RESEARCH TECHNICAL REPORT

Evaluation of the Fire Performance of Aluminum Composite Material (ACM) Assemblies using ANSI/FM 4880

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Evaluation of the Fire Performance of Aluminum Composite Material (ACM) Assemblies using ANSI/FM 4880

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Executive Summary

External wall systems are assemblies of building products, often provided by multiple manufacturers, that form the façade of many present-day commercial and residential buildings. One widely used example of such external wall systems is external cladding assemblies made of composite panels, namely metal composite materials (MCMs) or more commonly aluminum composite materials (ACMs). The ACM/MCM assemblies can be installed on new and existing building façades to improve their energy efficiency, weatherability, and aesthetics. Despite their advantages, the building products used in ACM (or MCM) assemblies can be combustible. Recent catastrophic high-rise building fires involving ACM wall assemblies have caused significant life and property losses. These fire incidents warrant an international effort to reinvestigate and scrutinize building codes and the corresponding standard testing methods for such external wall assemblies. The purpose of this study is to examine the fire hazards of ACM cladding assemblies using the 16 ft high parallel panel test (16-ft PPT) method of ANSI/FM 4880[i], compare the results with NFPA-285[ii] and BS-8414[iii] fire tests, and establish improved, repeatable, and cost-effective fire-testing methods that can be used to assess wall assembly fire performance.

The three main combustible components of an ACM assembly include the ACM cladding, the continuous insulation (CI) layer behind the ACM, and the water/weather resistive barrier (WRB) layer behind the CI. The assemblies are either mounted on non-combustible masonry construction (in older constructions) or non-combustible gypsum (in newer construction).

In the present study, seven different ACM assemblies were evaluated; the ACM assemblies were made of three types of ACM panels, two types of CI, and one type of WRB coating. The chosen assemblies cover the range of materials typically available in the market and their installation practices. Six of the seven constructed assemblies are noted to have passed NFPA-285[ii] testing for unrestricted height installation in the US, either through actual tests or via desktop assessments.

The chosen assemblies were tested using the 16 ft high parallel panel test (16-ft PPT) method of ANSI/FM 4880[i] fire test standard. The 16-ft PPT method simulates a realistic fire scenario and imparts heat fluxes of the order of 100 kW/m^2 to the wall panels. This fire scenario is representative of both exterior fires in corner situations and post-flashover fires from the building interior. The heat flux exposure of the 16-ft PPT is higher and more realistic than that provided in the NFPA-285 test (40

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[i] ANSI/FM 4880-2017, American National Standard for Evaluating the Fire Performance of Insulated Building Panel Assemblies and Interior Finish Materials. Norwood, MA, USA: FM Approvals LLC, 2017.

[ii] NFPA-285, Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components. Quincy, MA, USA: National Fire Protection Association, 2012.

[iii] BS 8414-1:2015 + A1:2017, Fire Performance of External Cladding Systems. Test Method for Non-load bearing External Cladding Systems Applied to the Masonry Face of a Building. London, UK: British Standards Institution (BSI), 2015.

kW/m^2). The results from the 16-ft PPT method were compared with the evaluation of the same assemblies conducted per the NFPA-285 test method. The results from the recent series of BS-8414 tests[iv,v,vi] for similar-type ACM assemblies, were also compared with 16-ft PPT evaluations; the peak heat flux exposure of BS-8414 tests is ~ 75 kW/m^2, with a variance between 45-95 kW/m^2 permitted per the test method.

Two assemblies that had passed NFPA-285, one via physical testing and the other by means of desktop assessment, decisively failed the 16-ft PPT test. Both assemblies produced high heat release rates (> 6 MW) with flame heights extending higher than 25 ft (7.6 m) within 4 minutes of ignition, at which time the test was terminated. Both assemblies used a combustible thermoplastic-core ACM with relatively thick aluminum facers.

Two other assemblies that had passed NFPA-285, and hence are granted unrestricted installation heights in the US, failed for unlimited height and only passed for up to 50 ft (15 m) limited-height installation using the criteria in ANSI/FM 4880[i]. These two assemblies used a fire-retardant-core ACM and a combustible polyisocyanurate insulation behind the ACM. The results of the 16-ft PPT were found to be comparable with those from recent BS-8414 fire testing[iv,v,vi] with similar type ACM wall assemblies.

The 16-ft PPTs captured all relevant phenomena of fire spread over external cladding systems, including the external fire spread and air cavity fire spread phenomena. The test results provided in this report demonstrated the effectiveness of the 16-ft PPT in evaluating the fire hazard of ACM assemblies, clearly differentiating wall assembly fire performance under conditions reflective of actual end-use. The test method is repeatable, fast to set up, and provides an objective and robust means of evaluating the fire performance of ACM wall assemblies. Therefore, ANSI/FM 4880 16-ft PPT is recommended for evaluating fire performance of external wall assemblies, such as ACMs.

[iv] “Fire Test Report: DCLG BS 8414 Test no. 2," BRE Global, Test Report, B137611-1037 (DLGC Test 2) Issue: 1.0, 3 August 2017.

[v] “Fire Test Report: DCLG BS 8414 Test no. 3," BRE Global, Test Report, B137611-1037 (DLGC Test 3) Issue: 1.1, 8 August, 2017.

[vi] “Fire Test Report: DCLG BS 8414 Test no. 4," BRE Global, Test Report, B137611-1037 (DLGC Test 4) Issue: 1.1, 11 August, 2017.

Abstract

Recent catastrophic high-rise building fires involving external cladding systems, especially ACM wall assemblies, have caused significant life and property losses. The fire incidents warrant an international effort to reinvestigate and scrutinize building codes and the corresponding standard testing methods for such external wall assemblies. This research evaluated the fire hazards of ACM wall assemblies using the 16 ft high parallel panel test (16-ft PPT) method of ANSI/FM 4880, and compares the results with NFPA-285 (US) and BS-8414 (UK) fire tests. Seven different ACM assemblies, with a combination of three types of ACM panels, two continuous insulations, and a WRB are evaluated. The chosen assemblies cover the range of materials typically available in the market, and their installation practices. The tests demonstrate the effectiveness of the 16-ft PPT in evaluating the fire hazard of ACM assemblies, clearly differentiating the fire-resistant systems from hazardous assemblies. The results also show that some assemblies that have passed NFPA-285 perform inadequately in the 16-ft PPT primarily due to the relatively low heat flux exposure in the NFPA-285 test as compared to realistic fire scenarios.

Acknowledgments

The author gratefully acknowledge Research Campus Staff, including Kevin Mullins, Jason Tucker and Derek Mencarini, for carrying out the parallel panel tests; Stephen Ogden for carrying out the bench-scale experiments; Richard Davis, John Harrington, Dr. Dong Zeng, Dr. Yi Wang, and Dr. Sergey Dorofeev for their helpful input and discussions during the course of this work; and all reviewers for their insightful comments and recommendations.

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1. Introduction

External wall systems are assemblies of building products, often provided by multiple manufacturers, that form the façade of many present-day commercial and residential buildings. One widely used example of such external wall systems is cladding assemblies made of metal composite materials (MCMs) or more commonly aluminum composite materials (ACMs). The ACM/MCM assemblies can be installed on new and existing building façades to improve their energy efficiency, weatherability (air/moisture), and aesthetics. Although ACM assemblies are also used in internal wall systems and building roofing systems, their primary application is in external wall systems.

The building products used in external cladding assemblies can be combustible. In the past few years, there have been several instances of severe fires involving ACM cladding assemblies with predominantly vertical and accelerated flame spread. These fire incidents have gained prominent international attention regarding ACM assembly applications in high-rise residential buildings [1-7]. Besides property and smoke damage, such fire incidents unfortunately result in loss of life, particularly in situations where the building's interior is unsprinklered [8]. A detailed compilation of recent ACM/MCM cladding-related fires is provided in various literature references [8-11].

As designers and architects gain interest in ACM/MCM cladding solutions and the usage of such products increases, it becomes essential for FM Global to provide corresponding installation, testing, and certification guidelines to properly assess the fire performance of these assemblies in end-use conditions. The purpose of this study is to examine the fire hazards of ACM/MCM wall assemblies using the 16 ft high parallel panel test (16-ft PPT) method of ANSI/FM 4880 [12], compare the results with those from NFPA-285 [13] and BS-8414 [14] fire tests, and establish improved, repeatable, and cost-effective fire testing methods that can be used to assess wall assembly fire performance.

2. **Components of External Cladding Assembly**

To examine the fire hazards related to ACM/MCM assemblies, it is essential to understand their components and usual installation practices. Figure 2-1 shows a schematic of the generic components of an external cladding assembly, as documented in the International Building Code (IBC) [15]. The external wall is the part of the assembly from the exterior sheathing to the exterior cladding in Fig. 2-1. The exterior sheathing in Fig. 2-1 can be the outside masonry wall of an existing building, which is a non-combustible construction (brick, stone, concrete, granite, etc.), or a new construction, which widely uses non-combustible gypsum as external sheathing. Hence, the combustibility and installation of building products behind the exterior sheathing, which may include steel studs, cavity insulation, and interior drywall are not considered when evaluating the fire hazard of an external wall assembly. The three main combustible components of an external cladding assembly are the exterior cladding, the layer of insulation, which is also referred to as continuous insulation (CI), and water/weather resistive barriers (WRBs). The description of these three components is provided below:

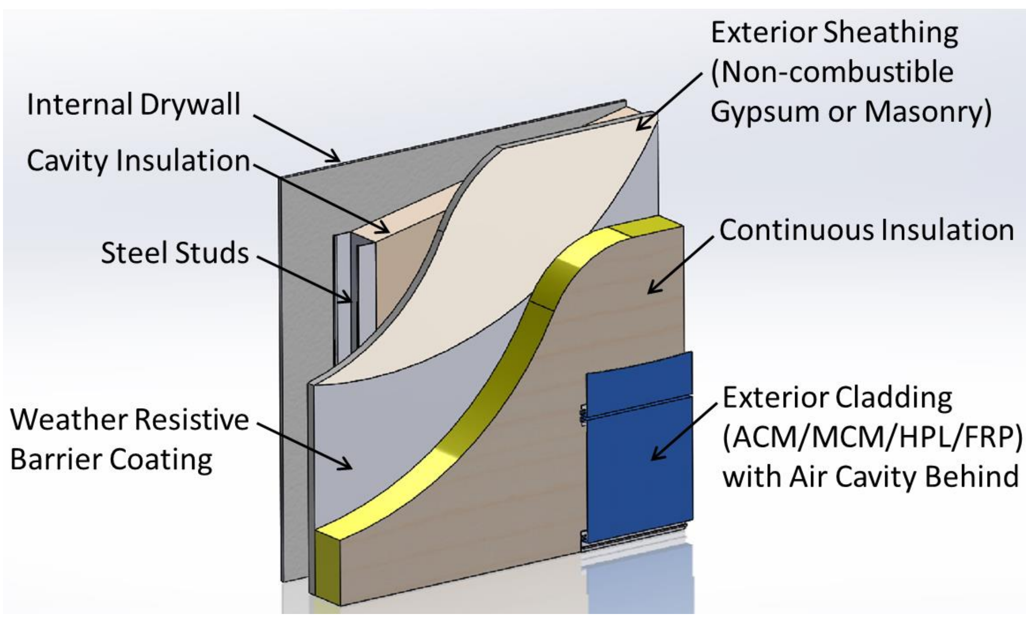


Figure 2-1: Example of a complete cladding assembly system. The external wall assembly is from exterior sheathing to exterior cladding.

2.1 Exterior claddings

Exterior cladding is the outermost component of a cladding assembly. These claddings are designed to protect the building against rainwater and are often referred to as rain-screen claddings. The claddings are installed using joint systems, such as brackets, channels, or other attachment systems, to the substrate, thereby creating an air cavity directly behind the cladding (see Fig. 2-1). The air cavity allows the rainwater to drain down the building, and upward air flow within the cavity during hot weather facilitates removal of any remnant moisture, thereby keeping the façade ventilated. The air cavity thickness behind the cladding is typically 1 to 4 in. (25 to 100 mm). In a fire event, both external flame spread on the cladding and internal cavity fire spread can cause vertical flame propagation on a building façade.

Various types of products can be used as cladding, including ACM/MCMs, high-pressure laminates (HPLs), fiber reinforced plastics (FRPs), etc. Other than aluminum, MCM panels may include facers with alloys of stainless steel, copper, titanium, and zinc for specific applications. However, ACM panels have been most popular as a choice of cladding product in the building industry due to their lower cost and wider availability.

As shown in Fig. 2-2, ACM (or MCM) panels are essentially composite panels, which consist of a core material sandwiched between two thin layers of aluminum (or other metal) sheets/facers. While the thickness of the aluminum or metal facers is usually on the order of 0.02 in (0.5 mm), the total thickness of the complete panel is generally 0.12 to 0.24 in. (3 to 6 mm). Aluminum/metal facers are covered with durable and weather-resistant coatings.

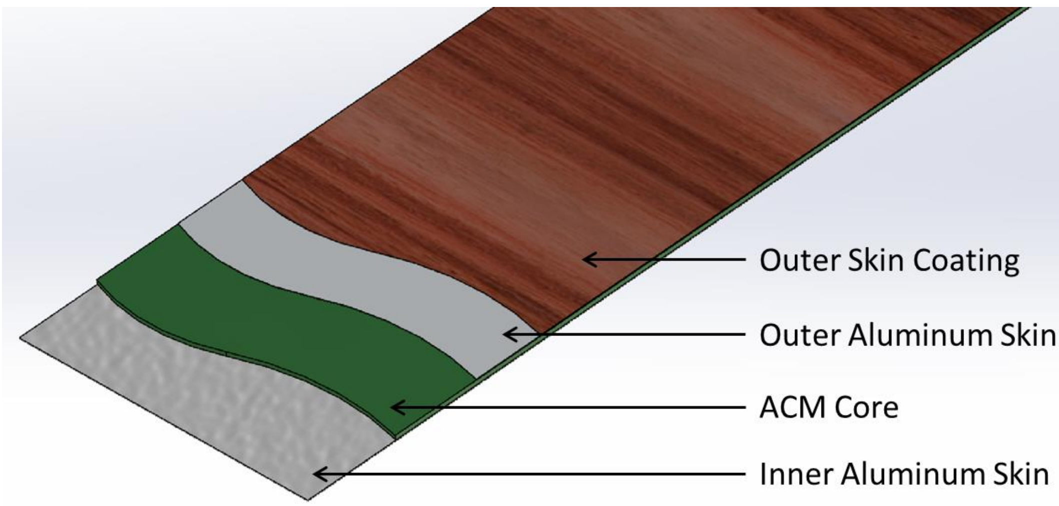


Figure 2-2: Cross-section of an ACM/MCM panel.

