NISTIR 6293

PAINTED STAIRWELL FIRES IN HIGH-RISE BUILDINGS

Henri E. Mitler

Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

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U.S. Department of Commerce
William M. Daley, *Secretary*
Technology Administration
Gary R. Bachula, *Acting Under Secretary for Technology*
National Institute of Standards and Technology
Raymond G. Kammer, *Director*

Federal Emergency Management Agency
James L. Witt, *Director*
U.S. Fire Administration
Carrye B. Brown, *Administrator*

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Painted Stairwell Fires in High-Rise Buildings

Henri E. Mitler*

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1 Introduction

The United States Fire Administration (USFA) sponsored the National Institute of Standards and Technology's (NIST) Building and Fire Research Laboratory (BFRL) to conduct a preliminary examination of fire spread in painted stairwells to provide a better understanding of reported stairwell fires in high-rise buildings. This report provides an analysis of such fires and documents the results of bench- and intermediate-scale tests involving painted surfaces in stairwells.

1.1 Background

Starting in 1994, officials of the New York City Housing Authority (NYCHA) and the New York City Fire Department (NYCFD) noted an increase in the frequency of stairwell fires in high-rise buildings. The number of reported incidents increased from 5 in 1993 to 17 in 1995. These fires were observed to spread with unusual speed and severity, traveling rapidly up multiple floors of the stairwell. A number of such fires extended all the way to the stairwell's roof bulkhead. These were reportedly started by ignited furniture, rubbish, and/or old mattresses that had been placed on a stairwell landing. Lasting only a few minutes; the fires were generally out by the time the fire department arrived. The real danger of such stairwell fires lies in the fact that the occupants rely upon the stairwells as a means of egress. In a fire on November 4, 1995, set on the first floor, the fire raced up eighteen flights, killing two people in the stairwell. There were at least three known fatalities as of December 1995, and the potential for further fatalities.

These fires are not unique to New York; they have occurred elsewhere in the U.S. and abroad. The Fire Research Station, in England, reports similar occurrences in London. Murrell and Rawlins[1] discuss the response of multi-layered paint to fire and concluded the following points:

* Current address: Department of Fire Protection Engineering, University of Maryland, College Park, MD 20742

- Each repainting, even with water-based paints, increases the hazard during a fire.
- Any propensity of a coating to blister when heated increases the spread rate.
- The flame spread rating obtained by a standard fire test method bears little relationship to either the heat release or the fire propagation index of the paint as obtained with another method.
- The presence of a lacquer layer (sometimes used as an anti-graffiti measure) seems to cause a delamination/adhesion problem, and increases the potential fire hazard.

The most famous example of paint contributing to a fire is an escalator fire in the London Underground, known as the King's Cross fire.[2,3] While wood was found to be the principal fuel load, the next most significant fuel source was paint: much of the surface area in the station was painted with many coats. The layers were about 1 mm thick on average, and 2-3 mm in places. One possibly significant observation was that in maintaining the station, "anti-graffiti" coatings of clear polyurethane (PU) varnish were sometimes used on top of each new coat of paint; such layers make it harder to apply the graffiti and easier to clean it off. Additionally, the angle of the stairs may also affect the spread of the fire. In the King's Cross fire, the escalator rose at a 30 degree angle. The resulting buoyant flow followed the contour of the channel.

1.2 Previous New York City Fire Incidents

Between 3/18/90 and 7/17/96, there were 175 stairwell fires reported by the NYCFD. Of these, 92 were in buildings presumably protected against such fires either by having the walls scraped clean or repainted with a fire-retardant or an intumescent paint. The remaining 83 were in stairwells with many layers of paint. In 1995, the statistics were refined to indicate which fires demonstrated significant extension.

Starting at the end of 1995, the NYCHA decided to repaint the stairwell walls with water-based coatings. Approximately half of these were covered with an intumescent paint, half with a fire-retardant paint. The use of these fire-protective coatings has been partially successful. As of January 1996, 6 out of 8 fires that occurred did not extend beyond the floor of origin. In the two cases where the fires continued to the roof, the wall surface may not have been correctly prepared before the paint was applied. In June 1996, a new strategy was implemented by the NYCHA: they repainted only buildings with ten or fewer floors. In higher buildings, they proceeded to strip the paint off the walls entirely.

Table 1 shows an analysis of painted stairwell fires from 1990 to 1996 in New York City. Stairwells which had been repainted with a fire-protective paint are included as well as those which had not been repainted. The fires are categorized as either small (no) extension or large extension. Small or no extension refers to fires that were limited to the floor of origin or the flight above. Large extension refers to fires that involved more than two flights of stairs. They are further subdivided into small and large igniters. Small igniters are objects, such as rubbish bags, likely to yield 150 kW and less; and large igniters, such as mattresses, upholstered chairs, sofas, couches, etc., are likely to yield 250-1000 kW or more.

		Stairwells Without Fire-Protective Coatings	Stairwells with Fire-Protective Coatings
Large Extension	Large Igniter	17	4
	Small Igniter	21	0
Small Extension	Large Igniter	2	16
	Small Igniter	43	72
	Total	83	92

Table 1: Stairwell Fires in NYC 1990 - 1996

While the authorities decided to repaint the stairwells with fire-protective coatings, they also stipulated that the bulkheads (the doors to the roof) be closed when not in use. This makes a very large difference in the ventilation available to the fire.

