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Exterior Fire Suppression System for High-Rise Buildings with Combustible Cladding

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Abstract

An autonomous fire suppression system was developed to address the hazards associated with combustible facades on high-rise buildings. A full-scale fire test program was conducted to assess the ability of the autonomous fire suppression system to effectively detect and suppress an early-stage fire on the exterior of a building. The results of the test program indicate that an autonomous fire suppression system can provide rapid intervention and fire suppression.

1 Introduction

In recent years, fire incidents around the world have demonstrated that the use of combustible cladding can lead to rapid fire spread and propagation on the exterior of high-rise buildings [1]. The combination of the height of buildings, accessibility and combustible cladding place the fire service at an immediate disadvantage as the fire spreads rapidly to heights that standard firefighting equipment cannot reach [2].

To address these issues, an autonomous fire suppression system was developed to provide automatic detection and suppression of fire incidents on the exterior of high-rise buildings. Fundamentally, the system is designed to provide rapid intervention and deliver water during the incipient phase of a fire - thus cooling the cladding to contain and prevent the rapid growth that is typical in these types of fires [3]. A full-scale fire test program was conducted to assess the ability of the system to effectively detect and suppress and early-stage fire on the exterior of a building without human intervention.

2 Autonomous Fire Suppression System

The basic components of the autonomous fire suppression system evaluated consisted of two optical flame detectors, a motor operated firefighting monitor mounted on an extension boom, a remotely resettable deluge valve, and a programmable logic controller (PLC). The optical detectors were installed on fixed booms and oriented such that their respective fields of view were overlapped within the intended coverage area of the system. The detectors were connected to the PLC, which analyzed the detection signals with specialized software to identify and track the 3-dimensional location of a fire on a building surface. Upon detection, the system was programmed to identify the location of the fire, deploy the monitor on the extension boom, orient the monitor to point at the region in which water was to be delivered to the building, and activate the valve starting the water flow. The system was optimized to operate within the capacity of a typical NFPA 14 standpipe water supply used in high rise building applications [4].

3 Fire Performance Evaluation

A full-scale fire test program was conducted in accordance with SP Method 5483 at the Thomas Bell-Wright International Consultants (TBWIC) facility in Dubai, UAE, in cooperation with the Research Institute of Sweden (RISE), to evaluate the performance of the autonomous fire suppression system [5] [6]. The fire test program included a series of targeting tests (T1) and a series of full-scale combustible façade tests (T2) to determine the ability of the system to detect and locate early-stage fires and prevent spreading on the exterior surface of a building with combustible façade materials.

A 35 meter (115ft) wide by 25 meter (82ft) high test wall was erected at the TBWIC facility in Dubai, UAE - representing a portion of the maximum system coverage area. The two flame detectors were installed on top of the wall, spaced 50 meters (164ft) apart and 4 meters (13ft) off from the surface of the wall. Two separate and independent robotic monitors were installed on the wall. The first monitor was installed at the bottom of the wall to simulate a system fighting a fire vertically upwards and the second monitor was installed at the top of the wall to simulate system fighting a fire vertically downwards. With this configuration, the total coverage area of a single monitor could be assessed by combing both the upward and downward components. A schematic representation of the test configuration is shown in Figure 1.

During the series of tests, the size of the monitor orifice was changed to achieve two different nominal K-Factors: 370 $\mathrm{LPM}/\sqrt{\mathrm{bar}}$ (26 $\mathrm{GPM}/\sqrt{\mathrm{psi}}$) and 433 $\mathrm{LPM}/\sqrt{\mathrm{bar}}$ (30 $\mathrm{GPM}/\sqrt{\mathrm{psi}}$). These K-factor settings were selected to provide the optimal flow range of 850 LPM (225GPM) to 1230 LPM (325GPM) at pressures ranging from 5 bar (72.5 psi) to 8 bar (116 psi).

