ADVANCED ARCHITECTURAL PRODUCTS.

Use of high-performance Composite Metal Hybrid (CMH) for NFPA 285 fire-rated continuous insulation systems

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Glossary of Terms:

ASTM E84 – A standard test procedure to evaluate and compare surface burning characteristics for building materials used on exposed surfaces like walls and ceilings. A rating is given based on test performance, with Class A being the top rating. Class A is assigned to materials that have a maximum flame spread of 25 and a maximum smoke developed index of 450.

GreenGirt® – GreenGirt is an insulated composite sub-framing component that joins the building cladding and insulation to a building structure. GreenGirt can be used with rigid board polyisocyanurate, XPS, SPF, and mineral wool insulations.

NFPA 285 – A standardized test procedure to evaluate the usability of nonstructural wall assembly components that utilize combustible materials or components on non-combustible exterior walls.

CMH™ – Composite metal hybrid.

SMARTci™ – A continuous rigid foam insulation system that includes GreenGirt and the insulation in a package.

SMARTframe™ – A continuous insulation wall configuration utilizing GreenGirt that provides thermally isolated, redundant sub-framing attachment points for cladding attachments. In case of an NFPA 285-rated fire event, the cladding is still retained to the building.

SMARTsecure™ – A technology embedded within GreenGirt that creates a through-wall, non-flammable, mechanically attached cladding retention mechanism.

Fire-Rated, High-Performance Composites for Continuous Insulation Systems – NFPA 285-Rated GreenGirt Wall Assemblies

Introduction:

Before the engineering and analysis of the GreenGirt system is described, it is important to start with the relevant foundational information. With an increased significance in building codes, it is vital to know what the NFPA 285 test is, how it is performed, and what its results mean.

What is NFPA 285?

According to the 2012 edition of the NFPA 285 standard, NFPA 285 provides a fire test procedure for evaluating the suitability of exterior, non-load bearing wall assemblies and panels used as components of curtainwall assemblies constructed using combustible materials or that incorporate combustible components for installation on buildings where exterior walls are required to be non-combustible.[1] This test is required for most building types by the 2012 International Building Code.[2]

What Does NFPA 285 Address?

Fire propagation characteristics are determined for post-flashover fires of interior origin. NFPA 285 requires both visual observations made by laboratory personnel conducting the test and temperature data recorded during the test.[1]

The NFPA 285 Methodology:

The 30-minute test is conducted on a full-scale, two-story wall assembly, built as it would be in the field, on the front of a three-sided test structure. The test wall has a 78" x 30" window in the center of the lower floor (See Figures 1 and 2).
The test scenario is that a flashover fire, unrelated to the foam plastic insulation, has occurred in the lower-story room. This emits a fire plume out of the room of origin through the window. An interior burner in the middle of the first-story room begins the fire, and then five minutes into the 30-minute exposure, a window burner is lit, simulating a fire plume wrapping around the window head, extending up the exterior surface of the wall (see Figure 3).[1]

Test Description of NFPA Wall Assembly:

A three-walled, two-story mock-up is created at 15’8” tall. Each story is a 10’ wide by 10’ deep by 7’ tall test room, and is composed of steel, concrete, and concrete masonry. The interior wall and ceiling of the bottom story is covered with gypsum board over ceramic fiber insulation, while the floor of the first story is covered by two layers of gypsum board.[1]

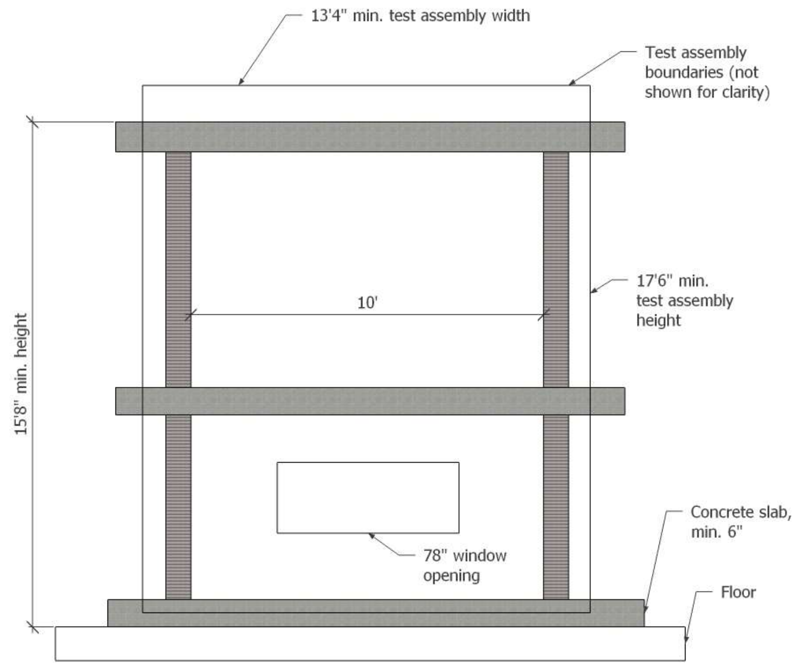


Figure 1: Front view of NFPA 285 test specimen setup (not to scale).

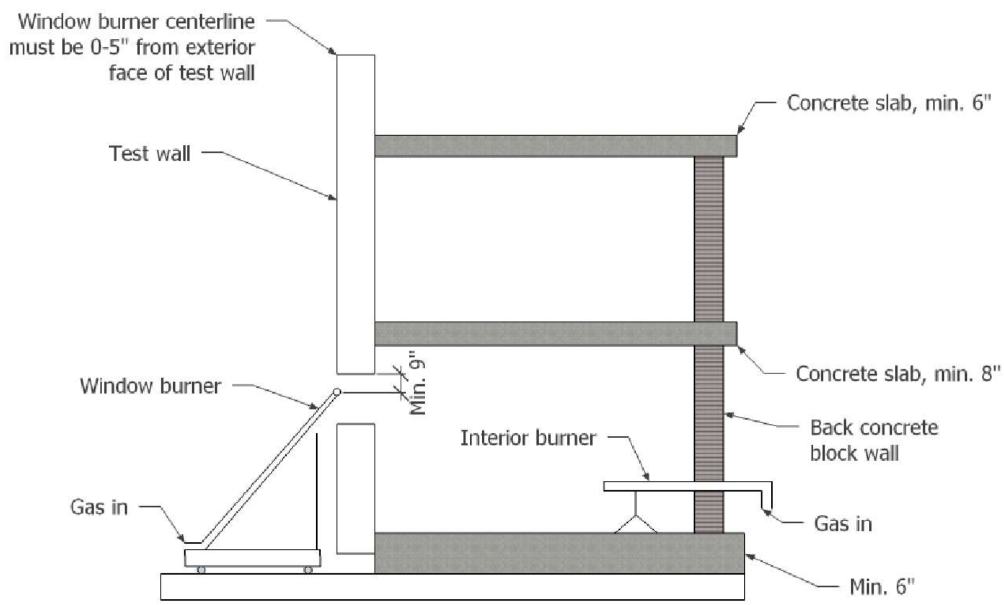


Figure 2: Section view of burner placements for NFPA 285 test (not to scale).

Figure 3: An NFPA 285 test is shown with a fire plume extending up the wall.

Passing the NFPA 285 Test:

The assembly is considered to have failed the test, and categorized as allowing unacceptable flame propagation, if any of the following are observed (slightly simplified):

1. A temperature > 1,000°F at 10 feet above the top of the window opening, as measured by thermocouples mounted on the surface of the test specimen. This temperature is considered evidence of a luminous flame at that location.
2. Flames observed on the exterior face of the specimen at 10 feet or higher above the top of the window opening.
3. Flames observed on the exterior face of the specimen at 5 feet or farther horizontally from the vertical centerline of the window opening.
4. Temperature rise > 750°F within any combustible wall components more than ¼" thick.
5. Temperature rise > 750°F within the wall cavity or stud cavity insulation.
6. Temperature > 1,000°F within the wall cavity air space.
7. Temperature rise > 500°F in the second-story room, measured 1" from the interior surface of the wall assembly.
8. Flames observed within the second-story room.
9. Flames observed past where the test specimen and the side wall of the test apparatus meet.[1]

Additional Considerations for NFPA 285 Assemblies:

Fire damage triangles (see Figure 3) from successful NFPA 285 assemblies can be as large of an area as nearly 10' wide x 10' tall at the base,[1] an approximate area of 50 square feet. Siding may be all or partially damaged in this area, and insulation may be all or partially damaged in this area, depending on the system tested.

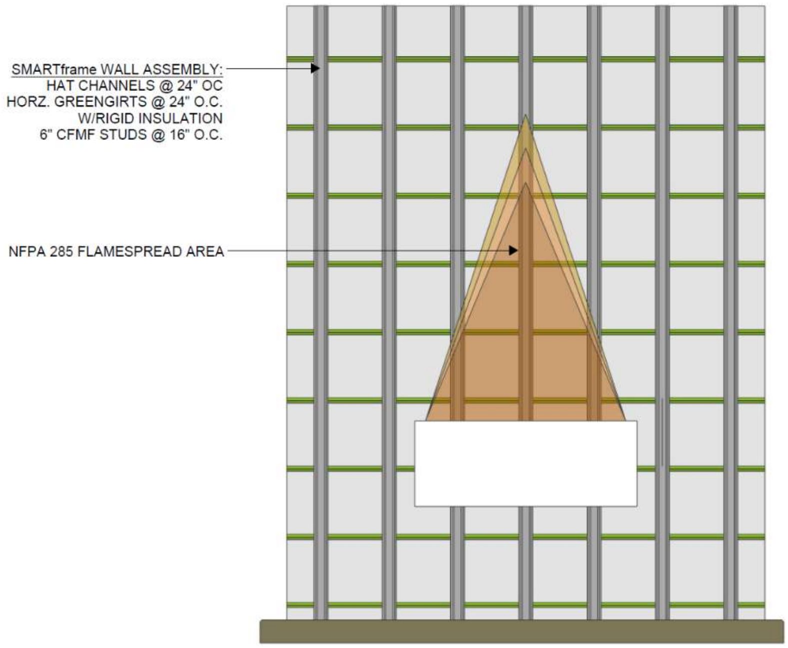


Figure 3: Fire triangles in a successful NFPA test can be nearly 10' tall by 10' wide at the base.