For the stairwells with protective coatings, 4 out of 20 large ignitions produced extended burning. For small ignitions (72 cases), there were no failures, but the bulkheads were closed in all but one case.

For the stairwells which had not been repainted with protective coatings, 17 out of 19 large ignitions produced extended burning. For small ignitions, 21 out of 64 cases led to extended burning.

1.3 Stairwell Fire Damage

Three sites where stairwell fires took place in NYC during 1994 and 1995 were examined. In all three cases, fire damage in the stairwells was severe. The typical appearance of a stairwell post-fire is shown in figure 1. In the three fires, the damage was most severe on the floor of fire origin with lesser damage on higher floors. Not all of the paint was consumed in any of the fires and in some of the fires the spread was limited to several floors.

Figure 1. Stairwell fire on floor of fire origin

1.4 Overview of Flame Spread

Flame spread up a painted stairwell involves classical vertical flame spread. A large ignition source ignites the wall through direct flame impingement and radiant heat flux to the walls. As the paint layers on the wall ignite, a flame front develops. The preferred direction of flame propagation is upwards, due to buoyancy forces.[4] Buoyant forces then carry heated gases up the stairwell. The heated gases convectively preheat the walls as they travel up the stairwell. The flame front propagates up the stairwell until either the fuel runs out, conditions become oxygen limited, the burnout region at the end of the flame region reaches the pyrolysis front, or the fire department manually suppresses the fire. The critical variables in the propagation of the flame include heat flux at the flame front, flammability of the surface, thickness of the fuel (thermal inertia, $k\rho c$), the geometry of the surface, and composition of the atmosphere.[5] Painted stairwells present a favorable flame spread environment, provided the paint surface is sufficiently flammable. All combustion gases are contained within the stairwells, all heat fluxes produced by the flames are absorbed by the walls and ceiling, the surface area is large, and the orientation of the wall surfaces is vertical, which leads to favorable flame spread conditions.

2 Experiments

Two kinds of experiments were conducted to study flame spread in stairwell configurations: bench-scale tests to establish material and flammability properties of multi-layer paint on a given substrate and intermediate-scale tests to determine if the phenomenon can be reproduced in a laboratory and to compare to the results to the bench-scale tests.

2.1 Bench-Scale Tests

The bench-scale test methods used in this study are the LIFT[6] (ASTM E 1321) and the Cone Calorimeter[7] (ASTM E 1354). The LIFT test determines ignition temperature, the parameter Φ for lateral (counter-current) flame spread rate, and the mean thermal inertia, ($k\rho c$), for a material. The Cone Calorimeter yields the heat release rate, and the time to ignition under varying external fluxes, from which the critical flux (and hence the ignition temperature) can be determined.

2.1.1 Lateral Ignition and Flame Spread Test (LIFT)

The Lateral Ignition and Flame Spread Test (LIFT) was proposed in 1983 by Harkleroad and Quintiere.[8] The purpose of the test procedure is to determine flame spread parameters for materials related to downward or lateral flame spread on a vertical surface. These parameters include the effective ignition temperature, the parameter Φ for lateral (counter-current) spread rate, and the mean thermal inertia, ($k\rho c$). The rate of flame spread for a particular material can be calculated as a function of external heat flux. The geometry of the experiment consists of an angled radiant panel, a vertically oriented sample, and an acetylene-air pilot flame located in the out gassing flow. Figure 2 shows the geometry.

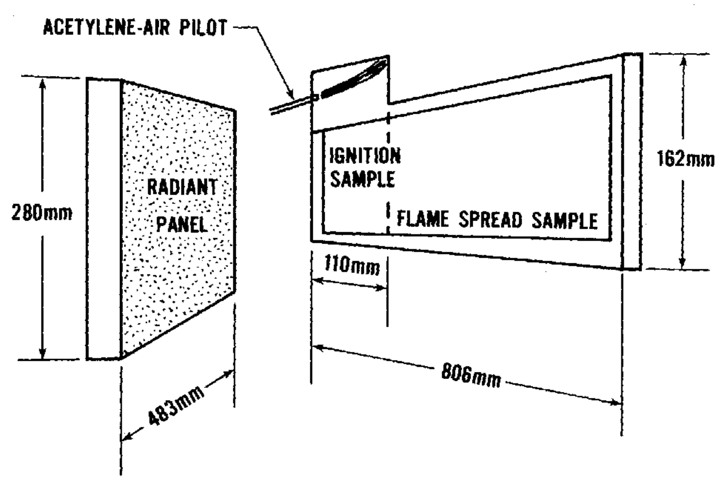


Figure 2. Lateral Ignition and Flame spread Test

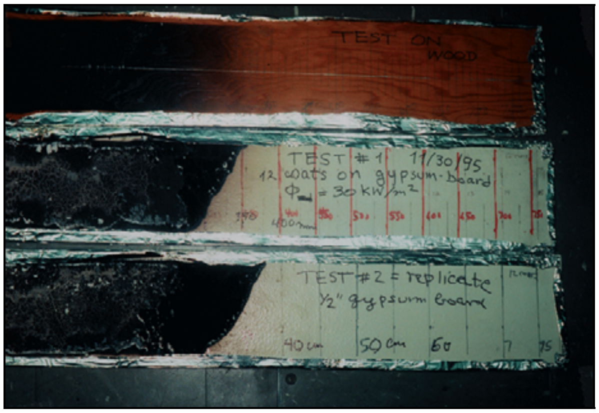
A series of LIFT tests was performed using two substrates, gypsum board and masonry-block to determine effect on flame spread with multiple layers of paint. Six and twelve layers were used to represent initial estimates of the bounds of the numbers of paint layers observed in post-fire examinations.

