|---|---|
| External wall (from inside to outside) | | | | |
| Gypsum panel | 0.015 | 0.36 | 1150 | 1100 |
| Plywood | 0.065 | 0.13 | 500 | 1600 |
| Wood–fiber insulation | 0.200 | 0.04 | 160 | 2100 |
| Waterproof layer | 0.002 | 0.16 | 300 | 1300 |
| Air layer (still air) | 0.030 | – | 1.2 | – |
| Wood covering | 0.020 | 0.15 | 600 | 1600 |
| Roof | | | | |
| Gypsum panel | 0.015 | 0.360 | 1150 | 1100 |
| Air layer (still air) | 0.025 | 0.026 | 1.2 | 1005 |
| Moisture barrier | 0.001 | 0.160 | 300 | 1300 |
| Mineral wool and wood frame | 0.250 | 0.048 | 77 | 1400 |
| Medium density fiberboard | 0.015 | 0.120 | 600 | 1700 |
| Waterproof layer | 0.002 | 0.160 | 300 | 1300 |
| Air layer (ventilated) | 0.050 | – | 1.2 | – |
| Roof tiles | 0.015 | 0.900 | 2000 | 840 |
| Ground floor | | | | |
| Floor tiles | 0.015 | 1.000 | 550 | 800 |
| Lightweight concrete subfloor | 0.060 | 1.400 | 2000 | 880 |
| Waterproof layer | 0.004 | 0.230 | 100 | 1410 |
| Polystyrene | 0.150 | 0.035 | 40 | 1600 |
| Concrete slab | 0.200 | 1.160 | 2000 | 920 |

**Table 2**
Features of the glazing systems.

| Glazing code | Composition | Thermal transmittance $W\,m^{-2}\,K^{-1}$ | Solar transmittance $g$ | Spacer type |
|---|---|---|---|---|
| Double glazings #1 | 4/15/4 | 1.4 | 0.61 | Aluminium |
| Double glazings #2 | 4/15/4 | 1.1 | 0.61 | Aluminium |
| Triple glazings #3 | 4/16/4/16/4 | 0.6 | 0.40 | Aluminium |
| Triple glazings #4 | 4/15/4/16/4 | 0.7 | 0.59 | Aluminium |

in Table 2, while frames are considered always the same with a thermal transmittance of $1.2\,W\,m^{-2}\,K^{-1}$)
- four different window sizes: 16%, 25%, 34% and 41% of window to floor area (Fig. 1)
- four orientations, starting from windows mainly south oriented and considering mainly east, west and north solutions; the whole building was rotated towards the desired orientation
- two internal gain levels: without gains and with internal gains set at $4\,W/m^2$.

Moreover the effects of shading overhangs on the side with the main part of windows have been investigated comparing the south oriented results obtained with and without the shading of the roof and of the balcony overhangs.

The different parameters have been varied one each time in order to consider any combination of values, so 640 configurations were obtained considering the four climates. The results comprise both winter and summer energy need and winter and summer peak load.

## 3. Simulation method and assumptions

The building performance has been calculated by means of TRNSYS software and its multi-zone building simulation subroutine called Type 56. The simulation hypotheses are the following:

- direct and diffuse solar radiation on internal surfaces are distributed by absorptance weighted area ratios; in particular absorptance has been considered 0.6 for the floor surfaces, 0.3 for the others
- for the long wave radiation internal exchanges, view factors equal to the area fraction and black surfaces are considered
- fixed value convection coefficients are calculated from the standard EN ISO 6946:2007 [15]

**Table 3**
Selected independent variables and models in the regression analysis.

| Variables | Unstandardized | | Standardized |
|---|---|---|---|
| | Coefficients | Std. error | Coefficient |
| | Model: Heating energy needs $[kWh/m^2]$ | | $R^2$-adj = 0.932 |
| (Constant) | 8.850 | 1.805 | – |
| HDD | 0.023 | $0.323 \times 10^{-3}$ | 0.820 |
| $\phi_{int}/A_f$ | −3.693 | 0.107 | −0.397 |
| $I_H$ | −0.010 | $0.298 \times 10^{-3}$ | −0.388 |
| $A_{int}/A_f$ | −0.224 | 0.025 | −0.103 |
| $U_g$ | 10.397 | 0.929 | 0.179 |
| $g$ | −32.330 | 3.363 | −0.154 |
| | Model: Cooling energy needs $[kWh/m^2]$ | | $R^2$-adj = 0.741 |
| (Constant) | 69.772 | 3.945 | – |
| $A_g/A_f$ | −1.511 | 0.063 | −0.538 |
| CDD | $3.15 \times 10^{-3}$ | $0.122 \times 10^{-3}$ | 0.628 |
| $U_g$ | −21.651 | 2.523 | −0.288 |
| $\phi_{int}/A_f$ | −2.948 | 0.271 | −0.245 |
| $g$ | −25.958 | 8.664 | −0.095 |
| | Model: Heating peak load $[W/m^2]$ | | $R^2$-adj = 0.892 |
| (Constant) | 4.969 | 0.607 | – |
| $\theta_{sol-air,g\,l\,min}$ | −1.907 | 0.041 | −0.675 |
| $\phi_{int}/A_f$ | −0.957 | 0.034 | −0.405 |
| $U_g$ | 5.777 | 0.297 | 0.392 |
| $A_g/A_f$ | 0.182 | 0.008 | 0.329 |
| $I_H$ | −0.001 | $95.5 \times 10^{-6}$ | −0.152 |
| $g$ | −3.847 | 1.075 | −0.072 |
| | Model: Cooling peak load $[W/m^2]$ | | $R^2$-adj = 0.820 |
| (Constant) | 92.362 | 3.147 | – |
| $A_g/A_f$ | −1.903 | 0.053 | −0.671 |
| $\bar{\theta}_{sol-air,g\ \ l}\Big\|_{2dd,max}$ | −0.375 | 0.012 | −0.675 |
| $U_g$ | −42.065 | 1.690 | −0.554 |
| $\phi_{int}/A_f$ | 92.362 | 3.147 | – |

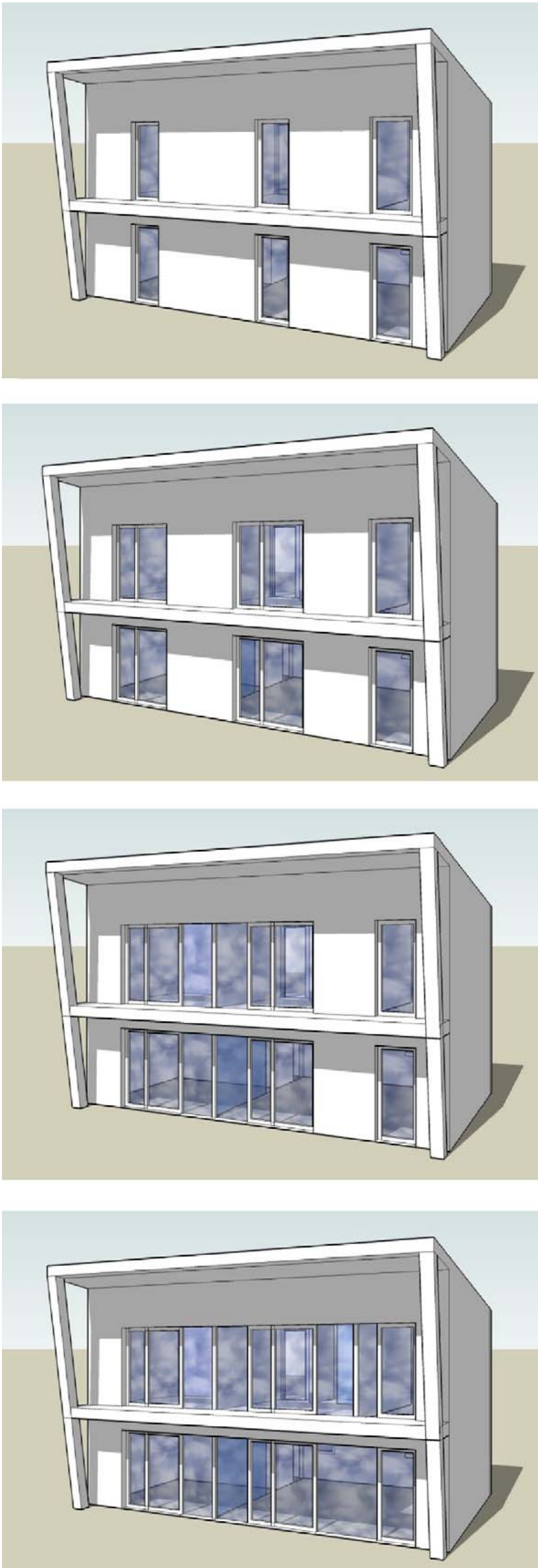

**Fig. 1.** The considered building in the four window configurations from 16% to 41% window to floor area.

- a ventilated air layer is considered according to the EN ISO 6946:2007 approach
- thermal bridges are considered explicitly for the corners towards external air and a C2 linear transmittance value according to the standard EN ISO 14683:2007 [16] was assumed while the thermal bridge attached to the ground floor of vertical walls (assuming a GF8 linear transmittance value) has been included in the calculation of the ground floor equivalent features
- the ground floor is considered according to the standard EN ISO 13370:2007 annex D [17]
- shading effects are accounted only on the transparent surfaces situated on the most windowed side of the building using the TRNSYS subroutine Type 34 Overhang and Wingwall; overhangs depth is considered of 1 m for the balcony over the first floor and 1,6 for the roof
- hourly climatic data were calculated from average monthly values (from the Italian Standard UNI 10349:1994 [18] for Milan and Rome and from TRY weather files [19] for Trappes and Nice) using the TRNSYS subroutine Type 54 Weather Data Generator
- heating set point was fixed at 20 °C while the cooling one at 26 °C.

## 4. Results and discussion

The results are shown in Figs. 2 and 3 only for the climates of Milan, which is representative of both the situations with relevant energy needs (as is the case of Paris) and the conditions with evident cooling needs (as are for instance Nizza and Rome). Trends concerning Paris, Nizza and Rome were found to be very often quite similar to these of Milan. As west and east orientation energy needs differ for less than 1 kWh/m$^2$ the results for those orientations are averaged. The same has been done for the peak loads although in this case the values can significantly differ in cooling operations, in particular for southern latitudes. In the most critical case of Rome, the difference between west and east cooling peak loads increases from 6 W/m$^2$ at 16% window surface ratio to 12 W/m$^2$ at 41% window surface ratio.

### *4.1. Winter energy need*

The data show some common trends for all the considered climates. As regards the cases without internal gains, the winter energy need always decreases with increasing window area for orientations different from north. The reduction is more important for the triple glazings than for double, as for the former the increase of thermal losses is lower: the only exceptions are the case of Paris (Trappes) and Milan (Fig. 2) for orientation east or west, for very large window area and for double glazings. This behavior is enhanced and extended to the south orientation by the internal gains, which moderate the decreasing slope of all the lines. This is due to the larger relevance of thermal losses when internal gains are present.

Quite stable or increasing trends are shown for the north orientation and for the double glazings, and, when internal gains are assumed, also for triple glazings. In those cases the solar gains can only compensate but not overcome the thermal losses.

Triple glazings are the preferred choice only for the type #4, for which the solar transmittance is close to the one of the double glazings.

The south orientation for the building and, for this orientation, an increase of the window surface are the most effective expedients to reduce the winter energy need.

### *4.2. Summer energy need*

The summer energy need increases very much while increasing window area except for the north orientation on which, as seen for winter, solar radiation is less important. Yet for Milan (Fig. 2), the

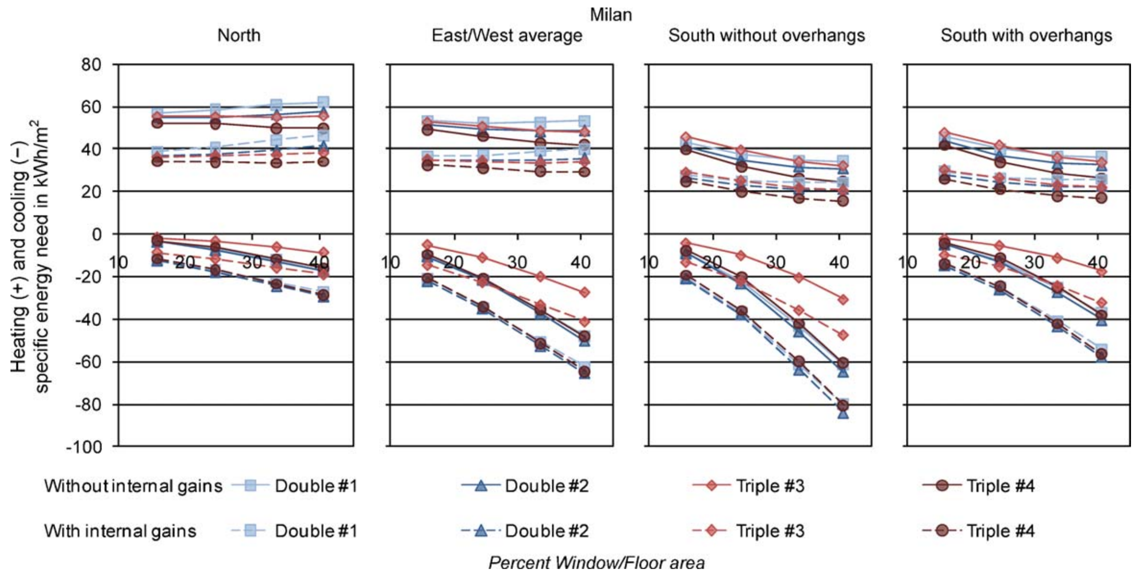


**Fig. 2.** Trends of heating and cooling energy need for different window to floor area ratios: Milan.

summer energy need of the considered building with internal gains becomes larger than the winter one (raising the ventilation rate or using the night ventilation would reduce the effect). The winter benefits coming from higher window area are much less than the increase of the summer energy need, that requires better control strategies for instance using night ventilation or moveable shading devices.

Triple glazings #4 behaves very closely to the double glazings #1 and #2, while the best performing is the triple glazings #3: its lower solar transmittance can neutralize the rise of summer energy need effect due to the internal gains.

Shadings on the south oriented configurations help to keep the summer energy need to the levels of the west–east orientations, while the winter energy need is only marginally affected by the roof and balcony overhangs.

### 4.3. Winter peak load

Winter peak loads values varies in a quite narrow range, with higher values around 20–30 W/m$^2$ for Paris and Milan (Fig. 3) and lower values around 15–25 W/m$^2$ for Nice and Rome.

For all the considered climates, the winter peak loads variation with windows percent area is very little. All localities show slightly increasing loads with windows area for the north, east and west orientation. For lower latitudes (Nice and Rome) and triple glazings peak loads tend to stay constant for any windows surface. Double glazings show a higher variation due to the higher thermal transmittance. Internal gains downshift the loads by a constant amount.

The results are coherent with the consideration that winter peak loads are more affected by the external temperature conditions and therefore by the heat losses than by the solar gains. Solar transmittance is then irrelevant in determining the peak loads as is shown by the superposition of the triple glazings #3 and triple glazings #4 results.

For the above considerations, triple glazings are always the preferred choice.

### 4.4. Summer peak load

Summer peak loads emphasize the summer energy need trends. First of all the values show a very wide variation between the

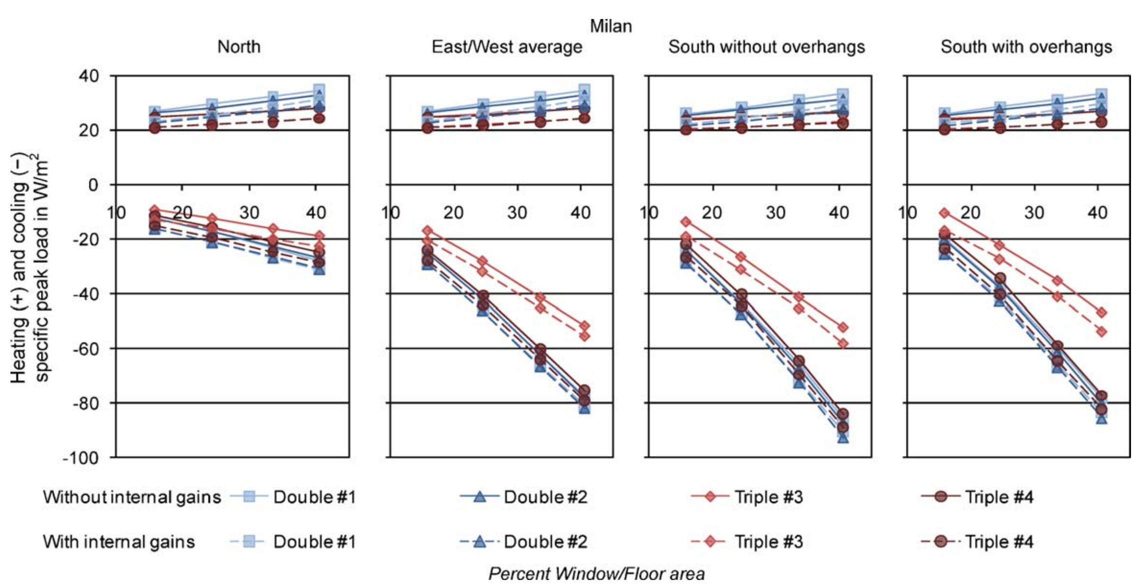


**Fig. 3.** Trends of heating and cooling peak loads for different window to floor area ratios: Milan.

quite null values for Paris and north orientation and values around 80–100 W/m$^2$ for the east, west and south orientation with double glazings or triple glazings #4.

The climate dependence is lower than the one on windows surface. Except for north orientation, peak loads tend to duplicate or more when the windows surface doubles.

Glazings with higher solar transmittance obviously show a worse behavior with higher variation due to the higher thermal transmittance.

Internal gains downshift the loads by a constant amount.

Summer peak loads are more affected by the solar gains than by the external temperature conditions and therefore by the heat losses. Thermal transmittance is then irrelevant in determining the peak loads as is shown by the superposition of the double glazings #1, double glazings #2 and triple glazings #4 results.

For the above considerations, triple glazings #3 are always the preferred choice.

## 5. Statistical analysis

In order to validate the information which can be derived from the whole set of data for the four considered localities, a statistical analysis has been performed. In this work, the statistical technique employed, the multiple linear regression, is not aimed to create a general model but to understand the influence of some independent variables on the heating energy needs, the heating peak load, the cooling energy needs and the cooling peak load. The selection of the independent variables has been performed with the stepwise method and each confidence interval is at 95% level. In Table 3, each variable selected is listed in order of decreasing importance on the adjusted coefficient of determination. The cases with overhangs have not been considered.

### 5.1. Winter and summer energy needs

In the winter case, the correlation of heating energy needs with the window features as thermal transmittance $U_g$ and solar transmittance $g$, the ratio between glazing surface and floor surface $A_g/A_f$, the radiation received on the surface with the larger amount of glazing only in positive heating degree-hours conditions $H_{\mathrm{sol,g},H}$, the specific internal gains $\phi_{\mathrm{int}}/A_f$, and heating degree-days HDD was investigated. Table 3 reports the selected variables, which appeared to be statistically relevant and were selected for the regression model.

During the cooling period, loads are strongly dependent on the contemporaneousness of external temperature and solar radiation. Moreover, it is impossible to know exactly if the radiation entering through the windows will cause a cooling load or not, particularly if the behavior of the other components of the building are not known.

To take into account the contemporaneous effect of the temperature and entering radiation, their values have been considered in a single variable, defined as a *modified equivalent sol–air temperature* for glazings suitable to be used for the calculations of equivalent cooling degree-hours:

$$\theta_{\mathrm{sol-air},g} = \theta_e + \frac{gI_{\mathrm{sol},g}}{U_g} + R_{se} \cdot h_{r,\mathrm{sky}} \cdot (\theta_{\mathrm{sky}} - \theta_e) \tag{1}$$

This definition has been derived from the relations used by the EN ISO 13790:2007 [4] to express the energy balance terms through the transparent components, and which can hold also in non-steady state due to the negligible heat capacity of the glazings.

The heat fluxes through the glazings are then determined as the sum of thermal losses and solar gains in the form of:

$$\begin{aligned}\phi_{\mathrm{tr},g} &= \phi_{\mathrm{sol},g} + U_g A_g(\theta_e - \theta_{i,C,\mathrm{set}}) \\ &\quad + [gI_{\mathrm{sol},g} + R_{se} U_g h_{r,\mathrm{sky}}(\theta_{\mathrm{sky}} - \theta_e)]A_g\end{aligned} \tag{2}$$

Equating (2) to an equivalent dispersion through a glazing with the same thermal transmittance subjected to a temperature difference between the internal node and the equivalent external sol–air node in the form of

$$\phi_{\mathrm{tr},g} + \phi_{\mathrm{sol},g} = U_g A_g(\theta_{\mathrm{sol-air},g} - \theta_{i,C,\mathrm{set}}) \tag{3}$$

one can get the expression (1).

The term $h_{r,\mathrm{sky}}$ is defined as:

$$h_{r,\mathrm{sky}} = 4\sigma\varepsilon \cdot F_{\mathrm{sky}} \cdot T_m^3 \tag{4}$$

where the glass emissivity $\varepsilon$ was set to 0.837.

For the cooling energy needs analysis, the hourly differences between the internal cooling set point temperature $\theta_{i,C,\mathrm{set}}$ and the $\theta_{\mathrm{sol-air},g}$ have been summed all year long, only when negative and with no heating degree-hours present. The result was divided by 24 h/d to give equivalent cumulative degree-days CDD. In such a way, the radiation which is a gain in heating period has been separated from the one which could cause cooling loads in the cooling period. The other variables considered in the summer analysis are the window thermal transmittance $U_g$, the solar transmittance $g$, the internal gains $\phi_g/A_f$, the ratio between glazing surface and floor surface $A_g/A_f$. Table 3 summarizes the ones which resulted to be statistically relevant.

### 5.2. Winter and summer peak loads

For winter peak loads the tested independent variables are the same as for energy needs (Table 3), except for the heating degree days that have been replaced with the minimum $\theta_{\mathrm{sol-air},g}$ temperature.

For the summer peak load analysis, instead, to take into account of the dynamic behavior of the environment, the yearly maximum value for two days rolling-average of $\theta_{\mathrm{sol-air},g}$ has been considered (indicated as $\bar{\theta}_{\mathrm{sol-air},g}\big|_{2dd,\max}$). Other variables considered in the summer analysis are the window thermal transmittance $U_g$, the internal gains $\phi_g/A_f$, the ratio between glazing surface and floor surface $A_g/A_f$. Table 3 summarizes the ones which resulted to be statistically relevant.

### 5.3. Findings

The regression analysis evidenced:

- for winter energy needs, the strong and comparable weight of thermal and solar transmittance which follows only the influence of the climatic conditions expressed by the heating degree-days, the internal gains and the solar radiation;
- for summer energy needs, the large influence of the windows area and of the contemporaneous contribution of temperature and solar radiation, which are accounted in the CDD parameter;
- for winter peak loads the project conditions (i.e., minimum sol–air glazing temperature), internal gains, thermal transmittance and windows area are the most influencing variables, while the solar transmittance effect is modest;
- for summer peak loads, the large influence of the windows area, of the contemporaneous effect of temperature and solar radiation and of the thermal transmittance.

It should be noted that the effect of the variable $g$ is in part accounted in its interaction with $I$, within the $\theta_{\mathrm{sol-air},g}$ definition.