Exceptions for NFPA 285 Testing:

There are limited exceptions for fiber reinforced polymers in which they are not required to be tested for NFPA 285 compliance. GreenGirt fulfills the conditions given in the first exception in Section 2612.5 of the 2012 International Building Code, which states that compliance is not required when:

1. Area of component is not more than 20% of wall area, and any single element (or a contiguous set of elements) shall not exceed 10% of the area of the wall to which it is attached.
2. Flame spread index is less than or equal to 25 according to ASTM E84.
3. Wall system fire blocking per IBC 2012 Section 718.2.6 is installed.
4. Component is installed directly to a noncombustible substrate, or separated from the exterior wall by a base metal or other approved non-combustible materials. Base metals may be either corrosion-resistant steel of .016" minimum thickness, or aluminum with .018" minimum thickness. [2]

Introduction – GreenGirt Composite Sub-framing is a CMH Product

What is CMH?:

CMH is composite metal hybrid. It is specifically designed for construction sub-framing applications, using the best characteristics of steel and fiberglass to achieve a superior product. The use of CMH aids in structural strength, fire performance, thermal capability, fastener attachment, and constructability of the application.

Structural

- Makes the girt up to eight times stronger with mechanically bonded steel inserts
- Eliminates concentrated load "singularities" by distributing the load
- Creates a continuous structural member across a plane without laps, and with superior sealing
- Thermal expansion compatible with traditional substrate and cladding options

Fire performance

- Fire retardant, self-extinguishing
- Class A rating from ASTM E84 testing
- NFPA 285 tested with certified assemblies
- Compatibility with SMARTframe
- Compatibility with SMARTsecure

Thermal capability

- Eliminates thermal bridges, making it the highest performing product on the market

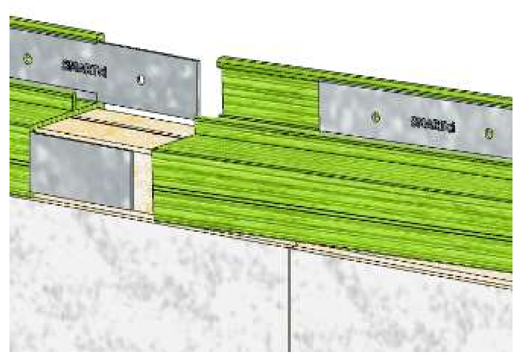
Fastener attachment

- Provides superior standard fastener retention
- Eliminates fastener stripping/screw spin-out
- Compatible with standard Tek screws
- Makes for a universal mounting system

Constructability

- Allows use of standard fasteners, tools, cladding, insulation, and construction methods

CMH GreenGirt



GreenGirt in wall assembly

Utilizing CMH – GreenGirt in NFPA 285 Wall Assemblies

How Fire Retardant GreenGirt Performs in a Fire – Thermochemically:

CMH GreenGirt is a system designed to utilize the properties of its constituents to maintain the performance of the system prior to, during, and after exposure to a fire situation. The product takes advantage of the selective placement of its major components – steel and fiberglass reinforced composite laminate – to create solid structural performance and lower thermal transfer than standard products in a typical working environment.

When exposed to a fire, CMH GreenGirt has low thermal conductivity between the fire zone and the supporting structure to limit loss of structural integrity over a maximum area of the structure. It has low thermal expansion to eliminate distortion and thermally induced stresses. It also adds low additional fuel to the fire. The CMH GreenGirt system is formulated such that more than 85% of its total weight is non-flammable, creating a self-extinguishing product. The fiberglass laminate uses a flame spread and smoke suppressant system which releases water/steam when the organic portion of the laminate degrades. No corrosives are released from the organic portion during its degradation to minimize safety issues for first responders.

The design of the system also aids in its fire performance. CMH GreenGirt is embedded within the insulation system with only a single flange (12% of the product surface area) exposed to elevated temperatures at the insulation face. This limits the total thermal driving force through the product. Testing indicates that the maximum temperature rise inside the continuous insulation system does not exceed 750°F. In other words, GreenGirt provides no measurable fuel to the fire beyond what's provided by the foam insulation.

Post-fire, the glass that houses the continuous steel insert provides extra thermal protection beyond traditional methods. The fiberglass reinforcement system in the laminate and the steel portions of the CMH GreenGirt remain stable when exposed to standard fire temperature conditions. Both steel and glass, the major components of CMH GreenGirt, have melting temperatures of more than 2,400°F. The softening point of fiberglass is more than 1,550°F, beyond that of steel's critical temperature of approximately 1,025°F.[3,8] In the event of localized damage during a fire event, the embedded steel and continuous fiberglass reinforcements in CMH GreenGirt will bridge and support the area, helping maintain a stable working platform for repair and reconstruction.

How GreenGirt Performs in a Fire – Structurally

SMARTframe – Introduction:

The mechanically bonded steel inserts in GreenGirt provide structural redundancies that will maintain the system's integrity in an NFPA 285-rated fire. The contiguous steel inserts within GreenGirt constitute an exterior supporting attachment system known as SMARTframe.

SMARTframe – Redistributing the Load:

- A GreenGirt system provides continuous steel fasteners mechanically bonded to a continuous steel sub-frame member.
- GreenGirt provides redundant load distribution outside the fire area. This setup is referred to as SMARTframe, and is done through a continuous metal attachment structure outboard the insulation via vertical and/or horizontal steel inserts (see Figure 4). The inserts extend past the fire damage triangles, allowing distribution of the load to non-flammable support structures and/or areas outside the fire zone.
- SMARTframe provides a continuous, metal-free thermal break with low thermal conductivity for the continuous insulation and cladding system.
- Each SMARTframe NFPA 285 project is designed to accommodate the cladding dead loads specified for the application.

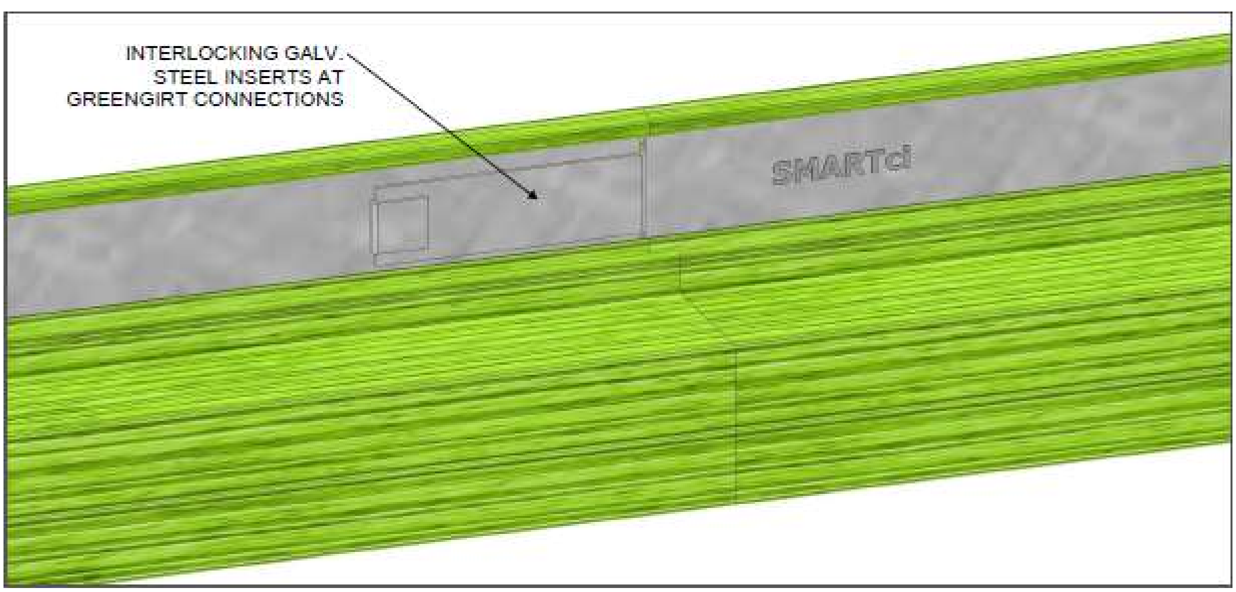


Figure 4: A continuous metal attachment structure is used for the NFPA 285 test.

Finite Element Analysis of SMARTframe During an NFPA 285 Simulation:

Using finite element analysis in SOLIDWORKS, the resulting analysis shows that a SMARTframe wall assembly will withstand the loading involved with the NFPA 285 fire test.
With the following conditions,

1. A wall assembly of horizontal or vertical 3” GreenGirt at 24” on center
2. Vertical hat channels at 24” O.C. for the horizontal setup
3. Rigid insulation
4. An attachment to 6” CFMF studs at 16” O.C.
5. Cladding dead loads of 2.5 PSF, 5 PSF, and 15 PSF

SMARTframe will hold up to the deflection criteria as well as the stress requirements for a maximum fire damage area (see Finite Element Analysis Data section).
At a 15 PSF cladding dead load, the deflection fulfills up to an L/360 criteria in a horizontal orientation and beyond that in a vertical orientation. The stress safety factor calculates to be more than seven for the 30 KSI yield stress of the GreenGirt.