Table 2 summarizes the LIFT experiments. Figure 3 shows the results of the LIFT tests. Tests 1 and 2 (figure 3a) were replicate tests consisting of 12 coats of paint on gypsum board at a peak incident flux of 30 kW/m^2. The maximum extent of spread was 0.37 m, along the upper edge. Figure 3b shows tests of 12 coats of paint on masonry block at a peak incident flux of 30 and 50 kW/m^2. At a peak incident flux of 30 kW/m^2, the painted masonry block shows a lower value of 0.14 m compared to 0.38 at the higher incident flux of 50 kW/m^2. Tests at 50 kW/m^2 on masonry block (figure 3c) show similar results to the gypsum tests.

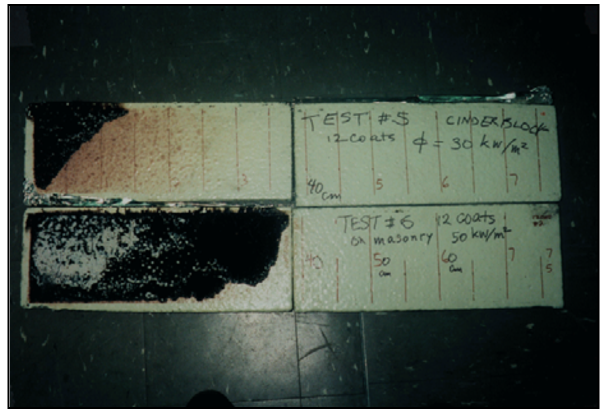
From table 2, the amount of paint on the surface also has an effect on the flame spread. With six coats of paint, flame spread to 0.20 m. With 12 coats of paint, the spread is nearly double at 0.37 m.

Substrate	# of Paint Layers	Heat Flux (kW/m^2)	Flame Spread (m)
Gypsum Board	0	30	0.42
Gypsum Board	6	30	0.20
Gypsum Board	12	30	0.37
Gypsum Board	12	30	0.37
Gypsum Board	12	50	0.40
Masonry Block	12	30	0.14
Masonry Block	12	50	0.38

Table 2: Summary of Results from LIFT Tests



(a) Two replicates with 12 coats of paint on gypsum board



(b) 12 coats of paint on masonry block at 30 and 50 kW/m^2

(c) Two replicates with 12 coats of paint on gypsum board and masonry block

Figure 3. LIFT test samples for paint on gypsum board and masonry block

2.1.2 Cone Calorimeter

The Cone Calorimeter, ISO 5660[9] or ASTM E 1354[7] is used worldwide to measure heat release rate and other material flammability parameters for a 100 x 100 mm material sample. The apparatus is a general-purpose one, which may be used to test products for various applications. Thus, the heater had to be capable of a wide variety of heating fluxes; the actual capability spans 0 to 100 kW/m^2. The technical features of the Cone Calorimeter are documented in several references.[10, 11, 12, 13] Some of the most salient features include:

- horizontal or vertical specimen orientation
- composite and laminated specimens can be tested
- continuous mass loss load cell readings
- feedback-loop controlled heater operation
- HRR calibration using methane metered with mass flow controller
- smoke measured with laser-beam photometer and also gravimetrically
- provision for analyzing CO, CO_2, H_2O, HCl, and other combustion gases

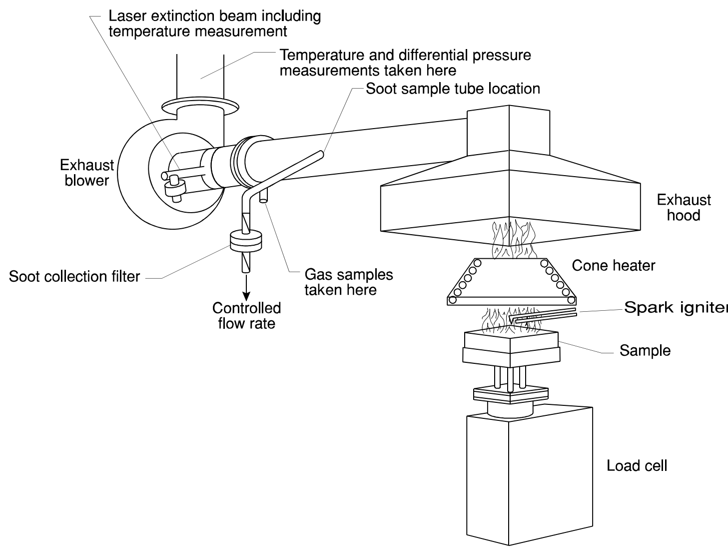


Figure 4. General view of the Cone Calorimeter (ASTM E 1354, ISO 5660)

Applications of the Cone Calorimeter are discussed in detail in a textbook which comprehensively examines heat release in fires.[14] Figure 4 shows the Cone Calorimeter.

