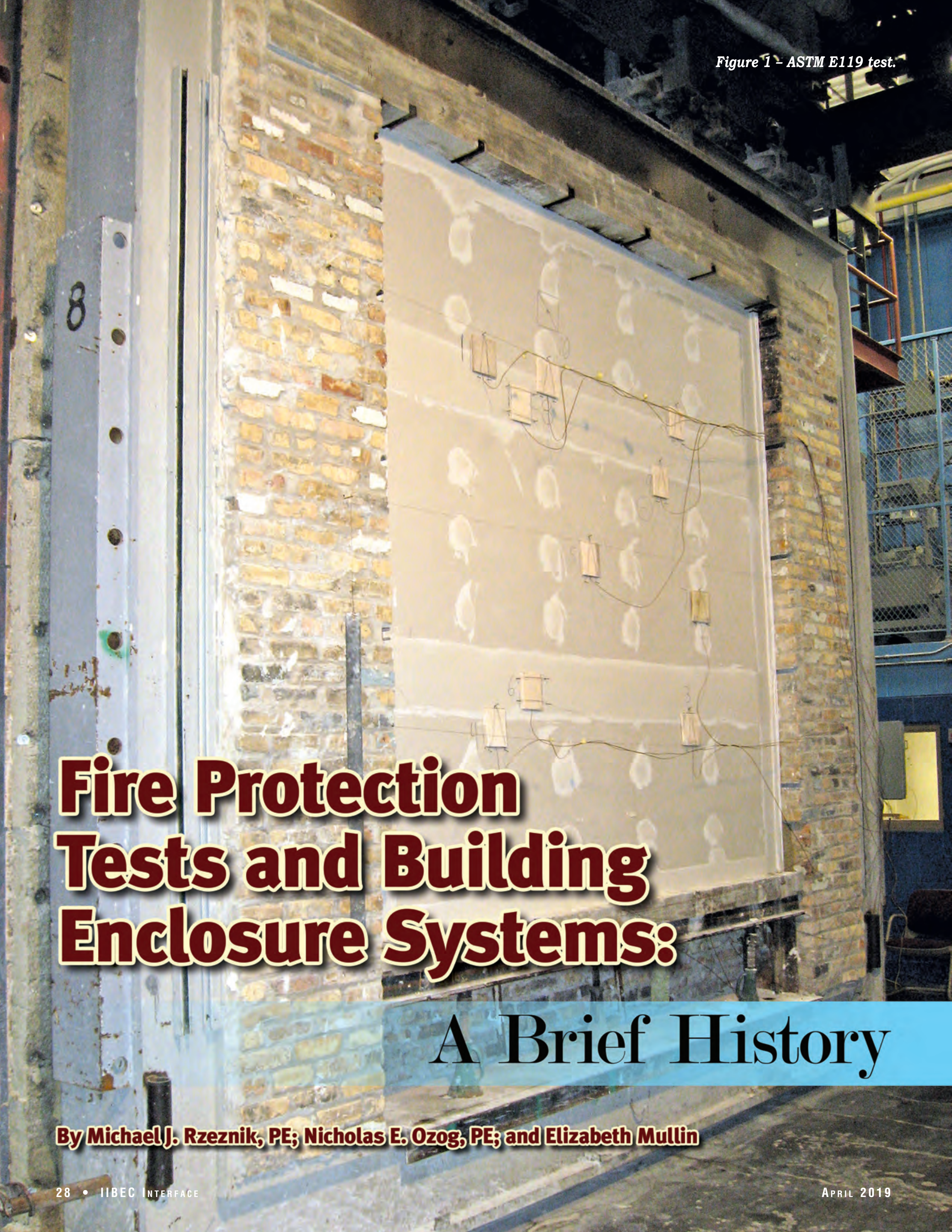


Figure 1 – ASTM E119 test.

Fire Protection Tests and Building Enclosure Systems:

A Brief History

By Michael J. Rzeznik, PE; Nicholas E. Ozog, PE; and Elizabeth Mullin

The proper design of exterior walls and enclosure systems for buildings is critical to a building's performance. Fire protection requirements associated with the exterior wall envelope are similarly critical performance aspects of these systems that must be carefully considered when designing a building's exterior wall and/or building enclosure system.

