SIX FREQUENTLY MISUNDERSTOOD TOPICS RELATED TO COMMERCIAL BUILDING ENCLOSURES

ABSTRACT

Discussions between architects, building enclosure consultants, product manufacturers, and contractors frequently center around common misunderstandings regarding commercial building enclosures. This presentation will address five common topics using case studies, specific project examples, and citations from previous literature. These topics are: 1) The importance of relative humidity, dew point, and how they are managed in a building enclosure and the difference between a static analysis and dynamic analysis (WUFI). 2) How the permeability of individual layers of the building enclosure versus moisture flow through an entire assembly. 3) The importance of aligning the control layers at penetrations such as windows and how to ensure continuity at important interfaces such as the roof and foundation. 4) An analysis of when structural sheathing is needed in commercial construction compared with wood-framed construction and when structural sheathing can be used to improve the efficiency of a building schedule. 5) An overview of NFPA 285 testing, the information it provides, and its importance for the safety of buildings. Finally, the presenters will discuss a bonus topic citing specific examples of how results found via lab test methods can set unrealistic expectations for in-field conditions.

LEARNING OBJECTIVES

- Define the terms "relative humidity," "dew point," and "vapor permeability," and describe how each can impact a project.
- Explain NFPA 285 and how fire-rated assemblies are critical components for life safety.
- Discuss how and when to incorporate structural sheathing in a project.
- Review how to properly interpret and apply lab testing of products and assemblies to field conditions

SPEAKER

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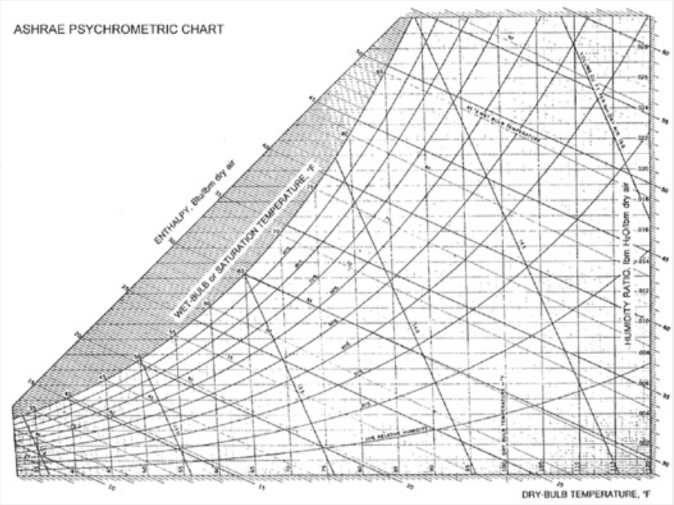

FIGURE 1. ASHRAE Psychrometric Chart

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The building enclosure industry is filled with jargon and technical terms that are assumed to be known and understood by everyone involved. Although these terms are frequently related to topics that are not necessarily taught in school, they are embedded in codes, standards, and other documents from industry organizations. Unless an experienced colleague or mentor has taken the time to teach these terms, new professionals are left to assume their full meanings based on context. Additionally, the definitions and understanding of this information is continually evolving as building science progresses. As a result, people working in the industry frequently make assumptions and have misconceptions about terms and topics important to the construction of commercial building enclosures.

This paper covers several of the biggest areas of misunderstanding related to commercial building enclosures:

- The importance of relative humidity (RH) and dew point, how they are managed in a building enclosure, and the difference between a static analysis and dynamic analysis
- How the permeability of individual layers within the building enclosure affect moisture flow through an entire assembly
- The importance of aligning the control layers at penetrations such as windows, and how to ensure continuity at important interfaces such as the roof and foundation
- The purpose of structural sheathing in commercial construction and load considerations when structural sheathing is used
- The scope of the National Fire Protection Association's *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components*[1] (NFPA 285), the information NFPA 285 testing provides, and the importance of such tests for the safety of buildings
- The distinctions between laboratory testing of materials and in-field evaluations of quality during construction, including differences in the objectives, methods, and measures

While multiple papers have been previously written on each of these topics individually, the goal of this paper is to provide a simplified explanation of each of these topics as well as resources for in-depth study for when a more thorough understanding of the topic is desired.

RELATIVE HUMIDITY AND DEW POINT ANALYSIS

The introduction of code requirements for continuous insulation, air barriers, and water-resistive barriers (WRBs) has increased the amount of attention paid to the movement of moisture through the building enclosure. These requirements, requirements for increased airtightness, known issues with portions of the current building stock such as sick building syndrome,[2] and increased use of user-friendly modeling software have made questions of moisture movement and dew point within the building enclosure important during the design and material-substitution phases of the building construction process. These are complex topics that cannot always be described in one sentence or one data point.