Tables 3 – 5 summarize the Cone Calorimeter tests for this study. Each table provides the imposed external flux, the time to ignition for the sample, the peak HRR, peak mass loss rate, average HRR, and the total heat released by the sample. An important result is the determination of the critical external heat flux necessary to ignite the paint. The critical value lies between 27.4 and 37.5 kW/m^2, depending on the paint/substrate combination. The second crucial observation is the relationship between the number of layers of paint and HRR. For 6 layers of paint on masonry block, the average HRR ranges from 20 to 49 kW/m^2, depending on the external heat flux. With twelve layers of paint on masonry block, however, a significantly higher average HRR was observed, ranging from 41 to 61 kW/m^2, depending upon the external heat flux. The six layer paint/gypsum board combination exhibited higher HRRs, leading to the conclusion that pyrolysis of the gypsum board contributed to the HRR. The average HRR ranged from 120 to 240 kW/m^2. As a basis for comparison, Babrauskas, et al.[15] reported Cone Calorimeter data for unpainted 13 mm gypsum board having a peak HRR of 97 kW/m^2.

External Flux (kW/m^2)	Ignition Time (s)	Peak Heat Release Rate (kW/m^2)	Peak Mass Loss Rate ($g/s\text{-}m^2$)	Average Heat Release Rate (kW/m^2)	Total Heat Released (MJ/m^2)
50	22	340.1	18.8	211.4	3.1
50	23	369.9	20.3	240.1	3.5
40	37	289.1	17.4	167.5	3.3
40	52	289.9	17.2	140.6	2.8
40	39	332.0	19.4	193.0	2.8
30	83	227.4	14.5	177.9	2.6
30	87	216.5	14.7	120.0	2.4
27.4	∞	--	--	--	--
25	∞	--	--	--	--

Table 3: Cone Calorimeter Data for Gypsum Board Substrate with 6 Layers of Paint

External Flux (kW/m^2)	Ignition Time (s)	Peak Heat Release Rate (kW/m^2)	Peak Mass Loss Rate ($g/s\text{-}m^2$)	Average Heat Release Rate (kW/m^2)	Total Heat Released (MJ/m^2)
50	37	95.6	3.9	48.7	10.0
50	33	78.7	3.5	49.4	8.4
40	92	56.8	2.9	25.2	5.7
40	631	39.4	5.6	19.5	2.1
40	633	64.2	5.1	30.8	3.1
37.5	631	62.3	4.9	32.3	3.9
35	∞	–	–	–	–
30	∞	–	–	–	–

Table 4: Cone Calorimeter Data for Masonry Block Substrate with 6 Layers of Paint

External Flux (kW/m^2)	Ignition Time (s)	Peak Heat Release Rate (kW/m^2)	Peak Mass Loss Rate ($g/s\text{-}m^2$)	Average Heat Release Rate (kW/m^2)	Total Heat Released (MJ/m^2)
50	22	187.7	6.8	61.0	21.0
50	18	193.5	7.6	58.2	18.6
40	42	160.7	7.5	49.8	7.7
40	284	186.3	4.7	63.2	9.7
40	36	168.4	6.7	49.7	8.0
30	98	100.6	4.7	40.7	6.5
30	88	124.4	5.4	47.0	6.3
27.4	∞	–	–	–	–
24.7	∞	–	–	–	–

Table 5: Cone Calorimeter Data for Masonry Block Substrate with 12 Layers of Paint

2.2 Intermediate-Scale Tests

The primary objective of the intermediate-scale tests was to replicate fire spread through a painted stairwell in the laboratory. Space restrictions in the test facility precluded the possibility of erecting a full-story mock-up of a stairwell. Therefore, several half-scale models of one flight of stairs were built.

2.2.1 Test Configurations

Test 1: The first test was conducted to evaluate the effect of small ignition sources upon the test configuration. From Table 1, small ignition sources tend not to lead to full-burnout of an painted stairwell.

The test was conducted using 9.5 mm (3/8") gypsum board as the substrate (the "wall" and "ceiling" material). Three 4' x 8' sheets were each covered on one side with six coats of an alkyd/oil-based paint supplied by the NYC Housing Authority. Aging was simulated by covering the surfaces with dust, soot, and graffiti, then rinsing the surface with water to simulate cleaning prior to repainting, between coats. While no attempt was made to age each layer, each layer of paint was allowed to dry thoroughly before the next coat was applied. An average of 0.48 kg/m^2 of paint was applied to the wall surfaces. The three panels were joined so as to simulate the ceiling and two side walls in a stairwell and inclined at approximately a 10 degree angle from the vertical (see figure 5).

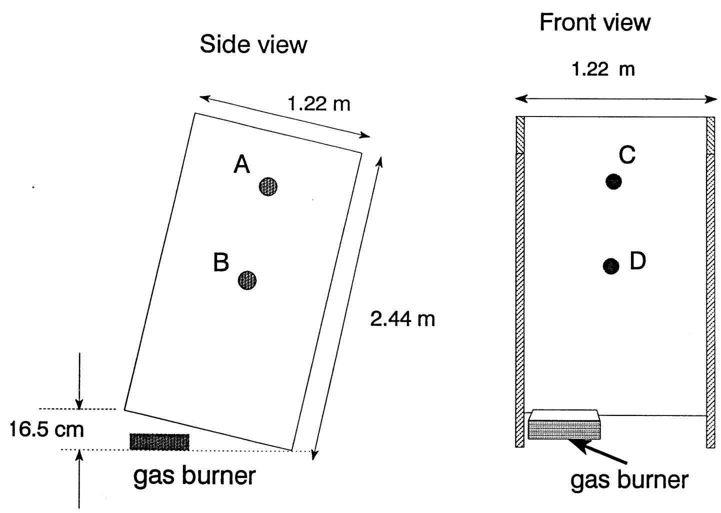


Figure 5. Experimental arrangement for test 1. Location A to D are locations of total flux meters embedded into the side and back walls.