Structural Analysis of SMARTframe in an NFPA 285 Simulation:

While SMARTframe has been shown to withstand the loads of the NFPA 285 test, in a worst-case scenario where the system’s tensile strength diminishes due to the higher temperatures inside the fire triangle, the steel inserts as well as the hat channels will help hold the cladding in place. The deflection on the steel works out to .041 inches, which is less than an L/360 deflection criteria (see Structural Calculations section).
The deflection on the GreenGirt due to the cladding dead load will be minimal, with the shear stress on the fasteners coming in at a safety factor of more than 30 if using a #12 T3 fastener. When using the hat channel, the deflection due to a 15 PSF cladding dead load is .002”, less than the required L/360 deflection criteria.
The low thermal expansion coefficient of the steel limits the total expansion at a temperature increase of 1,000°F to be less than an inch per eight feet, minimizing potential thermally induced stresses.

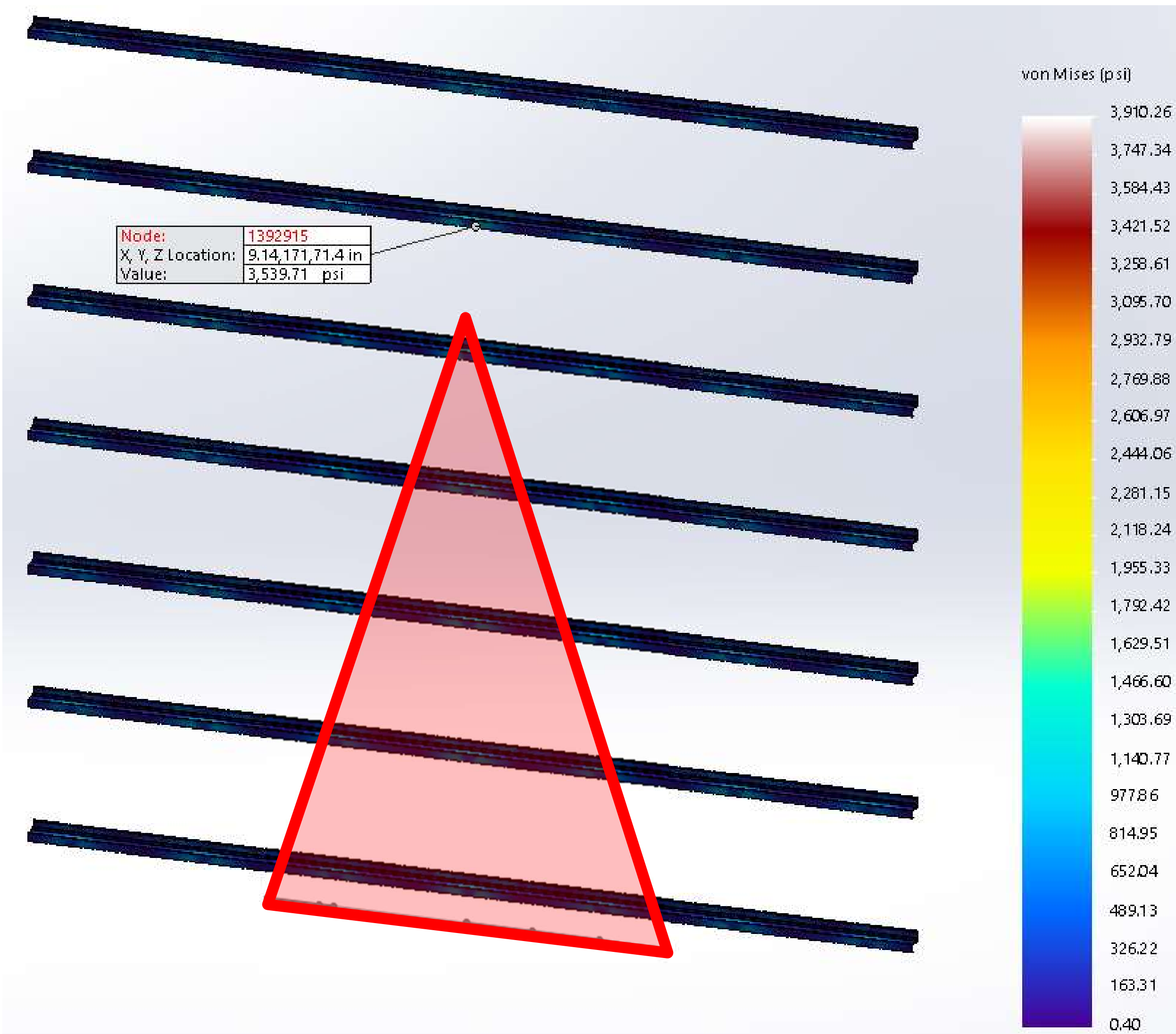
Results Summary:

Both the composition of GreenGirt and the setup of SMARTframe contribute to a system that will handle the various loads of an NFPA 285 test. The high melting temperatures of the constituents of GreenGirt along with a built-in fire retardant allows the GreenGirt to handle the fire and heat of the test. Meanwhile, the strength of the GreenGirt and steel inserts will manage the distributed load should any of the fire-affected areas decrease in material strength. The fasteners will handle the shear stress involved in a 15 PSF cladding dead load, and thermal expansion will not be significant.

Finite Element Analysis Data:

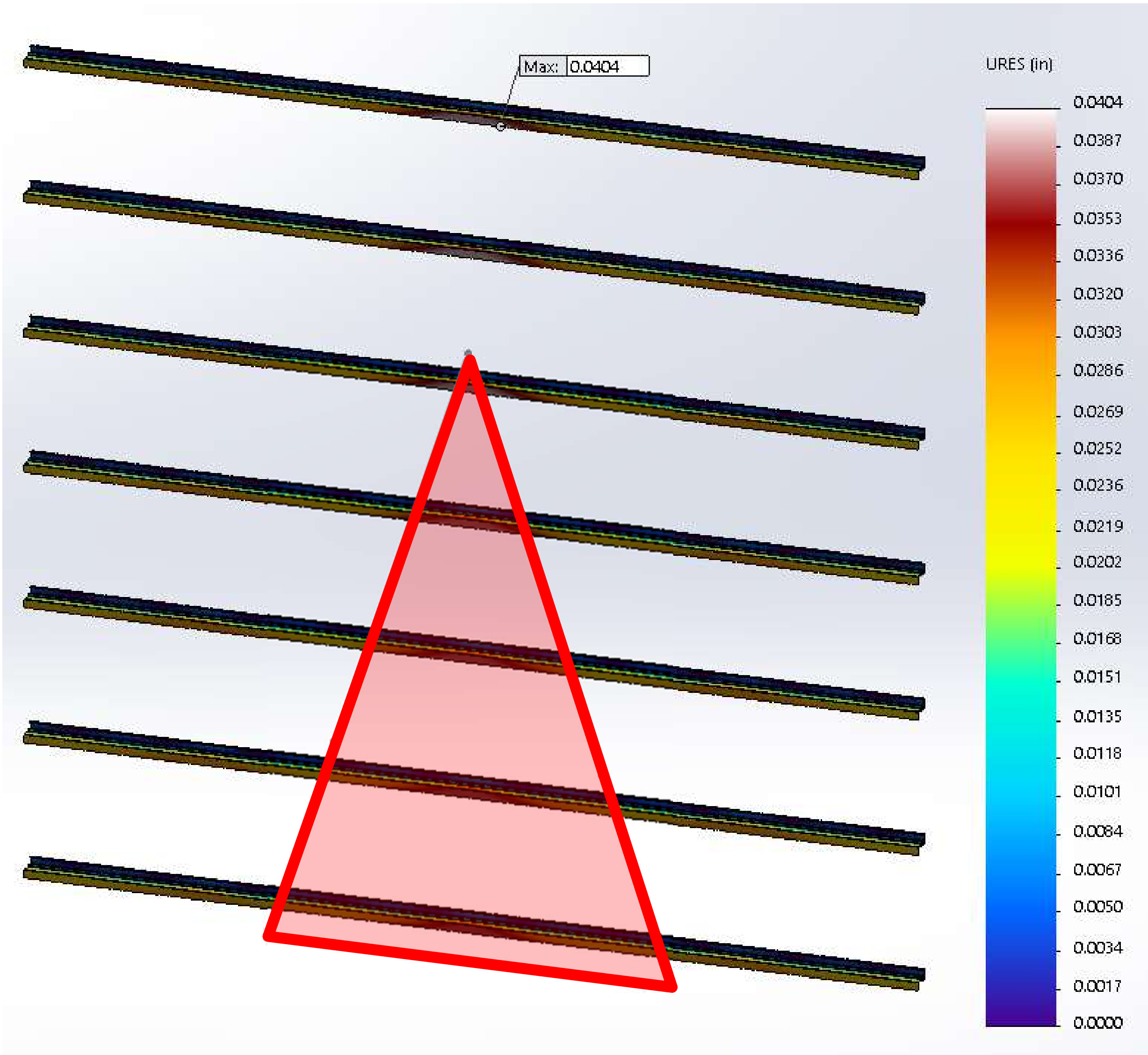
SZ300 horizontal at 24" O.C. to metal stud framing, fasteners 16" O.C., 18 Ga. vertical hats 24" O.C., 15 PSF cladding dead load equally distributed with point loads on the edge of the fire triangle

Maximum stress (Von Mises) plot on the GreenGirt (vertical hats are omitted for clarity)