As shown in Table 2-1, the core material of the ACM panel usually defines its combustibility. Some of the most combustible panels use combustible thermoplastic polymers like polyethylene (PE) or polypropylene (PP) in their core. Thereafter, there are cores with different levels of mineral fill added to the thermoplastic core to improve the fire performance of the panel. The “fire-retardant” ACM/MCM panels are typically referred to as FR-rated ACM panels and consist of approximately 70% non-combustible mineral fill added to the combustible thermoplastic core. Next, the “mineral fill” ACM/MCM panels are popularly referred to as A2 ACM panels in Europe due to their Euro class A2 rating from the EN 13501-01 [16] standard resulting from approximately 90% mineral fill added to the combustible thermoplastic core. Lastly, there are also products with 100% non-combustible (mineral fill or metal fill) cores. In the US, usually FR-rated ACM panels pass the large-scale NFPA-285 [13] fire test requirement of the IBC [15], and better fire rated ACM panels are therefore not required. Better fire rated ACM panels are also less popular due to their higher price in comparison to FR-core ACMs.

Table 2-1: Different core materials used in ACM/MCM panels.

Core Material[Δ] ↓	Combustibles (%)^	Mineral fill (%)^	Gross Heat of Combustion (kJ/g)^
Combustible	100%	0%	~ 45
Fire-retardant	30%	70%	~ 13
Mineral fill	10%	90%	~ 3
Non-combustible	0%	100%	< 1

[Δ] Manufacturers may use different types of core materials than listed in the table.
^ Values may vary with manufacturer.

2.2 Continuous insulation (CI)

Continuous insulation (CI) is a layer of insulation batting that is installed on the structure of the building (exterior sheathing), as shown in Fig. 2-1, such that it adds to the overall R-value of the external wall for energy saving purposes. CI application guidance is provided by ASHRAE 90.1 [17] and IECC [18] for various climate zones, as shown in Table 2-2; Table 2-2 shows separate R-values for stud cavity insulation behind the exterior sheathing and the CI (see Fig. 2-1).

Table 2-2: Guidance of CI application in external walls based on climate zones [17, 18].

Climate Zone ↓	2012 IECC	2012 ASHRAE 90.1
1	R13 (Studs) + R5.0 (CI)	R13 (Studs)
2	R13 (Studs) + R5.0 (CI)	R13 (Studs) + R3.8 (CI)
3	R13 (Studs) + R5.0 (CI)	R13 (Studs) + R5.0 (CI)
4	R13 (Studs) + R7.5 (CI)	R13 (Studs) + R7.5 (CI)
5	R13 (Studs) + R7.5 (CI)	R13 (Studs) + R10.0 (CI)
6	R13 (Studs) + R7.5 (CI)	R13 (Studs) + R12.5 (CI)
7	R13 (Studs) + R7.5 (CI)	R13 (Studs) + R12.5 (CI)
8	R13 (Studs) + R7.5 (CI)	R13 (Studs) + R18.8 (CI)

A variety of continuous insulation materials can be used on ACM wall assemblies, including mineral wool batting, extruded polystyrene (XPS) foam, aluminum foil-faced polyisocyanurate (PIR), and phenolic foam. Table 2-3 provides a comparison of these insulation materials.

Table 2-3: Types of continuous insulations that can be used with ACM wall assemblies.

Continuous Insulation	R-value (h.ft^2.°F /BTU)	Combustibility	Water Permeability
Mineral wool	~ 4.0 per inch	Low	High
Foil faced PIR foams	~ 6.5 per inch	Medium	Low
Phenolic foams	~ 5.0 to 8.0 per inch	Medium	Low
XPS	~ 5.0 per inch	High	Low
PIR - Polyisocyanurate; XPS - Extruded polystyrene			

As shown in Table 2-3, these insulation materials differ based on their combustibility, which directly affects the fire performance of the entire cladding assembly. For example, mineral wool insulation can be non-combustible, while the other listed insulations are combustible products. It is important to note that the definition of non-combustibility varies with country codes and test standards [19, 20]; some of these tests are discussed by Alpert and Khan [21]. Based on Alpert and Khan's research [21], the present FM Global guidelines for a non-combustible insulation include meeting all three following tests and limits: (a) the minimum ash content of the insulation per ASTM D482 [22] shall be 90%; (b) the maximum gross heat of combustion per ISO 1716 (bomb calorimeter) [23] shall be 2 kJ/g; and (c) bench-scale Fire Propagation Apparatus (FPA) [24, 25] combustion test at 40% inlet O_2 atmosphere shall not reveal any visible flaming for a 15 minute exposure at 50 kW/m^2 heat flux. The FM Global requirements for non-combustibility of an insulation are also specified in the ANSI/FM 4880 [12] standard.

In Table 2-3, PIR and phenolic foams are charring thermoset polymers that are usually covered with 1-1.5 mil (1 mil = 1/1000 in.) aluminum foil facers, while EPS foams are melting thermoplastic polymers that can also form a pool fire in case of a fire event. The insulation products vary based on their R-value per unit thickness, with PIR and phenolic foams providing higher R-values than mineral wool. Further, these products also demonstrate different levels of susceptibility to water permeability, with mineral wool products generally having higher permeability than other insulations. Beside the insulations listed in Table 2-3, metal sandwich panels (also termed insulated metal panels - IMPs) may also be used as CI. The sandwich panels are usually composed of PIR or polyurethane (PUR) charring thermoset foams sandwiched between two relatively thick layers (20-26 gage) of galvanized steel facers. Such sandwich panels will generally have better fire resistance than foil-faced PIR foams and lower water permeability. However, sandwich panels are comparably more expensive than the other listed CI materials.

2.3 Water/weather resistive barrier (WRB)

A water/weather resistive barrier (WRB) is a material that is installed on the wall assembly to prevent moisture from seeping inside the building and causing moisture damage. It also manages the diffusion of water vapor and helps maintain the relative humidity comfort level in the buildings. Like continuous insulations, guidance for the application of WRBs on exterior cladding assemblies is also provided by the IECC [18].

WRBs can be installed either over the exterior sheathing (and under the CI — see Fig. 2-1) or over the CI, with the former being the more widely used approach. WRB products are available in various forms, with the primary types being fluid-applied membranes and building wraps. The fluid-applied membranes are typically deployed over exterior sheathing using a roller or sprayer; the paint dries out to become a rubber-like polymer cover that blocks air and water penetration. The building wraps are sheets that are typically made of polyethylene fiber and can be self-adhered or mechanically fastened to exterior sheathing or the CI. Both types of WRB products can contain combustible polymers that can influence the fire performance of the external wall assembly.

3. Large-scale Fire Tests for ACM Assemblies

3.1 Types of façade fires and large-scale fire tests

Fires involving the exterior façade of the building can result from many types of scenarios. The most statistically relevant scenarios of external façade fires are broadly classified into two main types [10, 26-29].

(a) Post-flashover interior fires: These fires originate inside the building and flash over to the exterior façade via openings such as windows.

(b) External fires: Such fires originate outside the building and spread externally to and over the façade. Examples of such fires include combustible outdoor storage near the building, dumpster fires, etc.

The relative severity of either fire scenario varies from case to case. The severity of a fire scenario is defined in terms of the heat flux it imparts on the façade, and the size of the area of impact. Heat flux expresses the thermal insult experienced by an external wall system, thereby exposing the vulnerabilities of wall joint systems, exterior facers/claddings, and other components of the wall system. Therefore, a fire test representing an accident scenario should impose an appropriately high heat flux to the wall system. The length-scale of a fire scenario defines the length of façade exposed to high heat fluxes. A high length-scale of a fire scenario ensures sufficiently high residence time for fuel vapors igniting along the height of the façade to develop resulting in a more realistic fire; vertically propagating fires require a high length-scale of a fire test, beyond the ignition zone, to capture the physics of fire propagation. For this reason, small-scale tests alone cannot fully assess the vertical propagation tendency of a fire from gasifying building materials, even when exposed to high heat fluxes in a small-scale configuration. To summarize, a robust fire test will ensure that both length-scale and the heat flux levels employed in the test are sufficiently high to reveal the vulnerabilities of the wall systems in a realistically severe fire scenario.

The differentiating factor of most large-scale fire tests, which represent high length-scale fire scenarios, is the heat flux exposure employed to test the external wall system. The fire test may be large-scale in nature, but it won't capture the vertical fire spread behavior of the wall system if the heat flux exposure is too low. Given that the new and developing wall systems may use highly combustible plastics behind apparently non-combustible cladding and facers (e.g. aluminum), it is important to employ a realistically high heat flux to fully test the joint mechanisms and melting/gasifying temperature of such claddings/facers.

There are multiple large-scale fire tests available globally to test wall systems, which are used in local building codes to determine fire performance of a wall assembly for life safety purposes; a comprehensive summary of dimensions, heat flux, and pass/fail criteria of such fire tests is provided by White and Delichatsios [10]. These large-scale fire tests use a wide variety of heat flux exposures to test building components. While the North American fire tests, including the NFPA-285 in the US [13] (40 kW/m^2 heat flux) and CAN ULC-S134 in Canada [30] (~45 kW/m^2 heat flux), use heat flux exposures at the lower end of the range, the BS-8414 [14, 31] in the UK use a relatively higher heat flux exposure (~75 kW/m^2 average heat flux but can vary within the 45-95 kW/m^2 range). These tests, and most of the other large-scale fire tests, all aim to simulate a post-flashover fire exiting from a window; the heat flux exposure for the large-scale fire tests simulating post-flashover fires ranges from 40 to 75 kW/m^2 according to [10]. In comparison, ANSI/FM 4880 consists of three types of large-scale fire tests, including two corner fire tests and a 16 ft high parallel panel test (16-ft PPT), to evaluate wall assemblies for property loss prevention. The ANSI/FM 4880 fire tests simulate a realistic external or post-flashover fire with a heat flux exposure to the wall panel in the order of 100 kW/m^2.

The literature on post-flashover fires is extensive and a summary is provided in references [10, 26-29]; some studies that highlight heat flux exposure from post-flashover fires are discussed. One of the detailed studies on post-flashover fires was conducted at the NRC Canada by Oleszkiewicz [32]. Full-scale post-flashover fire experiments were conducted on two non-combustible walls; one was 20 ft (6.1 m) high x 8 ft (2.4 m) wide and the other was of 32 ft (10.3 m) height and unspecified width. A wood crib or a propane burner was placed inside a compartment behind the walls as a flashover fire source; the heat release rate (HRR) of the fire source was varied to simulate fires of different severities. The compartment was connected to the external façades via a window opening, whose dimensions and aspect ratio (height/width) were varied in multiple tests. In these tests, it was found that the peak heat flux to the façade section immediately above the window (0.25 to 0.5 m) varied based on HRR and the window aspect ratio. The peak heat flux in the tests ranged from ~20 kW/m^2 to up to 200 kW/m^2 in certain cases; the peak heat flux to the façade increased with an increase in the HRR and with decrease in the aspect ratio of the window (i.e., wider windows provide higher heat flux flashover fires). Many similar studies in the literature [27, 33-36], including both experiments and simulations, have shown that a heat flux of the order of 40 kW/m^2 is not representative of a realistic fire hazard, and instead heat fluxes of the order of 70-80 kW/m^2 to be more realistic representations of post-flashover fire scenarios.

In the context of exterior fires, Alpert and Davis [37] presented a realistic exterior fire scenario; the scenario simulated a dumpster or a combustible storage fire placed at the re-entrant (right-angle) corner location near the external wall of a building. The fire from such storage was estimated to present an HRR hazard of 3-8 MW, based on the composition of fuel source (plastics, paper, etc.). A 3.3 ft x 3.3 ft (1 m x 1 m) square wooden pallet of 4.9 ft (1.5 m) height was used to represent such a fire source, resulting in heat fluxes of about 100 kW/m^2 to the external wall. Therefore, this heat flux exposure is used in FM Global corner fire tests and 16-ft PPTs, which are all part of ANSI/FM 4880 [12] fire tests. The high heat flux in this scenario is a result of the presence of a re-entrant corner situation, which increases the re-radiation effects from the adjacent walls. Such re-entrant walls are a common occurrence in building façades; for example, the well-known 1991 Knowsley Heights fire in the UK [38] resulted from a dumpster placed at the exterior of the building in a re-entrant corner location. The work conducted by Oleszkiewicz [32] showed that the presence of such corners, near window openings, in post-flashover fires can also result in substantially higher heat fluxes than fires on a single-wall (increase from about 50 kW/m^2 for a single wall to 150 kW/m^2 for a corner wall for same wood crib size and window opening). Therefore, usage of heat fluxes of the order of 100 kW/m^2 is a realistic representation of both exterior and post-flashover fires.

The difference in the heat flux exposure of various large-scale tests can result in different evaluations for the fire performance of wall assemblies. In the following sections, three such large-scale test standards, including NFPA-285 [13] of the US, BS-8414 [14, 31] of the UK, and ANSI/FM 4880 [12] are discussed.