Fire protection requirements included in the International Building Code (IBC) and other nationally recognized and adopted standards are primarily concerned with 1) maintaining the structural integrity of exterior fire-resistance-rated walls, 2) controlling and/or limiting horizontal and vertical flame propagation, and 3) flame spread along the surface of exterior building enclosure assemblies and their constituent components. To accomplish this, the code-making bodies that develop these requirements rely on a variety of standardized fire tests to assist them in providing a means to gauge the relative performance of the assemblies and components that make up exterior wall systems.

Despite heavy reliance on these standardized test procedures, the origin and intent of the various fire tests are often overlooked. A closer look at laboratory tests can be helpful in reestablishing our understanding of how these tests apply to building construction, as well as to some of their limitations.

In this article, we examine three standardized tests that are relied upon by building code organizations throughout the United States, perform a brief review of the origins and history of each test, and discuss critical aspects of each test as applicable to modern building design.

ASTM E119 TEST

The standardized fire test familiar to most architects and engineers is the American Society for Testing and Materials (ASTM) E119 test, *Standard Methods of Fire Tests of Building Construction and Materials.*[1] This test is used as a means of evaluating the ability of a given wall, column, beam, floor, or roof assembly to withstand exposure to a defined standard fire test curve. The unique story behind this test provides some interesting context regarding how the test was developed, what it evaluates, and how it applies to modern building design.

From approximately the late 1870s to the early 1900s, the United States experience a rash of fires in cities like Chicago, Baltimore, and Spokane, that spread extensively within these urban areas. As a result, a number of U.S. cities were prompted to pursue a means for evaluating building construction with the goal of establishing "fireproof" structures that were capable of withstanding severe fire conditions. A variety of test methods were developed. Many of these initial tests subjected various floor systems to fires having durations that ranged from four to as long as 24 hours.[2] Several of these tests incorporated a requirement that the floor assemblies be subject to static loads, either during or after fire exposure—or both. Many also required that the assembly be subjected to a hose stream test following the fire exposure.

The New York City Building Department's method for evaluating building floor assemblies, developed originally in 1896,[3] subjected the floor assembly to a static load of 150 pounds per square foot while subjecting the assembly to a five-hour fire duration. The test fire generally consisted of standard wood fuel, and was required to maintain a temperature as closely as possible to 2000°F (1093°C) during the last four hours of the test. A hose stream test[4] was administered at the conclusion of the five-hour fire test, and the fire was then extinguished. Following fire extinguishment and application of the hose stream, the floor assembly static load was then increased to 600 pounds per square foot for an additional 24 hours. New York City ultimately codified the requirement for fireproof structures to comply with a slightly modified version of this test. The modified test reduced the sustained temperature requirement to 1700°F (927°C). Pass/fail criteria as described for the test at that time was that the assembly not suffer "appreciable" damage or permit the passage of flame through to the unexposed side.

The Baltimore City Fire of 1904 eventually prompted ASTM to develop a true standardized method for testing and evaluating buildings of fireproof construction. The committee formed to develop this standard eventually settled on a test method very similar to that ultimately adopted by the City of New York. The sole significant change was that in all but the first half hour

Figure 2 – NFPA 285 test.

of the fire test, the temperature of the fire was to be maintained as closely as possible to 1700°F (927°C). Similar to the New York City test, floor assemblies exposed to this standard were required to be subjected to static loads and a fire hose test.

The ASTM E119 test developed four criteria to assess the performance of various assemblies subject to the test while bearing a load. A failure to pass any single criterion resulted in a determination of failure. These test criteria were:

1. Limit the passage of flame or hot gases through to the unexposed side.
2. Limit the average temperature rise on the unexposed side to no more than 250°F (121°C).
3. Prevent the ignition of cotton waste on the unexposed side.
4. Prevent the development of a water stream on the unexposed side when the assembly is exposed to the fire stream test (hose stream test).

Assemblies tested using the ASTM E119 test are only eligible to be tested on the full hour. Those that successfully achieve each of the above criteria after one hour are said to be one-hour fire resistance rated; those that achieve the test criteria for two hours are two-hour fire resistance rated, and so on. The ASTM E119 test remains largely unchanged to this day (see *Figure 1*), and, to many, the repeatability of the test is its primary value. The ASTM E119 test has proven to be capable of providing a consistent measuring stick against how various structural construction methods will perform when subjected to a severe fire test—even considering when tests for the same design assembly are performed by various testing labs and agencies.

