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Field Burnout Tests of Apartment Dwelling Units

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Field Burnout Tests of Apartment Dwelling Units

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Building Research Division
Institute for Applied Technology
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Results are reported of three burnout tests in an experimental test building, using a wood crib fuel load of 6 lb/ft^2, representing combustible contents, and a structural design load of 40 lb/ft^2 applied to the floor or roof above the test room. Measurements were made of temperature, radiation, smoke, gas composition, and structural deflection. A discussion of the fire performance of materials and methods of construction, and conclusions with regard to specific fire-protective objectives are presented.

Key words: Burnout test, fire performance, apartment dwelling, smoke, flame penetration, structural load, potential heat, fire load.

1. Introduction

The conventional method for evaluating the fire performance of large-scale structural building components such as walls, columns, floors, etc., is by means of a standardized laboratory fire endurance test [1][1]. The essence of the laboratory test is the application of heat to provide a specified and closely controlled increase in temperature to the structural component in a specially-designed furnace. The results are reported in terms of the time period during which the structure resists the fire exposure without the occurrence of one of several failure criteria. Other standardized laboratory tests are employed for evaluating surface flame spread, heat production, combustibility, and smoke.

Such laboratory tests permit comparative evaluation of the individual components of a building, and thus provide the means for establishing building code requirements in terms of performance standards. Additional research, both in the laboratory and in the field, has been directed toward an understanding of the factors which govern the growth and severity of accidental or unwanted fires, so that the fire endurance periods required of building components may be related to the expected fire severity which could occur in the building.

Field studies of the growth of experimental fires in buildings have usually been conducted on and within structures destined for demolition. Although such buildings may still be in good structural condition, they are not generally representative of current building practices and architectural innovations. This paper describes a field study conducted on a "new" test structure specifically designed and built as a vehicle for a variety of construction, sound transmission and fire tests. In this way, field evaluation could be accomplished on the integrated construction, rather than on components or individual assemblies.

The overall program was developed by the Research Department of the School of Architecture of Pratt Institute as part of its work under a Low Income Housing Demonstration grant from the U. S. Housing and Home Finance Agency. The primary objective of the Pratt Institute study was to demonstrate that significant reductions could be achieved in the cost of high-rise housing by the use of new materials and advanced methods of construction. While this demonstration is to be accomplished in an actual high-rise building to be erected subsequently, information on construction details, on sound transmission, and on the fire-protective features of candidate constructions was to be obtained by means of field studies on a second, or test building, specially designed and erected by Pratt Institute. The Fire Research Section, National Bureau of Standards, undertook the responsibility for the planning and the conduct of full-scale burnout tests in the test building.

[1] Figures in brackets indicate the literature references on page 1.

2. Objectives

With respect to fire protection, the primary aims of Pratt Institute were the protection of the occupants and the prevention of fire spread to other apartments and buildings. The protection of the building itself or of property within it was not a primary aim.

In the test building, structural and planning features were incorporated with the aim of accomplishing the following specific objectives:

1. Confinement of fire and smoke within the dwelling unit or other space in which the fire starts.
2. Protection of the building structure against failure to carry load.
3. Use of minimum quantities of combustible construction materials.

To the extent possible, the burnout tests were designed to obtain information on the degree to which these objectives could be accomplished.

Pratt Institute established additional fire resistance requirements [2], conformance to which was outside the scope of the burnout tests. The following tentative requirements, based on performance during the standard fire endurance test [1], were established by Pratt Institute:

Component	Requirement	
	Fire Endurance [1]	Non-combustible [3]
Structural—columns, bearing wall, girders, floor slabs, beams	Thermal ½ hr Structural 1 hr	
Exterior non-bearing walls		Noncombustible, if 30 ft or more from another building
Partitions between adjacent dwelling units; Partitions between dwelling units and public or service areas	Thermal ½ hr	
Partitions within dwelling unit; Closet shelving and kitchen cabinets		Noncombustible
Tenant storage area	Thermal 1 hr	

3. Description of Test Building

The test building was located in Carteret, N. J., and consisted of two two-story wings connected by a wood platform and stairs (see fig. 1). One wing was of steel frame construction with exposed exterior columns and dry floor construction; the other was of precast concrete, bearing wall construction. Each wing contained three rooms per story: two rooms, each about the size of a small bedroom, and the third representing a room of an adjacent apartment. The latter room contained a half-bath and an entrance to an outside balcony. The steel wing was approximately 12 by 34 ft in outside dimensions (balcony not included) with floor

FIGURE 1. *Test building viewed from southwest.*

area per room ranging from 114 to 134 sq ft; the concrete wing was approximately 14 by 32 ft outside with floor area per room ranging from 100 to 123 sq ft. Ceiling height was 8 ft. Three types of curtain wall construction, two types of party walls (between apartments), two types of floating floor construction, and innovations in plumbing and heating were incorporated in the test building. Additional details of the test building construction are supplied elsewhere [4].

Erection of the steel wing was started in May, the concrete wing in June, with the entire interior fiinishing completed by mid-July. Following acoustical tests of sound transmission through walls and floors in early August, burnout tests were conducted in the steel wing on August 24th, and in the concrete wing on September 1 and November 3, 1965.

4. Test Plan

Figure 2 is a plan view of the test building showing the arrangement of instrumentation for the first two burnout tests. The third test was similarly, but less completely, instrumented. During each test, a photographic record and visual observations were made and measurements were also made of temperature, radiation, smoke, gas composition, and structural deflection. However, because of staff and budgetary limitations, and the fact that the test site was located 200 miles from the laboratory, certain measurements were limited in scope, while others, e.g., ventilation effects, were not considered feasible.

For Test No. 1, a fire load of 6 lb/ft^2 of floor area was placed in room 1–6 of the steel wing. The same fire load was placed in rooms 1–3 and 2–3 of the concrete wing for Test No. 2 and Test No. 3, respectively. The fire load consisted of nominal 2- by 4-in dry Douglas fir lumber nailed into lattice-type cribs (see fig. 3). The cribs were supported 16 inches above the floor and were ignited by means of a flammable liquid (6 or 10 qt of normal heptane) placed in pans beneath the wood cribs. The overall dimensions of the aluminum sliding windows were 4 ft by 5 ft 5 in (21.7 sq ft) in the steel wing and 4 ft by 4ft 5in (17.7 sq ft) in the concrete wing. The initial window openings (11 in wide by 60 in high for room 1–6, and 14 in wide by 50 in high for rooms 1–3 and 2–3) were chosen to limit the maximum burning rate and to extend the burning period beyond 30 min, if possible, but no effort was made to prevent the breakage and fallout of glass due to the effects of fire. All other doors and windows were closed during test. No combustible material was placed in the adjoining rooms.

For Tests 1 and 2, the three second-floor rooms (except bathroom) were loaded to the 40 lb/ft^2 design load using concrete block set on end. For Test 3, the 20-ft long roof slab

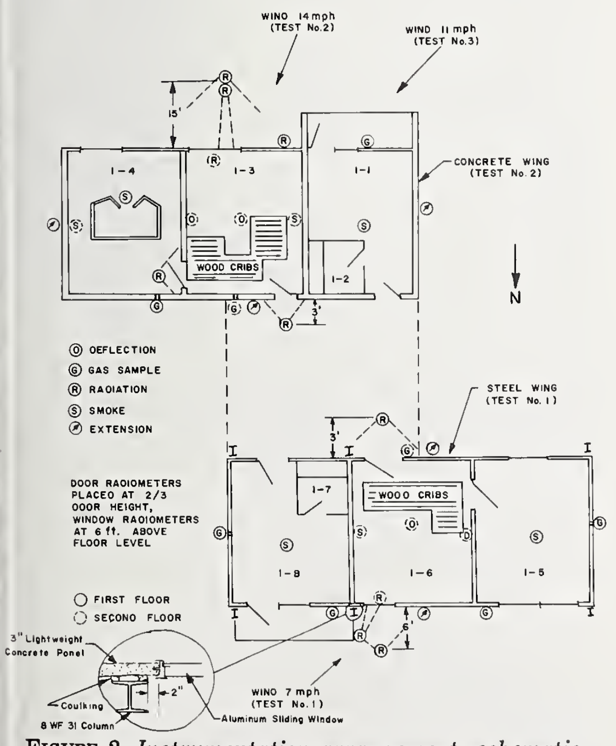
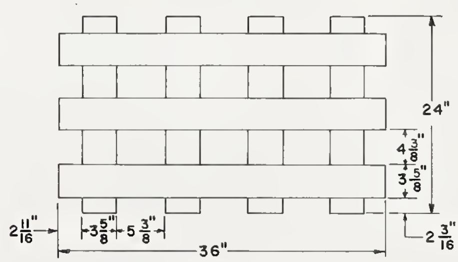


FIGURE 2. *Instrumentation arrangement—schematic.* All doors and windows closed during test except for window in fire room, which was partially open.



TEST	NO. OF LAYERS	APPROX. WEIGHT, lb EACH CRIB	TOTAL (5 CRIBS)
1	13	137	685
2	14	148	740
3	14	148	740

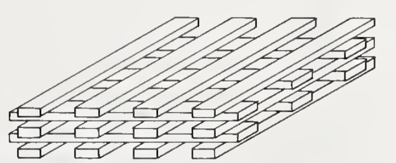


FIGURE 3. *Construction of wood crib.*

above the fire test apartment was similarly loaded.

Photographic coverage included 16 mm color movies from several locations, 16 mm color

TABLE 1. *Location of thermocouples*

Thermocouple No.	Location	Thermocouple No.	Location
	Test No. 1		
1	Room air NE	21	Exterior column 11 ft outer
2	Room air NW	22	Exterior column 11 ft inner
3	Room air SE	23	Exterior column 14 ft outer
4	Room air SW	24	Exterior column 14 ft inner
5	10-in. girder SE	25	Room 2–6 floor NE
6	10-in. girder NE	26	Room 2–6 floor NW
7	South joist E	27	Room 2–6 floor SE
8	South joist center	28	Room 2–6 floor SW
9	South joist W	29	Exterior (conc) wall, center
10	North joist E	30	Room 1–8 wall, center
11	North joist center	31	Room 1–8 wall, N, top
12	North joist W	32	Room 1–8 wall, N, bottom
13	South 12-in. beam E	33	Room 1–5 wall, N, top
14	South 12-in. beam W	34	Room 1–5 wall, N, bottom
15	North 12-in. beam E	35	Room 1–5 wall, center
16	North 12-in. beam W	36	Room 1–5 door, center
17	Exterior column 5 ft outer		
18	Exterior column 5 ft inner		
19	Exterior column 8 ft outer		
20	Exterior column 8 ft inner		
	Test No. 2		
1	Room air NE	24	Reinforcing wire level N
2	Room air NW	25	Room 2–3 floor NE
3	Room air SE	26	Room 2–3 floor NW
4	Room air SW	27	Room 2–3 floor SE
5	Steel angle S	28	Room 2–3 floor SW
6	Steel angle S	29	Room 1–1 wall, S, top
7	Steel angle N	30	Room 1–1 wall, S, bottom
8	Steel angle N	31	Room 1–1 wall, center
9	Reinforcing wire level E	32	Room 1–4 wall, center.
10	Reinforcing wire level E	33	Room 1–4 wall, S, top
12	Room 1–4 air	34	Room 1–4 wall, S, bottom
13	Room 1–3 floor	35	Room 1–4 door, center
17	Reinforcing wire level S	36	Exterior (S'wich) wall, center
18	Reinforcing wire level S	37	No. 3 bar, grout joint, W
19	Reinforcing wire level center	40	No. 3 bar, grout joint, N, center
20	Reinforcing wire level center	41	Steel strap N, center
21	Reinforcing wire level center	42	Steel strap NE
22	Reinforcing wire level N		
23	Reinforcing wire level N		

TABLE 1. *Location of thermocouples*—Continued

Thermocouple No.	Location	Thermocouple No.	Location
	Test No. 3		
44	Room air NE	48	Room 2–1 wall, center
45	Room air NW	49	Room 2–1 wall, air
42	Room air SE	50	Room 2–4 door, center
41	Room air SW	51	Room 2–4 wall, center
46	Room air NW (ASTM-type)	52	Room 2–4 air
43	Room air SE (ASTM-type)	53	Exterior (S'wich) panel
47	Reinforcing wire level, ceiling center	54	Fire room, 1 ft, bare thermocouple

time-lapse movies from a fixed location and 35 mm color transparencies.

