White Paper

Fire Analysis of Fire Retardant Treated Wood Alternate

Client Name: Scott Edwards Architecture

Project Name: Pettygrove Apartments

Project Address: 2231 NW Pettygrove Street, Portland, OR 97210

Date: 10/28/2020

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1 OVERVIEW

1.1 Project Description

The Pettygrove Apartments is a new building to be constructed in Portland, OR. The proposed design is five stories of Type III-B construction residential building in the Portland NW district. The building is fully sprinklered throughout per NFPA 13, with a fire alarm and detection system per NFPA 72. It will be under the jurisdictional review of the City of Portland.

The design team is interested in using untreated wood instead of fire-retardant-treated (FRT) wood in the exterior wall of the Type III structure. Code Unlimited has developed this technical white paper to support the construction. The City of Portland has reviewed and approved similar appeals based on this approach. Scott Edwards Architecture has asked Code Unlimited to prepare a similar comprehensive analysis for this project. This white paper will be used in conjunction with an appeal to the City of Portland.

Type III construction requires that exterior walls be of noncombustible construction or of Fire-Retardant Treated Wood (FRTW) construction provided the exterior wall is 2-hour rated or less. The project proposes to use conventional wood studs without the Fire-Retardant Treatment (FRT). There are structural and environmental benefits for this approach.

1.2 Executive Summary

Fire-retardant treated (FRT) wood framing is permitted by code within exterior Type III wall assemblies with a fire-resistance rating of a 2 hours or less. This is based on the improved fire performance of such wood compared to regular wood of same species. Fire-retardant treatment of wood delays ignition and resists flame spread once heated to ignition temperature. The proposed design of the exterior wall assembly for this project uses friction fit mineral wool insulation between non-treated wood framing members to provide equal or better fire performance a Fire Retardant Treated Wood (FRTW) wood wall assembly.

Code Unlimited has analyzed the alternative of using non-FRT wood in place of FRT wood on multiple projects. This has been driven by many stakeholders within the Pacific Northwest region; local and state governments, universities and other research groups, manufacturers, real estate developers, and design and construction industry professionals. This white paper is the most current knowledge on this subject, based on rigorous analysis, review, and input from senior fire protection engineers and code experts.

This white paper will provide the following information to show that the use of non-treated wood in Type III exterior wall assemblies with friction fit mineral wool insulation is equivalent to FRT wood allowed in Type III exterior walls:

- A detailed understanding of the building code regulations that are driving the requirement for FRT in Type III exterior walls, with excerpts from the International Building Code (IBC) commentary to clarify intent where necessary.
- Code citations in the Oregon Structural Specialty Code (OSSC) and the IBC where the use of mineral wool delays ignition and inhibits flame migration.

Many code provisions have evolved from traditional construction practices and then undergo rigorous analysis and/or testing to substantiate performance in those applications. This white paper follows that time-tested path by including a rigorous performance analysis based on currently available test data in support of non-FRT wood in an exterior wall assembly of a Type III construction building.

Our analysis found that the fire performance of a non-FRT wood framed wall with mineral wool insulation is equal or superior to an FRT wood framed wall. Research from other authorities shows that this approach also reduces the potential for chemical exposure to the environment and to the occupants of these buildings compared to the current practice of using FRT wood.

1.3 Applicable Codes and Standards

Applicable Code or Standard
• *2019 Oregon Structural Specialty Code (OSSC)*
• *2019 Oregon Fire Code (OFC)*
• *2009 ASTM E-84 Test Methods for Surface Burning characteristics of Building Materials – American Society for Testing and Materials*
• *2007 ASTM E-119 standard Test Methods for Fire Tests of Building Construction and Materials – American Society for Testing and Materials*

1.4 Additional References

1 2007 Performance of a non-load-bearing steel stud gypsum board wall assembly: Experiments and modelling, Samuel L. Manzello, et al, Fire and Materials (Issue 31, pp 297-310)

2 2015 A Model for predicting heat transfer through insulated steel-stud wall assemblies exposed to fire, Sultan, M. A.; Alfawakhiri, F.; Bénichou, N., Fire and Materials - 2001 International Conference, San Francisco, January 22-24, 2001, pp. 495-506

3 2007 Analysis of Inter-laboratory Testing of Non-loadbearing Gypsum/Steel-Stud Wall Assemblies, William Grosshandler, Samuel L. Manzello, Alexander Maranghides - Building and Fire Research Laboratory, Tensei Mizukami - Center for Better Living

4 1977 Effect of fire-retardant treatments on performance properties of wood. In: Goldstein, I.S., ed. Wood technology: Chemical aspects. Proceedings, ACS symposium Series 43. Washington, DC: American Chemical Society.

5 1992 Charring Rate of Wood for ASTM E119 Exposure, Fire Technology Volume 28, Number 1, Robert H. White, and Eric V. Nordheim

6 1977 National Board of Standards Technical Note 945: An Investigation of the Fire Environment in the ASTM E 84 Tunnel Test

7 2016 Calculating the Fire Resistance of Exposed Wood Members, Technical Report No 10, American Forest & Paper Association, Inc, American Wood Council, 1111 19th St., NW, Suite 800, Washington, DC 20036

[8] 2010 Wood Handbook, Wood as an Engineering Material, Chapter 17 Fire Safety, Robert H. White, and Mark A. Dietenberger, Forest Product Laboratory, United States Department of Agriculture Forest Service, Madison Wisconsin

[9] 2003 Ignition Handbook: Principles and Applications to Fire Safety Engineering, Fire Investigation, Risk Management and Forensic Science, Dr. Vytenis Babrauskas – Fire Science Publishers

[10] 2006 Performance of a Non-load Bearing Steel Stud Gypsum Board Wall Assembly: Experiments and Modelling, Samuel Manzello, Richard Gann, Scott Kukuck, Kuldeep Prasad, and Walter Jones – Building and Fire Research Laboratory (BFRL), National Institute of Standards and Technology (NIST), Weapons and Materials Research Directorate, US Army Research Laboratory, APG

2 PROPOSED WALL ASSEMBLY

The proposed design is to provide a two layers of 5/8” thick type-X gypsum wall board on the interior over untreated 2x6 wood stud framing and one layer of plywood sheathing with two layers of 5/8” thick type-X gypsum wall board on the outside with either stucco or metal panel as the exterior member. Rockwool insulation will be friction fit between studs to fill the entire 6-inch nominal wall cavity. The conclusions of this report are limited to the proposed Wall type shown in Figures attached in Appendix A of this white paper.

§705.5 of the 2019 OSSC states the exterior wall assembly is required to be rated for fire exposure from the interior only if the fire separation distance (FSD) is greater than 10 feet (in accordance with Tables 601 and 602), and is required to be rated from both sides if the FSD is less than or equal to 10 feet from the property line. To comply with §705.5, the proposed wall assembly includes two layers of 5/8” thick Type X gypsum board on the exterior side where the FSD is greater than 10 feet, and two layers of 5/8” thick Type X gypsum board on the exterior side where the FSD is less than or equal to 10 feet from the property line.

3 ROCKWOOL USE PERMITTED IN CURRENT CODES

The 2019 OSSC Section 602.3 for Type III exterior wall construction permits the use of fire-retardant treated wood (FRTW) in lieu of non-combustible materials if wall is 2-hour rated or less.

Rockwool has been allowed as a means to retard or prevent the ignition of wood in concealed spaces in the following code sections:

- OSSC 803.11.1.1 allows untreated wood to be used for furred walls or ceilings where non-combustible or fire rated construction is required when the cavity is filled with a Class A material like mineral wool.
- OSSC 718.2.1(7) allows mineral wool batts to be used as fire blocking to cut off concealed draft openings.
- OSSC 718.3.1 permits the use of mineral wool batts as an approved draft stopping material.
- ORSC 316.5.3 permits the use of 1.5-inch-thick mineral wool to satisfy the requirements for an ignition barrier.
- NFPA 13 Section 8.15.1.2.17 allows untreated wood joist spaces to be treated as FRT wood when the cavity is filled with mineral wool insulation.
- OSSC 722.6 contains procedures by which the fire resistance ratings of wood assemblies are established by calculations.

IBC Section 722.6 Commentary states:

"Rockwool insulation provides additional protection to wood studs by shielding the studs from exposure to the furnace, thus delaying the time of collapse."

OSSC table 722.6.2(5) allows glass fiber, or mineral wool, or cellulosic fill within stud cavity prescriptively to increase the fire resistance of a wall assembly by 15 minutes.

- IBC Section 602.2 Commentary:

  "Fire Retardant-treated wood (FRTW), although combustible, is permitted in limited uses in building of Type I and Type II construction… it is not assumed to be fire-resistance rated, and generally does not afford any higher fire-resistance rating than untreated wood material."