In Figs. 4–7 the values obtained with the regression models are compared to the ones calculated by TRNSYS. In winter conditions, the points are well aligned and the majority of them are included between the two dotted lines which represent a deviation of 20%

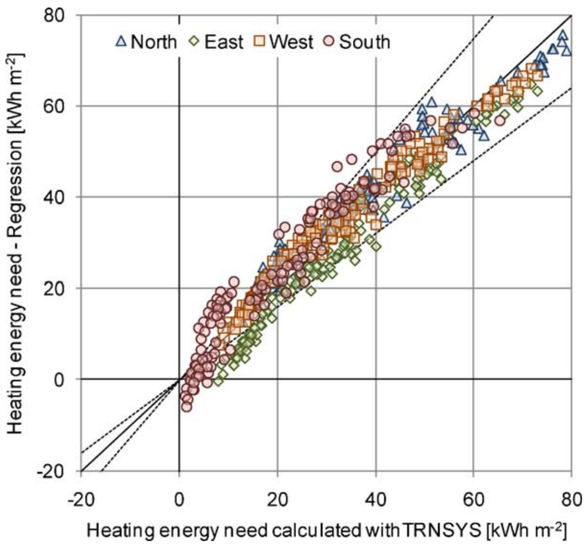


**Fig. 4.** Regression model for the heating energy needs.

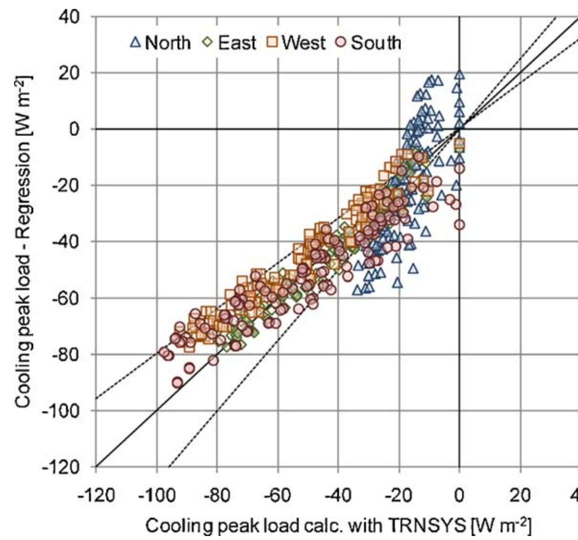


**Fig. 7.** Regression model for the cooling peak loads.

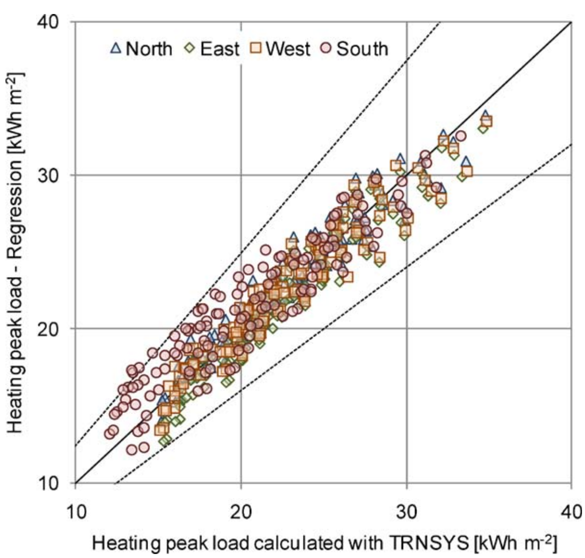


**Fig. 5.** Regression model for the heating peak loads.

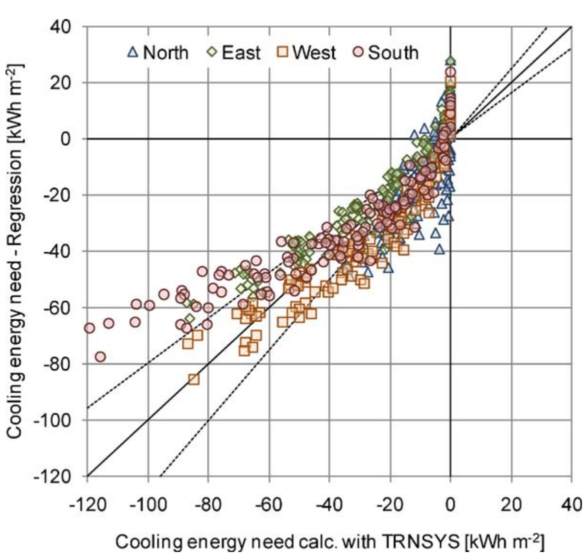


**Fig. 6.** Regression model for the cooling energy needs.

from the middle values. In winter energy needs calculations the worst data fit is due by south orientation and low energy demand.

About summer needs, the correspondence is not so good. In part this can depend on the description of the environment: in the definition of the parameter CDD all the radiation not involved in the winter heating balance has been considered. With a detailed balance, only the radiation responsible for cooling load could be identified in order to get a better model. Also the envelope heat capacity variation with the window to floor area should be accounted for a possible improvement of the model.

In cooling energy needs and peak loads, the different behaviors of the north oriented glazings can be underlined. This is probably due to a different weight and composition of the radiation component on this orientation.

## 6. Conclusions

It is possible to summarize the above results as follows:

- the use of large glazings enhances winter performance but worsens slightly the peak of winter loads (the adoption of shutters for night hours could limit this problem);
- there is an improved effect for the south orientation, which is the best performing in winter;
- in winter the use of windows with low thermal transmittance is useful if accompanied by high solar transmittance;
- however higher solar transmittance considerably worsens summer performance;
- selective shading systems should then be installed to improve summer performance without affecting the winter one.

According to the regression analysis, the thermal transmittance is relevant in winter and summer conditions both for energy and peak loads. The solar transmittance appears to be more important for winter and summer energy needs and for summer peak loads.

As a consequence of the results obtained from the computer simulations on the utilized buildings typologies, it is important to propose preliminary optimization of the solar exposition, the geometry and of the solar and thermal properties of the glazing system.

The windows surface appears to be of minor importance for winter energy needs.

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# PREVENTING BIRD–WINDOW COLLISIONS

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# PREVENTING BIRD–WINDOW COLLISIONS

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ABSTRACT.—Birds behave as if clear and reflective glass and plastic windows are invisible, and annual avian mortality from collisions is estimated in the billions worldwide. Outdoor flight cage and field experiments were used to evaluate different methods to prevent collisions between birds and windows. Stripe and grid patterns of clear UV-reflecting and UV-absorbing window coverings presented an effective warning that birds avoid while offering little or no obstructed view for humans. Birds used UV-reflected signals to avoid space occupied by clear and reflective sheet glass and plastic. Window coverings with effective UV-reflecting and UV-absorbing patterns as warning signals can prevent unintentional killing of birds from collisions with windows. One-way films that made the outer surface of windows opaque or translucent were successful in deterring bird strikes. Ceramic frit glass consisting of a visual pattern of densely spaced 0.32-cm diameter dots, 0.32 cm apart was an effective collision deterrent. Uniformly covering windows with decals or other objects that are separated by 5 to 10 cm was completely or near-completely effective in preventing strikes. Twice the number of window strikes occurred at non-reflective sheet glass compared to conventional clear panes. Continuous monitoring of windows revealed one in four bird strikes left no evidence of a collision after 24 hrs and, without continuous monitoring, 25% of bird strikes were undetected. *Received 11 September 2008. Accepted 19 January 2009.*

Avian mortality resulting from collisions with clear and reflective sheet glass and plastic is estimated to be in the billions worldwide (Klem 1990, 2006). Collisions are predicted and expected wherever birds and windows coexist (Klem 1989, 1990, 2006). Birds behave as if windows are invisible, and it is important to prevent this unintended killing, estimated to represent the largest human-associated source of avian mortality except habitat destruction (Klem 2006, 2009a, b). The diversity of species and the invisible threat suggest that birds in general are vulnerable to windows, but documented casualties of species of special concern indicates that avian mortality from window collisions is contributing to population declines of specific species and birds in general (Klem 2009a, b).

I evaluated several methods to prevent bird strikes at windows using previously effective outdoor flight cage and field experiments (Klem 1989, 1990). Most preventive treatments examined the use of ultraviolet (UV) signals to alert birds to windows, and the availability of materials affected the composition of what was tested in each experiment. The ability of birds to avoid clear plastic and the ability of one-way films, fritted glass, and feathers to prevent collisions were also evaluated. Specifically, I tested: (1) clear plastic with a UV-absorbing component, (2) single and uniform covering of multiple UV-reflecting maple leaves, (3) a string of colored contour feathers, (4) a one-way external film having an unobstructed view from inside and an obstructed view of dot pattern from outside, (5) a ceramic frit glass with a uniform covering of translucent dots, (6) a variety of UV-absorbing stripe patterns created by plastic strips, and different UV-absorbing and UV-reflecting complete covering, striped, and grid patterns created by external films.

## METHODS

Flight cage and field experiments were conducted on a 0.2-ha open mowed grass suburban backyard surrounded and isolated from neighbors by mature shrubs and evergreens in Upper Macungie Township, Lehigh County, Pennsylvania (40° 34′ 35″ N, 75° 34′ 57″ W). Four field experiments were conducted on a 2-ha open rural area of mowed pasture bordered by second growth deciduous forest and shrubs in Henningsville, Berks County, Pennsylvania (40° 27′ 53″ N, 75° 40′ 07″ W).

*Flight Cage Experiments.*—These tests were conducted from 13 March to 30 April 2004. The basic design was reported previously by Klem (1990) and consisted of a trapezoidal flight cage 1.2 m high, 3.6 m in length, and 0.3 m wide at the narrow end and 2.6 m wide at the broad end. Five Dark-eyed Juncos (*Junco hyemalis*), one White-throated Sparrow (*Zonotrichia albicollis*), and one House

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Sparrow (*Passer domesticus*) were captured in March for use as subjects, housed in small cages, and tested from mid-March and throughout April. Except for the House Sparrow which was an adult female, age and gender of all other subjects were unknown; previous studies of collision casualties document equal vulnerability for all age and gender classes (Klem 1989).

Individuals were released from a holding box at the narrow end and forced to discriminate between left and right flight paths as they attempted to escape to wooded evergreen habitat visible outside the broad end of the cage. One half of the cage at the broad end was left unobstructed in all experiments. The other half was obstructed by clear plastic or objects tested to prevent bird strikes. During testing of a subject, the obstructed and unobstructed sides were changed for half the trials to ensure no bias flight path preference for one side or the other. Actual clear plastic was tested with two Dark-eyed Junco subjects to learn if they were capable of discriminating between clear plastic and unobstructed airspace. Previous studies revealed that Dark-eyed Junco subjects were not capable of discriminating between clear glass and unobstructed airspace (Klem 1990). Objects tested were hung on the obstructed side with clear monofilament line to appear as if taped, stuck, or applied as a coating to clear glass or plastic to prevent accidental collision injuries to subjects in subsequent experiments. No Institutional Animal Care and Use Committee existed during this study, but guidelines for the care of wild birds in research were followed (Gaunt and Oring 1999). All subjects were released unharmed at the end of the experimental period.

Eight flight cage experiments were conducted. Each experiment tested one to five subjects, and each subject flew a minimum of 10 trials per experiment with additional trials (up to 24) to clarify results (Table 1). A trial consisted of recording a subject passing through the unobstructed side of the cage or the side containing the object tested. If the subject chose the obstructed side it was scored as a window strike; if the subject flew through the unobstructed side it was scored as avoidance. Two to three objects were evaluated on any test day. Individuals were tested with a single object on any one test day, and subjects tested with more than one object were tested on different days. The objects tested were: (1) clear plastic with a UV-absorbing component, (2) single translucent UV-reflecting maple leaf (WindowAlert Decal) measuring 10 × 10 cm; (3) uniform covering of 12 UV-reflecting maple leaves as in #2, placed 10 cm apart in vertical columns and 5 cm apart in horizontal rows; (4) a single clear monofilament line attached to the quill of four colored (from top: red, blue, yellow, and green) contour feathers (FeatherGuard™) measuring 14.4–19.6 cm long and separated by 33 cm; (5) 0.32-cm thick vertically oriented 2.5-cm wide UV-absorbing plastic strips forming stripes separated by 10 cm; (6) vertically oriented 2.5-cm wide UV-absorbing strips forming stripes as in #5 but separated by 5 cm, (7) 2.5-cm wide UV-absorbing plastic strips forming stripes as in #5 but horizontally oriented and separated by 5 cm; and (8) ceramic frit glass uniformly covered with a pattern of translucent-appearing dots 0.32-cm in diameter separated by 0.32 cm. Binomial tests were used to examine the significance of each experiment (Siegel 1956).

*Field Experiments.*—The basic design of all field experiments was reported previously (Klem 1989, 1990) and consisted of wood-framed picture windows, accurately simulating those in houses; all were placed in the same habitat oriented in the same direction 1 m from a tree-shrub edge facing an open field (Klem 1989: figure 1). Each window measured 1.2 m wide × 0.9 m high and was mounted 1.2 m above ground. Plastic mesh trays were placed under each window to catch casualties. Three window units were used in the first and second experiments, and were separated by 4.2, 3.8, and 4.1 m. Three and seven window units were used in the third to sixth experiments separated by 7.8, 7.4, 7.9, 9.0, 7.4, and 8.3 m. A single platform feeder measuring 30.5 cm on a side and 1.2 m above ground mounted on crossed wooden-legs was centered and placed 10 m in front of each window to simulate a feeding station at a rural residential home. Feed consisted of a 1:1 mixture of black-oil sunflower seeds and white proso millet. All feeders were kept full throughout each experiment. No object was permitted at the same window on consecutive days for all experiments, and each object test-

TABLE 1. Preventive methods used in outdoor flight cage experiments to examine avoidance of bird–window collisions.

| Preventive method Species tested | Number tested | Number significantly avoiding method[a] | Number test trials | Avoidance | Non-avoidance | *P* |
|---|---|---|---|---|---|---|
| Clear sheet plastic | | | | | | |
| Dark-eyed Junco | 2 | 0 | 14 | 8 | 6 | 0.395 |
| | | | 10 | 6 | 4 | 0.377 |
| Single UV-reflecting maple leaf in center of pane | | | | | | |
| Dark-eyed Junco | 5 | 1 | 16 | 15 | 1 | <0.001 |
| | | | 17 | 7 | 10 | 0.834 |
| | | | 10 | 2 | 8 | 0.989 |
| | | | 15 | 7 | 8 | 0.696 |
| | | | 10 | 5 | 5 | 0.623 |
| Uniform covering of 12 UV-reflecting maple leaves, 10 cm separating 2 vertical columns, 5 cm separating 6 horizontal rows | | | | | | |
| Dark-eyed Junco | 4 | 2 | 24 | 18 | 6 | 0.011 |
| | | | 10 | 4 | 6 | 0.828 |
| | | | 10 | 2 | 8 | 0.989 |
| | | | 12 | 10 | 2 | 0.019 |
| Feathers on monofilament line | | | | | | |
| Dark-eyed Junco | 1 | 0 | 18 | 11 | 7 | 0.240 |
| White-throated Sparrow | 1 | 0 | 10 | 4 | 6 | 0.828 |
| UV-absorbing 2.5 cm wide stripes forming vertical columns 10 cm apart | | | | | | |
| Dark-eyed Junco | 5 | 1 | 10 | 6 | 4 | 0.377 |
| | | | 10 | 10 | 0 | <0.001 |
| | | | 10 | 8 | 2 | 0.055 |
| | | | 10 | 6 | 4 | 0.377 |
| | | | 10 | 7 | 3 | 0.172 |
| UV-absorbing 2.5 cm wide stripes forming vertical columns 2.5 cm apart | | | | | | |
| Dark-eyed Junco | 5 | 3 | 10 | 10 | 0 | <0.001 |
| | | | 10 | 8 | 2 | 0.055 |
| | | | 10 | 10 | 0 | <0.001 |
| | | | 10 | 8 | 2 | 0.055 |
| | | | 10 | 9 | 1 | 0.011 |
| UV-absorbing 2.5 cm wide stripes forming horizontal rows 5.0 cm apart | | | | | | |
| Dark-eyed Junco | 5 | 5 | 10 | 10 | 0 | <0.001 |
| | | | 10 | 10 | 0 | <0.001 |
| | | | 16 | 13 | 3 | 0.011 |
| | | | 15 | 12 | 3 | 0.018 |
| | | | 10 | 10 | 0 | <0.001 |
| Ceramic frit pane with translucent dot pattern, 0.32 cm diameter dots separated by 0.32 cm spaces | | | | | | |
| Dark-eyed Junco | 5 | 5 | 10 | 10 | 0 | <0.001 |
| | | | 12 | 10 | 2 | 0.019 |
| | | | 18 | 13 | 5 | 0.048 |
| | | | 10 | 10 | 0 | <0.001 |
| | | | 10 | 10 | 0 | <0.001 |
| House Sparrow | 1 | 1 | 10 | 9 | 1 | 0.011 |

[a] Binomial tests were used to examine if results of 10 to 24 trials per subject differed ($P < 0.05$) from the expected equal distribution.

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ed in each experiment was randomly assigned and moved to a new window unit daily. Windows were checked each day 30 min after first light and checked and changed daily 30 min before last light for all experiments. Windows were covered with opaque tarps and not monitored during inclement weather such as high winds, rain, or snow.

The parameter measured in all experiments was the number of detectable bird strikes. A strike was recorded when either dead or injured birds were found beneath a window, or when fluid or a blood smear, feather, or body smudge was found on the glass. The data are likely incomplete and conservative because some strikes may not have left evidence of a collision (Klem 1989, 1990, Klem et al. 2004). Predators and scavengers also are known to remove some injured or dead birds (Klem 1981, Klem et al. 2004). The length of each experiment was ascertained by the number of recorded strikes required to statistically evaluate the differences between treatments. The experiments for some species occurred during non-breeding and migratory periods, but previous studies indicate no seasonal difference in the ability of birds to avoid windows (Klem 1989).

The first experiment was conducted over 20 days from 5 to 27 December 2005 and tested the clear glass control, non-reflective clear glass pane exhibiting no glare when viewed from any angle, and the same plastic strips and spacing used in flight cage experiment #6; the 0.32-cm thick edges of the plastic strips were visible as translucent lines except when viewed from directly in front of the window.

The second experiment was conducted over 50 days from 1 February to 29 March 2006 and tested the clear glass control, complete covering of a commercially available clear UV-absorbing film supplied by CPFilms Inc. (Martinsville, VA, USA), and the same clear UV-absorbing film cut and applied as 2.5 cm wide UV-absorbing strips forming stripes separated by 5 cm of clear glass; no edgings of the strips were visible from any angle of view.

The third experiment was conducted over 90 days from 22 November 2006 to 23 February 2007 and tested five commercially available exterior window films by CPFilms Inc. UV measurements for wavelengths between 300 and 380 nm were recorded with a Cary 5000 Spectrophotometer. The clear glass control transmitted 74.6% UV while each of the films absorbed most UV, allowing UV transmittance of 0.13% or less. Each film type reflected 8.8% UV or less. The experimental windows were: (1) clear glass control; (2) complete covering of clear UV-absorbing film applied to exterior glass surface (UVC-O), (3) same as #2 but applied to interior glass surface (UVC-I); (4) complete covering of UV-absorbing REX20 film transmitting 20% and reflecting 65% visible light, having a high reflective quality; (5) complete covering of UV-absorbing REX35 film transmitting 35% and reflecting 55% visible light, having a high reflective quality; (6) complete covering of UV-absorbing NEX1020 film containing a metallic layer with a moderate reflective quality, and (7) complete covering of UV-absorbing RK20 Rynar film with a low reflective quality.

The fourth experiment was conducted over 50 days from 10 March to 3 May 2007 and retested the clear glass control, UVC-O film applied as 2.5 cm wide vertically oriented strips forming stripes separated by 2.5 cm clear glass, and commercially available CollidEscape film supplied by Large Format Digital Inc. (Edgerton, WI, USA) applied to the exterior glass surface, permitting a relatively unobstructed view looking at the inside surface of a covered pane and a completely obstructed view looking at the outside surface. Windows covered in CollidEscape appear uniformly white.

The fifth experiment was conducted over 90 days from 29 October 2007 to 9 February 2008 and tested a new clear UV-reflecting film, alone and in combination with existing exterior clear UV-absorbing film from CPFilms Inc. The new clear film reflected 80% UV. The experimental windows were: (1) clear glass control; (2) complete covering of clear UV-reflecting film applied to exterior surface (CUV-O); (3) same as #2 but applied to interior glass surface (CUV-I); (4) 2.5-cm wide UV-reflecting film strips forming stripes oriented vertically and separated by 5 cm UV-absorbing film strips forming stripes oriented vertically and applied to the outside glass surface (S-1R); (5) 5-cm wide UV-reflecting film strips forming stripes oriented vertically and separated by 2.5 cm UV-absorbing film strips forming stripes oriented vertically and applied to the outside glass surface (S-2R-O); (6) same as #5 but applied to the interior glass surface (S-2R-I); and (7) a grid pattern consisting of 10-cm wide UV-reflecting vertical columns separated by 2.5-cm wide UV-absorbing vertical columns, and 8-cm wide UV-reflecting horizontal rows separated by 2.5-cm wide UV-absorbing horizontal rows applied to the outside glass surface (GRID).

The sixth experiment was conducted over 50 days from 29 February to 25 April 2008 and retested the clear glass control and clear UV-reflecting and UV-absorbing films CUV-O, S-1R, and S-2R-O.

All windows were continuously monitored for 17 hrs over 4 days (6, 12, 24, and 30 Jan 2007) during the fourth experiment to learn if strikes occurred without leaving any visible evidence. Additionally, 60 hrs of continuous observation were conducted over 14 days (11, 13, 14, 17, 18, 21, 25, and 28 Mar and 3, 7, 8, 10, 14, and 15 Apr 2008) during the sixth experiment to observe active avoidance or failure to avoid the experimental windows. The flight path of individual birds moving from a platform feeder toward a window was recorded and assessed as active avoidance if the bird changed direction immediately in front and passed around or over a window.

I used SPSS (SPSS Inc. 2006) for all statistical analyses of the field experiments. Chi-square goodness-of-fit was used to evaluate experimental results: number of strikes per treatment compared to a uniform distribution of strikes across all treatments per experiment. Test results were considered statistically significant when $P < 0.05$.

## RESULTS

*Flight Cage Experiments.*—Dark-eyed Juncos did not discriminate between clear plastic and unobstructed airspace. There was mixed discrimination among Dark-eyed Juncos and individual White-throated and House sparrows compared with other preventive methods evaluated (Table 1). Only the UV-absorbing 2.5-cm wide horizontally oriented plastic strips forming stripes separated by 5 cm and the ceramic frit dots uniformly covering the entire window resulted in statistically significant avoidance for all subjects. The UV-reflecting maple leaves were more effective in alerting birds to a barrier when applied in enough numbers to be separated by 10 cm in vertical columns and 5 cm in horizontal rows; a single UV-reflecting maple leaf in the center of a window was ineffective in alerting four of five subjects to the presence of a clear window barrier.

*Field Experiments.*—Forty-two strikes were recorded in the first experiment; 17 (41%) were fatal. The number of strikes differed significantly across all treatments with 14 (33%) at the clear glass control, 28 (67%) at the non-reflective glass, and none at the vertically oriented 2.5-cm UV-absorbing plastic strips forming stripes separated by 5 cm ($\chi^2 = 28.0$, df = 2, $P = 0.001$). Species numbers and window at which fatalities occurred were: two White-throated Sparrows and three House Sparrows at the clear glass control; and four Northern Cardinals (*Cardinalis cardinalis*), two House Finches (*Carpodacus mexicanus*), four White-throated Sparrows, and two Dark-eyed Juncos at the non-reflecting glass.

Fifty-five strikes were recorded in the second experiment; 11 (20%) were fatal. The number of strikes differed significantly across all treatments with 35 (64%) at the clear glass control, 12 (22%) at the complete UV-absorbing film covering, and 8 (14%) at the vertically oriented 2.5-cm wide UV-absorbing film strips forming stripes separated by 5 cm ($\chi^2 = 23.2$, df = 2, $P = 0.001$). Species numbers and window at which fatalities occurred were: two Northern Cardinals and one Dark-eyed Junco at the clear glass control; two White-throated Sparrows, two Song Sparrows (*Melospiza melodia*), and one House Sparrow at the complete UV-absorbing film covering; and one White-throated Sparrow, one Song Sparrow, and one House Sparrow at the vertically oriented 2.5-cm wide UV-absorbing film strips forming stripes separated by 5 cm.