Temperature measurements were made using thermocouples placed in the test room, on or near structural elements and on "unexposed" wall and floor surfaces of the adjacent rooms. The location of thermocouples is shown in figures 4 and 5, and listed in table 1. Air temperature in each adjoining room was measured by a single mercury-in-glass thermometer or a single thermocouple placed 5 ft above floor level. Except for fire room air thermocouples, all thermocouples were of No. 24 B&S gage

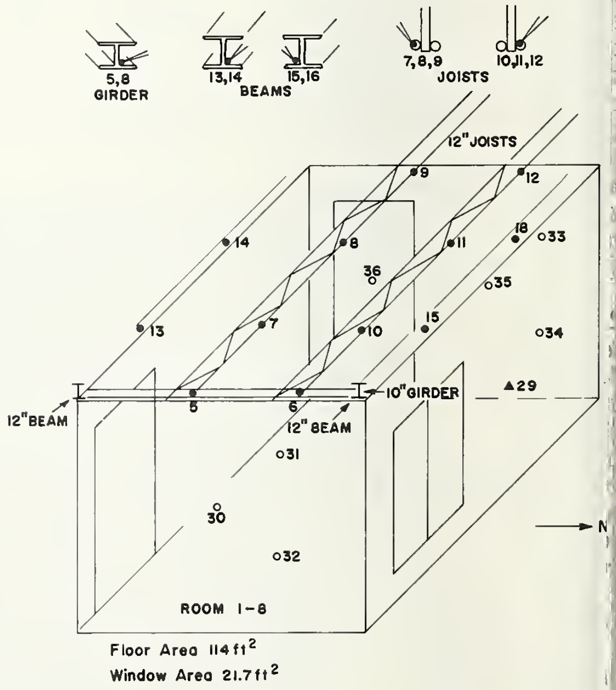


FIGURE 4. *Location of thermocouples, Test No. 1.*
• —on structural element; ○—on interior wall surface; ▲—on exterior wall surface.

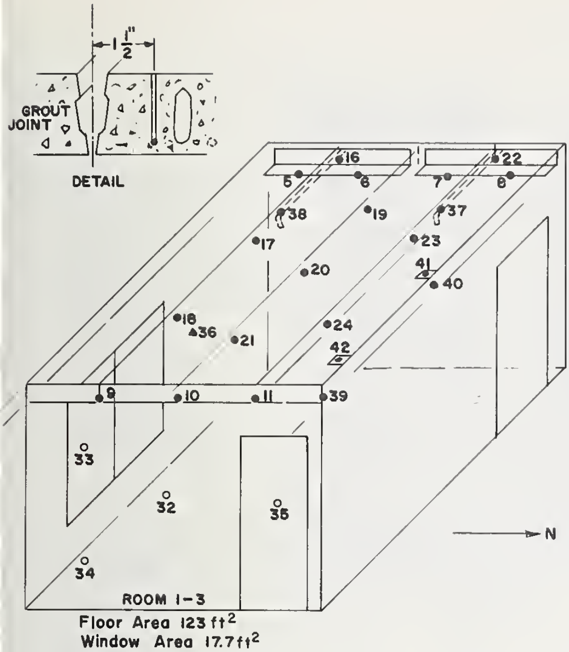


FIGURE 5. *Location of thermocouples, Test No. 2.*

Chromel and Alumel wires, the welded beads of which were mechanically fastened into predrilled holes in steel or concrete, or were placed under asbestos pads on "unexposed" surfaces. Four commercial 18-gage Chromel-Alumel thermocouples of the extruded metal-sheath, ceramic-insulated type with fast response times (less than 5 sec to 63.2 percent of step temperature change) were used to measure air temperature in the fire room in all tests. Fast response thermocouples give a more accurate measure of transient air temperatures compared to thermocouples placed in heavy pipes either for protective purposes or for minimizing the recorded temperature oscillations in standard fire endurance tests. In Test No. 3, two 18-gage Chromel and Alumel wire thermocouples mounted within porcelain insulators in steel pipes (ASTM-type [1]) were added for comparison purposes.

Radiometers were placed as shown in figure 2 with the objective of measuring irradiance levels and permitting estimates to be made of distances at which the spread of fire by radiation might occur through doors and windows, and between buildings. Irradiance levels were measured with a wide-angle single thermocouple disk radiometer [5] and with a wide-angle 10-junction thermopile radiometer. A commercial, narrow-angle total radiation pyrometer was used to measure the apparent blackbody temperature of the flaming interior of the fire room.

Smoke accumulation in rooms adjacent to or above the fire room was monitored by measuring the attenuation of a light beam (see fig. 2). The light source, consisting of a 30-W lamp, and the light detector, a type 1P39 vacuum phototube and battery, were assembled in a single box placed on the floor. Using a mirror flush-mounted on the ceiling, a double vertical light path was obtained, extending from 1 ft above the floor to the ceiling. This reduced errors in total smoke measurement due to stratification effects. The optical system was planned to exclude, as much as possible, all light not originating from the 30-W lamp source. As noted later, this was only partially achieved.

Indications were obtained of certain toxic combustion products in rooms adjacent to the fire room by means of direct reading colorimetric gas detecting tubes [6]. Using a manually-operated hand pump, a sample of the gas to be analyzed was drawn through the previously sealed detector tube where a chemical reaction occurred and gas concentration was indicated either by a color change or by a pre-calibrated length of stain. A separate tube was used to indicate the volumetric concentration of each particular component of interest. Measurements were made of CO, CO_2, HCl and HCN at a few selected locations indicated in figure 2.

Measurements were made of the deflection of the floor (or roof) above the fire room, both at the center of the room and near the partition at the approximate mid-span of the floor or roof system. In tests 1 and 2, invar wires were fastened to the surface of the finished floor above and passed upwards around pulleys mounted on the unloaded, relatively cool ceiling directly above the measuring points. The wires were then passed horizontally near the ceiling through a hole in the exterior wall to pulleys mounted entirely free of the building under test. Each wire passed downward and terminated with a weight to maintain wire tension. An indicating marker on each wire was used to follow the deflection changes on a graduated scale mounted behind the wire. In Test 3, a wooden boom, unsupported by the test building, was installed in order to mount the pulleys above the measuring points. A few measurements were also made of the lateral movement of exterior wall panels. In Test 1, the invar wire was fastened to the interior face of the light-aggregate concrete panel and passed to (and through) the opposite wall just above the finished surface of the second floor. In Test 3, the invar wire was fastened to the exterior aluminum face of the polystyrene-core sandwich panel. In Test 2, lateral movements of the north (concrete) wall and the concrete floor slab were made using dial gages. An invar wire was also fastened to the concrete party wall at the second-floor level to indicate longitudinal expansion of the 20-ft floor slab.

5. Test Results

5.1. Test Log

The following is an abbreviated log of visual test observations and measurements for each test. Detailed test observations as well as post-test investigation notes are given in the Appendix. Figures 6, 7 and 8 are photographs taken during the active burning stages of each test.

Test No. 1—Room 1–6, Steel Wing, August 24, 1965

Time (min)	*Summary Observations*
0	Test started at 11:22 a.m. Weather: Clear; Temperature: 74°F; rh 56%. Wind 7 mi/h, Direction: 30° (NE) (Newark Airport Weather Report)
5	Heavy smoke in Room 1–5.
15	Windows in fire room fell out. Flashover (complete involvement of room in flames).
16	Part of east partition wall fell into fire.
22-23	(Wallboard ceiling fell off; joists and beams exposed)[2]
25	Part of west partition wall fell into fire.
35	Fuel supply essentially consumed.

Test No. 2—Room 1–3, Concrete Wing, September 1, 1965

Time (min)	*Summary Observations*
0	Test started at 11:23 a.m. Weather: Partly cloudy; Temperature: 74°F; rh 69%. Wind 14 mi/h, Direction: 180-200° (S).
7	Section of upper right glass pane (½ ft^2) fell out.
8	Smoke at ceiling, Room 1–4.
9	Only one crib burning.
30	Upper two-thirds of right window pane fell out.
41	Window blown out by explosive concrete spalling; heavy black smoke; fire building up.
44	Flashover; flames out of window.
41-70	Intermittent violent spalling.
40-80	Development and enlargement of cracks in concrete walls, particularly at joints; water weeping from concrete walls; smoke and steam through cracks.
70	Decreased flaming; heavy smoke upstairs, Room 2–3.

[2] Not observed until later. Inferred from temperature recordings.

Test No. 3—Room 2–3, Concrete Wing, November 3, 1965

Time (min)	*Summary Observations*
0	Test started at 9:55 a.m. Weather: Clear; Temperature: 46°F; rh 68%; Wind: 11 mi/h, Direction 220° (SW)
3	Section of window glass (1½ ft^2) fell out.
4	Section of window glass (½ ft^2) fell out.
10	Bowing of aluminum sandwich panel and aluminum window frame.
20	Drops of boiling plastic expelled.
28	Remainder of window glass fell out.
31	Concrete spalling.
33	Sandwich panel fell out; room completely involved in flames.
45	Fuel supply exhausted.
45-150	Progressive smoldering and occasional flaming in sandwich panel with slow fire propagation to Room 2–4.

