Fire Hazards of Exterior Wall Assemblies Containing Combustible Components

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ABSTRACT

Many combustible materials are used today in commercial wall assemblies to improve energy performance, reduce water and air infiltration, and allow for aesthetic design flexibility. These assemblies include Exterior Insulation Finish Systems (EIFS or ETICS), metal composite claddings, high-pressure laminates, foam plastic in cavity walls, and water-resistive barriers (WRB). The combustibility of the assembly components directly impacts the fire hazard. For example, the insulation component of EIFS, and other emerging related systems (for example Structural Insulated Panel Systems (SIPS)) is combustible foam which exhibits rapid flame spread upon fire exposure. There have been a number of documented fire incidents involving combustible exterior walls but a better understanding is needed of the specific scenarios leading to these incidents to inform current test methods and potential mitigating strategies.

Accordingly, the Fire Protection Research Foundation undertook an international project with CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency) and FireSERT, the Institute for Fire Safety Engineering Research and Technology at the University of Ulster, with the objective to gather information on fire incidents involving combustible exterior walls, compile relevant test methods and listing criteria, identify the knowledge gaps, and identify relevant fire scenarios and a testing approach for future efforts.

INTRODUCTION

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of the National Fire Protection Association (NFPA).

In 2013, the Foundation initiated a project with the overall goal of developing the technical basis for evaluation, testing, and fire mitigation strategies for exterior fires exposing exterior wall systems with combustible components. This paper presents a summary of the results of a Phase 1 study that involved a review of available relevant literature and fire statistics, case studies of large fire incidents, international test methods and regulations relating to combustible exterior walls, and recommendations for work to fill knowledge gaps as well as on relevant fire scenarios. The full report can be downloaded on the Foundation's website (www.nfpa.org/foundation) (White and Delichatsios 2014). The following types of assemblies were included as part of this study:

- Exterior Insulation Finish Systems (EIFS, ETICS, or synthetic stucco)
- Metal Composite Material (MCM) cladding

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- High-pressure laminates
- Structural Insulation Panel Systems (SIPS) and insulated sandwich panel systems
- Rain Screen Cladding (RSC) or ventilated facades
- Weather-resistive barriers (WRB) and combustible wall cavity insulation
- External timber paneling and facades

SUMMARY OF MECHANISMS OF FIRE SPREAD

Existing research as well as reported fire incidents were reviewed to determine the key initiating events of fire involving exterior walls as well as the types of fire spread. The key initiating events are interior fires spreading to external wall systems via external openings such as windows and internal openings such as cavities and concealed spaces and exterior fires directly adjacent to the external wall system or that produce enough heat to ignite the wall system (e.g. fire in adjacent building).

The key mechanisms for fire spread that were identified included:

- Fire spread to the interior of the level above through openings (e.g. windows) causing secondary interior fires and level to level fire spread.
- Flame spread over the external surface of the wall.
- Flame spread via a vertical cavity.
- Heat flux causing degradation/separation of non-combustible protective skin resulting in flame spread to combustible elements internal to the wall system.
- Secondary external fires to lower levels due to falling burning debris.

Based on the research, the fire safety issues relating to exterior wall assemblies with combustible components can be summarized into four parts:

1. For fires originating in the interior of a building, specification of fire development and the heat flux distribution both inside the enclosure and from the façade flames.
2. Fire resistance of the façade assembly and façade.
3. Fire spread on the external surface of a wall assembly (if combustible).
4. Fire spread and propagation inside the assembly insulation (if combustible).

USA STATISTICS

The statistics for the United States were based on information from the National Fire Incident Reporting System Version 5.0 (NFIRS 5.0) for 2007-2011 as well as the findings of the NFPA's annual survey of fire department experience. The categorization choices related to exterior wall fires in NFIRS are limited, so details such as the type of exterior wall material, extent of fire spread, and mechanism of fire spread are not captured.

The building types included in the analysis were assembly, educational, health care, residential (excluding one-or two-family homes), mercantile, offices, laboratories and data centers, manufacturing, and selected storage properties. Of interest were fires where the exterior wall was the area of origin, where the exterior wall was the item first ignited, and fires where the fire spread beyond the object of origin and the exterior wall was the item contributing most to the fire spread. Also included in the analysis was the building height and the presence of automatic extinguishing systems (AES).