One-hundred and ninety-four strikes were recorded in the third experiment; 20 (10%) were fatal. The total number of strikes differed significantly across all treatments, with 51 (26%) at the clear glass control, 24 (12%) at UVC-O, 20 (10%) at UVC-I, 30 (15%) at REX20, 24 (12%) at REX35, 21 (11%) at NEX1020, and 24 (12%) at RK20 ($\chi^2 = 25.0$, df = 6, $P < 0.001$). Species killed and the windows at which fatalities occurred were: one White-throated Sparrow, one American Tree Sparrow (*Spizella arborea*), five Dark-eyed Juncos, and two House Finches at the clear glass control; one Black-capped Chickadee (*Poecile atricapillus*), one White-throated Sparrow, two House Finches, and one Northern Cardinal at UVC-O; one House Finch at UVC-I; two American Tree Sparrows at REX20; two Dark-eyed Juncos at REX35; and one Mourning Dove (*Zenaida macroura*) at RK20.

Seventy-seven strikes were recorded in the fourth experiment; two (3%) were fatal. The total number of strikes differed significantly across all treatments, with 49 (64%) at the clear glass control, 27 (35%) at the vertically oriented 2.5-cm wide UV-absorbing film strips forming stripes separated by 5 cm, and one (1%) at the CollidEscape covered window ($\chi^2 = 44.99$, df = 2, $P = 0.001$). Eight (30%) of the 27 strikes at the window with the UV-absorbing film stripes occurred over film, there were 14 (52%) strikes at clear glass between film, and five (18%) strikes included parts of both film and non-film areas; there was no significant difference between striped and no striped impact sites ($\chi^2 = 1.64$, df = 1, $P = 0.20$).

Eighty-six strikes were recorded in the fifth experiment; 13 (15%) were fatal. The total number of strikes differed significantly across all treatments with 60 (70%) at the clear glass control, eight (9%) at CUV-O, seven (8%) at CUV-I, two (2%) at S-1R, one (1%) at S-2R-O, four (5%) at S-2R-I, and four (5%) at the GRID ($\chi^2 = 219.23$, df = 6, $P < 0.001$). All 13 fatalities occurred at the clear glass control and were: one Black-capped Chickadee, one White-breasted Nuthatch (*Sitta carolinensis*), two House Finches, one American Goldfinch (*Carduelis tristis*), one American Tree Sparrow, and seven Dark-eyed Juncos.

Fifty-five strikes were recorded in a validating sixth experiment retesting selected treatments of experiment #5; 11 (20%) were fatal. The total number of strikes differed significantly across all treatments, with 38 (69%) at the clear glass control, 11 (20%) at CUV-O, three (5.5%) at S-1R, and three (5.5%) at S-2R-O ($\chi^2 = 60.13$, df = 3, $P = 0.001$). Species numbers and windows at which fatalities occurred were: one Black-capped Chickadee, two American Tree Sparrows, and five Dark-eyed Juncos at the clear glass control, and two American Tree Sparrows and one Dark-eyed Junco at CUV-O.

Flight paths of 67 individual birds flying from the bird feeders toward the windows were recorded during 60 hrs of continuous observation over 14 days to examine the movements of individuals during the sixth experiment. Six (55%) of 11 individuals flying toward the clear glass control moved to avoid and five (45%) hit the window. Fourteen (93%) of 15 individuals flying toward CUV-O moved to avoid and one (7%) hit the window. All 24 individuals flying toward S-1R moved to avoid the window. Fifteen (88%) of 17 individuals flying toward S-2R-O moved to avoid and two (12%) hit the window. One strike in four left no evidence of a collision lasting 24 hrs based on 17 hrs of continuous observation.

## DISCUSSION

The application of clear and reflective UV-absorbing films to the exterior of windows offered some protection from strikes by reducing the deceptive quality of reflections. The use of clear UV-absorbing external films to create stripe patterns had mixed results. The incremental use of 0.32-cm thick plastic strips used to form stripes and then external films in experiments were attempts to create UV signals to learn if test subjects and birds flying in the wild would behave as if they could see and avoid the treated panes. All attempts to create protective patterns visible to birds using a UV-absorbing plastic and film offered a weak UV-reflecting signal, no greater than 13% UV-reflectance. A new clear UV-reflecting exterior film that produced a UV-reflecting signal with 80% reflectance offered an improved opportunity to meaningfully test the utility of UV signals to deter bird–window collisions. The promise of UV signals serving to alert birds to danger was uncertain given that lower wavelengths of UV, blue, and purple colors are often associated with attraction behavior, sexual selection, and finding food (Burkhardt 1982, Bennett and Cuthill 1994, Vitala et al. 1995, Bennett et al. 1996, Hunt et al. 1998).

Color signals used by birds and other animals as warnings or an alert to danger (aposematic coloration) are most often in the upper visual wavelengths perceived as yellows, oranges, and reds. Supporting the questionable value of UV signals to deter window strikes were comparative records of strike rates at wind turbines painted with UV-reflecting and conventional non-UV-reflecting paints (Young et al. 2003). Notwithstanding the ability to attract, it is reasonable to suspect that UV signals could also be used to alert birds to the presence of clear and reflective sheet glass and plastic. Repeated validating field experiments supplemented by detailed recording of avoidance by individual birds revealed that a combination of UV-reflecting and UV-absorbing stripe and grid patterns were effective in preventing bird–window collisions. These results document that birds were able to recognize the window-covering UV stripes and grid pattern as barriers to avoid. Applications that combine alternating and contrasting UV-reflecting and UV-absorbing patterns to existing clear and reflective windows have promise of preventing bird strikes while offering little or no visual distraction for humans.

The results of both flight cage and field experiments provide additional confirmation that birds behave as if clear sheet glass and plastic in the form of windows are invisible, and that several methods are available to effectively prevent bird–window collisions. The clarity and lack of any visible cues best explains twice as many strikes at the non-reflective glass pane compared to a conventional clear window. These findings support the interpretation that decals or other objects such as feathers placed on or hung in front of a window are ineffective at preventing bird strikes when used alone. Increasing their numbers so they uniformly cover the window surface, and separating decals or strings of feathers and beads by 5 to 10 cm provides complete or near-complete avoidance.

One-way films that result in a complete opaque or translucent covering when viewed from outside, but only weakly diminish the view from inside, were expected and confirmed to be effective strike deterrents. The uniformly dense dot pattern created as ceramic frit was effective in alerting birds to the presence of a glass barrier. The presence of dotted ceramic frit glass in the science building at Swarthmore College in Swarthmore, Pennsylvania, USA since installation has experienced as few as two known collisions a year (E. C. Everbach, pers. comm.). This same dotted ceramic frit glass has experienced no known collisions at a corridor in the renovated science building on the campus of Muhlenberg College in Allentown, Pennsylvania, but a dozen collision fatalities have been documented at conventional clear glass panes elsewhere in this same building for 1 year since installation (DK, pers. obs.). The dot or other objects creating patterns of visual noise must be placed on the exterior surface of windows to be visible; exceptions are at see-through sites such as corridors and where glass walls meet at corners and where protective patterns will be visible when placed on interior surfaces.

These experiments further reveal that strike frequency at intensely monitored sites is likely to be incomplete and conservative because some impacts may not leave any evidence of a collision. Moreover, predators and scavengers may have removed some casualties that were not detected such as a Northern Shrike (*Lanius excubitor*) that was seen taking a window casualty during the final field experiment (Klem 1981, Klem et al. 2004).

Methods using UV signals to alert birds to window hazards should have special utility because they offer visual cues in wavelengths that birds are known to see but humans do not (Burkhardt 1982, Bennett and Cuthill 1994, Vitala et al. 1995, Bennett et al. 1996, Hunt et al. 1998). The promise of using UV signals to prevent collisions between birds and windows is especially relevant to architectural professionals for addressing and eliminating avian injury and mortality by retrofitting existing buildings and using new types of glass and plastic panes in new construction.

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# Windows and Vegetation: Primary Factors in Manhattan Bird Collisions

Yigal Gelb[1,*] and Nicole Delacretaz[1]

**Abstract** - Bird collisions in Manhattan (New York City) were studied by analyzing collision data collected from 1997 to 2008 by Project Safe Flight (PSF) participants, representing one of the largest collision monitoring efforts in the nation. Over 5400 bird collisions were recorded during this period, two-thirds of which were fatal. Collisions involved 104 bird species, primarily from the warbler, sparrow, and thrush families, and mostly during spring and fall migration. Most collisions were documented to occur during the day at the lower levels of buildings where large glass exteriors reflected abundant vegetation, or where transparent windows exposed indoor vegetation. Most collisions in Manhattan likely occurred at a smaller number of high-collision sites where strike rates of well over 100 birds per year are considerably higher than previously reported rates. We suggest here that improving our understanding of the factors involved in collisions at such sites could greatly assist in reducing bird collisions.

## Introduction

Bird collisions with human-made structures have been documented extensively for over a century (Klem 1989). After habitat loss and fragmentation, collisions with such structures represent the greatest human-related threat to bird populations (Klem et al. 2004). Species involved in collisions are also listed on the US Fish and Wildlife Service's *Birds of Conservation Concern* and on the *Audubon WatchList* (Shire et al. 2000). Collisions with reflective and transparent plate glass are estimated at 100 to 1000 million birds for the continental US (Klem 1990), posing a threat to resident and migratory birds (Klem 1989, 1990; Veltri and Klem 2005). This threat is likely to increase as more natural habitat is modified through development that incorporates such glass (Klem 1990). Night collisions with structures such as communications towers also pose a threat to nocturnal migrants, especially during inclement weather (Avery et al. 1976, Gauthreaux and Belser 2003, Shire et al. 2000, Veltri and Klem 2005).

In recent years, bird-rescue organizations in Chicago (Chicago Bird Collision Monitors), Toronto (FLAP–Fatal Light Awareness Program), and New York City (NYC Audubon's Project Safe Flight) have documented thousands of collisions at human-made structures, especially during spring and fall migration. However, to date, the majority of bird-collision research consists of data gathered from rural and suburban environments. Additionally, while well-lit skyscrapers were first believed to be involved in most urban

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collisions (Ogden 1996), recent research suggests that nighttime collisions may be more limited in scope (DeCandido 2005). Other research and anecdotal information clearly documents extensive daytime collisions at low-rise buildings (Gelb and Delacretaz 2006; Michael Mesure, FLAP, Toronto, ON, Canada, pers. comm.).

Participants in Project Safe Flight (PSF) have been monitoring bird collisions in Manhattan (New York City) since 1997. This monitoring effort represents one of the largest in the nation, involving tens of program participants who dedicated what amounts to thousands of monitoring hours. By July 2008, participants in this program had recorded over 5400 collisions, which were entered into an online database available on the NYC Audubon website. In this paper, we use these data to answer important questions relating to frequency, timing, and physical context of collisions in Manhattan. Specifically, we sought to test two hypotheses: (a) that the frequency of collisions is highest along those portions of the exterior glass surface that reflect outside vegetation (reflective windows) or display indoor vegetation (transparent windows); and, consequently, (b) that most of these collisions occur during daytime hours when birds are feeding.

## Methods

Since 1997, program participants have recorded a bird collision when a dead or injured bird was found at the base of a building (Dunn 1993; Klem 1989, 1990; Klem et al. 2004; O'Connell 2001). When monitoring the exterior of a building, participants walked the route slowly, looking for birds from the base of the building to the gutter on the near side of the street. Building exteriors (referred to here as "sites") were monitored once a day, usually in the morning hours during the spring (late March to early June) and fall (late August to early November) migration periods. Sites with high collision numbers (at least several collisions a day) were sometimes monitored more than once a day, while sites with low collision numbers (less than one a day) were sometimes monitored less than once a day. Daily monitoring was discontinued after collision numbers dropped substantially at the end of each migration season. Periodic monitoring of a high-collision site during non-migratory seasons indicated that strike rates remained low during these periods. Program participants were trained to follow the same monitoring procedures.

We analyzed Manhattan collision data collected from 1997–2008 to determine the top 20 species involved in collisions (Table 1) and to evaluate the role of daytime factors (vegetation and windows) and nighttime factors (building height and lighting) in causing bird collisions. We were unable to conduct a regression analysis here, as sites were not chosen randomly, and because monitoring effort and start dates differed across sites. Instead, we rank over 180 Manhattan sites to determine the top 10 sites with the highest collision numbers (Fig. 1). For these sites, as well as other sites described in this paper, we indicate total collisions recorded at the site, monitoring dates, and information relating to the factors involved in daytime and nighttime collisions. Window size and vegetation were categorized as follows: 1 = large windows opposite some vegetation; 2 = large windows opposite extensive vegetation, not adjacent to an urban park; and 3 = large windows opposite extensive vegetation, adjacent to an urban park. For the purposes of this analysis: large windows, either reflective or transparent, were 1 m x 2 m, or larger, along the building exterior; extensive vegetation signifies that 50% or more of the windows at the lower levels either reflected exterior vegetation or displayed indoor vegetation and that this vegetation was composed of at least a row of trees with interlocking canopies or dense shrubs, 5–15 m (for reflective windows) or 0–15 m (for transparent windows) from the windowed exterior; some vegetation signifies that less than 50% of the windows at lower levels reflected or displayed vegetation or that vegetation was less dense along the windows; and an urban park was an open space area one-half hectare or more in size, composed of trees and shrubs, opposite the building exterior. Building height was measured in meters. Artificial light emitted from building was categorized as follows: 1 = little to no light emissions, 2 = emissions from internal light source only, and 3 = emissions from internal light and external bright lights at the top of the building. Light intensity was gauged during random nighttime visits to the sites in question and by looking at photographs of the sites at night. In this analysis, we include the "Twin Towers" of the now destroyed World Trade Center complex, noting that monitoring was discontinued in fall 2001. We removed two sites from the top 10 list due to uncertainty relating to the precise building areas that were monitored.

Table 1. Top 20 species involved in collisions in Manhattan, 1997–July 2008. Taxonomy follows the American Ornithologists' Union 7th edition checklist (AOU 2005).

| Scientific name | Common name | Number of collisions 1997–July 2008 |
|---|---|---|
| *Zonotrichia albicollis* Gmelin | White-throated Sparrow | 884 |
| *Geothlypis trichas* L. | Common Yellowthroat | 479 |
| *Junco hyemalis* L. | Dark-eyed Junco | 377 |
| *Seiurus aurocapillus* L. | Ovenbird | 330 |
| *Regulus calendula* L. | Ruby-crowned Kinglet | 225 |
| *Catharus guttatus* Pallas | Hermit Thrush | 176 |
| *Regulus satrapa* Lichtenstein | Golden-crowned Kinglet | 146 |
| *Scolopax minor* Gmelin | American Woodcock | 133 |
| *Mniotilta varia* L. | Black-and-white Warbler | 130 |
| *Dumetella carolinensis* L. | Gray Catbird | 119 |
| *Melospiza melodia* Wilson | Song Sparrow | 118 |
| *Dendroica striata* Forster | Blackpoll Warbler | 103 |
| *Melospiza georgiana* Latham | Swamp Sparrow | 95 |
| *Dendroica caerulescens* Gmelin | Black-throated Blue Warbler | 83 |
| *Parula americana* L. | Northern Parula | 79 |
| *Sphyrapicus varius* L. | Yellow-bellied Sapsucker | 75 |
| *Colaptes auratus* L. | Northern Flicker | 69 |
| *Dendroica magnolia* Wilson | Magnolia Warbler | 62 |
| *Setophaga ruticilla* L. | American Redstart | 56 |
| *Seiurus noveboracensis* Gmelin | Northern Waterthrush | 55 |

In addition to ongoing monitoring of sites across Manhattan, we conducted extensive monitoring during 2005 at two separate locations—a downtown location comprised of six buildings and the midtown location of the Morgan Processing and Distribution Center (Morgan Mail Building) (Fig. 2a).

**Downtown study**

The week-long "downtown study" from 12:00 on May 7th to 12:00 on May 14th of 2005 tested the hypothesis that most collisions occur during the day by intensively monitoring six buildings (40°42'11"N, 74°00'43"W

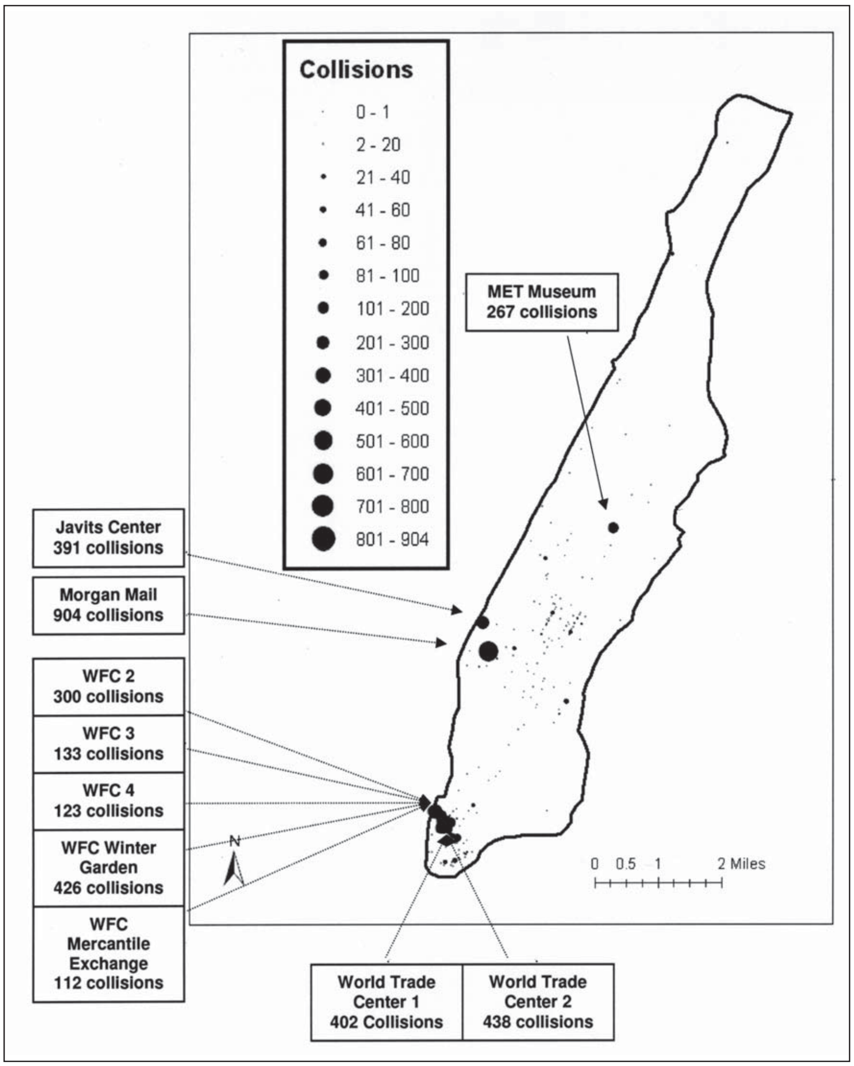


Figure 1. All collision locations across Manhattan 1997–July 2008. The building names and number of collisions are highlighted for the top ten sites with the greatest number of collisions.

at center of the route), four of which were skyscrapers that emitted artificial light during nighttime hours. All but one building included reflective exteriors with some to little vegetation nearby. All exterior walls extended vertically from the base of the buildings to the rooftops, with no setbacks or ledges that could prevent colliding birds from falling to the street level. Building exteriors were purposely chosen so that they faced the general direction of spring migration in order to maximize the potential number of collisions. Proximity to mass transit (i.e., subway stations) was also a factor in selecting study sites in order to ensure easy access for study participants.

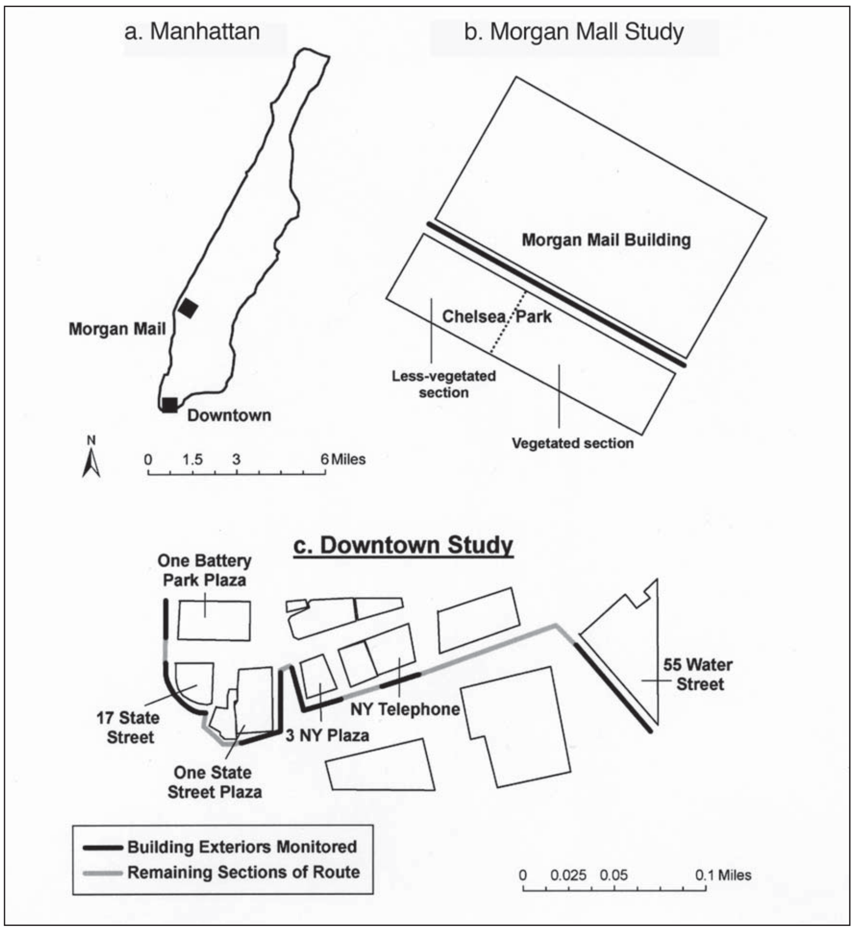


Figure 2. Study sites and sampling methodology, 2005. a) a map of Manhattan showing the location of the Downtown study and the Morgan Mail building. b) a diagramatic sketch of Morgan Mail building. The heavy black line between Chelsea park and the building represents the survey route. The northewest section of Chelsea Park was less vegetated than the southeast sector. c) a map of the Downtown Study. Heavy lines mark the survey route; light grey lines mark the route taken between building sites.

For comparison purposes, we monitored the Morgan Mail Building and the World Financial Center complex, sites not immediately in the study location, but which were already documented to be high-collision sites (defined here as sites with over 100 collisions per year).

The downtown study was conducted during the period when spring collisions generally peak (Fig. 3). In order to accurately document the time of collisions, 22 participants monitored the six building exteriors during the following time periods: 0:00–0:30, 4:00–4:30, 6:00–6:30, 8:00–8:30, 12:00–12:30, 16:00–16:30, and 20:00–20:30. The additional morning session of 6:00–6:30 was added in order to record collisions that would otherwise be hard to detect during the morning commute in this busy downtown area. The same route (590 m) was walked during each monitoring session, beginning at 1 Battery Park Plaza and ending at 55 Water Street. Participants recorded their findings on a data sheet that included the study route and a map on which to mark where birds were found. Morgan Mail and the World Financial Center, the two additional high-collision sites added for comparison purposes, were monitored only once each morning during this study. Skies were mostly clear during the week-long study. The first days had periodic overcast, beginning after midnight on the first night and lasting into the afternoon of the second day, and then beginning before midnight on the second night and dissipating by early morning; no precipitation was recorded throughout the study period. As was our experience in prior years, collisions at sites across the City clearly peaked in mid May. Given that only four collisions were recorded during this study, we were not able to analyze the data statistically.