4 PERFORMANCE BASED ANALYSIS AND VERIFICATION

4.1 Premise of Analysis

The list of prescriptive provisions in Section 3 establishes the code history for use of mineral wool insulation to improve the fire performance of wood wall and ceiling assemblies. These provisions are an outgrowth of tradition and historical construction practice. The values assigned to these are generic values, based on historical data. These are valuable in establishing precedence and intent of the code requirements. Our analysis is based on the full-scale test data documented in the research papers #1 and #2 listed in Section 1.4 in this white paper. The remaining references, #3, #4, #5, #6, #7, #8, #9 and #10, provide supporting evidence for the methodology used in this analysis as well as some other key metrics used in the analysis. The full-scale testing was performed with 4-inch metal stud wall assemblies, while the wall assemblies analyzed in this white paper are nominal 6-inch wood assemblies. Wood is a non-conductor of heat and a superior performer compared to metal within the context of this analysis. The test data includes wall assemblies with both fiber glass and mineral wool insulation within the stud cavity. Mineral wool outperforms fiber glass insulation at higher temperatures in terms of sag and ability to retain protection of the framing members. Our analysis takes the conservative value when there are multiple data points available.

Building structural component fire performance is predicated on the type of fire exposure. Most commonly, fire from combustible building contents or furnishings expose the components, such as walls of structural frame, to heat from the fire, causing loss of structural integrity of the wall and its eventual collapse. The point at which the load-bearing components of a Type III wall (in this case, the wall studs) are exposed to heat from the fire, the building would have long since been evacuated and the space become untenable, as the temperature required to breach the gypsum board membrane would be beyond occupant survivability. In this case, the sole concern is for the preservation of structural stability, to protect emergency personnel, and reduce spread of fire to adjacent structures. The studs of the walls provide the necessary structural, load-bearing capability to support the exterior wall. Gypsum board or other sheathing is solely relied on to provide resistance to the fire exposure in order to protect the load-bearing members, its contribution to the structural strength of the wall is negligible. The Commentaries to section 722.6 of the IBC state "It is assumed that once the structural members fail, the entire assembly fails."

OSSC section 602.3 defines Type III construction as “that type of construction in which the exterior walls are of noncombustible materials and the interior building elements are of any material permitted by this code. *Fire-retardant-treated wood* framing complying with Section 2303.2 shall be permitted within *exterior wall* assemblies of a 2-hour rating or less.”

Fire retardant treatment of wood does not prevent the wood from decomposing and charring under fire exposure. The rate of fire penetration through treated wood approximates the rate through untreated wood. Fire-retardant-treated wood used in walls can slightly improve fire endurance of these walls, but most of this improvement is associated with the reduction in surface flammability rather than any changes in charring rates.

4.2 Performance of FRT Wood

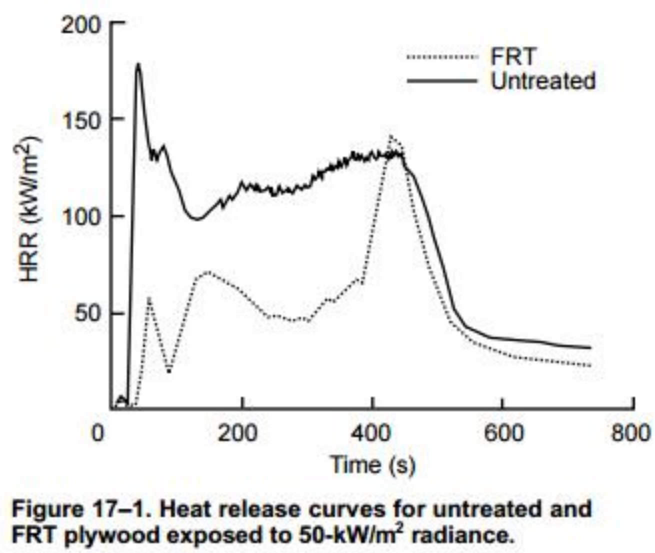

Fig.1. E84 Test Comparison (Wood Handbook Chapter 17)

Fire retardant treatment is a pressure applied surface treatment that slows ignition by interfering with heat transfer to the material and chemically interferes with combustion. It does so by converting combustible gases and tars to carbon char at temperatures below 550°F[4,8] and releases carbon dioxide and water vapor which dilutes the combustible gases. Above temperatures of 550°F, outgassing and pyrolysis effects of the FRT exceed the limits where the treatment inhibits ignition. Above 550°F, FRT heat release rate and burning rates become equivalent to untreated wood of the same species. Charts of the ASTM E84 (Standard Test Method for Surface Burning Characteristics of Building Materials) heat release rates (Fig. 1) show that at about 420 seconds (7 minutes), the heat release rate (HRR) for FRT wood and non-FRT wood are virtually identical, indicating that, after the fire retardant treatment has been exhausted, the non-FRT and FRT wood studs will provide the same level of protection of structural integrity for fire migration and for ignition. The amount of additional wood charred in non-FRT wood is .105 inches (less than 1/8”) than FRT wood.

Once the gypsum layers are compromised, the fire is free to attack the exposed studs. However, charring and consumption of the studs begins before failure of the gypsum membrane, as heat is conducted to the edge face of the studs and to the stud wall cavity by conduction through the gypsum board. In the stud wall cavity, the temperatures are already well over the auto ignition temperature of wood and the point at which FRTW becomes ineffective (550°F) by the time the two gypsum board layers have been compromised. Although the standard stud begins charring sooner than the FRTW stud, total time to fail for the standard stud is much longer due to the insulative effects of the mineral wool, slowing progressive char over the longer dimension (side) faces of the stud by preventing heat transfer to the stud cavity.

Above 550°F, FRTW studs behave similar to standard wood studs and charring continues until it fails in load. Char rates for softwoods such as used in framing lumber are at an average rate of 1. 5 in/hr [6]. By calculating the heated perimeter of the wood studs for an uninsulated, code-accepted FRTW stud and a mineral-wool insulated standard stud, and using the average char rate, a time to failure of the two studs can be determined.

The effective heated perimeter of a 2" x 6" nominal FRTW stud is 12. 5 inches at the point of its ignition. The effective heated perimeter of a mineral wool insulated stud is only 1. 5 inches at the same point, although the point of ignition is approximately 7 minutes earlier due to the effects of FRT and the delay of ignition of the FRTW stud. As the studs are consumed by charring, the 3-sided attack[6] on the FRTW stud results in much more material loss due to charring and more rapid reduction in load-bearing capability. While there is some charring of the sides of the standard stud, especially nearest the exposed edge, the insulative properties of the mineral wool significantly slow charring and loss of material.

4.3 Code Basis of Engineered Design Performance

OSSC Table 722.6.2(2) states that the time assigned for contribution of the wood frame to fire resistance is 20 minutes. Within that time, the fire is assumed to consume sufficient of the stud framing to compromise its structural strength such that it fails under load. Thus, it was assumed that, once the FRTW studs reach the point where the fire retardant treatment no longer interferes with charring, the stud will have 20 minutes of load-bearing capability before failure. This occurs with approximately 25% of the original stud cross-section remaining after charring. A similar failure point was used for analysis.

OSSC Table 722.6.2(5) notes that "Additional Protection" can be provided to a wall for fire rating purposes by the addition of mineral wool insulation at a specified minimum density. The Commentaries for IBC section 722. 6 note that "Mineral wool insulation provides additional protection to wood studs by shielding the studs from exposure to the furnace, thus delaying the time of collapse." Mineral wool does this by insulating the sides of the studs from direct heat and flame exposure and by interfering with flame spread by conduction, radiation, and convection within the wall cavity. In this respect, the assembly is superior to FRTW with only fiberglass insulation, in that its ability to interfere with ignition is not compromised by high exposure temperatures. Mineral wool has a melting point of 2150°F and can withstand a 4 hour test per ASTM E119 time-temperature curve, where the fire temperature reaches a maximum temperature of 2000°F, well above the temperatures expected in a flashover fire condition.

Unlike a simple, 2-hour rated FRTW stud wall, mineral wool provides protection on the sides of the studs, ensuring the main route of burn-through to be in the longest dimension of the lumber (See Fig 4-6). In FRTW, fire attack, once the thermal membrane has been compromised, is on three sides of the stud and burn through of the stud is much more rapid. Use of mineral wool insulation is specified as it has greater refractory qualities, higher installed density and remains in place long after fiberglass insulation has melted away.

Clearly, there is an advantage to the use of mineral wool in the wall that an ordinary FRTW assembly does not match.