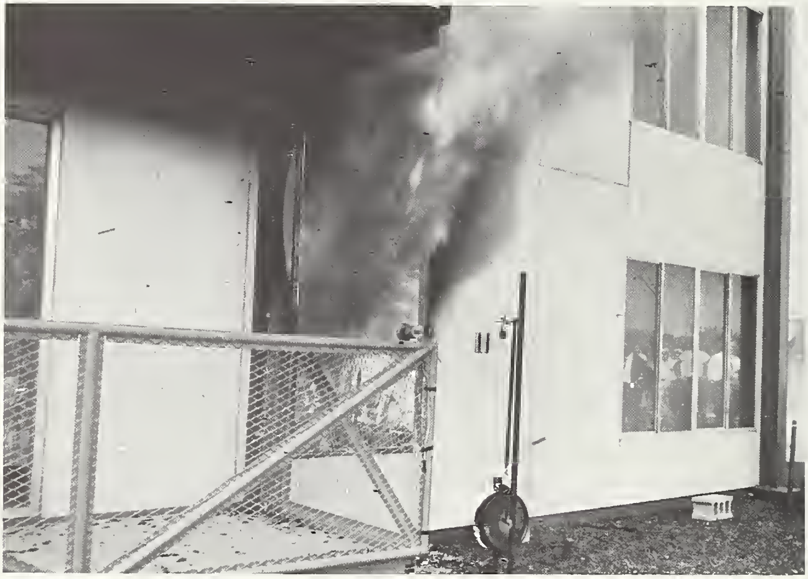


FIGURE 6. *Active burning stage, Test No. 1, approximately 26 min after ignition.*
Windows fell out at 15 min. Note radiometers in position.

Figure 7. Active burning stage, Test No. 2, 53 min after ignition.
Windows fell out at 41 min. Observer at left is making gas concentration measurement.

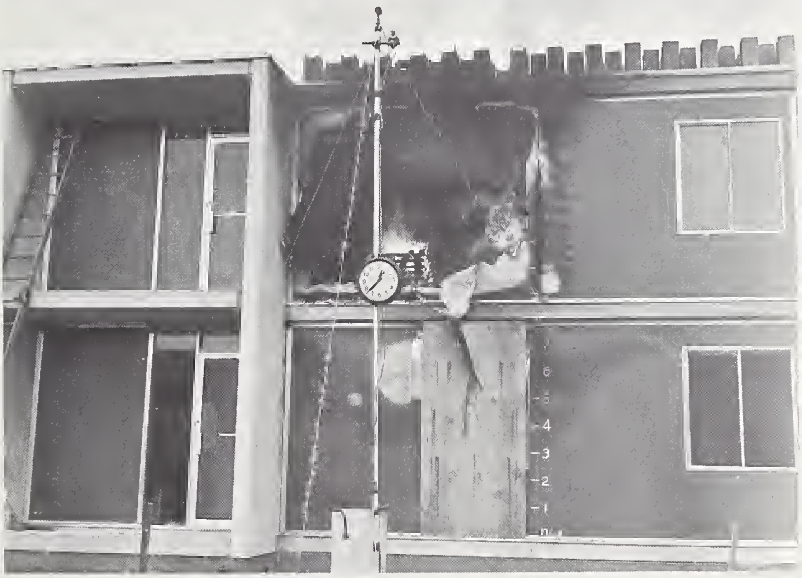


FIGURE 8. *Active burning stage, Test No. 3, 38 min after ignition.*
Sandwich panel fell out at 33 min. Note concrete block load on roof.

5.2. Moisture

The relative humidity in fire rooms 1–6 (Test 1) and 1–3 (Test 2) averaged 65 percent during the 7-day period prior to test.

The moisture content of the wood comprising the cribs was 10 to 12 percent, as measured with a prong-type electrical resistance moisture meter.

Measurements were made of the relative humidity of air in cavities within the second floor hollow-core concrete floor slabs and of the load-bearing partition wall one week prior to Test 2 with the following results:

Hollow-core floor slab, in web between cores, 73 percent rh

Hollow-core floor slab, near grout joint, 82 percent rh

Solid partition,

84 percent rh

These measurements are estimated to be within 2 percent of the values assumed in the calibration of the humidity probe.

Direct moisture content measurements of the concrete by extracting cores were attempted but did not prove successful.

5.3. Temperatures

Test No. 1

Selected temperatures recorded during Test 1 are shown in figure 9. The mean temperature in the fire room rose steadily until shortly after 15 min when flashover occurred, causing a further sharp increase. Air temperatures remained near 1830 °F from 18 to 32 min and then dropped off. The maximum temperature reading of an individual thermocouple was 2130 °F. The furnace time-temperature curve prescribed in the standard laboratory fire test [1] is included for comparison. In any comparison, however, it should be borne in mind that the latter test prescribes slow-response thermocouples (mounted in heavy protective iron pipes) compared to the faster response thermocouples actually used.

Also shown in figure 9 are average or representative temperature curves for the 12-in beam, the 10-in girder, the lower chord of the joist, and the exterior unprotected column at a height of 8 ft above the room floor. Temperatures on the interior structural members were rapidly elevated from about 212 °F to about 1470 °F when the gypsum board ceiling rapidly and completely dropped at 22½ min. Temperature measurements were made on the inner and outer flanges of the exterior column at heights of 5, 8, 11 and 14 ft above the floor of the fire room. The temperature was highest at the 8-ft height and lowest at the 14-ft height. The outer flange was generally, but not always, hotter than the inner flange due to the pattern of flow of flames and hot gases on the column. A maximum temperature of 968 °F at 30 min was recorded on the outer flange at a height of 8 ft. Temperatures in excess of 825 °F were recorded over appreciable areas of the column, corresponding to vertical distances of approximately 4 ft on the outer flange, 5 ft on the inner flange and 3 ft on the web. Some portions were exposed to this temperature for 15 min.

The prescribed temperature criterion for failure in ASTM E-119 is an average temperature rise of 250 deg F under an asbestos pad on the "unexposed" surface of a test wall or floor construction. This is based upon the attainment of a surface temperature, approximately 320 °F, at which some combustible materials, when in contact with the wall or floor, may begin to undergo progressive thermal decomposition leading to eventual ignition. This temperature rise was used as one means for evaluating the thermal performance of components during the burnout tests.

The temperature of the exterior face of the light-aggregate concrete panel under an asbestos pad reached a maximum of 176 °F at 90 min. The temperature at the center of the "unexposed" surface of the composite wall adjoining Room 1–5 attained a maximum of 238 °F at 105 min. A temperature rise of 250 deg F was reached beneath the thermocouple pad on the back surface of the connecting steel door between Rooms 1–5 and 1–6 at approximately 10 min. After 35 min, this temperature was within 70 deg F of the air in the fire room. The air temperature at the measuring location in Room

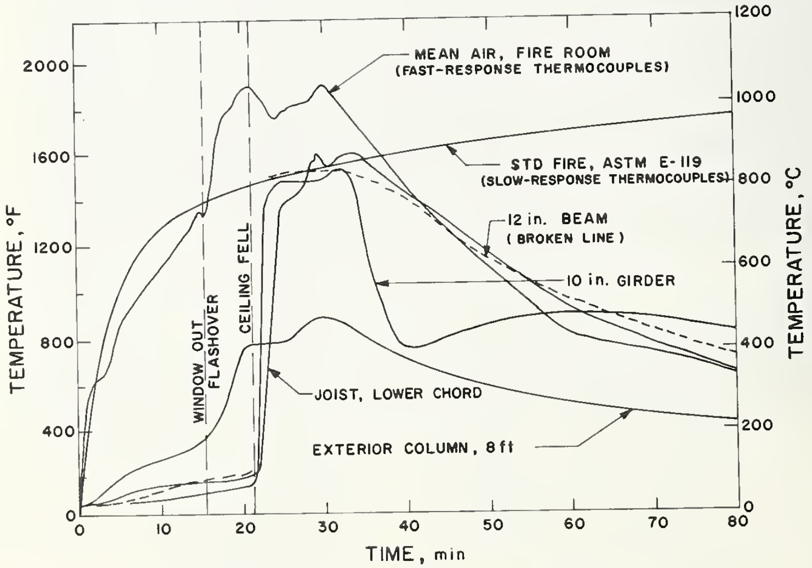


FIGURE 9. *Selected temperatures, Test No. 1.*

1–5 reached 150 ° F at 26 min and a maximum of 235 °F at 41 min. The temperature at the center of the "unexposed" composite wall surface of the adjoining apartment (Room 1–8) reached 156 °F at 2½ hr and was still rising slowly. The air temperature at the measuring location in the adjoining apartment reached a maximum of 108 °F after 31 min. The temperature on the finished floor (under thermocouple pads) of the room above the fire rose slowly to a maximum temperature of 170 °F at 85 min.

Test No. 2

As noted in the test log, only one of the cribs comprising the fire load remained burning after 9 min. The failure of all cribs to ignite simultaneously prevented the rapid and uniform buildup in temperature in the fire room. As shown in figure 10, the temperature measured by the NE thermocouple, situated above the burning crib, was considerably above the average of the three other thermocouples until after 41 min when complete window dropout and intense burning occurred. Because of the cooling effect of the southerly wind and fire room temperatures only slightly above the melting point of aluminum (1220 °F), the aluminum sandwich panel remained in place. The temperature on the exterior face of the aluminum sandwich panel under an asbestos pad reached a maximum of 770 °F at 55 min.

The temperature in the second floor slab above the fire at the level of the lower reinforcing wires is shown by a typical curve in figure 10. The maximum temperatures at six locations varied from 635 to 716 °F and occurred at approximately 80 min. At two other locations, temperatures remained at 212 °F for extended periods, presumably due to moisture evaporation endotherms, and the maximum temperatures reached were 260 and 365 °F.

A typical curve of temperature on the steel supporting angles is also shown in figure 10. At these east and west wall-ceiling joints, the migration (presumably through the hollow cores) and subsequent condensation of moisture, probably held the temperature at the steam point for extended periods. The maximum temperatures recorded on the steel angles ranged from 280 to 341 °F at about 100 min. In the grout joint along the north wall, a temperature of about 445 °F was measured during the period of 70 to 140 min.

The temperature at the center of the "unexposed" surface of the gypsum board partition between rooms reached a maximum of 206 °F at 120 min. A temperature rise of 250 deg F was reached on the connecting steel door at approximately 15 min. The air at one location in the adjoining Room 1–4 reached a temperature of 150 °F at 42 min, and a maximum temperature of 205 °F at 72 min. The temperature of the "unexposed" surface of the concrete partition to the adjoining apartment reached a maximum of 176 °F after 170 min. The air temperature at the measuring location in the adjoining apartment did not exceed 90 °F. The temperature on the finished floor (under thermocouple pads) of Room 2–3, above the fire, rose slowly and had reached 150 °F when measurements were discontinued after 5½ hr.

Test No. 3

Air temperatures measured in the fire room were intermediate to those measured in Tests 1 and 2, and slightly below the standard fire curve until 35 min. As shown in figure 11, room air temperature dropped rapidly when the aluminum sandwich panel wall fell out.