**Morgan Mail building studies**

We conducted two separate studies at the Morgan Mail Building (Fig. 2b), a six-story office building where relatively high numbers of collisions have

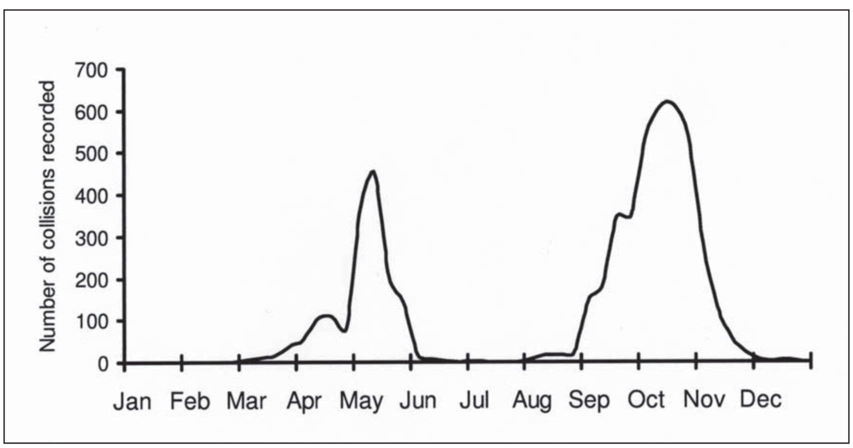


Figure 3. Weekly collision numbers, 1997–July 2008. Data points represent the cumulative number of bird collisions per week for all years during each month.

been recorded since 2002. The building is located in Manhattan between 28th and 29th Streets and between 9th and 10th Avenues (40°45'02"N, 74°00'01"W). The building's exterior was made up of windowless concrete walls for the first two stories and 440 large, reflective glass panels (each 2.3 m x 1.3 m) covering approximately 75% of the remaining four stories (the "windows" actually mask a concrete wall). All exterior walls extended vertically from the base of the building to the rooftop, with no major outcrops or ledges that could prevent colliding birds from falling to the street level. The southern perimeter of this building (247 m) faced a row of short street trees that did not reach the building windows. Across the street was a row of large street trees (mostly *Platanus x acerifolia* Muenchh [London Plane]), many of which were over 20 m tall and reached to the top of the six-story structure. Situated behind this row of trees was a 1.42-ha urban park (Chelsea Park) with more tall trees (mostly London Plane), some of which were also reflected in the building windows. The vegetation at this park was not uniformly distributed; whereas the eastern portion of the park included many large trees, the western portion of the park—amounting to slightly less than half of the entire park—was much less vegetated, partly due to the fact that most of the space was taken up by a large ball-field covered with artificial turf.

The first study, carried out during spring and fall, tested the hypothesis that the frequency of collisions is highest along those portions of the exterior glass surface that reflect outside vegetation by recording the locations of collision victims along the building's southern perimeter. As noted above, the eastern portion of the southern perimeter faced more vegetation than did the western portion. To estimate the quantity of vegetation in each of these sections, we divided the southern perimeter into approximately equal halves and counted the number of trees in each half that reached up to the fifth and sixth floors along the sidewalk opposite the building. There were 12 trees along the eastern half ("vegetated" section) and four trees along the western half ("less-vegetated" section). The positions of dead and injured birds found at the base of the building were carefully noted and assigned to one or the other of these two sections. In some instances, especially during the spring, volunteers did not record the precise locations of dead and injured birds, and those data were not included in the statistical comparison of collisions along the vegetated vs. less-vegetated sections.

The second study, referred to here as "the three-day study" (October 18 to October 20, 2005), tested whether most collisions occur during the day in areas where the exterior glass surface reflects outside vegetation. In this study, eight participants monitored the building exterior during the following time periods: 6:45–7:15, 9:00–9:30, 12:00–12:30, 15:00–15:30, and 19:00–19:30. Sunrise during this study was at approximately 7:10 and sunset was at approximately 18:10. Weather conditions during the study were generally favorable, with little to no cloud cover throughout the study period. Data were analyzed using an exact binomial test (R 2.7.2 software, R development Core Team, 2008, http://www.R-project.org).

The collision data presented here are very likely an underestimate of the true number of collisions because of our inability to continually monitor all sites. Additionally, "removal bias," i.e., the removal of dead and injured birds by predators and scavengers (Dunn 1993, Klem et al. 2004, O'Connell 2001) or by street sweepers and building maintenance staff (Klem 1990, O'Connell 2001) further reduces the true number. To correct for these sources of bias, we substantially increased the monitoring frequency at the two sites mentioned above. While not eliminating these sources of bias, the increased monitoring effort represents a considerable improvement over monitoring that is performed only once a day. It is unlikely that the downtown area included many scavengers, given the scarcity of natural habitat at the site; bird carcasses that remained intact for over a day at the base of the Morgan Mail building suggest that removal by predators was not a serious factor at this site as well. Street sweepers were more prevalent in the downtown study, and could have been a biasing factor.

We used binomial goodness-of-fit, two-tailed test (SPSS 12.0.0 for Windows, release September 2003) to evaluate experimental results. We considered test results to be statistically significant when $P < 0.05$.

## Results

### Downtown study

Participants recorded only four collisions during the downtown study, two of which were fatal. Birds found during the one-week study were distributed among monitoring periods as follows: 0:00–0:30, 0 birds; 4:00–4:30, 1 bird; 6:00–6:30, 1 bird; 8:00–8:30, 2 birds; 12:00–12:30, 0 birds; 16:00–16:30, 0 birds; and 20:00–20:30, 0 birds. The four collisions occurred at four different buildings and were distributed as follows: 17 State Street, 1 collision; 1 State Plaza, 1 collision; 3 New York Plaza, 1 collision; and 55 water street, 1 collision. All collision sites held large windows with some vegetation adjacent to them and were at least 77 m high. During the same period, we recorded 14 and 24 collisions at the Morgan Mail Building and the World Financial Center, respectively.

### Morgan Mail studies

Of the 251 collisions recorded during the spring and fall 2005 periods at Morgan Mail, we mapped the collision locations of 144. Strike frequency differed significantly between the vegetated (105) and less-vegetated (39) halves of the southern perimeter (exact binomial test: 2-tailed, estimated proportions are respectively equal to 73% and 27%, $P < 0.0001$).

During the three-day study at Morgan Mail, participants recorded 28 collisions involving 13 different bird species, 23 of which were fatal (82%). Dead and injured birds found during this study were distributed among monitoring periods as follows: 6:45–7:15, 6 birds; 9:00–9:30, 13 birds; 12:00–12:30, 7 birds; 15:00–15:30, 2 birds; and 19:00–19:30, 0 birds (Fig. 4). We analyzed the collision by splitting them in two categories: daytime collisions (7.10 am–6.10 pm) and nighttime collisions (6.10 pm to 7.10 am). Among the 28 collisions recorded, 23 occurred during the day and 5 during the night.

The data from Morgan Mail during the three-day study demonstrate that the proportion of dead birds found during the day is significantly higher than that found during the night (exact binomial test: 2-tailed,estimated proportions are respectively equal to 82% and 18%, $P = 0.0009$; Fig. 4).

Of the total number found, 27 were found along the vegetated southern perimeter, and only one was found along the un-vegetated western perimeter.

## Discussion

Our comparison of collision numbers between Morgan Mail's vegetated and less-vegetated sections supports our hypothesis that the frequency of collisions is highest along those portions of the exterior glass surface that reflect outside vegetation. The three-day study revealed a statistically significant disparity in collision rates of about five to two—very similar to the corresponding numbers of tall trees at each of these sections. Additionally, we recorded only four collisions along the less -vegetated exteriors of the six downtown buildings that were monitored intensively during the downtown study, compared with 38 collisions at the more vegetated, and less monitored, sites of Morgan Mail and World Financial Center. From 1997 to mid-2008, participants recorded more than 5400 bird collisions in Manhattan, two-thirds of which were fatal. One hundred four bird species were involved in these collisions (see Appendix 1), most of which were passerines from the warbler, sparrow, and thrush families. Most collisions involved passage-migrants during spring and fall migration (Fig. 3).

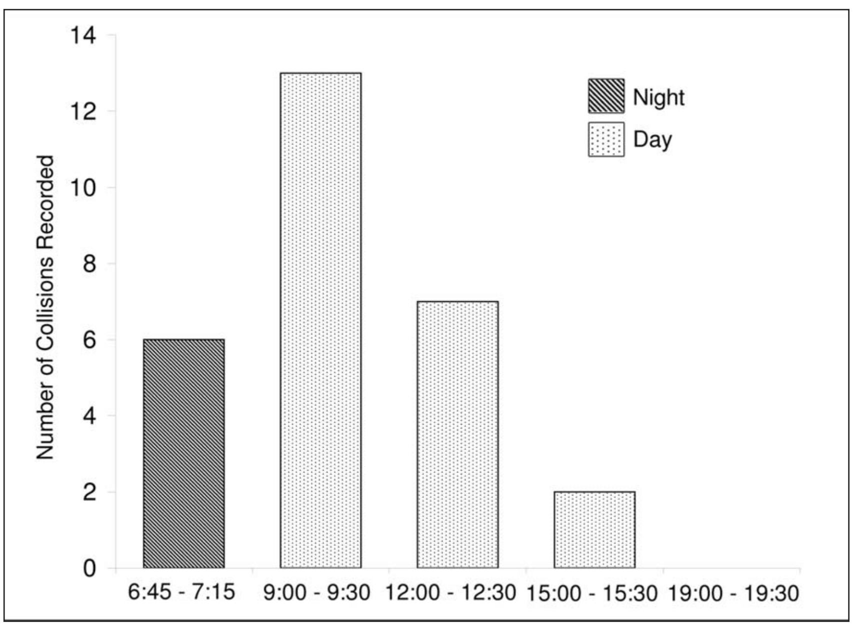


Figure 4. Time of collision at Morgan Mail–Three-day cumulative: October 18th–October 20th 2005.

Collision numbers for Manhattan's top-10 collision sites ranged from 904 to 112 (Table 2). Of the 180 sites analyzed, several of which were tall structures, about 66% registered collision numbers ranging only from 1–10 (Fig. 1). All ten sites on the top-10 list included large windows. All sites incorporated vegetation, with the Twin Towers and Winter Garden including visible indoor vegetation. Eight of the sites incorporated extensive vegetation, four of which were also opposite an urban park. Four of the sites were low-rise buildings (<40 m), three of which were mostly dark during the night. The analysis of Manhattan's top-10 collision sites lends further support to our hypothesis that both reflective and transparent windows are involved in collisions at vegetated sites by clearly documenting high collision numbers at sites with extensive vegetation opposite large windows. While more research is needed to quantify the extent of collisions across Manhattan, it is likely that the majority of collisions occur at only a handful of high-collision sites that incorporate these characteristics.

Given that most collisions seem to occur at windowed exteriors that incorporate vegetation, we find strong evidence to support our second hypothesis: that most collisions occur during daytime hours. Data gathered from the three-day study at Morgan Mail show that most collisions occurred between 6.45am and 9am, but also show that collisions occurred during daytime, as dead and injured birds were retrieved as late as 3 pm. Additionally, the single nighttime collision recorded during the spring week-long downtown study, although not representative statistically, suggests that nighttime collisions at tall urban structures may not be as pervasive as once thought especially since the nighttime monitoring during that study was intense and included four skyscrapers during the week of peak migration. This finding also supports previous research conducted in Manhattan, which documented very few nighttime collisions at the very tall and well-lit Empire State Building (DeCandido 2005).

Table 2. Top 10 collision sites in Manhattan, 1997–July 2008. N = cumulative number of collisions during the study period, W+V = window size and vegetation[A], Height = building height (m), and AL = artificial light emitted from building[B].

| Location | N | W+V | Height | AL |
|---|---|---|---|---|
| Morgan Mail | 904 | 3 | 30 (est.) | 1 |
| World Trade Center 2 | 438 | 1 | 415 | 2 |
| World Financial Center Winter Garden | 426 | 2 | 38 | 2 |
| World Trade Center 1 | 402 | 2 | 417 | 3 |
| Jacob Javits Convention Center | 391 | 3 | 30 (est.) | 1 |
| World Financial Center 2 | 300 | 3 | 197 | 2 |
| Metropolitan Museum of Art | 267 | 3 | 30 (est.) | 1 |
| World Financial Center 3 | 133 | 3 | 225 | 2 |
| World Financial Center 4 | 123 | 2 | 152 | 2 |
| WFC - Mercantile Exchange | 112 | 2 | 78 | 2 |

[A]1 = large windows, some vegetation, 2 = large windows, extensive vegetation, no park, and 3 = Large windows, extensive vegetation, near urban park.
[B]1 = little to no light, 2 = internal light only, and 3 = internal and external light.

Our analysis of Manhattan's top-10 collision sites further supports our hypothesis by showing that four of the top collision sites were low-rise buildings (<40 m), most of which were dark during the night. Additionally, the five skyscrapers on this list (>100 m) were also found to incorporate large, reflective windows opposite vegetation.

While compelling, these findings do not prove that tall, well-lit buildings do not pose a threat to nocturnal migrants passing through an urban environment. The low number of bird strikes recorded during the downtown study may simply reflect the fact that during periods with good weather and relatively clear skies, the rate of nighttime collisions at tall structures is low; a phenomenon also documented at communications towers (Avery et al. 1976, Cochran and Graber 1958). Also, the high collision numbers reported for the Twin Towers may have been partly due to the buildings' ability to attract higher numbers of birds as a result of their extreme height (almost double the height of the next tallest skyscraper on the list) and bright lights. However, participants who monitored these buildings indicated that many of the collisions at these sites were still seen to occur during the day, and it remains unclear what proportion, if any, actually occurred during the night. It is also possible that nighttime collisions may be more prevalent in other geographic locations where wind patterns and other factors may differ.

Our research finds strike rates at high-collision sites to be significantly higher than previously reported. Other studies carried out in non-urban areas estimated about 30 collisions per year per building at various high-collision sites (Dunn 1993, Klem 1990, O'Connell 2001). At Manhattan's high-collision sites, well over 100 collisions were recorded annually. Additional anecdotal evidence from similar sites in Toronto, ON, Canada and Great Neck, NY suggests that even exteriors of 40 m or less can be associated with hundreds of collisions per year (Michael Mesure, pers. comm.; and Valerie DiNatale, Project Leader, Sterling Realty, Great Neck, NY, pers. comm.; respectively). Given that such sites can be found throughout the country, the true number of annual collisions may be higher than previously estimated.

In contrast with other research, we find that most collisions occur during spring and fall migration, involving mostly passage-migrants (Appendix 1). Both Klem (1989) and Dunn (1993) focused on sites with bird feeders, a fact which could have inflated the relative proportion of collisions that occur during winter. Both our results and those reported by Ogden (1996) and O'Connell (2001) indicate that sites without feeders witness significantly more collisions during spring and fall compared with summer and winter. More research is needed to accurately estimate seasonal strike rates across North America.

The increasing usage of exterior glass together with the continuing popularity of landscaping likely presents a threat to migratory bird species. Of particular concern are buildings that incorporate the characteristics of high-collision sites—large glass exteriors opposite abundant vegetation. Our findings suggest that more research is necessary to verify and document the role of such buildings in causing bird collisions, both in urban and non-urban environments. Given that our urban and suburban centers continue to expand into rural landscapes where many migratory birds can be found during spring and fall, this knowledge would prove very valuable in guiding efforts aimed at reducing bird collisions.

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**Appendix 1**. Totals of the 104 Species found from 1997–July 2008.

| Scientific name | Authority | Common name | Total # found |
|---|---|---|---|
| *Zonotrichia albicollis* | Gmelin | White-throated Sparrow | 884 |
| *Geothlypis trichas* | Linnaeus | Common Yellowthroat | 479 |
| *Junco hyemalis* | Linnaeus | Dark-eyed Junco | 377 |
| *Seiurus aurocapillus* | Linnaeus | Ovenbird | 330 |
| *Regulus calendula* | Linnaeus | Ruby-crowned Kinglet | 225 |
| *Catharus guttatus* | Pallas | Hermit Thrush | 176 |
| *Regulus satrapa* | Lichtenstein | Golden-crowned Kinglet | 146 |
| *Scolopax minor* | Gmelin | American Woodcock | 133 |
| *Mniotilta varia* | Linnaeus | Black-and-white Warbler | 130 |
| *Dumetella carolinensis* | Linnaeus | Gray Catbird | 119 |
| *Melospiza melodia* | Wilson | Song Sparrow | 118 |
| *Dendroica striata* | Forster | Blackpoll Warbler | 103 |
| *Melospiza georgiana* | Latham | Swamp Sparrow | 95 |
| *Dendroica caerulescens* | Gmelin | Black-throated Blue Warbler | 83 |
| *Parula americana* | Linnaeus | Northern Parula | 79 |
| *Sphyrapicus varius* | Linnaeus | Yellow-bellied Sapsucker | 75 |
| *Colaptes auratus* | Linnaeus | Northern Flicker | 69 |
| *Dendroica magnolia* | Wilson | Magnolia Warbler | 62 |
| *Setophaga ruticilla* | Linnaeus | American Redstart | 56 |
| *Seiurus noveboracensis* | Gmelin | Northern Waterthrush | 55 |
| *Certhia americana* | Bonaparte | Brown Creeper | 54 |
| *Dendroica coronata* | Linnaeus | Yellow-rumped Warbler | 54 |
| *Turdus migratorius* | Linnaeus | American Robin | 50 |
| *Hylocichla mustelina* | Gmelin | Wood Thrush | 50 |
| *Catharus ustulatus* | Nuttall | Swainson's Thrush | 42 |
| *Archilochus colubris* | Linnaeus | Ruby-throated Hummingbird | 36 |
| *Troglodytes troglodytes* | Linnaeus | Winter Wren | 36 |
| *Vermivora ruficapilla* | Wilson | Nashville Warbler | 30 |
| *Passerella iliaca* | Merrem | Fox Sparrow | 28 |
| *Dendroica virens* | Gmelin | Black-throated Green Warbler | 26 |
| *Vireo olivaceus* | Linnaeus | Red-eyed Vireo | 26 |
| *Dendroica palmarum* | Linnaeus | Palm Warbler | 25 |
| *Catharus fuscescens* | Stephens | Veery | 25 |
| *Zenaida macroura* | Linnaeus | Mourning Dove | 24 |
| *Melospiza lincolnii* | Audubon | Lincoln's Sparrow | 23 |
| *Passer domesticus* | Linnaeus | House Sparrow | 21 |
| *Poecile atricapilla* | Linnaeus | Black-capped Chickadee | 20 |
| *Wilsonia canadensis* | Linnaeus | Canada Warbler | 19 |
| *Dendroica pensylvanica* | Linnaeus | Chestnut-sided Warbler | 19 |
| *Dendroica pinus* | Wilson | Pine Warbler | 19 |
| *Sitta canadensis* | Linnaeus | Red-breasted Nuthatch | 19 |
| *Passerina cyanea* | Linnaeus | Indigo Bunting | 16 |
| *Columba livia* | Gmelin | Rock Dove | 16 |
| *Pipilo erythrophthalmus* | Linnaeus | Eastern Towhee | 15 |
| *Piranga olivacea* | Gmelin | Scarlet Tanager | 15 |

| Scientific name | Authority | Common name | Total # found |
|---|---|---|---|
| *Troglodytes aedon* | Vieillot | House Wren | 14 |
| *Oporornis philadelphia* | Wilson | Mourning Warbler | 14 |
| *Pheucticus ludovicianus* | Linnaeus | Rose-breasted Grosbeak | 14 |
| *Catharus minimus* | Lafresnaye | Gray-cheeked Thrush | 13 |
| *Bombycilla cedrorum* | Vieillot | Cedar Waxwing | 12 |
| *Vermivora peregrina* | Wilson | Tennessee Warbler | 12 |
| *Dendroica fusca* | Muller | Blackburnian Warbler | 10 |
| *Sitta carolinensis* | Latham | White-breasted Nuthatch | 10 |
| *Wilsonia pusilla* | Wilson | Wilson's Warbler | 10 |
| *Toxostoma rufum* | Linnaeus | Brown Thrasher | 9 |
| *Cistothorus palustris* | Wilson | Marsh Wren | 9 |
| *Rallus limicola* | Vieillot | Virginia Rail | 9 |
| *Cyanocitta cristata* | Linnaeus | Blue Jay | 8 |
| *Coccyzus americanus* | Linnaeus | Yellow-billed cuckoo | 8 |
| *Icterus galbula* | Linnaeus | Baltimore Oriole | 7 |
| *Oporornis agilis* | Wilson | Connecticut Warbler | 7 |
| *Dendroica castanea* | Wilson | Bay-breasted Warbler | 6 |
| *Vireo solitarius* | Wilson | Blue-headed Vireo | 6 |
| *Sayornis phoebe* | Latham | Eastern Phoebe | 6 |
| *Carpodacus mexicanus* | Muller | House Finch | 6 |
| *Melanerpes carolinus* | Linnaeus | Red-bellied Woodpecker | 6 |
| *Dendroica petechia* | Linnaeus | Yellow Warbler | 6 |
| *Carduelis tristis* | Linnaeus | American Goldfinch | 5 |
| *Spizella passerina* | Bechstein | Chipping Sparrow | 5 |
| *Passerculus sandwichensis* | Gmelin | Savannah Sparrow | 5 |
| *Helmitheros vermivorum* | Gmelin | Worm-eating Warbler | 5 |
| *Icteria virens* | Linnaeus | Yellow-breasted Chat | 5 |
| *Spizella pusilla* | Wilson | Field Sparrow | 4 |
| *Zonotrichia leucophrys* | Gmelin | White-crowned Sparrow | 4 |
| *Quiscalus quiscula* | Linnaeus | Common Grackle | 3 |
| *Oporornis formosus* | Wilson | Kentucky Warbler | 3 |
| *Falco peregrinus* | Gmelin | Peregrine Falcon | 3 |
| *Baeolophus bicolor* | Linnaeus | Tufted Titmouse | 3 |
| *Empidonax flaviventris* | Baird | Yellow-bellied Flycatcher | 3 |
| *Hirundo rustica* | Linnaeus | Barn Swallow | 2 |
| *Megaceryle alcyon* | Linnaeus | Belted Kingfisher | 2 |
| *Vermivora pinus* | Linnaeus | Blue-winged Warbler | 2 |
| *Wilsonia citrina* | Boddaert | Hooded Warbler | 2 |
| *Seiurus motacilla* | Vieillot | Louisiana Waterthrush | 2 |
| *Dendroica discolor* | Vieillot | Prairie Warbler | 2 |
| *Vireo flavifrons* | Vieillot | Yellow-throated Vireo | 2 |
| *Fulica americana* | Gmelin | American Coot | 1 |
| *Falco sparverius* | Linnaeus | American Kestrel | 1 |
| *Coccyzus erythropthalmus* | Wilson | Black-billed Cuckoo | 1 |
| *Molothrus ater* | Boddaert | Brown-headed Cowbird | 1 |
| *Dendroica tigrina* | Gmelin | Cape May Warbler | 1 |
| *Caprimulgus carolinensis* | Gmelin | Chuck-will's-Widow | 1 |

| Scientific name | Authority | Common name | Total # found |
|---|---|---|---|
| *Picoides pubescens* | Linnaeus | Downy Woodpecker | 1 |
| *Sialia sialis* | Linnaeus | Eastern Bluebird | 1 |
| *Tyrannus tyrannus* | Linnaeus | Eastern Kingbird | 1 |
| *Contopus virens* | Linnaeus | Eastern Wood-Pewee | 1 |
| *Passerina amoena* | Say | Lazuli Bunting | 1 |
| *Empidonax minimus* | Baird | Least Flycatcher | 1 |
| *Icterus spurius* | Linnaeus | Orchard Oriole | 1 |
| *Family Strigidae* | Wagler | Owl Unidentified | 1 |
| *Carpodacus purpureus* | Gmelin | Purple Finch | 1 |
| *Ammodramus maritimus* | Wilson | Seaside Sparrow | 1 |
| *Porzana carolina* | Linnaeus | Sora | 1 |
| *Vireo griseus* | Boddaert | White-Eyed Vireo | 1 |

# RIPARIAN BIRD COMMUNITY STRUCTURE IN PORTLAND, OREGON: HABITAT, URBANIZATION, AND SPATIAL SCALE PATTERNS

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# RIPARIAN BIRD COMMUNITY STRUCTURE IN PORTLAND, OREGON: HABITAT, URBANIZATION, AND SPATIAL SCALE PATTERNS

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*Abstract.* In 1999, we surveyed breeding bird and plant communities along 54 streams in the Portland, Oregon, metropolitan region to link bird community metrics with structural and spatial characteristics of urban riparian areas. Canonical correspondence analysis produced two explanatory axes relating to vegetation and road density. Total and non-native bird abundance was higher in narrow forests. Native bird abundance was greater in narrow forests surrounded by undeveloped lands; native species richness and diversity were greater in less-developed areas. Native resident and short-distance-migrant abundance was higher in narrow forests, and diversity was positively associated with developed lands. Neotropical migrant abundance, richness, and diversity were greater in open-canopied areas with fewer roads. We examined spatial relationships by regressing bird variables on satellite-derived forest canopy cover, area of undeveloped lands, and street density in a series of 50-m buffers within a 500-m radius around study sites. Non-native bird abundance decreased with increasing canopy cover within 450 m, but most other relationships were strongest at smaller scales (50–100 m). Our results suggest that increasing urban canopy cover is the most valuable land management action for conserving native breeding birds. A hierarchical scheme for Neotropical migrant conservation might include increasing forest canopy within 450 m of streams to control non-native species and cowbirds; reducing street density within a 100-m radius of streams; and conserving or planting onsite native trees and shrubs.