4.4 Rational Analysis

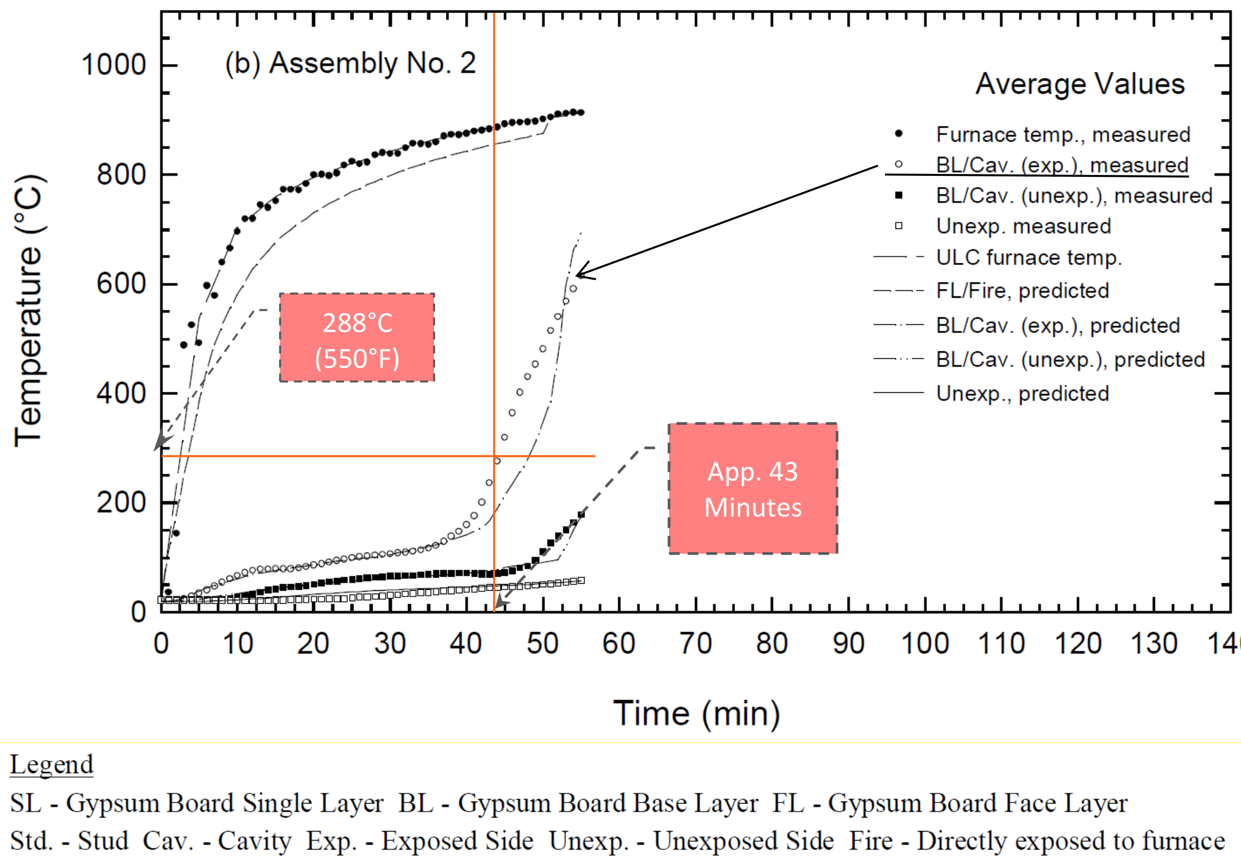

Figure 2: Time vs temperature curve – Double Layer 5/8" Gypsum Board, Studs 16" O. C. [7]

Note: Line (open dots) for temperature at inner surface of base layer, exposed side. This is the temperature of stud cavity/edge of stud.

<u>Derivation Calculation</u>

Utilizing test data from reference document #7, (equation #10) and Fig. 2 above. The calculated stud surface temperature can be derived and graphed.

Eq. 10[7]

$$T_m^{j+1} = T_m^j + \frac{\Delta t}{(\rho_i c_i)_m^j (\Delta y)^2}\left\{\left[\frac{(k_i)_{m-1}^j + (k_i)_m^j}{2}\right]\left(T_{m-1}^j - T_m^j\right) - \left[\frac{(k_i)_m^j + (k_i)_{m+1}^j}{2}\right]\left(T_m^j - T_{m+1}^j\right)\right\}$$

The calculated time to autoignition temperature for several depth increments into the mineral wool insulation (long direction of stud) are displayed below. (See Fig. 2A)

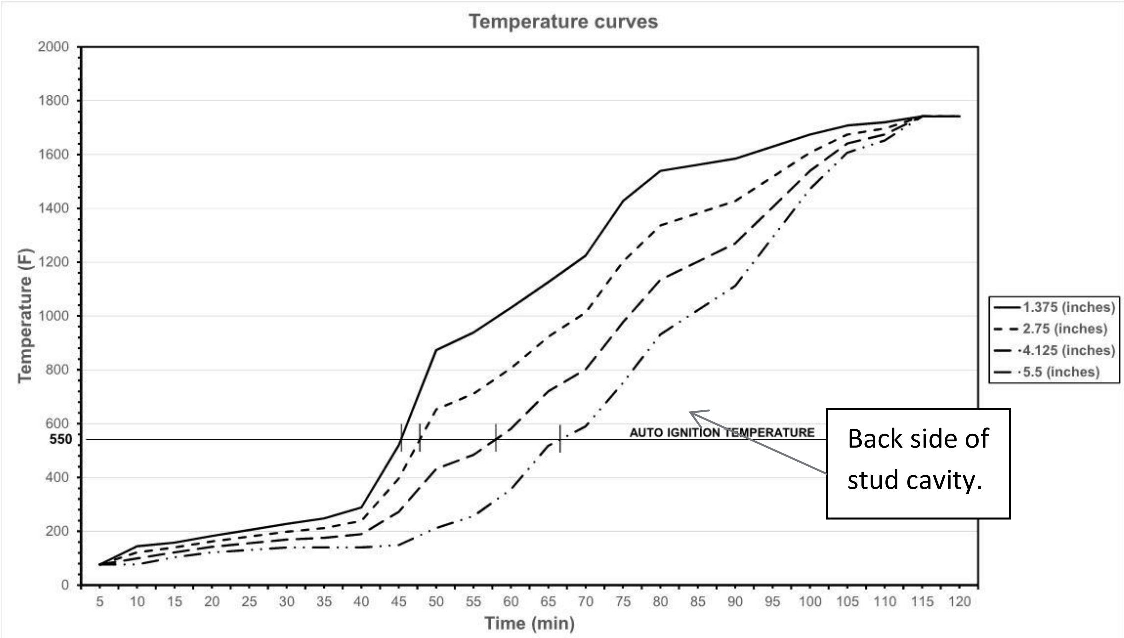

Figure 2A: Time vs Stud Surface Temperature curve – Calculated per Eq. 10. [7]

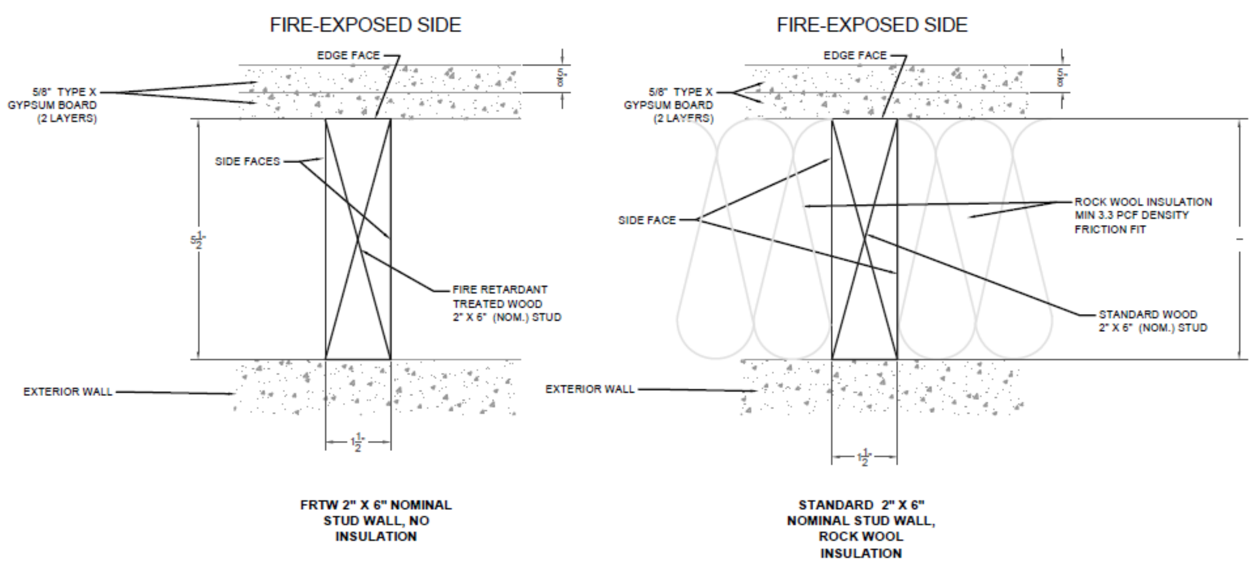

Figure 3: FRTW and Mineral Wool Stud Walls

Note: Figures 3 – 6 do not show composition of the exterior (non-fire exposed) side, as other constructions, allowed by code for non-fire exposed assemblies, may be used. All wall types shall be 2-hour rated as shown in Appendix A. In all cases addressed by this report, the Fire Separation Distance is greater than 10 feet and fire resistance rating may be calculated from the fire exposed side only in accordance with OSSC section 705. 5.