It is important to start with clear definitions of the key words at the center of this discussion. Relative humidity is the ratio of the amount of water vapor in the air to the amount of water vapor that the air can hold at saturation at a given temperature and pressure.[3] This ratio, which is typically stated as a percentage, is calculated as the amount of moisture in the air in vapor form divided by the total amount of moisture the air can hold. In warmer temperatures, air holds more moisture, increasing the absolute amount of water in the air. Conversely, in colder temperatures, air holds less moisture at saturation than it does at warmer temperatures at the same relative humidity. The change in absolute moisture content in the air is also referred to as the change in vapor pressure. Dew point is the temperature at which the RH is 100%, the air is completely saturated, and moisture will begin to condense.[4] Psychrometric charts, such as Chart 1 in the *ASHRAE Handbook: Fundamentals*,[3] are the simplest way to determine the dew point at a given temperature without a detailed calculation (**Fig. 1**).

Dew point can also be calculated using one of several formulas, some more complicated than others. For example, Lawrence's simple description of the relationship between RH and dew point can be summarized by the following equation for RH greater than 50%:[5]

$$T_d = T - \frac{100 - RH}{5}$$

where

T_d = dew point temperature, °C

T = observed temperature, °C

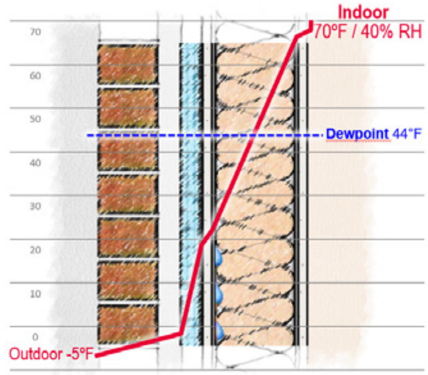


FIGURE 2. Dew point calculation through a wall assembly.

Laurence also presents a simplified general rule that the dew point temperature decreases by about 1°C for every 5% of RH. This rule is a good reference point when one is working to quickly understand the change in dew point temperature and other tools are not available.

The dew point temperature location can be calculated using the Glaser method or a heat, air, and moisture (HAM) model. **Figure 2** shows an example of how the Glaser method can be used to define the dew point temperature across a wall assembly. It is critical to understand that while the dewpoint can occur within any space of the wall assembly, moisture can only condense on a surface. The moisture will condense on the next cold surface after the dewpoint is reached. **Figure 2** shows an assembly where the dew point was reached within the batt insulation of the stud cavity. Because it could not condense within the cavity itself, moisture in the air condensed on the next coldest surface, which, in this case, was the interior side of the exterior sheathing. If the condensing surface is within a portion of the wall assembly where liquid water can be managed (for example, drained or wept), the condensed moisture is not an issue. However, the condensation can become a problem if it forms in a sensitive location, such as the back of exterior sheathing as shown in **Fig. 2**. One way to prevent this issue is to move more of the insulation out of the stud cavity onto the exterior. That moves the dew point and the potential condensation point outside of the exterior sheathing and into a space where the condensed moisture cannot cause damage to the structure.

For many years, it was assumed that calculating the location of a dew point temperature at one or several temperatures was sufficient to provide confidence in the design of a building enclosure assembly. However, these steady-state calculations say nothing about what happens over the life of the structure. The Glaser method does not account for moisture storage within materials or capillary flow of water through a material.[3] Questions such as "Does moisture accumulate within the wall assembly over time?" and "What is the moisture content of the interior gypsum within this building enclosure after 10 years?" can now be relatively easily answered using hygrothermal analysis and software such as WUFI (Fraunhofer Institute for Building Physics, Stuttgart, Germany), which incorporates heat and moisture transfer into the calculations. Straube and Schumacher have published several case studies showing how this type of modeling can prove beneficial in the building design process.[6]

VAPOR PERMEABILITY AND PERMEANCE

The next frequently misunderstood building science and material physics topic is that of vapor permeability and vapor permeance. The terms "vapor permeability" and "vapor permeance" are often used interchangeably in requests for material properties data from testing according to ASTM E96, *Standard Test Methods for Methods for Gravimetric Determination of Water Vapor Transmission Rate of Materials*,[7] or another similar method. ASTM E631, *Standard Terminology of Building Constructions*,[8] defines water vapor permeance as

> the time rate of water-vapor transmission through a unit area of a flat material or construction induced by unit vapor-pressure difference between the two specified surfaces, under specified temperature and humidity conditions.

ASTM E96 goes on to clarify that permeance is a performance evaluation of a material, not a property. Permeability, on the other hand, is the product of the thickness of a material and the tested permeance at a given humidity and temperature differential. The permeability calculation turns the data point into a material property, which is usually reported in perms.

Because of the humidity and temperature aspects of the datum, neither permeance nor permeability are steady-state numbers that apply to all conditions that a material will experience during its lifetime. Several manufactures are marketing "smart" or variable vapor retarders that are intended to work effectively in varying conditions. The variable permeance of materials, if known and characterized, can be used to help better understand how moisture moves through a wall assembly; the objective is to design materials that allow moisture to move through the enclosure when necessary and prevent the movement when it is not. This varying material characteristic is important to understand because it has a substantial impact on the total moisture content of the wall assembly. Recall that the total amount of water vapor that is available to move through a material is greater at higher temperatures than at lower temperatures. If the permeability of the material changes as the temperature and relative humidity change, the amount of absolute moisture moving through the assembly will also change. Wagner et al.[9] present an example of this behavior in which a silica-modified organic air and water-resistive barrier had a permeance ranging from 0.02 perms at 5°C/5% RH to 11.63 perms at 5°C/100% RH. Because this membrane has a permeance of 0.81 perms at the standard reporting conditions of 23°C/50% differential RH, the International Building Code[10] would classify the membrane as a vapor barrier or Class I vapor retarder. However, the membrane performs as a Class III vapor retarder under low-temperature, high-humidity conditions. This information is not typically found on a data sheet nor disclosed by many manufacturers.

