feedback

OPERATION BREAKTHROUGH

U.S. Department of Housing and Urban Development

A COMPENDIUM OF FIRE TESTING

5

VOLUME

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foreword

Operation BREAKTHROUGH was initiated by the Department of Housing and Urban Development (HUD) in May 1969 to demonstrate industrialized techniques that could be used for the volume production of quality housing for all income groups. With this goal in mind, HUD selected 22 Housing System Producers to design and build housing prototypes on nine specially selected sites which represented a wide range of geographic, climatic and marketing conditions.

This compendium summarizes the tests conducted and the results obtained from the fire safety performance evaluation of the broad range of innovative materials and housing construction techniques that were used in the BREAKTHROUGH Program. It is hoped that this report will contribute to the advancement of current housing construction technology in addition to being of use to other organizations and individuals concerned with the fire safety of residential construction.

Charles J. Orlebeke
Assistant Secretary, Policy
Development and Research

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1.

INTRODUCTION

1. INTRODUCTION

Operation BREAKTHROUGH, which was established by the Department of Housing and Urban Development (HUD) in 1969, had as one of its principal objectives the stimulation of the development of innovative industrialized residential construction concepts that would increase the housing production rate and thus help to meet the nation's housing needs.

Firms selected for participation in the BREAKTHROUGH Program utilized a broad range of housing concepts. Some were modifications of industrialized systems in use at the time; others were new concepts which showed great promise by virtue of innovative designs and applications of materials. The building systems employed by the various Housing System Producers participating in the BREAKTHROUGH Program were evaluated prior to prototype construction in terms of a set of recommended performance criteria developed for this purpose through the combined efforts of the National Bureau of Standards (NBS), the National Academies of Science and Engineering and HUD.

Since many of the life safety issues that are associated with innovative housing systems are related to fire safety considerations, considerable emphasis was placed in this area. Fire performance standards were established for all classes of residential occupancies from single family detached to multi-family dwellings. Due to limitations in the state-of-the-art of the performance concept, the criteria were based on the performance levels of conventional materials and designs that were known to have acceptable fire safety characteristics.

Conventional housing designs for which fire test data were already available were evaluated on the basis of a review of drawings, specifications, calculations and approved listings. However, extensive testing was required to determine the fire safety performance of systems which employed new materials and design concepts. In addition to flame spread and smoke generation tests conducted on interior finishes of walls, ceilings, cabinetry and floor coverings; properties such as the fire endurance of roof/ceiling, floor/ceiling and wall assemblies were determined.

This compendium of the fire testing conducted during Operation BREAKTHROUGH lists and describes the assemblies that were tested and the results that were obtained. Building researchers and product manufacturers, in addition to homebuilders and designers, should find this a useful resource document for the design of safe, quality housing.

The listing of a fire test and its results in this report should not be implied as an endorsement by HUD of any building component or assembly.

2.

FIRE ENDURANCE: WALL ASSEMBLIES

2. FIRE ENDURANCE: WALL ASSEMBLIES

Because of the industrialized nature of Operation BREAKTHROUGH housing, many different types of wall construction were used. Some wall systems utilized standard wood frame construction or precast concrete whose fire endurance was already known.

The fire endurance of other systems incorporating components such as sheet metal, paper honeycomb cores, polyurethane foam cores and glass fiber reinforced polyester resin was not known. In addition, because of the modular concept used for much of the BREAKTHROUGH housing, double wall constructions of unknown fire endurance were commonly encountered.

For these reasons a considerable amount of fire endurance testing was performed to determine compliance with the criteria set forth by HUD for the Operation BREAKTHROUGH Program. In some cases, several variations of the same basic design were tested. These variations represented either improvements in initial fire safety performance deficiencies or other product improvements.

2.1 Test Methods

Fire testing was generally conducted in accordance with Sections 10 through 14 of ASTM Standard E 119. These sections pertain to tests of bearing and non-bearing walls and partitions. The basic test procedure consists of: (1) mounting a typical wall assembly in the test frame of the furnace with the side to be exposed to the fire toward the furnace flames, (2) applying the appropriate load (if a bearing wall), and (3) raising the temperature of the fire on the exposed side in accordance with the standard time-temperature curve, shown in Fig. 2.1 together with the points on the curve that determine its character.

The fire endurance of the wall assembly is determined by the time required to reach the first occurrence of any one of the following:

1. Inability of the specimen to sustain the applied load (in the case of a loadbearing wall only).

2. Passage of flame or gases hot enough to ignite cotton waste on the unexposed side at the point of passage.

3. An average temperature rise of 250°F (139°C) above the initial temperature on the unexposed side, or a temperature rise of 325°F (181°C) at any one point on that side. Note: This criterion was not considered to be critical for the acceptance of exterior wall systems proposed for use in Operation BREAKTHROUGH.

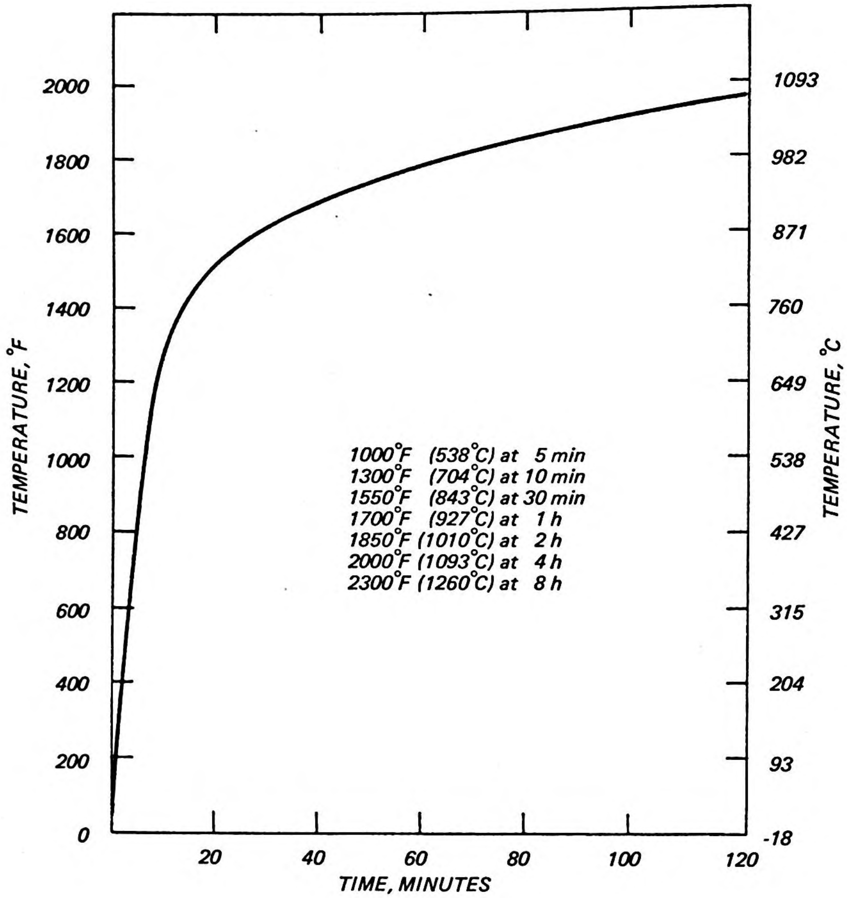

FIGURE 2.1
Standard ASTM E 119 Time-Temperature Curve

Due to factors such as the unique nature of modular construction and the philosophy that actual fire hazard conditions should be simulated as closely as possible, the following refinements were introduced into the testing program where applicable:

- Actual live and dead design loads as opposed to theoretical maximum design loads were applied to loadbearing wall assemblies. Loading requirements for a wall rated for use on the second story of a two-story house would be lower than the requirements for the same type of wall on the first story.

- The hose stream test suggested in ASTM E 119 was not required in the Operation BREAKTHROUGH Program, since primary emphasis was placed on damage occurring during a fire that would affect the life safety of the occupants of the building rather than on the material damage that could occur when a fire is extinguished.

- Loadbearing double walls formed by the juxtaposition of two factory-built housing modules were independently loaded, as would be the case in the actual structure.

- A split loading frame was used to prevent load redistribution wherein stiffer end members of the wall assembly take up the load when structural members in the center of the wall fail. When a solid loading frame is used, it is possible for this to occur without being observed.

- Eccentric loads were applied to wall assemblies during fire endurance tests when such loads would be expected in actual use.

- The fire endurance of an intra-dwelling interior wall assembly exposed to fire on *both* sides was determined (see Section 4.1). The data from this test were used to establish a basis of comparison with the data from the standard E 119 single side fire exposure test procedure.

- The NBS wall test furnace was operated with positive pressures over the upper two-thirds of the wall test specimens. The E 119 standard does not specify furnace pressures, and tests are commonly conducted with negative pressures. Under positive furnace pressures, which more closely represent the conditions that occur in actual building fires, gases are forced through fissures or openings in the wall assemblies. Wall tests discussed in this compendium that were not conducted at NBS (i.e., do not have an NBS reference) generally did not use positive furnace pressures.

REF: *Standard Methods of Fire Tests of Building Construction and Materials,* ASTM E 119, *1971 Annual Book of ASTM Standards,* Part 14.

2.2 Systems Evaluated and Results

2.2.1 Exterior Wall Assemblies

The wall systems in this category were single leaf constructions intended for use as the loadbearing exterior enclosures of single family detached housing units or of multifamily low-rise housing, such as garden apartments. The specimens tested included several different types of sandwich panels and a number of wood stud and steel stud walls.

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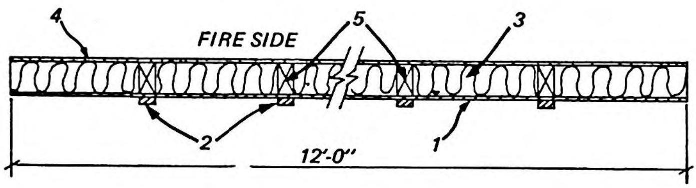
2.2.1.1 Wood Stud Exterior Bearing Wall

This wall assembly represents the first-story loadbearing walls of a two-story multifamily dwelling unit.

The construction (Fig. 2.2) consisted of 2 by 4 wood studs 16 in o. c. with 3/8-in exterior grade plywood siding and 1 by 2-in (nominal) vertical battens spaced 16 in o. c. The interior facing was 5/8-in type X gypsum wall board with the spaces between studs insulated with 3½-in fiberglass batts. The test wall was 12 ft long and 8 ft high. A load of 600 lb/ft was applied during the test.

Test Results:

An excessive temperature rise (325°F) was recorded at one thermocouple on the unexposed side at 57 min, and the test was terminated at 60 min with no other signs of failure.



Construction

1. 3/8-in exterior grade plywood siding, applied vertically, attached to studs with 8d nails spaced 6 in o. c. along the edges and 12 in o. c. at intermediate framing members.
2. 3/4 by 2-in wood battens 16 in o. c. nailed in line with studs at 16 in o. c.
3. 3 1/2-in glass fiber insulation stapled to studs.
4. 5/8-in type X gypsum wall board applied vertically, glued to studs with neoprene adhesive and attached with 4d S 449 DX nails spaced 6 in o. c. at the perimeter and at intermediate members. Joints taped with fiberglass mesh tape and spackled and nails spackled.
5. 2 by 4 studs spaced 16 in o. c.

Notes: Wall specimen was 8 ft 3/8 in high. Board joints were located at studs. 2 x 4 fire stops between studs at midheight of wall panel.

FIGURE 2.2
Horizontal Section of
Exterior Wall Assembly

REF: Baron, F.M. and Williamson, R.B., *Standard Fire Test of a Wood Stud Exterior Bearing wall,* Structural Research Laboratory Report No. 72-9, University of California, Berkeley, California, July 1972 (NTIS Accession No. PB 212 703*).

*Available from National Technical Information Service, 5285 Port Royal Rd. Springfield, Va. 22151.

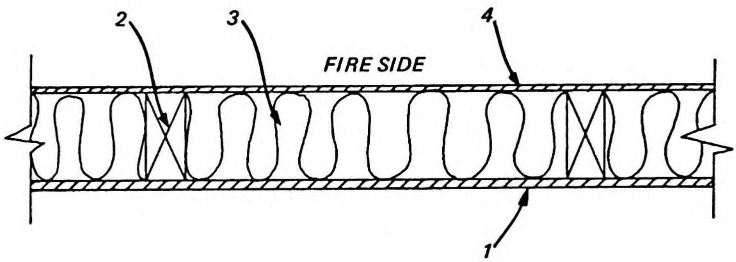
2.2.1.2 Exterior Bearing Wall With Wood Studs, Plywood Facings And Glass Fiber Insulation

This wall assembly, intended to represent the exterior first-story bearing wall of a single family two-story detached residence, was composed of 2 by 4 wood studs, 16 in o. c., an exterior facing of 3/8-in exterior grade A-C plywood, an interior face of 1/4-in interior grade C-D plywood and 3 1/2-in aluminum foil-backed glass fiber insulating batts in the stud spaces (see Fig. 2.3).

The wall specimen was 8 ft high and 16 ft long and was subjected to a load of 600 lb/ft during fire exposure from the interior side.

Test Results:

Failure occurred at 15 min 45 s by flame-through near the middle of one of the center plywood sheets. Shortly thereafter, excessive temperature rises, both average and individual, were recorded on the unexposed side. The test was terminated at 26 min 20 s to avoid structural collapse.



Construction

1. 3/8-in exterior grade A-C plywood attached with 6d common nail 6 in o. c along the edges and 12 in o. c. at intermediate framing members.
2. 2 by 4 wood studs, 16 in o. c. nailed to 2 by 4 top and sole plates with 16d common nails.
3. 3 1/2-in glass fiber insulation stapled to studs with aluminum backing toward interior (fire) side.
4. 1/4-in interior grade C-D plywood attached with 4d finishing nails 8 in o. c. throughout.

Notes: 2 by 4 fire stops between studs at midheight of wall panel. Plywood boards installed vertically, with joints located at studs and not staggered.

FIGURE 2.3
Horizontal Section of Exterior Wall Assembly

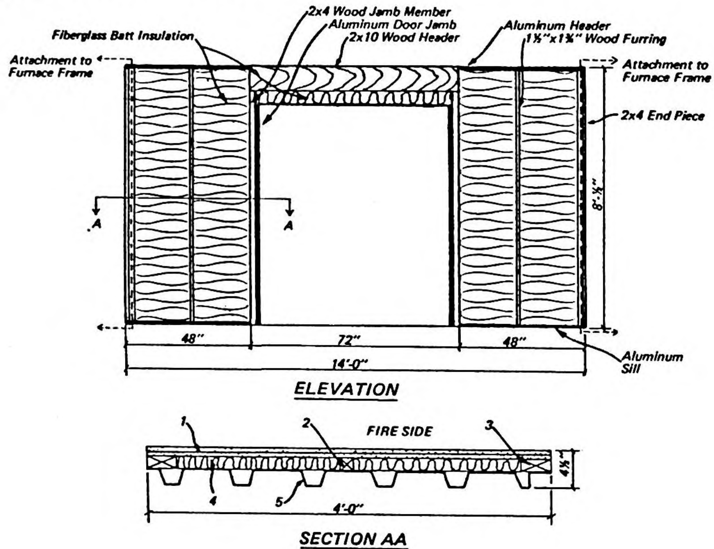
REF: Son, B.C., *Fire Endurance of a Conventional Plywood Faced, Wood Stud Exterior Wall Containing Fiberglass Insulation Batts,* NBS Report 10 407 (Revised October 1972), National Bureau of Standards, Washington, D. C. 20234. (NTIS Accession No. PB-214 781)

2.2.1.3 Corrugated Aluminum Sheet and Gypsum Board Loadbearing Exterior Wall Assembly

The test wall assembly, intended for use as the first floor exterior wall in multifamily low-rise housing (garden apartments), was composed basically of two 4-ft wide by 8-ft high panels (Fig. 2.4) on either side of a 6-ft wide opening for a sliding glass door. In the test, the door was omitted and the opening covered with three layers of 5/8-in type X gypsum board. A design live load of 530 lb/ft was applied to the test wall during the fire test.

Test Results:

Flame-through occurred at the top of the door frame at 54 min, followed by structural failure at 55 min.



Construction

1. Two layers of 5/8-in type X gypsum wall board installed vertically, with joints staggered. Each layer individually fastened to the wood furring and wood frames with No. 10 self-threading nails 10 in o. c.
2. 2 by 2 wood furring strips 24 in o. c.
3. 2 by 4 wood door jamb and panel edge.
4. 2 1/2-in glass fiber batts compressed into 1 1/2-in cavity.
5. 0.026 in corrugated aluminum exterior siding glued to wood members with code-approved construction adhesive.

Notes: The test specimen was 14 ft long and 8 ft 1/2 in high, with one wall panel on each side of a 6-ft door opening covered with three layers of 5/8-in type X gypsum wall board. 2 x 10 wood header installed above aluminum door frame installed in the opening. Top and bottom of panel sealed with extruded aluminum header and sill.

FIGURE 2.4
Exterior Wall Assembly
with Door Opening

REF: Son, B. C., *Fire Endurance of a Corrugated Aluminum Sheet and Gypsum Board Exterior Wall Assembly,* NBS Report No. 10 418, National Bureau of Standards, Washington, D. C., 20234. (NTIS Accession No. PB-217 365)

2.2.1.4 Steel Stud, Plywood and Gypsum Board Exterior Loadbearing Wall

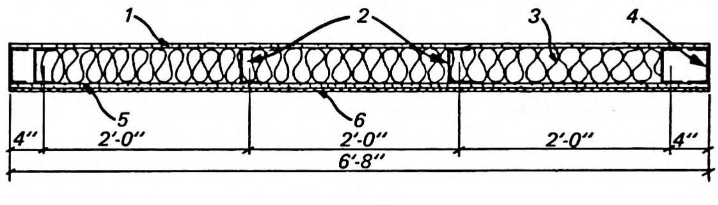
This exterior wall panel system (Fig. 2.5) was intended for use as the exterior bearing wall in low-rise housing units. Two fire tests were conducted: one with the panel construction as shown in Fig. 2.5, and the second test in which the exterior plywood siding was omitted, and the gypsum sheathing was attached with screws spaced 8 in o. c. along the edges and 12 in o. c. at intermediate framing members. In each test, the specimen size departed from that required in ASTM E 119 in that it was 6 ft 8 in wide and 8 ft high. Thus, only 47.25 sq ft of wall area was exposed to fire in contrast to the 100 sq ft specified in ASTM E 119.

In the first test, a 1017 lb per stud load was applied during the first 63 min and then increased to 1692 lb for the remaining time. In the second test, a 1356 lb per stud load was applied for the duration of the test.

Test Results:

The test of wall 1 was terminated after 78 min when the specimen was unable to sustain the load. However, an excessive temperature rise of 325°F (181°C) was recorded at a screw head on the unexposed side after 63 min.

The test of wall 2 was terminated at 60 min, although a temperature rise of 325°F on a screw head on the unexposed side was recorded at 53 min.



Construction

1. 5/8-in type X gypsum wall board installed vertically and attached to studs with 1-in type S-12 screws spaced 8 in o. c. along the edges and 12 in o. c. at intermediate framing. Joints taped and spackled and screw heads spackled.
2. 18 ga steel studs spaced 24 in o.c. and welded to 24 ga runner track on top and bottom.
3. 3 1/2-in thick glass fiber insulation batts.
4. 25 ga steel studs at each end of panel.
5. 1/2-in firecode gypsum sheathing installed vertically and attached with 1-in type S-12 screws spaced 12 in o. c. along the edges and 16 in o. c. at intermediate framing members.
6. 3/8-in A-C exterior grade plywood installed vertically and attached with 1 5/8-in type S-12 screws spaced 8 in o. c. along the edges and 12 in o. c. at intermediate framing members.

Note: Plywood and gypsum sheathing joints located along studs and staggered.

FIGURE 2.5
Horizontal Section of
Exterior Wall Assembly

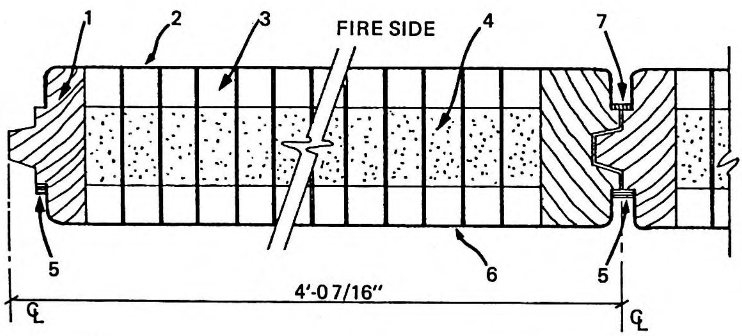
REF: Report, United States Gypsum Research Center, Des Plaines, Illinois, April 1971. (Unpublished)

2.2.1.5 Steel Panel Exterior Wall Assembly

Intended for use as exterior bearing walls of one-story, single family housing, this panel is composed of sheet steel facings, a paper honeycomb core partially filled with polyurethane foam and wood tongue and groove panel surrounds (Fig. 2.6). The individual panel size is 4 ft by 8 ft. The test wall assembly was composed of four such panels, resulting in an 8-ft high by 16-ft long test specimen. A load of 237 lb/ft was applied to the wall assembly during the fire test.

Test Results:

An excessive temperature rise at one point on the unexposed surface occurred at 7 min 50 s. Load failure occurred at 23 min, and flame-through occurred at 26 min at a joint between an end panel and the adjacent panel after the gas had been shut off at 23 min 30 s.



Construction

1. T and G wood end pieces (top and bottom surrounds are not T and G) attached to steel sheets with 14 ga 5/8-in staples at 12 in o.c.
2. 26 ga galvanized sheet steel on interior surface attached to the paper honeycomb core with epoxy adhesive.
3. 3-in thick phenolic resin impregnated paper honeycomb core with 3/4-in hexagonal cores.
4. 1 1/2-in rigid polyurethane insulation pressed into the honeycomb core.
5. 1/4 by 1/4-in butyl sealant.
6. 26 ga galvanized sheet steel finished with baked-on silicone paint on exterior surface and attached to the paper honeycomb core with epoxy adhesive.
7. Tongue and grooved joint on interior is sealed with 1/16 by 3/8-in vinyl tape.