5 FIRE RESISTANCE COMPARISON

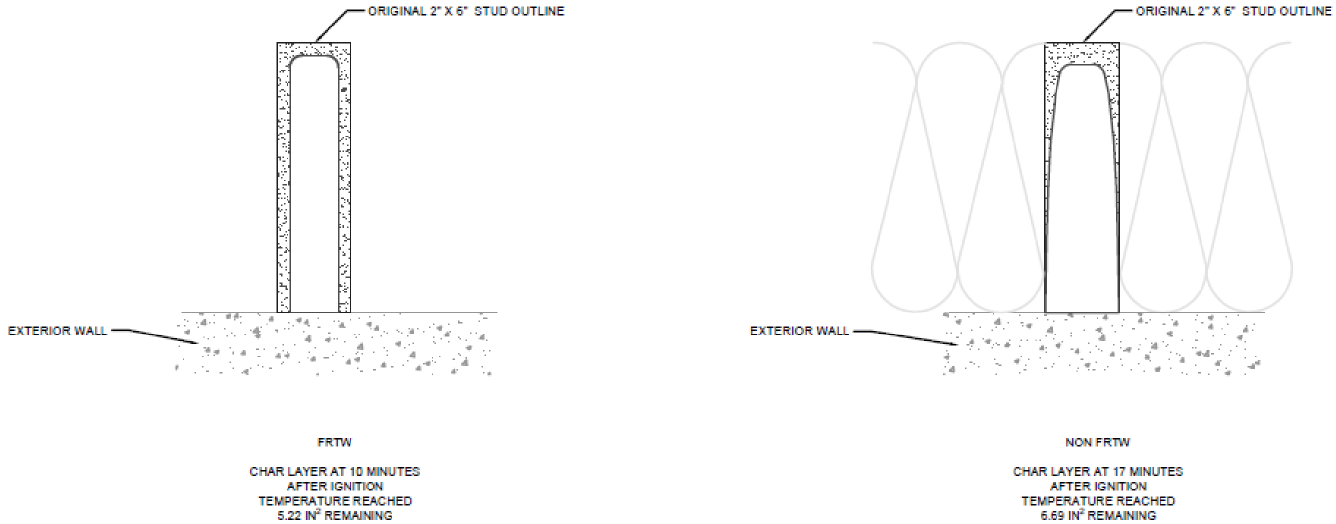

Figure 4: FRTW and non-FRTW stud wall at 60 minutes after fire exposure of gypsum board wall

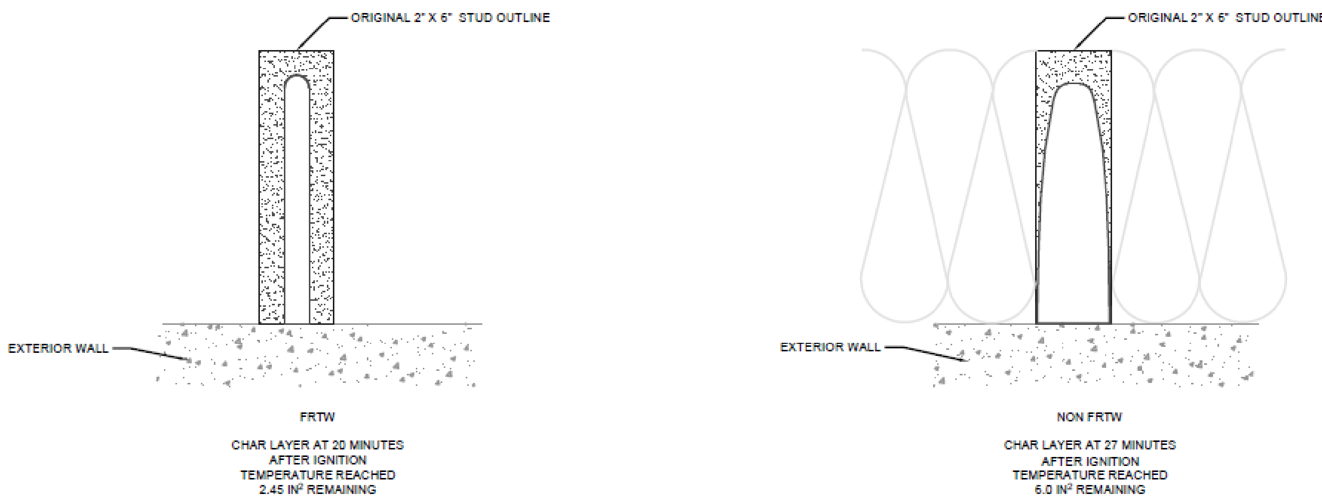

Figure 5: FRTW and non-FRTW stud walls at 70 minutes after fire exposure of gypsum board wall point of FRTW wall failure

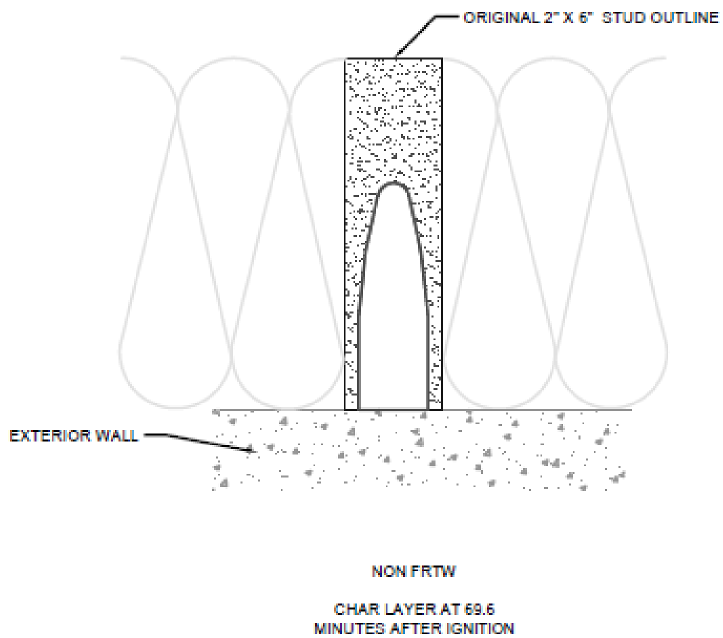

Figure 6: Non-FRTW stud wall at failure at 112 minutes – reduced cross sectional area equivalent to FRTW at failure

Charring and loss of load-supporting cross-section of the wood studs begins at approximately 43 minutes after exposure of the wall to fire, as heat conducts through the gypsum board and the temperature at the inside face of the gypsum board wall reaches the auto ignition temperature of wood. Ignition of the FRTW is delayed by approximately 7 minutes by the action of the fire retardant treatment. By approximately 50 minutes after exposure, both studs are experiencing charring.

At 60 minutes after exposure, approximately 50% of the allowable cross-section of the FRTW stud has been consumed by charring. Somewhat less (27%) of the insulated non-FRTW stud has been consumed at the same point, due to the effects of mineral wool in limiting heat transfer to the wood.

At 70 minutes, the FRTW has lost sufficient cross section that it fails in load. At this point, approximately 25% of the original FRTW stud cross-section remains. However, only 39% of the insulated stud has been consumed.

At approximately 112 minutes, charring of the insulated non-FRTW stud reaches the point at which less than 25% of the original cross-section remains and the stud fails.

The table below provides a comparative analysis that clearly shows that standard wood framing with mineral wool insulation performs better than FRT wood framing under fire conditions.