The simple rating scale that ASTM E119 uses to rate performance in terms of hours of fire resistance is a convenient means of expressing relative fire resistance properties, and it has been accepted in the industry for decades. That said, the ASTM E119 test does not, nor does it purport to, draw direct correlations as to how a given construction method will perform when subjected to an actual fire. This is widely known and understood by most experienced architects and engineers.

This lack of relevance to actual building fires was recently examined by the American Society of Civil Engineers and the Structural Engineering Institute (ASCE/SEI).[5] During the ASCE committee's review and consideration of the ASTM E119 test, they concluded that certain key aspects of a building's structural system were not being taken into consideration as a result of reliance on a standardized test that evaluates various generic structural assemblies against a standardized design fire demand. They found that the current evaluation method did not consider the impact of the design building's fuel load, structural member connections, or building height on the design's fire resistance requirements. The inability to compare the structural system's capacity in the context of the structural demand when subject to a fire load also made it impossible to determine what, if any, safety margin was included as part of the design. This fact essentially limited the analysis of fire performance to an evaluation of the required thickness of fire resistance insulation to achieve the desired rating for construction types that rely on application of insulation materials and do not otherwise rely on inherent fire-resistive properties, such as concrete.

As a result of their efforts, the 2016 edition of ASCE/SEI-7, *Minimum Design Loads for Buildings and Other Structures*, includes code language related to structural fire resistance. The language added to this document continues to rely on prescriptive fire resistance ratings developed using the ASTM E119 test as the default method for designing fire resistance for structural systems. However, a new Appendix E to the document, entitled "Performance-Based Design Procedures for Fire Effects on Structures," is presented as an alternative performance-based design approach to standardized fire tests that allows evaluation of structural fire resistance based on fire design loads.[6]

Interior Wall and Ceiling Finish Flame and Smoke Spread Indexes[10]	
Class A	Flame Spread Index – 0-25; Smoke-Developed Index - 0 - 450
Class B	Flame Spread Index – 26-75; Smoke-Developed Index 0-450
Class C	Flame Spread Index – 76-200; Smoke-Developed Index - 0 - 450

Table 1

ASTM E84 TEST – THE STEINER TUNNEL TEST

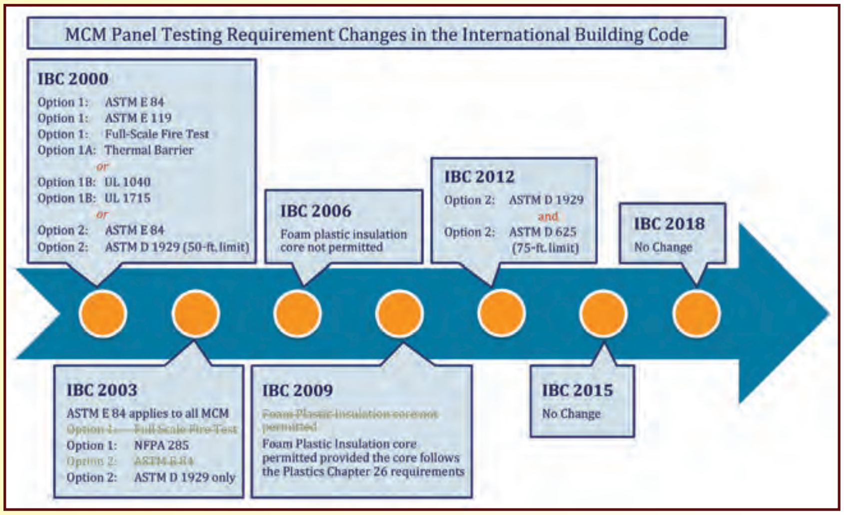
Since the early 1960s, manufacturers of various building material products (predominantly interior finishes) have been using ASTM E84, *Test for Surface Burning Characteristics of Building Materials*,[7] to evaluate the flame spread and smoke development characteristics of their products. The test, which was developed in the 1940s by an engineer named Albert Steiner who worked at Underwriter's Laboratory (now UL), is often referred to as the Steiner Tunnel test.