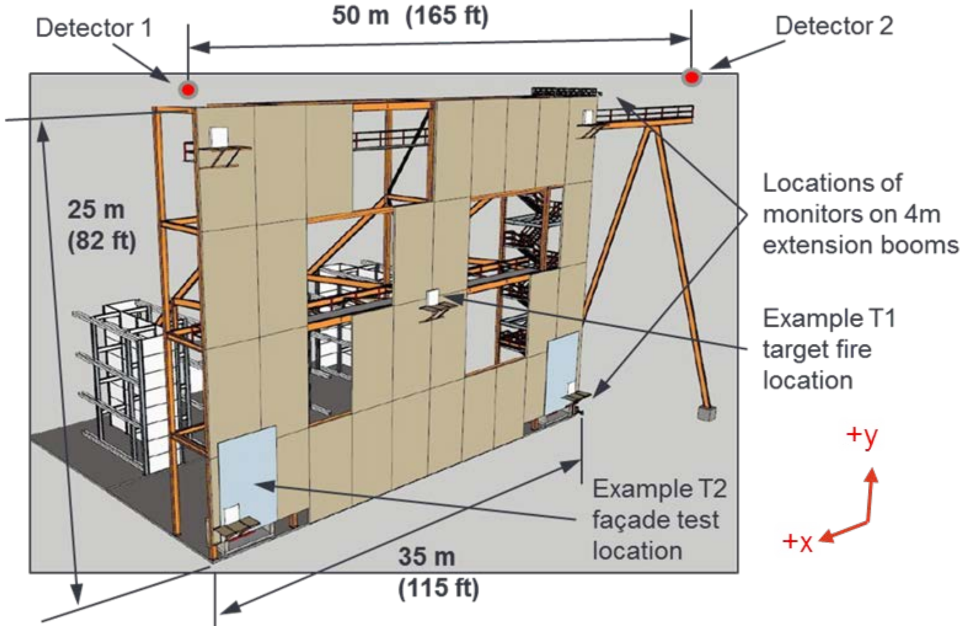

Figure 1 - Schematic representation of the test wall structure. Some wall panels are omitted to show the underlying structure.

3.1 Targeting Tests (T1)

The objective of the targeting tests was to verify that system could both detect and accurately direct the water spray at small target fires within the limits of its coverage area for a given orifice setting for a variety of operating pressures. The target fires consisted of various combinations fuel soaked mineral wool insulation sheets and fuel filled pans. The test fuel used consisted of lacquer thinner. Details of the specific fuel packages used can be found in Table 1. Targets were strategically placed in various locations on the wall to define the maximum coverage area under specific hydraulic conditions, as shown in Figure 2.

Table 1 - Arrangement of the available fire test sources.

Fire test source type	Set-up	Area [width x height]	Fuel
1	One vertical mineral wool insulation sheet	0.6m × 1.2m (2ft x 4ft)	2.5 liters of flammable liquid soaked in the sheet
2	Two vertical mineral wool insulation sheets, side-by-side	1.2m × 1.2m (4ft x 4ft)	2.5 liters of flammable liquid soaked in the sheet and 2.5 liters of flammable liquid in the fire tray
3	One vertical mineral wool insulation sheet plus one fire tray	0.6m × 1.2m (2ft x 4ft)	2.5 liters of flammable liquid soaked in the sheet and 2.5 liters of flammable liquid in the fire tray
4	Two vertical mineral wool insulation sheets, side-by-side plus two fire trays	1.2m × 1.2m (4ft x 4ft)	A total 5 liters of flammable liquid soaked in the sheets and a total of 5 liters of flammable liquid in the fire trays