A comparison between the temperature re-

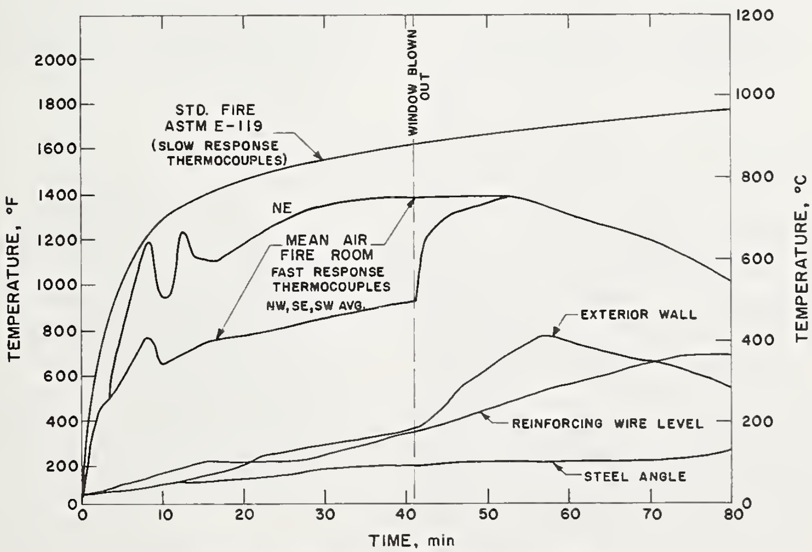


FIGURE 10. *Selected temperatures, Test No. 2.*

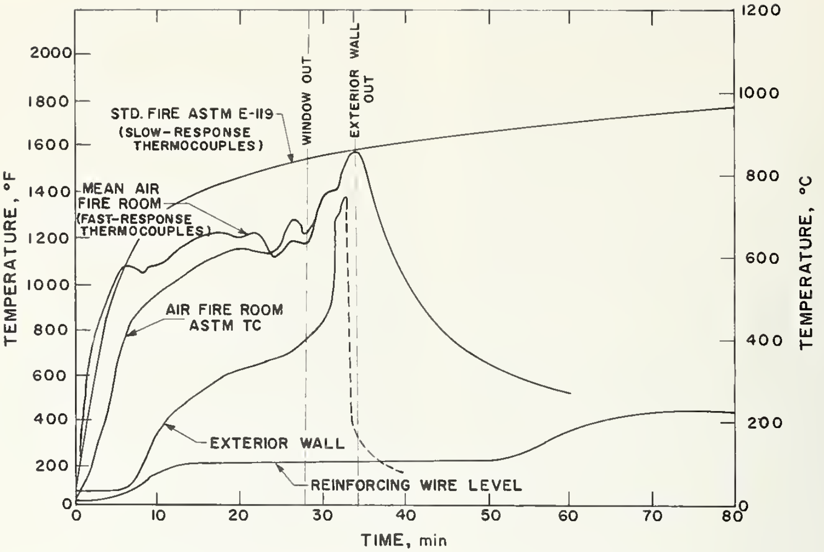


Figure 11. *Selected temperatures, Test No. 3.*

corded by a fast-response thermocouple and an ASTM E-119-type thermocouple is also shown. The thermocouple within the heavy steel pipe was in close proximity to a fast-response thermocouple whose temperature was in good agreement with the overall average. It is evident that, during a rapid buildup of temperature, a fast-response thermocouple may indicate temperatures 200 to 400 deg F higher than those indicated by the ASTM E-119-type thermocouple.

The temperature on the exterior face of the aluminum sandwich panel rose steadily to 840 °F at 30 min and then rapidly to a peak reading of 1380 °F immediately prior to panel fallout at 33 min.

Moisture evaporation appeared to limit the temperature in the roof slab at the level of the lower reinforcing wires to 212 °F for approximately 40 min, and the maximum temperature reached was 437 °F at 75 min.

The maximum temperature rise at the center of the "unexposed" surface of the gypsum board partition came within a few degrees of the ASTM prescribed limit (250 deg F) at about 75 min. This limit was reached on the connecting steel door at approximately 7½ min, and after 38 min, the door provided very little resistance to the flow of heat from the fire room. At the measuring location, the air in the adjoining room reached a temperature of 150 °F at 31 min, a temperature of 194 °F at 49 min, and a maximum temperature of 230 °F at 101 min.

The temperature at the center of the "unexposed" surface of the concrete partition to the

Table 2. *Selected temperatures and times*

Test	Maximum partition temperature and corresponding time				Time to 250 deg F temp. rise on door	Time to 150 ° F. air temp. in adjoining room	Maximum air temperature and corresponding time			
	Adjoining room		Adjoining apt.				Adjoining room		Adjoining apt.	
	Temp.	Time	Temp.	Time			Temp.	Time	Temp.	Time
	° F	*min*	*° F*	*min*	*min*	*min*	*° F*	*min*	*° F*	*min*
1	238	105	>156	>150	10	26	235	41	108	31
2	206	120	176	170	15	42	205	72	84+	78+
3	290	75	156	90	7½	31	230	101	86	160

adjoining apartment reached a maximum of 156 °F at 90 min. The air temperature at the measuring location in the adjoining apartment did not exceed 90 °F.

In table 2, a summary is presented of appropriate values of temperature, temperature rise and time for the three tests.

5.4. Radiation

Two types of radiation instruments were placed at a selected distance from the fire room window; a wide-angle thermopile radiometer to measure the irradiance level (often called radiation intensity), and a narrow-angle radiation pyrometer to measure the apparent blackbody temperature of a portion of the flames within the room.

Blackbody temperatures between 1450 °F and 1850 °F and averaging approximately 1650 °F, were recorded in Test 1 during the time period 15 to 35 min. This blackbody temperature corresponds to an actual (thermocouple) temperature of approximately 1830 °F during the same interval, and indicates a flame emissivity of about 0.7. In Test 3, a maximum blackbody temperature of 1690 °F was recorded during the relatively brief period of peak flaming.

Blackbody temperature and irradiance level measurements during active flaming were not obtained for Test 2.

To permit a comparison of irradiance levels between tests to be made, the maximum irradiance values were divided by the configuration factor F, normally used in radiant energy calculations based on the window openings only, in the manner suggested in reference [7]. These hypothetical window radiation intensity values, as well as those based on blackbody temperatures, are listed in table 3. Radiation levels at other points may be predicted by multiplying the hypothetical window radiation intensities by the configuration factor appropriate for the window area and point in question.

TABLE 3. *Maximum radiation levels*

	Fire room		Fire room window			Room above (or roof)	Exterior door
	Measured blackbody temperature	Equivalent radiation intensity	Measured irradiance I	Configuration factor F	Hypothetical window radiation I/F	Measured irradiance	Measured irradiance
	°F	*Btu/ft² sec*	*Btu/ft² sec*		*Btu/ft² sec*	*Btu/ft² sec*	*Btu/ft² sec*
Test No. 1	1650	9.4	3.0	0.148	20	>1.2	0.84
Test No. 3	1690	10.1	0.22	0.0224	9.8	0.15	0.32

For Test 1, the hypothetical window radiation intensity was approximately 20 Btu/ft^2 sec compared to an intensity of 9.4 Btu/ft^2 sec corresponding to the measured blackbody temperature. This means that radiation from flames above and surrounding the window in Test 1 contributed as much as that directly from the window opening. For Test 3, the hypothetical window radiation intensity was 9.8 Btu/ft^2 sec just prior to fallout of the aluminum sandwich partition.

Also listed in the table are maximum irradiance values for points close to the window above the fire room and at a distance of three feet from the exterior door. The irradiance level at the exterior door was appreciably higher in Test 1 due to flaming of the surface coatings on the door and adjacent wall. The irradiance level into room 2–6 through the closed window in Test 1 (as indicated by an outward-facing radiometer) may have been high enough to cause ignition of drapes or other furnishings.

5.5 Smoke

Smoke accumulation in various rooms was measured by the attenuation of light and expressed in terms of percent of initial light transmittance (T). Readings were converted to optical density per foot, $(1/L)\ \log_{10}\ (100/T)$, where L, the optical path length was twice the smoke meter-to-ceiling height, approximately 14 feet. No corrections were made for possible slight drift in the phototube circuits, for the moisture or soot deposits on the lenses and mirrors, or for the scattering of daylight by the smoke. The results are plotted in figures 12, 13 and 14.

These results represent the accumulated or total smoke concentration in the various rooms adjacent to the fire room as measured over a vertical path, and are essentially independent of smoke stratification effects. In a typical fire situation, smoke stratification could alter the time period prior to the onset of impaired visibility. Decreasing values following a maximum may be due to smoke settling or agglomeration, loss through openings, etc., but in the case of Tests Nos. 2 and 3, were principally due to the condensation of the moisture vapor portion of the "smoke" aerosol.

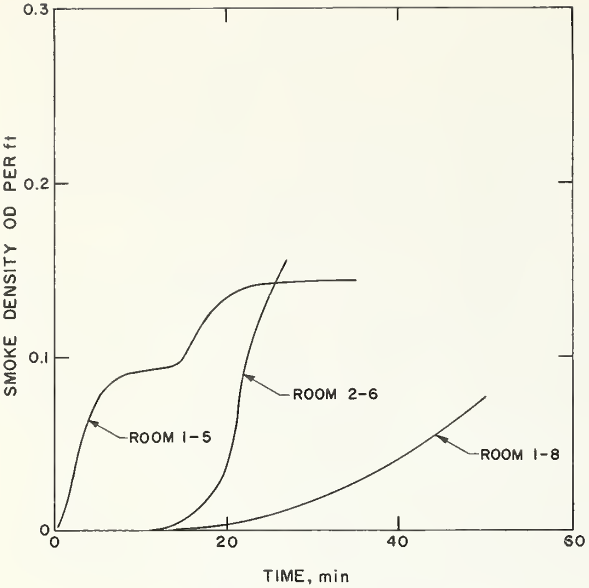


FIGURE 12. *Smoke density, Test No. 1.*

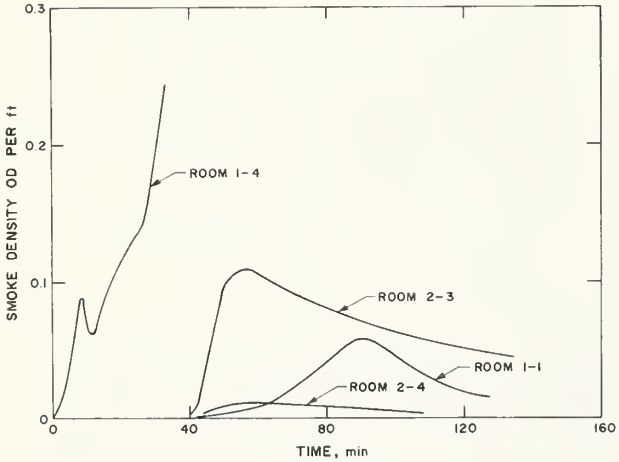


FIGURE 13. *Smoke density, Test No. 2.*

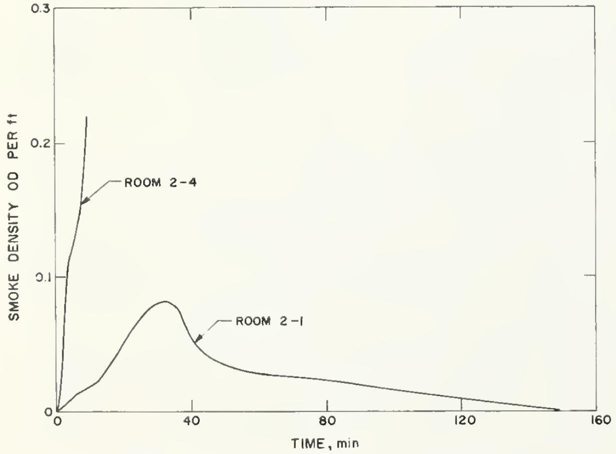


FIGURE 14. *Smoke density, Test No. 3.*

5.6 Toxic Combustion Products

In Test No. 1, positive indications were obtained for CO and HCN, but not for CO_2 nor HCl. In Test No. 2, several measurements for HCl also proved negative. In Test No. 3, observations were limited to CO, CO_2 and HCN and were taken only in Rooms 2–3 and 2–4. The maximum indicated gas concentrations and the corresponding times for all tests are given in table 4. Readings taken in the fire room (Room 2–3) in Test No. 3, although listed for information, are questionable because of: (a) excessive water vapor condensation in the sampling tube, and (b) temperatures in excess of the recommended operating range.