The vapor permeance of materials is most often referenced for air and water barriers; however, every material in a

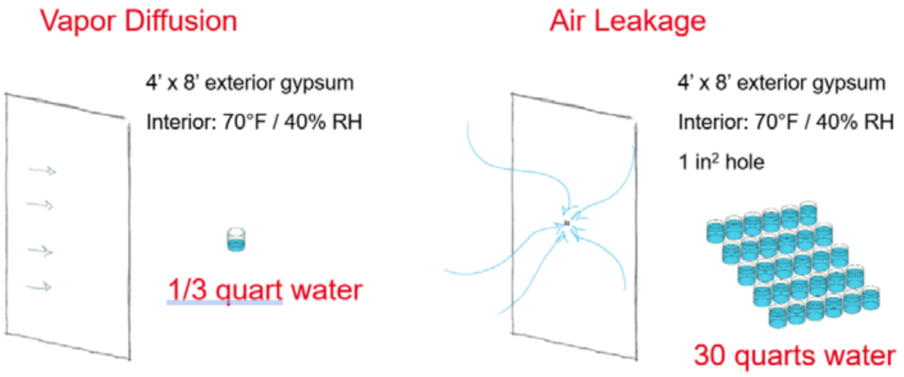


FIGURE 3. Difference in water-vapor movement through vapor diffusion verses air leakage.

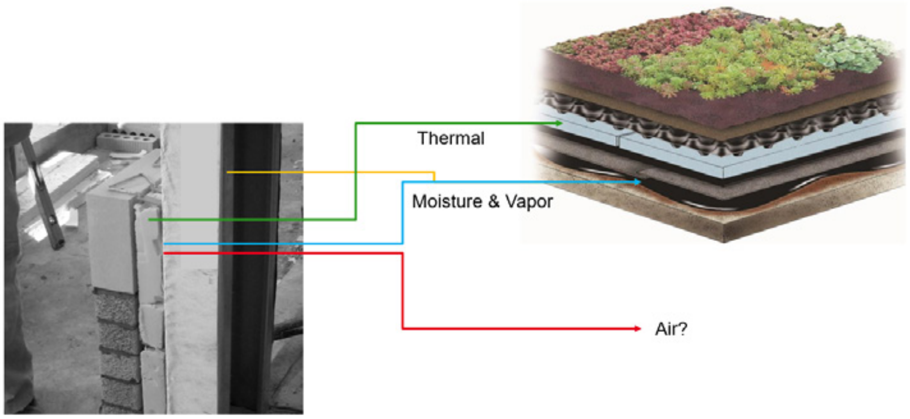


FIGURE 4. Control layers within a wall assembly verses a roof assembly.

wall assembly can be characterized in the same way. It is important to understand how water vapor will travel through the insulation, the sheathing, and even the aesthetic surfaces such as paint. One of these materials will end up being the limiting layer for how moisture moves through the assembly. Furthermore, water vapor is not usually an issue if it is able to move easily through the assembly, but it can become an issue if it is stopped within a moisture-sensitive material and that material cannot release it back as vapor.

There are two final points to keep in mind when working with vapor permeability of a wall assembly. First, the second law of thermodynamics still applies: moisture vapor will always move from an area of high pressure to an area of low pressure. The direction through a wall assembly is likely to change during at least an annual cycle of the building's life. Also, the vapor moving through the assembly only becomes a problem if it is able to condense in a moisture-sensitive location—which leads us back to the importance of hygrothermal analysis of the assemblies.

Second, as Lstiburek has highlighted, the amount of water vapor that will move through a hole in the air barrier assembly is more than 100 times the amount moved via vapor diffusion of a material.[11] His point is highlighted graphically in **Fig. 3**, which shows that only one-third quart of water will move through an entire 4 × 8 ft exterior gypsum board in a year whereas 30 quarts of water will move through a 1 × 1 in. hole in that same gypsum board under the same conditions over the same time frame.

CONTINUITY OF CONTROL LAYERS

There are four primary control layers within the building enclosure: air, water, thermal, and moisture vapor. High-performance, energy-efficient buildings (and, really, all buildings) can only perform well when each of these control layers is continuous on all six sides of the building enclosure. It is relatively easy to accomplish continuity of layers within the bulk, opaque portion of the wall assembly. However, continuity is much more challenging where different assemblies interface, such as where a window assembly meets a wall or where the wall meets the roof. Traditional wall assemblies will frequently put the control layers in a different order than a traditional roof assembly does; as a result, the layers must somehow cross each other at the transition points (**Fig. 4**).