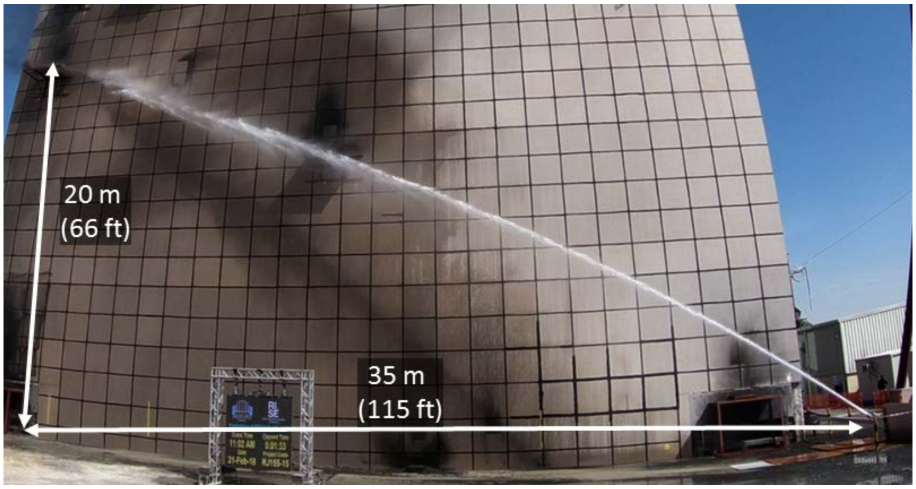

Figure 2 - Targeting Test (T1) where the extinguished target was located at the maximum diagonal reach for the active system

The general fire test procedure was to start with the smallest fuel package, apply the flammable liquid immediately prior to the start of a test and achieve ignition with a torch. If the smallest fuel package was not detected, the size of the fire test source was increased until fire detection was verified. Additional tests involving larger fire sizes were not conducted after detection was achieved.

For each targeting test, time to detection, time of water delivery to the burning fuel, and visible suppression were assessed. Additionally, fire type and location were recorded as well as hydraulic and wind conditions.

3.2 Targeting Test (T1) Results

A total of twenty-eight T1 tests were completed. The average detection time for the T1 test series was under 10 seconds after ignition of the fire, with the fastest detection time being 6 seconds and the slowest detection time being 19 seconds. The average water delivery time to the target after the system detected the fire was 12 seconds, with minimum time of 6 seconds and a maximum of 28 seconds. All targets were either highly suppressed or extinguished. Test results are summarized in Table 2 and an example of a T1 test is show in Figure 3.

Table 2 - Targeting Test Summary Table. Horizontal and Vertical distances measured using the monitor location as the origin

Test Ref	Monitor Location	Horizontal Distance [m]	Vertical Distance [m]	Nominal Pressure [bar]	Nominal K-Factor [LPM/√bar]	Fire type	Detection Time [s]	Water Delivery Time [s]
1	Bottom	33	18	8	433	3	7	28
2	Bottom	17.5	12.5	5	433	1	7	11
3	Bottom	17.5	12.5	8	433	1	8	11
4	Bottom	2	23	5	433	2	6	14
5	Bottom	33	2	5	433	1	19	9
6	Bottom	2	2	5	433	1	8	8
7	Bottom	2	2	8	433	1	8	8
8	Bottom	25	2	5	433	1	9	8
9	Bottom	2	23	5	433	2	7	20
10	Top	33	-23	5	370	1	8	13
11	Top	2	-23	5	370	1	17	6
12	Top	17.5	-12.5	5	370	1	8	8
13	Top	17.5	-12.5	5	433	1	8	6
14	Top	2	-2	8	370	2	10	6
15	Bottom	20	20	5	433	2	11	14
16	Bottom	15	25	5	370	2	13	10
17	Bottom	20	20	5	370	2	11	14
18	Bottom	2	20	5	370	2	7	13
19	Bottom	2	23	8	370	2	8	14
20	Bottom	30	2	8	370	2	8	12
21	Bottom	25	3	5	370	3	7	14
22	Bottom	10	10	5	370	1	6	10
23	Bottom	2	2	8	370	3	8	10
24	Bottom	17.5	12.5	8	370	2	11	15
25	Top	2	-23	8	433	1	8	8
26	Top	17.5	-12.5	8	433	2	8	8
27	Top	17.5	-12.5	5	433	1	8	6
28	Bottom	33	18	8	370	4	10	26