The test is composed of a 25-ft.-long tunnel measuring 18 in. wide by 12 in. tall. The test sample, consisting of a material that is 18 in. wide by 24 ft. long and up to 6 in. thick, is installed along the top of the tunnel and exposed to a 5000 Btu/min, 4½-ft.-high flame propagating from two burner outlets spaced 8 in. apart to the underside of the test material.[8] The test duration is 10 minutes, with a 240-ft.-per-minute inlet air draft provided to assist in horizontal flame spread.

Technicians then record the spread of the flame front at 30-second intervals through the tunnel, using graduated vision panels for the duration of the test. Smoke-developed ratings are measured by examining obscuration[9] data recorded by a light source and photoelectric cell mounted at the exhaust duct of the tunnel. Both flame spread and smoke-developed ratings are measured against the performance of a base specimen (red oak) when exposed to the test. Red oak's corresponding flame spread and smoke-developed ratings of 90 and 100, respectively, form the baselines against which other materials are measured. Reinforced cement board, in comparison, generates ratings of zero for both flame spread and smoke-developed ratings. *Table 1* provides a correlation between the test results and the classifications provided in many model building codes.

Though the ASTM E84 test was originally developed for the purpose of evaluating flame propagation along building interior finishes, the building industry started seeing more and more combustible elements being added to exterior cladding systems. As a result, IBC continued to require individual components of an exterior building enclosure system to comply with the flame spread and smoke-developed ratings of ASTM E84, while at the same time requiring the entire exterior wall envelope to comply with NFPA 285.

MCM Panels in Exterior Walls in the IBC: *A Timeline*



MCM panel testing requirement changes in the IBC over time.

IBC 2000 Edition

The first edition of the IBC addressed combustible materials on the outside face of exterior walls in Chapter 14, Exterior Walls. IBC 2000 provides a dedicated section within Chapter 14 for Aluminum Composite Materials (ACM) that includes separate testing requirements based on building height, separation distance, and construction type, and also requires façades containing plastics to comply with Chapter 26 (Plastics). Where ACM systems are proposed for use on exterior walls, supporting information is required to be submitted to the code official demonstrating that the system maintains its required fire resistance rating. The base code requirements for installation of ACMs on Types I, II, III, and IV construction specify (with some exceptions) an ASTM E84 test and a "full-scale fire test." The required "full-scale fire test" is not specified. A thermal barrier is also required; however, the thermal barrier is not required where the ACM is specifically approved based on tests conducted per UL 1040 or UL 1715 with the ACM in the maximum thickness intended for use. Exceptions or alternative testing methods to the ones listed above can be used based on various detailed criteria when ACM is used.

IBC 2003 Edition

IBC 2003 replaced the ACM section with the more general Metal Composite Materials (MCM) section, thus encompassing all panels that include a metal facing and plastic core, where in the previous code edition the section distinctly specified aluminum facing. All MCMs are required to be tested to ASTM E84, regardless of construction type; Chapter 14 requires that the MCM wall assembly pass NFPA 285, with some exceptions.

IBC 2006 and 2009 Editions

IBC 2006 does not permit the plastic core of the MCM panels to contain foam plastic insulation as defined by IBC Chapter 26 on plastics. IBC 2009 clarifies that foam plastic insulation complying with IBC Chapter 26 on plastics is allowed when a wall is clad in MCM.

IBC 2012 and 2015 Editions

The IBC provides additional guidance on MCM panels in the 2012 edition, where MCM panels are permitted for use on buildings up to 75 feet. With limitations and conditions, IBC 2012 adds ASTM D625 to the requirements that originally used only ASTM D1929 as an alternative to testing to NFPA 285. The 2015 edition of the IBC modifies the definition of an MCM panel to include that an MCM panel has a "solid plastic core" and deletes the Chapter 14 section that prohibits MCM panels from containing foam plastic insulation. The IBC sections on MCM panels remain similar in the 2018 edition.