3.2 NFPA-285 test and application in IBC

3.2.1 NFPA-285 test

NFPA-285 [13] was originated from UBC 26-4 [39] large-scale fire test, which was published in 1988 to evaluate external wall assemblies made from plastic foam insulation building products. UBC 26-4 [39] used a 26 ft (8 m) high two-story apparatus, with 580 kg of wood crib in the first floor to simulate a flashover fire impinging on the external façade. An intermediate-scale version of the test was then published in 1997 as UBC 26-9 [40] and in 1998 as NFPA-285 [13], after establishing a correlation with the original large-scale UBC 26-4 test. Development of both UBC 26-4 and NFPA-285 was sponsored by the Society of Plastics Industry (SPI) to incorporate plastic construction types (e.g., EIFS - exterior insulation and finish systems) into building external wall systems that were then required to be non-combustible (Type I to Type IV [15]).

Like its predecessor, NFPA-285 is also a two-story apparatus that instead uses propane burners to simulate a flashover fire scenario. A single test wall is installed without a re-entrant corner scenario. The test specimen is 17.5 ft high (5.3 m) x 13.5 ft (4.1 m) wide, as shown in Fig. 3-1. Each of the two floors has one room 6.5 ft high x 10 ft wide x 10 ft deep (2 m x 3 m x 3 m), with the bottom room including a window opening of dimensions 2.5 ft (0.8 m) high x 6.5 ft (2 m) wide. There are two separate fire sources; one propane burner is placed in the bottom room and another burner is a line burner located under the window opening.

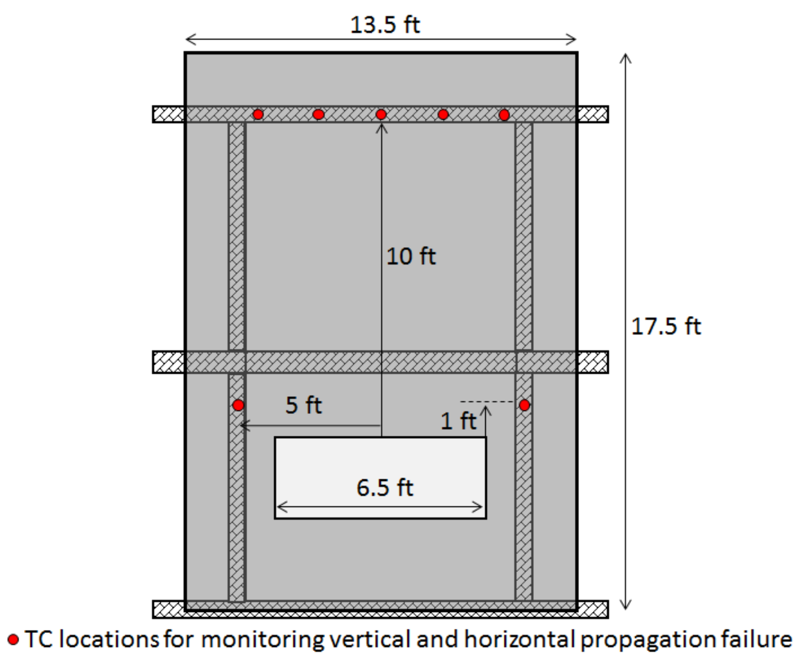


Figure 3-1: Schematic of setup and dimensions in NFPA-285 (not to scale).

The HRRs from the two burners are controlled to provide a calibrated heat flux to the external wall assembly. In the test procedure, this heat flux is gradually increased in steps from 10 kW/m^2 to 40 kW/m^2 within the span of 30 minutes of test duration, with 40 kW/m^2 heat flux provided only during the last 5 minutes of the test.

During the test, temperatures are monitored in front of the external wall, inside air cavities, and inside insulation. The pass criteria for a wall assembly are detailed below:

(a) Temperature from the thermocouples mounted on the exterior of the assembly at 10 ft (3.0 m) height above the window and 5 ft (1.5 m) horizontally from the vertical centerline of the window shall be less than 1000 °F (538 °C).

(b) Temperature from the thermocouples mounted in the air cavity at 10 ft (3.0 m) height above the window and 5 ft (1.5 m) horizontally from the vertical centerline of the window shall be less than 1000 °F (538 °C).

(c) Temperature from the thermocouples mounted in the insulation at 10 ft (3.0 m) height above the window and 5 ft (1.5 m) horizontally from the vertical centerline of the window shall be less than 750 °F (399 °C).

(d) Temperature from the thermocouples mounted in the second story room at 1 in. (25 mm) from the interior surface shall be less than 500 °F (260 °C).

3.2.2 NFPA-285 application in IBC and exceptions

In the US, the International Building Code (IBC) [15] and the NFPA 5000 code [41] require compliance with NFPA-285 for buildings; IBC is a model building code adopted by most US states while NFPA 5000 is an alternate building code. The two codes have some detailed differences in terms of external wall requirements, which are out of scope of this study; therefore, only the compliance requirements of ACM/MCM wall systems with the IBC are discussed.

In the IBC, there are specific exemptions from NFPA-285 compliance for MCM wall systems. These exemptions are dependent on complex contingencies of building heights, small-scale tests like ASTM D635 (small-scale horizontal burn of plastics) [42] and ASTM D1929 (ignition temperature test) [43], MCM installation coverage area and separation of adjacent MCM covered areas, building separation distance, and the presence of an automatic indoor sprinkler system. Therefore, only select exemptions are listed below.

(a) For MCM installations below 40 ft (12 m) height, NFPA-285 test compliance is not required if building separation is greater than 5 ft (1.5 m); in this case, the entire building can be covered with un-tested wall systems. If the building separation is less than 5 ft (1.5 m), then un-tested MCM installations are limited to 10% of the total exterior area

(b) For MCM installations up to 50 ft (15 m) height, NFPA-285 test compliance is not required if sections of MCM panels are smaller than 300 ft^2 (28 m^2) in size and the individual sections are vertically separated by a minimum of 4 ft (1.2 m). There is also a requirement for the MCM self-ignition temperature, per ASTM D1929 [43], to be higher than 650 °F (343 °C).

(c) MCM installations up to 75 ft (23 m) can waive NFPA-285 test requirements based on complex requirements of tabulated continuous MCM panel area, building separation distance, category of building occupancies, and small-scale test results. If the an automatic indoor sprinkler system is present then wall systems not-tested or not-passed by NFPA-285 can be installed to unlimited heights (refer to Chapter 14 of IBC [15] for complete details).

There is a similar set of complex exceptions for wall assemblies with other types of exterior claddings, *viz.,* HPLs and FRPs, and are documented in the IBC [15]. These exceptions indicate that combustible building products that are not tested to or will not pass the NFPA-285 fire test can still be installed on US buildings of all heights.

Moreover, a fire protection engineer or an engineering firm can analyze a select list of existing NFPA-285 test reports and can pass other wall assemblies and products, which may not have been tested through NFPA-285. This process, often known as desktop assessment, is used to obtain acceptance of several NFPA-285 compliant assemblies without actually conducting an NFPA-285 test.

3.3 BS-8414 test

BS-8414-1 [14] and BS-8414-2 [31] are large-scale fire tests used in the UK for testing external wall systems attached to masonry walls [14] or structural steel frames [31]. The dimensions, test procedure, and performance criteria for both BS-8414-1 and BS-8414-2 tests are the same [44], and the test standards are henceforth termed BS-8414 in this document.

As shown in Fig. 3-2, the BS-8414 setup consists of a minimum of 26 ft (8 m) high main and wing wall specimens arranged in a corner situation. The width of the main wall is at least 8 ft (2.4 m) and that of the wing wall is at least 4 ft (1.2 m). A combustion chamber of dimensions 6.6 ft high x 6.6 ft wide x 3.3 ft deep (2 m x 2 m x 1 m) is located at the base of the main wall. The combustion chamber houses a timber wood crib made of softwood of dimensions 3.3 ft high x 4.9 ft wide x 3.3 ft deep (1 m x 1.5 m x 1 m); the wood crib generates 4500 MJ energy over the 30-minute duration of the test, with a peak HRR of 3.0 ± 0.5 MW. The wood crib source produces approximately 75 kW/m^2 peak heat flux at 3.3 ft (1 m) height above the window opening on the external wall. The wood crib can be substituted with an alternate fuel source that can provide heat fluxes that vary in the range of 45 to 95 kW/m^2 over the first 20 minutes of the test with a steady-rate mean heat flux of 75 kW/m^2 within this period [10, 29].

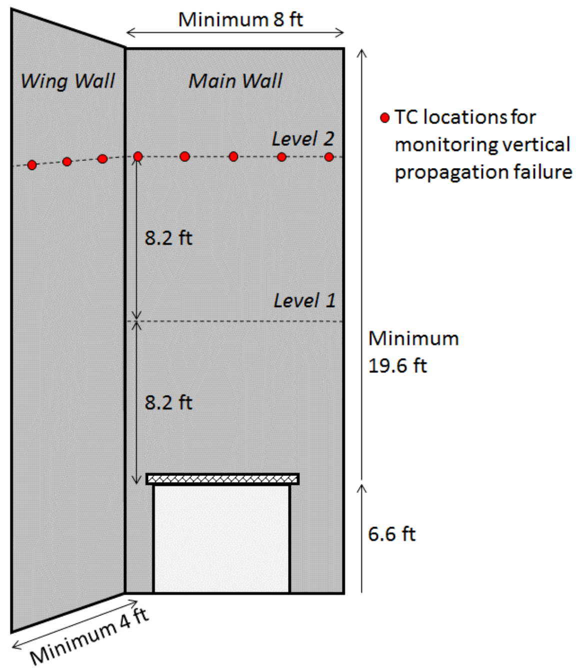


Figure 3-2: Schematic of wall specimen and dimensions in BS-8414-1 (not to scale).

During the 30-minute duration of the fire test, temperatures are monitored in front of the external wall, inside air cavities, and inside insulation at Level 1 and Level 2 locations above the window opening; Level 1 and Level 2 locations are defined as 8.2 ft (2.5 m) and 16.4 ft (5.0 m) heights above the window opening, respectively. The fail criteria for a wall assembly are detailed below [44]:

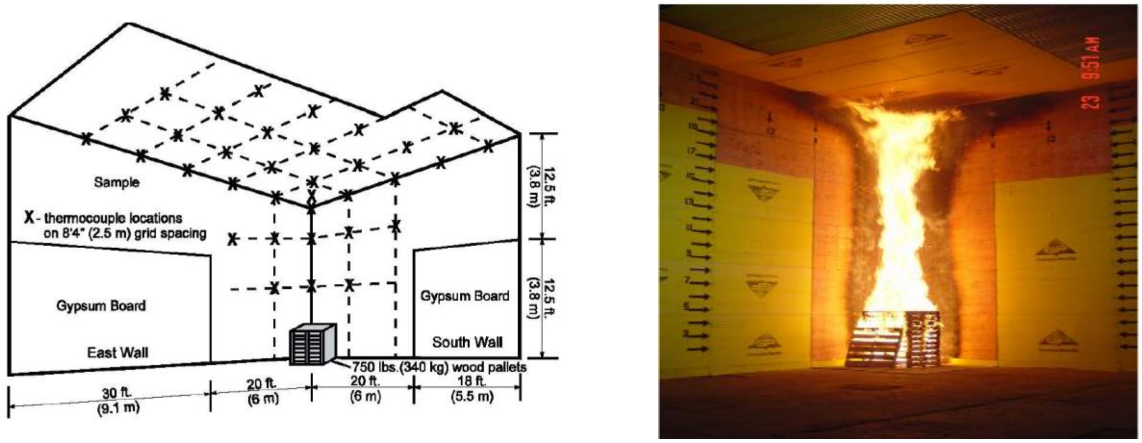
(a) The temperature rise of the thermocouples mounted on the exterior of the assembly at Level 2 is more than 1110 °F (600°C) above the ambient temperature, for at least 30 s duration within 15 minutes of fire spread start time.

(b) The temperature rise of the thermocouples mounted in the interior of the assembly (air cavity or insulation) at Level 2 is more than 1110 °F (600°C) above the ambient temperature, for at least 30 s duration within 15 minutes of fire spread start time.

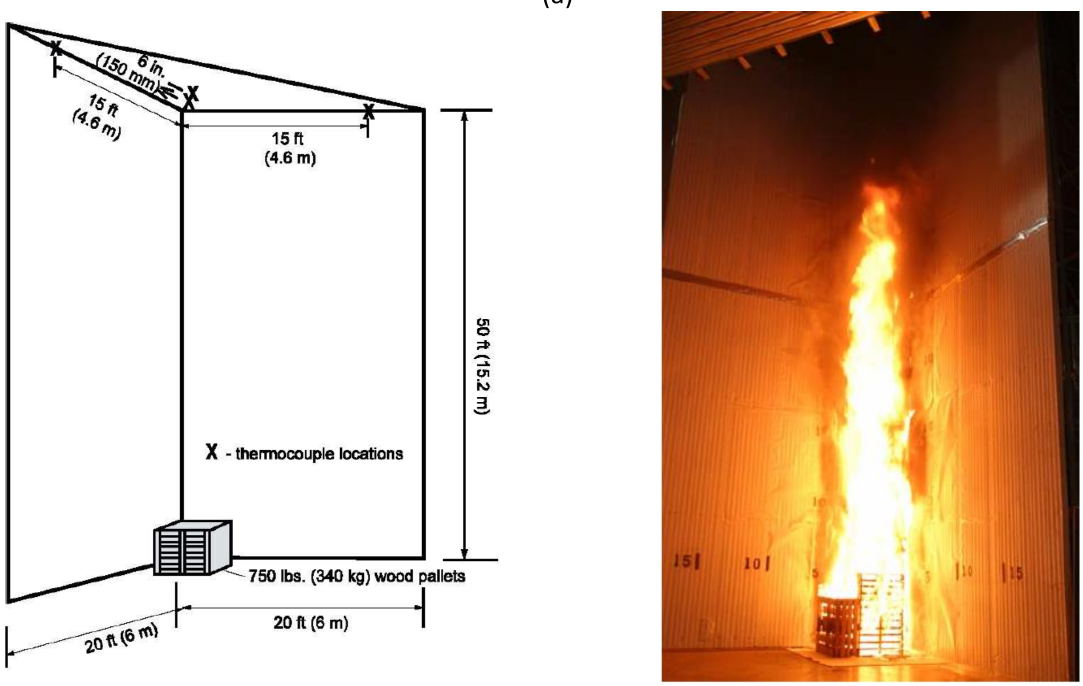
3.4 ANSI/FM 4880 fire tests for external wall assemblies

3.4.1 25-ft and 50-ft large-scale corner fire tests

At FM Global, since 1971, 25-ft and 50-ft corner fire tests have been used to evaluate the burning characteristics of external and internal wall assemblies (e.g., [37, 45, 46]). Figures 3-3 (a) and (b) show schematics and pictures of the 25-ft and 50-ft corner fire tests. Both corner fire tests are part of the ANSI/FM 4880 [12] and ANSI/FM 4881 [47] standards for evaluating the fire performance of internal and external wall systems, respectively. The test dimensions, test procedure, and fire performance criteria for both ANSI/FM 4880 [12] and ANSI/FM 4881 [47] standards are the same, and are henceforth termed ANSI/FM 4880 in this document.