For all building types analyzed, exterior wall fires accounted for 3% of all structure fires, 3% of civilian deaths and injuries, and 8% of property damage. Of the exterior wall fires, 42%

started on the exterior wall surface, 32% were where the item first ignited was exterior wall covering, and 26% were where the item contributing most to fire spread was an exterior wall. It should be noted that the specific construction of the exterior wall cannot be ascertained from the NFIRS data and this presents a more general view of fires involving exterior walls. Most exterior wall fires occur in low rise buildings, which is shown on Figure 1.

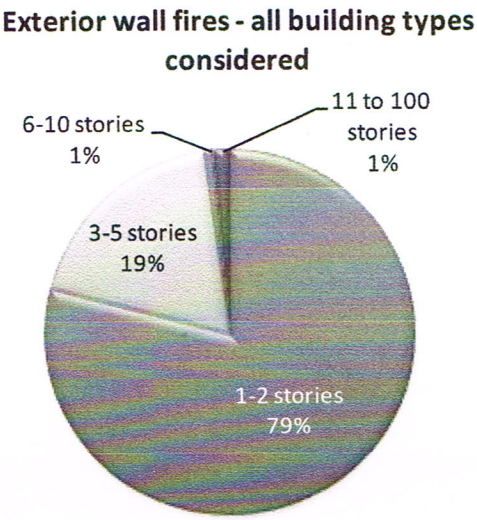

Fig. 1 – Percentage of exterior wall fires by building height (White and Delichatsios 2014)

The percentage of exterior wall fires occurring in buildings with installed sprinkler systems ranges from 15% to 39% of the building height groups considered (1-2 stories, 3-5 stories, 6-10 stories, and 11-100 stories). This indicates that while automatic sprinklers provide protection, there are still a significant number of fires occurring in protected buildings. The highest percentage of fires occurring in protected buildings 6-10 stories as shown in Figure 2.

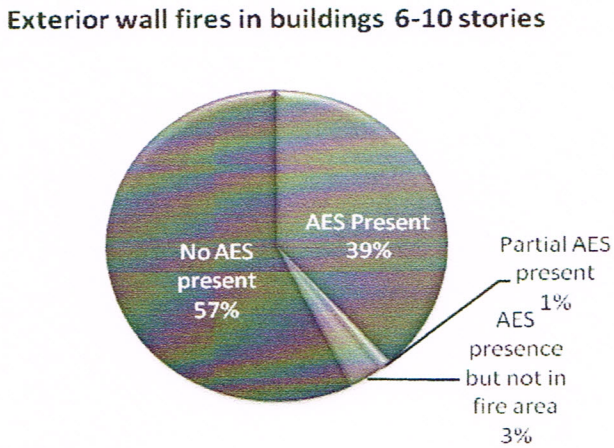

Fig. 2 – Percentage of exterior wall fires by presence of automatic extinguishing systems (AES) in buildings 6-10 stories (White and Delichatsios 2014)

SELECTED INTERNATIONAL FIRE STATISTICS

In addition to US statistics, other international statistics were also analyzed for this study.

New South Wales Fire Brigade (NSWFB) is one of the largest fire brigades in Australia and publishes annual fire statistics. Those statistics indicate that fires starting in wall assemblies/concealed wall spaces make up 0.5% of total fires and fires starting on exterior wall surfaces make up 1.3% of total fires in New South Wales.

The New Zealand Fire Service (NZFS) also publishes annual statistics, which indicate that fires starting in wall assemblies/concealed wall spaces make up 1.7% of the total fires and fire starting on the exterior wall surfaces make up 5.0% of total fires.

SELECTED CASE STUDIES

The full report contains details for several case studies of large exterior wall fires. This paper contains a summary of two of those incidents. It should be noted that most of the case study incidents from the U.S. detailed in the full report involve foam plastic insulation.

Monte Carlo Hotel, Las Vegas, USA, 2008

On 25 January 2008, the exterior wall near the roof of the 32-story Monte Carlo Hotel and Casino was ignited by welding activities. Exterior insulation and finish systems (EIFS) were installed at the exterior wall cladding. The polystyrene and polyurethane portions of the EIFS panels and trim installed on the building burned along with the building's parapet. Most of the fire spread progressed laterally along the exterior wall cladding, but there was some downward spread due to melting foam running down the building starting fires in other EIFS panels below. However, interior sprinklers did halt fire spread into the guest rooms. The fire was suppressed by the fire department. The total damage caused by the fire and the associated business interruption was estimated at $100 million (Duval 2008).