Time Interval (minutes)	Description	FRTW Stud Reaction	Standard Stud with Mineral Wool Insulation Reaction
t = 0	Gypsum board face of wall is first exposed to flames/heat, interior of stud wall at ambient temperature	None	None
t = 43	Temperature at edge face of stud attached to gypsum board exceeds autoignition point of wood (500°F), stud cavity of FRTW exceeds autoignition point of wood (500°F) (See Fig. 2)	FRT of wood stud inhibits ignition of FRT studs	Charring begins on narrow edge of stud (1. 5" wide)
t=50	Chemical and mechanical inhibition of ignition of FRT wood exhausted	Charring begins on narrow edge of stud (1. 5" wide) and along both exposed long faces (5. 5" wide each)	Charring along wide faces nearest to the gypsum board
t=60		Charring has consumed 50% of allowable	Charring has consumed approximately 27% of allowable
t =70		Char layer exceeds allowable, insufficient cross-section of stud available to support load, stud fails	Charring has consumed approximately 39% of allowable
t = 112. 6			Char layer exceeds allowable, insufficient cross-section of stud available to support load, stud fails

6 ADDITIONAL BENEFITS

Depending on the species, type of product (stud, joist, plywood, beam), and its application (wall, floor, roof), the strength originally associated with wood is reduced when treated with a fire retardant. Therefore, the FRTW manufacturer is required to provide strength adjustments based on the intended use of the wood. This reduction in strength must be factored into the structural design of the building. The effective spans and bearing capacity of the lumber is reduced, so beams are over-sized, and more lumber is used in the project than required with standard studs. Hence non-treated wood consumes less of the available resources and is structurally stronger than FRTW.

The process of pressure-impregnating chemicals into wood to achieve FRT lumber has a negative environmental impact, due to increased use of virgin chemicals and more waste chemicals that need to be treated before discharge into the sewer system. Additionally, there are health impact concerns to the occupants of the building from a long-term exposure to the chemicals used in pressure impregnation. Unlike the chemical FRT process, mineral wool is made from an inorganic fiber that does not have adverse impacts on the environment or individual health of occupants.

Due to the potential corrosion of steel, hot-dipped galvanized fasteners are required over standard zinc-plated type when using FRT wood. Mineral wool is made from inorganic fiber, it does not reduce the strength of the wood, and does not require hot dipped galvanized fasteners. Hence, it is a better alternative for the environment and overall structural design.

7 CONCLUSION

Rockwool wool batt insulation friction fit between the 2” x 6” studs and filling the entire depth of the wall cavity will provide better protection than FRT wood framing as permitted by OSSC 2303. 2 and 603. 2. The architect is proposing to use comfort batt insulation by Roxul Company. The MW batt insulation will be 5. 5 inches thick and will be friction fit within the stud cavity. This product is within the parameters of our analysis and the proposed wall assembly will exceed the performance of an FRT wood framed wall assembly. Code does not prohibit the use of better-quality products than what is mandated. As this proposed assembly exceeds the base code criteria, it will satisfy the code requirements.

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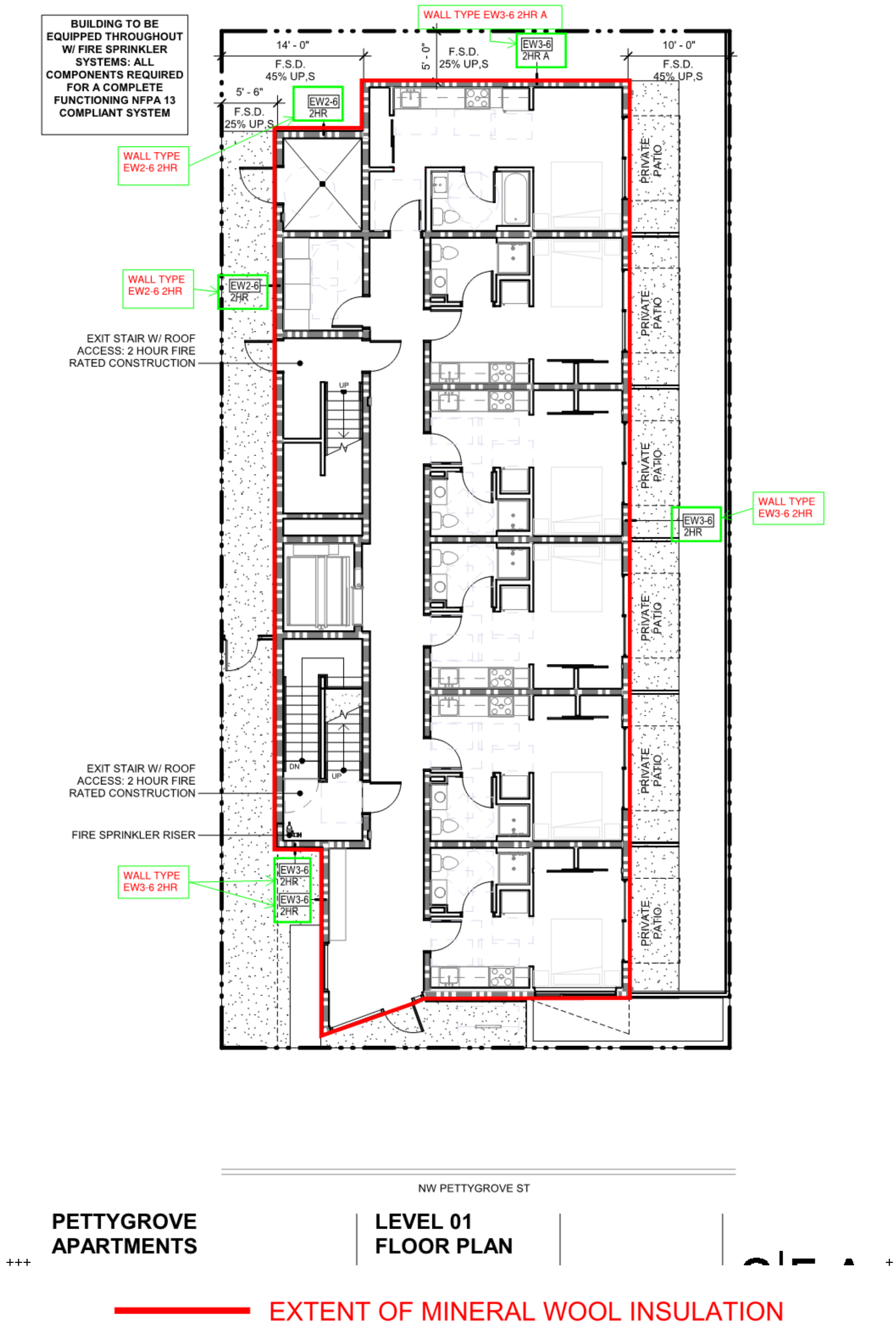
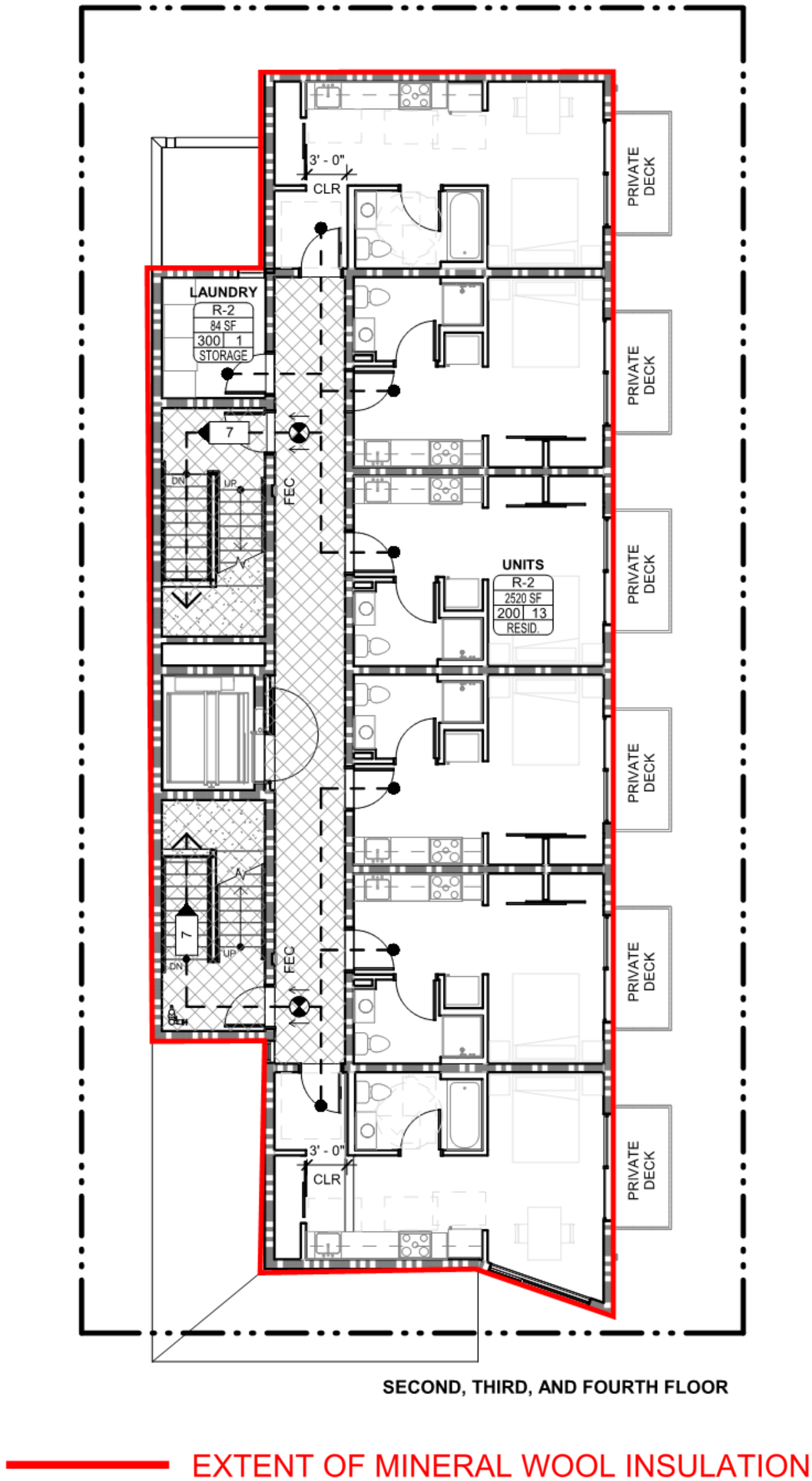
Appendix A