Fortunately, if careful thought is put into the required transition, continuity becomes not only possible but also simple for the tradespeople installing the systems to achieve. **Figure 5** shows an example in which the continuity of all four control layers at the roof-to-wall interface is provided. To ensure continuity to the thermal layer on the roof, the insulation goes around the entire parapet and additional insulating blocking is installed within the cavity. The primary air and water barrier is then taken from the face of the insulation (which is serving as the air and water barrier in this example) around the top of the parapet onto the top of the insulation on the roof. Finally, the vapor barrier can be applied to the roof deck and tied into the vapor-tight spray polyurethane foam on the wall.

Unfortunately, the control layers within a window assembly are not always as

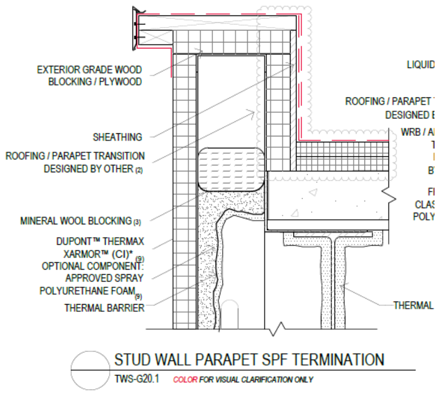


FIGURE 5. Continuity of control layers from the wall onto the roof.

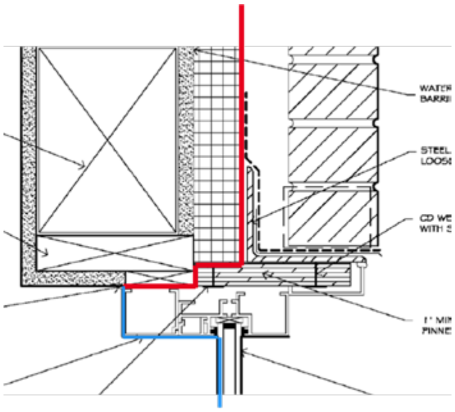


FIGURE 6. WRB continuity between a window head and a wall assembly.

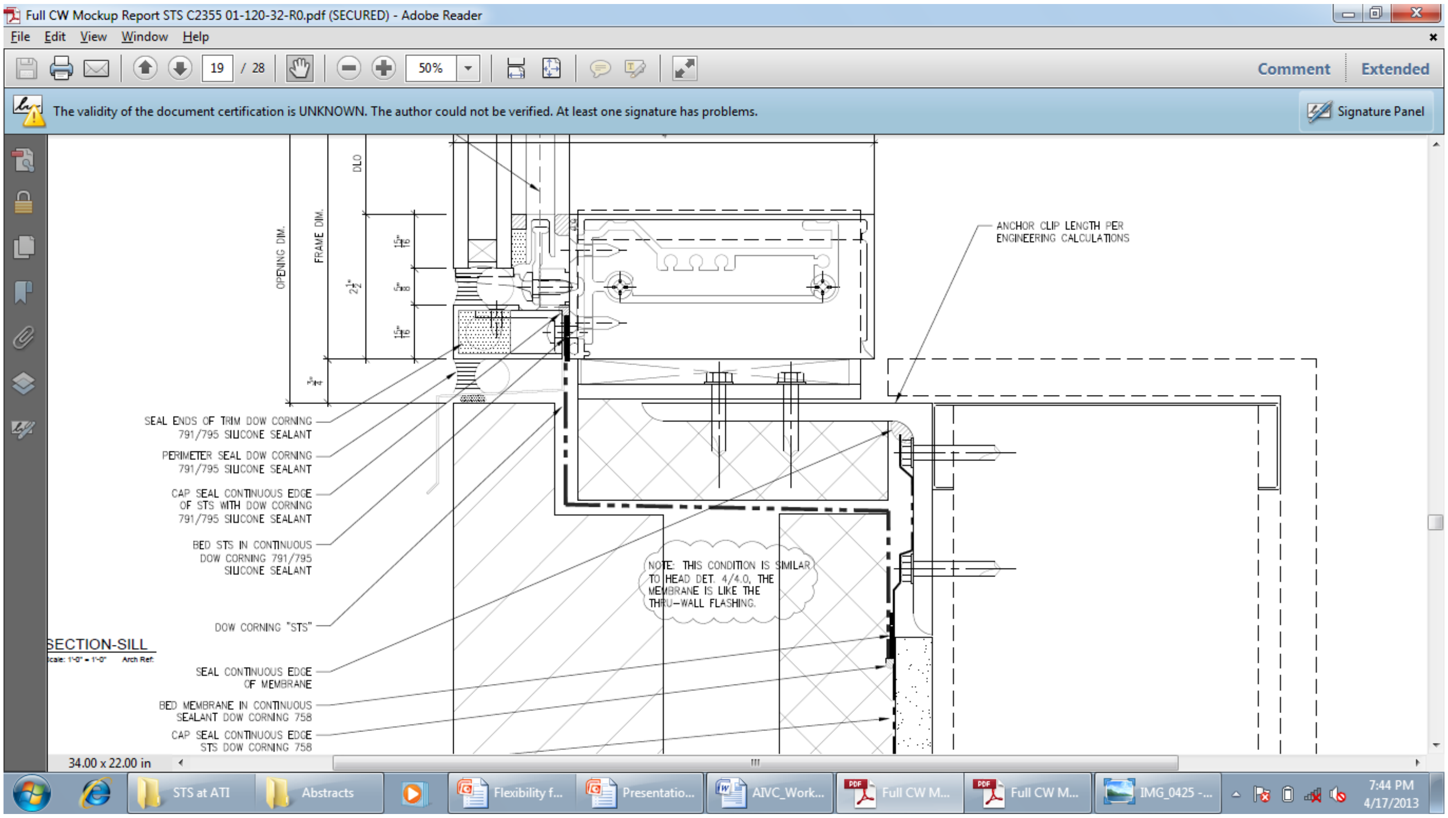
easy to clearly identify as they are in a roof assembly. **Figure 6** shows the head of a window assembly with the WRB in the wall highlighted in red and the WRB in the window highlighted in blue. The point at which the two lines in the figure meet is the most critical point for preventing water infiltration through the interface. The window rough opening must be flashed and tied into the wall WRB, and a sealant bead or other transition that is compatible and adheres to both substrates must be used to seal between the window frame and the WRB flashing. The window itself is in line with the continuous insulation in the example wall. This allows for a minimal thermal break between the assemblies. If the window were recessed or protruded, as in **Fig. 7**, there would be a disconnect between thermal layers in the window and the wall while the WRB is continuous. That type of design requires a different solution to tie the two thermal layers together, or it needs a more robust thermal break in the assembly to prevent the window frame and rough opening from getting cold and being at risk of condensation.