FIGURE 2.6
Horizontal Section of
Exterior Wall Assembly

REF: Son, B.C., *Fire Endurance Tests of Steel Sandwich Panel Exterior Wall and Roof/Ceiling Construction,* NBSIR 73-135, National Bureau of Standards, Washington, D.C. 20234, January 1972. (NTIS Accession No. PB-221 310)

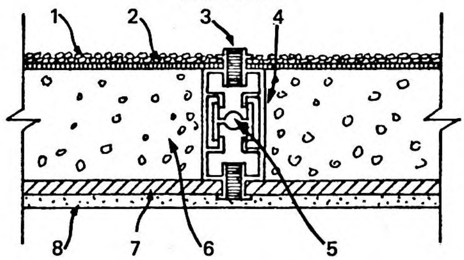
2.2.1.6 Exterior Sandwich Panel Bearing Wall Assembly

This panelized exterior loadbearing sandwich wall system was intended for use in single family, two-story detached housing. It consists of a 3-in polyurethane core foamed in place between an exterior facing of 1/8-in cement-asbestos board with stone aggregate set in an epoxy matrix and an interior face of 5/16-in plywood covered with 5/8-in type X gypsum wall board. The individual 4-ft by 8-ft panels are framed with aluminum surrounds (Fig. 2.7). Four such panels were used to construct an 8-ft. high by 16-ft long test wall.

The wall was subjected to a load of 310 lb/ft during the fire test, and the exterior face was fire exposed to ascertain the time that it would take for a fire to spread from one dwelling into another of the same type that is located immediately adjacent.

Test Results:

Impending failure under load due to excessive lateral deflection made it necessary to terminate the test after 23 min 30 s of exposure to fire. No excessive temperature rises were recorded on the unexposed side.



Construction

1. Stone aggregate set in epoxy matrix.
2. 1/8-in cement-asbestos board force-fit to the aluminum perimeter frame of the panel.
3. Synthetic rubber wedge.
4. Aluminum perimeter frame.
5. Aluminum "H" spline.
6. 3-in polyurethane foamed in place.
7. 5/16-in plywood force-fit to the aluminum perimeter frame of the panel.
8. 5/8-in type X gypsum wall board fastened to plywood with 1 1/8-in Type S bugle head screws spaced 4 in o. c. horizontally and 12 in o. c. vertically with first line of screws placed 6 in from the top and bottom edges of the assembly. Gypsum boards were installed after the four panels were placed in the test furnace frame. Panel joints and gypsum board joints were staggered.

FIGURE 2.7
Detail of Panel
Surround and Joint

REF: Son, B. C., *Fire Endurance Test of an Exterior Sandwich Panel Wall Assembly,* NBS Report 10 416, National Bureau of Standards, Washington, D.C. 20234. (NTIS Accession No. PB-217 363)

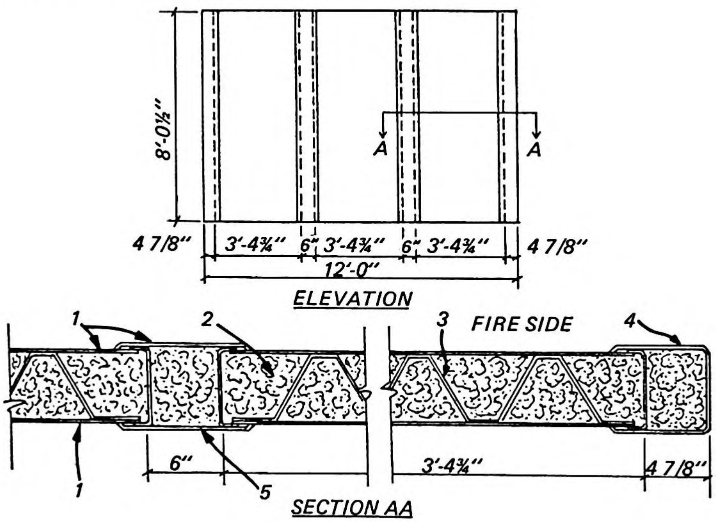
2.2.1.7 Glass Fiber Reinforced Polyester Resin Exterior Bearing Wall Assembly

This is a loadbearing wall system intended for the exterior walls of single family detached and low-rise multifamily housing units. It was composed of glass fiber reinforced polyester laminated sheets bonded to the two sides of corrugated stiffeners made of the same material (Fig. 2.8). The overall wall thickness is a nominal 4-in.

The test specimen was build with three 3-ft 4-in wide individual panels. Stiffeners were coated with an intumescent paint (except where bonded to the laminated faces).

Test Results:

Specimen was loaded with 700 lb/ft. After 30 min of exposure, an excessive temperature rise occurred at an individual point on the unexposed surface. The test was continued for an additional 60 min. When terminated after 90 min of exposure, the temperatures of none of the other thermocouples on the unexposed side had exceeded the permissible limits prescribed in ASTM E 119, and the wall was sustaining the load satisfactorily.



Constuction

1. 0.080-in thick glass fiber reinforced polyester laminate bonded to stiffeners with adhesive.
2. Mineral wool insulation packed into all cavities. Sodium silicate and water binder.
3. 0.050-in thick corrugated stiffeners made from same glass fiber reinforced polyester as 1.
4. Wall end stub molded from same composite material as stiffeners and laminated facing sheets.
5. Straight joint.

FIGURE 2.8
Details of Test Specimen

REF: Williamson, R. B. and Baron, F. M., *Fire Test of Fiberglass Reinforced Plastic Structural Wall Panel*, Structural Research Laboratory Report No. 71-4, University of California, Berkeley, California, June 1971. (NTIS Accession No. PB-222 900)

2.2.2 Intermodule Double Wall Assemblies

The use of factory built modules by many of the housing system producers in Operation BREAKTHROUGH resulted in loadbearing double walls formed by the juxtaposition of two module single leaf walls in the housing unit (Fig. 2.9). Such double walls may be either intra-dwelling or inter-dwelling. In some cases, the fire endurance of a single wall of similar construction was known from previous tests, but not that of the double wall. Therefore, a number of standard fire tests were conducted on such double wall constructions of various materials to obtain factual fire endurance data.

In actual use, each leaf of such a loadbearing double wall is loaded independently of the other. Therefore, in the fire tests of the loadbearing double walls, a split loading bolster was employed, which permitted each leaf of the wall assembly to be loaded separately (see Fig. 2.10).

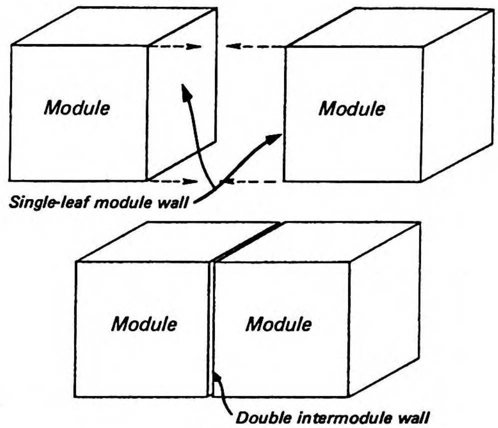


FIGURE 2.9
Intermodule Double Wall Assembly

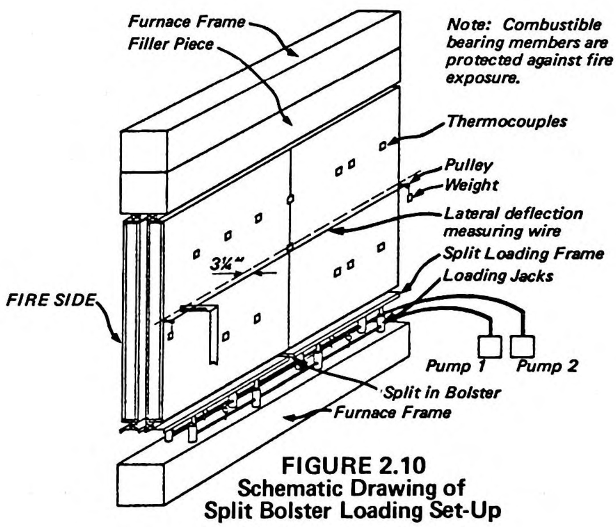


FIGURE 2.10
Schematic Drawing of
Split Bolster Loading Set-Up

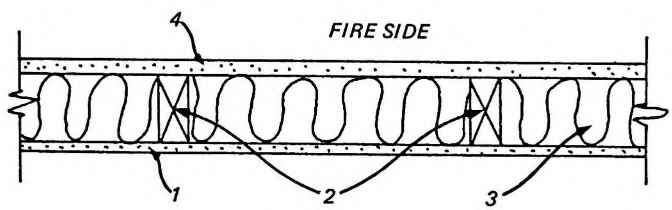
2.2.2.1 Wood Stud, Gypsum Wall Board and Glass Fiber Insulated Bearing Wall

The test wall was representative of a single leaf bearing wall of a housing module, which, when combined with an identical wall of an immediately adjacent module, formed a structural intermodule double wall system.

The wall construction consisted of 2 by 4 wood studs 16 in o. c. The side of the wall intended to be fire exposed was covered with 5/8-in type X gypsum wall board, while the opposite unexposed face was sheathed with 1/2-in non-rated gypsum board. Spaces between studs were insulated with 3 1/2-in thick glass fiber batts (Fig. 2.11). The test specimen was 8 ft high and 12 ft long. A load of 525 lb/ft was applied to the wall during the fire test.

Test Results:

Although flame-through occurred at 1 hr 7 min, when the test was terminated, the wall had met all E 119 criteria for a 1 hr fire endurance rating at 60 min.



Construction

1. 1/2-in non-rated gypsum wall board.
2. 2 by 4 wood studs 16 in o. c.
3. 3 1/2-in thick glass fiber insulation stapled into the spaces between studs.
4. 5/8-in type X gypsum wall board.

Notes: Gypsum board first glued to the studs with neoprene adhesive and then nailed to the studs and 2 x 4 floor and ceiling runners with #4 ring shank nails at 16 in o.c. All wall board joints and nails taped and spackled with 14 by 12-in ground fiberglass mesh and joint compound conforming to ASTM G-475. 2 x4 fire stops between studs at mid-height.

FIGURE 2.11
Horizontal Section of One Leaf of an Intermodule Double Wall

REF: Williamson, R. B., Mino, O., Dwelle, J.C., *Standard Fire Test of a Wood Stud One-Hour Bearing Wall Assembly*, Structural Research Laboratory Report No. 72-11, University of California, Berkeley, California, September 1972 (NTIS Accession No. PB 212 808).

2.2.2.2 Plywood and Gypsum Board Faced Wood Stud, Double Nonbearing Wall Assembly

The wall assembly evaluated during this test was intended to simulate both a single leaf exterior wall (as found in single family detached housing) and a double leaf wall assembly, which would occur at the interface of two adjacent parallel modules. The test was exploratory in nature, and no structural load was applied.

Two test walls were built. The first wall was 8 ft high by 16 ft long and was mounted in the furnace with the gypsum board face exposed to the fire side. The second wall was also 8 ft high but only 8 ft long. It was added to the unexposed side of the first wall at one end of the frame, forming a double wall with a 2 3/4-in air space between the two walls (see Fig. 2.12). The test was designed to obtain the fire endurance rating of both the single and double wall construction in one test.

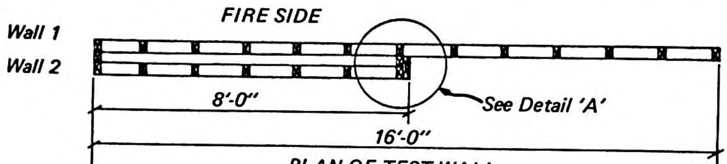
Each leaf of this assembly consisted of 2 by 4 wood studs, 16 in o.c. The exterior of the wall (facing the cavity side) was sheathed with 1/2-in plywood, while the interior, or exposed face, was 5/8-in type X gypsum wall board.

Test Results:

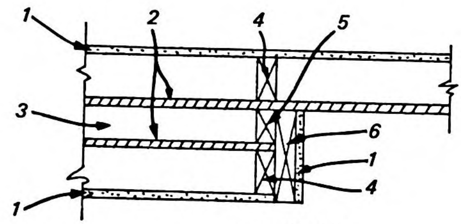
The single wall segment failed at 43 min when the average temperature rise on its unexposed face exceeded 250°F (139°C).

It was necessary to terminate the test at 47 min when flame penetration was observed at the top of the air space separating the two walls. The test results of the double wall segment, therefore, were inconclusive, although, based on judgment, it was estimated to have a fire endurance of 1 hr 2 min.

REF: Son, B.C., *Fire Endurance Test of Plywood Faced Exterior Walls for Single Family Housing,* NBSIR 73-140, National Bureau of Standards, Washington, D.C. 20234, March 1973. (NTIS Accession No. PB-220 226)



PLAN OF TEST WALL



DETAIL 'A'

Construction

1. 5/8-in type X gypsum wall board.
2. 1/2-in exterior grade A-C plywood.
3. 2 3/4-in air space.
4. 2 by 4 wood studs, 16 in o.c.
5. 2 by 2 3/4-in wood closure.
6. 2-in wood closure.

FIGURE 2.12
Horizontal Section of an Intermodule Double Wall

2.2.2.3 Wood Stud and Gypsum Board Intermodule Double Nonbearing Wall System

Most of the modules used by the HSP's for townhouses and garden apartments were placed so that the loadbearing walls ran from the front of the unit to the rear. With this arrangement, loadbearing double walls always occurred at party lines. Some HSP's, however, turned their modules so that the loadbearing double walls occurred always within the units and not on party lines. The party walls in these cases were always non-loadbearing. This was a test of such a nonbearing party wall, together with a 3-ft wide infill panel system installed between modules in order to gain an extra 3 ft in width at the party walls.

The basic construction (see Fig. 2.13) consisted of 2 by 3 wood studs 16 in o.c. with 2 layers of 1/2-in type X gypsum board on the room side of the wall and no sheathing nor insulation on the exterior side. The test assembly consisted of two identical 16-ft long by 8-ft high walls, made up of two 6-ft long panels separated by a 3-ft 4 1/2-in wide infill panel. Two different types of field applied, infill panel joint closure systems were included: one covered with wood trim and one with gypsum board.

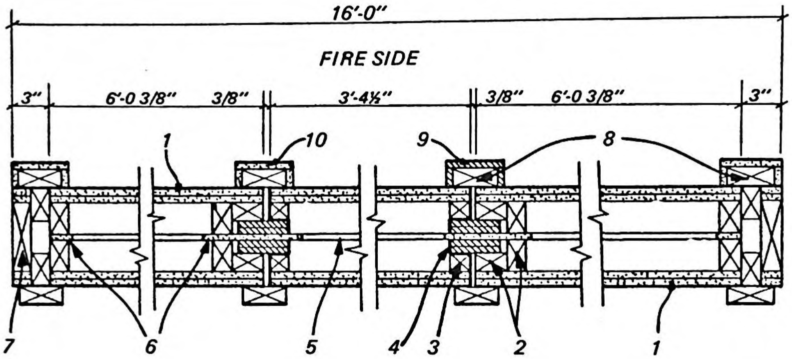
Test Results:

The overall fire endurance of the assembly was 2 hr 19 min, with failure by excessive temperature rise at one point on the unexposed surface of the assembly.

Failure of the fire-exposed wall leaf occurred at 1 hr 17 min, when flame penetrated through a gypsum board joint.

Neither of the two joints failed during the test, although it was apparent that the joint covered with wood trim would have failed before the one protected with gypsum board.

REF: Son, B. C., *Fire Endurance of a Wood Stud Interdwelling Double Wall Construction*, NBSIR 73-169, National Bureau of Standards, Washington, D.C. 20234, April 1973. (NTIS Accession No. PB-221 185)



Construction

1. 2 layers 1/2-in type X gypsum wall board. Base layer applied with 1 1/2-in bright ring-shank nails 12 in o.c. Face layer glued to base layer with construction adhesive and secured with 7d cement-coated box nails on 24-in centers. Joints of base and face layer were staggered.
2. 2 by 3 wood studs on 16-in centers with 2 by 3 wood top and bottom plates.
3. 2 by 2 wood filler.
4. 2 layers 1/2-in plywood.
5. 1/2-in space between wall panels.
6. 1/2-in type X gypsum board on top and bottom plates and at vertical joints.
7. 2 by 6 closure.
8. 2 by 4 battens at joints.
9. Wood archway trim.
10. 1/2-in regular gypsum board.

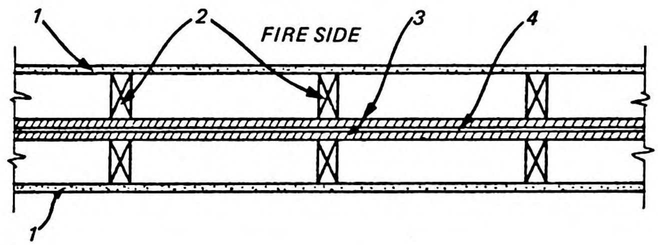
FIGURE 2.13
Horizontal Section of an Intermodule Double Wall

2.2.2.4 Wood Stud, Gypsum Board and Plywood Loadbearing Double Intra-dwelling Bearing Wall Assembly

This wall assembly, intended for use within a dwelling unit, was composed of two parallel walls consisting of 2 by 4 studs, 5/8-in type X gypsum board on the exposed room side and 1/2-in plywood on the other side (Fig. 2.14). The walls were separated by a 1/2-in air space. The test wall assembly was 12 ft long and 8 ft high. A load of 600 lb/ft was applied during the fire test.

Test Results:

The fire endurance of this wall assembly was 1 hr 15 min, at which time the temperature at one point on the unexposed side exceeded 325°F (181°C).

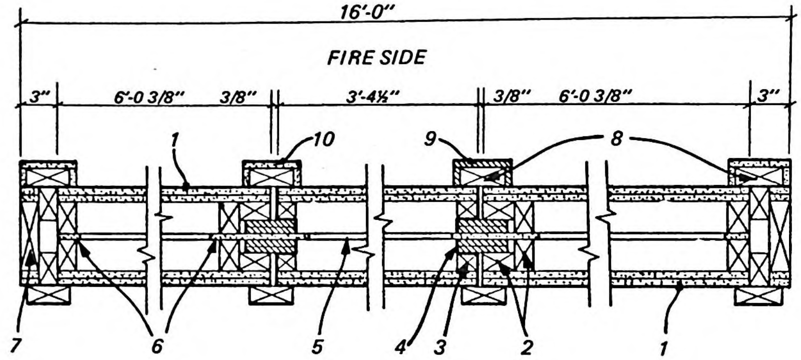


Construction

1. 5/8-in type X gypsum wall board attached to framing members by gluing with construction adhesive and nailing with 4d ring-shank nails 16 in o. c.
2. 2 by 4 wood studs, 16 in o. c., with 2 by 4 top and bottom plates.
3. 1/2-in plywood attached to framing members by gluing with construction adhesive and nailing with 8d wire shank nails 6-in o. c. along the edges and 12 in o. c. at intermediate framing members.
4. 1/2-in air space.

FIGURE 2.14
Horizontal Section of an Intermodule Double Wall

REF: Baron, F. M., Williamson, R. B., and Conklin, J. H., *Structural Research Laboratory Report No. 72-4,* University of California, Berkeley, California, January 1972. (Unpublished)



Construction

1. 2 layers 1/2-in type X gypsum wall board. Base layer applied with 1 1/2-in bright ring-shank nails 12 in o.c. Face layer glued to base layer with construction adhesive and secured with 7d cement-coated box nails on 24-in centers. Joints of base and face layer were staggered.
2. 2 by 3 wood studs on 16-in centers with 2 by 3 wood top and bottom plates.
3. 2 by 2 wood filler.
4. 2 layers 1/2-in plywood.
5. 1/2-in space between wall panels.
6. 1/2-in type X gypsum board on top and bottom plates and at vertical joints.
7. 2 by 6 closure.
8. 2 by 4 battens at joints.
9. Wood archway trim.
10. 1/2-in regular gypsum board.

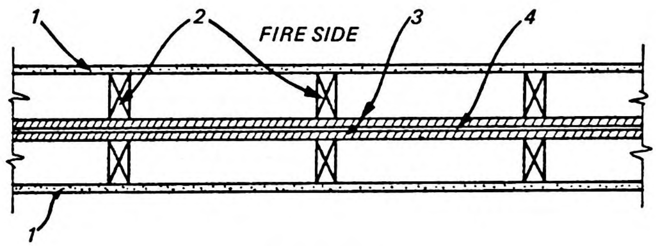
FIGURE 2.13
Horizontal Section of an Intermodule Double Wall

2.2.2.4 Wood Stud, Gypsum Board and Plywood Loadbearing Double Intra-dwelling Bearing Wall Assembly

This wall assembly, intended for use within a dwelling unit, was composed of two parallel walls consisting of 2 by 4 studs, 5/8-in type X gypsum board on the exposed room side and 1/2-in plywood on the other side (Fig. 2.14). The walls were separated by a 1/2-in air space. The test wall assembly was 12 ft long and 8 ft high. A load of 600 lb/ft was applied during the fire test.

Test Results:

The fire endurance of this wall assembly was 1 hr 15 min, at which time the temperature at one point on the unexposed side exceeded 325°F (181°C).



Construction

1. 5/8-in type X gypsum wall board attached to framing members by gluing with construction adhesive and nailing with 4d ring-shank nails 16 in o. c.
2. 2 by 4 wood studs, 16 in o. c., with 2 by 4 top and bottom plates.
3. 1/2-in plywood attached to framing members by gluing with construction adhesive and nailing with 8d wire shank nails 6-in o. c. along the edges and 12 in o. c. at intermediate framing members.
4. 1/2-in air space.