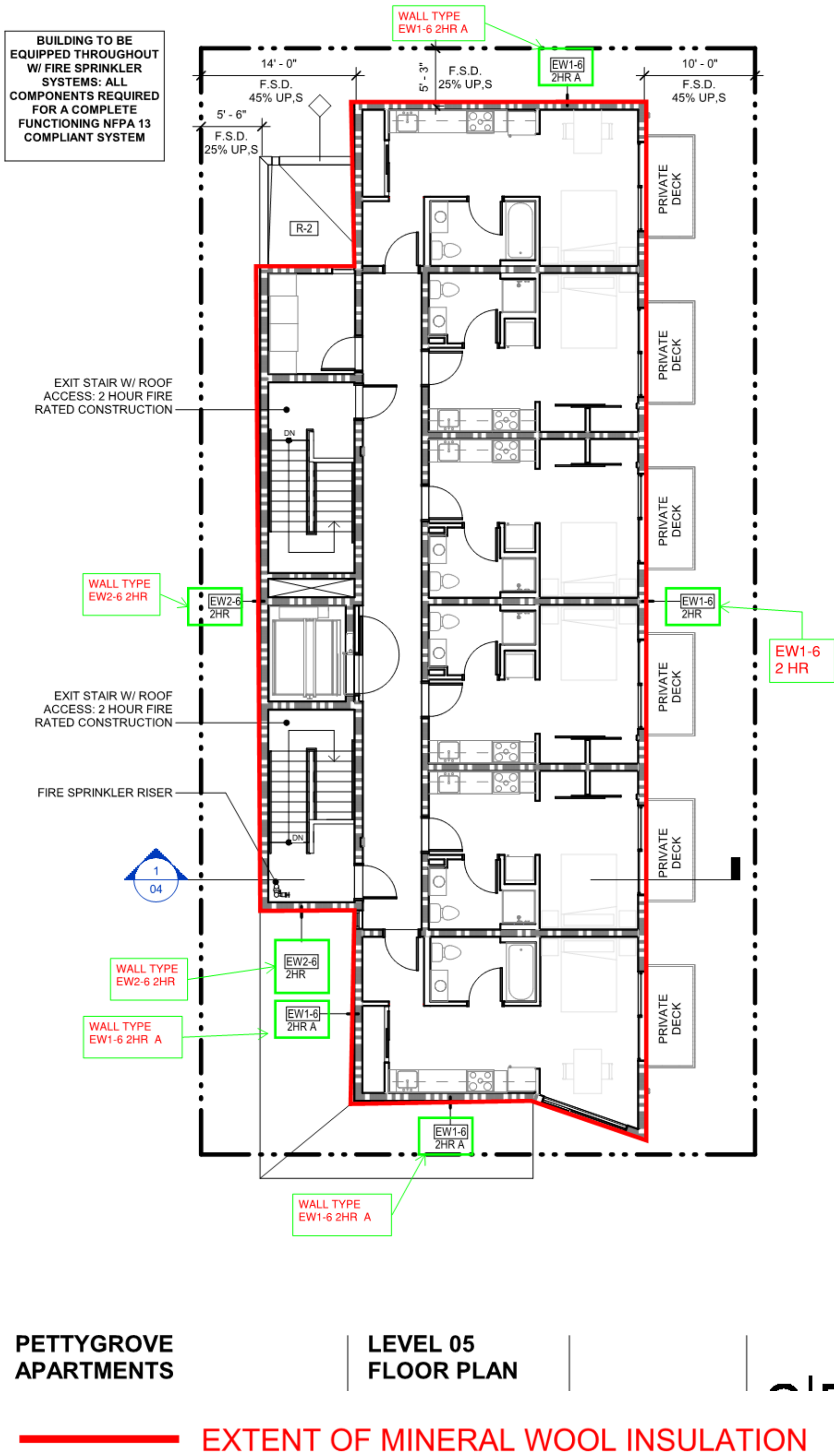
Proposed Floor Plan and Wall Section



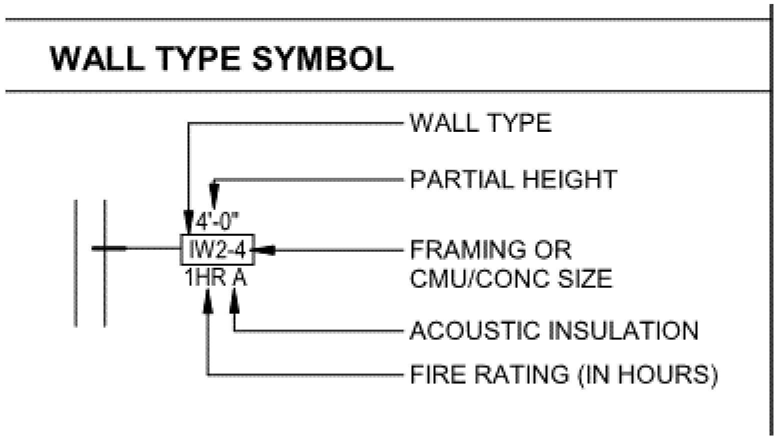
Appendix A; Figure 1: First Floor, Floor Plan



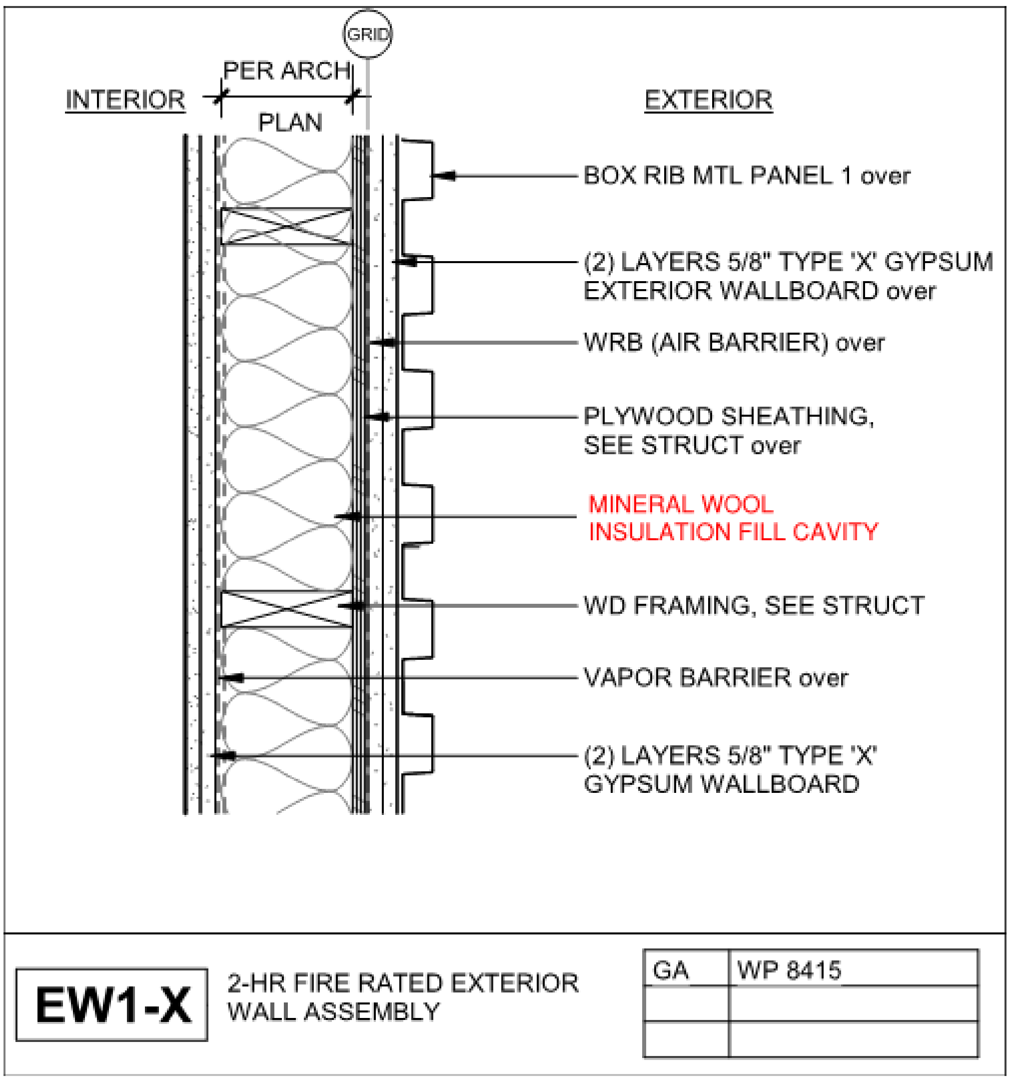
Appendix A; Figure 2: Second, Third and Fourth Floors Typical Exterior Wall