In general, the best time to solve any potential issues with continuity at building assembly interfaces is during the design process. If possible, involve the contractors who will be installing the systems to ensure that they can correctly install whatever detail is designed. Manufacturers are continuing to work to develop materials to simplify interfaces between assemblies for all four control layers in different configurations. Improved materials will make the process of both designing and installing the interface transitions less complicated while still allowing for the design freedom desired.

STRUCTURAL SHEATHING IN COMMERCIAL CONSTRUCTION

The need for structural sheathing (if any) in commercial construction can be a complicated subject, which typically gets delegated to the structural engineer. However, it is important for building enclosure consultants and contractors to understand the basics. The first thing to understand for both commercial and wood-framed construction is what the structural sheathing is expected to do. Structural sheathing is used to help support the loads acting on the structure, including wind loads, shear loads, live loads, and more. For commercial construction, when structural sheathing is required, it typically supports wind loads and transfers them back to the structure. Wind loads are both positive and negative, pushing and pulling on the structure.

The studs behind the sheathing provide bracing for the pushing of the positive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NOTE: THIS CONDITION IS SIMILAR TO HEAD DET. 4/4.0. THE MEMBRANE IS LIKE THE THRU-WALL FLASHING.

FIGURE 7. Misaligned thermal barrier at the window to wall interface.

FIGURE 8. NFPA 285 wall assembly while burning from both the exterior and interior.

wind loads, whereas the negative wind loads are typically the limiting factor of the design. The same can be stated for other structural requirements such as the requirements for structural glazing joints in curtainwalls, where wind loads can suck the insulating glass units off the building. Furthermore, wind loads are typically highest at the corners of the building. These corner wind load zones become the limiting loads used for calculations to provide consistency of design and construction throughout the building whenever possible. The maximum load is then used in combination with the deflection properties of the material to design the stud spacing of the structure. This material property is defined as a ratio of the maximum deflection to the length between the span being braced, with the most common ratiosbeing *L*/240 and *L*/360. The more brittle the material is, the less wind load it can take at wider spans; therefore, stud spacing of 12 in. on center or less is used for weaker, more-brittle materials whereas stud spacing of 16 in. or more on center is used for stronger, less-brittle sheathing and claddings.

Another important aspect of structural sheathing to consider is the ability of a sheathing to take on the loads of the structure and also carry and transfer the loads from the cladding back to the structure. In residential construction, for example, plywood is often referred to as a "nail base." Cladding (often siding) nails can go directly into the sheathing without being required to also penetrate the stud. In contrast, when exterior gypsum is used, all cladding attachments must be secured to the stud to achieve the amount of support required. Fastening back to the stud can become more complicated when clips or girts are needed to attach cladding (such as metal panels) over exterior continuous insulation; in these situations, the project may require a structural engineer to calculate the fastening pattern and screw strength if the insulation is thicker than the prescribed thicknesses in Table 2603.12.1 of Chapter 26 of the *International Building Code*.[10]

Recently, several products have been introduced to the commercial construction market that can take on these cladding loads and perform as a fastener base without requiring the fasteners to continue through to the stud. The use of these products allows for flexibility regarding where to attach girts and fasteners since it is not necessary to rely on the structural stud spacing or workmanship to hit the stud during installation. Eliminating the need to find a structural stud can then help prevent additional holes through other layers of the wall assembly, specifically the air barrier and WRB.