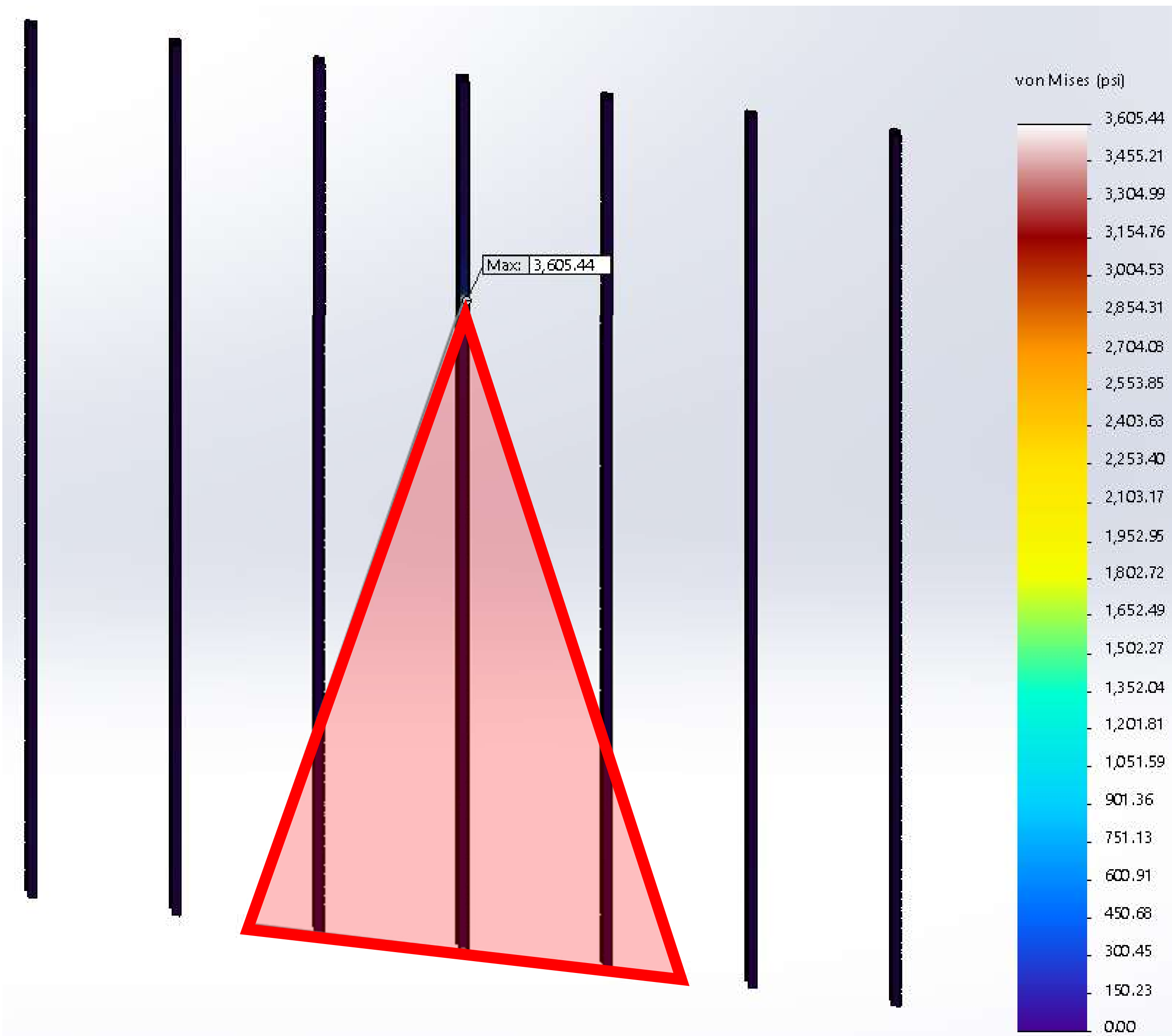
SZ300 horizontal at 24" O.C. to metal stud framing, fasteners 16" O.C., 18 Ga. vertical hats 24" O.C., 15 PSF cladding dead load equally distributed with point loads on the edge of the fire triangle

Maximum displacement (resultant displacement) plot on the GreenGirt (vertical hats are omitted for clarity)



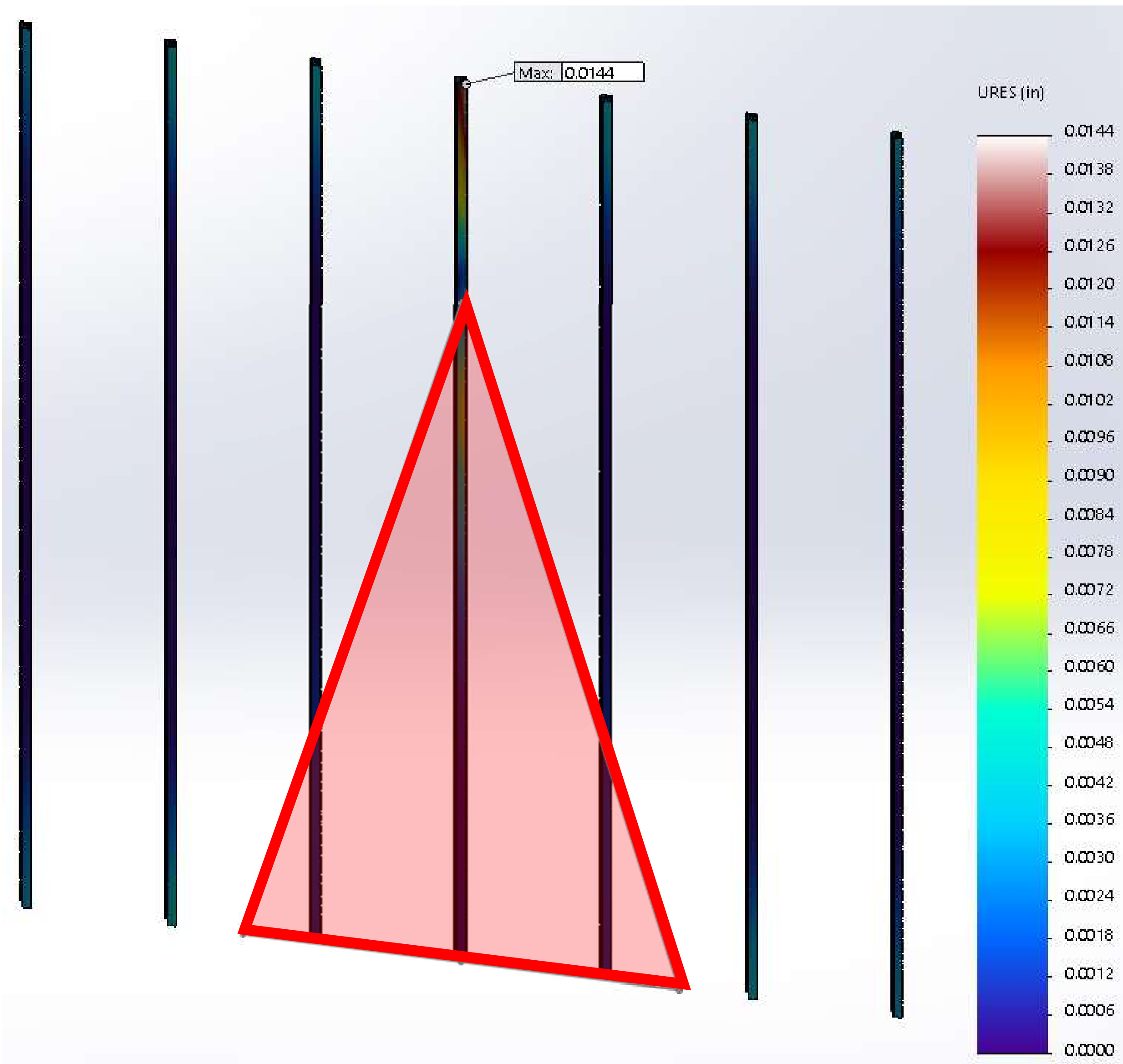
SZ300 vertical at 24" on center to metal stud framing, fasteners 16" O.C., 15 PSF cladding dead load equally distributed with point loads on the edge of the fire triangle