FIGURE 2.14
Horizontal Section of an Intermodule Double Wall

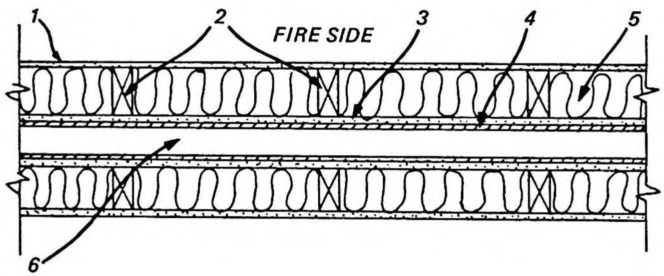
REF: Baron, F. M., Williamson, R. B., and Conklin, J. H., *Structural Research Laboratory Report No. 72-4,* University of California, Berkeley, California, January 1972. (Unpublished)

2.2.2.5 Wood Stud, Gypsum Board and Plywood Insulated Loadbearing Double Wall Assembly

The construction of this wall assembly consisted of two prefabricated walls, each 8-ft high and 10-ft long. In the test, the wall panels were placed in the test frame with the gypsum board to the exterior (exposed) faces and a 2-in air space between the plywood facings on the interior (Fig. 2.15). Each panel was subjected to a load of 740 lb/ft during the test.

Test Results:

The fire endurance of the double wall assembly was 62 min, at which time the wall on the exposed side failed under load.



Construction

1. 1/2-in type X foil-backed gypsum wall board.
2. 2 by 4 wood studs, 16 in o.c.
3. 1/2-in type X gypsum wall board.
4. 3/8-in plywood.
5. 3 1/2-in thick glass fiber insulation batts.
6. 2-in air space.

FIGURE 2.15
Horizontal Section of an
Intermodule Double Wall

REF: Fire Test Report WP-245, *National Gypsum Company, December 1971 (Unpublished).*

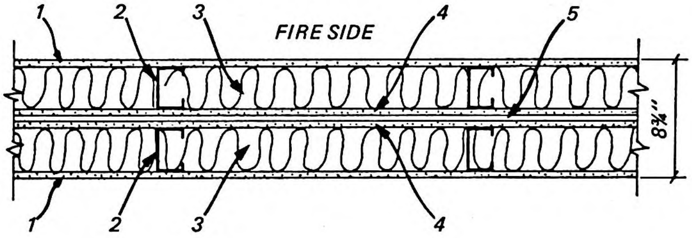
2.2.2.6 Steel "C" Stud and Gypsum Board Double Intermodule Bearing Wall

This wall assembly, intended for use as the first-story bearing wall of a three-story housing structure, was composed of two walls, each with 18 ga steel "C" studs, 24 in o.c., with 5/8-in type X gypsum wall board on the fire exposed (room) side, and 1/2-in regular gypsum board on the exterior side. The latter sides of each wall faced each other, separated by a 1/2-in air space (Fig. 2.16). The spaces between the studs in both walls were filled with glass fiber insulation.

The test assembly was 8 ft high by 16 ft long and was loaded with 1078 lb/ft during the test.

Test Results:

The fire endurance of the wall assembly was 42 min, when the fire exposed wall could not sustain the load. The test was continued and the unexposed wall failed similarly at 1 hr 13 min. Flame penetration to the unexposed surface occurred at 1 hr 15 min.



Construction

1. 5/8-in type X gypsum wall board installed vertically and attached to steel framing members with 1-in type S-12 bugle head screws spaced 12 in o.c. at intermediate framing members and 8 in o.c. along the edges. Joints were taped and spackled.
2. 3-in by 1 3/4-in cold-rolled, 18 ga steel "C" studs, 24 in o.c. and welded at top and bottom to 3 1/8 by 1 1/8-in steel channels, 1/16 in thick.
3. 2 1/2-in thick friction-fit glass fiber insulation batts.
4. 1/2-in type X gypsum wall board installed vertically and attached to steel framing members with 1-in type S-12 bugle head screws spaced 12 in o.c. at intermediate framing members and 8 in o.c. along the edges.
5. 1/2-in air space.

FIGURE 2.16
Horizontal Section of an Intermodule Double Wall

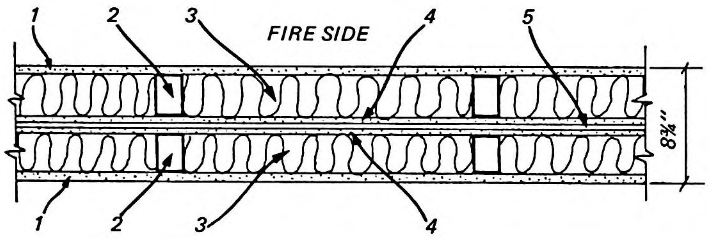
REF: Son, B.C. and Shoub, H., *Fire Endurance Tests of Double Module Walls of Gypsum Board and Steel Studs,* NBSIR 73-173, National Bureau of Standards, Washington, D.C. 20234, April 1973. (NTIS Accession No. COM 73-10844)

2.2.2.7 Tubular Steel Studs and Gypsum Board Double Intermodule Bearing Wall

This wall assembly was similar in size and construction to that described in Section 2.2.2.6, except that the "C" studs were replaced with 3 by 2 by 0.065-in tubular steel studs (Fig. 2.17), and 3 1/2-in thick glass fiber insulating batts were compressed into the cavities between studs. Its intended use was the same, and the same 1078 lb/ft load was applied during the test. The test assembly was 8 ft high by 16 ft long.

Test Results:

The fire endurance of this wall assembly was 1 hr 7 min when the wall exposed to the fire failed under load. Failure by passage of hot gases through the entire wall assembly occurred at 1 hr 37 min, and the unexposed wall member failed under load at 1 hr 43 min.



Construction

1. 5/8-in type X gypsum wall board installed vertically and fastened to steel studs with 1-in type S-12 bugle head screws spaced 8 in o.c. along the edges and 12 in o.c. at intermediate framing members. Joints were taped and spackled.
2. 3 by 2 by 0.065-in tubular steel studs, 24 in o.c. and welded on top and bottom to 3 1/8 by 1 1/8-in steel channels, 1/16 in thick.
3. 3 1/2-in thick glass fiber insulating batts compressed into 3-in cavity.
4. 1/2-in type X gypsum wall board installed vertically and fastened to steel studs with 1-in type S-12 bugle head screws spaced 8 in o.c. along the edges and 12 in o.c. at intermediate framing members.
5. 1/2-in air space.

FIGURE 2.17
Horizontal Section of an Intermodule Double Wall

REF: Son, B.C. and Shoub, H., *Fire Endurance Tests of Double Module Walls of Gypsum Board and Steel Studs,* NBSIR 73-173, National Bureau of Standards, Washington, D.C. 20234, April 1973. (NTIS Accession No. COM 73-10844)

2.2.2.8 Steel "C" Stud and Gypsum Board Double Intermodule Bearing Wall

This wall assembly was similar to that described in Section 2.2.2.6, with the following exceptions:

1. The "C" studs were 16 ga instead of 18 ga.

2. A 1-in air space left between the two walls in the assembly instead of 1/2 in.

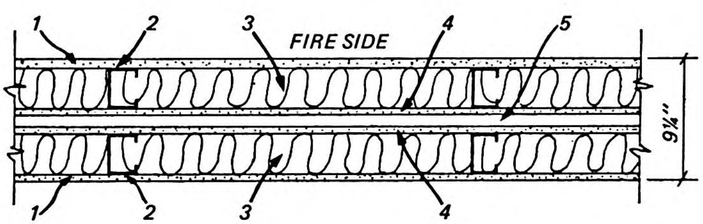
3. 3 1/2-in thick glass fiber insulating batts instead of 2 1/2 in (Fig. 2.18).

4. The test wall assembly was 8 ft high by 10 ft long rather than 8 by 16 ft.

5. A load of 680 lb/ft was applied during the test instead of 1078 lb/ft since the wall was representative of the first-story wall of a two-story unit rather than the three-story unit referred to in 2.2.2.6.

Test Results:

The fire endurance time of the wall assembly was 2 hr 8 min when the fire exposed wall of the assembly failed under load.



Construction

1. 5/8-in type X gypsum wall board applied vertically. Attached with 1-in type S-12 drywall screws spaced 8 in o.c. along the edges and 8 to 10 in o.c. along intermediate framing members. Joints finished with tapeless joint compound.
2. 3 by 1 3/4-in 16 ga galvanized steel "C" studs, 24 in o. c.
3. 3 1/2-in thick glass fiber, paper-backed insulating batts.
4. 1/2-in type X gypsum wall board applied vertically with type S-12 drywall screws spaced 8 in o. c. along the edges and at intermediate framing members. Joints were offset 24 in from the 5/8-in gypsum wall board.
5. 1-in air space.

FIGURE 2.18
Horizontal Section of an Intermodule Double Wall

REF: *Fire Test Report WP-254,* National Gypsum Company Research Center, Buffalo, New York 14217, January 1972. (Unpublished)

2.2.2.9 Steel "C" Stud and Gypsum Board Double Intermodule Bearing Wall

This wall assembly was similar to that described in Section 2.2.2.8, with the following exceptions:

1. 18 ga steel "C" studs used instead of 16 ga.

2. Test wall 12 ft long instead of 10 ft.

3. 3/4-in air space between two leaves instead of 1 in. Overall wall assembly thickness 9 in instead of 9 1/4 in.

Test Results:

Structural failure of the fire-exposed leaf under the 680 lb/ft applied load occurred at 2 hr 9 min.

REF: Gauntlett, J. F., *Fire Test of Inter-Dwelling Wall,* Test Report No. 71-10, National Gypsum Company Research Center, Buffalo, New York, February 1972 (Unpublished).

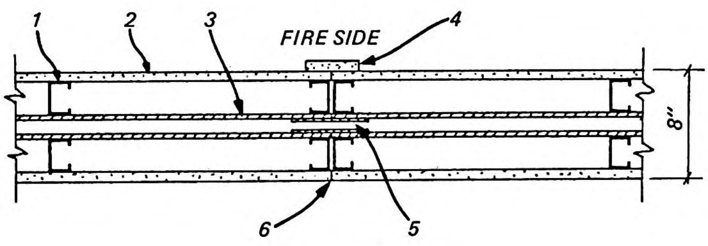
2.2.2.10 Steel "C" Stud, Cast Plaster and Plywood Intermodule Double Bearing Wall System

Each wall in the double wall assembly represented a wall in a housing module and consisted of 18 ga steel "C" studs spaced 24 in o. c., 11/16-in thick cast plaster on the room (fire exposed) side, 3/8-in standard C-D grade plywood on the exterior side (Fig. 2.19).

The test assembly was 8 ft high and 16 ft long, comprised of two 8-ft by 8-ft wall panels on each side. The panels were placed in the furnace frame with the plywood sides facing each other. A load of 1100 lb/ft was applied to the test wall assembly during the fire test.

Test Results:

The fire endurance of the double wall assembly was 1 hr 23 min, at which time the wall on the fire exposed side failed under load. The plaster on the unexposed wall delaminated immediately after the first wall failed, and flaming occurred through a large gap at the top of the panel at 84 min, followed almost immediately by structural collapse.



Construction

1. 2 1/2 by 1 5/8-in 18 ga steel "C" studs, 24 in o. c.
2. 5/8-in nominal (11/16-in actual) cast glass fiber reinforced vermiculite plaster mix.
3. 3/8-in standard (C-D) grade plywood, with exterior glue, nailed to steel studs with 1 1/2-in galvanized annular nails on 6-in centers.
4. Panel joint on exposed side covered with 4-in wide strip of 5/8-in type X gypsum board attached through plaster to the studs with 2-in long type G bugle head laminating screws.
5. Panel joint on plywood side covered with 6-in wide strip of 3/8-in C-D grade plywood, with exterior glue, nailed with 6d common nails on 12-in centers.
6. Panel joint in cast plaster packed with mineral wool and finished with perlite plaster.
7. Cast plaster attached to 2-in wide strips of corrugated wire lath stapled along the steel studs with 1/2-in #18 round tinned high carbon wire staples on 12-in centers.

FIGURE 2.19
Horizontal Section of an
Intermodule Double Wall

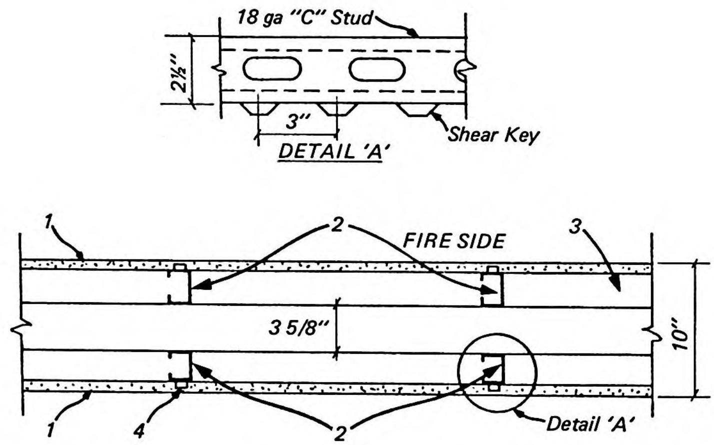
REF: Son, B. C., *Fire Endurance Test of an Interdwelling Double Wall Assembly for Single Family Housing,* NBS Report 10417, National Bureau of Standards, Washington, D.C. 20234. (NTIS Accession No. PB-217 364)

2.2.2.11 Steel "C" Stud and Cast Plaster Intermodule Double Limited Bearing Wall System

The wall system was similar to that described in Section 2.2.2.10 except that the plywood on the exterior surface was omitted, and shear keys were used instead of wire lath to attach the cast plaster to studs. The two wall panels were separated by a 3 5/8-in air space, and no insulation was installed between studs (Fig. 2.20). Each wall panel was 8 ft high and 10 ft long. A load of 1225 lb/ft, with an eccentricity of 7/16 in was applied to each wall during the test.

Test Results:

The fire endurance of the test assembly was 2 hr 43 min, reached when the temperature rise at one point on the unexposed side exceeded the maximum permitted by ASTM E 119.



Construction

1. 11/16-in cast glass fiber reinforced vermiculite plaster, attached to the steel studs through shear keys (see Detail 'A').
2. 2 1/2 by 1 5/8-in 18 ga steel "C" studs, 24 in o. c.
3. 2 1/2 by 1 3/4-in 20 ga steel channel top and sole plates welded to studs.
4. Shear keys stamped on 3 in centers in metal studs (Detail 'A').

FIGURE 2.20
Horizontal Section of an Intermodule Double Wall

REF: *Report No. 5047,* Building Research Laboratory, Engineering Experiment Station, Ohio State University, Columbus, Ohio 43210, January 1973. (Unpublished)

2.2.2.12 Steel "C" Stud and Cast Plaster Insulated Intermodule Double Limited Bearing Wall System

This wall assembly was identical to that described in Section 2.2.2.11, with the exception that the spaces between the studs in each wall were filled with 2 1/4-in thick glass fiber insulating batts with a density, including the vapor barrier, of 0.81 lb/ft.

A load of 904 lb/ft, with an eccentricity of 7/16 in, was applied to each wall during the test.

Test Results:

The fire endurance time of the wall assembly was 2 hr 29 min, at which time the wall exposed to the fire could no longer sustain the applied load.

REF: *Report No. 5048,* Building Research Laboratory, Engineering Experiment Station, Ohio State University, Columbus, Ohio 43210, July 1973. (Unpublished)

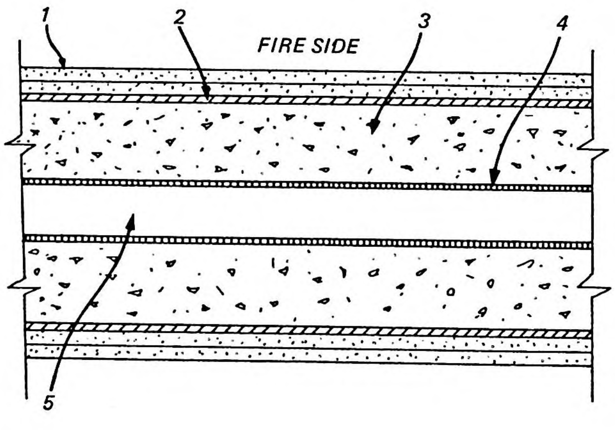
2.2.2.13 Plywood and Gypsum Board, Polyurethane Foam-Filled Sandwich Panels Forming a Double Wall Intermodule Wall System

This wall assembly (Fig. 2.21) was composed of two identical single leaf walls each similar to that described in Section 2.2.1.6 except that the stone aggregate was omitted from the exterior (cement asbestos board) side, and the one layer of 5/8-in type X gypsum board on the room side was replaced with two layers of 1/2-in type X gypsum wall board attached to the plywood with type S bugle head screws, as shown in Figure 2.21b, after the panels were installed in the furnace frame.

Four wall panels, each 4 ft wide by 8 ft high, were joined together as shown in Figure 2.7 to provide a wall panel 16 ft long. Two such larger parallel wall panels, separated by a 2-in air space, made up the test wall assembly. A load of 735 lb/ft was applied to each wall during the test.

Test Results:

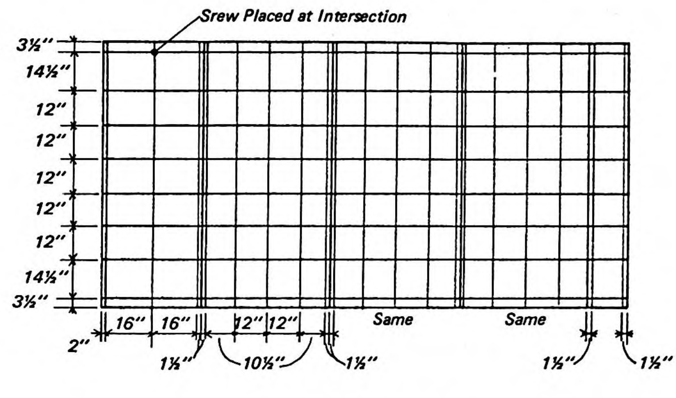
The fire endurance time of the double wall system was 1 hr 4 min, at which time the exposed wall became unable to sustain the applied load. The test was discontinued at 1 hr 6 min because of untenable conditions in the test building, resulting from smoke and combustion gases released by the polyurethane foam insulation in the wall assembly.



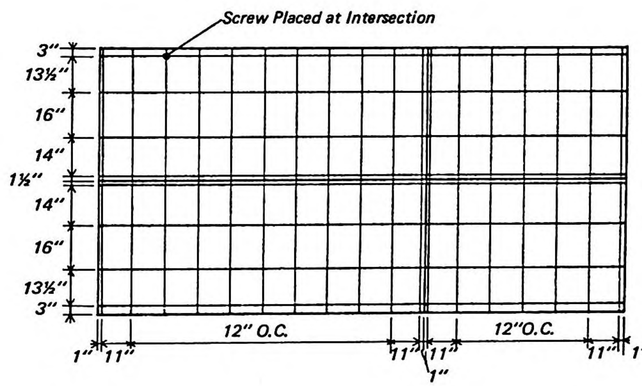
Construction

1. Two layers of 1/2-in type X gypsum wall board fastened to plywood with type S bugle head screws in pattern indicated in Figure 2.21b.
2. 5/16-in plywood force-fit to aluminum perimeter frame.
3. 3-in polyurethane foamed in place.
4. 1/8-in cement-asbestos board force-fit to aluminum perimeter frame.
5. 2-in air space.

FIGURE 2.21a
Horizontal Section of an
Intermodule Double Wall



FIRST LAYER OF ½" TYPE X



SECOND LAYER OF ½" TYPE X

FIGURE 2.21b
Fastener Schedules

REF: Son, B. C., *Fire Endurance Test of an Interdwelling Double Wall Constructed of Polyurethane Foam-Filled Sandwich Panels*, NBSIR 73-170, National Bureau of Standards, Washington, D.C. 20234, April 1973. (NTIS Accession No. PB-221 193)

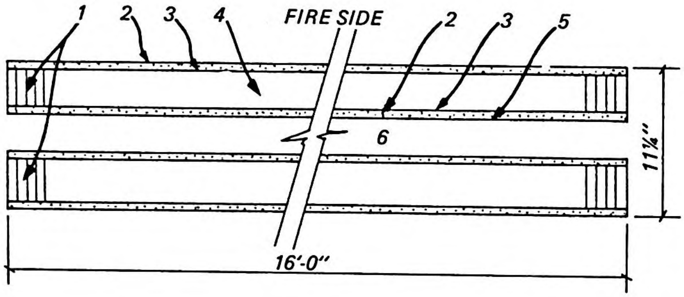
2.2.2.14 Paper Honeycomb and Gypsum Board Intermodule Double Bearing Wall Assembly

The wall assembly shown in Figure 2.22 was constructed of two identical parallel walls, separated by a 2 3/4-in air space. Each 8 by 16-ft wall panel consisted of a 3-in thick paper honeycomb core, surfaced on both sides with glass fabric impregnated with polyester resin, and one sheet of adhesively bonded type X gypsum board, 5/8 in thick. The surface of each wall facing the air space sprayed with polyester resin containing chopped glass fibers.

Each 16-ft-long wall panel was loaded with 636 lb/ft.

Test Results:

Fire endurance time for the complete wall assembly was 1 hr 19 min 15 s, as determined by the observed collapse of the interior face of the unexposed wall. The exposed wall failed at 1 hr 5 min 30 s by flame-through.



Construction

1. End closures of 4 layers of 3/4-in plywood.
2. 5/8-in type X gypsum wall board adhesively bonded to each face of the structural core with polyester base adhesive. All joints between gypsum boards were taped and filled with plaster joint compound. Joints not staggered.
3. Skin of woven glass fiber roving (5 x 4 count, 20 oz, 0.04 in thick) impregnated with polyester resin.
4. 3-in thick paper honeycomb core treated with flame retardant.
5. Sprayed polyester resin containing chopped glass fibers (applied only on gypsum board facing the air space).
6. 2 3/4-in air space.