(a)



(b)

Figure 3-3: ANSI/FM 4880 corner fire tests (a) 25-ft test; (b) 50-ft test.

Image sources: [12, 45]

Both 25-ft and 50-ft corner fire tests consist of metal frames to which external or internal wall systems are attached. In the 25-ft corner test, two 25 ft (7.6 m) high test walls form a right-angle corner; one wall is 50 ft (15.2 m) long, while the other is 40 ft (12.2 m) long. Similarly, in the 50-ft corner test, the two 50 ft (15.2 m) high test walls are 20 ft (6.1 m) long and form a right-angle. Thermocouples are mounted onto the external wall of the assembly, as marked in Fig. 3-3.

Both fire tests use a 750 ± 10 lb (340 ± 4.5 kg) oak wood crib of dimensions 5 ft high x 3.5 ft x 3.5 ft wide (1.5 m x 1.1 m x 1.1 m) as the fire source. The wood crib is placed in the bottom corner location and 1 ft (0.3 m) away from each wall. The moisture content of the oak wood crib is conditioned to 6.0 ± 1 %, and the crib is ignited using two cellucotton rolls soaked in 8 oz. (0.24 L) of gasoline in a plastic bag placed inside the bottom pallet in the stack. This wood crib results in a 25 ft (7.6 m) tall fire with peak HRR of about 4 MW, which imparts approximately 100 kW/m^2 peak heat flux to the wall surfaces [37].

The test is run for a duration of 15 minutes. In both corner fire tests, the material pyrolysis front is investigated after the completion of a test and the test performance criteria of the wall assembly are based on the extent of fire propagation. Based on test results, approval of external/internal wall assembly up to 30 ft (9.1 m), 50 ft (15.2 m), or unlimited height is provided, as shown in Table 3-1.

Table 3-1: ANSI/FM 4880 performance criteria for wall assemblies based on corner fire tests.

Approval Height ↓	Test Type	Test Criteria
30 ft (9.1 m)	25-ft corner fire test	Fire does not reach eave wall extremities of test setup
50 ft (15.2 m)	50-ft corner fire test	Fire does not reach eave wall extremities of test setup
Unlimited height	50-ft corner fire test	Fire does not reach ceiling of test setup

These large-scale corner fire tests simulate realistic-scale fires for scenarios where a combustible load is present in a vertical corner situation, e.g., dumpster fire (Section 3.1). In fire accident scenarios, a vertical corner presents a more conducive and realistic environment for fire propagation on the external walls in comparison to a single wall [32, 37]. This is due to high radiation view factors and limited air entrainment in a corner configuration leading to extended flame heights and high fire plume temperatures and heat fluxes [48]. However, these corner fire tests are expensive to run and require extensive amounts of test materials and preparation time.

3.4.2 16 ft high parallel panel tests (16-ft PPTs)

In the 1990s, efforts were made at FM Global to develop large-scale experiments that correlate with the results of corner tests, and are cost-effective, faster to setup and more repeatable than the corner fire tests. Correspondingly, 16 ft high parallel panel tests (16-ft PPTs) were developed, which incorporated significant features of corner fire tests and, therefore, correlate well with the results from these tests [45]. Currently, 16-ft PPT is used as an alternate test to corner fire tests in ANSI/FM 4880 [12].

A standard 16-ft PPT consists of two 16 ft (4.9 m) high and 3.5 ft (1.1 m) wide test specimens mounted on insulated panels and kept at 1.75 ft (0.5 m) separation, as shown in Fig. 3-4. A sand burner of dimensions 3.5 ft x 1.75 ft x 1 ft (1.1 m x 0.5 m x 0.3 m), with 360 kW HRR propane fire exposure imparts on the order of 100 kW/m^2 peak heat flux to the wall panels [45]. The test duration of a 16-ft PPT is 15 minutes with propane HRR of 360 kW and extra 5 minutes with the burner turned off. The test setup is placed under a 5-MW fire products collector (also termed a calorimeter hood), compliant with ISO 24473 [49], to measure the HRR and smoke generated during the test.

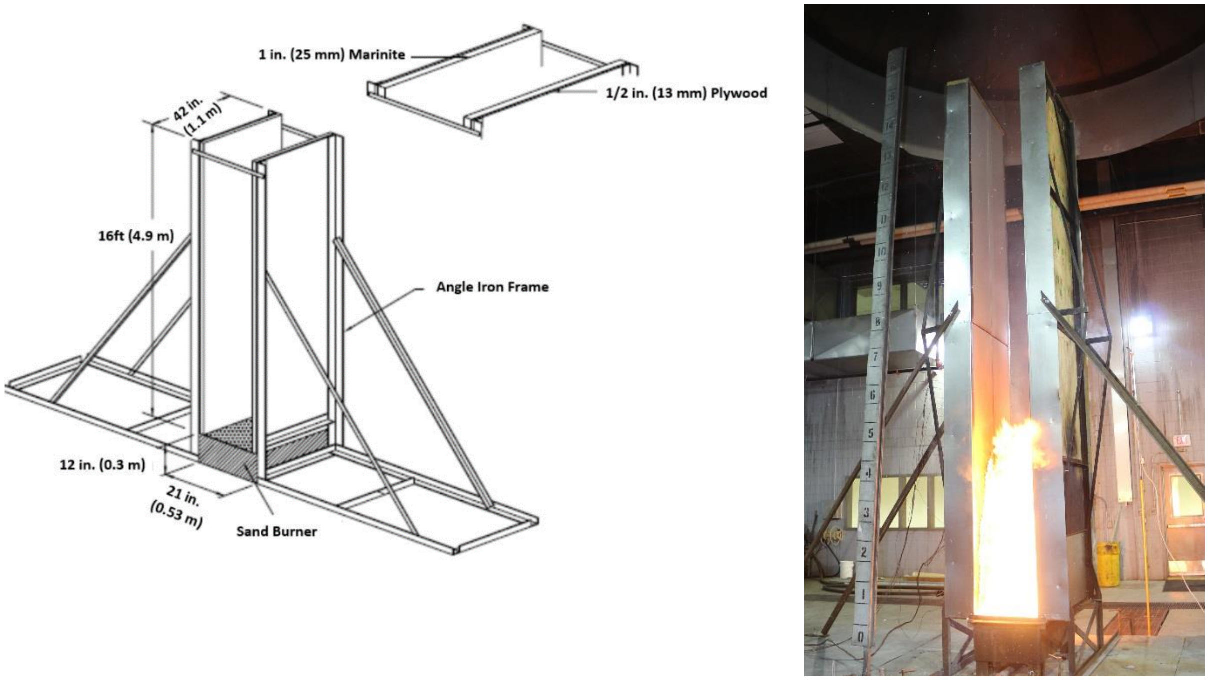


Figure 3-4: ANSI/FM 4880 16-ft PPT schematic and picture.

The peak HRR generated during the 16-ft PPT has been correlated with the test results from 25-ft and 50-ft corner fire tests [45]. The rationale behind the correlation rests on the assertions that firstly, the radiation view factor between panels in the 16-ft PPT is similar to that in a corner fire test, and secondly, the peak heat flux in the 16-ft PPT and corner fire tests are both of the order of 100 kW/m^2 [45]. The ANSI/FM 4880 approval criteria of the wall assembly tested with 16-ft PPT is based on the peak HRR generated during the first 15 minutes of the test. Based on test results, approval of wall assemblies up to 50 ft (15.2 m) or unlimited height are provided [12, 47], as shown in Table 3-2. The wall assembly fails the 16-ft PPT if the peak HRR during the test is greater than 1100 kW.

FM Global also uses 16-ft PPTs to evaluate the smoke hazard of the internal wall assemblies used in smoke sensitive occupancies (including cleanrooms, pharmaceutical manufacturing and storage areas, food preparation and storage areas, and other occupancies susceptible to smoke damage) [50].

Table 3-2: ANSI/FM 4880 approval criteria for wall assemblies based on 16-ft PPTs.

Approval Height ↓	Test Type	Test Criteria
50 ft (15.2 m)	16-ft PPT	830 < Peak HRR ≤ 1100 kW
Unlimited height	16-ft PPT	Peak HRR ≤ 830 kW

3.5 Comparison of fire tests

This section compares the key features of the ANSI/FM 4880 16-ft PPTs, BS-8414 tests, and NFPA-285 tests. Table 3-3 compares key attributes for the three tests discussed in the study.

Table 3-3: Comparison of the main characteristics of the three fire tests.

Large-scale Fire Test	Burner and HRR	Peak Heat Flux to Panels	Wall Specimen Height Above Window/Burner	Primary Criteria for Failure
16-ft PPT	Propane burner: HRR = 360 kW	~100 kW/m^2	16 ft (4.9 m)	Peak HRR > 1100 kW
BS-8414	Wood crib: HRR = 3 ± 0.5 MW	~75 kW/m^2	20 ft (6.0 m)	Temperature at 16.4 ft (5 m) height rises 1110 °F (600 °C) above ambient
NFPA-285	2 Propane burners: HRR = 1.3 MW	40 kW/m^2	13 ft (4.0 m)	Temperature at 10 ft (3 m) height > 1000 °F (538 °C)

The BS-8414 test uses a 53 ft^3 (1.5 m^3) timber wood crib as its ignition fire source. While both NFPA-285 and 16-ft PPT use a propane burner to provide a more consistent heat exposure, the requirements of the burner size and propane flow are lower in the 16-ft PPTs. Despite the low propane requirements and smaller burner size, the peak heat flux from the 16-ft PPT is considerably higher than that from the NFPA-285 test, thereby effectively simulating a realistic exterior and post-flashover fire.

Figure 3-5 (a) shows a comparison of the calibration heat fluxes and peak heat flux range for the three fire tests; the heat fluxes for 16-ft PPT are the peak values after taking a 15 s moving average. As shown in Fig. 3-5 (a), the peak heat flux for the BS-8414 test is mentioned to be at 3.3 ft (1 m) height above the window with an average value of 75 kW/m^2, but instantaneous values can vary between 45 and 95 kW/m^2 [29]. It may take up to 10 minutes in the BS-8414 test [51] to reach the peak heat flux and the fire growth time may vary between subsequent tests (the test setup in [51] has combustibles attached to the BS-8414 walls, which affect the peak heat flux). The peak heat flux to the panels in the 16-ft PPT is of the order of 100 kW/m^2 for the first 1.5 ft (0.5 m) of panels, and remains above 30 kW/m^2 for the first 4 ft (1.2 m) of panels above the burner. In comparison to the other two tests, the peak calibrated heat flux for the NFPA-285 test is low and of the order of 40 kW/m^2; this is the lower limit of the heat flux to façades for post-flashover scenarios in the literature (Section 3.1). The time variation of the heat flux to the panels as a function of time is shown in Fig. 3-5 (b). For the 16-ft PPT, the peak heat flux of the order of 100 kW/m^2 is reached in about 2 minutes from the start of the test, and then is maintained throughout the duration of the fire test (non-combustible calcium silicate boards of low emissivity ~0.5 are used as panels in this calibration); 15 s moving average is shown for 16-ft PPT data at 0.5 ft (0.15 m) height from the base. In contrast, the NFPA-285 test calibration at 3 ft (0.9 m) uses a gradual increase in the peak heat flux to the panels with the values increasing from 10 kW/m^2 at the start of the test to 40 kW/m^2, with the peak heat flux applicable only during the last five minutes of the test.