TABLE 4. *Maximum gas concentrations indicated by Draeger and MSA colorimetric tubes.*

Test No.	Room	Time	Indicated concentrations		
			CO	CO_2	HCN
		min	*ppm*	*%*	*ppm*
1	1–5	25, 47			30
		50	7,500		
	1–8	---------	No positive readings		
	2–6	52	2,500		
		54			5
2	1–1	72	70		
	1–4	27, 69	700		
		62, 70		8	
		58, 63			50
	2–3	33	150		
3	2–3	3	10,000		
		5½		13	
		21			25
	2–4	10	3,000		
		50		4	
		26			25

Because of the limited number of spot readings taken, the lack of positive readings should not be taken as proof of the absence of the component. Also, no verification was made of the manufacturer's claims for accuracy of the gas indicator tubes. The use of the recorded values as true concentration values may be limited by a number of factors, including the effects of elevated temperature, the absorption of gas on the surfaces of walls and on smoke particles, interpretation of the color change and interfering reactions by other gases and water vapor.

5.7. Deflection

Test No. 1

Vertical and lateral deflection measurements are shown in figure 15. Rapid deflection of the floor at the center of the room above followed shortly after the ceiling of the fire room dropped and all structural members became directly exposed to fire. The maximum deflection observed was 7.4 in, with a permanent sag of about 6 in after cooling. At the mid-span of the joists, the maximum deflection observed was 2¼ in.

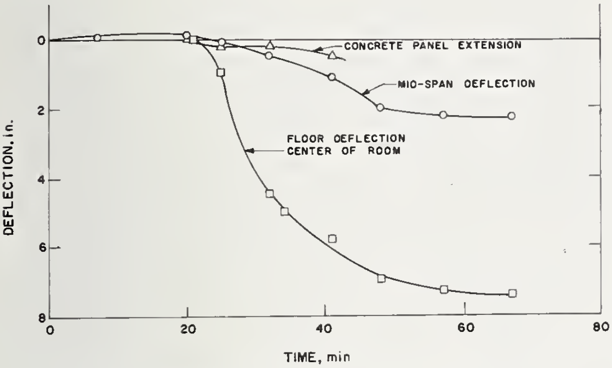


FIGURE 15. *Deflections and extensions, Test No. 1.*

The exterior light aggregate concrete panel at the measurement location had deflected (bowed out) 0.5 in at 41 min when the wire fastening came loose. After the test, it was noted that the panels had bowed out a maximum of about two inches.

Test No. 2

Vertical and lateral deflection measurements are shown in figure 16. The maximum deflection of the floor of the room above was 0.95 in at its center and 0.60 at the center of the span, both reached at 65 min.

The outward movement of the concrete north wall, at a point centrally located with respect to the fire room, reached a maximum of 0.06 in at 30 min, and then slowly receded. At 85 min, when readings were discontinued, the net movement with respect to the original position was 0.06 in inward.

Expansion of the 20-ft second floor slab (east-west), measured by means of an invar wire, occurred gradually and reached a maximum of 0.44 in at 70 min. A complementary measurement using dial gages on the east and west exterior walls (total span 32 ft) gave an overall extension of 0.49 in maximum at 89 min with a drop-off to 0.34 in after nearly 5 hr. The maximum east-west expansion at the first floor level was 0.08 in.

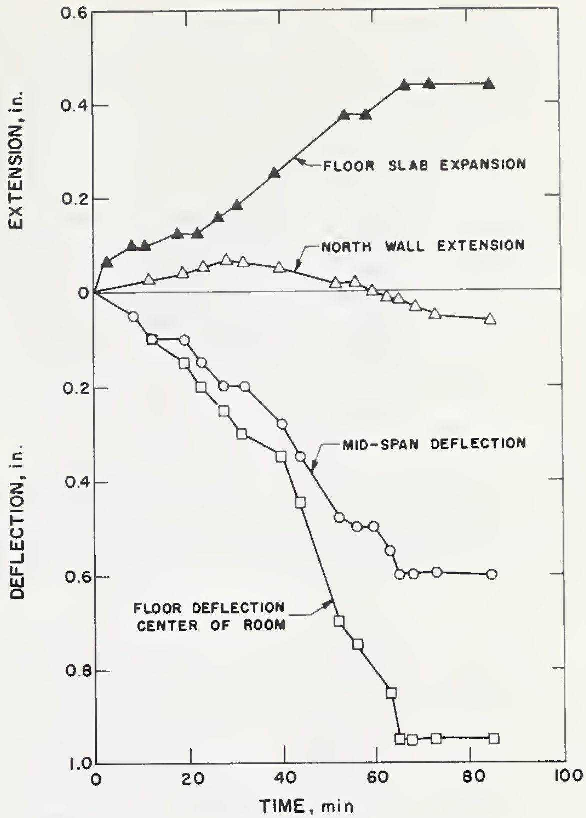


FIGURE 16. *Deflections and extensions, Test No. 2.*

Meaningful dial gage extension measurements on the exterior aluminum sandwich panel were not possible due to frequent flexures inward and outward, following burnout of the polystyrene core. Visual observation of 1½ in extensions were noted during test.

Test No. 3

Maximum deflections of the roof slab were 1.3 and 1.2 in at the center of the room and at mid-span, respectively. These occurred at 40 min. After 2½hr, when readings were discontinued, the slab had recovered about ½ in of this deflection.

The aluminum sandwich panel bowed in ½ in within 2 min, and then reversed, bowing outward gradually and continuously to a reading of 2¾ in at 30 min.

6. Discussion

Because of time and monetary limitations, field burnout tests are performed under a very restricted number of possible conditions. Such tests are neither standardized nor completely controllable, and considerable variations in time-temperature exposure may be encountered. It is clear that the area of ventilation openings (windows, cracks, etc.), the direction and magnitude of winds, and the type and orientation of the combustible load are of vital importance.

6.1. Burnout Tests

A burnout test is one which involves complete burnout of the combustible contents of a room or building. Such tests may be performed simply to measure the temperatures attained, but are more commonly done to gauge, directly, the possible life hazards which might result from an actual fire involving actual or assumed contents.

It is generally recognized that the customary furnishings of most dwelling rooms provide enough fuel to create a serious fire, and that the critical survival point in accidental dwelling-room fires may be reached in less than 10 min [7,8]. The critical survival point may result from toxic concentrations of combustion gases, decreased levels of oxygen content, impaired visibility due to smoke, or elevated temperatures, and of these, the decrease in visibility (and associated irritating effects) due to smoke is generally reached earliest [7,8]. For multi-story apartment buildings, it is also necessary to protect the building against any local structural failure which could endanger occupants.

The expression "fire severity" is commonly used to denote the intensity (i.e. temperature rise) and duration of a fire in terms of the equivalent exposure time in the standard fire endurance test. Nearly 40 years ago, Ingberg [9] reported the results of a series of burnout tests in experimental fire-resistive structures at the National Bureau of Standards, and formulated an approximate relationship between the combustible load (lb per sq ft of floor area) and the "equivalent fire duration" (hr). To make convenient the determination of "equivalent fire duration" from the burnout tests, the area under the standard furnace time-temperature curve plus cooling curve, and above an assumed baseline temperature, was measured in degree-hours. This was done for a number of fire exposure periods, and a curve was prepared in which these areas were plotted against the standard fire durations. Then, by measuring the area under the time-temperature curve from a burnout test in the same units and above the same baseline temperature, the equivalent fire duration of the latter could be read directly.

The assumption that equal areas under temperature-time fire exposure curves stand for equivalent severity of exposure, was realized at that time to be an approximation only, since temperature and time do not both enter into the heat conduction equation as linear factors. It must be further realized that the amount of combustible load (or its total calorific value) is not the only factor governing the resultant temperature history within a room, but that the type and distribution of the load, as well as the number, size and arrangement of ventilation openings, the thermal insulating qualities of the enclosing structure, and the presence of "external" factors such as wind and humidity, are usually of considerable importance. For example, the lower the thermal conductivity of the interior surfaces, the higher the room air temperature. Calculations indicate that a decrease in thermal conductivity by a factor of 10 could result in a 300 to 400 deg F higher room temperature [10].

The best available information on the combustible contents of representative types of occupancies and buildings was obtained about 1940 [11, 12]. From a total of 13 apartments and residences which comprised the survey, it was found that the movable-property combustible contents of an entire apartment or residence averaged 3.4 lb/ft^2 (range 2.4 to 4.9 lb/ft^2) over all areas, including basement, bathroom, bedroom, kitchen, living room, etc. The average value for bedrooms, closets included, was 5.0 lb/ft^2 (range 2.5 to 7.3 lb/ft^2), and for living rooms 3.9 lb/ft^2 (range 1.4 to 6.8 lb/ft^2). It was on the basis of these considerations that Pratt Institute suggested and we concurred in the selection of a fuel load corresponding to 6 lb/ft^2 floor area.

The total heat released by the complete burnout of 6 lb/ft^2 of nominal 2- by 4-in lumber arranged in lattice-type cribs is no greater than that from the complete burnout of 6 lb/ft^2 of wooden furniture arranged in a conventional manner. However, since the rate of fire growth in a "typical" furniture fire could vary widely depending upon its type, and upon the orientation of furniture with respect to sources of ignition, the use of closely-stacked cribs and simultaneous ignition was considered preferable and more readily reproduced. This arrangement produced a fire of considerable severity. For evaluating the fire safety of a structure by a single test demonstration, such a burnout test is not considered unreasonable or unrealistic.

6.2. Fire Intensity

For comparison purposes, the average fire room air thermocouple temperatures are plotted in figure 17 for all three tests. The differences may be attributed to: (a) wind and ventilation effects, including the vagaries associated with fallout of window glass and the development of other wall openings, and (b) differences in thermal, physical and combustible properties of the room surfaces.