NFPA 285[11]

The ever-increasing cost of energy in the 1970s created a need for improvements to the efficiency of both new and existing buildings. It also created a market for new insulation products that those in the plastics industry wanted to fill by incorporating foam plastic insulation into modern building construction.[13] Building codes in place at the time, however, created a barrier to that market for the plastics industry. The model building codes did not recognize or permit the use of combustible materials in construction types typically used for commercial building construction. As a result, a new standardized fire test was required that could be used to evaluate these products, and which could be used to convince authorities having jurisdiction and those in the building fire protection, design, and construction industry that combustible insulation products could be installed as part of a building enclosure system without creating unsafe conditions when exposed to fire.

The first full-scale test developed to address this need was an exterior fire test that was adopted into the 1988 Uniform Building Code (UBC).[13] Cost considerations and difficulties associated with conducting tests outside resulted in modifications that led to a smaller indoor test, which was ultimately adopted by UBC's 1992 edition. The NFPA committee on fire tests adopted the test as an NFPA standard in 1998. (See *Figure 2*.)

As building enclosure systems continued to advance technologically, requirements for weather-resistive barriers (WRBs), exterior insulation finishing systems (EIFSs), metal composite material/panels (MCMs), fiber-reinforced panels (FRPs), and high-pressure laminate (HPL) components were periodically adopted into the IBC, including where testing per NFPA 285 was required.

During this timeframe, there was some confusion among designers, specifiers, and local authorities as to whether some of these additional building enclosure components were required to be included as part of the NFPA 285 test, or whether the ASTM E84 surface flame spread tests were adequate.

Currently, with the exception of combustible construction, non-load-bearing exterior wall envelopes must pass the NFPA 285 test if they contain any foam plastic, regardless of building height.[14] The same is true, in most cases, if any component of the assembly is combustible and installed on buildings that are more than 40 feet above grade. In addition to the NFPA 285 test, the exterior wall envelope must pass ASTM E119 when a fire-rated exterior wall is required, and the components themselves may be subject to ASTM E84 requirements for flame spread and smoke developed. Other, more-detailed requirements, limitations, and/or exceptions may also apply, including local amendments, depending on building properties and/or component properties not addressed by the three tests that are the subject of this article.

While the NFPA 285 test is widely referenced by national building codes, there are those who would argue that, perhaps, alternative test methods better reflect fire challenges faced by the exterior wall envelope. FM Global,[15] for example, would like to see building code requirements reinforced to require compliance with additional test protocols, specifically ANSI/FM 4880, *Evaluation of the Fire Performance of Aluminum Cladding Materials (ACM) Assemblies*,[16] sometimes referred to as the parallel panel test (PPT). A discussion of the merits of each test is beyond the scope of this article; however, the ongoing dialogue in the industry regarding exterior wall envelope testing requires mentioning in order to point out that the means with which engineers are considering these systems continue to evolve.

SUMMARY

This brief discussion on three key fire tests associated with exterior wall enclosures and their constituent parts provides some context regarding the evolution of the fire tests used to help design professionals select assemblies and systems for implementation into their building designs. This also highlights some of the continued challenges faced by these same professionals to refine these requirements, where appropriate, in our continuing effort to protect occupants of these buildings from the hazards of fire. Though some of the core elements that we use to evaluate these systems go back more than 100 years, our efforts to develop alternative, and perhaps more appropriate, means to evaluate these systems continue.

ENDNOTES

1. American Society for Testing and Materials (ASTM). ASTM E119, *Standard Methods of Fire Tests of Building Construction and Materials.*
2. American Iron and Steel Institute. *Fire Protection Through Modern Building Codes.* Fifth Edition. 1981. https://www.buildusingsteel.org/~/media/Files/Build%20Using%20Steel%20Website/AISI%20Fire%20Protection%20Through%20Modern%20Building%20Codes%20(1981).pdf.
3. Ibid.
4. Current testing standards generally require that the hose stream test be administered to a test specimen duplicate to that which underwent the fire endurance test. The test is administered at the halfway point of the duration test, but no later than one hour. Water is applied to the tested assembly using specified parameters for variables such as pressure, test duration, and application area. The hose stream test is intended to evaluate the assembly's mechanical integrity when exposed to the impact, erosion, and cooling effects of the stream.
5. American Society of Civil Engineers: Structural Engineering Institute. ASCE/SEI 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.*

ENGINEERING JUDGMENT IN EXTERIOR CLADDING DESIGN

By Nicholas E. Ozog, PE

After the tragedy at Grenfell Tower in London, architects and engineers have been tasked with solving for "Why?"[1] As such, the immediate reaction has led to a closer review of all aspects of design and construction. When exercising the responsibility of developing and delivering an "engineering judgment," the authority responsible for that judgment must adopt a first-principles approach to the issue at hand, based on science.