Figure 3 - Test Ref 15 shown at time of detection (left) and water delivery time (right)

3.3 Large-Scale Fire Performance Tests (T2)

The objective of the large-scale performance tests, or T2 test series, was to verify that the system was able to adequately prevent fire spread on a simulated full-scale façade. The T2 test was modeled after the SP 105 test program [7]. SP 105 is similar to the NFPA 285 and BS 8418 test programs in that it consists of a shielded fire source designed to apply constant heat from a simulated flashover condition to assess resistance to fire attack and vertical spread on a building façade surface [1] [8] [9].

The fire scenario consisted of an insulated combustion chamber containing two pans filled with 60 L of heptane – corresponding to a total fire load of approximately 75 MJ/m^2 and a sustained burn time of 15-20 minutes. A 24 m^2 (258 ft^2) simulated façade surface was installed directly above the opening of the combustion chamber consisting of aluminum composite panels with polyethylene combustible core installed on a framework creating an exposed 50mm (2in) cavity as shown in Figure 4 .The test specimens were located at the bottom corners of the test wall as shown in Figure 1.

Tests were conducted at the minimum pressure and flow determined to reach the target distance during the T1 test series. Three different attack types were assessed: vertical downward (top system), diagonal downward (top system), and horizontal (bottom system). In addition, a free-burn was conducted to verify the combustibility and response of the façade material without suppression. Performance of the system was determined based on visual observations both during and after the test in conjunction with the temperature data obtained during the fire test.

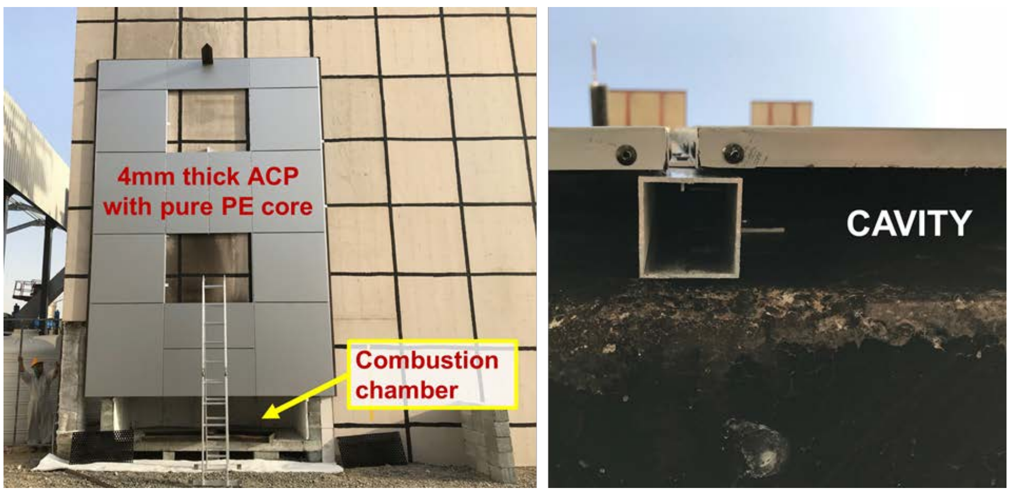

Figure 4 - Performance test specimen (left) and 50mm cavity as viewed looking up at top of combustion chamber opening (right)

3.4 Large-Scale Fire Performance Tests (T2) Results

A total of three T2 tests and a free-burn were successfully completed with positive results. Visual observations after all three T2 tests with suppression showed less than 10% exterior cladding material fire damage – significantly less than observed during free-burn conditions. The temperature data collected in the eave and in the cavity of the cladding system showed a peak temperature of 95°C (203°F) for less than one minute collectively. The temperature was controlled and under 40°C (104°F) for over 90% of the test duration in all cases. An example of the fire development and subsequent damage observations can be found in Figure 5.