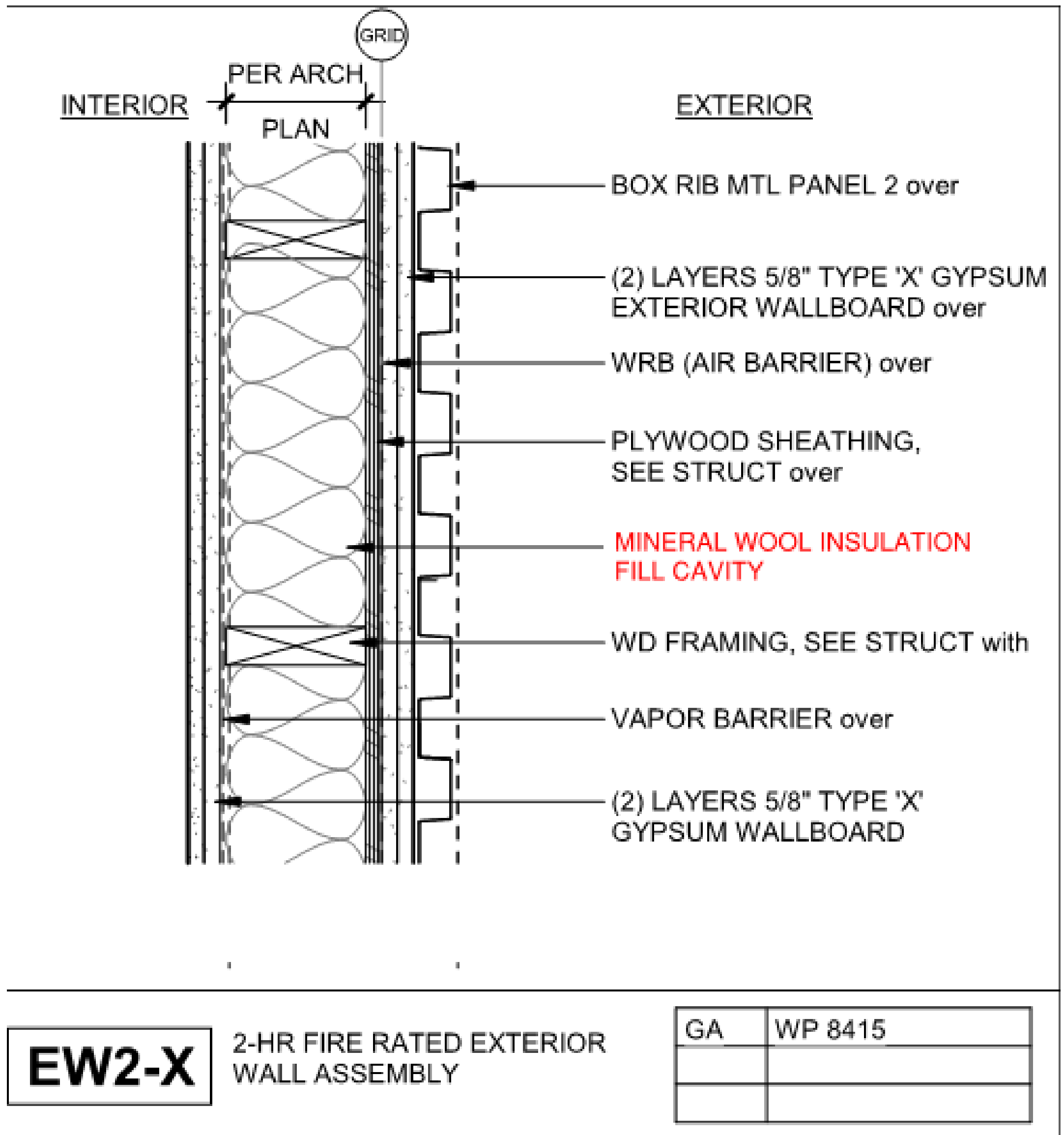
Appendix A; Figure 3: Fifth Floor Typical Exterior Wall



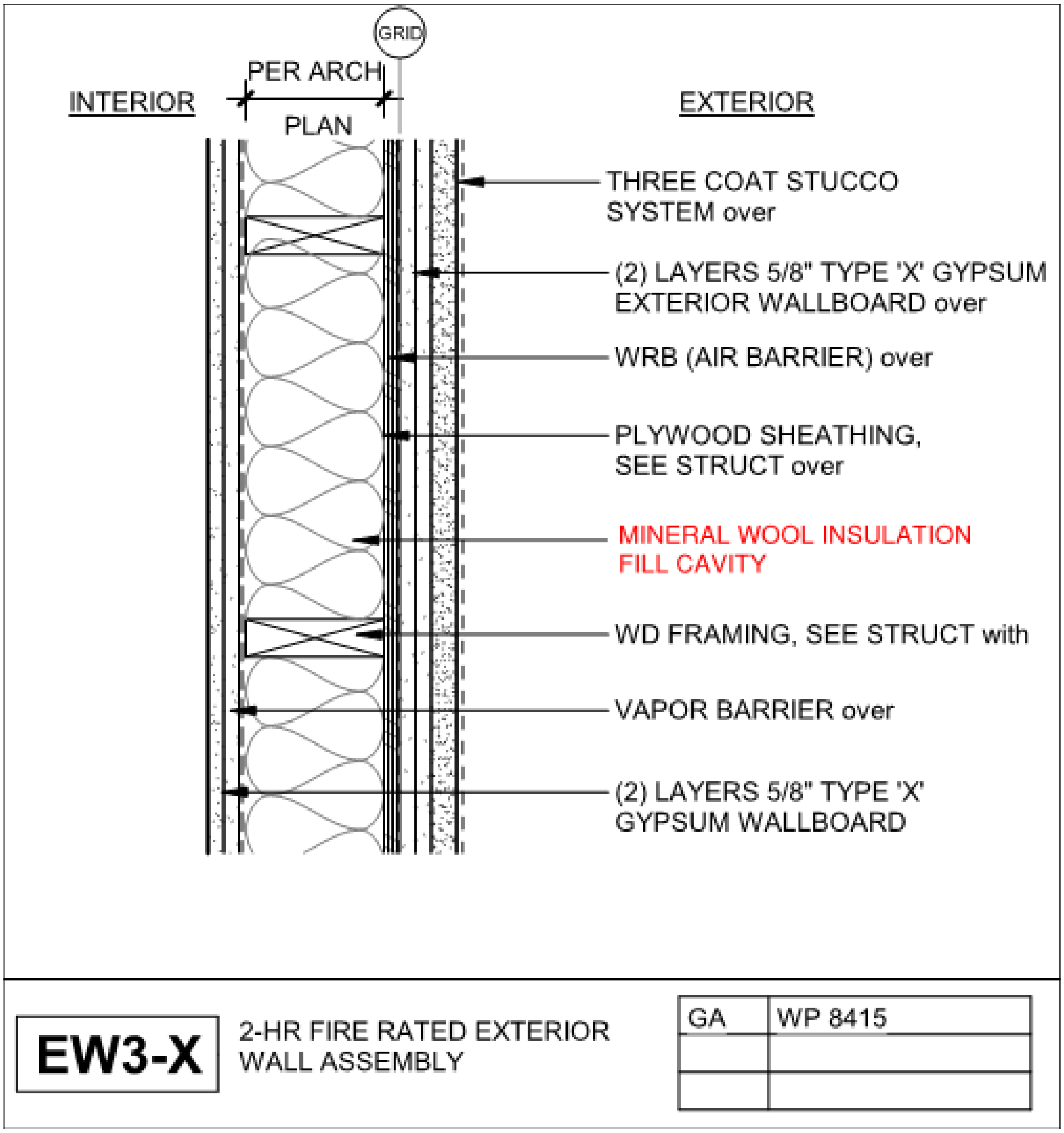
Appendix A; Figure 4: Key for Wall Assembly Symbols