The fire was investigated by Clark County, Nevada and Hughes Associates and found the following (Beitel and Evans 2011):

- The primary contributor to the fire spread was the combination of materials in the decorative band at the top of the building wall (expanded polystyrene (EPS) foam plastic core covered with a rigid non-EIFS coating), the decorative band at the top of the 32nd floor (EPS with a polyurethane resin coating), and the undetermined materials in the decorative medallions.
- Analysis indicated that the EIFS was coated with an encapsulant, but it was thinner than required.

Mermoz Tower, Roubaix, France, 2012

The 18-story residential Mermoz Tower was refurbished in 2003 and metal composite cladding was installed on a part of the exterior wall including walls within the balconies. The cladding above the first story was 3 mm thick polyethylene core sandwiched between two 0.5 mm (0.02 in) thick aluminum sheets. A domestic fire started on a 2nd story balcony on 14 May 2010. The fire spread rapidly to the top of the building. Video of the fire indicates that the spread could have been enhanced by the vertical "U" shaped profile created by the balconies. The fire resulted in one fatality and six injuries (White and Delichatsios 2014).

SUMMARY OBSERVATIONS FROM STATISTICS AND CASE STUDIES

Based on the statistics, exterior wall fires are low frequency events, but the potential for loss can be very high. The major fire incidents found in the study appear to have predominantly have occurred in countries with poor regulatory controls on combustible exterior walls at the

time of building construction or where the construction as not in accordance with regulations. Internal fires that then spread to the exterior wall are the most common ignition scenario. Re-entrant corners and channels that form "chimneys" have led to more extensive flame spread and this scenario should be further investigated. It was also found that combustible exterior wall systems may present an increased fire hazard during installation and construction prior to the protection of these systems being finished.

FAÇADE FIRE TESTS

Various international façade fire tests were reviewed as part of this study. A summary of the full scale, intermediate scale, and small scale tests is provided here.

Full Scale Façade Tests

The research indicates that the exposure to the exterior wall system is generally more severe for an internal post-flashover fire that spreads via windows, etc. Most full scale façade fire tests simulate this scenario. Table 1 below summarizes the full scale façade tests from around the world.

Test	Arrangement	Fire Source	Façade Dimensions	Std Fire Source	Test Duration	Failure Criteria
ISO 13785:2002 Part 2 (International Standards Organization)	Re-entrant corner "L" arrangement (wing wall)	Flames emerging from window	H: 4m above window lintel W: 3m Wing Width: 1.2m	5.5 MW gas burner in enclosure	23-27 minutes	None specified
BS 8414 Part 1 and Part 2 (British Standard)	Re-entrant corner "L" arrangement (wing wall)	Flames emerging from a window	H: 6m above window soffit W: 2.6 m Wing Width: 1.5 m	3 MW timber crib in opening	30 minutes	Exterior or interior fire spread 5 m above window within 15 minutes
DIN 4102-20 (Draft of German standard)	Re-entrant corner "L" arrangement (wing wall)	Flames emerging from a window	H: 5.5 m W: 2 m Wing Width: 1.4 m	320 kW gas burner in opening	20 minutes (combustible facades); 30 minutes (noncombustible facades)	Exterior or interior fire spread 3.5 m above window
NFPA 285 (US standard)	Single wall surface	Flames emerging from a window	Two story test frame; H: 5.3 m W: 4.1 m	900 kW gas burner in bottom enclosure and 400 kW gas burner in window (ignited 5 min after room burner)	30 minutes	Exterior fire spread > 3.05 m above window
SP FIRE 105 (Swedish standard)	Single wall surface	Flames emerging from a window	H: 6 m W: 4 m Includes a 500 mm eave at top	2.5 MW Heptane fuel tray in enclosure	15 minutes	Exterior fire spread > 3.2 m above window

Test	Arrangement	Fire Source	Façade Dimensions	Std Fire Source	Test Duration	Failure Criteria
CAN/ULC S134 (Canadian standard)	Single wall surface	Flames emerging from a window	H: 7.25 m above window W: 6 m	5.5 MW propane burner or timber crib in enclosure	25 minutes	Exterior fire spread > 5 m above window
GB/T 29416 (Chinese standard)	Re-entrant corner "L" arrangement (wing wall)	Flames emerging from a window	H: 9 m W: 2.6 m Wing width: 1.5 m	Timber crib or gas burner in enclosure	Unknown	Unknown
ANSI FM 4880 25 ft corner test*	Re-entrant corner "L" arrangement (wing wall) for end use up to 30 ft	External fire source located at base of wall of a re-entrant wall corner; Can mount ceiling assemblies on test rig	H: 7.54 m Wall 1 W: 15.7 m Wall 2 W: 11.96 m	340 kg timber crib (oak pallets stacked to 1.5 m)	15 minutes	Fire spread to the limits of test structure
ANSI FM 4880 50 ft corner test*	Re-entrant corner "L" arrangement (wing wall) for end use over 30 ft	External fire source located at base of wall of a re-entrant wall corner; Can mount ceiling assemblies on test rig	H: 15.2 m W (both walls): 6.2 m	340 kg timber crib (oak pallets stacked to 1.5 m)	15 minutes	Walls up to 50 ft: fire spread to limits of test structure; Walls over 50 ft: fire spread to limits of test structure or to the intersection of top of wall and ceiling