Maximum stress (Von Mises) plot on the GreenGirt



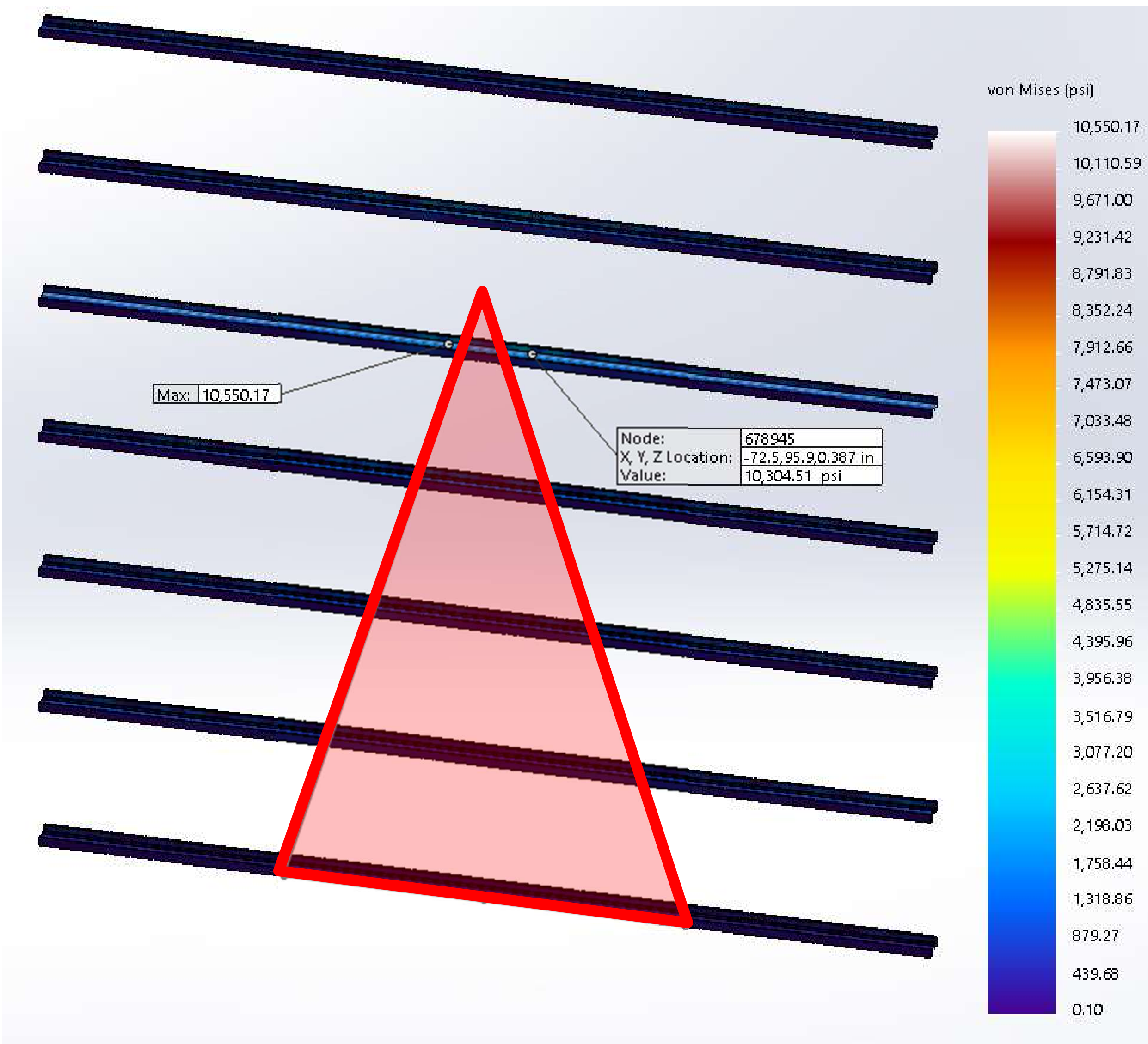
SZ300 vertical at 24" on center to metal stud framing, fasteners 16" O.C., 15 PSF cladding dead load equally distributed with point loads on the edge of the fire triangle

Maximum displacement (resultant displacement) plot on the GreenGirt



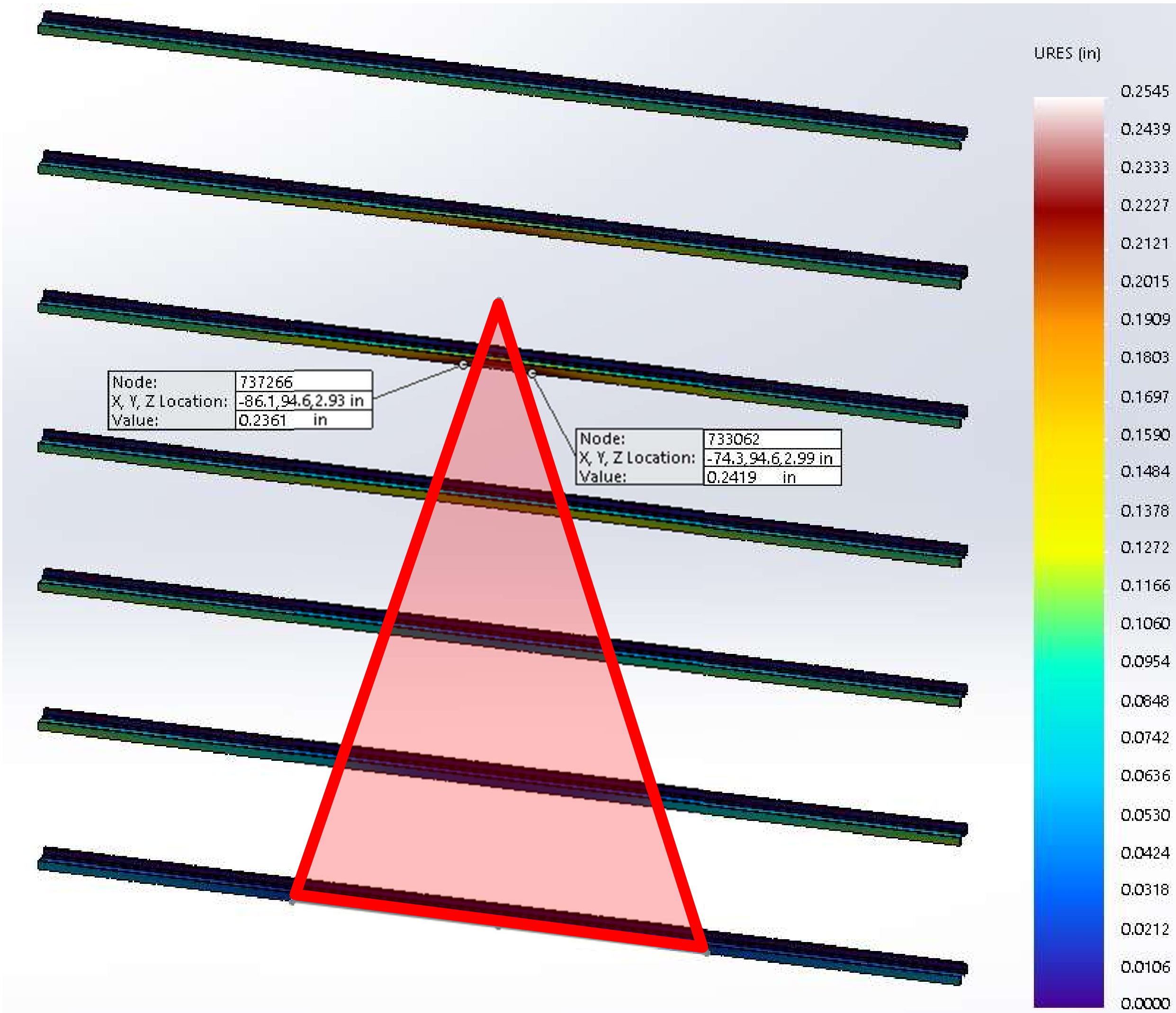
SZ300 horizontal @ 24" O.C. to metal stud framing, fasteners 16" O.C., 15 PSF cladding dead load equally distributed with point loads on the edge of the fire triangle

Maximum stress (Von Mises) plot on the GreenGirt



SZ300 horizontal @ 24" O.C. to metal stud framing, fasteners 16" O.C., 15 PSF cladding dead load equally distributed with point loads on the edge of the fire triangle

Maximum displacement (resultant displacement) plot on the GreenGirt



Structural Calculations[a]:

SZ300 horizontal @ 24" O.C., fasteners @ 16" O.C.

Shear stress on fastener: (96")*(16")*(15psf)/(144in^2) = 160 lb
160 lb < 339.5 lb, ultimate shear value for #12 screw with safety factor of 4

Deflection of steel inserts:
Vmax = 850 lb, P =.850kips
L=96 in., E = 29,000 ksi
Fy = .850kips/.0675in^2 = 12.59 ksi
e = 12.59 ksi / 29,000 ksi = .0004
Deflection = .0004 * 96in. = .041in.
.041 in. < L/360 deflection criteria *OK*

Thermal expansion of inserts:
L = 96 in., T = 1,000°F
Coefficient of thermal expansion for steel = 10.2*10^-6 in./in. °F
Thermal expansion = 96 * 10.2 *10^-6 * 1,000 = .98 in. ***OK***

SZ300 horizontal @ 24" O.C., fasteners @ 16" O.C., 18 Ga. vertical hats @ 24" O.C.

Hat deflection due to cladding: 5wl^4/384EI
½", 18 Ga. steel hat: Iyy = .13 in^4, E = 29,000,000 psi

5*(15*96/12/12)*(16^4)/384/29,000,000/.158 = .002 in.
.002 in. < L/360 deflection criteria *OK*