Comparing the two concrete wing tests, the cooling effect of the strong southerly wind in Test 2 prevented simultaneous ignition of all cribs and the pattern of fire development was appreciably slower than that of Test 3. Although the wind in Test 3 was also southerly and somewhat unfavorable to rapid fire development, complete flame involvement with subsequent fallout of the aluminum-faced polystyrene core sandwich panel occurred.

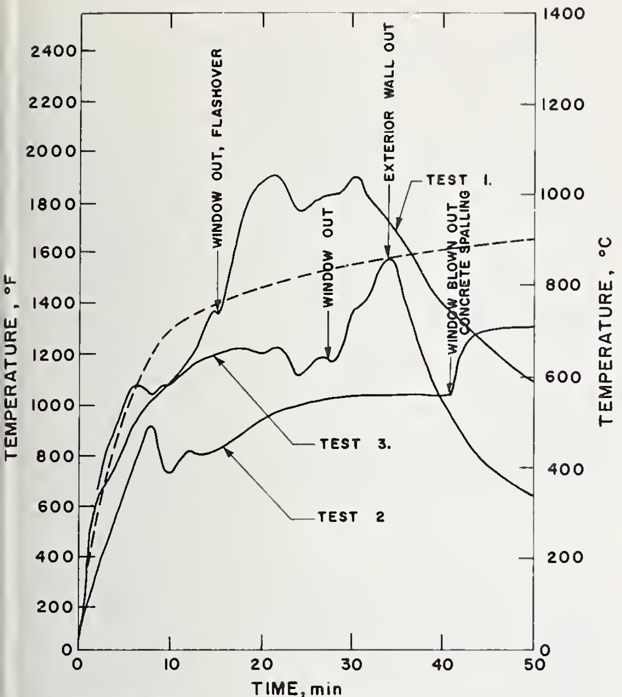


FIGURE 17. *Comparison of fire room mean air temperature.*

__________ measured with fast-response thermocouples, 1 ft. below ceiling

\- - - - - - ASTM E-119 fire exposure, slow-response thermocouples prescribed.

In Test 1, wind did not appear to affect fire development significantly. The flashover which occurred at 15 min is not unusual for rapidly developing fires in rooms with suitable ventilation and a fire load of 6 lb/ft^2. Flashover has been noted in previous burnout tests, including some with mock furnishing of less than 4 lb/ft^2 [13]. However, the involvement of the asphalt-impregnated paper and glass-fiber composite wall structure may have been a contributing factor to the severity of the fire which developed. It is estimated in Section 6.7 that the composite combustible floor, burnout of which was extensive, could have provided nearly 15,000 Btu per sq ft or the equivalent of 1.9 lb/ft^2 of fire load.

The collapse of the gypsum board ceiling was probably the result of the combination of the contraction of the gypsum board due to calcination shortly after flashover, and the thermal expansion of the steel supporting members.[3]

There is some evidence that concrete structures, especially when uninsulated and relatively moist (as for example, the ceiling and party wall slabs in Rooms 1–3 and 2–3), may have a moderating effect on the temperature built up during fires. For example, the additional heat required to vaporize and raise the temperature of 1 lb of water to 1382 °F is 1700 Btu. If 10 percent of the moisture content (assumed to be 10 percent by weight) in the two directly exposed concrete members were vaporized and heated to fire temperature, this would represent over 5 percent of the heat supplied by the fire load. Although the temperatures in both concrete wing tests were considerably below those in the steel wing test, no definite conclusions on this point appear justified. The use of heat flow transducers to measure the heat absorption of walls would be desirable in future tests.

6.3. Radiation

A principal means for fire spread from one burning building to another building across an open space is by radiant heat transfer. Radiant ignition can occur at distances considerably greater than those to which flames generally extend. Fire may also be spread by the flow of hot gases (convection) or by flying brands, but the heating of surfaces by radiation greatly increases the likelihood of ignition from these sources. The radiation hazard is reduced by providing adequate separation between buildings, or by providing a barrier wall with sufficient fire resistance to prevent the passage of an appreciable amount of heat for the duration of a fire.

The two factors which govern fire spread by radiation are (1) the radiation level which will ignite materials both on exterior building surfaces and on the interior building contents near window openings, and (2) the intensity of radiation from a building fire. Since the radiation emitted depends upon the flaming area and the fire temperature, it is clear that fire in a building with large windows (or other openings) may be more hazardous than one in which the percentage of openings to wall area is small. A reliable evaluation of the fire exposure hazard is important in urban area design, especially in view of the trend towards larger windows, and lightweight curtain walls of low fire resistance.

Techniques for determining permissible separation distances between buildings [14,15] are usually based on an irradiance of 1.1 Btu/ft^2 sec, since dry, bare wood may ignite at this level in the presence of a small pilot flame, as for example, a spark or flying brand. Neglecting the effects of wind and of flames outside of windows, a radiation intensity of 15 Btu/ft^2 sec is stated to represent a conservative estimate of the emission from the openings of a burning building. However, as noted for Test 1, the peak radiation level was 1.4 times this value due to flames extending outside the window. (In field burnout tests of typical single-family homes [7], peak radiation levels of 5

[3] Such rapid and complete dropout of the gypsum board ceiling was not observed during a recently-performed ASTM E-119 test on a floor-ceiling assembly of similar construction.

to 10 times this level were measured). Also, for the purposes of such calculations, it is important to consider as an opening any non-fire-resistant wall, i.e., a wall that might collapse and fall out during the course of a fire.

6.4. Smoke

Measurements were made for the purpose of estimating the extent of smoke buildup which could seriously obstruct human vision during a building fire. From past experience with accidental fires, and in controlled burnout tests [7, 8], decrease in visibility is often considered to represent a major life hazard to occupants.

A criterion sometimes used is based on the assumption that, when the "visibility" (or visual range) of a handlamp-illuminated sign drops to 4 ft, a room is smoke-logged to a degree that would seriously impede the escape of occupants [16]. It was inferred that this limit was reached when the light transmitted over a 4-ft path was reduced to 0.25 percent of the value in the absence of smoke, or an optical density of 0.65 per ft. Williams-Leir [17] has experimentally verified this threshhold level and determined that it corresponded to the ability to distinguish a 10-W lamp in a smoke-filled room at a distance of 11 ft, under idealized conditions involving dark-adapted observers stationed outside a smoke-filled room. On the other hand, it has been reported that observers within a smoke-filled room became "apprehensive about personal safety" when smoke concentration reached levels corresponding to approximately 40 percent and 80 percent light transmittance at a distance of 10 ft, depending on whether or not self-contained breathing apparatus was used [18].

Laboratory studies of smoke measurement [19] have indicated the desirability of making measurements over a vertical rather than a horizontal light path, since this provides a distinctive measure of the total smoke accumulation irrespective of vertical smoke stratification. Total smoke accumulation values, expressed in units of optical density per foot, may be considerably different from smoke density values measured horizontally at some particular level, say 5 ft above the floor ("eye level"), especially during the initial smoke buildup. As the smoke quantity increases, greater mixing and a close approach to uniform smoke distribution generally occurs. In this study, all results represent total smoke accumulation values, and not smoke density at eye level.

If it is assumed that a light transmittance of 16 percent over a viewing distance of 12 ft is critical, the limiting optical density would be 0.066 per foot. On the assumption of uniformly distributed smoke within the room, comparative critical times are summarized in table 5. The similarity in time periods for the three measurement locations may be noted. As expected, smoke penetration to the adjacent room (through openings around the closed connecting door) became critical in 2 to 7 min.

TABLE 5. *Time to reach smoke density 0.066 per foot*

Location in relation to fire room	Test No. 1	Test No. 2	Test No. 3
Adjacent room (same apartment)	4 min	7 min	2 min
Adjacent apartment	21 min	not reached	24 min
Room above	47 min	47 min	not applicable

It was determined, subsequent to completion of the tests, that the smoke meters probably were not completely free from the effect of smoke-scattered daylight entering through the windows. (This is generally minimized by proper collimation of the light beam source and the use of appropriate apertures in the smoke meter). Laboratory evaluation of the meters following the test series revealed that the smoke density test readings were lower than they should be, approximately 10 percent low at the limiting optical density. However, the effect upon the times listed in table 5 is estimated to be relatively minor.

6.5. Toxic Combustion Products

The upper and lower limits of the measuring ranges for the colorimetric indicator tubes used, and some references to the toxic hazard limits of these gases are summarized in table 6. The toxic limits are not well defined, but may serve as a guide in evaluating the indicated concentrations of toxic combustion products.

It can be seen from the values in table 4, that the indicated concentrations of CO, HCN and CO_2, in the room adjacent to the fire room, approach or exceed those which can produce breathing difficulties upon brief exposure. In Test 1, where an appreciable separation between the floor and wall panel occurred, a critical concentration of CO was measured in the room above the fire room. No measurements in the critical concentration ranges of these gases were obtained in the adjacent apartment of the steel or concrete wing. In all cases, the indicated concentration values apply to the particular measuring location, rather than to an "average" room concentration.

Table 6. *Measuring range of colorimetric indicator tubes and toxicological data for selected gases*

Data	Gas				
	CO		CO_2	HCN	HCl
Indicator tube data:					
Measuring range, lower	0.3%	0.001%	1%	2 ppm	2 ppm
Measuring range, upper	4.0%	0.1%	20%	150 ppm	30 ppm
Recommended upper temperature limit (tube and test gas)	50° C.	38° C.	50° C.	30° C.	40° C.
Toxicological data:[a]					
M.A.C.[b]	100 ppm		5000 ppm	10 ppm	5 ppm
Difficulty in breathing or irritation on brief exposure	1000 ppm		5%	50 ppm	35 ppm
Immediate danger to life (2 to 5 min)	1%		12–15%	200–300 ppm	1000–2000 ppm

[a] Draeger Information Sheets (includes toxicological references).
[b] Maximum average atmospheric concentration for 8-hr exposure without injury to health, as adopted by the American Conference of Governmental Industrial Hygienists, 1963.

6.6 Structural Effects

There was no evidence of rupture or other sudden structural failure of the floor and roof assemblies tested. Nevertheless, since excessive deflection of a structural member under the combined effects of load and fire exposure may be of critical importance, a careful evaluation of deflection is necessary.

Deflection limits for fire-exposed assemblies in buildings have not as yet been established. However, vertical deflection criteria in terms of general design features have been proposed [20] though not formally standardized for defining load failure of beams, floors and roof constructions during fire tests. Based on a survey of laboratory fire endurance tests on representative constructions, the requirement was proposed that both a maximum deflection $D>L^2/800d$, and a maximum hourly deflection rate $R>L^2/150d$ be exceeded as an indication of load failure. In these formulas, L is the span between supports of the member or element found to be critical under fire exposure, and d is the distance between upper and lower extreme fibers of the particular structural component or assembly. For those tests in which the construction was subjectively judged to have failed to sustain the applied load, the computed failure times according to these criteria were generally consistent and in good agreement.