* Note: ANSI FM 4880 test are not specifically external façade tests and are not referred to by building codes for regulation of external facades. The test is summarized in this table because it provides a possible method for assessing performance in response to external fire sources.

Table 1 – Summary of Full-Scale Façade Tests (White and Delichasios 2014)

Intermediate Scale Façade Tests

Examples of three intermediate scale façade tests are summarized in Table 2.

Test	Arrangement	Fire Source	Façade Dimensions	Std Fire Source	Test Duration	Failure Criteria
ISO 13785:2002 Part 1 (International Standards Organization)	Re-entrant corner "L" arrangement (wing wall)	External fire source located at base of main wall	H: 2.4 m W: 1.2 m Wing width: 0.6 m	100 kW gas burner	None specified	None specified
Vertical Channel Test (Canadian standard)	Single wall surface installed at rear of a channel formed by noncombustible projections on each side of the specimen wall	Flames emerging from a window	H: 7.32 m W: 0.8 m	1.16 MW propane burner in enclosure	20 minutes	Fire spread > 5 m above bottom of specimen
FM Parallel Panel Tests	Two parallel panels with burner at the bottom	External fire source located between panels	H: 4.9 m W: 1.1 m Separation of panels: 0.5 m	360 kW sand burner	None specified	HRR > 1100 kW (Used to predict results for the 25 ft and 50 ft corner tests)

Table 2 – Summary of Intermediate-Scale Tests (White and Delichatsios 2014)

Small Scale Fire Tests Applied to Facades

In some countries, exterior wall materials are regulated using small scale tests. In addition, some regulations allow exemption from full-scale tests based on small-scale test results. The

small-scale tests applied to exterior walls include combustibility tests. Various combustibility tests exist internationally, but they are similar. Criteria for non-combustibility is typically no sustained flaming and specimen surface temperature must not exceed 50°C (122°F). Another type of small scale tests applied to combustible materials is the cone calorimeter, which is used to measure the flammability properties of materials.

The Euroclass system was developed to characterize the fire behavior of construction materials and was designed to control flammability internal materials used in the interior of buildings. However, the system is often applied to exterior wall systems. For non-flooring applications, the following four tests are applied to determine the material classification:

- EN ISO 1182 – Reaction to fire tests for products – Non-combustibility test
- EN ISO 1716 – Reaction to fire tests for products – Determination of the gross heat of combustion (calorific value)
- EN 13823 – Reaction to fire tests for products – Building products excluding floorings exposed to the thermal attack by a Single Burning Item (SBI)
- EN ISO 11925-2 – Reaction to fire tests – Ignitability of building products subjected to direct impingement of flame – Part 2: Single-flame source test

Class A1 products under the Euroclass system are non-combustible, Class A2 products have a low combustibility, Class B products are combustible but will not lead to flashover but will lead to a fully developed fire, and Class C-E products may lead to flashover.

The UK Approved Document B applies the following small-scale tests to exterior walls:

- BS 476 Part 6 – Fire tests on building materials and structures. Method of test for fire propagation for products.
- BS 476 Part 7 - Fire tests on building materials and structures. Method of test to determine the classification of the surface spread of flame of products
- BS 476 Part 11 - Fire tests on building materials and structures. Method for assessing the heat emission from building materials

There are also several US small-scale tests:

- NFPA 268 – Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source
- ASTM E 84, UL 723, and NFPA 255 – Steiner Tunnel Test
- NFPA 259 – Standard Test Method for Potential Heat of Building Materials
- ASTM D 1929 – Standard Test Method for Determining Ignition Temperature of Plastics
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SUMMARY OF INTERNATIONAL REGULATIONS

In the United States, the International Building Code (IBC) requires compliance with full-scale test NFPA 285 for buildings over 12.192 m (40 ft). There are a large number of exceptions to this rule relating to different types of materials which have been tested using small-scale tests. The National Fire Code of Canada requires a full scale façade test to CAN/ULC S134.