*Key words:* *edge effects, Neotropical migrant, non-native species, riparian, spatial scale, urban.*

## Estructura de Comunidades Riparias de Aves en Portland, Oregon: Hábitat, Urbanización y Patrones de Escala Espacial

*Resumen.* Censamos las comunidades de aves reproductivas y plantas a lo largo de 54 arroyos en el área metropolitana de Portland, Oregon en 1999 para conectar medidas de comunidades de aves con características estructurales y espaciales de zonas riparias urbanas. Análisis de correspondencia canónica produjeron dos ejes explicativos relacionados con la vegetación y la densidad de carreteras. La abundancia total de aves y la de aves no nativas fueron mayores en bosques estrechos. La abundancia de aves nativas fue mayor en bosques estrechos rodeados por terrenos rurales y la riqueza y diversidad de especies fueron mayores en áreas menos desarrolladas. La abundancia de residentes nativas y migratorias de corta distancia fue mayor en bosques estrechos y su diversidad estuvo asociada positivamente con terrenos desarrollados. La abundancia, riqueza y diversidad de las migratorias neotropicales fueron mayores en áreas de dosel abierto y con pocas carreteras. Examinamos las relaciones espaciales mediante regresiones entre variables de aves y la cobertura del dosel derivada de imágenes satelitales, el área de terrenos sin desarrollar y la densidad de calles en una serie de áreas de 50 m de ancho en un radio de 500 m alrededor de los sitios de estudio. La abundancia de aves no nativas disminuyó con aumentos en la cobertura del dosel hasta 450 m, pero la mayoría de las demás relaciones fueron más fuertes a escalas menores (50–100 m). Nuestros resultados sugieren que el incremento de la cobertura del dosel en áreas urbanas es la estrategia de manejo más valiosa para conservar las aves nativas que se reproducen en el área. Un esquema jerárquico para la conservación de las migratorias neotropicales podría incluir aumentar la cobertura de bosque a menos de 450 m de los arroyos para controlar a las especies no nativas y a los *Molothrus*, reducir la densidad de calles dentro de un radio de 100 m alrededor de los arroyos y conservar o plantar árboles y arbustos nativos.

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## INTRODUCTION

Human population growth, combined with an increasing proportion of citizens living in or near cities, is fundamentally altering wildlife habitat in developed areas (Parlange 1998, Pickett et al. 2001). From 1992 to 1997, the pace of U.S. development increased to 890 000 ha per year, more than 1.5 times that of the previous decade (USDA Natural Resources Conservation Service 2000). Ecologists view urban areas as ecosystems with distinct structures, processes, and functions (McDonnell and Pickett 1990, Marzluff et al. 1998, Parlange 1998). However, we are still learning how to manage urban ecosystems for both people and wildlife, and research results are confounded by lack of consensus for defining and measuring urbanization. The rapid proliferation of urban habitats adds a sense of urgency to these efforts.

Urbanization creates buildings and road systems, altering the quality and quantity of available bird habitat, patch dynamics, and disturbance regimes (Baschak and Brown 1995, Martin and Finch 1995, Marzluff et al. 1998). Urban forests typically become fragmented and simplified, structurally and biologically, compared to native habitats (Case 1996, Germaine et al. 1998, Pavlik and Pavlik 2000). Some bird community changes, such as increased abundance of non-native and generalist species and decreased species richness, appear common to cities worldwide (Clergeau et al. 1998, Marzluff et al. 1998). Other changes may be region specific (Clergeau et al. 2001). For example, Neotropical migratory birds are negatively associated with urbanization in some parts of the U.S. and Canada, but whether this pattern exists in the northwestern U.S. is uncertain (Croonquist and Brooks 1993, Friesen et al. 1995, Mancke and Gavin 2000). Brown-headed Cowbird (*Molothrus ater*) abundance may increase or decline with forest structure or canopy cover, possibly due to geographical, spatial scale, or fragmentation differences among studies (Gates and Giffen 1991, Hahn and Hatfield 1995, Larison et al. 1998).

Evidence linking urbanization to habitat structure and non-native plant communities has important implications for native birds. Native birds tend to be associated with native plants and structurally complex habitats (Goldstein et al. 1986, Mills et al. 1991, Case 1996), while non-native birds are typically associated with non-native plants and structurally simplified habitats (Mills et al. 1991, Case 1996, Pavlik and Pavlik 2000). In areas with naturally complex vegetation structure such as the Pacific Northwest, the habitat loss and simplification, non-native species invasions, and disturbance accompanying urbanization are likely to alter native bird communities.

In 1999, we surveyed breeding bird and plant communities in 54 sites along small perennial streams in the Portland, Oregon, urban region. Our first goal was to determine what habitat or development variables were associated with bird community measures (total, non-native, native, and Neotropical migratory bird abundance, species richness, and Shannon diversity). Our second goal was to explore the spatial extent, within 500 m of each site, of the relationships between bird community variables, forest canopy cover, and paved street density as a measure of urbanization.

## METHODS

### STUDY AREA

The Portland metropolitan area lies in northwestern Oregon in the Pacific Northwest (45°N, 122°W). The study area includes the 95 648-ha urban growth boundary set by Metro, the greater Portland area's elected regional government, plus a buffer of 1.6 km. The three counties in which the study area is located comprise approximately 3% of the state's total area and more than 42% of the state's population, or 1.44 million residents; of these, 94% live in urban and suburban areas (Loy et al. 2001). Projections estimate a 65% population increase by 2040 (Portland State University 2000, Torgerson 2000).

Portland's climate is mild, with wet winters and warm, dry summers. Precipitation averages 95 cm per year, falling primarily as rain from October through May (Portland Parks and Recreation 1995). The average temperature is 3.8°C in January and 19.8°C in July (Torgerson 2000). Rivers and their numerous tributaries flow for over 1600 km within the urban growth boundary. The study area originally contained approximately 2092 km of perennial streams, but an estimated 644 km (31%) have been lost or diverted underground (Metro Regional Services 2002). In undisturbed conditions, lowlands and

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riparian areas were dominated by Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), Oregon white oak (*Quercus garryana*), with extensive black cottonwood (*Populus trichocarpa*) stands along larger streams and rivers (Lev and Sharp 1991, Poracsky 1991). Present-day riparian habitats are predominately deciduous and contain Oregon ash (*Fraxinus latifolia*), red alder (*Alnus rubra*), willow (*Salix* spp.), and a few remnant cottonwood patches.

In 1989, an estimated 59 489 ha of natural areas remained in the Portland region; a decade later 6475 ha (11%) had been lost (J. O. Price, Metro Data Resources Center, pers. comm.). However, nearly 11% (10 092 ha) of total lands within the urban growth boundary are preserved as parks, greenspaces, and open spaces.

### SITE SELECTION

We used ArcView version 3.1 (Environmental Systems Research Institute 1998) and Metro's GIS themes including parks and open space, stream routes, tax lots, and 1998 and 1999 high-resolution aerial photos to identify study sites on public lands (for metadata see Metro Regional Services 2003). Our *a priori* selection criteria were small, deciduous-dominated perennial streams (approximately 1–8 m channel width), on primarily public lands, and of sufficient size to accommodate four or five point-count stations (550–700 m). We focused on small streams because they are numerous in the region and on deciduous habitat because it is currently the most common habitat type along small streams in the study area. We identified 57 sites meeting our criteria within the study area, but omitted three of those sites: one for safety concerns, and two because steep slopes caused too much water noise to hear birds.

The study sites represent a wide variety of forest widths along a gradient of habitat and urbanization from narrow forests in highly developed areas, to wide forests with a variety of adjacent land uses. All sites contained some forest cover along the stream; some sites' forests were hundreds of meters wide, while two sites had only a few streamside trees. In narrow forests, the surrounding urbanization level is probably more influential on riparian bird community dynamics than in wide forests. We did not distinguish between development types, but residential development was the predominant use, with some industrial lands. We did not attempt to control for forest width or urbanization, but used all available study sites meeting our criteria.

### BIRD SAMPLING

At each site we established four or five 50-m-radius point-count stations centered at the edge of the stream for bird surveys, each separated by 150 m. One result of this method is that the stream comprises part of the land cover within the 50-m point-count radius; streams were generally small but variable; thus stream width may have introduced variation that was unaccounted for in the results. For bird surveys, a line-transect method is appropriate in linear habitats and could alleviate this drawback, but we used point-counts because streams were not linear and because we were frequently unable to walk through the invasive Himalayan blackberry (*Rubus discolor*) brambles.

Ralph et al. (1993) comment that under most circumstances, one seasonal visit to 9–12 point-count stations should be adequate to characterize avifauna at a site in an intensive, within-study plot survey effort. However, our sites were not sufficiently large to yield 9–12 stations; instead we increased the number of visits to each site. We surveyed birds three times per site during May and June 1999 following Ralph et al.'s (1993) point-count protocol. Flyovers, waterfowl, and migratory flocks were recorded but excluded from analysis. Three observers surveyed each site once to reduce observer bias. We alternated starting ends and survey order (first or second site surveyed that day) to reduce time-of-day bias. We recorded each bird seen or heard at a point-count station within a 50-m radius; point-counts lasted for 8 min (recorded as detected in 0–5 or 5–8 min to enable comparison with other studies). We began surveys at sunrise and ended by 09:30, avoiding rainy or windy conditions.

Our index of bird abundance is the average number of bird detections per point-count station, per survey because our sites contained either four or five point-count stations. We calculated species richness and Shannon diversity (Magurran 1988) using this index of abundance.

### VEGETATION SAMPLING

In June and July 1999, we measured or visually estimated habitat variables relating to riparian forest structure, composition, and human development (Table 1). We established three 7-m-radius plots near the stream for each point-count station (6% of total point-count area). One plot was located adjacent to the stream at the point-count station, and the other two were located 15 m perpendicular to the stream and 25 m from each side of the first plot. Within each plot we visually estimated total cover in each vegetation layer; percent total for each plant species; percent native and non-native cover in herbaceous, shrub, and tree canopy layers; and percent cover of trails, buildings, and paved surfaces within each vegetation plot. The experienced field crew practiced visual estimation together for one week prior to surveys. Our goal was consistency: a two-person team surveyed each site and we continually alternated team members and calibrated estimates to reduce observer bias. We were usually within 10% of one another's estimates.

Data for the three vegetation plots were averaged for each point-count station, then stations were averaged to yield site-level habitat information. We measured total forest width (stream excluded) perpendicular to the stream at each point-count station using ArcView GIS Version 3.1 and 1999 aerial photos, and averaged data by site.

### MEASURES OF DEVELOPMENT AND NATURAL LAND COVER

The combination of site-specific information and the scale of our study limited our land-cover data sources. For example, we were unable to use U.S. Census Bureau data because the census blocks were too large to accurately characterize a site or buffer. Calculating building density would have required hand-digitizing all structures, and many were not visible beneath canopy cover. Thus, for onsite urbanization, we estimated the percent cover of buildings, human trails, and paved surfaces in vegetation plots.

We used three measures for larger-scale analyses: satellite imagery canopy cover (24-m rasters), the proportion of undeveloped lands (measured annually by Metro), and paved road density, a surrogate measure for urbanization. In the Puget Sound region of Washington State, which is similar in terms of ecology and urban development to our study area (although a larger urban region), transit systems account for over 60% of pavement in urbanized watersheds and provide a viable indicator of the intensity of urbanization and associated negative ecological impacts on streams and wildlife (May et al. 1997, May and Horner 2000).

### SPATIAL ANALYSES

To assess the spatial influence of tree canopy cover and development variables on bird communities, we drew ten buffers at 50-m-radius increments, centered on the stream, around each study site using ArcView GIS version 3.1 (Environmental Systems Research Institute 1998). Once buffered, some of our sites overlapped. We minimized this problem of nonindependence by discarding one site in each pair of sites with more than 10% overlap, selecting the discard to maximize spatial distribution of the remaining sites. Six sites were removed and the remaining 48 sites were retained for spatial analyses. We used separate buffers (i.e., larger-radius buffers did not include the area already measured by smaller-radius buffers) to further minimize spatial nonindependence. For example, the first buffer covered 50 m laterally along each side of the stream reach, the second buffer covered 50–100 m, and so on until each side of the stream was buffered out to 500 m.

Metro's 1998 canopy cover GIS layer (24-m raster resolution satellite imagery) generalized each raster into four canopy cover classes (0–25%, 26–50%, 51–75%, and 76–100%; Metro Regional Services 2003). Adjacent same-class pixels were aggregated and converted to polygons in a shape file; polygons could then be ''clipped'' to precisely fit site buffers. We calculated average canopy cover class for each buffer. We used canopy cover instead of riparian corridor width for spatial analyses because narrow corridors fell only within the first 50-m buffer, whereas satellite canopy cover could be calculated for every buffer.

### STATISTICAL ANALYSES

*Canonical correspondence analysis.* We performed Canonical Correspondence Analysis (CCA) using PC-ORD v. 4.20 (McCune and Mefford 1999) to linearly relate multiple response and explanatory variables (ter Braak 1986, Palmer 1993). Three of our 54 study sites were missing one or more data values because no aerial photographs were available, and were omitted from this portion of the analysis. We retained all CCA axes that explained more than 10% of variation in the data.

TABLE 1. Mean ± SE variables describing the bird community, vegetation, and urban development of 54 riparian sites surveyed around Portland, Oregon, May and June 1999. We used Canonical Correspondence Analysis (CCA) to cluster response and explanatory variables, producing two explanatory axes (Fig. 1). The "Correlation with canonical axes" columns show correlations with each CCA explanatory axis, where significant ($P < 0.05$; Pearson correlation coefficient). Correlations among variables and species-habitat relationships are available in Hennings (2001).

| Variable | Mean ± SD | Range | Correlation with canonical axes: Axis 1 | Correlation with canonical axes: Axis 2 |
|---|---|---|---|---|
| Bird community variables | | | | |
| Bird abundance[a] | 11.8 ± 3.1 | 6.5–20.4 | 0.77 | |
| Total species richness[a] | 6.6 ± 1.2 | 4.1–9.0 | 0.30 | 0.36 |
| Total Shannon diversity[b] | 1.7 ± 0.2 | 1.2–2.1 | | 0.33 |
| Non-native abundance | 2.1 ± 1.9 | 0.0–7.8 | 0.91 | |
| Native birds | | | | |
| Abundance | 9.6 ± 2.0 | 4.9–16.7 | 0.35 | 0.36 |
| Proportion of all individuals observed | 0.9 ± 0.1 | 0.5–1.0 | –0.88 | |
| Species richness | 4.5 ± 0.8 | 1.6–6.0 | | 0.41 |
| Shannon diversity | 1.6 ± 0.2 | 0.8–2.0 | | 0.36 |
| Native resident and short-distance-migrants | | | | |
| Abundance | 7.6 ± 1.7 | 0.3–12.1 | 0.32 | |
| Proportion of all individuals observed | 0.7 ± 0.1 | 0.3–0.9 | –0.77 | –0.35 |
| Species richness | 4.5 ± 0.8 | 1.6–6.1 | | |
| Shannon diversity | 1.2 ± 0.2 | 0.5–1.6 | | –0.48 |
| Neotropical migrants | | | | |
| Abundance | 2.1 ± 0.9 | 0.7–4.8 | | 0.68 |
| Proportion of all individuals observed | 0.2 ± 0.1 | 0.1–0.3 | | 0.69 |
| Species richness | 1.6 ± 0.6 | 0.6–2.9 | | 0.69 |
| Shannon diversity | 0.4 ± 0.2 | 0.1–1.0 | | 0.66 |
| Vegetation variables | | | | |
| Non-native herb proportion[c] | 0.7 ± 0.4 | 0.0–1.0 | 0.86 | |
| Lawn (% cover)[c] | 11.7 ± 16.8 | 0.0–69.8 | 0.71 | |
| Shrubs (% cover)[c] | 39.9 ± 16.6 | 0.4–79.1 | –0.73 | |
| Proportion non-native shrubs of all shrubs[c] | 0.46 ± 0.2 | 0.0–0.9 | 0.57 | |
| Proportion native shrubs of all shrubs[c] | 0.64 ± 0.1 | 0.2–1.0 | | |
| Native canopy cover (%)[c] | 31.9 ± 20.3 | 0.0–74.6 | –0.85 | –0.38 |
| Non-native canopy cover (%)[c] | 1.2 ± 2.1 | 0.0–11.3 | | |
| Urban development variables | | | | |
| Buffer canopy cover[d] | 2.7 ± 0.8 | 1.0–4.0 | | |
| Forest width (m)[e] | 154.8 ± 301.0 | 3.1–1881.2 | –0.77 | |
| Distance to forest edge (m)[e] | 29.1 ± 51.1 | 1.2–316.2 | –0.45 | |
| Trails ($m^2$)[c] | 2.4 ± 2.2 | 0.0–9.7 | | |
| Paved surfaces ($m^2$)[c] | 2.9 ± 4.4 | 0.0–16.9 | 0.38 | |
| Buildings ($m^2$)[c] | 1.0 ± 2.3 | 0.0–8.7 | 0.30 | |
| Distance to nearest building (m)[e] | 68.8 ± 67.3 | 18.5–389.2 | –0.47 | |
| Street density ($m\ ha^{-1}$)[f] | 27.3 ± 29.0 | 1.0–120.0 | | –0.57 |
| Distance to nearest paved road (m)[e] | 94.0 ± 82.8 | 17.0–423.3 | –0.48 | 0.38 |
| Vacant lands (proportion of total area)[g] | 0.7 ± 0.2 | 0.3–1.0 | –0.54 | |
| Amount of variation explained by axis | | | 57% | 12% |

[a] Calculated per visit, per point count station.
[b] Shannon diversity ($H'$; see Magurran 1988 for equation) is diversity per visit, per point count station.
[c] Data collected from 12–15 vegetation subplots in each site.
[d] Derived from 24-m raster satellite imagery, based on four canopy cover classes: 0–25%, 26–50%, 51–75%, 76–100% (used only for spatial analyses).
[e] Derived from high-resolution aerial photographs. Forest width was log transformed for analyses.
[f] Derived from GIS Streets data layer from Metro's RLIS Lite dataset (Metro Regional Services 2003).
[g] Derived from GIS Vacant Lands data layer from Metro's RLIS Lite dataset (Metro Regional Services 2003).

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*Spatial analyses.* We regressed bird community variables against satellite canopy cover, proportion of undeveloped lands, and street density (see Table 1 for variable descriptions) for each of 10 separate buffers. For example, the first regression for each bird community variable measured near the stream was against Buffer 1 data (first 50 m around the stream), the second was against Buffer 2 (50–100 m from the stream), the third against Buffer 3 (100–150 m), etc. This resulted in an $r^2$ statistic measuring the strength of each relationship for increasingly distant buffers out to 500 m; we plotted the $r^2$ statistic against distance from the stream to assess how these relationships varied spatially. We examined scatterplots prior to these analyses and observed curvilinear relationships between forest canopy cover and total and native species richness and diversity. We included a squared term in these relationships to account for the curvature.

## RESULTS

### VEGETATION CHARACTERISTICS

There was considerable variability among sites for habitat descriptors (Table 1). Cover of non-native invasive species was highest in the herb layer, followed by the shrub layer. Reed-canary grass (*Phalaris arundinacea*) and Himalayan blackberries were the major invaders. Canopy cover was largely native except in backyards.

### POINT COUNTS

We recorded 8901 detections of 90 bird species at 54 sites during May and June, 1999 (Appendix; see Hennings 2001 for species-habitat relationships). We omitted species that were detected only once or twice, as well as waterfowl and shorebirds, from all analyses. Of all bird detections, 21% were non-native, 62% were residents or short-distance-migrants, and 17% were Neotropical migrants. The 10 most abundant species comprised 68% of total bird detections. In descending order, these were European Starling (see Appendix for scientific names), Song Sparrow, American Robin, Barn Swallow, Spotted Towhee, Brown-headed Cowbird, Black-capped Chickadee, Red-winged Blackbird, Bewick's Wren, and House Finch.

### CANONICAL CORRESPONDENCE ANALYSIS

Our CCA model included 13 bird and 17 habitat variables (results in Table 1 and Fig. 1). Some variables, such as forest width and non-native vegetation measures, were highly correlated but still necessary in the model to specifically identify the variables important to bird communities. However, CCA performs well with intercorrelated environmental variables (Palmer 1993). Two CCA axes cumulatively explained 69% of variation in the data. The first CCA axis represented a gradient from wide, structurally complex riparian forests dominated by native vegetation to narrow, simplified, less-native urban forests. Axis 2 represented a gradient from areas

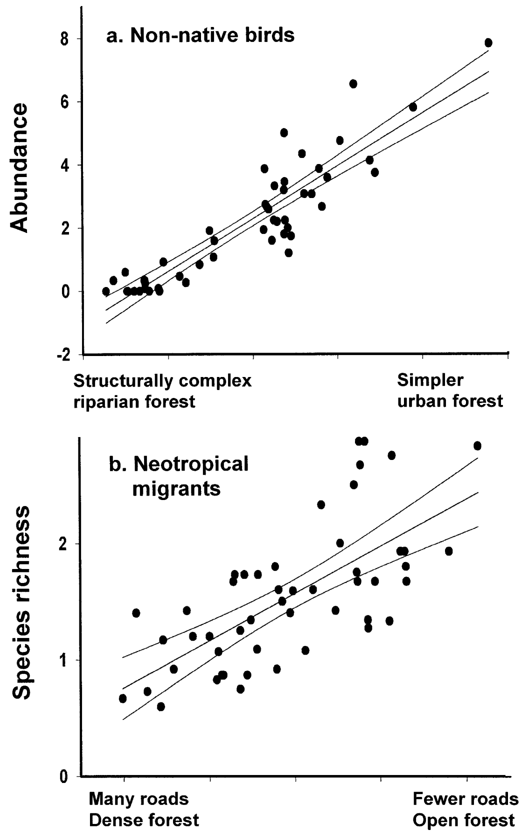


FIGURE 1. Partial results of Canonical Correspondence Analyses (CCA) for birds and habitat surveyed in 51 riparian sites around Portland, Oregon, May–June 1999. (a) Non-native bird abundance, driven by European Starlings (*Sturnus vulgaris*), was positively related to the first CCA axis, which represented a gradient from wide, structurally complex riparian forests dominated by native vegetation to narrow, simplified, less native urban forests. (b) Species richness of Neotropical migrants was positively related to Axis 2, which represented a gradient from areas with high road densities and denser forest, to areas with low road densities and more open forest canopy.

with high road densities and denser forest, to areas with low road densities and more open forest canopy.