FIGURE 2.22
Horizontal Section of an Intermodule Double Wall

REF: Son, B. C., *Fire Endurance Test of an Interdwelling Double Wall Construction of Paper Honeycomb and Gypsum Board*, NBSIR 73-166, National Bureau of Standards, Washington, D.C. 20234, April 1973. (NTIS Accession No. PB-222 297)

2.2.2.15 Paper Honeycomb and Gypsum Board Intermodule Double Bearing Wall Assembly

This wall assembly was similar to that described in Section 2.2.2.14 except that the air space between the two wall panels was 2 in instead of 2 3/4 in. The overall wall assembly thickness was, therefore, 10 1/2 in. Each 8-ft high by 10-ft long wall panel was loaded with 700 lb/ft during the test.

Test Results:

The exposed wall panel failed structurally at 53 min, thus exposing the unexposed wall to the fire. The unexposed wall failed structurally at 1 hr 15 min.

REF: *Fire Test Report WP-212,* National Gypsum Company, Buffalo, New York, May 1971. (Unpublished)

2.2.2.16 Paper Honeycomb and Gypsum Board Intermodule Double Wall Wall Assembly

The wall assembly was similar to that described in Section 2.2.2.15 except that two layers of 5/8-in type X gypsum board, instead of one, were applied vertically to the fire exposed (room) sides of the wall panels. The second layer was laminated to the first layer with 3/16-in beads of construction adhesive spaced approximately 16 in o.c. Each panel was loaded with 755 lb/ft during the test.

Test Results:

The exposed wall failed under load at 1 hr 9 min, while the unexposed wall failed structurally at 1 hr 43 min.

REF: *Fire Test Report WP-221,* National Gypsum Company, Buffalo, New York, July 1971. (Unpublished)

2.2.2.17 Glass Fiber Reinforced Polyester Resin Double Loadbearing Wall Assembly

The double wall, representative of an inter-dwelling (party wall) separation between single family attached housing units, was made up of two identical parallel wall panels separated by a 2 1/4-in air space. The two wall panels were similar to that described in Section 2.2.1.7 except that four 4-ft wide panels were used for each wall instead of three, and the panel ends were not closed as they were in the tests described in 2.2.1.7. The applied load was 700 lb/ft for each wall.

Test Results:

Structural failure of the fire exposed wall occurred at 27 min 25 s. Maximum permissible temperature rise occurred on the unexposed surface of the other wall at 42 min.

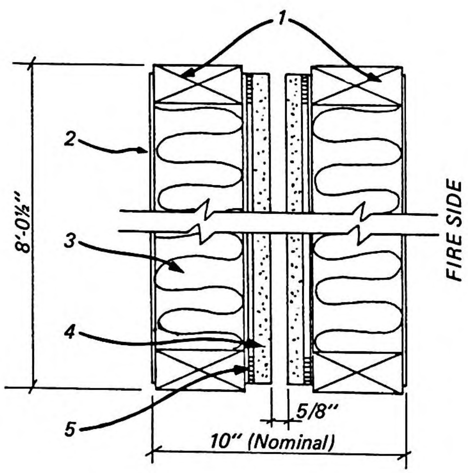
REF: Son, B.C., *Fire Endurance Test of a Fiber Glass Reinforced Polyester Double Wall Assembly,* NBSIR 73-168, National Bureau of Standards, Washington, D.C. 20234, April 1973. (NTIS Accession No. PB-221 184)

2.2.2.18 Glass Fiber Reinforced Polyester Intermodule Double Loadbearing Assembly

The test wall assembly was made up of two single leaf walls similar to that described in Section 2.2.1.7 except that 5/8-in type X gypsum wall board was applied to one face of each wall panel. The two walls were placed in the furnace frame with the gypsum board sides facing each other, and a 5/8-in gap or air space between them. The wall board was applied over 3/16-in thick asbestos mill board furring strips (Fig. 2.23). The 12-ft long double wall assembly was loaded with 700 lb/ft during the test.

Test Results:

The fire endurance time of the wall assembly was 1 hr 39 min, at which time the temperature rise at one thermocouple on the unexposed side exceeded the permissible limit of 325°F (181°C). The exposed wall had collapsed under load at 1 hr 5 min. The test was terminated at 1 hr 44 min 10 s when flame-through occurred at the unexposed face of the remaining wall panel.



Construction

1. 2 by 4 wood plates top and bottom.
2. 0.08-in glass fiber reinforced polyester structural laminate adhesive bonded to corrugated stiffener.
3. Glass fiber reinforced polyester corrugated stiffeners (vertically) with cavities filled with rock wool insulation containing a binder of sodium silicate and water. Intumescent paint applied to stiffener (except where bonded to composite faces).
4. 5/8-in type X gypsum wall board installed vertically, bonded and nailed to the joints between FRP panels. Joints in layers on opposite sides of the 5/8-in air cavity staggered by 24 in o. c.
5. 3/16-in thick asbestos mill board furring strips used as sealer top and bottom.

FIGURE 2.23
Vertical Section of an Intermodule Double Wall

REF: Williamson, R.B. and Baron, F.M., *Structural Research Laboratory Report No. 71-11*, University of California, Berkeley, California, November 1971 (Unpublished).

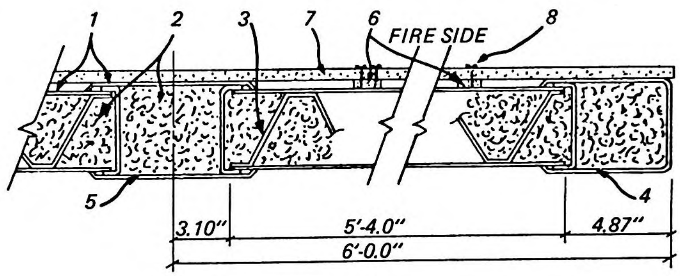
2.2.2.19 Glass Fiber Reinforced Polyester Resin Intermodule Party Wall

This test was conducted in order to ascertain compliance with a local code requirement that exterior walls adjacent to lot lines resist fires that occur outside the dwelling. In the case of dwellings with double wythe party walls, the lot line was considered to be at the centerline of the space between wythes, and a fire endurance rating of one hour was required on either side of the property line.

The test wall assembly (Fig. 2.24) represents one leaf of a double leaf intermodule wall system intended for use as such a party wall between townhouse units. Its construction is similar to that described in Section 2.2.1.7 except that one side of the wall was covered with 5/8-in type X gypsum wall board installed vertically over 3/8-in asbestos mill board furring strips. The furring strips served as a seal between the gypsum board and the wall face on top and bottom of the wall (in a manner similar to that shown in Section 2.2.2.18) and at the joints of the gypsum board panels as is shown in Figure 2.23. The gypsum wall board surface, which would normally face the interior of a double wall cavity, was exposed to the fire in the test furnace. The test wall was 8 ft high by 12 ft long, and a load of 700 lb/ft was applied during the test.

Test Results:

The test wall sustained a fire exposure of 1 hr 3 min with no failure due to either temperature rise, passage of flame or load. The test was then terminated, since the desired one hour rating had been achieved.



Construction

1. 0.080-in thick glass fiber reinforced polyester laminate bonded to stiffeners with adhesive.
2. Mineral wool insulation packed into all cavities. Sodium silicate and water binder.
3. 0.050-in thick corrugated stiffeners made from same glass fiber reinforced polyester formulation as 1.
4. Wall end stud molded from same laminate as 1.
5. Straight joint molded from same laminate as 1.
6. 3/16-in asbestos mill board furring strips spaced 23 in o. c.
7. 5/8-in type X gypsum wall board with taped joints.
8. #10 x 1-in sheet metal screws spaced 12 in o. c.

FIGURE 2.24
Horizontal Section of One Leaf of an Intermodule Double Wall

REF: Williamson, R.B., Brauer, F.B., Baron, F.M., *Structural Research Laboratory, Report No. 72-7,* University of California, Berkeley, California, June 1972 (Unpublished).

2.2.3 Interior Single Wall Assemblies

Interior single leaf wall assemblies can be either non-loadbearing or loadbearing. Non-loadbearing interior walls are commonly classified as "partitions." In either case, such walls serve to divide the enclosed space within a dwelling unit into rooms.

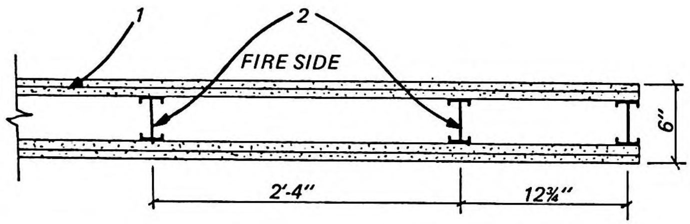
2.2.3.1 Aluminum Stud and Gypsum Wall Board Non-Loadbearing Partition

This wall assembly was composed of 2 by 4-in (nominal) aluminum "I" studs spaced 24 in o. c., with two layers of 5/8-in type X gypsum wall board on each side. The top and bottom plates of the partition framing were aluminum channels. The test wall assembly was 10 ft high and approximately 10 ft 1 1/2 in long.

Test Results:

The fire endurance time for the partition was 2 hr 2 min. When the test was terminated at that time, the temperature rises on the unexposed side had not exceeded the permissible limits, nor had there been any passage of flame, hot gases or smoke through the wall.

Note: Subsequent to the above fire test, an identical wall assembly was tested as a loadbearing wall with a superimposed load of 440 lb/ft. This wall successfully withstood a fire endurance of 1 hr 2 min, the hose stream test and double the initial applied load 4 hr after the hose stream test.



Construction

1. Two layers of 5/8-in type X gypsum wall board each side, with joints staggered 24 in o.c. between the interior layers on opposite sides of the studs and between the first and second layers on each side. All joints occurred over studs. First layer attached to framing with 1-in type S-12 self-drilling screws spaced 12 in o. c.; second layer with 1 5/8-in type S-12 self-drilling screws spaced 12 in o. c. Exposed joints were reinforced with joint tape and covered with joint compound. Exposed screws heads were covered with joint compound.
2. 2 by 4-in (nominal) extruded aluminum studs with 0.055-in truss web, 24 in o. c. except at each end of test wall panel as shown. Aluminum channel plates screwed to studs at top and bottom of assembly.

FIGURE 2.25
Horizontal Section of One Leaf of an Intermodule Double Wall

REF: *Reports No. 20310 and 20614,* Factory Mutual Research Corporation, Norwood Massachusetts 02062, December 1970. (Unpublished)

3.

FIRE ENDURANCE: ROOF/CEILING, FLOOR/CEILING, AND FLOOR ASSEMBLIES

203-591 O - 76 - 4

3. FIRE ENDURANCE: ROOF/CEILING, FLOOR/CEILING AND FLOOR ASSEMBLIES

Several of the roof, ceiling and floor systems used by Housing System Producers in Operation BREAKTHROUGH incorporated design and materials concepts that were quite different from those used in conventional housing.

In design, for example, the use of the modular concept of construction results in a double floor/ceiling system from the juxtaposition of the ceiling system of one module with the floor system of a module placed immediately above it in housing of two or more stories (see Fig. 3.1).

Paper honeycomb and glass fiber reinforced polyester resin panels were among the several unconventional materials proposed for use.

Because of the lack of valid test data on the properties of such proposed unconventional systems, considerable fire endurance testing was required to obtain the needed information.

3.1 Test Methods

Testing was generally performed in accordance with the requirements of ASTM E 119 for floors and roofs. The test specimen is installed in a horizontal position as the roof of the furnace; a load is applied, and the temperature of the furnace is raised in accordance with the standard ASTM E 119 time-temperature curve. The specimen is exposed to the fire from its under side, as is shown in Figure 3.2.

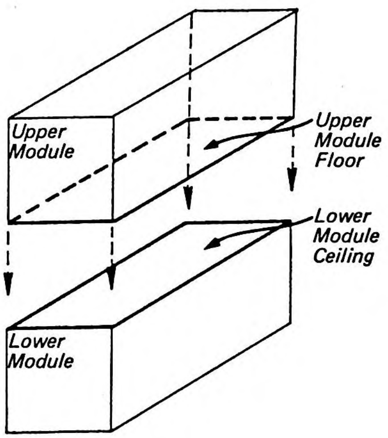


FIGURE 3.1
Double Floor/Ceiling Construction

The fire endurance of the test assembly is determined by the time required to reach the first occurrence of any of the following criteria:

1. Inability to sustain the applied load.

2. Passage of flame or gas through the structure to the unexposed surface hot enough to ignite cotton waste.

3. A temperature rise of 250°F (139°C) average, or 325°F (181°C) at one point, above the initial temperature on the unexposed surface.

Live loads applied to floor systems during the tests ranged from 21 to 63.7 lb/ft^2 with a typical value of 40 lb/ft^2 most commonly being used. Live loads applied to roofing systems ranged from 18.5 to 30 lb/ft^2 and varied with the roof load requirements specified for the geographical areas where the systems were to be used. Loading was generally applied either through the use of hydraulic jacks or through the direct application of dead weights such as cinder blocks in a uniform pattern over the surface of the test assembly.

Floor systems were tested with the floor coverings installed, although this is not common practice. It was, however, in keeping with the basic Operation BREAKTHROUGH practice of testing complete systems whenever possible.

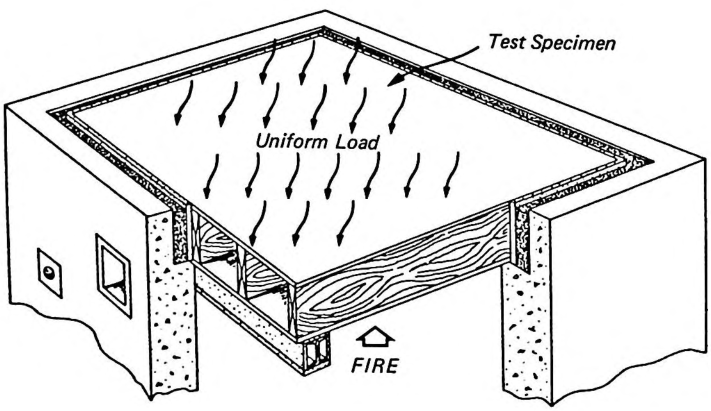


FIGURE 3.2
Furnace Test Assembly

REF: *Standard Methods of Fire Tests of Building Construction and Materials,* ASTM E 119, 1971, ASTM Book of Standards, Part 14, American Society for Testing and Materials, Philadelphia, Pennsylvania 19103.

3.2 Systems Evaluated and Test Results

3.2.1 Roof/Ceiling Systems

3.2.1.1 Double Wood Joist, Plywood and Gypsum Board System

The basic construction consists of separate roof and ceiling systems (Fig. 3.3) with the roof system sloping 3/16-in per foot perpendicular to its span.

The ceiling assembly consisted of 2 by 4 wood joists 16 in o. c., with one layer of 1/2-in gypsum board finish and one layer of 3 1/2-in thick glass fiber batt insulation between the joists. The ends of the joists were nailed to a double 2 by 6 edge beam, on top of which was built a 16-ft long and 16-in high stub or parapet wall, constructed with 2 by 4 studs 24 in o. c. Both sides of the stub wall were sheathed with 1/2-in plywood.

The roof assembly consisted of 2 by 6 wood joists 16 in o. c., nailed to 2 by 6 edge beams. The roof sheathing material was 1/2-in plywood. The roof assembly was supported on 2 by 2 wood ledgers glued and nailed to the inside of the parapet stub walls, sloping 3/16 in per foot, or 3 inches in the 16 ft length of the parapet wall. A sheet vinyl roofing material was bonded to the sheathing and continued up the inside of the parapet walls.

Three tests were conducted on three separate test assemblies, the construction for Test 1 being as described above. Each assembly measured 11 ft 9 1/2 in by 17 ft 5 in.

The test specimen for Test 2 was identical to that for Test 1 except that the ceiling assembly was insulated with *two* layers of 3 1/2-in thick glass fiber batts instead of one, and a 1/4-in bead of adhesive was applied to each joist before the wall board was nailed.

The test specimen for Test 3 was identical to that for Test 2 except that an additional layer of 1/2-in type X gypsum board was added to the ceiling surface. The first layer was applied with the long dimension parallel to the joists, as in Test 2. The second layer of wall board was applied parallel to the joists with the joints offset 16 in and attached with 7d cement-coated nails spaced 6 in o. c. at the joints and spaced 12 in o. c. at intermediate joists. Type G, 1 1/4-in drywall screws were placed 2 in back from the joints and driven into the first layer at 12 in o. c. on either side of the joints. The nail heads and wall board joints were finished with joint compound.

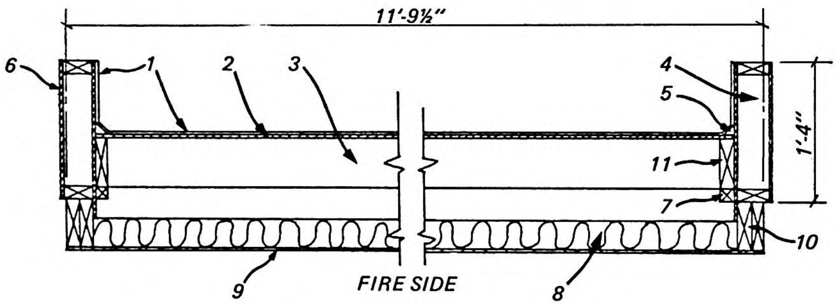
Before each test, a superimposed load of 30 lb/ft^2 was applied to the roof system.

Test Results:

Test 1: Structural collapse occurred at 34 min 30 s.

Test 2: At 45 min 10 s an excessive temperature rise was recorded at one thermocouple on the roof (unexposed) surface, followed by flame-through at that point at 45 min 20 s.

Test 3: At 83 min 40 s flame-through occurred on the unexposed side of the roof system.



Construction

1. Vinyl roofing bonded to plywood sheathing with adhesive.
2. 1/2-in plywood sheathing attached with long dimension parallel to the joists.
3. 2 by 6 wood roof joists 16 in o. c.
4. 2 by 4 wood studs 24 in o. c. and nailed to a top and bottom plate.
5. Wood fiber cant strip.
6. 1/2-in plywood sheathing both sides of parapet stud wall.
7. 2 by 2 wood ledger-slope 3/16 in per ft.
8. 2 by 4 wood ceiling joists 16 in o. c. with 3 1/2-in thick paper faced glass fiber insulating batts between.
9. 1/2-in thick type X gypsum board applied with long dimension parallel to the joists with No. 4 ring shank nails 6 in o.c. around perimeter and 12 in o.c. at intermediate joists. Wall board joints and nail heads finished with joint compound.
10. Double 2 by 6 wood ceiling perimeter beam.
11. 2 by 6 wood roof perimeter beam.

Note: On the open end of the roof assembly, created by the 3/16-in/ft slope, an "eyebrow" consisting of 2 by 6 joists and plates with 1/2-in plywood and asphalt shingles was placed to fill the open area. The asohalt shingles were replaced by 1/2-in type X gypsum wall board for Tests 2 and 3.

FIGURE 3.3
Cross Section of Roof/Ceiling Construction

REF: *Fire Test Reports RC-168, RC-169 and RC 171,* National Gypsum Company Research Center, Buffalo, New York 14217, January and February 1972. (Unpublished)

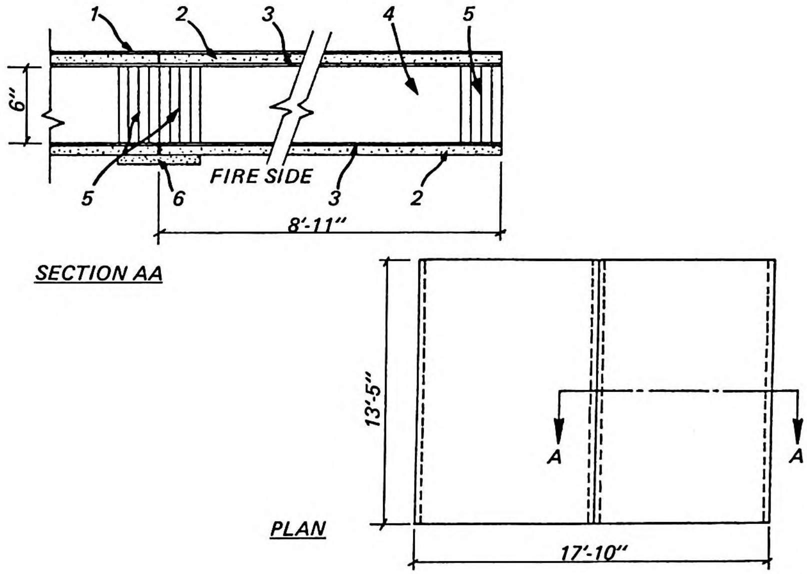
3.2.1.2 Paper Honeycomb and Gypsum Board Sandwich Panel

This roof/ceiling assembly (Fig. 3.4) consisted of two panels, each 8 ft 11 in wide and 13 ft 5 in long, butted together on the long sides to produce a test panel 13 ft 5 in by 17 ft 10 in. The nominal overall thickness of the assembly was 7 1/4 in.

A uniform load of 15.9 lb/ft^2 was applied to the test specimen. This load provided a bending moment for the 13-ft 5-in span equivalent to that produced by a conventional design load of 20 lb/ft^2 over a 12-ft span, the length such panels are normally used.

Test Results:

Failure occurred at a corrected time of 37 min 13 s by flame-through at the unexposed surface through a joint in the gypsum boards. About 10 seconds later, a local load failure occurred at the same joint.



Construction

1. Weather-resistant coating of resin with chopped glass fiber and sand applied to an exterior surface of panels.
2. 5/8-in type X gypsum board bonded to resin facing on core with polyester adhesive. Joints in the boards on the two sides of a panel were staggered. Joints between gypsum boards taped and filled with plaster joint compound.
3. Woven glass fiber roving and polyester resin facings both sides of core.
4. Flame-retardant treated paper honeycomb core.
5. 3 by 6-in edge beams consisting of 4 layers of 3/4-in plywood.
6. 5-in wide strip of 5/8-in type X gypsum board covering the joint between test panels.