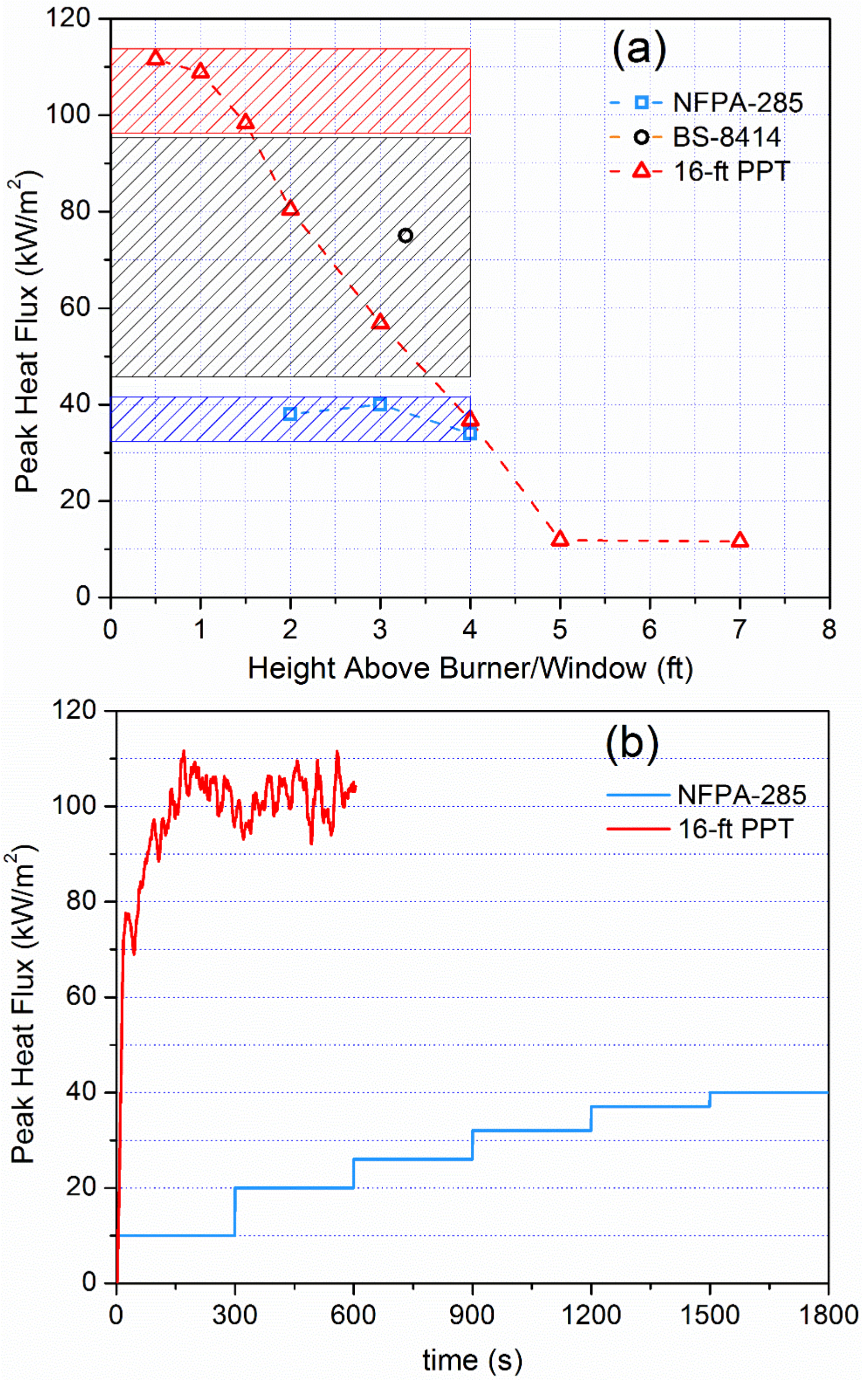


Figure 3-5: Comparison of heat fluxes to wall assembly in the three fire tests (a) heat flux as a function of height above the burner or window and shaded peak calibration heat flux range (b) peak calibration heat flux as a function of time for 16-ft PPT and NFPA-285.

Lastly, the failure criteria for the three tests are compared in Table 3-3. The primary failure criterion per the BS-8414 and NFPA-285 tests is based on use of thermocouples at the heights of 16.4 ft (5 m) and 10 ft (3 m), respectively. Thermocouples are a local measurement technique and therefore the spatial variation from test-to- test can introduce additional uncertainties especially in scenarios where the failure of a test assembly is borderline. Contrarily, the failure criterion in the 16-ft PPT is based on peak HRR measurements of the wall assembly; peak HRR is a global measurement of fire performance of wall assembly, more repeatable than local measurements, and has been well correlated with the peak fire propagation distance in the 16-ft PPT to the vertical extent of the setup (i.e., up to the 16-ft height of the panels) [45].

In summary, the 16-ft PPTs are less expensive to run and faster to set up in comparison to either NFPA-285, BS-8414, or FM Global large-scale corner fire tests. The 16-ft PPT setup simulates a realistic fire scenario that imparts heat fluxes of the order of 100 kW/m^2 to the wall panels. The usage of the sand burner makes the 16-ft PPT repeatable and pass/fail criteria based on HRR measurements are objective and robust means of evaluating the fire performance of an external wall assembly. Moreover, the test results from 16-ft PPTs have been well correlated with the results from FM Global large-scale corner fire tests [45]. Lastly, the 16-ft PPT setup also provides the potential to evaluate the smoke generation performance of wall panels during a fire scenario. Because of these clear advantages, the fire performance evaluation of ACM wall assemblies was conducted using 16-ft PPT in this study.

4. Materials and Specifications

Three different ACM claddings were acquired to investigate their fire propagation behavior. These products varied in the thickness of the aluminum cover and the core type used in their construction. Table 4-1 shows the specifications for the three ACM panels.

Table 4-1: Specifications of ACM claddings tested.

ACM	Total Thickness (mm)	Outer Aluminum Facer Thickness (mm)	Inner Aluminum Facer Thickness (mm)	Core Type (% Combustible in Core)	Gross Heat of Combustion of ACM Core (kJ/g)+
PP-core ACM	6	0.8	0.4	PP (100%)	~ 45
PE-core ACM	4	0.5	0.5	PE (100%)	~ 45
FR-core ACM	4	0.5	0.5	FR (~30%)	~13
+ Approximate values. PP – Polypropylene; PE – Polyethylene; FR – Fire retardant					

The PP-core ACM panel contains a polypropylene (PP) core sandwiched between two aluminum facers. The total thickness of the panel is 0.24 in. (6 mm); the outer aluminum facer on the “finished” side of ACM is 0.032 in. (0.8 mm) thick, and the inner side aluminum thickness on the “un-finished” end is 0.015 in. (0.4 mm). The thickness of both PE-core ACM and FR-core ACM panels is 0.16 in. (4 mm) and their outer and inner aluminum facers are 0.02 in. (0.5 mm) thick; this aluminum facer thickness is common for most ACMs (both PE and FR core). The core of PE-core ACM contains 100% polyethylene (PE) and the gross heat of combustion of the PE core is ~45 kJ/g. The core of FR-core ACM contains less than 30% polyethylene and more than 70% mineral fill (non-combustible), and the gross heat of combustion of the FR core is less than 13 kJ/g.

Two types of insulation products were used in this study, and their specifications are listed in Table 4-2. Both insulation products are glass fiber reinforced polyisocyanurate (PIR) foams. The first insulation is henceforth named PIR1, and the second is named PIR2. PIR1 insulation is a 2 in. (51 mm) thick foam and contains 1 mil (0.025 mm) aluminum foil facers on both sides of the foam. The PIR2 insulation is also 2 in. (51 mm) thick; the exterior side of PIR2 had a 1.25 mil (0.032 mm) thick aluminum facer while the interior side had a 0.9 mil (0.023 mm) facer. Both PIR insulations have a total R-value of 13.0 (h.ft^2.°F /BTU), which implies that both insulations meet ASHRAE 90.1 guidelines [17] for the minimum CI recommended for buildings located in climate zones 1 to 7 (Table 2-2). Both PIR insulations have a Class A fire and smoke rating per ASTM E84 [52] tunnel fire test; this is the minimum requirement for any insulation that is a part of an NFPA-285 passed wall assembly. Even though both foams have glass fiber reinforced into polyisocyanurate, the PIR2 insulation features better fire performance per bench-scale Fire Propagation Apparatus (FPA) [24, 25] testing conducted at FM Global.

Table 4-2: Specifications of the insulation materials obtained.

Product	Type	Total Thickness (in.)	Outer Aluminum Foil Thickness (mil)	Inner Aluminum Foil Thickness (mil)	Total R-Value ($h.ft^2.°F$ /BTU)	Standards	
						ASTM E84	Other
PIR1	Glass fiber reinforced PIR	2 (51 mm)	1.0	1.0	13.0	Class A	NFPA-285 assemblies+
PIR2	Glass fiber reinforced PIR	2 (51 mm)	1.25	0.9	13.0	Class A	NFPA-285 assemblies+
+ Part of various NFPA-285 passed wall assemblies. PIR – Polyisocyanurate; 1 mil = 1/1000 in. = 0.0254 mm							

One fluid membrane-type WRB coating was obtained which had passed multiple NFPA-285 tests per actual tests and per desktop assessments; the specifications are shown in Table 4-3.

Table 4-3: Specifications of the WRB material obtained.

Type of WRB	Application Coverage on Smooth Surfaces			Standards	
	Coverage per Unit Area (l/m^2)	Wet Film Thickness (mil)	Dry Film Thickness (mil)	ASTM E84	Other
Fluid coating	1.7 (4.25 gal/ft^2)	70	35	Class A	NFPA-285 +
+ Part of various NFPA-285 passed wall assemblies. 1 mil = 1/1000 in. = 0.0254 mm					

The WRB coating is a fluid-applied, elastomeric membrane coating which dries into a monolithic rubber-like cover. The application rate for gypsum surfaces is listed in Table 4-3. The coating also has a Class A rating per the ASTM E84 [52], which is the minimum requirement for any WRB to be compliant with NFPA-285.

The exterior sheathing obtained in this work is 5/8 in. (16 mm) thick gypsum; the product has a non-combustible gypsum core and has fiberglass facers for mold and moisture resistance.

5. Experiments and Test Matrix

A comprehensive investigation of the ACM cladding assemblies and its components was conducted via 16-ft PPTs [12]. This section provides the test description and the wall assemblies tested in this work.

5.1 Test configuration and procedure

For the preparation of wall assemblies, the two 16 ft high and 3.5 ft wide (4.9 m x 1.1 m) metal frames were first covered with ½ in. (13 mm) thick fire-retardant plywood and 1 in. (25 mm) thick non-combustible calcium silicate board, to form the base of the test setup. The ACM wall assembly, including exterior sheathing, WRB, CI, and ACM panels was mounted on top of the calcium silicate per the manufacturer recommended procedures.

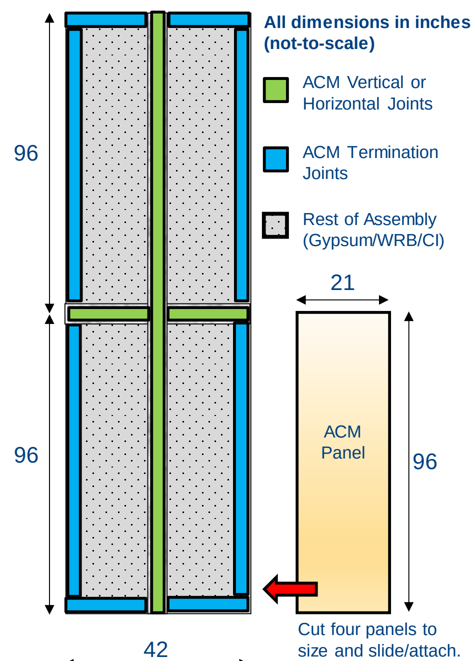
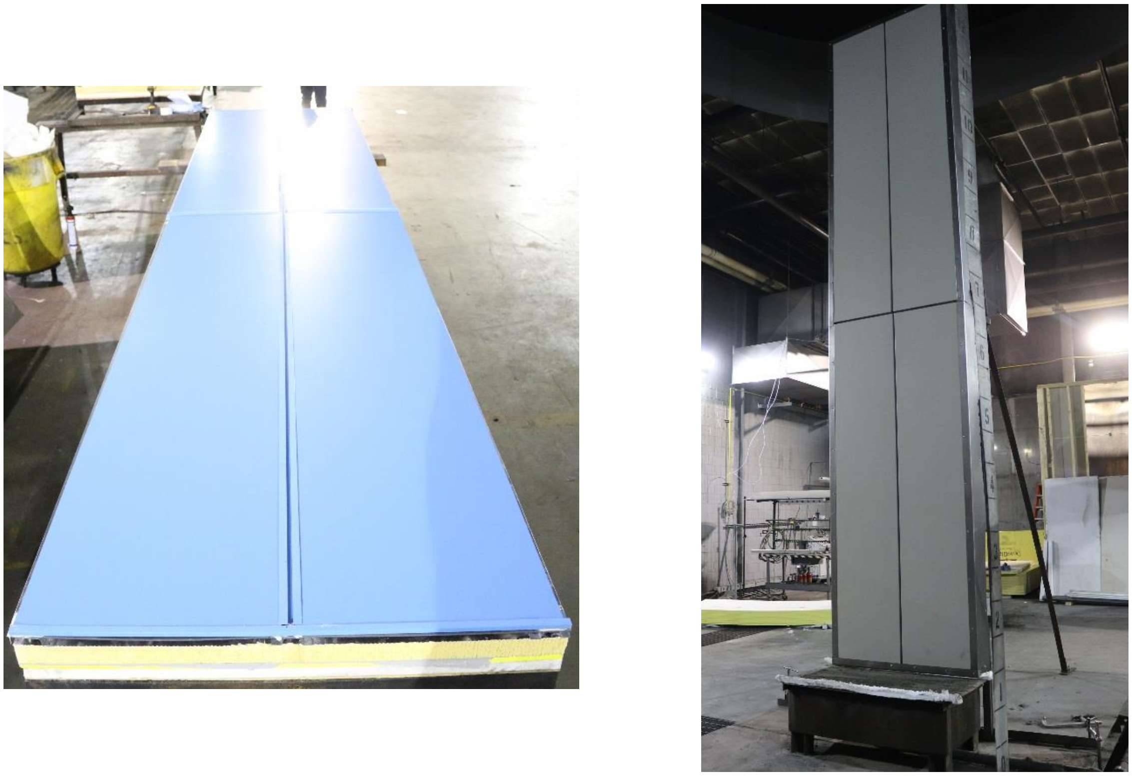


Figure 5-1: ACM layout on wall assembly for each frame of the 16-ft PPTs (dimensions in inches).

Figure 5-1 shows the final layout of the ACM panels on the wall assembly after mounting the sheathing, WRB, and CI. Four ACM panels of dimensions 8 ft x 1.75 ft (2.4 m x 0.5 m) were attached on top of the rest of the wall assembly such that the vertical and horizontal joints of the ACM panels were centrally located in both 16 ft x 3.5 ft (4.9 m x 1.1 m) wall assemblies. The vertical and horizontal joints are typically made of aluminum and can be attached using adhesives; therefore, such joints are susceptible to failure in a severe fire event and can expose the CI and WRB directly to fire. The termination joints of the ACM panels were located at the periphery of the wall assembly. Figures 5-2 (b) and (c) show examples of an ACM assembly mounted to the metal frames, with vertical and horizontal joints centrally located on the panels. The exposed edges of the ACM assembly were further covered with 16-ga steel covers, in a similar manner to the ANSI/FM 4880 test procedure.