SPATIAL ANALYSES

Between-buffer variation of satellite canopy cover and street density was highest within the first two or three buffers for each variable, after which changes between buffers were similar and relatively small. This reflects that these areas are vegetated parklands nested within a varying matrix of development; in highly developed areas with relatively narrow riparian forests, we can expect the changes between the first few buffers to be the most dramatic. In addition to bird community variables, we modeled Brown-headed Cowbird abundance as a function of canopy cover because several studies suggest relationships with landscape-scale forest canopy cover, and because of cowbird potential to influence the reproductive success of host species (Coker and Capen 1995, Hahn and Hatfield 1995).

Table 2 shows the regression results for each relationship, and Fig. 2 illustrates some of these relationships. The graphs reveal relatively large-scale relationships for non-native abundance (Fig. 2a). Non-native abundance was the primary driver for the proportions of both native birds and native resident and short-distance-migrants; therefore, all three spatial relationships appear similar and remain strong out to at least 400 m. Brown-headed Cowbird abundance, an important nest parasite on native species, appears negatively related to forest canopy on a large scale (>500 m). In contrast, total and resident and short-distance-migrant species richness and diversity related most strongly to canopy cover within 50 m of the stream (Fig. 2b), with curvilinear graphs suggesting a peak in areas with moderate to high canopy cover. Neotropical migrant proportion, species richness, and diversity related negatively to streets within 100 m of the stream (Fig. 2c).

The results suggest that larger spatial scales are most meaningful for examining bird community variables such as abundance (including cowbirds), native:non-native proportion, and the proportion of resident and short-distance-migrants, which comprised the majority of native birds. In contrast, relationships with species richness and diversity measures were strongest within the first few buffers, suggesting smaller spatial scales at work. The results also indicated consistent relationships across space: for example, Neotropical migrants were consistently negatively associated with street density, while non-native birds and cowbirds were consistently negatively associated with forest canopy cover. These results agree with CCA analyses, which were conducted only for the first buffer.

DISCUSSION

Land managers need to know what characteristics of urban habitats change bird communities in order to conserve species in increasingly urbanized landscapes. Our results suggest that breeding bird communities can be hierarchically organized based on native status and migratory behavior (Fig. 3). In our study area, narrow urban forests favored non-native plants and birds, and narrow forests combined with high onsite road density favored resident and short-distance-migrant species. Perhaps most important, Neotropical migrants appeared to be at risk from urbanization, as has been shown elsewhere in the U.S. (Croonquist and Brooks 1991, 1993, Friesen et al. 1995, Mancke and Gavin 2000).

Our spatial scale findings provide additional information to land managers; both site-specific and larger scale habitat and development variables appeared important in our study area, depending on the bird community variable. Adjacent and nearby land use clearly influences bird communities. Within the scales we examined, overall abundance measures, non-native birds, and Brown-headed Cowbird abundance appeared related to larger spatial scales than other bird community measures.

BIRD COMMUNITY STRUCTURE

Changes in bird species richness and diversity typically accompany urbanization, and studies sometimes yield conflicting patterns. These apparent conflicts probably relate to differences in defining and measuring urbanization, differences in vegetation communities, seasonality, and the particular aspects of the bird community that are examined.

Urbanization is variously described by development type, building or population density, or the percentage of paved surfaces (Marzluff et al. 1998, Ferguson et al. 2001, McIntyre et al. 2001). Classifications within the gradient of urbanization are arbitrary; many studies, including ours, do not examine the full gradient. For example, our study sites were parks with streams;

TABLE 2. Results ($r^2$) of linear regressions of bird community variables on landscape variables for 48 riparian sites in urban Portland, Oregon, July 1999. GIS-measured variables include forest canopy cover ($C$; some equations included a squared term, $C^2$), paved street diversity ($S$), and vacant lands ($V$). To assess the spatial influence of tree canopy cover and urban development variables around each site on bird communities, we drew 10 separate (non-overlapping) 50-m buffers around surveyed stream segments (500 m total on each side of the stream). Signs following variable abbreviations indicate the sign of the coefficient. For regressions involving squared terms, adjusted $r^2$ is reported.

| Bird community variable | Buffer distance (m) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0–50 | 50–100 | 100–150 | 150–200 | 200–250 | 250–300 | 300–350 | 350–400 | 400–450 | 450–500 |
| Total abundance[a] ($C$–) | 0.26 | 0.23 | 0.27 | 0.30 | 0.31 | 0.32 | 0.34 | 0.32 | 0.29 | 0.24 |
| Total species richness[a] ($C$+, $C^2$–) | 0.27 | 0.16 | 0.15 | 0.14 | 0.13 | 0.13 | 0.14 | | | |
| Total Shannon diversity[b] ($C$+, $C^2$–) | 0.28 | 0.27 | 0.15 | 0.14 | | | | | | |
| Non-native abundance ($C$–) | 0.49 | 0.44 | 0.42 | 0.43 | 0.42 | 0.42 | 0.43 | 0.42 | 0.39 | 0.31 |
| Native birds | | | | | | | | | | |
| Abundance ($V$–) | | 0.11 | 0.12 | 0.10 | 0.09 | 0.09 | 0.08 | 0.08 | | |
| Proportion of all individuals observed ($C$+) | 0.53 | 0.50 | 0.47 | 0.46 | 0.44 | 0.44 | 0.45 | 0.44 | 0.41 | 0.34 |
| Species richness ($C$+, $C^2$–) | 0.24 | 0.11 | | | | | | | | |
| Shannon diversity ($C$+, $C^2$–) | 0.33 | 0.17 | 0.10 | 0.09 | | | | | | |
| Native resident and short-distance-migrants | | | | | | | | | | |
| Abundance ($V$–) | | 0.13 | 0.15 | 0.14 | 0.12 | 0.12 | 0.10 | 0.11 | 0.09 | 0.09 |
| Proportion of all individuals observed ($C$+) | 0.47 | 0.40 | 0.38 | 0.40 | 0.37 | 0.39 | 0.40 | 0.39 | 0.38 | 0.34 |
| Species richness ($C$+) | 0.13 | | | | | | | | | |
| Shannon diversity ($C$+) | 0.14 | | | | | | | | | |
| Neotropical migrants | | | | | | | | | | |
| Abundance (no significant relationships) | | | | | | | | | | |
| Proportion of all individuals observed ($S$–) | 0.21 | 0.27 | 0.20 | 0.14 | 0.15 | | 0.13 | 0.15 | 0.10 | |
| Species richness ($S$–) | 0.14 | 0.17 | 0.10 | | 0.10 | | | 0.10 | | |
| Shannon diversity ($S$–) | 0.12 | 0.19 | 0.12 | | 0.15 | | | 0.13 | 0.10 | |

[a] Calculated per visit, per point count station.
[b] Shannon diversity ($H'$; see Magurran 1988 for equation) is diversity per visit, per point count station.

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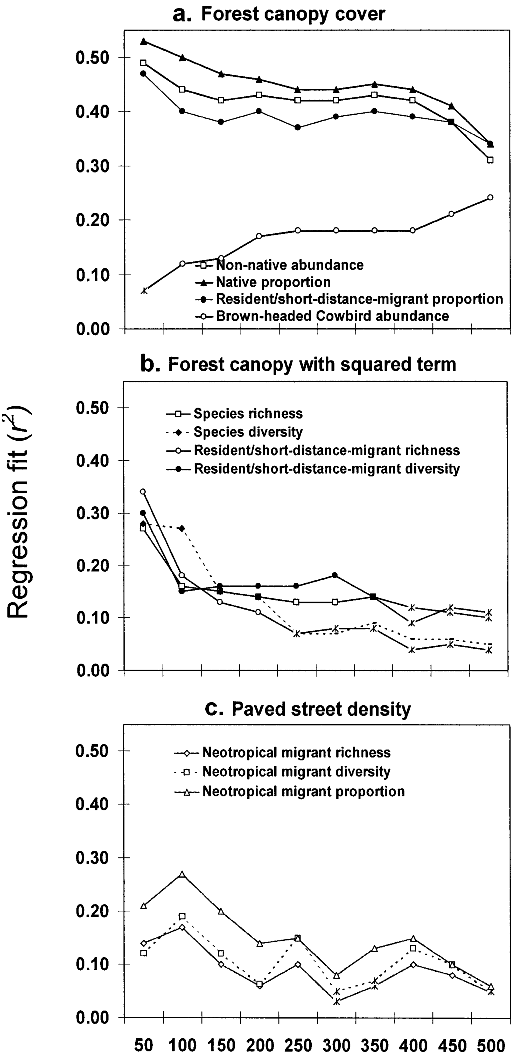


FIGURE 2. The spatial scale of importance depended on the bird community variable in our study of 48 riparian areas in urban Portland, Oregon, May–June 1999. Graphs show model fit ($r^2$) of bird community variables (measured within 50 m of the stream) regressed against canopy cover and street density measured in each of ten, 50-m buffers (to 500 m on each side of the stream) surrounding each site. The line's upward or downward direction does not indicate positive or negative relationships; rather, it reflects the ebb and flow of relationship strengths across space. In (a) and (c), filled symbols represent positive relationships and unfilled symbols represent negative relationships. In (b), for all relationships shown the coefficient was positive for canopy cover and negative for canopy squared. Where symbols are replaced with asterisks, the relationship was nonsignificant ($P > 0.05$).

these areas were limited in onsite development and always contained natural vegetation. Thus, our study excluded the most heavily urbanized areas of the Portland region. Clergeau et al. (1998) detected a pattern of decreasing breeding bird diversity from least to most urbanized areas in two major cities on different continents. By excluding downtown areas, our study was not designed to detect such a pattern.

Regional differences in urban and rural communities may be another source of conflicting results. Bird species richness and diversity may increase or decrease with urbanization, depending on which part of the urban gradient contains the richest vegetation communities. For example, in naturally sparse or fragmented habitats such as southern California or Arizona, enhanced vegetation cover and diversity in suburban habitats resulted in higher bird abundance and similar diversity when compared to native habitats (Guthrie 1974, Rosenberg et al. 1987). However, in Santa Clara County, California, where native vegetation is lusher, species richness and diversity peaked in moderately disturbed sites and development was detrimental to native bird communities (Blair 1996); these results appear similar to ours in the second level of community hierarchy (Fig. 3, Table 2).

Season must also be taken into account (Pearson 1993, Jokimäki and Suhonen 1998, Jokimäki 2000). For example, for Great Tits (*Parus major*) in Europe, urban habitats were better in winter, but worse in the breeding season, than rural habitats, and tit density was determined by weather conditions in the winter prior to the breeding season (Hõrak 1993, Solonen 2001). In North America, Hostetler and Holling (2000) found differences between spring and summer patch-size requirements for native birds.

Our study indicates that the bird community variables analyzed may be a key source of conflicting research results. In our study, native bird species richness and diversity peaked in areas with moderate canopy cover and high proportions of undeveloped lands. But these results are a combination of the variables important to the next level down in the community hierarchy. A critical distinction becomes apparent when native birds are distinguished by migratory habit: residents and short-distance-migrants are positively associated with development and more closed canopy, whereas Neotropical migrants are associated with undeveloped, open-canopied

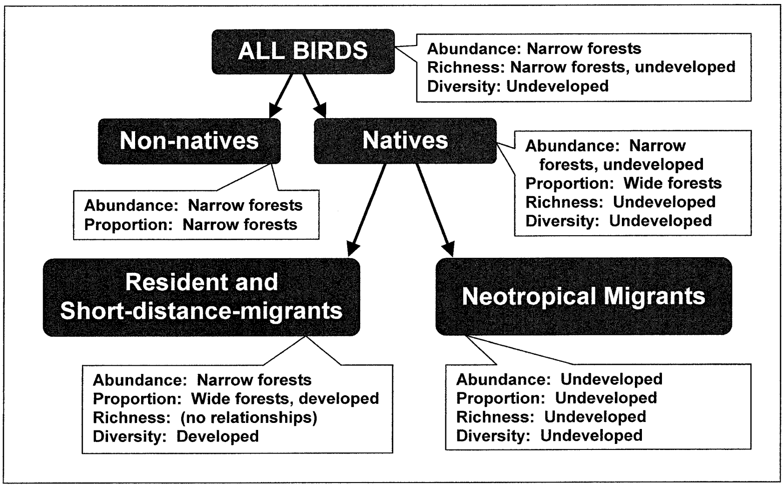


FIGURE 3. General habitat preference of subsets of the bird community of urban Portland, Oregon, based on results of Canonical Correspondence Analysis (CCA) relating birds and habitat variables surveyed in 54 riparian sites, May and June 1999. White boxes describe significant ($P < 0.05$) linear relationships between four bird community variables and the two significant CCA axes. Each description indicates the end of the CCA axis gradient to which the bird variable relates. Proportion is the proportion of all individuals observed, richness is species richness, and diversity is Shannon diversity ($H'$).

areas. This differs somewhat from the results of bird surveys in the Santa Clara Valley, California, where researchers found that the majority of species, including residents, were negatively correlated with urbanization surrounding riparian forests and positively correlated with native vegetation volume (Rottenborn 1999). However, this may relate to the suite of bird species using the habitats. For species studied in both Santa Clara and Portland, many species-habitat relationships were similar in terms of forest width requirements and urbanization tolerance.

In our study area and elsewhere in the U.S., the overarching theme for Neotropical migrants appears to be a general aversion to development. In other parts of the U.S., Neotropical migrants in particular tend to respond negatively to human development (Friesen et al. 1995, Nilon et al. 1995) and habitat fragmentation (Martin and Finch 1995, Robinson et al. 1995, Saab 1999) to the point that these factors override local habitat characteristics. For example, in Ontario, Canada, increasing the number of houses surrounding a forest patch reduced Neotropical migrant species richness and abundance; larger habitat patches were also important (Friesen et al. 1995). In Missouri, forest-interior Neotropical migratory species were most abundant in wildland sites and least abundant in high-density housing developments (Nilon et al. 1995). In Pennsylvania, only 2–3% of Neotropical migrants that were habitat specialists used disturbed habitats during the breeding season, compared to 17–20% in undisturbed areas (Croonquist and Brooks 1991). Other studies reported similar patterns (Gotfryd and Hansell 1986, Theobald et al. 1997, Mancke and Gavin 2000). The precise mechanisms underlying these patterns are unknown, but may relate to disturbance issues such as road noise, human proximity, or increased predation.

The high abundance of European Starlings in some sites is probably a function of the structure and configuration of urban habitats. Starlings nest in cavities, and they occupied many of the natural cavities near forest edges in our study area. Starlings frequently forage on lawns (Fischl and Caccamise 1986, Ehrlich et al. 1988); thus the juxtaposition of forest edges with residential or park lawns may provide ideal starling habitat.

The associations between wide forests and the proportions of native birds and resident and short-distance-migrants should be interpreted with caution, because they are an artifact of the strength of the relationship between the proportion of non-native birds and narrow forests;

abundance measures for the former are associated with narrow forests.

Breeding bird surveys have clear advantages over reproductive studies in that they are inexpensive and extensive areas can be covered, but they cannot detect source-sink dynamics, which are influenced by bird habitat selection (Férnandez-Juricic 2000, Jokimäki and Huhta 2000, Fauth et al. 2000). Factors affecting habitat selection can be categorized as proximate or ultimate (Hilden 1965). While proximate factors include site-specific cues a bird uses to assess a site's suitability, the ability for an individual or species to persist is governed by ultimate factors such as forage availability, shelter, and predators. Because the cues birds use to select habitat may be decoupled from their short or long-term success (Van Horne 1983), it is vital to identify habitat measures likely to reflect urban-specific ultimate factors. Studies on reproductive success, particularly for Neotropical migratory species, should follow our study to identify the ultimate factors responsible for negative associations with urbanization. For example, nest success could be tested against variables such as noise, physical habitat disturbance, human presence, predator abundance, and habitat characteristics to determine the reasons for nest failure.

### SPATIAL SCALE

Community responses to habitat conditions change depending on the scale at which they are viewed (Freemark and Merriam 1986, Hansen et al. 1993, Pearson 1993). Scale-dependent questions may be particularly difficult to study in urban areas due to landscape heterogeneity (Pearson 1993, Hostetler and Holling 2000, Pickett et al. 2001). We limited our examination of community relationships to canopy cover and urban development out to 500 m on each side of the stream because overlap between sites was too extensive beyond that distance. A long-term, hierarchical approach to spatially explicit ecological questions, arranged on a clearly defined gradient, is desirable (Wiens 1989). However, our exploratory approach appears useful because it revealed relatively fine (50-m increment) changes in bird community patterns relating to spatial scale, and in some cases, suggested specific scales of interest. In addition, this approach prevents a loss of information when hierarchical levels are crossed. For example, canopy cover appears important to non-native bird and Brown-headed Cowbird abundance at scales of 450 m or more, but to native community measures at smaller scales of 50–150 m. Thus, considering multiple spatial scales in urban habitat management schemes is critical.

Our spatial analyses revealed that explanatory variables change most within 150 m of a stream, and it was within this zone that the strongest native bird community–habitat relationships occurred. Recommended riparian buffer widths for protecting fish stocks and stream health (Northwest Forest Plan; Forest Ecosystem Management Assessment Team 1993) fall within this zone, adding credence to the utility of this spatial scale.

### MANAGEMENT RECOMMENDATIONS

Our results, in the face of projected urban growth, suggest that Neotropical migrants are the most at-risk group in our study area and as such, they should receive primary management focus. However, European Starlings were the most abundant species in our surveys and are also a major management concern. In our study area, broad-scale increases in urban canopy cover provide a valuable land management action for conserving native breeding birds, because with more canopy cover comes an increase in structural diversity and a decrease in non-native birds and cowbirds. A hierarchical scheme for Neotropical migrant conservation might include increasing canopy cover within 450 m of important riparian habitats; decreasing street density within a 100-m radius; and conserving or increasing important on-site variables such as native tree and shrub cover.

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APPENDIX. Bird species detected at 54 riparian sites in Portland, Oregon, during May and June, 1999. We omitted species with ≤2 detections,[a] as well as waterfowl and shorebirds, from all analyses. Species with 3–5 observations[b] were analyzed but are omitted from this appendix for brevity. For migratory status, R = resident or short-distance-migrant, N = Neotropical migrant.

| Species | Migratory status | No. of sites | No. of detections | % of total detections |
|---|---|---|---|---|
| Great Blue Heron (*Ardea herodias*) | R | 8 | 9 | 0.1 |
| California Quail (*Callipepla californica*) | R | 3 | 6 | 0.1 |
| Band-tailed Pigeon (*Columba fasciata*) | R | 5 | 61 | 0.7 |
| Mourning Dove (*Zenaida macroura*) | R | 16 | 34 | 0.4 |
| Vaux's Swift (*Chaetura vauxi*) | N | 11 | 44 | 0.5 |
| Anna's Hummingbird (*Calypte anna*) | R | 3 | 6 | 0.1 |
| Rufous Hummingbird (*Selasphorus rufus*) | N | 24 | 31 | 0.4 |
| Red-breasted Sapsucker (*Sphyrapicus ruber*) | R | 10 | 14 | 0.2 |
| Downy Woodpecker (*Picoides pubescens*) | R | 34 | 57 | 0.6 |
| Northern Flicker (*Colaptes auratus*) | R | 24 | 36 | 0.4 |
| Olive-sided Flycatcher (*Contopus cooperi*) | N | 4 | 8 | 0.1 |
| Western Wood-Pewee (*Contopus sordidulus*) | N | 30 | 75 | 0.8 |
| Willow Flycatcher (*Empidonax traillii*) | N | 11 | 15 | 0.2 |
| Pacific-slope Flycatcher (*Empidonax difficilis*) | N | 23 | 73 | 0.8 |
| Hutton's Vireo (*Vireo huttoni*) | N | 7 | 12 | 0.1 |
| Warbling Vireo (*Vireo gilvus*) | N | 26 | 53 | 0.6 |
| Steller's Jay (*Cyanocitta stelleri*) | R | 40 | 138 | 1.6 |
| Western Scrub-Jay (*Aphelocoma californica*) | R | 34 | 128 | 1.4 |
| American Crow (*Corvus brachyrhynchos*) | R | 33 | 104 | 1.2 |
| Tree Swallow (*Tachycineta bicolor*) | N | 8 | 12 | 0.1 |
| Violet-green Swallow (*Tachycineta thalassina*) | N | 27 | 102 | 1.2 |
| Barn Swallow (*Hirundo rustica*) | N | 14 | 626 | 7.0 |
| Black-capped Chickadee (*Poecile atricapilla*) | R | 53 | 352 | 3.4 |
| Chestnut-backed Chickadee (*Poecile rufescens*) | R | 12 | 28 | 0.3 |
| Bushtit (*Psaltriparus minimus*) | R | 41 | 218 | 2.5 |
| Red-breasted Nuthatch (*Sitta canadensis*) | R | 17 | 38 | 0.4 |
| White-breasted Nuthatch (*Sitta carolinensis*) | R | 4 | 6 | 0.1 |
| Brown Creeper (*Certhia americana*) | R | 22 | 78 | 0.9 |
| Bewick's Wren (*Thryomanes bewickii*) | R | 50 | 285 | 3.2 |
| Winter Wren (*Troglodytes troglodytes*) | R | 18 | 114 | 1.3 |
| Golden-crowned Kinglet (*Regulus satrapa*) | R | 3 | 7 | 0.1 |
| Swainson's Thrush (*Catharus ustulatus*) | N | 33 | 96 | 1.1 |
| American Robin (*Turdus migratorius*) | R | 53 | 691 | 7.8 |
| European Starling (*Sturnus vulgaris*) | R | 47 | 1527 | 17.2 |
| Cedar Waxwing (*Bombycilla cedrorum*) | R | 39 | 242 | 2.7 |
| Orange-crowned Warbler (*Vermivora celata*) | N | 31 | 66 | 0.7 |
| Yellow Warbler (*Dendroica petechia*) | N | 14 | 27 | 0.3 |
| Yellow-rumped Warbler (*Dendroica coronata*) | R | 9 | 18 | 0.2 |
| Black-throated Gray Warbler (*Dendroica nigrescens*) | N | 8 | 11 | 0.1 |
| Common Yellowthroat (*Geothlypis trichas*) | N | 21 | 83 | 0.9 |
| Wilson's Warbler (*Wilsonia pusilla*) | N | 42 | 151 | 1.7 |
| Western Tanager (*Piranga ludoviciana*) | N | 27 | 55 | 0.6 |
| Spotted Towhee (*Pipilo maculatus*) | R | 51 | 452 | 5.1 |
| Song Sparrow (*Melospiza melodia*) | R | 54 | 1178 | 13.2 |
| White-crowned Sparrow (*Zonotrichia leucophrys*) | R | 6 | 7 | 0.1 |
| Dark-eyed Junco (*Junco hyemalis*) | R | 14 | 23 | 0.3 |
| Black-headed Grosbeak (*Pheucticus melanocephalus*) | N | 41 | 165 | 1.9 |
| Red-winged Blackbird (*Agelaius phoeniceus*) | R | 19 | 313 | 3.5 |
| Brewer's Blackbird (*Euphagus cyanocephalus*) | R | 3 | 11 | 0.1 |
| Brown-headed Cowbird (*Molothrus ater*) | N | 50 | 352 | 4.0 |
| Bullock's Oriole (*Icterus bullockii*) | N | 7 | 23 | 0.3 |
| Purple Finch (*Carpodacus purpureus*) | R | 3 | 6 | 0.1 |
| House Finch (*Carpodacus mexicanus*) | R | 46 | 283 | 3.2 |
| Pine Siskin (*Carduelis pinus*) | R | 17 | 54 | 0.6 |
| American Goldfinch (*Carduelis tristis*) | R | 24 | 48 | 0.5 |

APPENDIX. Continued.

| Species | Migratory status | No. of sites | No. of detections | % of total detections |
|---|---|---|---|---|
| Evening Grosbeak (*Coccothraustes vespertinus*) | R | 4 | 16 | 0.2 |
| House Sparrow (*Passer domesticus*) | R | 26 | 265 | 3.0 |

[a] Green Heron (*Butorides virescens*), Sharp-shinned Hawk (*Accipiter striatus*), Cooper's Hawk (*Accipiter cooperii*), American Kestrel (*Falco sparverius*), Osprey (*Pandion haliaetus*), Ring-necked Pheasant (*Phasianus colchicus*), Western Screech-Owl (*Otus kennicottii*), Great Horned Owl (*Bubo virginianus*), Belted Kingfisher (*Ceryle alcyon*), Cassin's Vireo (*Vireo cassinii*), Cliff Swallow (*Petrochelidon pyrrhonota*), Marsh Wren (*Cistothorus palustris*), Townsend's Warbler (*Dendroica townsendi*), Fox Sparrow (*Passerella iliaca*), and Lincoln's Sparrow (*Melospiza lincolnii*).