FIGURE 3.4
Roof/Ceiling Assembly
Test Specimen

REF: Son, B. C., *Fire Endurance Test of a Roof/Ceiling Construction of Paper Honeycomb and Gypsum Board,* NBSIR 73-167, National Bureau of Standards, Washington, D.C. 20234, January 1973. (NTIS Accession No. PB-222 298)

3.2.1.3 Paper Honeycomb and Gypsum Board Sandwich Panel

The construction of this assembly was identical to that described in Section 3.2.1.2 except that the gypsum board strip covering the panel joint on the exposed side was 6 in wide instead of 5 in, type C wall board was used instead of type X on the ceiling (fire exposed) side, and resin impregnated 10 mil continuous strand glass fiber mat was used as the weather-resistant coating on the upper (roof) surface.

A uniform load of 17 lb/ft^2 was applied during the test.

Test Results:

Flame-through at the panel joint occurred at 29 min.

REF: *Fire Test Report FC-156,* National Gypsum Company, Buffalo, New York 14217. (Unpublished)

3.2.1.4 Paper Honeycomb and Gypsum Board Sandwich Panel

This sandwich panel was produced by the same HSP and was identical in construction to that reported in Section 3.2.1.3 except that two layers of 5/8-in type C gypsum board were applied to the ceiling side of the roof system, and type C board was used instead of type X on the roof side. The exposed layer was bonded with 3/16-in beads of adhesive spaced 12 in o. c. and stapled to the under layer with 1 1/2-in long staples driven at a 45° angle through the exposed layer into the first layer. The staples were spaced 24 in o.c. along each edge and down the center of each board and 12 in o.c. at end joints.

A uniform load of 18.5 lb/ft^2 was applied to the test specimen.

Test Results:

Flame-through at a gypsum board joint at the unexposed side occurred at 1 hr 4 min 45 s.

REF: *Fire Test Report FC-159,* National Gypsum Company Research Center, Buffalo, New York 14217 (Unpublished)

3.2.1.5 Paper Honeycomb and Sheet Steel Panel

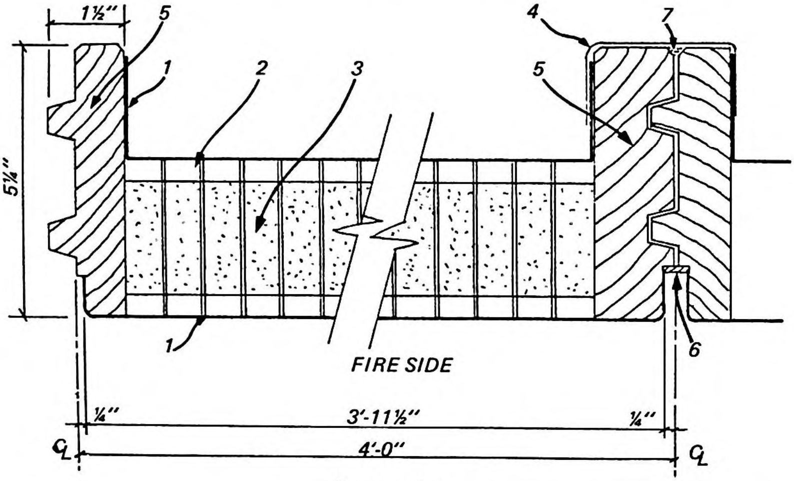
The construction of this roof/ceiling system consisted of a 3-in thick paper honeycomb core, partially filled with solid polyurethane foam, and 26 ga sheet steel facings on both sides.

The test assembly consisted of four 4-ft by 13-ft 5-in panels and one 1-ft 10-in by 13-ft 5-in panel. Long edges of the panels were closed with 1 1/2 by 5 1/4-in tongue and groove wood closures (See Fig. 3.5). The overall dimensions of the test assembly were, therefore, 13 ft 5 in by 17 ft 10 in.

A uniform load of 28.6 lb/ft^2 was applied during the test (equivalent to 40 lb/ft^2 over a 12-ft span).

Test Results:

A maximum temperature rise of 325°F (181°C) occurred at one thermocouple on the unexposed side at 9 min 9 s.



Construction

1. 26 ga sheet steel facing bonded to honeycomb core with epoxy adhesive. Steel sheets were galvanized, phosphatized and finished on exterior surfaces with a baked on silicone paint.
2. 3-in thick paper honeycomb core with 3/4-in hexagonal cores, paper impregnated with phenolic resin (11 per cent by weight).
3. 2 1/4-in thick rigid and friable polyurethane foam insulation (1.5 lb/ft^3density) pressed into honeycomb core.
4. 26 ga galvanized sheet metal joint cap (field applied).
5. Tongue and groove wood panel edging on long ends of each panel. Short ends closed by 1 1/2 by 3-in wood edge members.
6. 1/16 by 3/8-in vinyl tape (field applied).
7. 1/4 by 1/4-in butyl tape (field applied).

FIGURE 3.5
Cross Section of
Roof/Ceiling Assembly

REF: Son, B. C., *Fire Endurance Tests of Steel Sandwich Panel Exterior Wall and Roof/Ceiling Constructions,* NBSIR 73-135, National Bureau of Standards, Washington, D.C. 20234. (NTIS Accession No. PB-221 310)

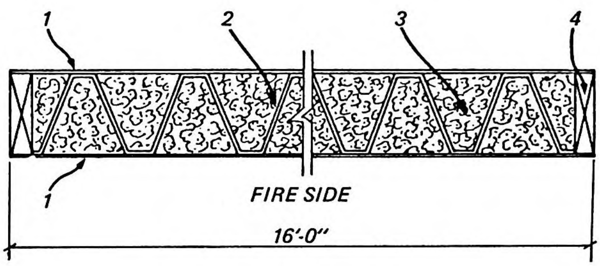
3.2.1.6 Glass Fiber Reinforced Polyester Resin Roof/Ceiling System

The test specimen was composed of 0.151-in thick glass fiber reinforced polyester skins bonded to the top and bottom of truss type stiffeners made of the same material. The cavities formed by the stiffeners were filled by a proprietary insulating material. Wood rim joists, 2 by 6 in nominal, provided a surround for the nominal 6-in thick roof panel. The stiffeners and the external surfaces of the rim joists were coated with intumescent paint.

The 11-ft 7 1/2-in by 16-ft test specimen was loaded at eight load points to develop a maximum bending moment equivalent to that resulting from a uniform live load of 20 lb/ft^2 over the 11-ft 7 1/2-in span.

Test Results:

The test assembly could no longer sustain the applied load after 48 min of exposure to fire.



Construction

1. 0.151-in thick structural glass fiber reinforced polyester resin composite bonded to stiffeners with modified polyester adhesive.
2. 0.05-in thick structural glass fiber reinforced polyester resin composite stiffeners coated with intumescent paint except on bonding surfaces.
3. Mineral wool insulation with 10 percent sodium silicate and water binder.
4. 2 by 6 kiln dried Douglas Fir rim joists with external surface coated with intumescent paint. Bonded to composite skins with modified epoxy adhesive.
5. Load span 11 ft 7 1/2 in.

FIGURE 3.6
Cross Section of
Roof/Ceiling Assembly

REF: *Report No. 5067, Standard ASTM Fire Endurance Test on a Roof and Ceiling Assembly,* Building Research Laboratory, Engineering Experiment Station, Ohio State University, Columbus, Ohio 43210, September 1971. (Unpublished)

3.2.1.7 Sheet Metal Pans, Plywood, Rigid Fiberglass Insulation, Fiberglass Batts and Gypsum Board Roof/Ceiling Panels

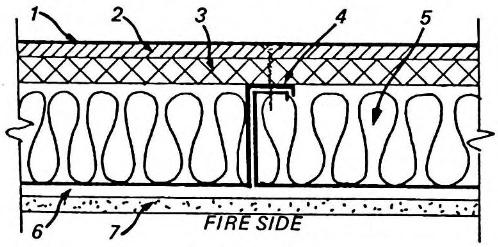
This roof/ceiling system, intended for use by one HSP in multifamily low-rise housing, consisted of 20 ga galvanized sheet steel interlocking pans, 4 in deep by 16 in wide by 12 ft 5 in long. The pans are installed with their vertical legs up (Fig. 3.7). Unfaced 3 1/2-in thick glass fiber insulation batts are placed in the recesses formed by the vertical legs, and 1-in thick rigid glass fiber insulation installed over the assembly. Roof sheathing in the form of 1/2-in exterior grade plywood is placed over the rigid insulation and coated with a silicone rubber waterproofing compound.

The ceiling side of the construction consisted of 1/2-in type X gypsum board attached to steel furring channels 24 in o. c. perpendicular to the steel pans.

The 12-ft 5-in by 16-ft test specimen was loaded so as to produce the equivalent maximum bending moment at mid-span resulting from a uniform load of 30 lb/ft^2 over an 11-ft 11-in clear span.

Test Results:

After 42 min of exposure to fire, the hydraulic loading jacks in one section had reached their limits of extension and were no longer able to apply load due to the deflection of the test specimen. The test, however, was continued for another 5 min. When terminated at 47 min, the system was still holding, although sagging more than 8-in. No flame-through was observed nor were any excessive temperature rises on the unexposed surface recorded.



Construction

1. Silicone rubber waterproofing compound.
2. 1/2-in exterior grade plywood attached to rigid insulation and steel decking with sheet metal screws.
3. 1-in rigid glass fiber insulation.
4. 20 ga galvanized sheet steel interlocking pans, 4 in deep by 16 in wide by 12 ft 5 in long.
5. 3 1/2-in thick unfaced glass fiber insulating batts.
6. Steel furring channels 24 in o. c. perpendicular to span.
7. 1/2-in type X gypsum board.

FIGURE 3.7
Cross Section of
Roof/Ceiling Assembly

REF: *Report of a Standard ASTM Fire Endurance Test of a Limited Load Bearing Roof and Ceiling Assembly,* Building Research Laboratory, Engineering Experiment Station, Ohio State University, Columbus, Ohio 43210, Project 5234, March 1972. (Unpublished)

3.2.2 Floor/Ceiling Assemblies

With the exception of the floor/ceiling construction described in Section 3.2.2.1, the constructions evaluated were double assemblies representative of the floor construction of one module placed over the ceiling construction of a module immediately below the upper one (see Fig. 3.1).

3.2.2.1 Steel Joists and Plywood Floor System with Furred Gypsum Board Ceiling

The floor construction (Fig. 3.8) consisted of 7 1/2-in steel "C" joists 24 in o. c., covered with 3/4-in tongue and groove interior grade C-D Plywood underlayment. One half of the plywood floor area was covered with a shag carpet over a pad. The remaining half was covered with 1/16-in vinyl asbestos tiles (12 in square) bonded to the plywood with adhesive. One layer of 1/2-in type SF-3 gypsum board was attached directly to the bottom flanges of the joists.

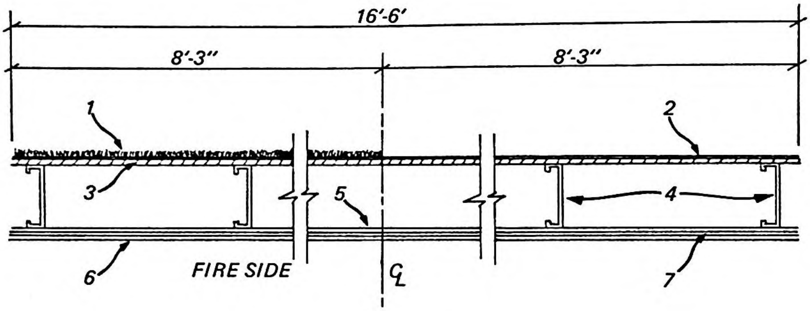
The ceiling consisted of 1/2-in type SF-3 gypsum board attached to 7/16-in deep steel furring channels spaced 12 in o. c. and running perpendicular to the joist span.

The 12-ft 5-in by 16-ft 6-in assembly was loaded uniformly with 45 lb/ft^2 before the start of the fire test.

Test Results:

At 52 min, flame-through occurred on the half of the exposed floor surface covered with vinyl floor tile, followed by structural collapse of the test assembly at 52 min 45 s.

REF: *Report on Fire Endurance Test of Floor and Ceiling Construction,* U. L. File R6946-1, Underwriters Laboratories, Inc., Northbrook, Illinois, February 1972. (Unpublished)



Construction

1. Shag carpet and hair jute pad, 12 ft by 8 ft 6 in, installed on half of the assembly. Carpet identified as complying with FHA Bulletin No. UM44B (Shag Rug).
2. 1/16-in thick vinyl asbestos floor tile installed with water emulsion floor tile adhesive on the other half of the assembly.
3. 3/4-in T and G plywood underlayment, PS 1-66 interior grade with exterior glue, 47 7/16 by 96-in. Attached to upper flanges of the joists with #12 self drilling, self tapping steel screws spaced 12 in o. c. Plywood panels placed with long dimensions perpendicular to the joists. Butt ends of the plywood panels glued with structural adhesive. End joints were staggered 4 ft o. c. and located over joists.
4. 1 3/4 by 7 1/2-in 18 ga galvanized steel floor joists 24 in o. c. (12 ft 5 in long). Lower flange of each joist end attached to the flange of a boundary structural beam with a #10 machine screw in a 1/2-in slotted hole. Ends of each joist stiffened with 3/4-in by 1 3/4-in by 16 ga (0.06-in) galvanized steel channel sections placed with the folded leg inserted over the web of each joist.
5. 1/2-in type SF-3 gypsum board attached to lower joist flanges (ceiling side) with 0.115-in diameter, 1-in long type S-12 bugle head self drilling, self tapping steel screws at 12 in o. c. Gypsum board panels placed with long dimension perpendicular to the joists. End joints staggered 4 ft between adjacent rows. Side joints were in line.
6. Second layer of 1/2-in type SF-3 gypsum board was attached to furring channels with 0.115-in diameter type S-12 bugle head self drilling, self tapping screws at 12 in. o. c. Long dimension installed perpendicular to first layer. End joints staggered a minimum of 12 in from side joints of first layer. Joint compound applied over all screw heads and along the gypsum board joints in the exposed surface followed by perforated joint tape along all the joints and a second layer of joint compound.
7. Resilient furring channels, 7/16-in deep, 28 ga (.021-in) galvanized steel, spaced 12 in o. c. Attached to bugle head screws used to attach gypsum board. Furring channels perpendicular to joists.

FIGURE 3.8
Cross Section of Floor/Ceiling Assembly

3.2.2.2 Wood Joists, Plywood and Gypsum Board Double Floor/Ceiling System

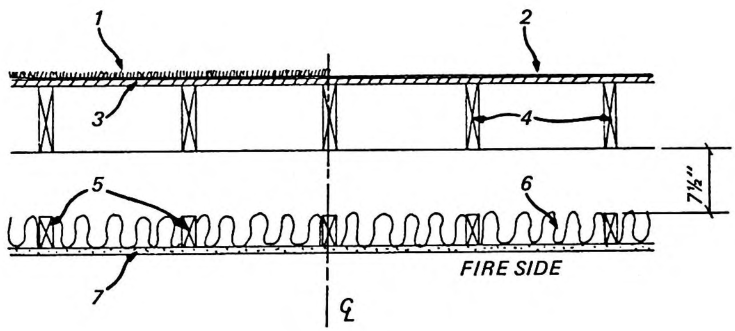
The floor system for an upper module consisted of 2 by 8 wood joists, spaced 16 in o. c., with 5/8-in plywood subflooring. One half of the floor area (see Fig. 3.9) was covered with vinyl asbestos floor tile and the other half with nylon shag carpet with a foam backing.

The ceiling system for the lower module was made up of 2 by 4 joists, spaced 16 in o. c., with one layer of 5/8-in type X gypsum board applied to the under side of the joists. Paper faced 3 1/2-in thick glass fiber insulation batts were installed between the ceiling joists.

A uniform floor load of 40 lb/ft^2 was applied to the 10-ft 10 1/2-in by 17-ft 5-in test assembly during the test.

Test Results:

Flame-through on the unexposed side occurred at 45 min 30 s.



Construction

1. Nylon shag carpet with foam backing on approximately one half of the floor area.
2. 1/8-in vinyl asbestos floor tile adhered to plywood subfloor on remainder of floor area (8 ft 8 in by 11 ft 9 1/2 in).
3. 5/8-in plywood subfloor attached to joists with 1/4-in bead of structural adhesive and 6d nails spaced 6 in o. c. at the joints and 12 in o. c. at intermediate joists. Long dimension parallel to joists.
4. 2 by 8 wood floor joists 16 in o. c. nailed to perimeter joists.
5. 2 by 4 wood ceiling joists 16 in o. c. nailed to perimeter joists.
6. 3 1/2-in thick, paper faced, glass fiber insulating batts.
7. 5/8-in type X gypsum board applied with long dimension parallel to joists. Attached to joists with 1/4-in bead of structural adhesive and No. 4 ring shank nails spaced 6 in o. c. at the joints and 12 in o. c. at intermediate joists. Wall board joints and nail heads finished with joint compound.

FIGURE 3.9
Cross Section of
Floor/Ceiling Assembly

REF: *Fire Test Report FC-170,* National Gypsum Company Research Center, Buffalo, New York 14217, February 1972. (Unpublished)

3.2.2.3 Steel Joists, Plywood and Gypsum Board Double Floor/Ceiling System

The floor system (Fig. 3.10) of this double assembly consisted of 6-in deep, 18 ga galvanized steel "C" joists spaced 24 in o. c., with 3/4-in tongue and groove plywood subflooring attached to the joists. Half of the plywood subflooring was covered with carpet over a cushion type pad and the other half with a resilient sheet vinyl floor material.

The ceiling assembly was composed of 3-in deep, 18 ga galvanized steel "C" joists spaced 24 in o. c. The ceiling membrane consisted of 3/8-in plywood attached to the under side of the steel joists, to which 5/8-in type C gypsum board was applied. The gypsum board was painted with one coat of latex paint. One layer of 2-in thick glass fiber blanket insulation was laid over the ceiling joists.

Three 11-ft 8-in by 17-ft 4-in specimens were tested, the construction for Test 1 being as described above. A load of 40 lb/ft^2 over the 11-ft 8-in span was applied to each of the specimens.

The test specimen for Text 2 was basically the same as that for Test 1 except that the ceiling membrane consisted of two layers of 1/2-in type C gypsum board, the exposed surface of which was left unpainted.

The test specimen assembly for Test 3 differed slightly in overall size from those used in Tests 1 and 2. It was 11 ft 9 in by 17 ft 11 in. The ceiling membrane was a single layer of 5/8-in type X gypsum board, and a continuous 3-in wide, 24 ga steel bracing strap was welded to the tops of the ceiling joists at midspan.

Test Results:

Test 1*: At 50 min flame-through occurred on the carpeted half of the unexposed floor surface.

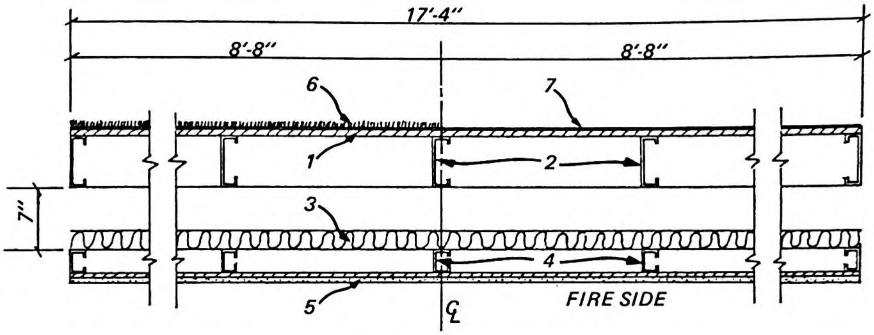
Test 2**: The test was terminated at 1 hr 10 min 30 s, when structural failure appeared imminent.

Test 3***: Failure occurred at a corrected time of 30 min by flame-through to the unexposed floor surface.

*REF: Fire Test Report FC-166, National Gypsum Company Research Center, Buffalo, New York 14217, December 1971. (Unpublished)

**REF: Fire Test Report FC-167, National Gypsum Company Research Center, Buffalo, New York 14217, January 1972. (Unpublished)

***REF: Son, B. C., *Fire Endurance Tests of Plywood on Steel Joist Floor Assemblies With and Without Ceilings,* NBSIR 73-141, National Bureau of Standards, Washington, D. C. 20234, March 1973. (NTIS Accession No. PB-220 430)



Construction

1. 3/4-in tongue and groove plywood subflooring attached to joists with special drywall screws spaced 8 in o. c. along the edges and 12 in o. c. at intermediate joists. Tongue and groove edges bonded with neoprene structural adhesive. Plywood laid with long edges perpendicular to joists for Tests 1 and 2. Attached with 1 1/8-in long hi-lo bugle head screws 12 in o. c. for Test 3.
2. 6 by 1 3/4-in 18 ga galvanized cold-rolled steel "C" joists, 24 in o. c., spanning 140 in. Joists end-welded to cold rolled steel "H" section boundary members.
3. 2-in thick R-6 glass fiber insulating blankets laid over ceiling joists.
4. 3 by 1 3/4-in 18 ga galvanized cold-rolled steel "C" joists, 24 in o. c., plug welded to "C" section channel boundary members on each flange.
5. For Test 1: 5/8-in type C gypsum board over 3/8-in plywood. Plywood screwed with long edges perpendicular to joists with 1-in type S-12 bugle head screws 12 in o. c. Gypsum board screwed with 1 7/8-in type S-12 bugle head screws, 12 in o. c. (staggered with screws in plywood). Long edges were parallel to joists and joints finished with tapeless joint compound. Ceiling surface painted with one coat of latex paint.
   Test 2: 2 layers 1/2-in type C gypsum board. First layer applied with long edge perpendicular to joists and attached with 1-in type S-12 screws 12 in o. c. Second layer applied with long edge parallel to joists and attached with 1 5/8-in type S-12 screws spaced 12 in o. c. Joints finished with tapeless joint compound. No paint applied. Joints between the face boards reinforced by 1 1/2-in type G bugle head screws at 12 in o. c., staggered 6 in from 1 5/8 in S-12 screws.
   Test 3: 1 layer 5/8-in type X gypsum board attached with 1-in type S-12 bugle head screws spaced 6 in o. c. along the edges and 12 in o. c. at intermediate joists.
6. 3/8-in nylon pile carpeting on 1/8-in jute backing, laid over 1/4-in rubberized hair pad.
7. Resilient sheet vinyl flooring bonded to floor deck with latex adhesive.