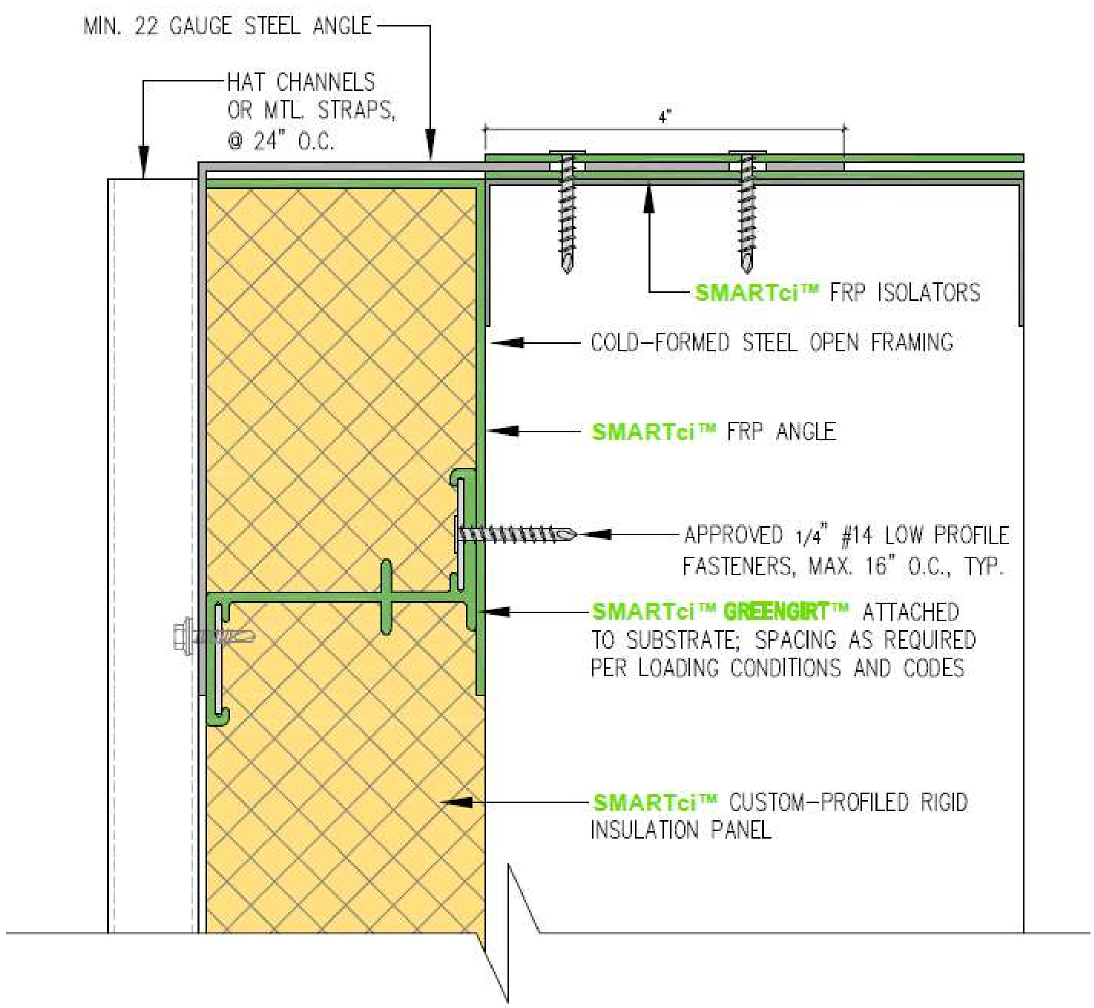
SZ300 vertical @ 24" O.C., fasteners @ 16" O.C.

Shear stress on fastener: (96")*(16")*(15psf)/(144in^2) = 160 lb
160 lb < 339.5 lb, ultimate shear value for #12 screw with safety factor of 4

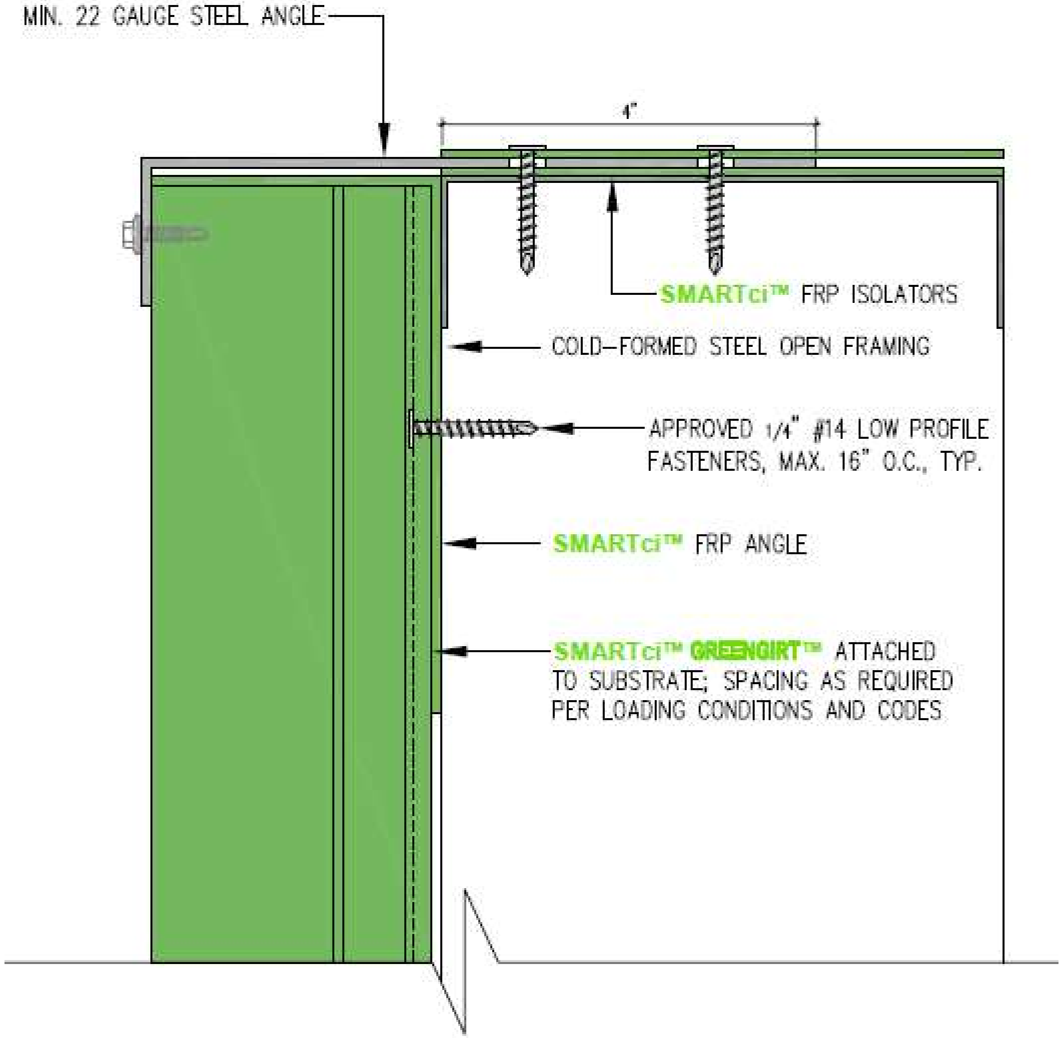
Deflection due to cladding: 5wl^4/384EI
Iyy = 0.35851, E = 2,500,000 psi
5*(15*96/12/12)*(16^4)/384/2,500,000/.35851 = .00952 in.
.00952 < L/360 deflection criteria *OK*

Structural Analysis of SMARTframe in an NFPA 285 Fire with Atypical Conditions:

In a fire event where two windows are spaced with less than 9' of height between them vertically and a 15 PSF cladding dead load is used, the SMARTframe system can handle the loads involved. The vertical hats, as well as the attachment method shown below to anchor at the sill, will provide added strength to a system in a horizontal orientation. In the vertical orientation, SMARTframe will also support the increased loading.
In a worst-case scenario with the tensile strength diminishing due to the higher temperatures within the fire triangle, the GreenGirt outside the fire zone and the continuous steel inserts will aid in supporting the distributed load as seen in the Structural Calculations section.
#12 T3 fasteners will manage the shear stress, and the deflection of hats due to the cladding will be minimal. The thermal expansion of the steel and the GreenGirt will also be minimal.



Horizontal orientation



Vertical orientation

Structural Calculations:

Maximum shear stress on fasteners:
(96”) * (16”) * (15psf) / 144in^2 = 160 lb
160 lb < 339.5 lb ultimate shear value with safety factor of 4

Deflection of GreenGirt:
Vmax – 850 lb, P = .850 kips
L = 96”, E = 2,500 ksi
Fy = .850kips / .89811in.^2 = .94643 ksi
E = .94643ksi / 2,500ksi = .0004
Deflection = .0004 * 96” = .041”
.041 < L/360 deflection criteria *OK*

Thermal expansion of GreenGirt
L = 96”, T = 1,000°F
Coefficient of thermal expansion for GreenGirt = ~ 8*10^-6 in./in.°F
Thermal expansion = 96” * 8*10^-6 * 1,000°F = .768” ***OK***

Hat deflection due to cladding: 5wl^4/384EI
Iyy = .15806in^4, E = 29,000,000 psi
5 * (15*96/12/12) * (16^4) / 384 / 29,000,000 / .15806 = .0019”
.0019 < L/360 deflection criteria *OK*

Deflection of steel inserts:
Vmax = 850 lb, P =.850kips
L=96 in., E = 29000 ksi
Fy = .850kips/.0675in^2 = 12.59 ksi
e = 12.59 ksi / 29,000 ksi = .0004
Deflection = .0004 * 96in. = .041in.
.041 < L/360 deflection criteria *OK*

Thermal expansion of inserts:
L = 96 in., T = 1,000°F
Coefficient of thermal expansion for steel = 10.2*10^-6 in./in. °F
Thermal expansion = 96 * 10.2 *10^-6 * 1,000 = .98 in. ***OK***

GreenGirt deflection due to cladding: 5wl^4/384EI
Iyy = 0.35851, E = 2,500,000 psi
5*(15*96/12/12)*(16^4)/384/2,500,000/.35851 = .00952 in.
.00952 < L/360 deflection criteria *OK*

SMARTsecure Technology – Through-Wall Insulated, Non-Flammable, Mechanically Attached Cladding Retention System

Building Upon SMARTframe:

Adding on to SMARTframe technology, which redundantly distributes the load to the sub-frame, SMARTsecure is a technology embedded within GreenGirt that creates an additional optimized cladding retention mechanism.