[b] Red-tailed Hawk (*Buteo jamaicensis*), Hairy Woodpecker (*Picoides villosus*), Pileated Woodpecker (*Dryocopus pileatus*), Hammond's Flycatcher (*Empidonax hammondii*), Ruby-crowned Kinglet (*Regulus calendula*), Hermit Thrush (*Catharus guttatus*), Savannah Sparrow (*Passerculus sandwichensis*), Golden-crowned Sparrow (*Zonotrichia atricapilla*), Lazuli Bunting (*Passerina amoena*).

**Bird Safe Windows List Admin Rule**
**February 22, 2018**
**Meeting Agenda**

<u>Meeting Attendees:</u> Mindy Brooks, Marc Asnis, Rachael Hoy, Mary Coolidge, Dave Helzer

<u>Agenda</u>

1. **Meeting Purpose**
   a. Review the substantive requirements for glazing treatments
   b. Review process for updating the list, including how stakeholders will be involved

2. **Requirements for the Ground Floor (Section 4)**
   *Note – The agenda starts with the substantive requirements of the admin rule; comments on the intro, etc. will be discussed at the end and/or the comments can be sent to staff after the meeting.*
   a. Materials
   b. Spacing and Dimensions
   c. Figures

3. **Requirements for the Upper Floors (Section 5)**
   a. Materials
   b. Space and Dimensions
   c. Figures

4. **Process to Modify the List (Appendix A)**
   a. General process
   b. Stakeholder Involvement
   c. Stakeholder List

5. **Sections 1, 2 and 3** *(if time allows; if not comments can be sent to staff)*
   *Note – The format will change based on working with BPS teams creating other Admin Rules (Low Carbon, Trails, Building Energy Performance, etc.) and review by the City Attorneys*
   a. Background/Intro (will likely get shortened)
   b. How to use this document (format may change but content will stay the same)
   c. Overview of Standard (may move to an appendix)

6. **Next Steps**
   a. Finalize the Admin Rule (Feb)
   b. Review by BPS staff working on other Admin Rules (early March)
   c. Review by City Attorneys (early March)
   d. Notice of Hearing on Admin Rule (mid March)
   e. Hearing on Admin Rule (April)
   f. Adoption of CC2035 (May 24)
   g. Implementation of Admin Rule with Effective Date for CC2035 (TBD, likely early July)

CITY OF PORTLAND
ENVIRONMENTAL SERVICES

1120 SW Fifth Avenue, Room 1000, Portland, Oregon 97204 ▪ Nick Fish, Commissioner ▪ Michael Jordan, Director

# TECHNICAL MEMORANDUM

Date: December 12, 2016
To: Sallie Edmunds, Rachael Hoy
From: David Helzer
CC: Marie Walkiewicz, Marc Asnis, Paul Ketcham, Kaitlin Lovell
Re: CC2035: Technical Elements of Proposed Bird Safe Standards

Collisions with windows are estimated to kill between 365 and 988 million birds per year in the United States. In terms of anthropogenic threats to birds, window collisions are second only to feral and free-ranging domestic cats as a cause of direct mortality. Local studies in Portland by Audubon Society of Portland and Environmental Services have documented the mortality threat is real here in the city's built environment. Songbirds are most at risk, as opposed to other avian species groups.

The proposed Bird Safe Exterior Glazing Standards in the CC 2035 Plan District address this threat to native bird populations, many species of which are in serious decline. It is estimated from 2% to 9% of the entire North American bird population dies annually due to collisions with windows. The highest risk occurs where vegetation is found adjacent to reflective glass.

This memorandum summarizes key findings and recommendations to inform the proposal. These are based on a literature review, local studies of bird window strikes, consultation with local and national experts, and best professional judgment. Key findings and recommendations are:

1. Neotropical migratory songbirds, such as warblers, thrushes, and vireos, are disproportionally affected by window collisions, and as a group are a priority for conservation locally and nationally.

2. Large surface areas of glass cause more strikes than smaller surface areas of glass.

3. The highest risk on a building façade is the first 60 vertical feet because the majority of bird activity (including migrating birds) occurs in this zone and due to the presence of adjacent vegetation (trees and shrubs). **Bird safe glass treatment should prioritize this 60-foot zone**, including the ground level.

4. BPS has identified a need to set the zoning standard based on a threshold for the percentage of glazing on a building façade. Façades that exceed that percent would be required to use bird safe glazing in the first 60 feet of height. Based on findings in peer reviewed studies and consultation with leading national experts, **there is a sound scientific basis for setting the trigger at 20-30% glazing** in the first 60 vertical feet.

    a. Borden et al. found a statistically significant increase in strikes on facades with >31% glazing (excerpt from paper attached).

    b. Dr. Daniel Klem, a leading national researcher, recommends 20% for CC 2035, based on his research (correspondence attached).

    c. Keith Russel, another expert, recommends 25% for CC 2035.

5. **The standard should apply to the entire CC 2035 Plan District**. Proposed map 210-22 is not a realistic representation of bird window collision risk in the CC 2035 District, for these reasons:

    a. The map is not based on location data for documented bird strikes, rather on existing vegetation (> 1 acre); its assumptions about the risk of bird window collisions are not consistent with bird behavior and distribution in the central city.

    b. Resident and migratory birds are found throughout urban landscapes and are not limited to areas with one acre or larger patches of vegetation. In fact, neotropical migrant songbirds, such orange-crowned warblers or yellow-rumped warblers, are conspicuous for their use of isolated, tiny, or unexpected vegetation patches. Examples includes downtown sidewalk landscaping or small street trees on a block dominated by impervious surfaces and glass.

    c. The map is based on existing tree canopy conditions. City of Portland policies, programs and regulations actively encourage an increase in the presence, size and canopy coverage of trees throughout the Central City. As a result, the location and extent of tree canopy coverage is expected to increase over the life of the CC 20235 Plan and over the expected life cycle of the buildings that will be constructed under the new zoning requirements.

**ORNITHOLOGICAL LITERATURE REVIEWED** (partial list, focused on research related to the correlation between the percentage of glazing and risk to birds):


Bayne, Erin M., Corey A. Scobie and Michael Rawson, 2012. Factors influencing the annual risk of bird–window collisions at residential structures in Alberta, Canada. Wildlife Research

Borden, W.C., O.M. Lockhart, A.W. Jones and M.S. Lyonn, 2010. Seasonal, taxonomic and local habitat components of bird-window collisions on an urban campus in Cleveland, OH. Ohio J Sci 110(3):44-52.

Collins, K. A. and D. J. Horn. 2008. published abstract. Bird-window collisions and factors influencing their frequency at Millikin University in Decatur, Illinois. . Bird-window collisions and factors influencing their frequency at Millikin University in Decatur, Illinois 101(supplement):50.

Cusa, Marine, Donald A. Jackson and Michael Mesure, 2015. Window collisions by migratory bird species: urban geographical patterns and habitat associations. Urban Ecosystems doi:10.1007/s11252-015-0459-3)

Gelb, Y. and N. Delacretaz. 2006. Avian window strike mortality at an urban office building. Kingbird 56(3):190-198.

Hager, S.B., H. Trudell, K.J. McKay, S.M. Crandall, L. Mayer. 2008. Bird density and mortality at windows. Wilson Journal of Ornithology 120(3):550-564.

Hager SB, Cosentino BJ, McKay KJ, Monson C, Zuurdeeg W, and B. Blevins, 2013. Window Area and Development Drive Spatial Variation in Bird-Window Collisions in an Urban Landscape. PLoS ONE 8(1): e53371. doi:10.1371/journal.pone.0053371

Kahle LQ, Flannery ME, Dumbacher JP (2016) Bird-Window Collisions at a West-Coast Urban Park Museum: Analyses of Bird Biology and Window Attributes from Golden Gate Park, San Francisco. PLoS ONE 11(1): e0144600. doi:10.1371/ journal.pone.0144600

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Klem, D. Jr., C. J. Farmer, N. Delacretaz, Y. Gelb and P.G. Saenger, 2009. Architectural and Landscape Risk Factors Associated with Bird-Glass Collisions in an Urban Environment. Wilson Journal of Ornithology 121(1): 126-134.

Loss, Scott R., Tom Will, Sara S. Loss and Peter P. Marra, 2014. Bird–building collisions in the United States: Estimates of annual mortality and species vulnerability. Condor 116:8-23. DOI: 10.1650/CONDOR-13- 090.1

Ocampo-Peñuela N, Winton RS, Wu CJ, Zambello E, Wittig TW, Cagle NL. (2016) Patterns of bird-window collisions inform mitigation on a university campus. PeerJ 4:e1652

Parkins, Kaitlyn L, Susan B. Elbin and Elle Barnes, 2015. Light, Glass, and Bird–building Collisions in an Urban Park. Northeastern Naturalist 22(1): 84-94.

Sloan, Allison, 2007. Migratory bird mortality at the World Trade Center and World Financial Center, 1997-2001: A deadly mix of lights and glass. Transactions of the Linnaean Society of NY 10:183-204.

**From:** Daniel Klem [mailto:klem@muhlenberg.edu]
**Sent:** Thursday, November 10, 2016 11:50 AM
**To:** Peter Saenger <PSaenger@muhlenberg.edu>; Helzer, David <David.Helzer@portlandoregon.gov>
**Cc:** Mary Coolidge (mcoolidge@audubonportland.org) <mcoolidge@audubonportland.org>
**Subject:** Re: inquiry on glass building facades and bird strike risk - City of Portland

10 November 2016, Thursday

Dear Environmental Specialist Helzer,

Thanks for your question. My most relevant study (conducted with others) to your question looked at architectural risk factors using proportional hazards models (Klem et al. 2009; attached). For the data we collected and analyzed for architectural features, these mathematical models revealed that % of glass was important in calculating the risk of a bird strike, as you justifiably identify. Using fall and spring migration data, our analyzes found that a 10% increase in % of glass increased the risk of a strike by 19% and 32%, respectively (see p. 129 in Klem et al. 2009 attached). This study conducted in New York City provides quantitative evidence and suggests to me that you should consider 20% or greater glazing as your trigger for your requirement. More generally, I, at least, believe this study offers you information to permit you to decide at what level of risk you are willing to accept to trigger your requirement. The paper by Borden et al. 2010 you provide highlights, at least for me, the importance of architectural and landscape context. Contrasting to those modest % of glass facades where many strikes were documented, the all or near all glass corridors (90% glass) that no strikes were recorded are far different than what occurs at other sites, many of which I have monitored and are part of other published works of mine. My interpretation and suggestion is a trigger point for your requirement should be below, legitimately far below the 50% level, not unreasonably at the 20% level.

Hope this helps you and your colleagues in assessing what is most relevant for your city and its part in trying to protect more bird lives from the windows. I continue to be sincerely and respectfully yours, Dan (D. Klem, Jr.)

Daniel Klem, Jr., Ph.D., D.Sc.
Professor of Biology, and
Sarkis Acopian Professor of Ornithology and Conservation Biology
Muhlenberg College, Allentown, PA 18104-5586 USA

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morning descent birds appear most susceptible to collisions. This scenario may also suggest why building height is a poor predictor of bird mortality (DeCandido 2005, Klem and others 2009).

In urban and suburban areas such as metropolises bordering the Great Lakes, stopover sites increasingly take the form of residential neighborhoods, parks, and landscaped green spaces. Bird fatalities at CSU are clustered into a few hot spots (i.e., green spaces), characterized by large areas of sheet glass windows and adjacent vegetation taller than five meters. Sites where vegetation, glass windows, and permanent water converge and cause disproportionately high numbers of bird deaths are "migrant traps" (O'Connell 2001). These traits are consistent with campus hotspots (e.g., Fig. 2A, 2D) and help explain the variability of bird deaths among buildings. Our results support the tenet that local habitat characteristics can greatly exacerbate the prevalence of bird-window collisions (Klem 1990, O'Connell 2001, Klem and others 2004, 2009, Gelb and Delacretaz 2006, 2009, Hager and others 2008). Finally, the three extreme data points are informative and hint that building attributes not measured in this study (e.g., glass treatments, the area of contiguous glass surface rather than strictly the percentage of total glass) may be relevant parameters when assessing causative factors leading to bird-window collisions. For example, reflective glass yields more collisions (Klem and others 2009).

This year-long study is the first to investigate the association between local habitat and building factors with bird fatalities among a suite of low-rise buildings aligned within an important migratory pathway. Our results support many of the published temporal, taxonomic, and habitat patterns in deaths from bird-window collisions. More importantly, we demonstrate that low-rise buildings with adjacent green spaces are significant hazards to migrating birds, even when such buildings occur within a highly urbanized environment. The large number of dead migrants highlights their abilities to find small green spaces hidden within a city and emphasizes the biological value of fragmented green spaces to migrating birds. It also reinforces the urgency to mitigate the impact of architecture on the number of bird-window collisions. Additional studies that contrast urban coastal and urban inland sites and quantify the effect of site proximity to migration routes are needed.

Acknowledgments. We thank Jen Milligan for help with data collection. Birds were salvaged under Federal Fish and Wildlife Permit MB124772-0 and Ohio Division of Wildlife Wild Animal Permits 342 and 11-135 to A. W. Jones at the Cleveland Museum of Natural History. Robert Gibson, Tom Labedz, Bob Krebs, and several anonymous reviewers provided constructive critiques that greatly improved the manuscript. Since the completion of the study, four additional species have been documented as collision deaths on campus: Peregrine Falcon (*Falco peregrinus*), Belted Kingfisher (*Ceryle alcyon*), Fox Sparrow (*Passerella iliaca*), and Killdeer (*Charadrius vociferus*).

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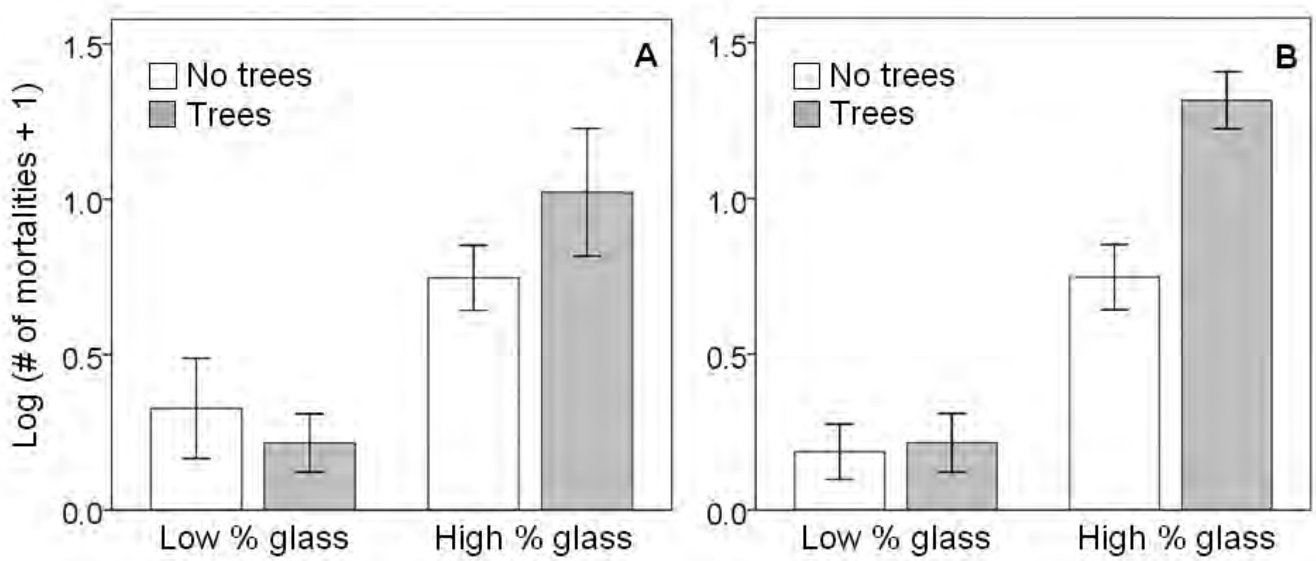


Figure 4. Effect of glass surface area and tree proximity on the frequency of bird mortality with the (A) inclusion and (B) exclusion of three data points greater than 5 SE from the mean (see text). Larger glass surfaces ($F_{1,26}$ = 67.25, P < 0.001), trees ($F_{1,26}$ = 8.70, P = 0.007), and the interaction between trees and glass ($F_{1,26}$ = 7.089, P = 0.013) were associated with statistically more bird deaths following the removal of three extreme outliers. Bars represent the mean number of deaths per building surface (log-transformed values) ± 1 SE.

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Hope this helps you and your colleagues in assessing what is most relevant for your city and its part in trying to protect more bird lives from the windows. I continue to be sincerely and respectfully yours, Dan (D. Klem, Jr.)

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Acopian Center for Ornithology, Website: http://ACO.muhlenberg.edu

>>> "Helzer, David" <David.Helzer@portlandoregon.gov> 11/9/2016 8:38 PM >>>
Mr. Klem and Mr. Saenger:

I am a biologist with the City of Portland government in Portland, Oregon. My background is in ornithology and I work with Mary Coolidge of Audubon Society of Portland on several projects, including studying bird-window collisions locally. You recently provided some input on one of our building studies (thank you).

I am writing today on a different project with a specific question. The City of Portland is considering expanding on our *voluntary* bird friendly building guidelines by adding new *requirements* for bird safe glass in the downtown district. I am tasked with helping craft the proposal. This would be for commercial low-rise and high-rise buildings. The current draft proposal would requires bird safe glass in the first 60 feet and adjacent to vegetated roof/patios. Mary Coolidge is assisting with this proposal and I have also gained advice and tips from Christine Sheppard.

The requirement would be triggered for new construction when the building design exceeds a percent threshold of glazing in the first 60 vertical feet of the facade. The key question I am trying to answer: what is a reasonable percent glazing to trigger the requirement?

I understand multiple factors contribute to risk of bird-glass collections and a simple measure of percent glazing on a façade is not necessarily highly relevant. That said, in order to establish this in city code, we need to set a percent glazing trigger. We know large areas of continuous glass increase risk of strikes, especially when combine with adjacent vegetation. We are assuming a lower percentage of glass presents less risk. In order to gain support for the proposal, we need to set a threshold that will exclude some of the lower risk facades and focus on the higher risk ones. I am looking at a trigger somewhere between 10% and 50% glazing, based on other established policies.

In order to determine a sound and defensible percent glazing trigger for the building requirements, I am currently conducting a review of published bird strike literature that includes investigations into building attributes (this includes some of your work). One study (Borden, attached) touches on the answer with a finding that high % glass (>47%) facades have a statistically significant association with more bird deaths that low % glass (<31%) facades. I am continuing this literature review and hope to find more relevant information.

Do you have research, or a best professional opinion, about how what percent glazing on a façade should trigger a requirement for bird safe glass?

Thank You.

David Helzer
Environmental Specialist | Terrestrial Biologist
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http://www.portlandoregon.gov/bes/

morning descent birds appear most susceptible to collisions. This scenario may also suggest why building height is a poor predictor of bird mortality (DeCandido 2005, Klem and others 2009).

In urban and suburban areas such as metropolises bordering the Great Lakes, stopover sites increasingly take the form of residential neighborhoods, parks, and landscaped green spaces. Bird fatalities at CSU are clustered into a few hot spots (i.e., green spaces), characterized by large areas of sheet glass windows and adjacent vegetation taller than five meters. Sites where vegetation, glass windows, and permanent water converge and cause disproportionately high numbers of bird deaths are "migrant traps" (O'Connell 2001). These traits are consistent with campus hotspots (e.g., Fig. 2A, 2D) and help explain the variability of bird deaths among buildings. Our results support the tenet that local habitat characteristics can greatly exacerbate the prevalence of bird-window collisions (Klem 1990, O'Connell 2001, Klem and others 2004, 2009, Gelb and Delacretaz 2006, 2009, Hager and others 2008). Finally, the three extreme data points are informative and hint that building attributes not measured in this study (e.g., glass treatments, the area of contiguous glass surface rather than strictly the percentage of total glass) may be relevant parameters when assessing causative factors leading to bird-window collisions. For example, reflective glass yields more collisions (Klem and others 2009).

This year-long study is the first to investigate the association between local habitat and building factors with bird fatalities among a suite of low-rise buildings aligned within an important migratory pathway. Our results support many of the published temporal, taxonomic, and habitat patterns in deaths from bird-window collisions. More importantly, we demonstrate that low-rise buildings with adjacent green spaces are significant hazards to migrating birds, even when such buildings occur within a highly urbanized environment. The large number of dead migrants highlights their abilities to find small green spaces hidden within a city and emphasizes the biological value of fragmented green spaces to migrating birds. It also reinforces the urgency to mitigate the impact of architecture on the number of bird-window collisions. Additional studies that contrast urban coastal and urban inland sites and quantify the effect of site proximity to migration routes are needed.

Acknowledgments. We thank Jen Milligan for help with data collection. Birds were salvaged under Federal Fish and Wildlife Permit MB124772-0 and Ohio Division of Wildlife Wild Animal Permits 342 and 11-135 to A. W. Jones at the Cleveland Museum of Natural History. Robert Gibson, Tom Labedz, Bob Krebs, and several anonymous reviewers provided constructive critiques that greatly improved the manuscript. Since the completion of the study, four additional species have been documented as collision deaths on campus: Peregrine Falcon (*Falco peregrinus*), Belted Kingfisher (*Ceryle alcyon*), Fox Sparrow (*Passerella iliaca*), and Killdeer (*Charadrius vociferus*).