ASSEMBLY FIRE TESTING

The appropriate use of NFPA 285[1] is a complex subject that relies on project-specific discussions about the application of the testing method and the materials involved. It is so complex it is frequently a topic of daylong learning sessions. Very simply put, NFPA 285 is an assembly testing method that is designed to evaluate how a wall assembly will burn when (a) a fire is on the interior of a building burning out through an opening, and (b) when the fire is on the exterior of the building burning upward at the opening. Chapters 14 and 26 of the *International Building Code* require this test for all buildings that contain combustible components such as foam plastic insulation.[10] The base assembly used in the test (**Fig. 8**) consists of a two-story wall with a floor-to-wall intersection and an opening designed to emulate a window opening (window openings are among the weakest points within the building assembly during a fire). The intent of the test is to ensure that a fire cannot easily spread up the exterior face of the building or through the interior along the wall from floor to floor. The test results are used to quantify fire propagation up a building facade.[1]

NFPA 285 is not used to determine whether a wall has a 1-hour (or more) fire rating; these fire resistance ratings are determined by ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*,[12] or ANSI/UL 263, *Standard for Safety of Fire Tests of Building Construction Materials*.[13] For example, if a Type I building has a wall assembly that contains foam plastic insulation along with a wall that must achieve a 2-hour fire rating due to proximity to a lot line, that specific exterior wall assembly must comply with both NFPA 285 and have a 2-hour rating by way of ASTM E119.

Both NFPA 285 and ASTM E119 tests are completed on full wall assemblies. No individual material can be tested

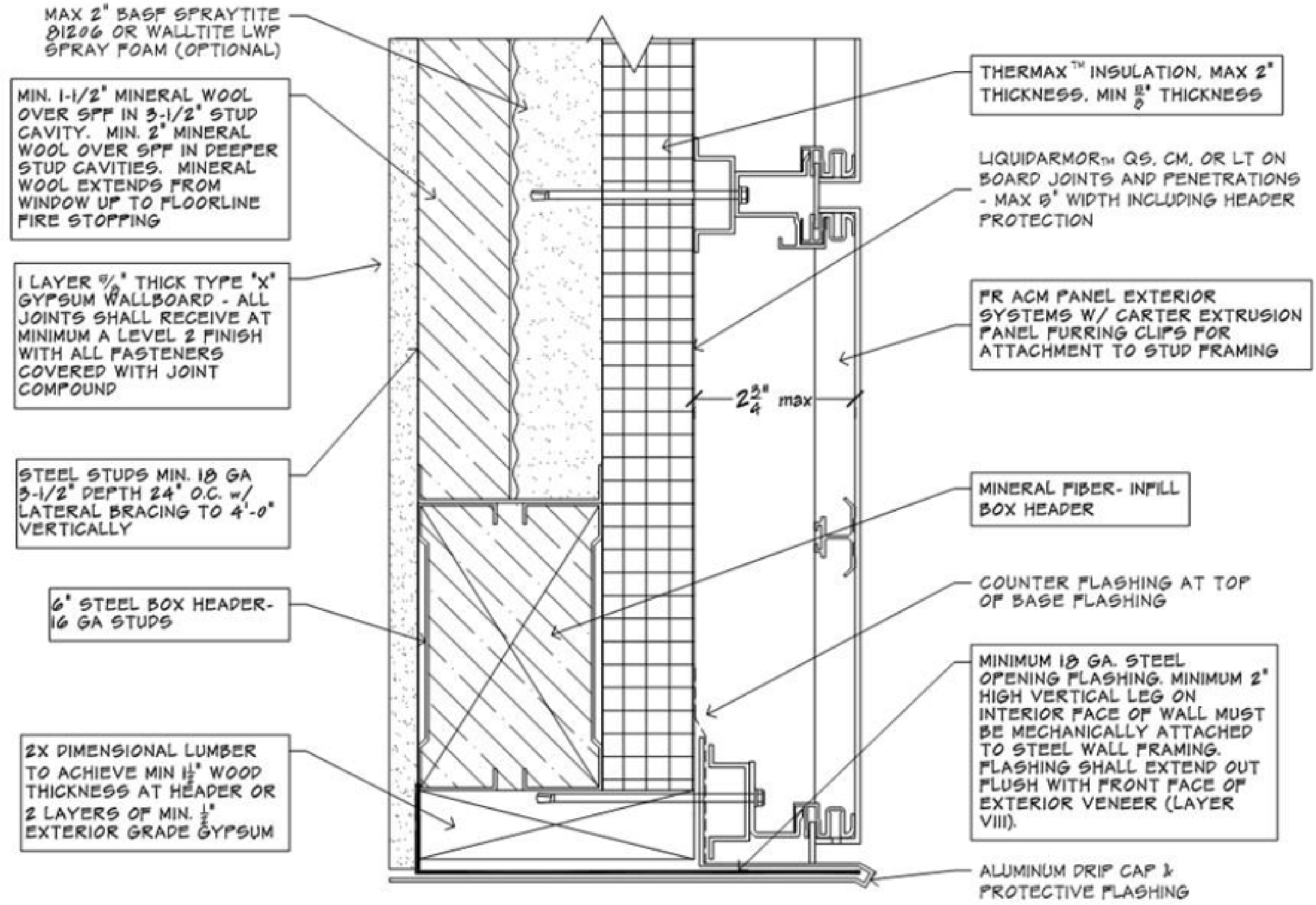

FIGURE 9. NFPA 285 window header detail with MCM cladding panels.

or pass these tests on their own; they must be tested as part of an assembly. It is common for product manufacturers to have multiple wall assemblies tested to these standards. Additionally, engineering evaluations are used to extend the testing to additional assemblies that will also meet the requirements of these standards based on tests performed and the fire-performance characteristics of materials not tested in the specific assembly. Fire engineers perform these engineering evaluations based on a set of criteria that will soon be officially added to the NFPA 285 standard.