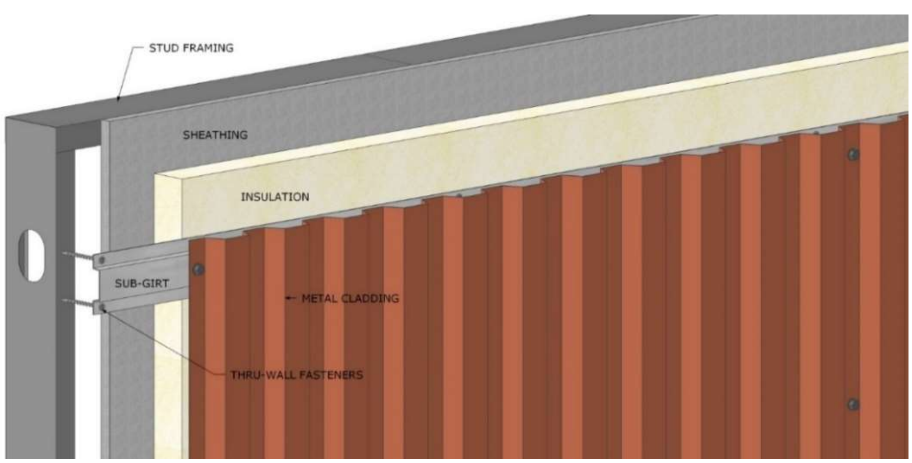
Background – Cladding Retention:

In addition to meeting NFPA 285 testing criteria, it is necessary to retain cladding so it does not fall off the building during a severe fire event. Currently, there are three basic methodologies for doing so.

Legacy Securing System #1:

System #1 uses through-wall steel fasteners that penetrate the wall from outside the exterior face of the exterior insulation into the interior of the wall cavity – typically through a stud as shown below. This fastener also attaches to an exterior metal track made out of steel, or the exterior cladding mechanically attaches to aluminum. This design provides a cladding retention system, but at the price of:

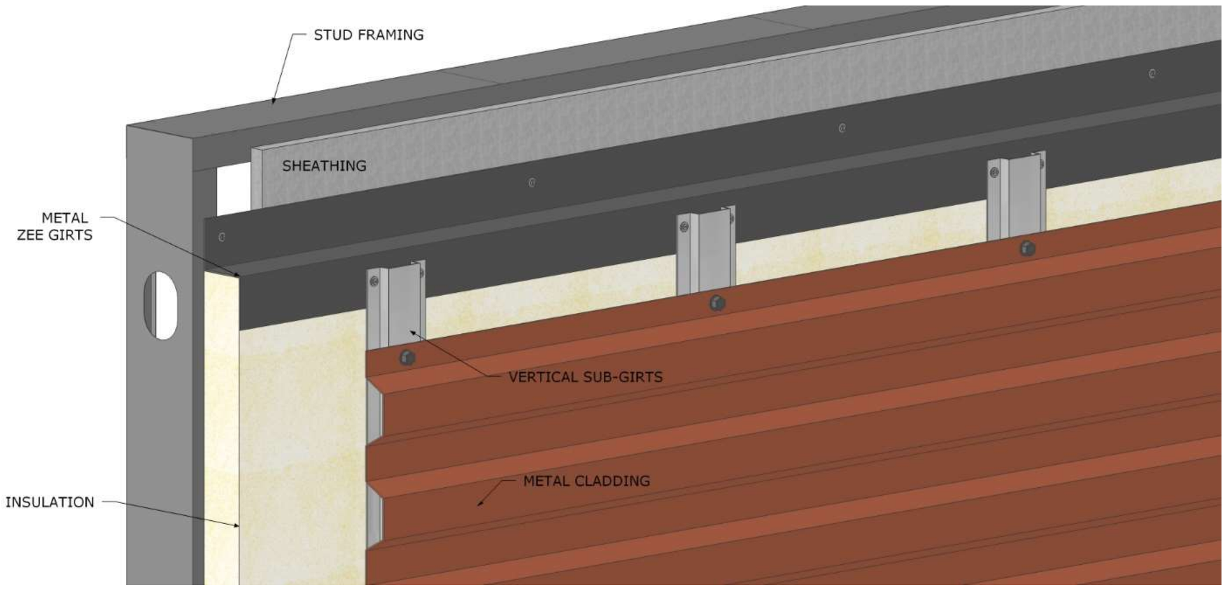
- through-wall fastener penetration that goes through the insulation and vapor barrier.
- a thermal short circuit of a metal fastener.
- potential problems meeting thermal requirements detailed in the 2012 International Energy Conservation Code[4] and ASHRAE 90.1.[5]



Legacy Securing System #2:

System #2 uses metal Z-girts or hat girts attached to the building sheathing and framing via metal screws and cladding mechanically attached to the exterior flange. This configuration is perhaps the most traditional. It does provide a continuous mechanical attachment for the cladding system to the building frame as shown below, yet it contributes to:

- a larger thermal short circuit than system #1.
- potential problems meeting thermal requirements detailed in the 2012 International Energy Conservation Code[4] and ASHRAE 90.1.[5]

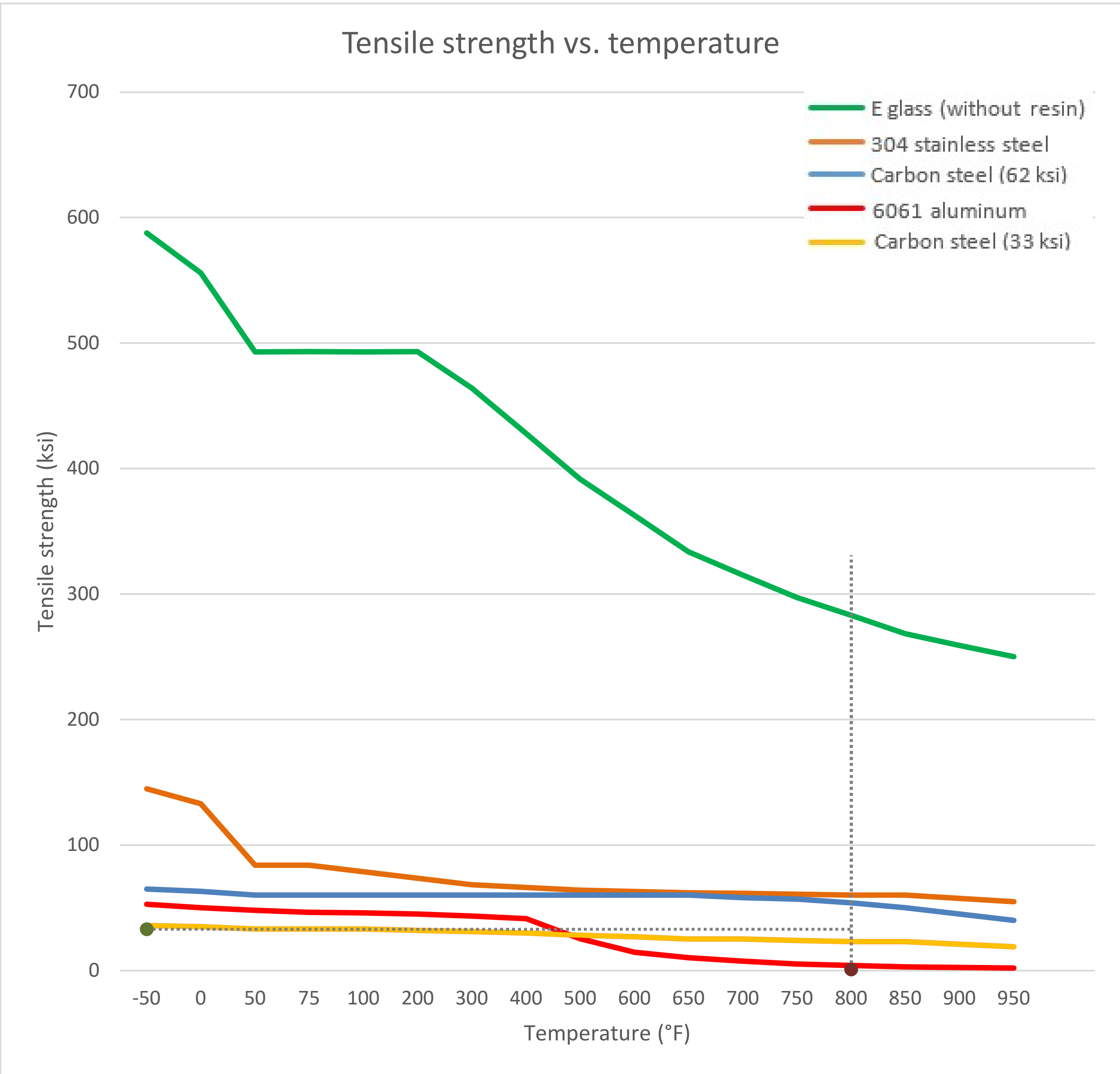


Shortfalls:

These systems were designed to provide a non-flammable, fail-safe way to secure cladding to walls in the event of a severe fire. However, these systems fail to eliminate thermal bridging, resulting in poor thermal performance, poor hygrothermal performance, and potential code compliance issues.