Note: Stub walls erected around the perimeter of the floor and ceiling assemblies used to maintain the assemblies in position.

FIGURE 3.10
Cross Section of
Floor/Ceiling Assembly

203-591 O - 76 - 5

3.2.3 Floor Assemblies

The floor assemblies evaluated were representative of systems used over crawl spaces or unfinished basements in which the floor joists are unprotected (no ceiling material).

3.2.3.1 Wood Joist and Plywood Construction

Two wood joist floor systems were evaluated. The test assemblies were identical in size and basic construction, differing primarily in the size of the joists. Each was 13 ft 6 in by 18 ft. Figure 3.11 shows the construction details of each test assembly, the primary difference being that 2 by 10-in joists were used in Specimen L-1 and 2 by 8-in joists in Specimen L-2.

Note: The effects of different floor coverings over such construction were investigated in a series of small-scale fire endurance tests described in Section 4.5 of this publication.

Test Results:

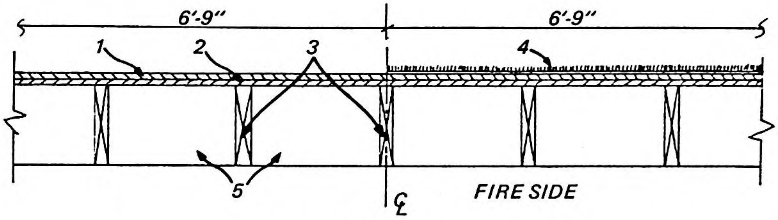
Specimen L-1: A load of 63.7 lb/ft^2 was applied to the floor assembly before the start of the test. This load produced the design stress in the joists.

At 11 min 38 s, the specimen indicated the inability to sustain the applied load, and at 13 min 30 s, flame-through occurred at a joint between plywood sheets on the bare floor. When the test was terminated at 15 min, no excessive temperature rises on the upper surface had been recorded.

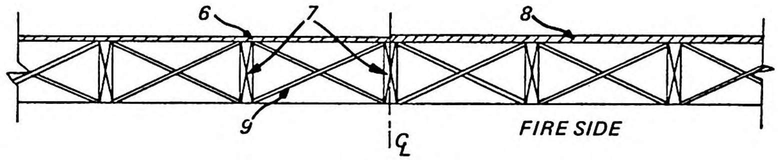
Specimen L-2: Specimen L-2 was loaded with 21 lb/ft^2 before start of test. This load was representative of the live loads anticipated in actual use.

Failure by excessive temperature rise occurred at 9 min for the 1/2-in plywood floor section and at 10 min for the section with 5/8-in plywood flooring.

REF: Son, B. C., *Fire Endurance Tests of Unprotected Wood Floor Constructions for Single-Family Residences,* NBSIR 73-263, National Bureau of Standards Washington, D.C. 20234, July 1973. (NTIS Accession No. PB-225 284)



SPECIMEN L - 1



SPECIMEN L-2

Construction

1. 1/2-in grade A-C plywood underlayment nailed with 6d coated nails spaced 12 in o. c. Gap of 1/16 in at plywood joints. Joints staggered between underlayment and subfloor layers.
2. 1/2-in grade C-D plywood subflooring nailed with 8d coated nails spaced 6 in o. c. along the edges and 10 in o. c. at intermediate joists. Gap of 1/16 in at plywood joints.
3. 2 by 10-in construction grade Douglas Fir joists, 16 in o.c., with a span of 13 ft 6 in.
4. Nylon 501 carpet (weight 66.7 oz/yd^2) over hair pad covered one half of specimen. Remainder was bare and had no finish floor.
5. 2 by 10 solid bridging between joists, 5 ft o. c., staggered for direct nailing.
6. 1/2-in interior grade A-C plywood with square edge joints protected by 2 by 3 blocking placed in line for toe nailing. Nailed with 8d common nails spaced 10 in o. c.
7. 2 by 8 construction grade Douglas Fir joists, 16 in o. c., with a span of 13 ft 6 in.
8. 5/8-in tongue and groove plywood, underlayment grade. Nailed with 8d common nails spaced 10 in o. c.
9. One row adjustable metal bridging at midspan.

FIGURE 3.11
Cross Sections of Floor Assemblies

3.2.3.2 Plywood Over Steel Joists

This test specimen represents the floor assembly in a first floor module of a low-rise multifamily residential structure. It would be located over a foundation (or crawl space). The overall size of the floor assembly was 11 ft 9 in by 17 ft 11 in and consisted of 3/4-in tongue and groove underlayment grade plywood over 6 by 1 3/4-in cold-rolled steel "C" joists spaced 24 in o.c.

Half of the plywood surface (8 ft 11 1/2 in) was covered with 3/8-in nylon pile carpeting with jute backing laid over 1/4-in rubberized hair padding. The floor specimen was identical to the floor portion of the floor/ceiling assembly used for test No. 3 in Section 3.2.2.3 (see Figure 3.10). A load equivalent to 51.4 lb/ft^2 was applied to the floor specimen.

Test Result:

Failure occurred at 3 min 15 s when flame-through occurred at the unexposed surface, followed by collapse of the entire assembly at 3 min 45 s.

REF: Shoub, H. and Son, B. C., *Fire Endurance Tests of Plywood on Steel Joist Floor Assemblies, With and Without Ceiling,* NBSIR 73-141, National Bureau of Standards, Washington, D.C. 20234, March 1973. (NTIS Accession No. PB-220 430)

3.2.3.3 Sandwich Panels of Paper Honeycomb Core with Steel Sheet and Plywood Facing Over Steel Joists

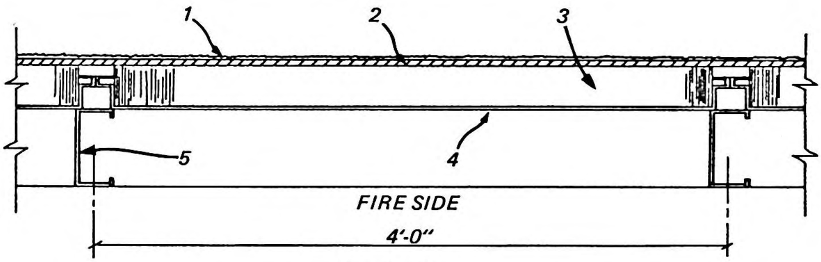
This sandwich panel floor system (Fig. 3.12) was designed for use in single family housing. The steel joists supporting the panels were unprotected from the effects of fire and so were representative of constructions applied over habitable basements and crawl spaces. The structural frame of the floor assembly consisted of 6 by 3 in, 14 ga steel "C" joists and stringer beams, the joists being 48 in o. c. The overall size of the assembly was 10 ft 7 1/4 in by 17 ft 11 in.

The sandwich panels consisted basically of a 3-in thick paper honeycomb core with a top surface of 3/8-in C-D plugged interior grade plywood (with exterior glue) and a bottom surface of 26 ga galvanized sheet steel.

All panels were 10 ft 7 1/4 in long. Three 4-ft wide panels were placed in the middle of the floor framing, with one 2-ft 11 1/2-in wide panel at each end, for a total of 5 panels. Joints between panels were sealed with 3/8-in wide butyl sealant strips. Carpeting was bonded to the plywood with a commerical natural latex releasable adhesive. A 40 lb/ft^2 load was applied to the floor assembly during the test.

Test Results:

Failure by flame-through occurred at a joint between two sandwich panels at 8 min 45 s, followed by structural failure at 9 min.



Construction

1. Carpeting bonded with natural latex releasable adhesive.
2. 3/8-in C-D plugged interior grade plywood (with exterior glue). Gaps between plywood top sheets did not exceed 1/16 in.
3. 3-in thick paper honeycomb core.
4. 26 ga galvanized sheet steel bent up on long sides of panel to cover bottom 1 1/2-in of paper core and shaped to contain a 5/16 by 5/16-in boss to compensate for a 5/16-in setback in the paper core from the joint edge.
5. 6 by 3-in 14 ga steel "C" joists, 48 in o. c., welded to perimeter frame. Panel joints located over joists.

FIGURE 3.12
Cross Section of Floor Assembly

REF: Son, B. C., *Fire Endurance Test of a Steel Sandwich Panel Floor Construction*, NBSIR 73-164, National Bureau of Standards, Washington, D.C. 20234, April 1973. (NTIS Accession No. PB-221 642)

4.

FIRE ENDURANCE: OTHER TESTS

4. FIRE ENDURANCE: OTHER TESTS

In addition to the fire endurance tests conducted on floor, roof and ceiling assemblies, several other tests of this type were conducted on other systems.

A wall system whose endurance when exposed to fire on one side, as is normally the case in ASTM E 119, was already known, was tested with exposure to fire on both sides to determine the effects of such fire exposure on its endurance. The fire endurances of a mechanical/electrical core assembly and of a protected steel tubular column were determined, as were the effects of coating structural elements with intumescent paints. Also described in this section are the many small-scale fire endurance tests used to screen out potential floor and roof systems and thus decrease the amount of costly and time-consuming large-scale testing required.

4.1 Fire Endurance of a Wall Assembly Exposed on Both Sides

Wall structures inside a dwelling unit can be exposed to fire on both sides, since the fire can travel from one room to another through open doorways and corridors.

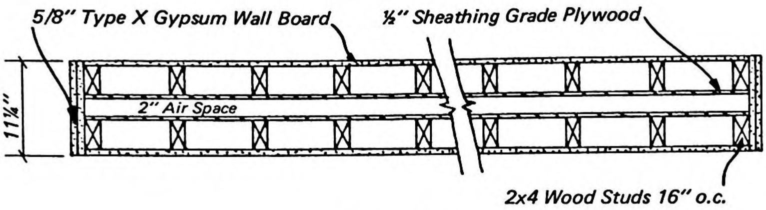
This test was performed to experimentally determine any correlation between the fire resistance of a wall when it is exposed to flames on both sides and the fire resistance of a similar wall assembly when it is exposed to flames on one side, as is the case in the standard ASTM E 119 test procedure for walls.

A typical wood frame intermodular double wall assembly with 5/8-in fire resistant gypsum wall board on the module interior wall surfaces and 1/2-in plywood on the module exterior surfaces was used for the test (see Figure 4.1 for construction details).

Since ASTM E 119 wall test furnaces do not have the capability of exposing wall assemblies to fire on both sides, the wall test assembly was mounted vertically in a floor test furnace. Two rows of burners on either side of the wall assembly were removed from the furnace to accommodate the partition. The top of the furnace was closed off by a gypsum wall board ceiling, which protected the top surface of the wall assembly. A concrete floor assembly, including bar joists, was placed over the ceiling.

The test was conducted without a superimposed load, and the furnace temperatures were raised in accordance with the standard time-temperature curve of ASTM E 119. One side of the double wall partition was instrumented with 42 thermocouples. Thirty-six of these were installed in nine locations, with one on each surface of the gypsum wall board, one on the air space side of the plywood sheathing and the fourth thermocouple located in the air space between the wall elements. The remaining six thermocouples were placed on the wood studs in the wall cavity. Temperatures in the furnace were controlled by 16 thermocouples set near the wall assembly at a height of 4 ft.

The test was terminated after a fire exposure of 54 min, when it became obvious that the plywood between the two walls was burning. A similar wall assembly (see Section 2.2.2.4) had a fire endurance rating of 75 min when exposed to fire on one side.



Construction

1. 16-ft long double wall partition is 8 ft high.
2. 2 by 4 wood studs spaced 16 in o. c.
3. 1/2-in sheathing grade plywood attached to studs with 6d nails spaced 6 in o. c. at the perimeter and 12 in o. c. in the field.
4. 5/8-in type X gypsum wall board attached to studs with 6d nails spaced 7 in o. c.
5. Gypsum wall board joints covered with paper tape and 2 coats of joint compound.
6. 2 by 4 wood plates attached to studs with two 12d nails per stud at top and bottom.

FIGURE 4.1
Horizontal Section of
Intermodular Double Wall

REF: National Gypsum Company, *Fire Test FC-157. (Unpublished)*

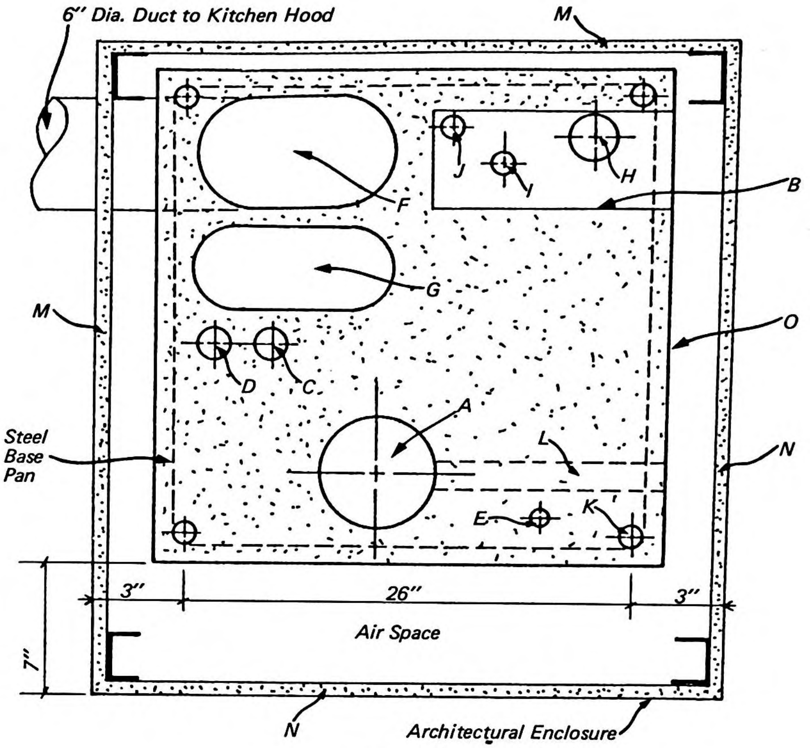
4.2 Fire Endurance of a Mechanical/Electrical Core Assembly

The use of prefabricated mechanical/electrical cores in multi-story housing construction was investigated as a potential path for the spread of fires.

This test was conducted to determine the fire endurance of a vertical mechanical/electrical core assembly intended for use by one of the Operation BREAKTHROUGH Housing System Producers. It is believed to be the first fire endurance test of a complete prefabricated service core in the United States. Two vertically adjacent levels of a mechanical/electrical core designed to serve multiple floors in an apartment building were used for the test. The core assembly was placed inside an architectural enclosure which simulated the walls surrounding the core in actual construction.

The mechanical/electrical core assembly contained copper water pipes, PVC drain pipe, sheet metal kitchen and bathroom exhaust ducts and steel electrical junction boxes and conduit, embedded in loose foamed urea formaldehyde insulation within a corrugated paper jacket.

The core was placed inside an architectural enclosure constructed from 3/4-in particle board on two sides and 5/8-in type X gypsum wall board on the other two sides. The enclosure was framed with C-shaped light gauge steel studs using 1 1/2-in standard Phillips-head self-tapping drywall screws on 12-in centers. Details of the core assembly are shown in Figure 4.2 a.



LEGEND

A. 6" Diam. Main Sanitary Stack, PVC
B. 5"x12"x16" Electric Junction Box 14 ga Enamel Steel
C. 1 1/2" Diam. Copper Pipe, Domestic Hot Water, Type M
D. 1 1/2" Diam. Copper Pipe, Domestic Recirculation Hot Water, Type M
E. 1/2" Diam. Copper Pipe, Domestic Recirculation Hot Water, Type M
F. 10"x6" Kitchen Exhaust Duct, 22 ga Galvanized Steel
G. 10"x4" Bathroom Exhaust Duct, 22ga Galvanized Steel
H. 2 1/2" Diam. Electrical Conduit Galvanized Electrical Metallic Tubing
I. 1" Diam. Telephone Conduit, Galvanized E.M.T.
J. 1"Diam. Intercom and Television Conduit, Galvanized E.M.T.
K. 1" opening for Electrical Cables (one in each corner)
L. 1 1/2" Diam. Sink Connection Pipe, P.V.C.
M. 5/8" Type X Gypsum Board
N. 3/4" Particle Board
O. Urea-Formaldehyde Foam Core

FIGURE 4.2a
Construction Details of
Core Assembly

The test assembly shown in Figure 4.2 b consisted of the lower core unit, which was mounted in the NBS floor test furnace, a 6 1/2-in thick concrete slab, 6 ft square, which represented the floor in the building and served as part of the furnace closure, and an upper core unit which was mounted outside the test furnace. The upper core unit had a lightweight concrete base, cast into an integral 16 ga sheet metal pan, which fitted closely into a 2-ft by 2-ft hole in the center of the concrete floor. An asbestos and glass fiber caulking compound was used to seal the joint between the concrete base and the pan closure.

Pipes in the upper and lower units were joined with couplings of the same material. Galvanized steel ducts were connected with flexible steel clamps. A floor extension consisting of 2 by 12 wood joists protected on the fire side by two layers of 5/8-in type X gypsum wall board, followed by a coating of vermiculite plaster applied on metal lath attached to the gypsum board, was used to seal those portions of the furnace not sealed by the concrete floor slab.

Furnace temperatures were programmed to follow the standard ASTM E 119 time-temperature curve. In accordance with the intent of ASTM E 119, the fire endurance of the core assembly was determined by the first occurrence of one of the following two criteria:

1. Passage of flame or gases through the architectural enclosure above the concrete slab hot enough to ignite cotton waste.

2. Transmission of heat through the architectural enclosure above the concrete slab that raises the average temperature more than 250°F (139°C) or 325°F (181°C) at one point.

The fire endurance of the test assembly was considered to be 35 min when flames penetrated to the top of the upper level of the core.

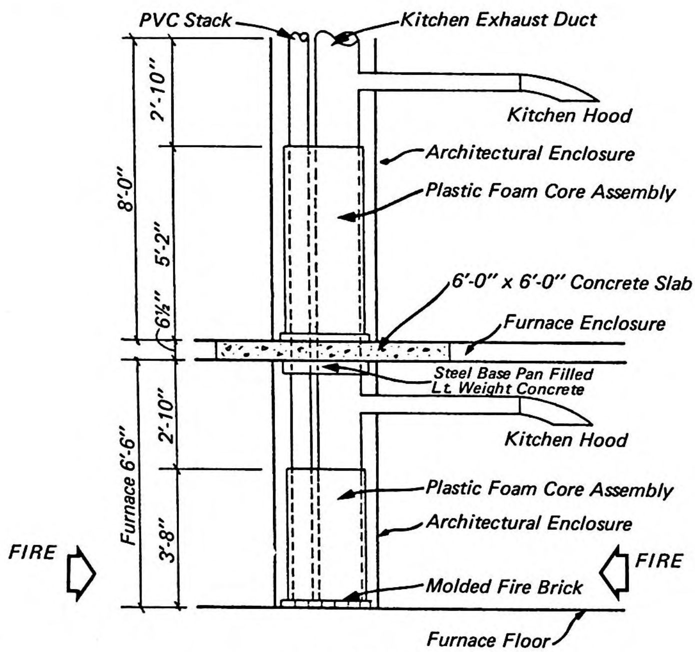


FIGURE 4.2b
Test Specimen
Mounted in Furnace

REF: Son, B.C., *Fire Endurance Test of Mechanical/Electrical Core Assembly for Use in Multifamily Housing,* NBS Report 10415, National Bureau of Standards, Washington, D. C. 20234. (NTIS Accession No. PB-217 362)

4.3 Fire Endurance of a Steel Tubular Column Protected with Gypsum Board

A fire endurance test was conducted on a protected rectangular hollow tubular steel column proposed for use in single family attached and multifamily low-rise housing by one of the Operation BREAKTHROUGH Housing System Producers to determine its loadbearing capabilities in a fire situation.

The column assembly, which is shown in Figure 4.3 a, was made up of a 3 by 2 by 3/16-in hot rolled rectangular structural (ASTM Grade A-36) steel tube protected by two layers of gypsum board. The underlayer was 3/8-in regular gypsum board and the face (fire-exposed) layer 1/2-in type X gypsum board. The fire-exposed face was plastered with 1/8-in thick joint compound. At the top and the bottom of the column assembly 6 by 9 by 3/16-in thick bearing plates were attached with a continuous fillet weld around all sides of the column, leaving an overall column length of 10 ft 8 in (including the two 3/16-in bearing plates). Each bearing plate had four 1/2-in diameter bolt holes located in the corners of the plate 1 in from each edge. The measured weight of the column assembly was 120 lb.

Fasteners used to attach the gypsum board to the test column consisted of 1-in self drilling bugle head metal screws on the gypsum board underlayer and 2 1/4-in self-drilling Phillips recessed flat head metal screws on the face layers. Both were spaced approximately at 16-in centers along the center line of each side of the column assembly. The corner reinforcement (ECONO standard dur-a-bead) was crimped to hold it onto the gypsum board.