(a) (b)

Figure 5-2: Examples of ACM assembly layout with vertical and horizontal joints.

Figure 5-3 show examples of the final ACM wall assembly setup placed along with the sand burner under the 5-MW calorimeter hood. The test procedure of the PPTs was the same as the standard 16-ft PPT procedure for ANSI/FM 4880 [12] (also discussed in Section 3.4.2).

During the tests, gas species concentration (O_2, CO_2, and CO), smoke concentration, and load cell outputs were continuously measured. The gas species concentration ranges and the exhaust flow rate (40,000 cfm) were kept the same as those mentioned in the standard 16-ft PPT procedures. The thermochemistry constants to evaluate HRR from PPTs were selected to represent those of polymer materials [53], *viz*. ΔH_{O2} = -12.8 kJ/g, ΔH_{CO2} = 13.3 kJ/g, and ΔH_{CO} = 11.1 kJ/g. The CO-CO_2 generation calorimetry was used to calculate the chemical heat release rate generated during the fire tests [12, 53].

5.2 ACM test assemblies

Table 5-1 shows the list of ACM assemblies tested using the 16-ft PPT standard. The assembly description is based on Fig. 2-1 and is given per the sequence of component installation in order of exterior sheathing → WRB (if present) → CI (if present) → air cavity spacing → ACM panels. Table 5-1 also shows whether the assembly has passed NFPA-285, either through actual test or by a desktop assessment. Tests #1 to #3 wall assemblies use combustible core ACMs while those in Tests #4 to #7 use FR-core ACMs.

(a) (b)

Figure 5-3: Examples of final ANSI/FM 4880 ACM wall assembly setups.

The Test #1 assembly, PP-core ACM mounted on WRB coated gypsum with 0.2 in. (6 mm) air cavity, has passed NFPA-285 test and is replicated per its NFPA-285 test report. The Test #2 assembly consists of PP-core ACM with PIR1 insulation backing and 1.2 in. (31 mm) air cavity; PIR1 is mounted on WRB coated gypsum. This assembly is also considered to pass NFPA-285 per the desktop assessment of PIR1, which states to use “any” MCM system that has been successfully tested by the NFPA-285 test method, and the PP-core ACM has been successfully tested per NFPA-285 in Test #1 configuration.

The assemblies in Tests #3 and #4 use PE-core and FR-core ACMs respectively, and only have non-combustible exterior sheathing (fiber glass faced gypsum) behind the ACM panels, with 2 in. (51 mm) air cavity separation. These assemblies are essentially replicating installation of ACMs on non-combustible substrates (e.g., metal/concrete walls) or non-combustible CI (e.g., mineral wool); it is noted that the “non-combustible” definition of a CI must be compliant with the test requirements of ANSI/FM 4880 [12] (discussed in Section 2.2) and compliance through vertical furnace tube tests (ASTM E136/ISO 1182 [19, 20]) alone does not qualify as meeting the FM Global definition of non-combustibility. The Test #3 assembly is not a part of any known NFPA-285 tested/passed assemblies. Test #4 assembly has passed the NFPA-285 test.

The Test #5 assembly is similar to that in Test #4 except that the gypsum backing is coated with WRB paint. This assembly has also passed the NFPA-285 test.

Table 5-1: List of ACM assemblies tested using 16-ft PPTs.

Test #	Exterior Sheathing	WRB	CI	Air Cavity (in.)	ACM	NFPA-285 Passed
1	Gypsum	Yes	--	0.2 (6 mm)	PP-core ACM	Yes^
2	Gypsum	Yes	PIR1	1.2 (31 mm)	PP-core ACM	Yes+
3	Gypsum	--	--	2.0 (51 mm)	PE-core ACM	No
4	Gypsum	--	--	2.0 (51 mm)	FR-core ACM	Yes^
5	Gypsum	Yes	--	2.0 (51 mm)	FR-core ACM	Yes^
6	Gypsum	Yes	PIR1	2.0 (51 mm)	FR-core ACM	Yes+
7	Gypsum	Yes	PIR2	2.0 (51 mm)	FR-core ACM	Yes+
-- Not used in the assembly. ^ Passed NFPA-285 per actual test. + Passed NFPA-285 via desktop assessment.						

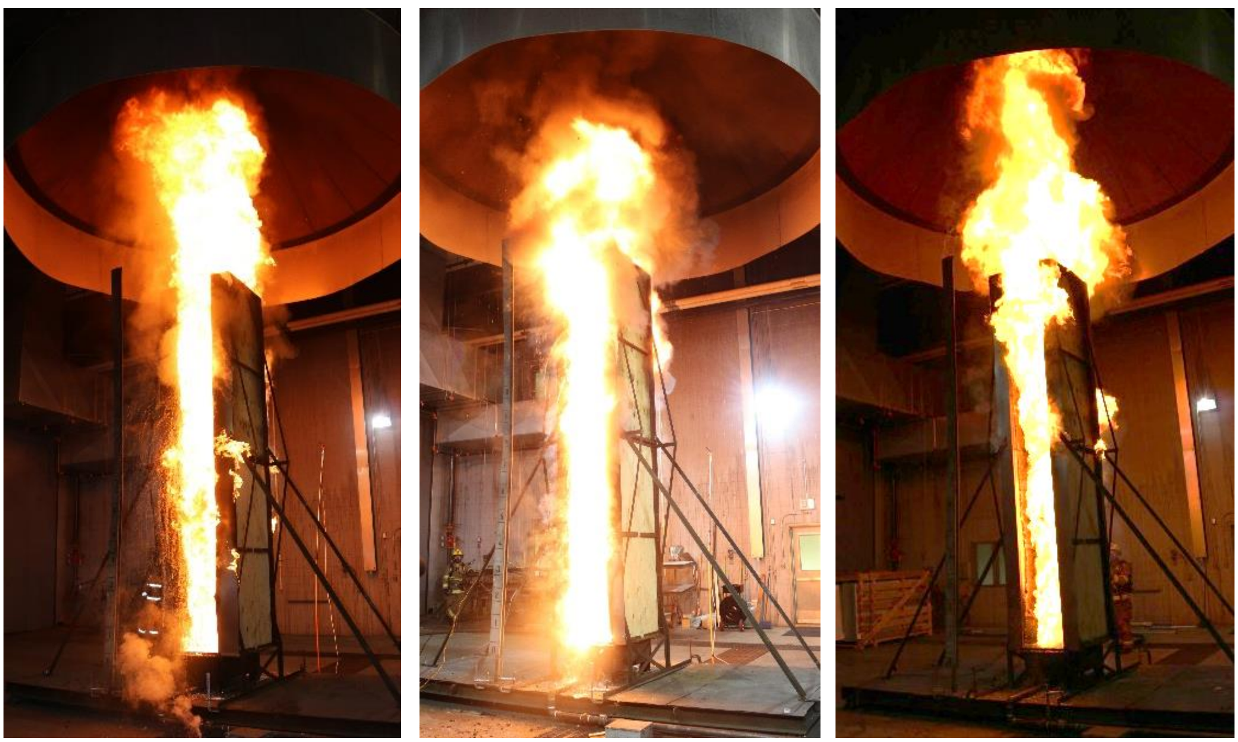
The Test #6 and #7 assemblies consist of FR-core ACM with PIR1 and PIR2 insulation backings, respectively, and 2 in. (51 mm) air cavity; PIR insulations are 2 in. (51 mm) thick and are mounted on WRB coated gypsum. The assemblies in both Tests #6 and #7 have passed NFPA-285 per desktop assessments. In fact, the desktop assessments of both PIR1 and PIR2 pass assemblies similar to those in Tests #6 and #7 per NFPA-285 with up to 3 in. (76 mm) thickness insulations.

6. **Results and Discussion**

This section is divided into three parts. First, the results for assemblies with combustible core ACM (PP-core ACM and PE-core ACM) are discussed, including Tests #1-3. Next, the results from assemblies with FR-core ACM are discussed, including Tests #4-7. Lastly, all test results from 16-ft PPTs are compared with the test results for similar-type assemblies evaluated using NFPA-285 and BS-8414 testing standards.

6.1 Combustible core ACM wall assembly test results

Figure 6-1 shows the images of Tests #1, #2 and #3 during the 16-ft parallel panel tests. The flames in all three tests propagated to the top of the 16-ft PPT assembly and the test had to be terminated (water suppressed) within 4 minutes of the start of the test, to avoid further exceeding the capacity of the calorimeter.



(a) (b) (c)

Figure 6-1: Images from the 16-ft PPTs at approximately 4 minutes from the ignition (a) Test #1: PP-core ACM with WRB-coated gypsum; (b) Test #2: PP-core ACM with PIR1 and WRB-coated gypsum; and (c) Test #3: PE-core ACM with non-combustible gypsum.

Figure 6-2 shows the chemical HRR profiles and Table 6-1 provides the peak HRR and peak burnt heights of the different wall assembly components during the 16-ft PPTs. All three tests show accelerated vertical flame spread. The rate of increase of the HRR profiles of the assemblies that had passed NFPA-285 (*viz.*, Test #1 and #2) are similar to that of the PE-core ACM test (Test #3). The HRR during the tests, for all three assemblies, quickly exceeded the ANSI/FM 4880 [12] thresholds for unlimited height installation (peak HRR threshold = 830 kW) and 50 ft limited- height installation (peak HRR threshold = 1100 kW). The peak HRR listed in Table 6-1 would have been higher if the tests had been allowed to continue. All the components in the three wall assemblies were entirely burnt or charred to the top of the panels.

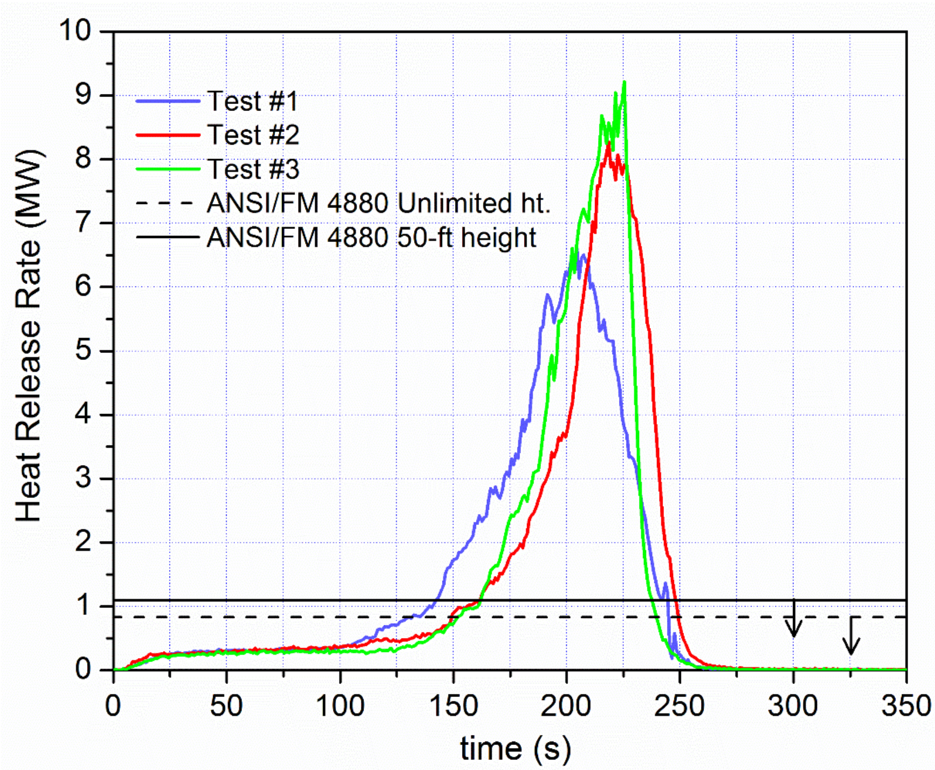


Figure 6-2: Chemical HRR results for combustible core ACM wall assemblies.

Table 6-1: 16-ft PPT results for combustible core ACM wall assemblies (Tests #1 to #3).

Test #	Assembly Description	Peak HRR^ (kW)	Peak Burnt Height (ft)		
			ACM	CI	WRB
1+	PP-core ACM → WRB → Gypsum	6600	16	--	16
2x	PP-core ACM → PIR1 → WRB → Gypsum	8270	16	16	0
3	PE-core ACM → Gypsum	9200	16	--	--

^ Early test termination.
+ Passed NFPA-285 per actual test.
x Passed NFPA-285 per desktop assessment.
-- Not used in the assembly.

Figure 6-3 shows the post-test images of assemblies in Tests #1, #2, and #3. The combustible ACM panels were mostly consumed in Tests #1, #2 and #3 before the test termination. In all tests, flames nearly reached to the top of the calorimeter hood, which is located approximately 30 ft (9 m) above the lab floor level (Annex A of [49]); this implies that the flames from the assembly rose up to 10-15 ft (3.0 to 4.6 m) above the top of the 16 ft (4.9 m) high assembly, before the test was terminated and suppressed. It is important to note that the IBC [15] allows the installation of non-tested ACM panels, the same as the PE-core ACM, to more than 40 ft (12 m) heights if the panel section area is limited to 300 ft^2 (28 m^2) in size and the individual sections are separated by 4 ft (1.2 m). Considering the 16-ft PPT results of combustible core ACMs, where 112 ft^2 (10 m^2) of ACM panels were burnt, the IBC limit of 4 ft separation distance for un-tested ACM panel sections will not prevent the fire from propagating in buildings conforming to the IBC criteria.

(a) (b) (c)

Figure 6-3: Post-test images after test termination (a) Test #1; (b) Test #2; and (c) Test #3.