An Optimized Approach:

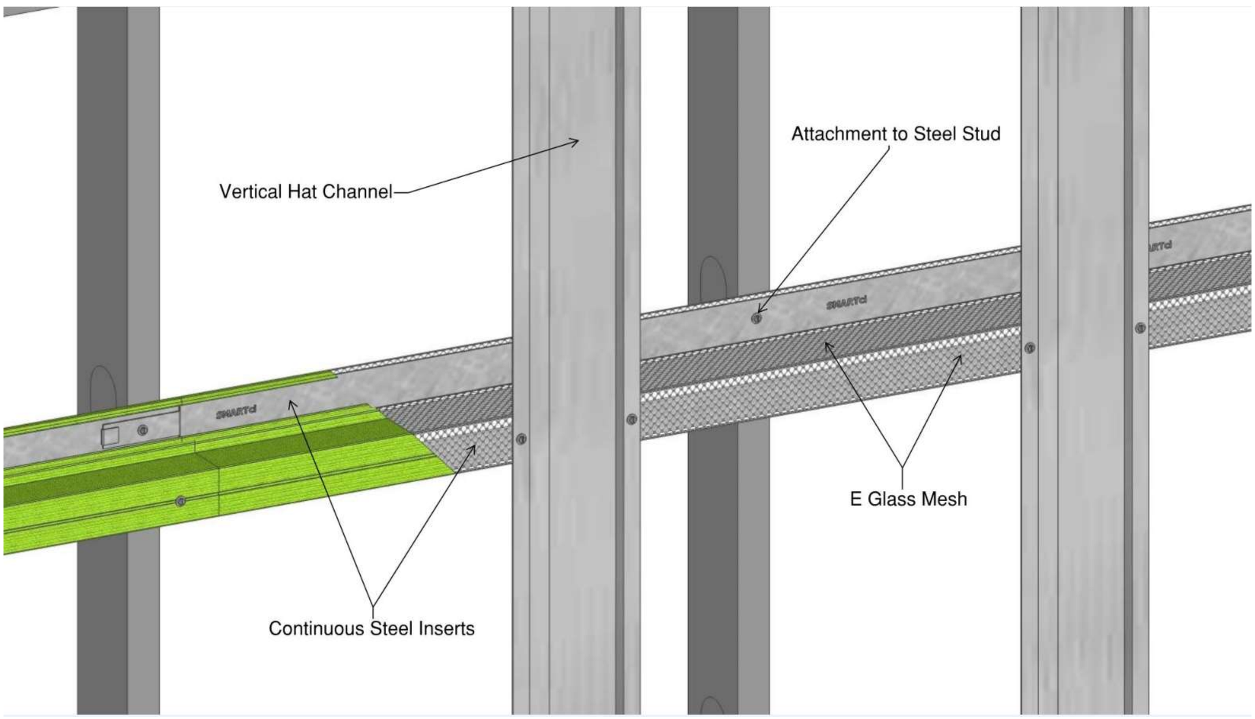
A superior method can be created by using the best material for the insulated product (see chart below). The maximum temperature rise inside a wall assembly in an NFPA 285 condition is 750°F. When analyzing time-tested building materials, it becomes apparent the utilization of E glass can provide not only a thermally insulated product, but also optimal fire performance if used with an appropriate anchor system.



Note: Vertical dashed line represents the NFPA 285 750°F maximum allowable insulation layer temperature rise; horizontal dashed line represents 33 KSI tensile, a standard substructure framing yield.[6-14]

System #3 – Putting it all Together with a SMART Securing System:

SMARTsecure technology is embedded within GreenGirt, which is stronger than steel alone[5]. It is non-flammable, yet insulated. This is achieved through the use of a continuously embedded E glass mesh inside a composite GreenGirt, which is mechanically attached to the building structure and cladding with fasteners and continuous steel inserts. Shown below is an illustration of the mesh used in GreenGirt as part of the SMARTsecure system.



Physical Validation of GreenGirt

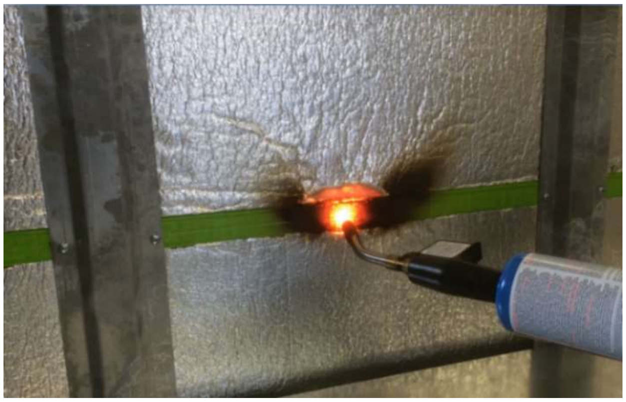
Testing – Introduction:

To evaluate the performance of the GreenGirt, SMARTframe, and SMARTsecure combination, tests were carried out on the system and its components. In addition to having the NFPA 285 test completed by a certified outside vendor, A2P performed fire tests of its own.

Focused Fire Testing – Description:

Before proceeding with official NFPA 285 testing, A2P conducted several fire tests to see how GreenGirt would react to a focused fire test with the girt as part of an assembly as shown below and on its own. Fifteen stand-alone tests were conducted by using a propane torch to apply a flame 1" away from a 3" GreenGirt. Tests were performed on 24" long samples with vertical and horizontal orientations used. The location of the flame also varied from the edge of the GreenGirt to the center, and tests were run for five or 15 minutes.

Three 30-minute tests were also performed on assemblies, one with mineral wool and two with polyisocyanurate insulation. The torch was held 1 1/2" away from the GreenGirt as shown below, and two vertical tests and one horizontal test were completed.



Focused Fire Testing – Results:

After the specified time with a flame directly on the girt, there was charring and discoloration, but the girt remained intact in all instances. Once the flame was turned off, the girt self-extinguished in a short amount of time in occurrences where there were visible flames. This happened whether the flame was applied at the edge or the center, whether a vertical or horizontal orientation was used, and regardless of the insulation used or lack thereof. Surface temperatures on the front averaged 1,655°F.

How GreenGirt Responds to an NFPA 285 Fire:

In its official NFPA 285 testing, GreenGirt was shown to not add to the flame spread of an assembly and retain the cladding by resisting fire propagation. This is due to its non-flammable constituents, as well as a built-in flame retardant that allows GreenGirt to be self-extinguishing. The fiberglass and steel in the CMH remain in place for extended periods of high temperatures, keeping the cladding attached. NFPA 285 testing with GreenGirt is shown in Figure 5.

Figure 5: NFPA 285 testing with GreenGirt is shown.

Third-Party Validation of NFPA 285 Testing:

By using a worst-case wall design of ACM panels without exterior sheathing for its NFPA 285 testing, A2P has been approved for use with multiple configurations via an Engineering Judgment from Priest & Associates Consulting. These configurations include NFPA 285-approved products from Atlas, Rmax, Hunter, Carlisle, and Dow, mineral wool, and high-pressure laminate claddings in an NFPA 285-approved window header design.[15]

For additional information on GreenGirt's NFPA 285 qualifications, see Advanced Architectural Products' Technical Evaluation Report online at http://www.drjcertification.org/system/files/drj/ter/node/1022/ter150106smartci.pdf.

Summary:

Thermal Performance

GreenGirt successfully provides a completely tested composite girt and continuous insulation system that eliminates thermal bridges and provides a universal insulation and cladding platform for optimum design flexibility.

Fire Performance

A GreenGirt system from A2P can provide multiple levels of redundancy for fire protection – levels not typically found in construction assemblies. These include the following properties:

1) ASTM E84 Class A rating
2) NFPA 285 tested and certified for numerous assemblies
3) Inherent SMARTframe redundant loading capability
4) Inherent SMARTsecure insulated mechanical attachment

Even with cladding options up to 15 PSF dead load, the GreenGirt system will perform as designed, accommodating NFPA 285-rated fire events while retaining the wall cladding. From the CMH constituents and numerous redundancies designed in, GreenGirt provides performance that exceeds testing/code performance fire requirements. This is a new, high-performance baseline for the product category.

Sources:

[1] "NFPA 285: Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load Bearing Wall Assemblies Containing Combustible Components." *National Fire Protection Association.* 2012.

[2] "2012 International Building Code." *International Code Council*, 2011.

[3] Wallenberger, Frederick T.; Watson, James C.; and Li, Hong. "Glass Fibers." *ASM International Handbook*, Vol. 21. 2001.

[4] "2012 International Energy Conservation Code." *International Code Council.* 2011.

[5] "ANSI/ASHRAE/IES Standard 90.1-2013 – Energy Standard for Buildings Except Low-Rise Residential Buildings." *American Society of Heating, Refrigerating, and Air-Conditioning Engineers; American National Standards Institute; Illuminating Engineering Society.* 2013.

[6] Wallenberger, Frederick T.; MacChesney, John B.; Naslain, Roger; Ackler, Harold D. "Advanced Inorganic Fibers: Processes – Structure – Properties – Applications." *Springer Science & Business Media,* April 27, 2011.

[7] Summers, Patrick T; Chen, Yanyun; Rippe, Christian M.; Allen, Ben; Mouritz, Adrian P.; Case, Scott W.; Lattimer, Brian Y. "Overview of Aluminum Alloy Mechanical Properties During and After Fires." *Fire Science Reviews,* 2015.

[8] American Iron and Steel Institute. "High-temperature Characteristics of Stainless Steels."

[9] Kalpakjian, Serope; Schmid, Steven. "Manufacturing Engineering & Technology." 6th Edition. 2010, Pearson Education.

[10] Jenkins, Peter G.; Riopedre-Mendez, Sara; Saez-Rodriguez, Eduardo; Yang, Liu; Thomason, James L. "Investigation of the Strength of Thermally Conditioned Basalt and E-glass Fibres." July 2015.

[11] "Carbon Steel Handbook." Electric Power Research Institute, Palo Alto, CA: 2007. 1014670.

[12] "Flat Products Stainless Steel Grade Sheet." North American Stainless.

[13] Hickey Jr., Charles F. "Mechanical Properties of Titanium and Aluminum Alloys at Cryogenic Temperatures." Watertown Arsenal Laboratories, March 1962.

[14] Yan, Jia-Bao; Liew, Jay Yuen Richard; Zhang, Min-Hong; Wang, Jun-Yan. "Mechanical Properties of Normal Strength Mild Steel and High Strength Steel S690 in Low Temperature Relevant to Arctic Environment. *Materials and Design,* Sept. 2014.

[15] "TER No. 1501-06." DrJ Engineering.

[a] In the event of a 30% increase in surface area of the fire-affected region, the system will continue to perform with an effective safety factor. SMARTci is not constrained to E glass, as it can be utilized with R glass, S glass, and others.

U.S. Patent 8,826,620; U.S. Patent 8,833,025; U.S. Patent 9,187,946; U.S. Patent 9,151,052; U.S. Patent 9,387,596; U.S. Patent D736,954
U.S. and international patents pending.