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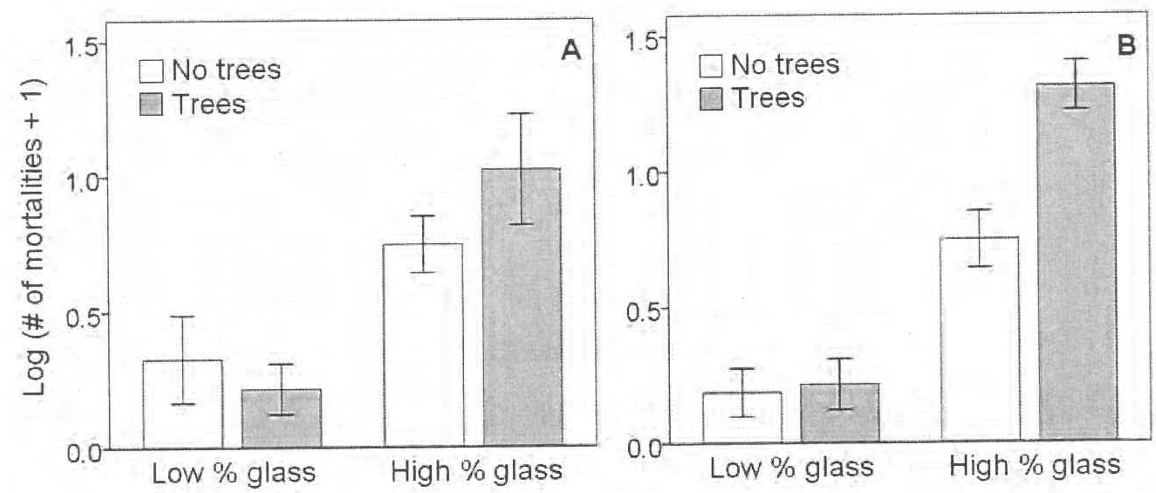


Figure 4. Effect of glass surface area and tree proximity on the frequency of bird mortality with the (A) inclusion and (B) exclusion of three data points greater than 5 SE from the mean (see text). Larger glass surfaces ($F_{1,26} = 67.25$, $P < 0.001$), trees ($F_{1,26} = 8.70$, $P = 0.007$), and the interaction between trees and glass ($F_{1,26} = 7.089$, $P = 0.013$) were associated with statistically more bird deaths following the removal of three extreme outliers. Bars represent the mean number of deaths per building surface (log-transformed values) ± 1 SE.

| | |
|---|---|
| **From:** | Hickory, DH Strongheart |
| **To:** | Dauphin, Derek; Asnis, Marc |
| **Subject:** | FW: Glazing data for the Towne Storage rebuild |
| **Date:** | Thursday, October 27, 2016 12:21:37 PM |

First useful data on glazing percentages. Based on this data, the highest percentage of glazing is on the South façade, and comes out to 33% (E: 28%; W: 27%; N: 1%).

---

**From:** Zachary Freund [mailto:zfreund@lrsarchitects.com]
**Sent:** Thursday, October 27, 2016 11:46 AM
**To:** Hickory, DH Strongheart <Dependable.Hickory@portlandoregon.gov>
**Cc:** Michael Roberts <mroberts@lrsarchitects.com>
**Subject:** [User Approved] RE: Glazing data for the Towne Storage rebuild

D.H.,
See comments below in red:
Let me know if you have any questions.
Thanks,

**Zachary Freund | LRS Architects | Portland | Shanghai**
971.242.8133 direct · 720 NW Davis Street Suite 300 · Portland, OR 97209 · www.lrsarchitects.com · vCard
***Celebrating our 40th Anniversary***

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**From:** Hickory, DH Strongheart [mailto:Dependable.Hickory@portlandoregon.gov]
**Sent:** Monday, October 24, 2016 11:47 AM
**To:** Michael Roberts
**Subject:** Glazing data for the Towne Storage rebuild

Thanks again for your willingness to help us out on this analysis. The data we are hoping to get from you pertains to the Towne Storage building project, and would include:

- Separated by façade (N,S,E,W) the building façade area for the first 4 stories;
    - South: 11,145 SF
    - East: 4,998 SF
    - West: 6,181 SF
    - North: 6,189 SF
- Separated by façade (N,S,E,W) the glazing area (incl. spandrel glass) for the first 4 stories;
    - South: 3,666 SF
    - East: 1,397 SF
    - West: 1,645 SF
    - North: 42 SF
- Any spec sheets for the specific glazing types used on the Towne Storage building project. If you don't have spec sheets, then the brand and type of glazing will suffice.
    - Cardinal IG ¾" Low E 272 / Clear ARG

Thanks again for your help on this, and please don't hesitate to call or write me back for any reason.

D.H. Strongheart

Dependable Hickory (D.H.) Strongheart
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Bureau of Planning and Sustainability
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!SIG:580e574b192459189319108!

| | |
|---|---|
| **From:** | Asnis, Marc |
| **To:** | Asnis, Marc |
| **Subject:** | reflectivity ratio |
| **Date:** | Friday, September 16, 2016 10:02:38 AM |

Toronto Green Standard:

*Low reflectance, opaque materials may include spandrel glass with one of the following: (i) Solid back-painted frit or silicone backing opaque coatings OR; (ii) Reflective or low-e coatings that have an outside reflectance of 15% or less. Spandrel glass with reflective or low-e coatings that have an outside reflectance of greater than 15% should be used in combination with other strategies.*

**Marc Asnis**
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| | |
|---|---|
| **From:** | lisa.schon@k-i-consulting.com |
| **To:** | Asnis, Marc |
| **Subject:** | [Approved Sender] Re: City of Portland Bureau of Planning and Sustainability |
| **Date:** | Friday, September 16, 2016 5:12:49 AM |

Hi Marc,

Thought I'd follow up with an email as we did not connect via phone yesterday. It is a bit difficult for me to state pricing impact as a percentage of overall budget as there are many factors involved that I do not see. I have heard from some architects that using a bird-friendly glass type can add + 15% - 40% to the overall window framing system. If you have not already, I would recommend to reach out to the San Francisco Planning Department folks who worked on their bird-friendly guidelines....I believe they have some better data on this topic.

I do not have cost information on the UMASS and Vassar projects but could facilitate an introduction to the architects on each project. They might be able to give you feedback on that. Let me know....

That said though, I can give you an idea of what our pricing is to our suppliers (window / curtain wall installers). Ornilux double glazed units range approx. $25 - $38 / sq ft depending on which low-E or solar control coating they are paired with; + transport costs.

Please let me know if you need additional information. All the best with the City Council meeting!

Regards,
Lisa

On Tue, May 31, 2016 at 6:42 PM, Lisa Welch <lisa.welch@arnold-glas.de> wrote:

> Hi Marc,
>
> It was nice speaking with you today and I am pleased to hear of Portland's progress on the bird collisions issue. The PNW is so important in leading the US towards greater sustainability on many fronts.
>
> I will work with our technical team in Germany to define the information needed for the implementation of the code, and as I mentioned, this is something we would incorporate into our spec sheet which is the reigning document for architects specifying Ornilux (attached). We recently updated this document so maybe you want to review it to see if you are working with our most recent configurations.
>
> Please feel free to contact me for any needed support related to Ornilux or glass and coating production in general. Hopefully you will not encounter too many obstacles with your efforts. :)
>
> I will follow up with you on point #1, and consider point #2 a given.
>
> Regards,
> Lisa

On Tue, May 31, 2016 at 3:11 PM, Asnis, Marc <Marc.Asnis@portlandoregon.gov> wrote:

Lisa,

Thanks again for taking the time to talk.  Per your request, here are our questions:

1. With a coating of 1/16'' lines and an irregular pattern of max 2" spacing, what does that equate to in terms of overall coverage?

2. Would Ornilux be able to provide architects with a graphic spec sheet that clearly show thickness, spacing and coverage percentage?

Thanks again, I appreciate any additional information you can provide.  I will be sure to keep you posted on the progress of the code update.

Marc

**Marc Asnis**

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> --
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> www.ornilux.com

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*Arnold Glas offers standard, low-e insulated glass types to match ORNILUX for non-bird protection glass areas of the building. Please visit www.arnold-glas.com*

--
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**From:** Soud, Faez
**To:** Asnis, Marc
**Subject:** RE: Bird Safe Question regarding 30% glazing
**Date:** Thursday, September 15, 2016 1:20:35 PM

Hi Marc,

Please see the references below for the amount of glazing/windows required in the design guidelines.  The oriel windows requirements are part of the Oregon Structural Specialty Code (OSSC), which I do not have an access to.  I hope this will help point you in the right direction.

Thanks,

**33.510.221 Required Windows Above the Ground Floor**

**A. Purpose.** Windows on building facades above the ground floor ensure opportunities for active uses, contribute to the skyline, and add interest to the built environment in the area near the streetcar alignment.

**B. Where this regulation applies.** The regulation of this section applies to sites near the streetcar alignment shown on Map 510-12.

1. In the River District, the regulation applies to the portion of a site within 200 feet of a streetcar alignment, if the site is in the EX zone.
2. In the West End, the regulation applies to the portion of a site within 200 feet of a streetcar alignment.

510-43

Chapter 33.510 Title 33, Planning and Zoning Central City Plan District 6/5/15

3. In the South Waterfront Subdistrict, the regulation applies to the portion of a site within 200 feet of a streetcar alignment. The regulation also applies to the portion of a site within 200 feet of a proposed streetcar alignment, as shown on the street plan for the area that has been accepted by City Council. The street plan is maintained by the Portland Office of Transportation.

**C. Standard.** Windows must cover at least 15 percent of the area of street-facing facades above the ground level wall areas. This requirement is in addition to any required ground floor windows. Ground level wall areas include all exterior wall areas up to 9 feet above the finished grade.

**33.510.225 Ground Floor Active Uses**

**A. Purpose.** The ground floor active use standards are intended to reinforce the continuity of pedestrian-active ground-level building uses. The standards are also to help maintain a healthy urban district through the interrelationship of ground-floor building occupancy and street level accessible public uses and activities. Active uses include but are not limited to: lobbies, retail, residential, commercial, and office.

**B. Sites and development subject to the ground floor active use standard.** Ground floor active use areas are shown on Map 510-7 at the end of this chapter. On identified sites, all new development and all major remodeling projects must meet the standard below.

**C. Ground floor active use standard.** Buildings must be designed and constructed to accommodate uses such as those listed in Subsection A., above. Areas designed to accommodate these uses may be developed at the time of construction, or may be designed for later conversion to active uses. This standard must be met along at least 50 percent of the ground floor of walls that front onto a sidewalk, plaza, or other public open space.

Areas designed to accommodate active uses must meet the following standards:

1. The distance from the finished floor to the bottom of the structure above must be at least 12 feet. The bottom of the structure above includes supporting beams;
2. The area must be at least 25 feet deep, measured from the street-facing facade;
3. The area may be designed to accommodate a single tenant or multiple tenants. In either case, the area must meet the standards of the Accessibility Chapter of the State of Oregon Structural Specialty Code. This code is administered by BDS; and

4. The street-facing facade must include windows and doors, or be structurally designed so doors and windows can be added when the space is converted to active building uses.

**Faez Soud**
*Portland Housing Bureau*
Senior Housing Construction Coordinator
421 SW Sixth Ave., Suite 500
Portland, OR 97204
PH: 503-823-3771
Cell:503-853-5795

---

**From:** Asnis, Marc
**Sent:** Thursday, September 15, 2016 1:01 PM
**To:** Soud, Faez <Faez.Soud@portlandoregon.gov>
**Subject:** Bird Safe Question regarding 30% glazing

**Marc Asnis**
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503-823-4174 | Marc.Asnis@portlandoregon.gov

**From:** Hoy, Rachael
**To:** Raggett, Mark; Asnis, Marc; Walkiewicz, Marie; Heron, Tim; Helzer, David; Lovell, Kaitlin; Edmunds, Sallie
**Subject:** follow up Bird Safe glazing meeting
**Date:** Friday, September 09, 2016 9:00:57 AM

Hi all- thank you for attending the meeting this week on bird safe glazing. BPS staff will meet to discuss potential changes to the provision. What I heard:

1) Expand area where standard applies to entire Central City for ease of implementation ( this would potential include industrial zones)
2) Consider limiting the types of glazing that could be applied on ground floor for transparency purposes – such as UV, light friting patterns
3) Consider adding a drawing to the code to show types of patterns and dimension to eliminate some of the complex measurement language

One thing we did not talk about that has been raised in testimony is the request to prohibit highly reflective/ mirrored glass. I'm going to ask Mark A. to do a little more digging to see how/if other cities address this.

Thanks, Rachael

Rachael Hoy, Senior City Planner, Central City Team
Bureau of Planning and Sustainability
1900 SW 4th Ave, 7th floor
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# Central City 2035 – Proposed Draft - Bird-Safe Exterior Glazing Standards

- **Bird mortality due to window strikes.** An estimated 1 billion birds die each year from collisions with buildings in the US. Bird strikes can occur anywhere there is exterior clear glass, but particularly near water or vegetated habitat areas or where exterior glazing reflects vegetation, such as street trees or sky. A number of cities and states in the nation have adopted regulations to address bird-building collisions.

- **City Council direction and new policies.** Recognizing this hazard, the City Council adopted Resolution 37034 (Oct. 2, 2013) directing City bureaus to seek opportunities to incorporate bird-friendly building design into City plans and projects, including the Comprehensive Plan, Central City 2035, and the City's Green Building Policy.

- Portland's updated Comprehensive Plan and CC 2035 include policies calling for bird-friendly building design. The recently updated Green Building Policy requires bird-friendly building design for all new City buildings and encourages retrofits of existing buildings.

- **Central City 2035 direction.** Consistent with this direction, CC2035 concept plan and quadrant plans call for actions to advance bird-friendly building design. The draft code includes new lighting standards to reduce negative impacts on wildlife, and exterior glazing treatment standards designed to decrease the risk of bird-to-building collisions by reducing the transparency or reflectivity of exterior windows and other glazed surfaces in the Central City.

- **Applicability.**

  A new map shows that the standards will apply throughout the Central City, except in industrial zones that are outside the Greenway or River overlay, or are further than 300 feet of the river. This is because industrial buildings typically have limited glazing and the industrial land has relatively little tree canopy and vegetated areas.

  For sites within the applicable area, the standard requires bird-friendly treatments on at least 90 of glazing on: (1) first four floors, (2) windows on floors located directly adjacent to an ecoroof, roof garden, or other vegetated or landscaped roof, (3) glazed portions of balcony railings, sky bridges, and atria, and (4) glass partition walls.

  The standards also specify required width and spacing of window markings. It is intended that applicants provide BDS with appropriate documentation from their vendor.

  The standard applies to most new forms of construction as well as major remodels that alter at least 75 percent of a building's facade. The standards include exemptions for certain residential developments and that pertain to sites containing Historic or Conservation Landmark, or a contributing resource in a Historic or Conservation District. The standards may be adjusted.

- **Treatment options.** The proposal allows for eight different technologies to fulfill the bird-safe glazing requirements. The proposal allows projects to use: exterior fritting, etching, netting, permanent stencils or frosting, screens, grilles or louvers, films, ultra-violet coating, or mullions.

  Developers can choose which option or options best fit the goals and needs of a given project. Developers can choose options that have been tested for their effectiveness at reducing bird strikes, as well as those that have not.

- **Cost.** The cost to comply with these new standards will vary depending on the amount of glazing, the scale of the project, and the option(s) selected. Potential synergies between bird-safe glazing to meet energy efficiency goals and requirements or other project objectives could offset the incremental costs of the bird-safe glazing standards substantially, potentially making the requirements cost neutral.

- **LEED Credit -** It is possible to receive credit toward LEED certification for projects that pursue LEED Pilot Credit 55, Bird Collision Deterrence. The new Fire Station 21 on the east bank of the Willamette River near the Hawthorne Bridge met the requirements of LEED Pilot Credit 55 as part its LEED certification.

| | |
|---|---|
| **From:** | Brooks, Mindy |
| **To:** | Jortner, Roberta; Asnis, Marc; Bischoff, Debbie |
| **Subject:** | Lighting Policy |
| **Date:** | Tuesday, December 29, 2015 3:38:23 PM |

Here is a draft policy for the Central City. It would go in the Health and Environment section, which is CC-wide. Let me know what you think.

**Light, Noise and Vibration Pollution.** Encourage land use patterns, building design and landscaping to limit and mitigate negative impacts of lighting, noise and vibration on public health and safety, disruption of ecosystems, and hazards to wildlife.

For Reference, here are the Comp Plan Policies:

**4.32 - Off-site impacts.** Limit and mitigate public health impacts, such as odor, noise, glare, light pollution, air pollutants, and vibration that public facilities, land uses, or development may have on adjacent residential or institutional uses, and on significant fish and wildlife habitat areas. Pay particular attention to limiting and mitigating impacts to under-served and under- represented communities.

**4.34 - Noise impacts.** Encourage building and landscape design and land use patterns that limit and/or mitigate negative noise impacts to building users and residents, particularly in areas near freeways, regional truckways, major city traffic streets, and other sources of noise.

**4.37 - Light pollution.** Encourage lighting design and practices that reduce the negative impacts of light pollution, including sky glow, glare, energy waste, impacts to public health and safety, disruption of ecosystems, and hazards to wildlife.

**4.71 - Hazards to wildlife.** Encourage building, lighting, site, and infrastructure design and practices that provide safe fish and wildlife passage, and reduce or mitigate hazards to birds, bats, and other wildlife.

***~~~~~~~~~~~~~***
***Mindy Brooks***
***City of Portland***
***Bureau of Planning and Sustainability***
***503-823-7831***
**mindy.brooks@portlandoregon.gov**

Accepted on 12/2/2015 11:22 AM.

Organizer Asnis, Marc

Sent Tue 12/1/2015 10:59 AM

Subject Bird Friendly Building Design Collaboration

Location BPS Conf 7E (16)

Start time Wed 12/16/2015 2:00 PM All day event

End time Wed 12/16/2015 3:00 PM

Hey Sustainability at Work,

Roberta and I have been working with the Audubon Society and our partner agencies to help promote bird friend building and lighting design within the Portland business community. Our efforts have been spurred from the adoption of the City's updated Green Building Policy as well as a NFWF grant that Audubon has received in order to launch a 2-year Bird Friendly Portland campaign to raise awareness. We've noticed that there is overlap between the strategies that we are advocating for and the actions/criteria that you specify in the certification process for aspiring green businesses, specifically the use of energy efficient glazing products and internal/external lighting practices. A big part of our messaging is that there are many synergies between achieving green building goals and bird friendly design.

I'm setting up a meeting to update you guys on what we've been working on and to start a discussion that can hopefully lead to future collaboration.

Thanks,

Marc

**Marc Asnis**
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| | |
|---|---|
| **From:** | Mary Coolidge |
| **To:** | Asnis, Marc |
| **Cc:** | Jortner, Roberta; Agarwal, Maya; Roth, Emily; Johnson, Connie |
| **Subject:** | Re: Bird Friendly Design Meeting with BPS and Audubon |
| **Date:** | Tuesday, December 01, 2015 11:14:00 AM |

Thanks for setting this up, Marc.
Unfortunately, I'm booked on the 17th. Anytime Monday, Tuesday or Friday that week could work.
Could we find a different time?
Best,
Mary

On Tue, Dec 1, 2015 at 10:08 AM, Asnis, Marc <Marc.Asnis@portlandoregon.gov> wrote:

> Good Morning,
>
> Over the past couple of months, BPS has been partnering with Audubon Society of Portland to help raise awareness of bird strike hazards and to promote bird friendly building and lighting design within the architecture and landscape architecture community. This work is being done in conjunction with City Council resolution (37122) adopted in April 2015, which updated the City's Green Building Policy. The updated policy now requires all new City buildings to incorporate bird-friendly building design and for bureaus to seek opportunities to reduce bird collisions when planning for retrofits of existing buildings. Additionally, city owned properties will also be required to consider best practices in lighting design. In the case of exterior light fixtures, a design that uses full cut off shields to minimize light spill is preferable.
>
> We are reaching out to Parks to coordinate the efforts and keep you abreast with what we are currently working on. We would also like to hear more about what tactics are being implemented in your work and what is already being considered during the planning and design process for new city parks. I asked Maya the other day who would be the right people to contact, and she recommended you two, so thank you in advance for taking the time to meet with us.
>
> Thanks again,
>
> Marc
>
> **Marc Asnis,** City Planner
> Urban Design Studio
> City of Portland Bureau of Planning and Sustainability
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>
> 

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Mary Coolidge
BirdSafe Portland Campaign Coordinator
Audubon Society of Portland
http://audubonportland.org/issues/hazards/buildings/birdsafe
mcoolidge@audubonportland.org
971.222.6143 Audubon Cornell
503.866.3779 cell

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| --- | --- |
| **From:** | Foreman, Stacey |
| **To:** | Jortner, Roberta; David Heslam |
| **Cc:** | Asnis, Marc |
| **Subject:** | RE: reminder: call today at 3pm; 503-823-9322 |
| **Date:** | Wednesday, October 14, 2015 12:52:48 PM |

Let's continue as planned for today, since it is really hard to find a time for all of us to get together…
I think we can still benefit from the call - and David – I promise I won't make you talk much. ☺
-Stacey

**From:** Jortner, Roberta
**Sent:** Wednesday, October 14, 2015 12:10 PM
**To:** David Heslam <dheslam@earthadvantage.org>
**Cc:** Foreman, Stacey <Stacey.Foreman@portlandoregon.gov>; Asnis, Marc <Marc.Asnis@portlandoregon.gov>
**Subject:** RE: reminder: call today at 3pm; 503-823-9322

Hi David,

Stacey is actually the meeting organizer and is coordinating the presentations w/OAME.  Stacey, would you like to reschedule this meeting for when David's voice returns?

Roberta

**From:** David Heslam [mailto:dheslam@earthadvantage.org]
**Sent:** Wednesday, October 14, 2015 11:48 AM
**To:** Jortner, Roberta <Roberta.Jortner@portlandoregon.gov>
**Cc:** Foreman, Stacey <Stacey.Foreman@portlandoregon.gov>; Asnis, Marc <Marc.Asnis@portlandoregon.gov>
**Subject:** Re: reminder: call today at 3pm; 503-823-9322

Roberta,

Unfortunately I have a very hoarse voice today as a result of trying to work through a cold for the past few days.

I can call in at 3pm, but my commentary will be very limited.

-David


**David Heslam**
*Executive Director*

**E** dheslam@earthadvantage.org
**T** 503.968.7160 x34 / **C** 971-344-7173

**Earth Advantage** // Better Buildings Now
earthadvantage.org / portland, or

Earth Advantage just surpassed the **14,000 certified homes** mark!

On Wed, Oct 14, 2015 at 10:58 AM, Jortner, Roberta <Roberta.Jortner@portlandoregon.gov> wrote:

Hi all,
Here's our draft PowerPoint presentation outline, if you have time to peruse it before our meeting. We can go over it then too.
Let me know if you have questions.
Roberta

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**From:** Foreman, Stacey
**Sent:** Wednesday, October 14, 2015 8:52 AM
**To:** Jortner, Roberta <Roberta.Jortner@portlandoregon.gov>; David Heslam <dheslam@earthadvantage.org>; Asnis, Marc <Marc.Asnis@portlandoregon.gov>
**Subject:** reminder: call today at 3pm; 503-823-9322

Hello,
Just a quick reminder about our planning call today for the Nov 13 info session at OAME. Below is a proposed agenda for the Nov 13 event. Today, we will go over the objectives for the event, establish key talking points for each speaker, and set a timeline for when to submit presentation/handout materials.
-Stacey

CALL IN NUMBER FOR TODAY: 503-823-9322

**Green Building Design Hot Topics Info Session: Bird-Friendly Design and Earth Advantage Commercial Certification**

OAME, November 13, 2015, 9:15am to 10:35am

**Objectives:**
**Attendees Leave With:**

- Awareness of the updates to the City's Green Building Policy
- Basic knowledge of Bird-Friendly Design concepts
- Initial resources for where to learn more about Bird-Friendly Design

- Basic knowledge of the Earth Advantage Commercial Green Building Certification
- Initial resources for where to learn more about Earth Advantage Commercial Certification

**Attendees Provide Feedback on:**

- What kind of training/resources they would like to see for each topic.

**Nov 13 Agenda**

- Welcome and Introductions (5 minutes)
- City of Portland Green Building Policy Update Highlights (5 minutes) – Stacey Foreman, City of Portland Procurement Services
- Introduction to Bird-Friendly Design (20 minutes) – Roberta Jortner and Marc Asnis, City of Portland Bureau of Planning and Sustainability
- Q&A (10 minutes)
- Introduction to Earth Advantage Commercial Green Building Certification (20 minutes) – David Heslam, Earth Advantage
- Q&A (10 minutes)

**Stacey Foreman**, LEED AP O+M | Sustainable Procurement Coordinator | City of Portland, Procurement Services
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