For buildings 18 m (59 ft) or higher or less than 1 m (3.3 ft) from a boundary, the UK Building Regulations and Approved Document B requires the use of full-scale tests BS 8414

Part 1 and 2 or materials need to be non-combustible or limited combustibility materials based on small-scale test BS 476 Part 6 and Part 11 tests or Euroclass system. However, often UK insurers require full-scale testing to BS 8414.

In Europe including the Nordic countries, the regulations for exterior wall materials are generally based on the Euroclass system. Acceptable solutions vary from non-combustible materials to variations of Euroclass B. In Sweden, full-scale testing to SP Fire 105 is accepted as an alternative. France and Germany also alternatively allow full-scale façade tests.

The Australian National Construction Code does not have any requirements except that residential and public assembly buildings of 2 stories or more and all other classes of buildings 3 stories or more are not permitted to have combustible exterior walls. However, performance-based fire engineering solutions are used to gain acceptance of combustible wall materials. These are sometimes based on small scale tests.

The New Zealand Building Code regulates external wall assemblies based on two criteria: peak heat release rate and total heat released in cone calorimeter testing. Alternatively, compliance with NFPA 285 or other full-scale tests can be used. These requirements are applicable to buildings over 7 m (23 ft) or if building is less than 1 m (3.3 ft) from boundary.

Prior to 2012, the UAE Fire & Safety Code did not have any requirements for exterior wall materials related to reaction to fire. In response to some large fires, Annexure A.1.21 of the Code was released and does provide fire safety requirements for exterior walls. For buildings 15 m (49.2 ft) or higher or less than 3 m (9.8 ft) from a boundary, a full-scale test per BS 8414 is required in addition to small-scale tests. For buildings lower in height but less than 3 m (9.8 ft) from a boundary, compliance is required with smoke-scale or room corner tests.

In Singapore, exterior wall cladding must be non-combustible or Class 0 materials (flame spread index $\leq$ 12 and sub index not exceeding 6 when tested to small-scale test BS 476 Part 6) for buildings over 15 m (49.2 ft) high or less than 1 m (3.3 ft) from a boundary. Malaysia has the same requirement for exterior wall cladding for buildings greater than 18 m (59 ft) high or less than 1.2 m (3.9 ft) from a boundary. China applies a full-scale test method as described in the previous section.

RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the findings of this research study, it was not recommended to develop a new full-scale test, but to instead conduct further research to validate the existing full-scale and small-scale tests and to develop a more affordable and dependable intermediate-scale test. The specific recommendations for future work from the full research report (White and Delichatsios 2014) are to:

1. **Existing Full-Scale Façade Test Round Robin** – The range of test geometries, fire exposures, and acceptance criteria for the existing full-scale tests could potentially result in variations of test results. A full-scale façade test round robin could be conducted between labs around the world that currently operate the various tests.
2. **Development and Validation of Intermediate-Scale Façade Test** – Develop an intermediate-scale test method that could be an alternative to full-scale testing.

3. **Validation of Small-Scale Test Regulatory Requirements** – In some countries exterior wall materials are regulated by small-scale tests and in many others, results from small-scale testing could permit exemption from full-scale tests. It is not apparent that these requirements are based on test-based validation, so a test program could be undertaken to ensure that regulatory requirements for small-scale tests are appropriate.
4. **Investigation of Effect of Vertical "U" Channel on Full-Scale Test** – Some of the fire incidents reviewed in this project showed rapid fire growth involving vertical "U" shaped channels (e.g. balconies). It is suggested that this orientation be investigated to find if it has any significant impact on performance of materials that pass full-scale tests in standard geometries (e.g. single wall or wing wall orientations).
5. **Development of Façade Flame Spread Models** – Flame spread models have the potential to provide links between small-scale and full-scale test performance, but the models currently available are not sophisticated enough to account for the many complexities of this issue (e.g. multiple layers, cavities). To move beyond this, research on developing and validating flame spread models should continue.

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REFERENCES

Beitel, J.J. and Evans, D. H. 2011. "The Monte Carlo exterior façade fire". SFPE Fire Protection Engineering. October 2011.

Duval, B. "Monte Carlo hotel casino fire". NFPA Journal. May/June 2008.

White, N. and Delichatsios, M. June 2014. "Fire Hazards of Exterior Wall Assemblies Containing Combustible Components". Fire Protection Research Foundation, Quincy, MA.