Whereas, in a laboratory fire test, the entire span length L is loaded and fire-exposed, in these tests only one-half the span was exposed to fire. Although the effective span length under non-symmetrical heating conditions has not been defined, use of the shorter, fire-exposed length appears to be a reasonable approximation. This is supported by the measured deflections, shown in figure 15, where the maximum deflection of the floor occurred at the center of the fire room and was always more than three times the corresponding deflection at the midspan of the joists. Thus, using $L=10$ ft and d (the depth of the joist) $=1$ ft, load failure was arbitrarily considered to have occurred in Test No. 1 at 26 min. It should be noted, however, that the structure continued to support the 40 lb/ft^2 design load without collapse throughout the test.

Bowing of the unprotected steel column adjacent to the fire window of about ½ in. occurred in Test 1 according to visual estimate. This bowing may have resulted from thermal expansion of the 10-in. girder, and was recovered on cooling. However, it should be noted that the column was stressed to only a small fraction of its design load. Temperatures in excess of 825 °F and extending over vertical distances of approximately 4 ft on the outer flange, 5 ft on the inner flange and 3 ft on the web were recorded. Some areas were exposed to this temperature for 15 min. The maximum temperature recorded was 968 °F. In recent burnout tests at the British Fire Research Station, it was found that external unprotected columns and beams directly exposed to the flames, reached excessively high temperatures (more than 1022 °F) for fire loads of 6.2 and 12.4 lb/ft^2, but this did not occur for fire loads of 1.44 and 3.1 lb/ft^2 [21].

Prior to test, concern was expressed regarding the possible spalling of concrete if fire-tested while moist. Such spalling did actually occur, and in Test 2, was sufficient to expose a considerable number of reinforcing bars (see fig. 18). It is anticipated that, with adequate conditioning resulting in a close approach to moisture equilibrium, the tendency of concrete members to spall under fire exposure should decrease.

Figure 18. *Reinforcing bars exposed by explosive spalling of concrete wall, Test No. 2.*

6.7. Potential Heat

Laboratory measurements were made of the potential heat of many of the actual components of the floors, walls and ceilings of the test building. For component materials which were not available, estimates were made of their weights and potential heats based on previous measurements on similar materials. All values are summarized in table 7, which is arranged according to the locations of the materials in the steel or concrete wing.

Table 7. *Potential heat of construction materials*

Material		Nominal thickness	Density		Residue after firing	Potential heat	
						Weight basis	Unit area basis
Steel Wing Room 1–6:		*in.*	*lb/cu ft*	*lb/sq ft*	*%*	*Btu/lb*	*Btu/sq ft*
Finish floor 114 sq ft	Asphalt tile	⅛	124	1.25	63.3	3410	4260
	Particle board	¼	45	0.95	0.1	8050	7650
	Gypsum board*	½	--------	(2.0)	(75.)	(650)	(1300)
	Glass fiber	⅜	15	0.44	90.7	890	390
	Gypsum board*	½	--------	(2.0)	(75.)	(650)	(1300)
Vinyl cove strip molding		--------	0.136 lb per ft		16.2	9050	
Ceiling	Gypsum board*	½	52	2.16	(75.)	(650)	(1400)
	Steel joist*	--------	8.1 lb per ft		(90.)	(1000)	--------
	Gypsum plank*	2	--------	(10.5)	(80.)	(0)	(0)
Walls	Composite wall*	6½	--------	--------	--------	--------	(9420)
	Steel curtain wall	3/16	219	3.40	95.4	1210	4110
	Glass fiber insulation*	3	--------	(0.16)	(80.)	(2000)	(320)
	Gypsum board*	½	--------	(2.0)	(75.)	(650)	(1300)
	Light aggr. concrete panel	3	36	9.0	67.2	1120	10100
Concrete Wing, Room 1–3:							
Finish floor, 123 sq ft, same as above		1¾	--------	6.64	--------	--------	14900
Ceiling, hollow-core concrete slab		8		--------	92.9	−20	−1200
Walls	Composite wall*	6½	--------	--------	--------	--------	(9420)
	Reinforced concrete*	8	--------	--------	(95.)	--------	(0)
	Polystyrene foam	1	2	0.16	0.0	17020	2720
	Gypsum board*	⅜	--------	1.48	(75.)	(760)	(1120)
	Aluminum sandwich panel*	3	--------	(1.66)	(61.)	(6660)	(11060)
Concrete Wing, Room 2–3:							
Gypsum board partition		2½	--------	4.20	71.7	1000	4200

*Not measured. Figures in parentheses were estimated on the basis of previous measurements on similar materials.

The potential heat test method was developed several years ago [22] to measure the total heat released under standardized conditions representing a severe fire exposure, but without regard to the rate at which the heat was released. The method makes use of standard calorimetric techniques in which the burning of small quantities of combustible material in an otherwise inert material is assured by use of a combustion promoter which is added prior to test. By measuring heat of combustion in an oxygen bomb calorimeter both before and after exposure to a "standardized fire" (2 hr in air at 1382 °F), the difference may be considered as the potential heat of the material. Determinations may be made on simple materials, or on composite assemblies of materials from which a representative sample can be taken.

The potential heat values in table 7 are listed on a unit weight and a unit area basis, calculated from the gross heats of combustion and the percent residue. On an area basis, the potential heat values range from slightly negative for the hollow-core concrete ceiling slab (−1200 Btu/ft^2), to nearly 15,000 Btu/ft^2 for the finish floor assembly. The light aggregate concrete panel in the steel wing had a potential heat of 10,100 Btu/ft^2. It was estimated that the gypsum board/glass fiber composite wall and the aluminum/polystyrene core sandwich panel had potential heats of 9420 and 11,060 Btu/ft^2, respectively. The steel curtain wall assembly including gypsum board and glass fiber insulation was estimated to have a potential heat of 5730 Btu/ft^2.

It is quite evident that the burnout of the 6 lb/ft^2 of combustible furnishings produces a severe fire, but one which cannot possibly release the total heat stored within the complete thicknesses of the floor, walls and ceiling construction. As previously noted, the additional heat which was released during the burnout tests came primarily from the surface layers, from layers exposed when the surface layers fell off, or from combustible cores into which heat could readily penetrate. For example, a measurement was made on the light aggregate concrete panel removed from an area near the window on the steel wing after the burnout test. Its potential heat was measured as 550 Btu/lb, just one-half of its value prior to test. Other materials released smaller or larger fractions of their potential heat during the burnout tests.

As a rough estimate for the entire room, the potential heats of the floor, walls and ceiling have been computed on the basis of their respective areas and totalled in table 8. Of the approximately 6.57 million Btu of total potential heat in Room 1–6 of the steel wing an estimated 2.89 million Btu is considered to be "readily available" for release during fire burnout. This includes the potential heats of the gypsum board and steel joists of the ceiling, of the gypsum board and glass fiber insulation of the exterior steel wall, and of one-half of the exterior concrete wall and of the interior composite walls. For the floor, the potential heats of the asphalt tile and the particle board are included. Similarly, only 2.34 million Btu is

TABLE 8. *Estimated construction fuel load*

Material	Construction fuel load			
	Based on total potential heat		Based on estimated portion involved	
	Btu/sq ft	*Btu*	*Btu*	*lb/sq ft floor area* [1]
Steel Wing, Room 1–6:				
Ceiling/floor	17,730	2,022,000	322,000	
Exterior concrete wall	10,100	606,000	303,000	
Exterior steel wall	5,730	344,000	97,000	
Interior composite walls (2)	9,420	1,535,000	768,000	
Floor/ceiling	17,730	2,022,000	1,358,000	
Vinyl cove strip molding	----------	45,000	45,000	
TOTAL	----------	6,574,000	2,893,000	3.2
Concrete Wing, Room 1–3:				
Ceiling/floor	13,700	1,685,000	−37,500	
Exterior concrete wall	3,840	230,000	230,000	
Exterior aluminum sandwich panel	11,060	686,000	343,000	
Interior composite wall	9,420	670,000	335,000	
Interior concrete wall	0	0	0	
Floor/ceiling	13,700	1,685,000	1,465,000	
TOTAL	----------	4,956,000	2,336,000	2.4

[1] Equivalent combustible, taken as 8000 Btu per lb.

considered to be readily available of the approximately 4.96 million Btu of total potential heat in Room 1–3 of the concrete wing. The readily available portions of the potential heat in the steel and concrete wing rooms may be considered equivalent to 361 and 292 lb of combustible, respectively, taken as 8000 Btu per lb. On a floor area basis, this would be equal to 3.2 lb/ft^2 for the steel wing room and 2.4 lb/ft^2 for the slightly larger concrete wing. Of these totals, nearly 12,000 Btu per sq. ft, equivalent to 1.5 lb/ft^2, were contained in the composite finish floor.

7. Summary

The importance of full-scale burnout tests in providing valuable supplementary fire performance data was demonstrated in a series of three burnout tests in an experimental test building. Using a wood crib fuel load of 6 lb/ft^2 representing combustible contents, and a structural design load of 40 lb/ft^2 applied to the floor or roof above the fire room, these burnout tests permitted study of the fire effects on floor-wall joints, smoke penetration through doors and openings, and other complex interactions not generally feasible in conventional laboratory fire tests.

With regard to the specific objectives established by Pratt Institute for fire protection, the following results and comments were noted:

1. In both constructions, a small amount of flaming penetrated to the room above the fire room primarily through the development of separations between the floor assembly and the curtain walls. Some fire and smoke also penetrated through wall openings provided for electrical outlets. Fire penetrated gradually to the adjacent apartment in Test No. 1 through progressive smoldering of the composite party wall. Direct heat transmission through either the concrete floor or the joist and gypsum plank floor was not excessive. In both constructions, the party wall (between apartments) acted as an effective smoke barrier for about 20 to 25 min, based on an optical density (total smoke accumulation) of 0.066 per foot. This critical smoke level was not attained in the room above the fire room until after 45 min in both cases. Within the measurement limitations specified, critical toxic gas concentrations were either never reached, or in the case of carbon monoxide in the room above the fire room in Test 1, only recorded after the critical smoke level was reached.

2. There was no evidence of rupture, collapse, or other structural failure within the boundary of a floor or roof assembly during test. However, an appreciable vertical deflection of the floor system in Test No. 1 was recorded. In the absence of established deflection limits for fire-exposed building assemblies, proposed criteria based on laboratory fire endurance tests on floors and roof assemblies were applied, and, based on the assumptions used, "load failure" was considered to have occurred in Test No. 1.

The test plan did not include design load stressing of the unprotected exterior columns. However, sustained temperatures in excess of 825°F and a peak temperature of 968°F were recorded on the steel column adjacent to the fire window in Test No. 1, and at these temperatures, steel members are known to undergo appreciable loss in strength.

3. Laboratory measurements were made of the potential heat of many of the actual components of the floors, walls and ceilings of the test building. Estimates were made of that portion of the total potential heat stored within the complete thickness of the floor, walls and ceiling construction which is readily available for release during the burnout of the combustible contents of a room. On this basis, Room 1–6 of the steel wing contained a total "available" fuel load equivalent to 3.2 lb/ft^2 of combustibles, and Room 1–3 of the concrete wing contained the equivalent of 2.4 lb/ft^2. Of these totals, nearly 1.5 lb/ft^2 was contained in the composite finish floor. Slow fire propagation occurred in Test No. 3 from the prolonged burning of the foam polystyrene core of the aluminum-faced sandwich panel.