Flux gauge A was located on the left-hand wall, 0.3 m (1 ft) from the top surface and 0.6 m (2 ft) from the back wall. Flux gauge B was located on the left-hand wall 0.6 m (2 ft) from both the back wall and bottom surface. Flux gauge C was located on the back wall 0.3 m (1 ft) from the top surface and 0.6 m (2 ft) from the right-hand wall. Finally flux gauge D was located on the back wall 0.6 m (2 ft) from both the right-hand wall and the bottom surface. A natural gas burner measuring approximately 0.1 m^2 (1 ft^2) was placed on the floor, in the bottom right-hand corner of the unit. Upon ignition, the heat output of the burner was approximately 40 kW.

Test 2: For the second test, the experiment was modified by

- Using a longer simulated stairwell section, 3.6 m (12 ft.) in length.
- Inclining the unit approximately 36 degrees from the horizontal to more accurately simulate a stairwell configuration, and
- Increasing the ignition source to a heat release rate scaled to reflect those typically involved in stairwell fires.

Figure 6 shows the experimental setup. Four total heat flux gauges were used. Two were located along a side wall centerline and two along the ceiling centerline, 1.2 m (4 ft) and 2.4 m (8 ft) from the leading edge, respectively. The heat flux gauges provide an indication of the spread rate of the fire, and the magnitude of the flux incident on each surface as a function of position.

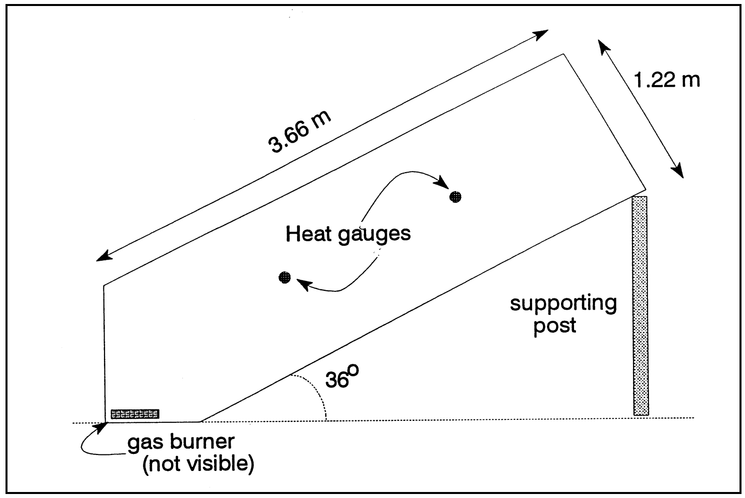


Figure 6. Experimental arrangement for test 2 and 3

Typical scaling shows heat release rate is proportional to the relative size to the 5/2 power of the size ratio[16], that is,

$$\frac{\dot{Q}}{\dot{Q}_0} = \left(\frac{l}{l_0}\right)^{5/2} \tag{1}$$

where l and l_o are the characteristic dimensions of the intermediate-scale and full-scale units, respectively. Assuming that the ignition source for actual fires in the stairwells is of the order of 800 to 1000 kW (typical of a fully-involved stuffed chair), the heat release rate for the intermediate-scale experiment should be approximately 150-200 kW. For test 2, a 150 kW ignition source was used.

For test 2, six layers of an alkyd/oil-based paint were applied. Each coat was allowed to dry for 24 hours before application of the next coat of paint. For this test, an average of 0.40 kg/m^2 of paint was applied to the wall surfaces.

Test 3: Test 3 was conducted as a continuation of test 2. The experimental setup of test 3 was identical to that of test 2, with the exception that the heat release rate of the burner was increased to 200 kW.

Test 4: For test 4, the walls and ceiling were covered by fifteen coats of paint – five of primer, to ensure that no water diffused into the paint from the gypsum-board walls, and ten layers of the alkyd/oil-based paint. The right-hand wall received a coat of anti-graffiti coating before the last coat of paint was applied, to simulate the technique that had been used to control graffiti. A total of 0.92 kg/m^2 of primer/paint/anti-graffiti coating was applied to the wall surfaces.

The upper two thirds of the fourth (bottom) side of the duct was covered with a sheet of clear polycarbonate plastic to prevent the (mostly horizontal) entrainment of cooling air into the duct while still permitting observation and videotaping of the test (figure 7). Four flux meters were placed on the left-hand side wall, 50 mm below the ceiling (figure 8). A 200 kW propane gas burner in the corner served as the ignition source.

Figure 7. Experimental arrangement for test 4

2.2.2 Test Results

The result of test 1, which utilized a 40 kW burner, was limited upward flame spread along the corner, and almost no lateral flame spread. This result is consistent with observations from actual stairwell fires with small ignition sources (Table 1).

Test 2 was run with a burner heat release rate of 150 kW and a modified setup from test 1. The major modifications were the angle of the stairwell, the size of the setup, and the burner HRR. The peak measured HRR was 270 kW (at t = 45 s). Of this, about 150 kW was directly attributable to the burner, so that the paint contributed approximately 120 kW. At 105 s, the burner was turned off, and the flames self-extinguished.