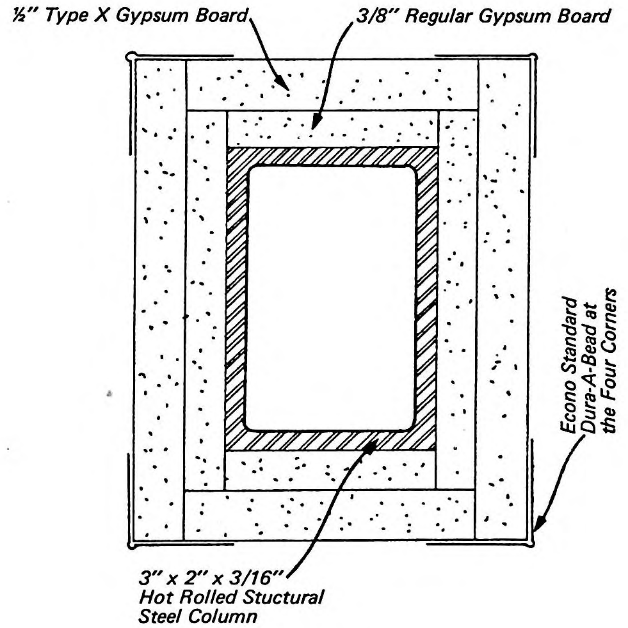


FIGURE 4.3a
Horizontal Section of Column Assembly

The column test assembly was placed into the test furnace as shown in Figure 4.3.b, a load of 7110 lb was applied, and the temperature was raised in accordance with the standard ASTM E 119 time-temperature curve. The column assembly tested had a fire endurance rating of 59 min, which was determined by the time at which the column was unable to sustain its applied load in accordance with the requirements of ASTM E 119.

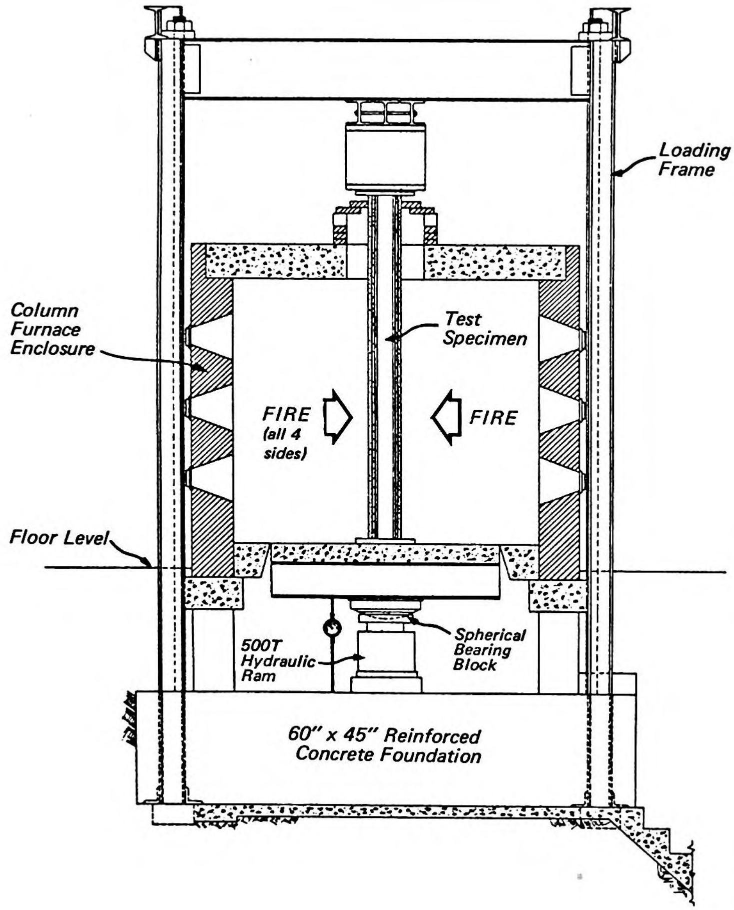


FIGURE 4.3b
Schematic of Column Fire Test Furnace Set-Up

REF: Son, B. C., *Fire Endurance Test on a Steel Tubular Column Protected with Gypsum Board,* NBSIR 73-165, National Bureau of Standards, Washington, D. C. 20234, (NTIS Accession No. PB-221 474).

4.4 Fire Resistance of Intumescent-Painted Structural Elements

In connection with Operation BREAKTHROUGH, several Housing System Producers proposed using intumescent paints applied to structural components for fire protection. At elevated temperatures, intumescent paints expand and form an insulating layer, which tends to reduce the rate of heat transfer to structural elements.

Since information on which an engineering evaluation could be based was not available, tests were conducted to provide a semi-quantitative indication of the effectiveness of the intumescent paints when applied to steel studs and to wood joists. In these applications the intumescent paint was expected to provide 15 minutes additional fire endurance for a steel stud and enough protection to a wood joist so that it would carry its applied load for at least 45 minutes.

In the case of the wood joists, it was felt that a layer of gypsum board would provide a high level of protection, so a portion of the wood joist test assembly was protected by type X gypsum board.

4.4.1 Steel Stud Test

Three cold-formed 18 ga channel steel studs (C-3 by 1 3/4 in) were assembled in a horizontal position between two layers of gypsum board on the unexposed side and an asbestos mill board on the fire side for the steel stud test. One stud was left bare: the second was painted with one coat of intumescent paint, and the third stud was painted with two coats of intumescent paint. In Figure 4.4.a, showing the test assembly, these are marked as B, A and C, respectively. Each coat of the modified vinyl phenolic resin intumescent paint used had a dry film thickness of 6 to 8 mils. Each stud was instrumented with two groups of three thermocouples; one located on the fire side flange, one on the web, and one on the unexposed side flange.

The assembly was then mounted as the roof of a 2 by 2-ft slab furnace, and the temperature of the furnace was raised in accordance with the standard ASTM E 119 time-temperature curve.

By analyzing the temperatures measured on the steel studs and the yield strengths associated with them, it was concluded that two coats of the intumescent paint used provided no more than three minutes of additional fire endurance protection, and that the paint would be of little value in protecting the steel.

4.4.2 Wood Joist Test

An assembly consisting of three 2 by 10 wood joists was constructed for the wood joist test. As is shown in Figure 4.4.b, the joists were placed next to each other, with the 10-in side flat, and separated by 5/8-in type X gypsum board spacers. The bottom surface of the first joist was bare; the second joist was protected with one layer of intumescent paint 7 to 8 mils thick; the third was protected with one layer of 5/8-in type X gypsum board. The unexposed side of the specimen was also covered with the same type of gypsum board.

The assembly was then exposed to the ASTM E 119 time-temperature conditions for 45 minutes in a small slab furnace, removed from the fire, extinguished with a carbon dioxide extinguisher and water gently poured over the assembly.

On the basis of the amount of char obtained, it was concluded that only the type X gypsum board would provide sufficient protection for a 45-minute fire endurance rating. The bare joist was entirely (1 5/8 in) charred; the painted joist was 7/8 in charred, and the gypsum board-protected joist was 1/8 in charred. Under normal design rules, a softwood joist could be expected to fail structurally by the time 48 percent of the cross section has been lost by charring. Since 55 percent of its cross section was charred in 45 minutes of test, it was inferred that the painted joist would have failed under load prior to 45 minutes of test time.

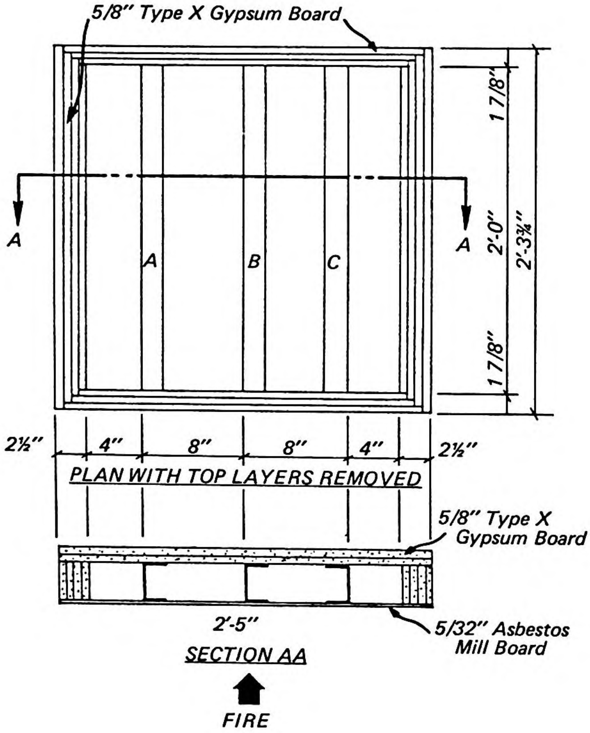


FIGURE 4.4a
Steel Stud Test Specimen

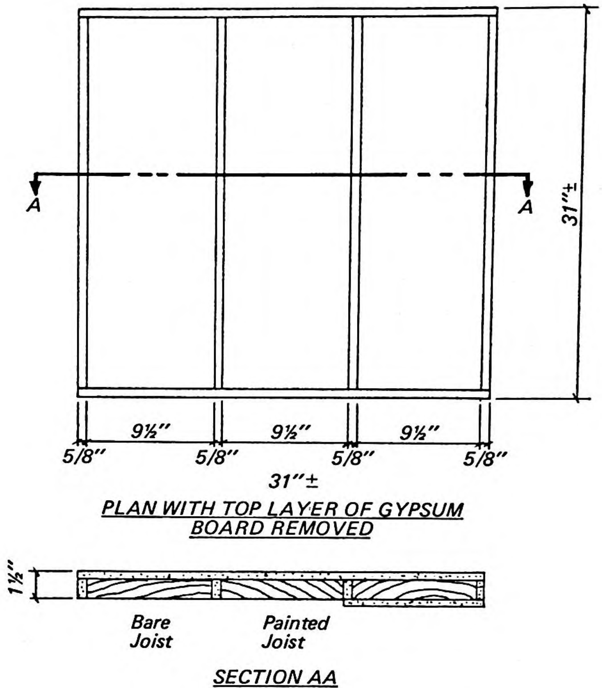


FIGURE 4.4b
Wood Joist Test Specimen

REF: Issen, L. A., *Tests of the Fire Resistance of Intumescent-Painted Structural Elements,* NBS Report 10412, National Bureau of Standards, Washington, D. C. 20234 (NTIS Accession No. PB-213 653).

4.5 Small-Scale Fire Endurance Tests: Floor Systems

A series of fourteen fire tests were conducted to measure the fire endurance of a variety of wood floor constructions representative of those used in single family residences. Since full-scale test specimens as required by ASTM E 119 are both costly and time-consuming to prepare and test, twelve of the fourteen tests were conducted on small-scale specimens loaded with dead weights to restrain the specimens in a 2 by 2-ft pilot fire test furnace (Specimens S-1 through S-12). The two full-scale tests were conducted on 13.5 by 18-ft specimens with superimposed loads intended to simulate in-service conditions (see Section 3.2.3 for a full description of these tests). One of the specimens (L-1) was constructed with 2 by 10-in wood joists spaced 16 in o. c. and the other (L-2) with 2 by 8-in wood joists. All of the small-scale specimens incorporated 2 by 10-in joists. The assemblies tested included a variety of plywood subflooring and underlayment combinations and strip flooring applied directly over the joists. In several tests carpeting was installed as part of the floor system. By using the same type of construction for several of the small-scale specimens as was used in the full-scale specimens, it was possible to obtain correlations between the results obtained from both types of tests.

The fire exposure conditions used were in accordance with the ASTM E 119 time-temperature curve. Test results were evaluated by means of the ASTM fire endurance criteria for floors described in Section 3.1 of this publication. However, in the case of the small-scale specimens, the criteria for failure under load were not considered, since it was not possible to apply enough load to provide stress levels equivalent to those provided in the full-scale specimens.

The 2 by 10-in joist framework for each of the twelve small-scale specimens is shown in Figure 4.5 a. Various combinations of flooring materials were installed on the 25 by 25-in framework. A joint was centrally located in each layer of flooring. The joints in adjacent layers of subfloor and underlayment were perpendicular to each other. In Tests S-1 and S-2, a 1/16-in joint gap was employed. In subsequent tests, which did not involve tongue and groove plywood, a gap of 1/8 in was used to simulate more closely the cracks caused in the full-scale specimens by the applied loads.

Test Specimen S-1

Specimen S-1 was similar in construction to full-scale specimen L-1, with 1/2-in plywood subflooring and underlayment layers and a 1/16-in gap between joints. This specimen was not loaded during the test. Because of some difficulty with the furnace control in this first test, the flame-through time was corrected according to the correction formula in ASTM E 119. *The corrected time of flame-through was 18 min 10 s.* Due to the absence of a superimposed load, the center of the joint tended to bend upward because of thermal stress.

Test Specimen S-2

Specimen S-2 was identical to S-1 except for an applied load of 10 lb/ft^2. No bending was observed, either upward or downward, during the test. *Flame-through occurred at 17 min 21 s.*

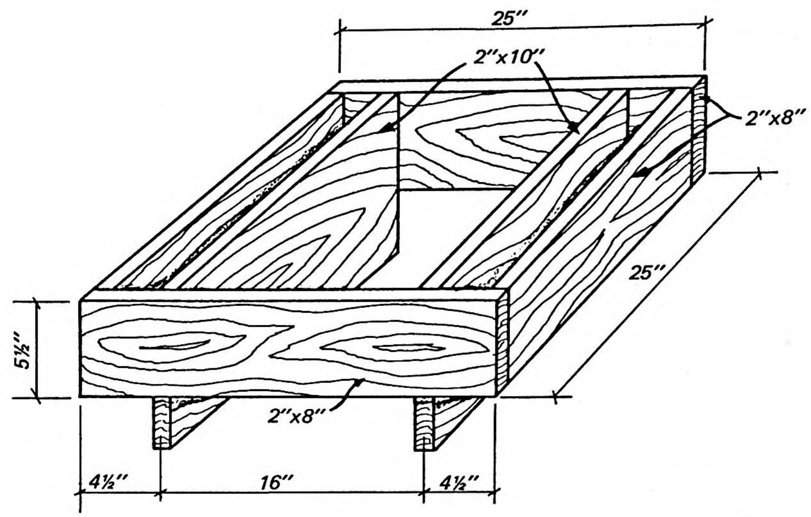


FIGURE 4.5a
Joist Framing for Small Scale Fire Test Specimen

Test Specimen S-3

Test specimen S-3 was identical to S-1 and S-2 except that the gap between joints in subflooring and underlayment was increased to 1/8 in. In this test the superimposed load was increased to 60 lb/ft^2. *Flame-through occurred at 12 min 45 s,* primarily through the joint, which compares well with the 13 min 30 s for full-scale specimen L-1. It is possible that the 1/8-in gap built in during construction of this specimen was comparable to the joint gap in the large specimen that opened up when the specimen was under load.

The 60 lb/ft^2 loading used in S-3 was also used for the subsequent small-scale tests that follow.

Test Specimen S-4

Specimen S-4 was identical to S-3 except that the same type of carpeting and pad used in the large-scale test L-1 were used to cover the underlayment. Flame-through originated in the same area as in Test S-3. The unexposed surface of the carpet charred over a large area during the last 3 min 50 s of test, *with surface ignition spreading rapidly over the char region at 25 min 50 s.* This was considered to be the flame-through time. Some deflection due to load was observed after 21 min of exposure to fire.

Test Specimen S-5

The flooring for S-5 was 25/32-in T & G pine strip flooring applied directly to the joists. *Flame-through occurred at 10 min 30 s through a joint.*

Test Specimen S-6

Specimen S-6 was constructed with a 1/2-in plywood subfloor and 2 by 4 blocking covering the 1/8-in gap, over which was applied the same type carpeting as for Specimen S-4. *Flaming occurred at 18 min 15 s,* directly through plywood and carpeting but not at the joint. An excessive temperature rise was observed after 11 min 30 s.

Test Specimen S-7

Specimen S-7 was identical to S-6 with the exception that the carpeting was left off. An excessive unexposed surface temperature rise was reached after 8 min, and *flame-through occurred at 9 min 25 s.*

Test Specimen S-8

Specimen S-8 was the same construction as S-4 except that 1/4-in plywood was substituted for the 1/2-in underlayment. Excessive temperature rise occurred at 22 min 30 s and *flame-through at 24 min.*

Test Specimen S-9

Specimen S-9 was constructed with 5/8-in tongue and groove plywood over the wood joists. Excessive temperatures occurred over the unexposed surface at 10 min 24 s. The joint started to char and open up at 6 min, and *flame-through occurred at 11 min 35 s.* These values are in good agreement with those for the 5/8-in T and G plywood section of large-scale specimen L-2, described in Section 3.2.3 in this publication.

Test Specimen S-10

Specimen S-10 was identical to S-7. An excessive temperature rise was measured at 6 min 30 s compared to 8 min for S-7. *Flame-through occurred at 11 min for S-10* compared to 9 min 25 s for S-7.

Test Specimen S-11

Specimen S-11 was identical to S-9 except for the addition of carpeting over the plywood. An excessive temperature rise was measured at 17 min 15 s, and *flame-through occurred at 19 min 20 s.*

Test Specimen S-12

The joist frame for Specimen S-12 was covered with 13/16-in oak tongue and groove strip flooring. An excessive temperature rise on the unexposed surface was observed at 13 min, and *flame-through occurred at 14 min 10 s.*

4.5.1 Discussion

The end point for this series of small-scale tests was considered to be the elapsed time at which flame-through occurred. The flame-through time for the twelve systems evaluated appears to be a linear function of the thermal resistance of the flooring system tested, as can be observed in Fig. 4.5 b. This means that the addition of a separate finish floor should increase the fire endurance of a floor system by an amount dependent upon its additional thermal resistance. This relationship can be noted in comparing the results of the tests of Specimens S-3 and S-4, both of which had the same basic construction, the only difference being that carpeting was added to S-4. The thermal resistances of S-3 and S-4 were 1.25 and 2.48 hr°F/Btu respectively, and their flame-through times were 12 min 45 s and 25 min 50 s, a 1:2 relationship in each case.

While total thermal resistance of the floor system can be used to estimate *flame-through* time or fire endurance, further study is necessary to determine the effects of the superimposed load and the gap size. Both large-scale specimens were tested to failure under load.

The results of both the small-scale and large-scale fire endurance tests on such wood floor constructions are summarized in Table 4.1, thus providing some comparison of the two types of tests.

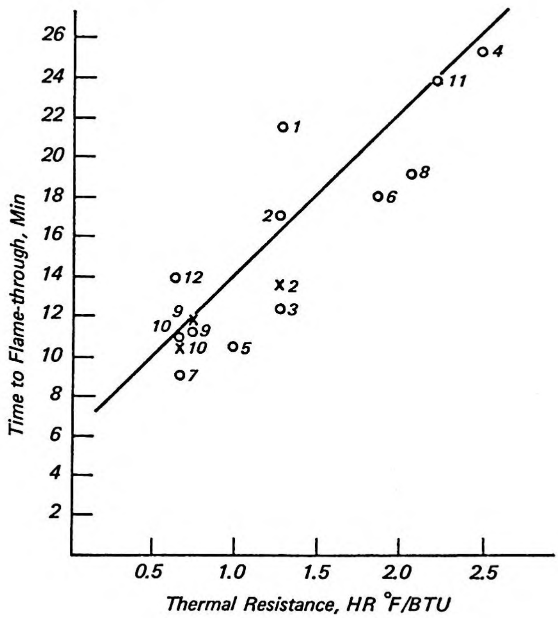


FIGURE 4.5b
Thermal Resistance of Floor Construction vs. Flame-through Time

REF: Son, B. C., *Fire Endurance Tests of Unprotected Wood-Floor Constructions for Single-Family Residences,* NBSIR 73-263, National Bureau of Standards, Washington, D. C. 20234 (NTIS Accession No. PB-225-284/9WB).

TABLE 4.1

COMPARISON OF FIRE ENDURANCE TIMES FOR SMALL AND FULL SCALE TESTS

		Small Scale Tests (2'x2')				Full Scale Tests (13'-6"x18'-0")				
Test	Construction	Load psf	Flame-thru min : sec	Load Fail min : sec	Temp. Fail min : sec	Load psf	Flame-thru min : sec	Load Fail* min : sec	Temp Fail min : sec	Thermal Resistance Hr°F/BTU
1	1/2"+1/2" Plywood + 1/16" gap	None	12:43	–	17:10	–	–	–	–	1.25
2	1/2"+1/2" Plywood + 1/16" gap	10	17:21	–	–	63.7	13:30	11:38	>15:00	1.25
3	1/2"+1/2" Plywood + 1/8" gap	60	12:45	–	–	–	–	–	–	1.25
4	1/2"+1/2" Plywood + 1/8" gap and carpet	60	25:50	–	20:00	63.7	Not reached	11:38	Not reached	2.48
5	25/32" T & G pine	60	10:30	–	–	–	–	–	–	0.98
6	1/2" Plywood + 1/8" gap with 2"x4" blocking and carpet	60	18:15	–	11:30	–	–	–	–	1.85
7	1/2" Plywood + 1/8" gap with 2"x4" blocking	60	9:25	–	8:00	–	–	–	–	0.62
8	1/2"+1/4" Plywood with 1/8" gap and carpet	60	24:00	–	22:30	–	–	–	–	2.16
9	5/8" T & G Plywood	60	11:35	–	10:24	21	11:50	13:00	10:00	0.78
10	1/2" Plywood with 1/16" gap and 2"x4" blocking (L-2) or same with 1/8" gap for S-10	60	11:00	–	6:30	21	11:00	13:00	9:00	0.62
11	5/8" T & G Plywood and carpet	60	19:20	–	17:15	–	–	–	–	2.01
12	13/16" Oak T & G	60	14:10	–	13:00	–	–	–	–	0.56

* Unable to maintain load application

4.6 Small-Scale Fire Endurance Tests: Roof Systems

A series of three small-scale fire endurance tests were conducted to measure the fire endurance of a corrugated roof and ceiling panel system fabricated with a glass fiber reinforced polyester laminate. A full-scale standard (ASTM E 119)fire test on such a panel is described in Section 3.2.1.6 of this publication.

The tests were conducted in a small-scale floor and ceiling test furnace and were exposed to the standard ASTM E 119 time-temperature curve.