Test #1, which exactly replicated an assembly that had passed NFPA-285 per an actual test, and the Test #2 assembly, which is stated to have passed NFPA-285 per desktop assessment, failed the 16-ft PPT. In the NFPA-285 test report of the assembly replicated in Test #1, the vertical fire propagation was limited up to 6 ft (1.8 m) above the window opening after 30 minutes from the start of the test; 10 ft (3 m) propagation above the window is the failure criterion of NFPA-285. As discussed in Section 3.5, the peak heat flux in the NFPA-285 test is increased from 10 kW/m^2 to 40 kW/m^2 during its 30-minute test duration; such a heat exposure will allow combustibles in the wall assembly to vaporize and escape unburnt while the panels are exposed to a low heat flux. In comparison, the PP-core ACM panels are completely burnt in the 16-ft PPT (Tests #1), which instead uses a fire source with heat flux of the order of 100 kW/m^2.

Both PE-core ACM and PP-core ACM have combustible thermoplastic polymer cores; the heat of combustion and burning characteristics of both PE and PP are the same [53]. While PE-core ACMs do not pass the NFPA-285 test, the PP-core ACM panel passes that test. The reason behind the difference between the NFPA-285 test results for PE-core ACM and PP-core ACM rests in the aluminum facer thickness of the two types of panels. The PE-core ACM have an aluminum facer thickness of 0.02 in. (0.5 mm). On the other hand, the thickness of the aluminum facer in the PP-core ACM is 0.032 in. (0.8 mm), which is 60% greater than that of the aluminum facer of the PE-core ACM.

In addition to external vertical and horizontal fire spread, the air cavity fire spread phenomenon is also well captured in the 16-ft PPTs. During the tests, the cavity fire spread was monitored by means of thermocouples inserted in the air cavity space at various heights of the wall assembly and by means of a small diameter (< 1 in.) camera located inside the air cavity. The thermocouple readings and the camera images indicated that internal cavity fire spread phenomena occurred right after the bottom part of the ACM panel melted away from ~100 kW/m^2 heat flux exposure. It was also found that the internal cavity fire spread occurred before the external fire spread. Figure 6-4 is a picture at the top of the assembly of Test #2, which had a 1.2 in. (31 mm) air cavity between the PP-core ACM and the PIR1 insulation, and shows cavity fire propagation occurring before the external fire spread in this test. However, the contribution of internal fire spread is limited by the amount of air entrained inside the cavity from the melted portion of ACM close to the sand burner. On the other hand, the external fire has no restriction to air entrainment and eventually grows more hazardous and propagating (e.g., Tests #2 and #3) than the internal fire. Hence, 16-ft PPTs capture both external and cavity fire spread phenomena in ACM wall systems.

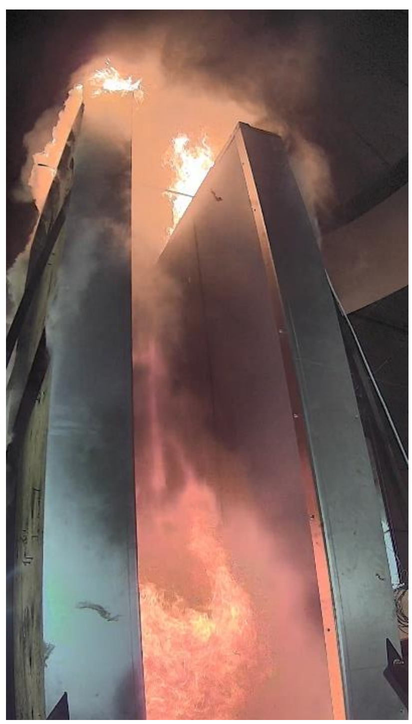


Figure 6-4: Cavity fire spread in Test #2: PP-core ACM with PIR1 and WRB-coated gypsum.

6.2 FR-core ACM wall assembly test results

FR-core ACM test results, including Tests #4-7, are discussed in this section. All four wall assemblies tested with FR-core ACM panels have passed NFPA-285 tests or desktop assessments for unrestricted height installations in the US.

An evaluation of Tests #4 to #7 is compiled in Table 6-2, which notes the peak HRR during the test, peak burnt height of wall assembly components, and the approval height per the ANSI/FM 4880 standard [12] based on peak HRR generated during the 16-ft PPTs; the ANSI/FM 4880 standard provides unlimited height approval if the peak HRR ≤ 830 kW and 50 ft (15 m) limited-height approval if the peak HRR ≤ 1100 kW.

Table 6-2: 16-ft PPT results for FR-core ACM wall assemblies (Tests #4 to #7).

Test #	Assembly Description	Peak HRR (kW)	Peak Burnt Height (ft)			Approval per ANSI/FM 4880 [12]
			ACM	CI	WRB	
4+	FR-core ACM → Gypsum	510	6	--	--	Unlimited height
5+	FR-core ACM → WRB → Gypsum	760	7	--	8	Unlimited height
6x	FR-core ACM → PIR1 → WRB → Gypsum	990	14	15	3	50 ft limited-height
7x	FR-core ACM → PIR2 → WRB → Gypsum	990	10	12	3	50 ft limited-height

+ Passed NFPA-285 per actual test.
x Passed NFPA-285 per desktop assessment for unlimited height.
-- Not used in the assembly.

The HRR profiles for all FR-core ACM tests are shown in Fig. 6-5. The HRR for Tests #4 and #5 stay below 830 kW during tests, which is the threshold for unlimited height installation approval via the ANSI/FM 4880 test method. The peak HRR for these two tests occur at around 400 to 500 s, and the HRR decreases to around 360 kW by the end of 900 s, which represents primarily the contribution from the propane ignition source. The HRR profiles for Tests #6 (with PIR1) and #7 (with PIR2) are essentially similar from the start of the tests to about 700 s into ignition, including the peak HRR and time to peak HRR. This period from t = 0 to 700 s was mostly related to the burning of the first 8 ft (2.4 m) half of both assemblies. After 700 s, the difference between the two types of PIRs governed the different HRR results for the two assemblies. While the HRR of Test #7 reduced to 360 kW by the end of 900 s due to good fire performance from the PIR2 insulation, the same is not true for Test #6 with PIR1. In Test #6, the HRR increased during the *t* = 700 to 900 s period from 470 kW to 650 kW due to increased involvement from the burning of PIR1 along the central vertical joint of the upper 8 ft (2.4 m) panels of the assembly. Both Test #6 and #7 are only approved for 50 ft (15 m) limited-height installation per ANSI/FM 4880 because the peak HRR exceeds 830 kW and is below 1100 kW. This is in contrast with the assemblies in Tests #6 and #7 passing NFPA-285, per desktop assessment, thus allowing installation for unlimited heights per IBC. The test observations are next discussed in detail.

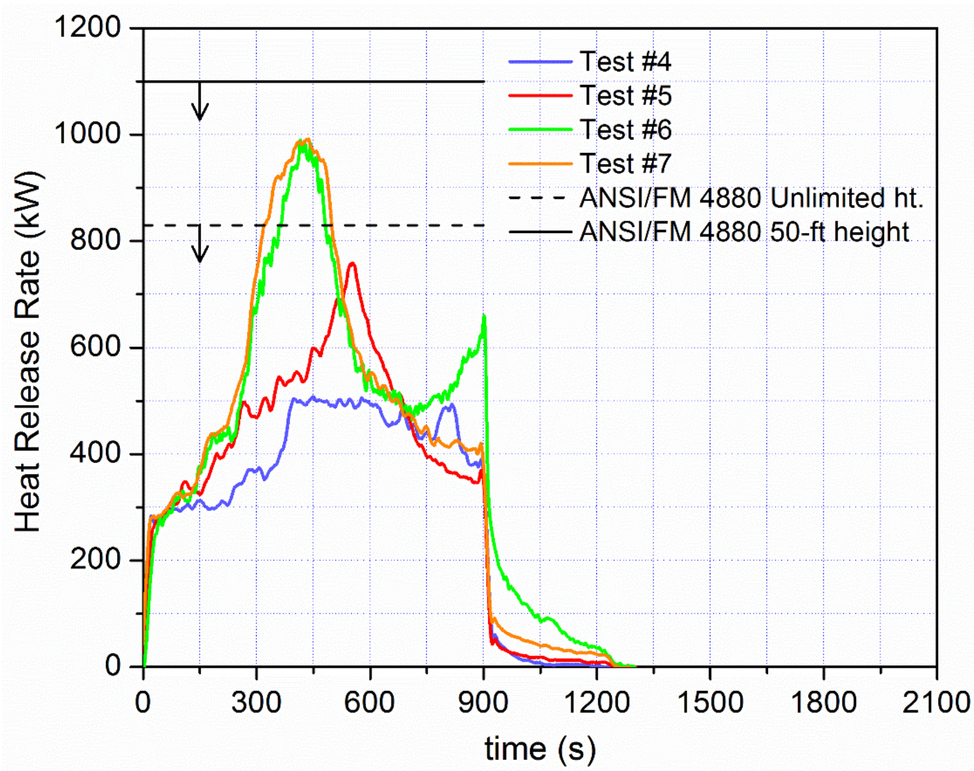


Figure 6-5: Chemical HRR results for FR-core ACM wall assemblies.

Figure 6-6 shows images of Test #4, which tested FR-core ACM on a non-combustible backing, with 2 in. (51 mm) air cavity separation. Figure 6-6(a) shows the instant during the peak fire propagation about 400 s into the start of the test, when the peak flame height reached approximately 8 ft (2.4 m) from the base of the assembly. The post-test images in Fig. 6-6 (b) and (c) show the extent of panel burnt during the test; it should be noted that when the panel assemblies were laid down on the lab floor to take the photographs, e.g., Fig. 6-6 (c), the vertical and horizontal joint opened due to handling of the burnt wall assemblies by the crane. The post-test image shows that the maximum height up to which the front aluminum facer of the FR-core ACM burnt was 6 ft (1.8 m) from the base and that for the back facer was about 3 ft (0.9 m). The assembly in Test #4 performed well in terms of restricting the vertical fire propagation and the amount of heat generated by the panels during the test.

(a) (b) (c)

Figure 6-6: Pictures from Test #4: FR-core ACM with non-combustible backing (a) peak propagation during test; (b) post-test assembly; and (c) post-test panel.

Images from Test #5 are shown in Fig. 6-7; Test #5 had a WRB-coated exterior sheathing (gypsum) behind the FR-core ACM panels, with 2 in. (51 mm) air cavity separation. Peak flame height during the tests was observed to be approximately 10 ft (3.0 m), as shown in Fig. 6-7. The peak height to which the ACM panel was consumed was 7 ft (2.1 m), as also shown in Table 6-2. Unlike Test #4, the back-side aluminum facer of the FR-core ACM panel was also consumed in Test #5 due to the relatively higher heat generated from the combustion of the WRB coating. The WRB coating was combusted only up to the 8 ft (2.4 m) height of the horizontal joint of the ACM panels. It should be noted that the horizontal joint details of FR-core ACM panels were designed by the manufacturer in a manner such that the horizontal aluminum channels acted as a barrier to the vertical cavity fire spread; therefore, the WRB combustion was limited only up to 8 ft (2.4 m) high in Test #5. Overall, the fire propagation in Test #5 was limited to only near the ignition area, and the horizontal channels in the FR-core ACM were designed well to control cavity fire spread of the WRB coating.

(a) (b) (c)

Figure 6-7: Pictures from Test #5: FR-core ACM with WRB-coated gypsum (a) peak propagation during test; (b) post-test assembly; and (c) post-test WRB-coated gypsum.

Figure 6-8 shows details of Test #6, which consisted of PIR1 insulation behind FR-core ACM panels with 2 in. (51 mm) air cavity; PIR1 was mounted on WRB coated gypsum. Figure 6-8 (a) shows the peak propagation height of flames up to 14 ft (4.3 m) from the base, which occurred at 415 s from the ignition of the assembly; the heat from combustion of the PIR1 insulation assisted in higher propagation in comparison to Tests #4 and #5. Figure 6-8 (b) shows the instant right before the propane burner was turned off at 900 s (15 min) after ignition; the image shows the bottom 8 ft (2.4 m) half of the assembly still burning, albeit at a lower rate than that at 415 s. Above 8 ft (2.4 m) height, fire propagated through the vertical joint of the ACM panel up to 14 ft (4.3 m) height; the vertical joint opened and exposed PIR1 insulation to fire. For the 900 s to 1200 s period from ignition, the propane burner was switched-off and self-sustainability of fire was monitored; the fire in the wall assembly self-extinguished during this period. Figure 6-8 (d), (e), and (f) show the post-test state of the assembly components. The ACM panels were completely consumed up to 8 ft (2.4 m) height, and were burnt only through the vertical joint from 8 to 14 ft (2.4 to 4.3 m) height. Similarly, PIR1 was completely burnt up to 8 ft (2.4 m) height and was partially burnt along the central vertical joint location from 8 to 15 ft (2.4 to 4.6 m) height. As previously discussed, one of the primary reasons of limited cavity burning beyond the 8 ft (2.4 m) height was the presence of horizontal channels at 8 ft (2.4 m), which acted as barriers to cavity fire spread. The WRB coating was largely protected by PIR1 insulation, and was only burnt up to 3 ft (0.9 m) height. Even though the flame spread in Test #6 is more severe than those in Tests #4 and #5, the flames did not reach to the vertical extent of the test assembly. It should be noted that this assembly has been deemed to pass NFPA-285 through desktop assessment for up to 3 in. (76 mm) thick PIR1, while in Test #6, a 2 in. (51 mm) thick PIR1 was used.

Figure 6-8: Pictures from Test #6: FR-core ACM with PIR1 and WRB-coated non-combustible backing (a) peak propagation during test at 415 s; (b) before propane shut-off at 900 s into test; (c) at 1200 s before test termination; (d) post-test assembly; (e) post-test insulation; and (f) post-test WRB-coated gypsum.

(a)

(b)

(c)

(d)

Figure 6-9: Pictures from Test #7: FR-core ACM with PIR2 and WRB-coated non-combustible backing (a) peak propagation during test at 415 s; (b) before propane shut-off at 900 s into test; (c) at 1200 s before test termination; and (d) post-test assembly

The assembly of the last test, Test #7, involved the PIR2 insulation behind FR-core ACM panels with a 2 in. (51 mm) air cavity; PIR2 was mounted on WRB-coated gypsum. The PIR2 insulation was expected to have better fire performance than PIR1, per bench-scale Fire Propagation Apparatus (FPA) [24, 25] testing conducted at FM Global. Therefore, results from Tests #6 and #7 are compared to evaluate the effect of the type of PIR on wall assembly fire performance.