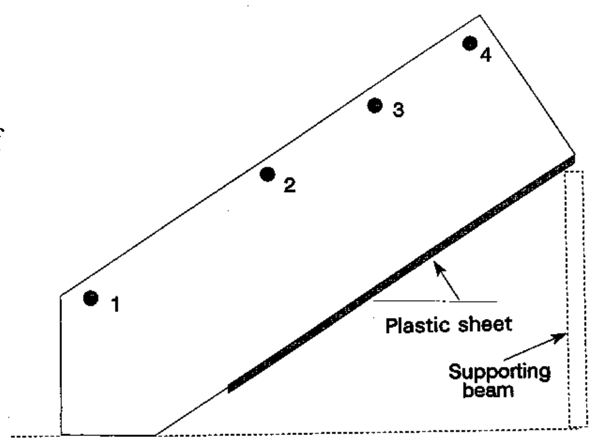


Figure 8. Schematic side view for test 4

Test 3 was conducted as a follow-on to test 2. The test used an approximately 200 kW ignition source. The flames spread upward rapidly so that flames extended approximately 0.30 m (1.0 ft) beyond the end of the mock-up, for several seconds. The peak measured HRR of 395 kW included a 200 kW contribution from the burner, 38 s into test 3. The peak HRR as a result of the paint was approximately 200 kW. The flame then gradually retreated and extinguished. Examination of the resulting damage showed that in the region where the ignitor flames impinged, all six layers of paint had been consumed. The fire extended about 45 cm downward from the ceiling of the stairwell. Near the exit, on the other hand, the fire narrowed to about a 0.15 m depth, and only the top one or two layers of paint were consumed. Although there was rapid upward spread, the comparably rapid exhaustion of the flame suggests that the spread might have been limited, rather than continuing up the stairs.

Test 4 had a significantly different geometry, as the experimental setup was covered with polycarbonate. The wall and ceiling paint layers ignited very quickly and the flame lengthened continuously. Within 30 seconds, the flame tip had extended 20-50 cm beyond the test apparatus. Less than three minutes into the test, the right-hand wall was significantly involved. Peak HRR for the test was 1170 kW.

3 Discussion

3.1 Heat Flux and Heat Release Rate

Like any vertical flame spread problem, spread of flame up the incline of the stairwell is driven by the heat release of the fire and its resultant heat flux incident on the region in front of the flame front. Both the Cone Calorimeter and intermediate-scale tests showed that the heat release rate of multiple layers of paint can be significant. Peak HRR from the Cone Calorimeter tests ranged from 220 to 370 kW/m^2, including some contribution from a gypsum board backing.. Lower values were observed for tests on masonry block. It is presumed that these lower values resulted from both the high heat capacity of the masonry block and from the lack of the paper coating present in the gypsum board.

For the intermediate-scale tests, peak heat release rate is shown in figure 9. The qualitative observations from each test are confirmed by the heat release rate. Tests 2 and 3 show similar growth and decay, with the higher ignition source contributing to a somewhat higher peak HRR. For test 4, two distinct peaks are apparent, one for the initial spread along the left wall followed by a second larger peak corresponding to the right-hand wall igniting and burning much more vigorously. Peak HRR for the tests ranged from 270 kW for test 2 to 1170 kW for test 4.

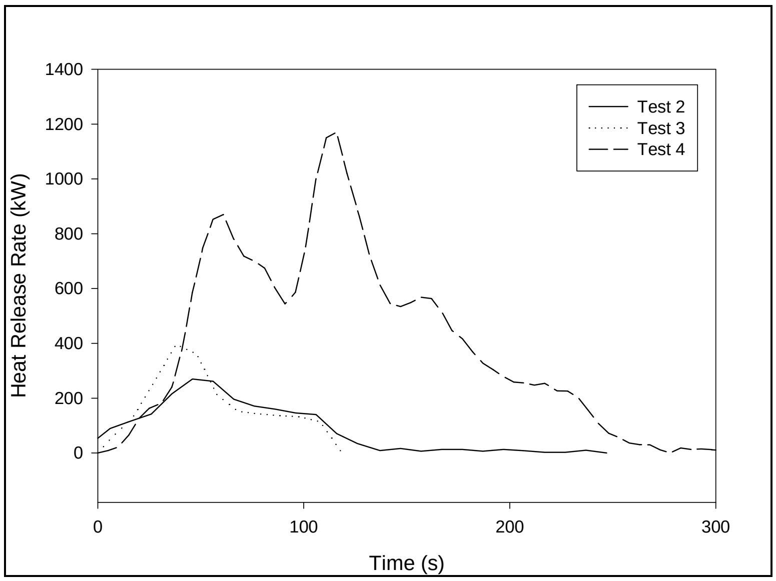


Figure 9. Heat release rate during several intermediate-scale stairwell fire tests

Figure 10 shows the measured heat flux to the wall surfaces for tests 2 to 4. For each test, peak heat flux is naturally lower at the locations further from the ignition source. Peak heat flux is significantly different for the three tests ranging from less than 6 kW/m^2 for test 2 to 98 kW/m^2 for test 4. Both the smaller ignition source (in test 2) and the test configuration (in tests 3 and 4) contributed to these differences.