The specific details of the wall is constructed for the test are as important as the materials used. For example, the treatment of the window header detail may determine whether a wall assembly passes NFPA 285. The details shown in **Fig. 9** and **10** show two different assemblies that can pass NFPA 285 as long as the thickness of the foam plastic insulation and the cladding type used are correctly specified and installed. If the cladding changes from a non-combustible cladding such as fiber-cement siding to a metal composite material panel, the treatment of the window-header detail may also need to change to ensure compliance with NFPA 285. These changes in material choices can affect whether an assembly will meet the fire requirements for a project and should therefore not be overlooked.

LABORATORY TESTING VERSUS FIELD TESTING

Manufacturer data sheets and material code testing requirements report results from testing done according to methods published by ASTM International, the Fenestration and Glazing Industry Alliance, and other organizations. These test methods are developed to be repeatable tests that are used to determine the performance and physical properties of a given material or assembly. Most often, they are designed to be performed within the controlled environment of a laboratory. These test methods are not necessarily designed to be completed on a project jobsite, where it may not be feasible to use the type of equipment required, prepare sample material, or otherwise conduct the test according to the standard requirements.

Adhesion testing of materials is one area where test methods and test data for quality control can differ from the test methods and test data used to create data sheets. Both sealants and air and water resistive barriers are subject to adhesion testing in a laboratory and in the field for quality control, but the test methods are not the same. For sealants, ASTM C794, *Standard Test Method for Adhesion-in-Peel of*