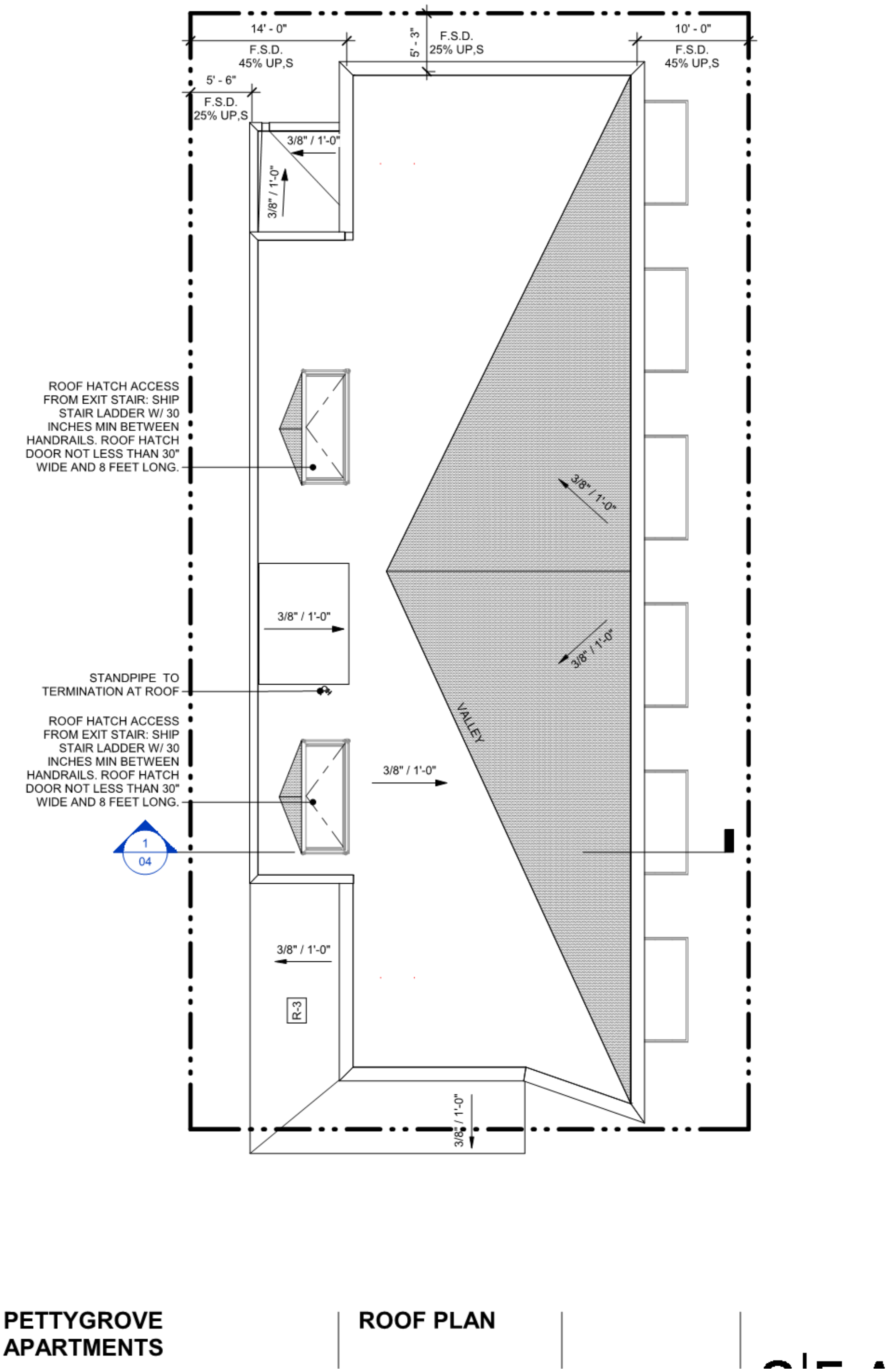
Appendix A; Figure 5: EW1-X Wall Assembly, See Above for location; Exterior Wall.



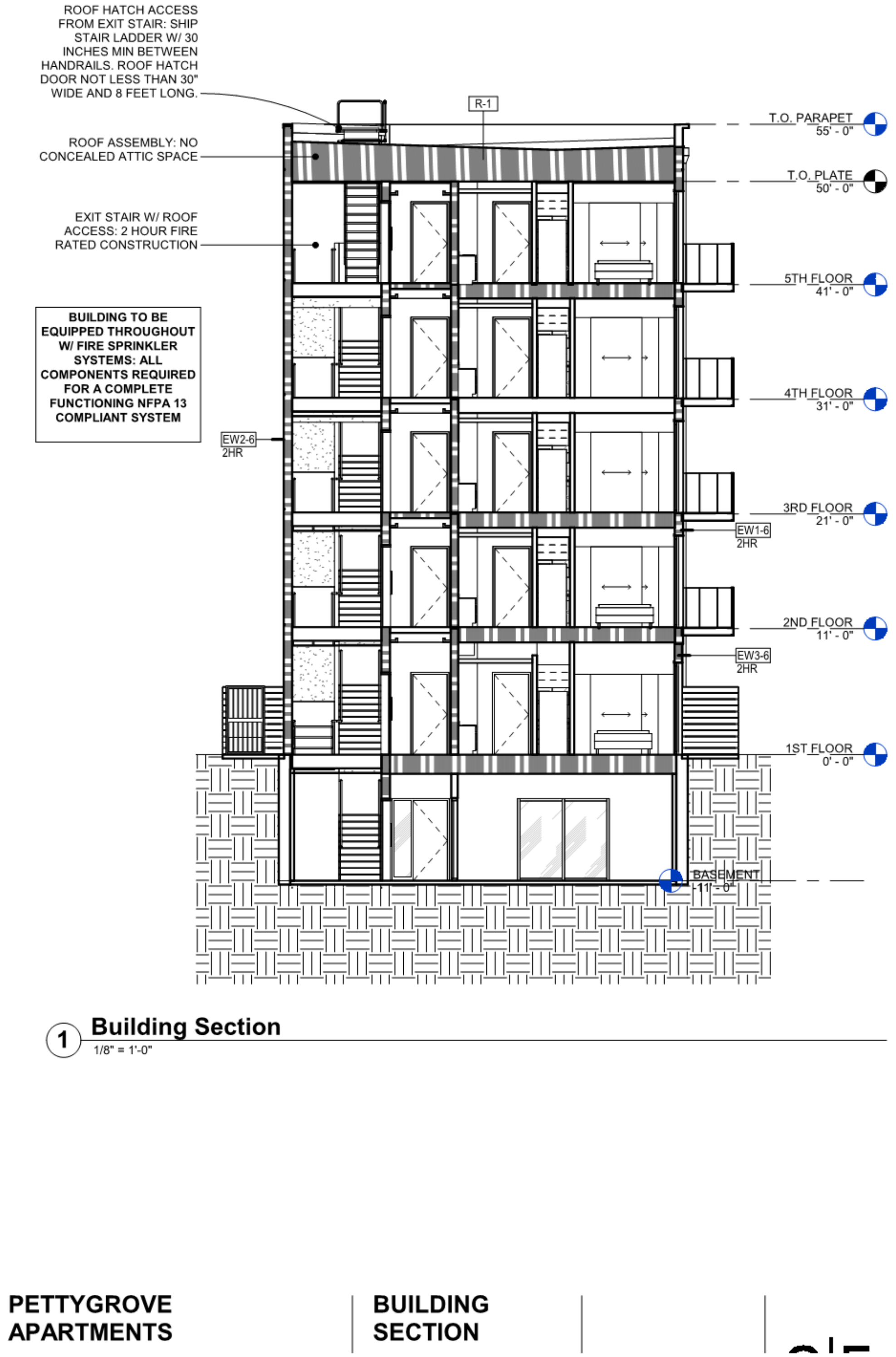
Appendix A; Figure 6: EW2-X Wall Assembly, See Above for location; Exterior Wall



Appendix A; Figure 7: EW3-X Wall Assembly See Above for location; Exterior Wall



Appendix A; Figure 8: Roof Plan Including Roof Hatch Access



Appendix A; Figure 9: Building Section