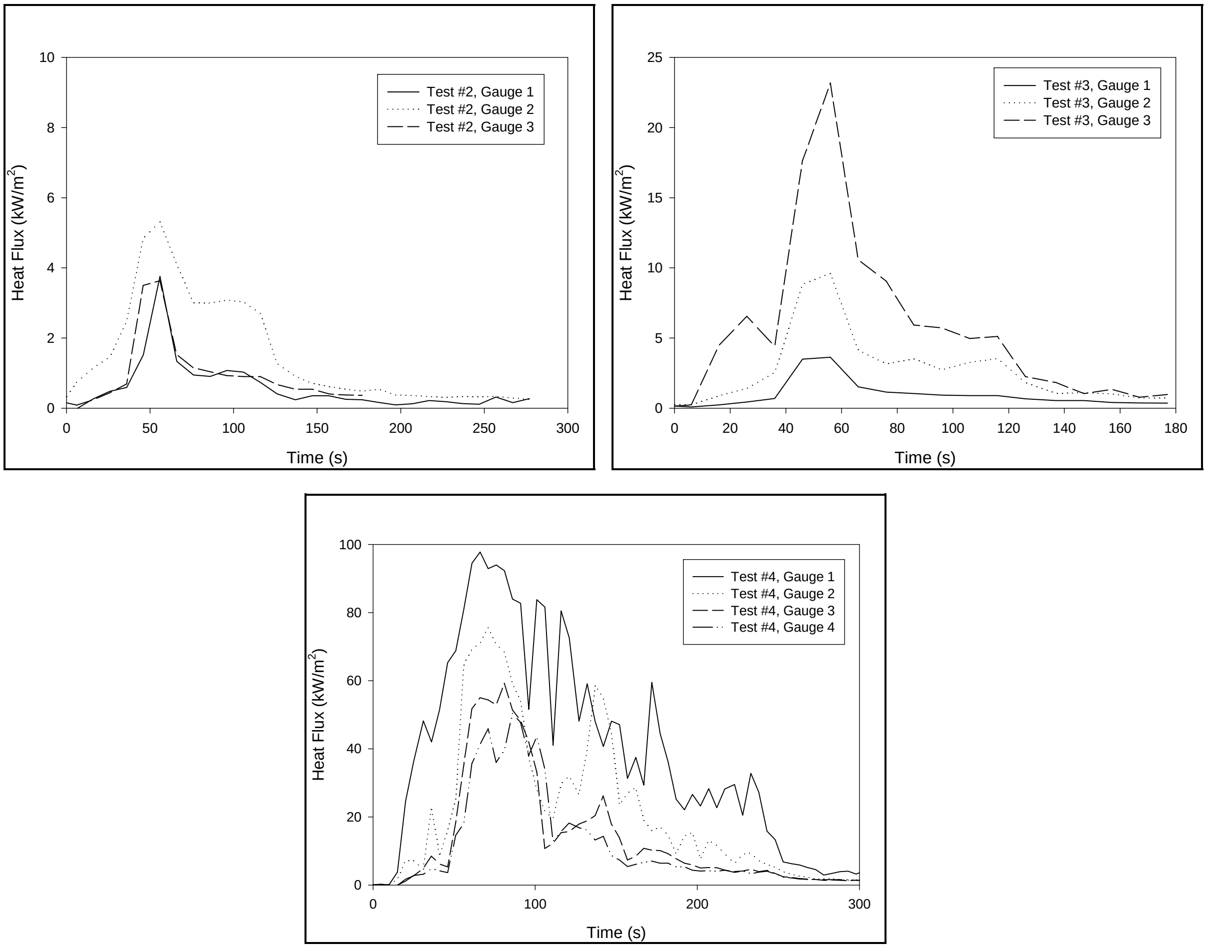


Figure 10. Total heat flux on wall and ceiling surfaces during several stairwell fire tests

Tests 3 and 4 were both performed with a 200 kW ignitor. There was a significant difference between the peak heat fluxes in the two tests. Test 3 (6-layers of paint, no polycarbonate floor) had a peak flux of 24 kW/m^2, whereas for test 4 (15-layers of paint, polycarbonate floor), peak flux was 98 kW/m^2. Beyond the obvious conclusion that test 4 was a significantly more severe fire than test 3, conclusions are difficult to draw, as the increase in heat flux may be attributable to:

- number of paint layers (6 in test 3 and 15 in test 4)
- area of involvement (one wall in test 3 and two walls and ceiling in test 4)
- anti-graffiti coating (only in test 4), or
- the polycarbonate floor lining, which may trap unburned fuel and reduce IR radiation losses.

Still, two observations are apparent comparing tests 3 and 4:

- Flame spread in test 4 continued beyond the wall adjacent to the ignition source with sufficient intensity to involve both the ceiling surface and opposite wall surface.

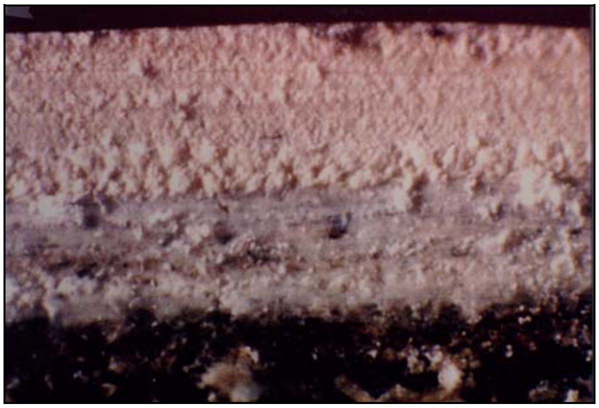
- The clear anti-graffiti coating on the wall opposite the ignition source contributed to a rapid rise in the HRR of the stairwell fire.