Figure 6-9(a) shows the peak flame heights during Test #7, which was up to 12 ft (3.6 m), in comparison to 14 ft (4.3 m) propagation in Test #6. Like Test #6, peak propagation occurred around the same time in Test #7, i.e., 415 s from the start of the test. However, unlike Test #6, by the end of 900 s from ignition, there were no visible flames from the wall assembly and only propane burns in Test #7, as shown in Fig. 6-9(b). Figure 6-9 (c) shows the assembly at 1200 s from the test start when flames in the wall assembly had self-extinguished. The post-test image of the assembly in Test #7 is shown in Fig. 6-9(d). The FR-core ACM panels were completely consumed up to 8 ft (2.4 m) height, and were burnt through the vertical joint from 8 to 10 ft (2.4 to 3.0 m) height. PIR2 was burnt up to 8 ft (2.4 m) height and was partially burnt along the central vertical joint location from 8 to 12 ft (2.4 to 3.6 m) height; PIR2 insulation burnt less in comparison to PIR1 in Test #6 which burnt up to 15 ft (4.6 m) height along the vertical joint location (Table 6-2). The results show that the extent of fire propagation in Test #7 is greater than in Tests #4 and #5, but is lower than in Test #6.

It is shown that the ANSI/FM 4880 16-ft PPT method and its HRR based approval criteria clearly differentiates the assemblies that provided adequate fire performance for unlimited height installation (i.e., Tests #4 and #5) from those that propagated more than the half-height of the assembly, 8 ft (2.4 m), but lower than the full 16 ft (4.9 m) height of the assembly (i.e., Tests #6 and #7).

Figure 6-10 shows the HRR profiles for all ANSI/FM 4880 tests conducted in this work; the performance of combustible-core ACMs, including the PP-core ACMs, shows distinctly more fire hazardous behavior than assemblies with FR-core ACMs and such clear distinction is not captured in the NFPA-285 test of the PP-core ACMs.

Figure 6-10 also demonstrates that using a global measurement parameter like HRR provides an objective and robust means of evaluating the fire performance of an external wall assembly. Through the value of peak HRR, the 16-ft PPT method can objectively distinguish between wall assemblies that clearly fail the test (combustible-core ACMs), the ones that clearly pass the test for unlimited height (FR-core ACMs with non-combustible insulation), and the borderline cases, which show limited propagation and are approved only for 50 ft limited-height installations (FR-core ACMs with 2 in. (51 mm) thick PIR insulation). Hence ANSI/FM 4880 provides a robust means of objectively evaluating the fire performance of ACM wall assemblies.

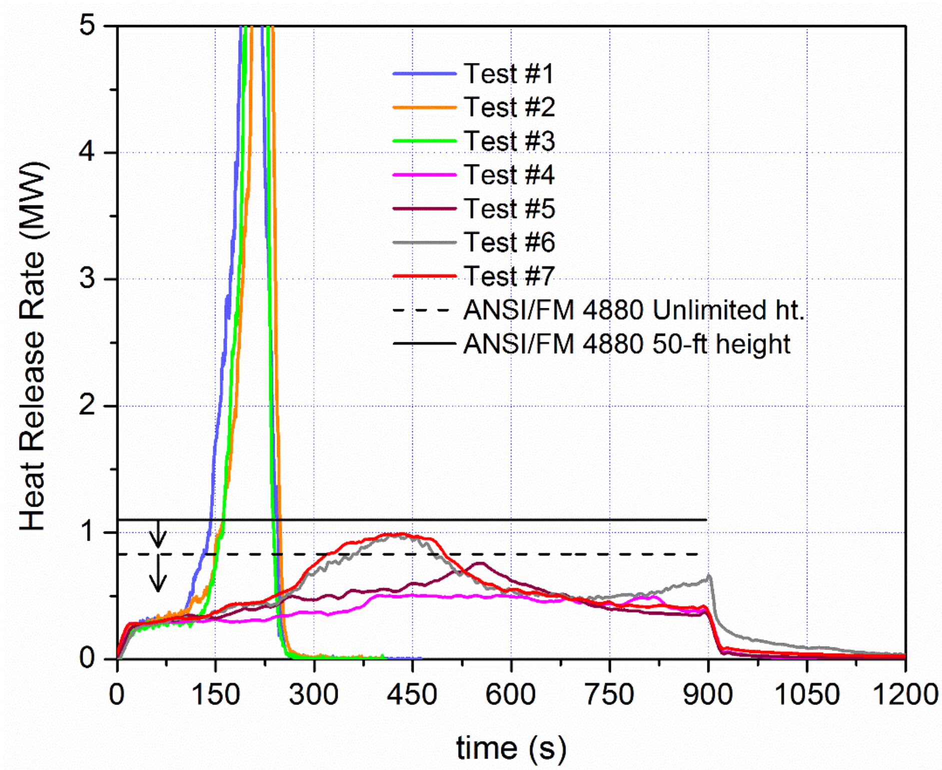


Figure 6-10: Chemical HRR profiles for all tests conducted using the 16-ft PPT procedure of ANSI/FM 4880.

6.3 Comparison of test results with BS-8414 and NFPA-285

In this section, the results of the 16-ft PPTs for all wall assemblies are compared with those of BS-8414 and NFPA-285. The test procedures and the acceptance criteria of the three tests have been discussed in Section 3.5. Except for the assembly tested in the Test #3, all other wall assemblies tested in this study pass NFPA-285 and are allowed for unlimited height installations in the US per IBC (Section 5.2).

For comparison with BS-8414, a recent test series of ACM assemblies [54-60] was used. The BS-8414 test series were conducted by the Building Research Establishment (BRE Global) for evaluating the fire performance of ACM panels with different insulation assemblies, following the tragic incident of Grenfell Tower in 2017. Per public records, Grenfell Tower was re-furbished with polyethylene core ACMs and 6 in. (152 mm) thick PIR and phenolic CI with a 2 in. (51 mm) air cavity in between.

In the BS-8414 test reports [54-60], the manufacturer information for ACMs and insulations were not provided. In the test series, three types of 0.16 in. (4 mm) thick ACM panels were tested with different types of insulations; in all tests, 2 in. (50 mm) air cavity separation was present between ACM panels and insulation. The ACMs included those with a polyethylene core, fire-retardant core, and mineral-fill core. The heat of combustion of ACM cores in the BS-8414 test series [54-57] were reported to be the same as those used in the present work. The insulations used in BS-8414 tests [54-60] were 6 in. (152 mm) thick non-combustible mineral wool and 6 in. (152 mm) thick aluminum foil-faced PIR insulation;

the thickness of aluminum foil and details on whether the PIR foam is infused with glass fibers were not provided in the reports. Table 6-3 show a summary of BS-8414 test series results.

Table 6-3: Summary of BS-8414 test series of ACM-based cavity wall assemblies [54-60].

CI Type → ACM Core Type ↓	Foil-faced PIR 6 in. (152 mm)	Mineral Wool 6 in. (152 mm)	Phenolic 6 in. (152 mm)
Polyethylene core ACM	FAIL	FAIL	--
Fire retardant core ACM	FAIL	PASS	FAIL
Mineral-fill core ACM	PASS	PASS	--
-- Not tested			

Table 6-3 details that all assemblies with polyethylene core ACM failed the BS-8414 tests, and all assemblies with mineral-fill core ACMs passed the BS-8414 test. For the wall assemblies with fire-retardant core ACMs, the one with non-combustible backing passed the BS-8414 test, and the assembly with 6 in. (152 mm) PIR insulation failed the BS-8414 test. One test was also conducted with fire-retardant core ACM and 6 in. (152 mm) phenolic insulation and it failed the BS-8414 test.

Table 6-4 presents the results of all ACM wall assemblies tested per ANSI/FM 4880, and compares them with the evaluations from BS-8414 and NFPA-285. First, the results for thermoplastic/combustible core ACMs, including Tests #1 to #3 are compared. The PE-core ACMs fail all three types of fire tests. However, the assemblies in Tests #1 and #2 decisively failed the ANSI/FM 4880 test with extremely high HRR, but passed the NFPA-285 test and desktop assessment, respectively. As discussed previously in Section 6.1, the reason why the assembly in Test #1 passed NFPA-285 is because the peak heat flux in NFPA-285 tests (40 kW/m^2) is at the lower end of heat fluxes measured in post-flashover fires (Section 3.1). Moreover, the heat flux in NFPA-285 is slowly increased over the course of 30 minutes to its peak value, a procedure that can allow the combustibles to escape without burning while the heat flux to the panels is low (Section 3.5). These two reasons result in the fact that PP-core ACMs, made of thicker aluminum panels but with a combustible thermoplastic core, passed the NFPA-285 test. Hence, the NFPA-285 test is not stringent enough to test aluminum panels with thick facers, for either post-flashover fires or exterior fires. It is also reiterated at this point that ACM panels not having been tested to NFPA-285 are currently accepted for installation in the IBC for up to 40 ft (12 m) heights, and even up to unlimited heights after passing complex exceptions.

Next, the results of FR-core ACMs are discussed. The assembly in Test #4, FR-core ACM panels with non-combustible backing/insulation, unanimously passed all three tests for unlimited height installations. Similarly, the results of Test #5 (FR-core ACMs on WRB coated gypsum) are consistent in passing both ANSI/FM 4880 and NFPA-285 tests. While the assemblies in both Tests #6 and #7 have passed NFPA-285 via desktop assessments for unlimited height installations in the US per IBC, the assemblies fail unlimited height approval by both ANSI/FM 4880 and BS-8414. Although these two assemblies will have up to 50 ft limited height approval per ANSI/FM 4880, it should be noted that 2 in. (51 mm) thick glass-fiber reinforced PIR were used in the present study, while the BS-8414 tests used 6 in. (152 mm) thick PIR insulation, and NFPA-285 examined 3 in. (76 mm) thick PIR insulations.

Table 6-4: Comparison of test results from ANSI/FM 4880, BS-8414, and NFPA-285.

Test #	Assembly Description	ANSI/FM 4880	BS-8414#	NFPA-285
1	PP-core ACM → WRB → Gypsum	FAIL	--	PASS^
2	PP-core ACM → PIR1 → WRB → Gypsum	FAIL	--	PASS+
3	PE-core ACM → Gypsum	FAIL	FAIL	FAIL
4	FR-core ACM → Gypsum	PASS - Unlimited ht.	PASS	PASS^
5	FR-core ACM → WRB → Gypsum	PASS - Unlimited ht.	--	PASS^
6	FR-core ACM → PIR1 → WRB → Gypsum	FAIL - Unlimited ht PASS - 50 ft (15 m) ht	FAILx	PASS+
7	FR-core ACM → PIR2 → WRB → Gypsum	FAIL - Unlimited ht PASS - 50 ft (15 m) ht	FAILx	PASS+

ACMs and CIs used in BS-8414 may have a different manufacturer than those used in 16-ft PPTs.
x PIR used in BS-8414 series is 6 in. (152 mm) thick, and fire-rating of foam is unknown.
^ Passed NFPA-285 per actual test.
+ Passed NFPA-285 via desktop assessment for unlimited height.
-- Not tested.

The test results show that the fire performance of ACM wall assemblies is comparable from the ANSI/FM 4880 16-ft PPTs and the BS-8414 test methods, and that these two methods are more conservative than the NFPA-285. The main reasons behind this assessment are that both 16-ft PPT (> 100 kW/m^2) and BS-8414 (~ 75 kW/m^2) provide higher and a more realistic heat flux exposure to wall panels than that in NFPA-285 (time varying up to 40 kW/m^2 by the end of the test).

7. Conclusions

The purpose of this work was to evaluate the fire hazards of ACM wall assemblies using the 16-ft PPT method of ANSI/FM 4880 [12], compare the results with NFPA-285 and BS-8414 fire tests, and establish an improved, repeatable, and cost-effective fire-testing method that can be used to assess wall assembly fire performance.

The 16-ft PPT method simulates a realistic fire scenario and imparts heat fluxes of the order of 100 kW/m^2 to the wall panels. This fire scenario is representative of exterior fires in corner situations and post-flashover fires from the building interior. The results of the 16-ft PPT have been previously correlated with the results of FM Global large-scale corner fire tests [45].

The tested ACM assemblies were constructed with various types of ACM cladding, continuous insulation, and WRB coating materials. Several of the constructed assemblies are noted to have passed NFPA-285 testing for unrestricted height installation in the US, either through actual tests or via desktop assessments.

Two assemblies that had passed NFPA-285, one via physical testing and the other by means of desktop assessment, decisively failed the 16-ft PPT tests. Both assemblies produced high heat release rates (> 6 MW) with flame heights extending higher than 25 ft (7.6 m) within 4 minutes of ignition, at which time the test was terminated. Both assemblies used a thermoplastic combustible core ACM with relatively thick aluminum facers.

Two other assemblies that had passed NFPA-285, and hence are granted unrestricted installation heights in the US, failed for unlimited height and only passed for up to 50 ft (15 m) limited-height installation using the criteria in ANSI/FM 4880 [12]. These two assemblies used a fire retardant core ACM and a combustible polyisocyanurate insulation behind the ACM. The results of the 16-ft PPT were found to be comparable with those from BS-8414 fire testing [54-60] with similar ACM wall assemblies.

The test results provided here demonstrate the effectiveness of the 16-ft PPT in evaluating the fire hazard of ACM assemblies, clearly differentiating their fire performance under conditions reflective of actual end-use. The 16-ft PPTs capture all relevant physics of fires over external cladding systems, including the external fire spread and air cavity fire spread phenomena. The test method provides an objective and robust means of evaluating the fire performance of an external wall assembly. The tests are repeatable, fast to set up, and offer the added potential to measure the smoke damage performance of wall panels during a fire scenario. Therefore, ANSI/FM 4880 16-ft PPT is recommended for evaluating fire performance of external cladding assemblies, such as ACMs.

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