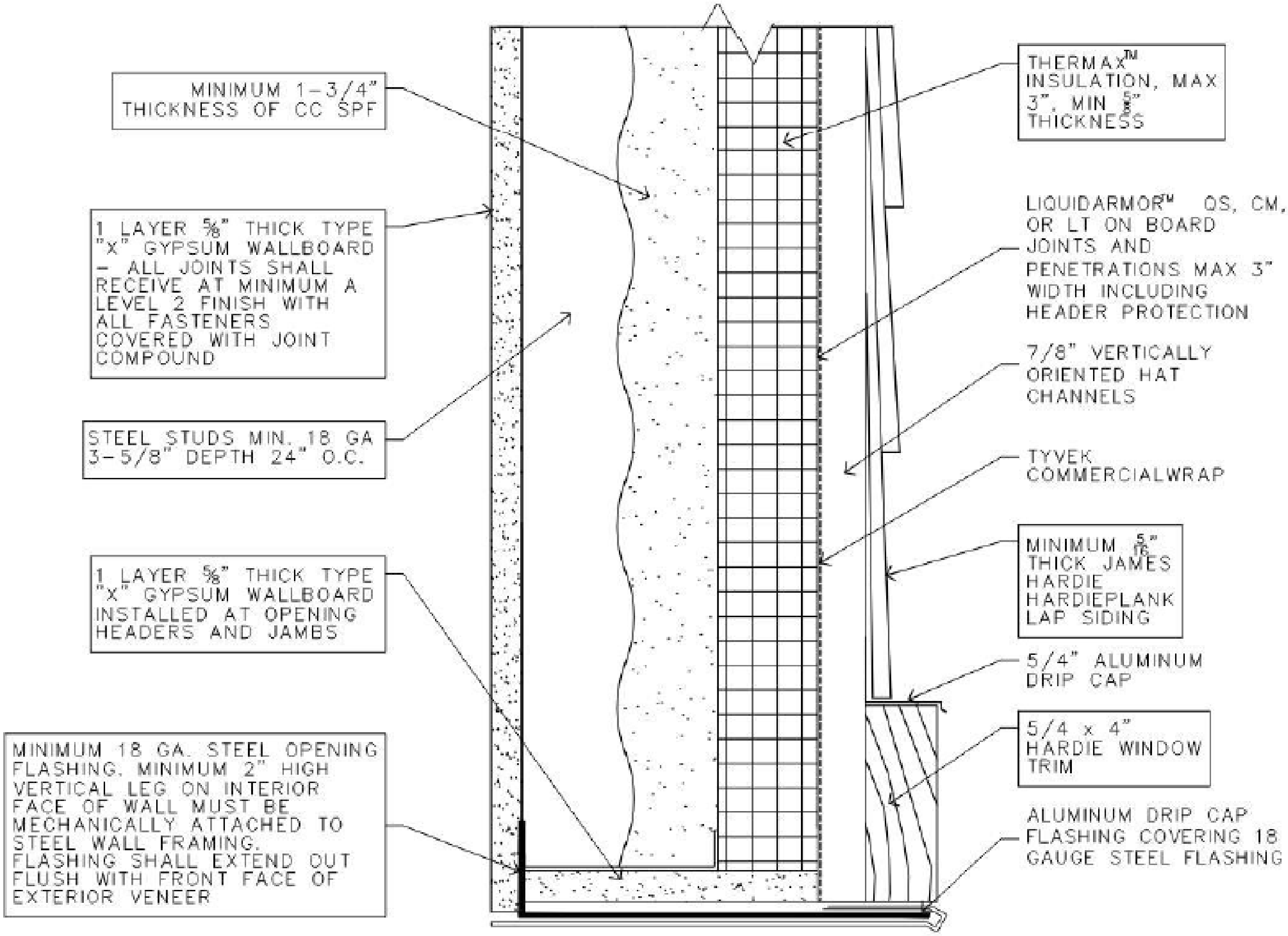

FIGURE 10. NFPA 285 window head detail with fiber-cement siding.

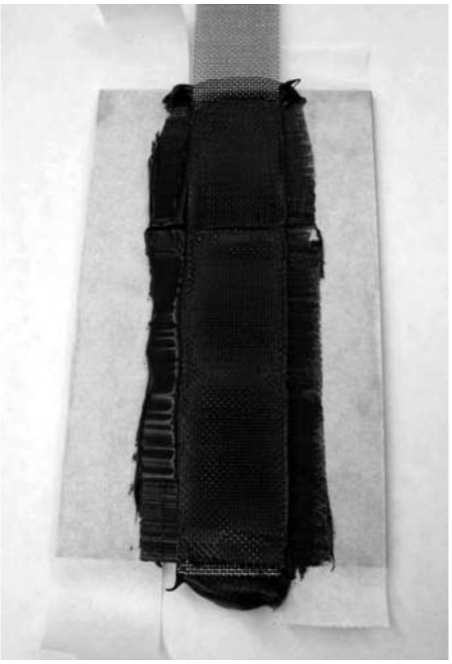

FIGURE 11. Adhesion-in-peel test specimen after imbedding wire mesh screen.[10]

Elastomeric Joint Sealants,[14] is the most-used test method for laboratory adhesion testing. This test method involves imbedding a wire mesh within a bead of sealant (**Fig. 11**). The mesh screen is installed into an tensile testing machine and pulled at 180 degrees from the surface of the substrate. The tensile strength required to pull the sealant is measured in pounds per linear inch, and observations of the failure mode (cohesive or adhesive) are taken. This is the test method that is cited by ASTM standards and specifications such as AAMA 714-20, *Voluntary Specification for Liquid Applied Flashing Used to Create a Water-Resistive Seal Around Exterior Wall Openings in Buildings*.[15] The specifications define a minimum peel value per this method that is required for the material in the intended application.

Laboratory adhesion testing is important because it is quantifiable and repeatable for the purposes of product development and adhesion comparison between specimens. It is not practical for in-field quality control of adhesion. ASTM C1521, *Standard Practice for Evaluating Adhesion of Installed Weatherproofing Sealant Joints*,[16] is the recommended standard for field adhesion testing of sealants. Method A of this test method describes how to test an in situ sealant joint by evaluating certain properties such as elongation of the sealant prior to adhesion loss and type of adhesion loss. Most sealant manufacturers will then set pass/fail criteria for acceptable performance based on this test method, such as 100% cohesive failure or a 100% elongation before any adhesion loss occurs. Other methods within the standard practice will have different types of pass/fail criteria.

In addition to differences in the tests being performed, other factors that affect the performance of a material in a laboratory setting versus in the field include the following:

- The cure conditions of materials are controlled in the laboratory (often set at approximately 23°C and 50% RH), whereas field conditions such as temperature and RH can vary considerably.
- There is minimal cross contamination with other materials, dirt, grime, and so on in a laboratory, whereas materials in the field are at risk for contamination, particularly when they are used in adverse conditions or when they are left exposed for extended periods of time.
- Laboratory instrumentation is controlled and frequently calibrated, whereas field testing is often completed only by hand, without the assist of specific equipment.

The differences in testing and differences in results do not necessarily mean that long-term performance will be compromised in the field relative to the laboratory. The best manufacturers set performance targets for laboratory testing that compensate for less-than-ideal field conditions. Laboratory testing requirements are intentionally set higher than what will be expected in the field so that crews can easily meet the required field quality control testing minimums through quality workmanship while still producing a completed assembly that is expected to perform per the life of the products. To prevent frustration, all parties (the installer, the designer and the manufacturer) must communicate clearly regarding what test method and pass/fail criteria will be used; these parties must all understand field quality control requirements expectations before installation begins.

CONCLUSION

Commercial construction involves many multifaceted systems and assemblies that are meant to perform for many decades. The successful design and installation of these systems and assemblies depend on expertise from a wide range of fields, including the building trades, architects, engineers from multiple engineering disciplines, building scientists, and materials scientists. To ensure smooth communication among all of these actors, it is important that all speak the same language and share a common baseline of knowledge on different topics that frequently come up during project design and construction.

ACKNOWLEDGMENTS

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