3.2 Flame Spread

The critical question regarding fires in painted stairwells centers around whether the paint can sustain flame spread. Three tests were performed to test the flame spread capabilities of painted substrates. The LIFT tests demonstrated that, for the masonry tests, the number of layers of paint present on the substrate has a direct relationship upon the flame spread properties of the paint. The flame spread properties of the paint/gypsum board combination were confounded with the effects from the substrate pyrolysis. The cone calorimeter tests also indicate that the number of layers of paint on the masonry block substrate directly affect the HRR and mass loss rate of the sample. More paint results in higher HRR and mass loss rates. Additionally, higher external heat fluxes result in generally higher average heat release rates. The same relationship exists between the average HRR of the gypsum board/ paint combination and the external heat flux. Finally, intermediate-scale tests were performed to determine the effect of the ignition source size upon the spread of flames. Ignition sources less than about 200 kW did not produce flame spread beyond the test apparatus. Tests 3 and 4 both produced flame spread beyond the test apparatus. Test 3 however, exhibited flame spread beyond the test apparatus with only 6 layers of paint, no enclosure (polycarbonate), and no anti-graffiti coating. This represents the minimum configuration which may produce flame spread. Adding polycarbonate, more paint, anti-graffiti coating, and changing the burner all enhanced the rate of flame spread. The intermediate-scale tests support the evidence of the bench-scale tests that paint can sustain and propagate flame spread through a stairwell enclosure.

3.3 Examination of the Paint Layers

Microphotographs of the cross-sections of the remains from Test 3 are shown in figure 11. The sample in figure 11a was taken from an unburned section of the left-hand wall, and shows a cross-section of the unburned surface. The various layers can be distinguished. The paper layer on the gypsum board lies at the bottom, followed by the five layers of primer, with the ten layers of paint on top. The ten paint layers are about 300 μm thick, while the five layers of primer are about 240 μm thick.



(a) Painted surface from unburned surface of test 4

(b) Burned surface taken from a position intermediate between **(a)** and **(c)**

(c) Burned surface near ignition source

Figure 11. Microphotographs of cross sections of paint surface after test 4

Figure 11b is from a heavily burned region near the exit. It can be seen that large gas bubbles or blisters have formed between the layers, probably from the anti-graffiti coating. When the heat causes a gas bubble to form, it forces lower layers, which have been plasticized, to flow, making the layer thinner. The lowest layer is about 110 µm thick; since the paper layer is only 60 ± 10 microns thick, this must be primer. This is consistent with having the lowest layers not pyrolyzing. The upper set of paint layers has begun to delaminate, and is ~80 - 120 µm thick. It shows that ~200 out of the 300 µm of paint have been pyrolyzed away; since there may be have been charring and expansion or shrinkage of the layers, it is difficult to determine exactly how many layers that corresponds to, but it is most likely between 6 and 7 layers.

Figure 11c is one of the most pyrolyzed of the samples which have not been totally burned away. It was taken from the right-hand wall, approximately 2 m from the exit. From the top of the photograph, there is a layer of paint approximately 160 – 170 µm thick, with a division within it ~80 - 90 µm below the surface. Delamination separates the paint from the primer. The primer is approximately 150 -- 160 µm thick. The dark band is probably the paper facing on the gypsum board and shadows. Finally, the cottony-looking region below the paper facing is the gypsum board. It is reasonable to conclude that 220 or more microns of paint have been pyrolyzed, and that delamination occurred within the primer layers.

Samples could not be taken from the rear wall: all that was left was extremely friable ash, loosely attached to the gypsum. Not only were the paint and primer all burned away, but so was the paper facing of the gypsum board. The microphotographs above confirm what is apparent to the naked eye; that is, the amount of paint removed is inversely proportional to the distance from the origin of the fire. This is partly a result of having burned longer in the lower reaches, and partly due to the higher heating fluxes there.

4 Summary

This report provides the results from a preliminary examination of fire spread in painted stairwells to better understand reported stairwell fires in high-rise buildings. This report provides a description of the background and theory of such fires and documents the results of bench- and intermediate-scale tests of fires involving painted surfaces in stairwells.

Cone Calorimeter tests were conducted to determine heat release rate and critical ignition flux for painted surfaces. The results indicated that the critical ignition flux necessary to ignite painted substrates was between 27.4 and 37.5 kW/m^2. Additionally, the HRR was a function of the substrate and the number of layers of paint.

Lateral Ignition and Flame spread Test experiments revealed that the rate and extent of flame spread was also a function of the number of layers of paint and the substrate.

Finally, four intermediate-scale experiments were performed to demonstrate that paint may sustain vertical flame spread beyond the floor of fire origin. The first experiment was conducted with a small ignition source (40 kW) and no significant flame spread was observed. The second intermediate-scale test was performed with an ignition source of 150 kW and 6 layers of paint. Although there was modest flame spread, it was contained within the test apparatus.

The third test was conducted as a continuation of test 2, but with a 200 kW gas burner. Flames spread beyond the test apparatus for a significant period of time.

Finally, the fourth intermediate-scale experiment was performed. This test was perhaps the most realistic of the intermediate-scale experiments, as the horizontal entrainment was reduced with polycarbonate, anti-graffiti coating was applied to one wall, the HRR of the ignition source was maintained at 200 kW, and 15 layers of paint were present. The observed and measured flame spread in the final experiment confirmed that paint, particularly when covered with anti-graffiti coating, can sustain vertical flame spread in a stairwell configuration. The extent of the flame spread beyond the parameters of the intermediate-scale experiments cannot be determined or predicted from these experiments.

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