The successful completion of the burnout test program was accomplished through the "team" efforts of many members of the Fire Research Section, and other individuals, whose assistance is gratefully acknowledged: Les Furlow and John Watkins of the Photographic Services Section, NBS; Dr. John Rockett and Larry Orloff, of the Factory Mutual Research Associate Program; Cliff Carlson, Mel Abrams, and Sam Selvaggio, of the Portland Cement Association; and Professors John H. Callender and Ed Shiffer, Mr. Bob Davison and Miss Pat Wilson, of the Research Department, Pratt Institute School of Architecture.

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9. Appendix

Test No. 1

Time (min)	**Detailed Test Observations**
1:30	Heavy smoke
2:30- 3:30	Cracking of window glass and fallout of vinyl stripping.
5:00	One sq ft section of window glass fell out; smoke filling room 1–5 through door separations.
9:00	Heavy white smoke, Room 1–5.
10:00	Window glass bowing out at top.
13:30	Floor tile burning.
14:45	Window glass fell out; first flames out of window.
15:15	Flashover
15:45	Part of east partition wall fell into fire
16:00	Exterior door badly charred upper half; bowed in ½ in.
16:15	Paint ignites on outside of exterior door.
16:45	Flaming from exterior wall panel above window.
17:00	Flames reach top of second floor window.
19:00	East partition wall burning; flames reach radiometer.
20:30	Clock stopped; paint burning on exterior column
20:45	Second floor window pane out.
22:00	Clock and stake on fire.
(22:00-23:00	Gypsum board ceiling fell)
25:00	Part of west partition wall fell into fire; heavy smoke from second floor window.
28:00	Flames dying down.
29:00	More active flaming
30:00	Flames dying down; stucco on steel curtain wall panel flaming; panels deforming.
33:00	No further flaming out of window.
34:00	Remainder of second floor window pane fell out.
35:00	Interior of steel curtain wall bare of gypsum board and insulation.
39:00-53:00	Sections of east and west partitions fell.

Post-Test Observations

1. *Steel Curtain Wall Panels*—Buckling and distortion to roof level. Exterior stucco surface had ignited and burned on a portion of panels. Poured gypsum firestop fairly effective except where pierced by electrical conduit. A few localized areas where fire propagated in the insulation of second-floor wall. No insulation or gypsum board remained on wall of fire room after fire test.

2. *Light Aggregate concrete Panels*—Severe outward bowing. 1- to 2-in. separation from floor system provided access for smoke and fire to upper floor. No access where panel butted up against exterior column. Polystyrene aggregate burned out. Very little structural strength remaining.

3. *Interior Door*—Passage of flame above door frame into Room 1–5. Floor tile blistered.

4. *Joists*—Maximum permanent deflection approximately 6 in. on both joists along centerline of Room 1–6. Web rods near walls badly buckled. No apparent break in welds between joist and girder.

5. *Spandrel Beam* (North)—Sag (less than 1 in.), distortion and warping.

6. *Girder* (East)—No excessive distortion. Fire stop above girder generally effective except where interrupted for structural members and electrical conduit.

7. *Exterior Column*—Temporary distortion and bowing, estimated at ½ in. over length, recovered on cooling.

8. *Gypsum Board-Glass Fiber Composite Wall*—Very little of the gypsum board panels on the fire-exposed layer of the walls remained after fire test. Holes for electrical conduit (BX conduit), radiant heaters and thermostats permitted the passage of smoke into adjoining rooms on the first floor. No smoke penetration through second floor partitions. Asphalt-impregnated paper flamed and produced heavy black smoke.

9. *Floor*—considerable burnout of asphalt tile floor.

10. *Window*—Upper two-thirds of aluminum window frame melted.

Test No. 2

Detailed Test Observations

0:30	Dark smoke, becoming light at 2 minutes.
6:00	Window glass cracking; heptane flames from two pans only.
7:00	Section of upper right glass pane (½ ft^2 area) fell out.
8:10	Smoke at ceiling, Room 1–4.
9:00	Single crib only burning; upper edge of glass pane leaning out approximately 2 in.
14:00	Heavy white smoke in Room 1–4.
20:00-26:00	Bulging of aluminum sandwich panel, approximately 1- to 1½ in. in some places.
26:00	Exterior door bowing about ¼ in.
29:30	Increase in smoke from fire room, upper two-thirds of right windowpane fell out.
31:30	Concrete spalled off back wall.
35:15	East wall of fire room bowed in.
41:00	Window blown out by explosive concrete spalling; heavy black smoke; fire building up.
44:00	Flashover; flames out of window.
47:00	Gypsum board layer on east wall of fire room down.
41:00-70	Intermittent violent spalling from south and west walls.
58:00	Joint crack on exterior (North) wall about ¼ in.; reinforcing bars in west wall exposed.
60:00	Water dripping down wall, Room 1–1; separation at wall of Room 1–2, approximately ¼ to ½ in.
67:30	Insulation in east wall exposed through large opening.
72:00	Smoke heavy in Rooms 1–4 and 2–3.
73:00	Handle and upper portion of exterior door charred badly.
75:00	Flames receding; water weeping down exterior (north) wall.
86:00	Joint crack on exterior (north) wall ranges in width from $^7/_{32}$ in. (base) to $^7/_{16}$ in. (top of bldg.).
88:00	Smoke (steam) in Room 1–1 increasing from ceiling down.

Post-Test Observations

Room 1–3—(Fire Room) Severe spalling of concrete on north and especially west walls, with many reinforcing bars exposed. Maximum spall depth, up to 2 in. Aluminum sandwich panels intact except for hole in inner ply at upper corner of window; polystyrene insulation burned out; aluminum straps distorted severely. No spalling of hollow-core concrete floor slabs forming ceiling, but gridwork pattern of cracks over entire ceiling with severe cracks ($^1/_{16}$ in.) at SW corner. Cracks at ceiling joints, $^1/_{16}$ in. to ⅛ in. Gypsum board cover for steel angle still in place for approximately 6 ft. East wall—outer ply of gypsum board ⅔ down, glass fiber insulation exposed. Large crack (1½ in.) between this and aluminum sandwich panel. Door frame warped; door bowed out slightly; wall above and around door badly blackened.

Room 1–1—East wall—floor to ceiling separation (⅛ in.) at concrete wall joint; separation from aluminum door frame, ⅛ in.; stain damage due to extensive condensation and runoff. No damage to south, north or west walls.

Room 1–2—No damage.

Room 1–4—Cracks in hollow-core concrete floor slabs forming ceiling. Fire damage along upper 3 ft of intersection of composite wall and aluminum sandwich panel (1½ in. separation). The composite wall caved in toward Room 1–3, maximum 5 in. Fire penetration damage between wall and door frame limited to upper 2 ft; door and frame reasonably undistorted. Scorch marks on upper 8 in. of closet facing composite wall. No apparent damage to basemold (along 4 walls) or vinyl molding around closet. Extensive and general smoke and water sweat marks.

Room 2–1—Floor to ceiling separation in East wall (party wall) joint, and corresponding roof slab joint. Maximum separation about $^5/_{16}$ in. closing up to about $^3/_{16}$ in. when cool. Additional hairline cracks at corner-joints between prefabricated gypsum board partition wall and concrete wall and roof slabs. Steam penetration through hairline cracks.

Room 2–2—Hairline cracks at ceiling joints; separation $^1/_{16}$ in. upper half of joint at poured concrete wall filler unit. No damage due to fire, smoke or water (from concrete sweating).

Room 2–3—North wall—separation of floor both horizontally and vertically approximately ⅜ in.; slight evidence of smoke penetration under basemold; floor to ceiling crack in gypsum board. East wall (gypsum board partition) intact. West wall—floor to ceiling cracks ($^3/_{16}$ in. max) at wall panel joint; hairline cracks and water (concrete sweating) damage up to 2 ft above floor. South wall (aluminum sandwich panel)—separation from floor approximately ⅛ in. vertically and horizontally; fire and smoke penetration between panel and basemold at two locations above floor, SW corner of room .

Room 2–4—Separation of partition from roof panels, $^5/_{16}$ in. max provides clear access to Room 2–3. Maximum separation at floor $^3/_{16}$ in. vertically in SW corner; ⅛ in. horizontally NW corner. Separations of closet and of gypsum board (east wall) from roof slabs. Cracks along all hollow-core concrete roof slab joints. No fire, smoke or water vapor damage.

Exterior—North side—major floor to roof cracks (⅛ in. max after cooling) along vertical mortar joint east of exterior door. Slight hairline cracks at other vertical joints further east. Foundation (concrete block) cracks at NE and NW corners. Shear crack at floor level of poured concrete filler unit (near exterior door) with $^3/_{16}$ in. horizontal displacement. South side—separation (¼ in.) of aluminum sandwich from concrete wall. Cracks and separation of concrete balcony units, both floors. East and west sides—hairline cracks in vertical mortar joints only.

Test No. 3

Detailed Test Observations

3:10	1½ sq ft section of window glass fell out.
4:00	Another ½ sq ft section of window glass fell

	out; strong flaming observed in west and center cribs.
7:00	Left aluminum sandwich panel warped at upper right corner.
9:50	Window frame and aluminum sandwich panel bowed out at top approximately 1 in.
10:30	Entire center portion of left aluminum sandwich panel bowed out.
19:10	Flames bathing entire rear wall.
20:30	Smoking drops of boiling plastic expelled from top of window frame.
24:00	Cracks developing in east (gypsum board partition) wall; flames reach window.
28:10	Remainder of window glass fell out.
28:30	Thick flames fill upper half of room.
30:15	Aluminum window frame melting and falling out.
31-32	Concrete spalling.
32:50	Aluminum sandwich panel fell out; entire side open; complete flame involvement.
33:20	Heavy spalling.
44:30	Collapse of last crib; occasional flames and smoke from aluminum sandwich panel of east room.
47:00	Flaming in partition near door to east room.
50:00	Very few flames visible in fire room.
58:00	Smoke issuing from bathroom vent to roof.
59:00	Asphalt dripping from floor ledge.
60 to 150	Slow smoldering and occasional flaming with smoke and charring progressing in aluminum sandwich panel of east room.

Post-Test Observations

Room 2–3—(Fire room) Concrete spalling on north and west wall, but no reinforcing steel exposed; maximum depth 1½ in. Gypsum board cover over steel angle still in place although sagging in spots. Slight asphalt dripping from roof through ceiling slab joint. Gypsum board partition wall erect, but practically unsupported. Opening along vertical joint of concrete wall; several other small cracks and separations. Separation between interior door frame and north concrete wall.

Room 2–4—Blisters on interior door except for lower 4 in. Scorch marks (from ceiling to mid-height) on wall adjacent to door. Several holes through aluminum sandwich panel; polystyrene core burned out except for sections above and on east side of window frame. Maximum separation of aluminum sandwich panel approximately 1¼ in. at southwest corner of room. Separations at hollow-core concrete roof panel joints not appreciably greater than from Test No. 2.

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