Figure 5 - Photos depicting the T2 fire scenario shortly after ignition (left), fully developed approximately 5-7 minutes after ignition (center), and subsequent damage (right) for the horizontal attack test.

4 Discussion

Based on the results of this evaluation, the autonomous fire suppression system presents several potential benefits to decrease the hazards associated with combustible cladding on high-rise buildings.

First, speed of detection and early intervention are essential to prevent rapid growth of fires on the exterior of buildings [2] [10]. The system was observed to provide a significant degree of fire suppression, preventing fire spread and limiting damage to the region proximal to the point of ignition by detecting fires early in their development and start active suppression in less than 30 seconds.

Second, the system demonstrated that it can fight a fire at any height and cover a large portion of a building. A single system can protect an area ranging from 2,400m^2 (25,800ft^2) to 4,200m^2 (45,200ft^2), as shown in Table 3. In principle, multiple of these systems, properly spaced, can be used as a fire protection solution for the exterior of a high-rise building.

Table 3 - Assessed coverage area for different hydraulic conditions

Pressure [bar]	Nominal K-Factor [LPM/√bar]	Flow [LPM]	HR [m]	VUR [m]	VDR (m)	Total Coverage Area [m^2]
5	370	838	20	20	40	2400
			25	15	40	2750
	433	967	20	25	40	2600
			30	20	40	3600
6	370	918	23	22	40	2878
			28	17	40	3211
	433	1059	23	25	40	3033
			32	20	40	3800
7	370	992	27	23	40	3378
			32	18	40	3694
	433	1144	27	25	40	3466
			33	20	40	4000
8	370	1060	30	25	40	3900
			35	20	40	4200
	433	1223	30	25	40	3900
			35	20	40	4200

Finally, the system was developed to mitigate fire hazards of existing construction and operates within the capacity of a typical NFPA 14 standpipe water supply. This provides building owners a cost-effective alternative where solutions such as replacing the building's façade are not considered feasible or safe.

5 Test Program Limitations

The test program did not directly evaluate the influence of external wind driven fire behavior on the performance of the system. However, the testing was conducted in an outdoor setting where wind conditions were documented throughout the program. The wind velocity ranged from 0.4 m/s (1.3 ft/s) to 7.6 m/s (25 ft/s), with gusts periodically over 10 m/s (33 ft/s). The system was programmed to oscillate around the location of the fire to compensate for wind conditions. Throughout the test program it was observed that water stream effectiveness was minimally affected by adverse wind conditions within the intended coverage area but not to the point where the system was unable to suppress or contain the test fires. It's important to note, that the oscillation has been programed such that the system will wet relatively large area on the order of 20-25 m^2 (215-269 ft^2) above the fire. The oscillation was tuned to ensure a significant portion of the discharge remains in the boundary layer condition on the building surface. This has qualitatively shown a capability to reduce the influence of wind on the monitor discharge.

The current test results are most closely aligned with applications where low-density-polyethylene core ACP based façade systems are present with either no void space present or in conjunction with a void space containing noncombustible insulation materials (e.g. mineral foam or fiberglass). Applicability to other façade systems utilizing combustible insulation materials must be evaluated on a case-by-case basis through thorough engineering analysis considering the types of materials used, the geometry of the void spaces (if any), and the presents of firestopping or other means of preventing void-space fire travel.

6 Conclusions:

The results of the test program indicate that the evaluated autonomous fire suppression system can provide effective fire suppression performance and prevent fires from spreading via the exterior surface of a building. The application of water by the monitor was observed to provide rapid knock-down and local extinguishment of flaming on the exposed combustible façade materials for the duration of the tests. In addition, the cascade of water on the cladding surface was observed to prevent significant delamination, failure, and breach of aluminum façade materials – likely due to the cooling effect of the water spray in preventing melting of the polyethylene core.

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