Broadly stated, engineering, in the context of exterior cladding and fire protection—and, more specifically, the research required to render a technically sound and defensible engineering judgment in this area of practice—is not performed in a vacuum. Instead, on this topic, engineers and architects are often licensed and required under statutory law in the U.S. and frequently in other countries to practice in a way that is consistent with the ethical[2] and professional standards that form the basis of their respective professions. This is the expectation of the general public who occupy our built environment and place their trust in all of us as design professionals. It should be noted that the United Kingdom's current regulatory environment is taking a much closer look at engineering judgments and, in some cases, effectively prohibiting them, which is in contrast to the U.S. and much of the European Union.

For exterior façades, one must recognize the wide variety and types of façades used on buildings, as well as the materials that make up the façades, such as weather and air barriers and thermal insulation.[3] Moreover, the materials within the exterior façade are combined and configured to provide an ever-increasing array of options to the design professional.

New products are often subjected to a variety of product (ASTM E84) and assembly tests (NFPA 285, ASTM E283, and ASTM E331).[4] This testing may be performed specifically to meet current model building codes, project-specific performance requirements tailored to the intended use and occupancy of a building, or as a means for manufacturers to pre-qualify their products for access to a given market based upon code-specified performance minimums. Such testing data may be valuable to engineering judgments where an integrated approach is pursued. Engineers are wise to take advantage of the various technical specialties to support a scientifically developed engineering judgment.

Given the increasing number of available façade products and configurations, there is a clear challenge for an engineer or architect tasked with evaluation of alternative materials, products, or applications as part of an exterior façade. The challenge includes an evaluation of the criteria and testing data that should be used during the review of the material and assembly. The context, use, and end purpose should all be considered as part of the exercise.

Simply, an engineer facing the challenge of rendering an engineering judgment involving the performance of a façade can rely upon existing ethical guides and adherence to a first-principles approach during the formulation of an opinion. This includes reference to established standards and analyses when addressing questions relating to performance, while placing such advice in its appropriate context.

FOOTNOTES

1. Daniel J. Lemieux and Nicholas E. Ozog. "Exterior Cladding and Fire Protection: More than Skin Deep." *Society of Fire Protection Engineering Magazine.* Q2 2018 Edition.
2. "Code of Ethics." National Society of Professional Engineers (NSPE). Revised July 2018.
3. Michael J. Rzeznik and Douglas Stieve. "Fire Resistance of Exterior Cladding Materials." *Interface.* IIBEC. September 2017.
4. International Code Council. International Building Code.

6. Kevin J. Lamalva. "Structural Fire Protection's Shifting Paradigm." *Fire Protection Engineering.* Q2 2017.
7. ASTM E84, *Test for Surface Burning Characteristics of Building Materials.*
8. Dwayne Sloan. "UL's Iconic Steiner Tunnel Withstands the Test of Time." *International Fire Protection.* January 12, 2016.
9. Obscuration is the impairment to visibility caused, in this case, by the presence of smoke.
10. International Building Code (IBC), 2015 Edition.
11. National Fire Protection Association (NFPA). NFPA 285, *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components.*
12. Barbara Horwitz-Bennet. "Navigating Wall Assembly Fire Testing." *Architectural Record.* 2013.
13. Jesse Beitel. "Past & Future: History of NFPA 285 and Remedial Actions Taken Today." Presentation - Meeting the Challenges of the Future Built Environment, New York Training Academy, Randall's Island, NY, sponsored by UL Laboratories, the Institution of Fire Engineers, and the Fire Department of the City of New York. 2015.
14. It is important to note that the soon-to-be-released 2019 edition of NFPA 285 will be increasing the scope to incorporate some combustible construction and load-bearing walls into the standard.
15. FM Global. "Cavity Wall Standard Being Revised to Reduce Risk." October 12, 2018. fmapprovals.com.
16. American National Standards Institute. FM Global: ANSI/FM 4880, *Evaluation of the Fire Performance of Aluminum Cladding Materials (ACM) Assemblies.*

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