Test No. 1:

The roof-ceiling panel assembly used for Test No. 1 is shown in Fig 4.6 a. It was composed of 0.10-in thick laminates bonded with a special modified polyester adhesive to the tops and bottoms of truss-type stiffeners made of the same material as the laminates. The size of the panel was 3 ft 4 in by 11 ft 8 in. At each end of the specimen, along the 3-ft 4-in dimension, a nominal 2 by 6-in kiln-dried Douglas Fir edge member was bonded to the upper and lower sheets of laminates with another type of special proprietary adhesive. The panel thickness, therefore, was a nominal 6 in. All

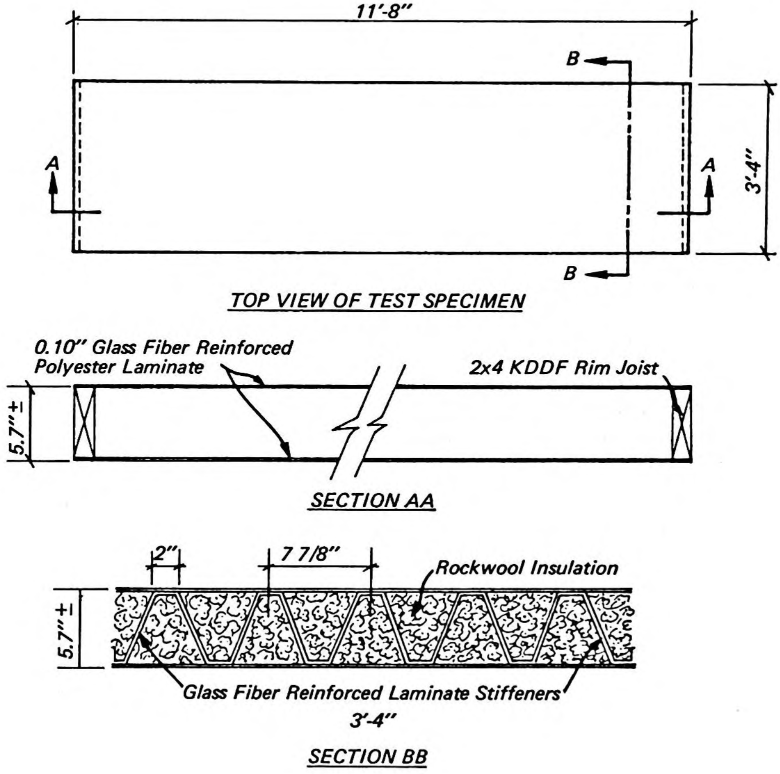


FIGURE 4.6a
Details of Test Specimen

external surfaces of the panel were coated with 0.01 in of intumescent paint, also a proprietary product of the panel manufacturer. The cavities between the stiffeners were filled with 11 lb/ft^3 rock wool.

The specimen for the first test was loaded with the equivalent of 20 lb/ft^2 by means of 18 concrete prisms, each weighting 40 lb. Unexposed surface temperatures were measured by thermocouples located on the upper surfaces of both the top and bottom skins and the under surface of the top skin. The furnace temperatures were controlled by five steel-jacketed thermocouples. All thermocouples were connected to a selector switch and monitored on a portable precision pyrometer.

The gaps along the long unsupported edges of the specimens, after being placed on the furnace, were tightly filled with rock wool to avoid edge burning. Deflections were read using a tautly stretched wire with an initial reading of 2 in.

During the first few minutes of exposure the intumescent paint on the exposed surface blistered, followed by black smoke from the burning laminate and the eventual falling off of the exposed skin.

One long edge of the panel was burning and deflecting excessively, while the other long side remained undeflected. The test was stopped at 60 min due to the excessive deflection along the burned edge. At that point (60 min) none of the thermocouples on the upper surface showed excessive temperature rise, although there was evidence of *hot spots* in other areas. In view of the erratic and non-uniform behavior of the test panel during the test, the results were not considered to be representative of the true performance of the construction.

Test No. 2:

Test specimen No. 2 was identical to Specimen No. 1 with the exception that 17 lb/ft^3 rock-wool insulation was used instead of the 11 lb/ft^3 insulation, and testing was conducted in an identical manner.

After 3 min 30 s the intumescent paint on the exposed surface began to blister; 15 s later, the appearance of black smoke indicated burning of the laminate. At 4 min the deflection was 2.5 in, and an *oil canning* effect due to thermal stresses was observed. At 8 min 30 s most of the exposed (lower) skin fell off, with continuing black smoke as the remainder of the skin and the exposed portions of the stiffeners burned. By 12 min 30 s the black smoke had abated, and the deflection measured 2.75-in.

The deflection had increased to 3.5 in after 24 min of fire exposure and increased at a rate of approximately 1/8 in every two min. At 90 min and a deflection of 6 1/8 in, the test was terminated with no apparent structural failure, nor had there been any flame-through. None of the thermocouples recorded any excessive temperature rise, nor were there any observable hot spots.

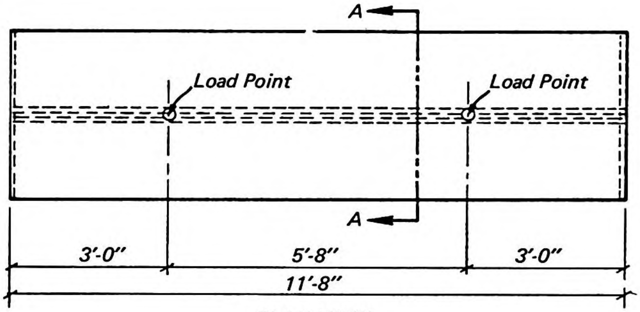
The performance of the specimens in both Test No. 1 and Test No. 2 indicated that intumescent paint is of minor importance in prolonging the fire endurance of panel systems such as these.

Test No. 3:

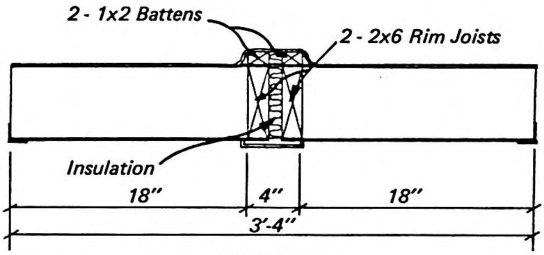
The purpose of this test was to determine the fire endurance of a joint in the same type of roof-ceiling system used in Tests Nos. 1 and 2. The test specimen was composed of two 19.5-in wide panels, joined at the center as shown in Fig. 4.6 b. Only the panel stiffeners were coated with intumescent paint, and they were insulated with 8 lb/ft^3 density rock wool. Otherwise, the panel construction was the same as those used in Tests No. 1 and No. 2.

During this test, the panel was loaded with two hydraulic rams located on the center batten (see Fig. 4.6 b), each one 3-ft from the end of the panel. A load of 2160 lb produced by each ram provided the equivalent of a 30 lb/ft^2 roof load. Deflection readings were taken using a tautly stretched wire with an initial reading of 5/8 in.

Within 2 min from the start of the test, black smoke was seen, indicating burning of the exposed lower laminate. At 7 min the exposed skins on both sections of panel had burned off, leaving the insulation exposed, at which time a small amount of the insulation fell out. The test was terminated after 45 min of exposure when the deflection had reached 2 1/8 in with no structural failure. No excessive temperature rises on the unexposed upper surface were recorded during the test.



PLAN VIEW



SECTION AA

FIGURE 4.6b
Detail of Test Specimen
for Joint Test

REF: Unpublished reports.

5.

SURFACE BURNING CHARACTERISTICS: COMPONENTS

5. SURFACE BURNING CHARACTERISTICS: COMPONENTS

Among the hazards to which the occupants of a residence are exposed are those relating to the surface burning properties of interior finish materials, e.g., flame spread and smoke generation.

Code requirements for flame spread in multifamily dwellings are generally based on the type of use intended. The requirements are usually most stringent for exit areas such as hallways and for furnace areas, moderately high for kitchen areas, and less stringent for areas such as bedrooms and living rooms.

Smoke generation is of primary importance, since most deaths that occur in residential fires are attributed to smoke inhalation.

5.1 Test Methods

Because of time and equipment limitations, flame spread (surface flammability) was determined primarily by the ASTM E 162 *radiant panel* test method, although some measurements were made by means of the ASTM E 84 *tunnel* test. ASTM method E 162 allowed the use of small specimens, which were frequently all that were available, and permitted the evaluation of kitchen cabinets whose small size would have made testing by ASTM method E 84 difficult. The two methods give comparable results for most materials, and some building codes use them interchangeably.

In most cases, smoke generation was measured in the NBS smoke density chamber; however, in the few cases where the E 84 test method was used to determine flame spread, smoke generation was also measured by this method.

Carpeting materials were also evaluated by means of the *pill* test, which determines the spread of combustion when a hot object such as a cigarette is dropped on a carpet.

5.1.1 Flame Spread Test Methods

5.1.1.1 ASTM E 84 (Tunnel Test)

The tunnel test, *Standard Method of Test for Surface Burning Characteristics of Building Materials,* ASTM Designation E 84-70* was originally published as a standard in 1950. It was last revised in 1975. The purpose of the test is to determine the rate and extent of travel of a flame over the exposed surface of the test material. It also provides a means for measuring the fuel contributed and the density of smoke generated.

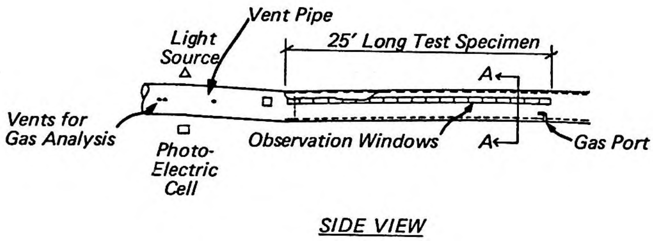
The size of the fire test chamber or tunnel (Fig. 5.1) is such as to require that the test specimen be at least 20 in wide and 25 ft long. After the test specimen is mounted over the open top of the furnace, the two gas burners are ignited and the flame adjusted in accordance with calibration tests using red oak flooring and 1/4-in asbestos-cement board as standards having

*Part 14, 1971 *Annual ASTM Book of Standards.*

flame-spread classifications (FSC) of 100 and 0 respectively. The actual distance of flame travel is measured from the end of the ignition flame, which is 4 1/2 ft from the burners.

The test method provides a series of formulas for calculating the FSC value as a function of the time and length of flame front travel relative to that for the red oak calibration standard (19 1/2 ft in 5 1/2 min). For example, if the flame front travels 5 ft beyond the end of the ignition flame, the FSC value for the material being tested would be 5.128 d or 25.64, where d equals 5 ft.

Smoke density is determined by measuring the output of a photoelectric cell as a function of time and plotting the results on coordinate paper. The area under the curve is compared with the areas obtained for asbestos-cement board and select-grade red oak flooring and a smoke rating between 0 and 100 assigned.



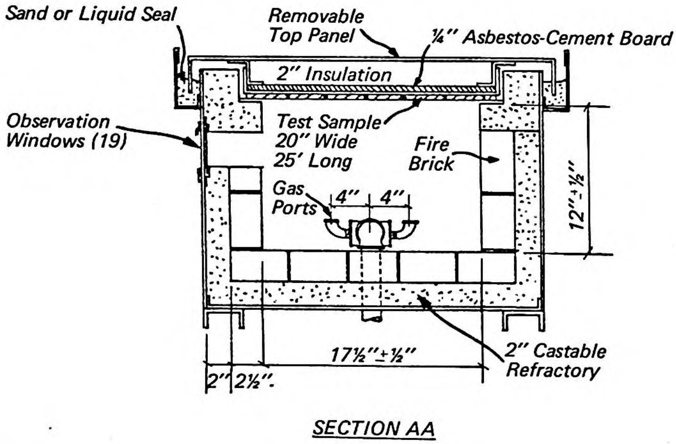


FIGURE 5.1
ASTM E 84 Test Furnace

5.1.1.2 ASTM E 162 (Radiant Heat Method)*

The *radiant panel* test, *Standard Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source,* ASTM Designation E 162* was first published as a standard in 1967.

Its advantage over ASTM Method E 84 is that it requires a much smaller test specimen (6 by 18 in compared to 20 in by 25 ft). The method (see Fig. 5.2) employs a vertical 12 by 18-in radiant heat panel, in front of which an inclined test specimen is placed, the top of which is 4 3/4 in from the radiant heat source, and the degree of inclination from the heat panel is 30°. The orientation of the specimen is such that ignition is forced near the upper edge of the specimen, and the flame front progresses downwards. The specimen holder or the specimen itself (or both) are marked at 3-in intervals from the top to provide means for measuring the rate of flame front travel.

A factor derived from the rate of travel of the flame front and another related to the rate of heat liberation by the material under test are combined to provide a flame spread index or classification.

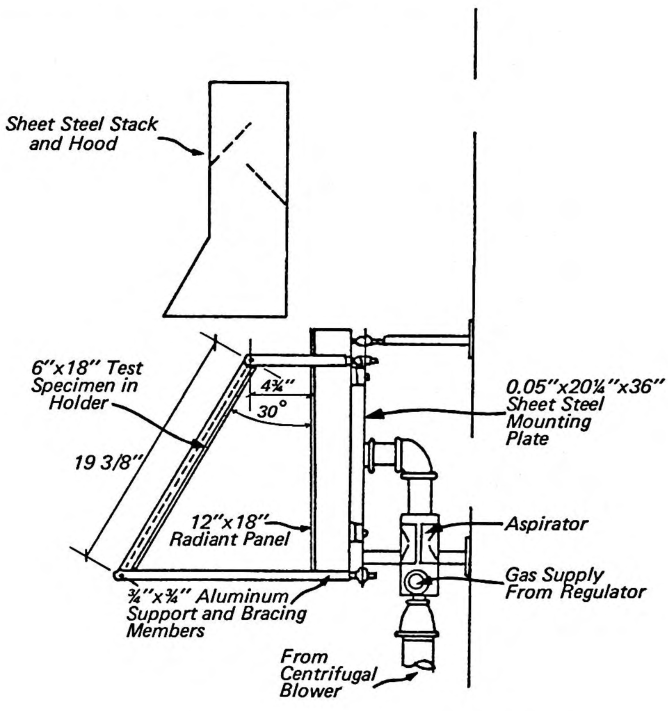


FIGURE 5.2
Test Set-Up for Radiant Panel
Test ASTM E 162

*Part 14, 1971 *Annual ASTM Book of Standards.*

5.1.1.3 DOC FF 1-70, Standard for the Surface Flammability of Carpets and Rugs (Pill Test)*

Fires in carpets or rugs are frequently caused from small ignition sources such as burning cigarettes or glowing embers from a fireplace. This Federal Standard, commonly known as the *pill* test, was developed to provide a relatively simple test method to determine the surface flammability of carpets and rugs when exposed to a standard small source of ignition under carefully prescribed conditions.

The test apparatus itself is simple (Fig. 5.3). It consists of a test chamber in the form of an open top hollow cube made of a noncombustible material having a minimum thickness of 1/4-in. Asbestos-cement board is a suitable material. The inside dimensions of the chamber are 12 by 12 in. The sides of the chamber are fastened together with screws or brackets and taped to prevent air leakage during the test. The bottom of the chamber is designed to be easily removable.

The test specimen consists of a 9 by 9-in section of carpet or rug, which, after the prescribed conditioning, is placed in the center of the floor of the chamber and over which a flattening frame is placed. This frame is a 9 by 9-in steel plate, 1/4 in thick, with an 8-in diameter hole in its center. The chamber is placed in a draft-protected environment (hood with draft off).

A standard igniting device (pill) in the form of a No. 1588 methenamine timed burning tablet, or equal, is placed on the test specimen at the center of the 8-in hole in the flattening plate. The tablet is then carefully ignited and the test permitted to continue until one of the following conditions occurs:

(1) The last vestige of flame or glow disappears, or
(2) the flaming or smoldering has spread to within 1 in of the edge of the hole in the flattening frame at any point, at which time the specimen is considered to have failed the test.

Eight samples are tested for each type of carpet being tested, and at least seven of the samples must meet the acceptance criterion.

5.1.2 Smoke Generation Test Methods

5.1.2.1 ASTM E 84

In the few cases where the ASTM E 84 Standard Test Method was used to determine flame spread, the optical density of the smoke generated was also measured with the photoelectric equipment that is a part of that test apparatus.

*Federal Register, Vol. 35, No. 74, April 16, 1970 and Vol. 35, No. 251, December 29, 1970.

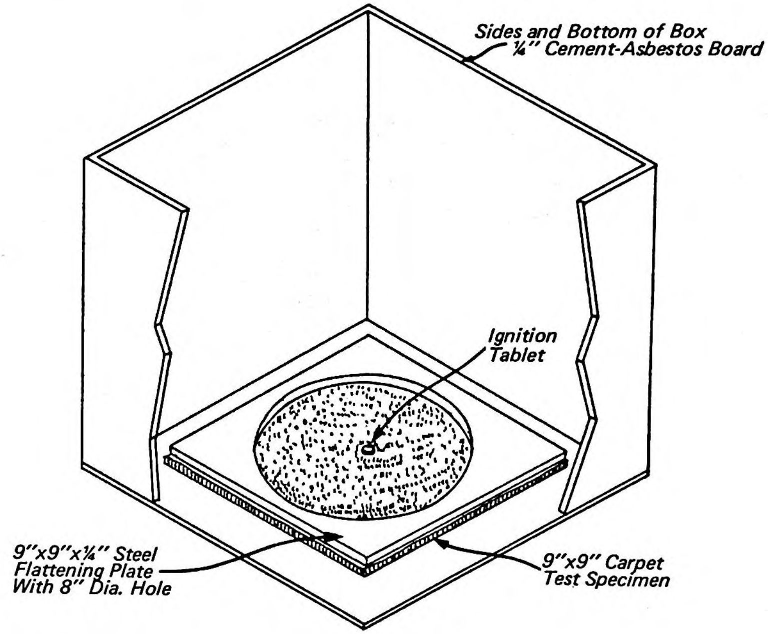


FIGURE 5.3
Cut-Away of *Pill* Test Apparatus

5.1.2.2 NBS Smoke Chamber

When flame spread was measured by ASTM E 162, smoke generation of the same type of material was measured in the NBS Smoke Density Chamber. The smoke chamber consists of a 16 ga sheet metal box 3 ft wide, 3 ft high and 2 ft deep. As shown in Fig. 5.4, openings are provided for a photometer with a 3-ft vertical light path, power and signal lead wires, air and gas supply tubes, an exhaust blower and damper, an aluminum foil blowout panel and a hinged door with a window. The chamber is tightly closed and usually not ventilated during test. The interior and all parts therein are either anodized black or painted with a flat black paint resistant to corrosive decomposition products.

A 3 by 3-in specimen is ignited either electrically (for non-flaming or smoldering tests) or by a gas jet (for flaming tests). The optical density of the smoke generated is measured by the photometer, thus providing a quantitative measurement of smoke under specific burning conditions (flaming or non-flaming).

REF: Gross, D., Loftus, J. J. and Robertson, A. F., *Method for Measuring Smoke from Burning Materials,* ASTM Special Technical Publication No. 422, 1967, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.

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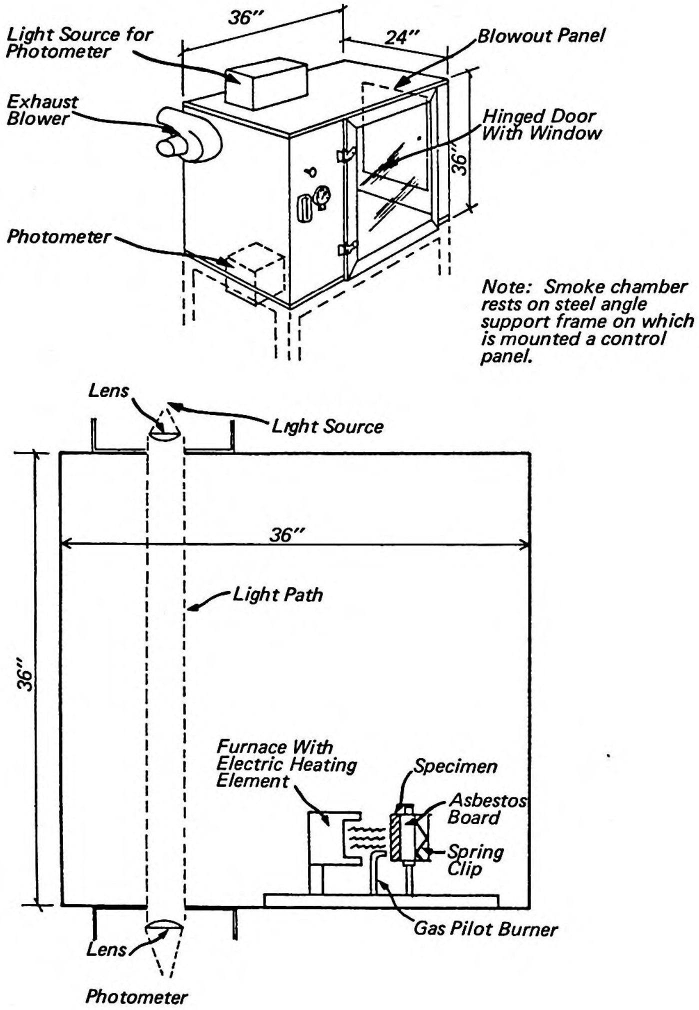

FIGURE 5.4
Details of NBS Smoke Chamber

5.2 Summary of Test Results

5.2.1 Wall and Ceiling Coverings

The results of the tests of wall and ceiling coverings are summarized in Table 5.1. Unless otherwise noted, all of the flame spread results were obtained by the radiant panel method (ASTM E 162) and the smoke generation by use of the NBS Smoke Chamber.

5.2.2 Floor Coverings

The results of the floor covering tests are summarized in Table 5.2. Again, most of the tests were made in accordance with ASTM E 162, except where noted otherwise. Where the *Pill Test* was also conducted when carpeting was being tested, the results are noted in the table. The absence of such a note indicates that no *Pill Test* was performed.

5.2.3 Kitchen Cabinets

The broad range of test values for flame spread shown in Table 5.3 were obtained when kitchen cabinet doors and end panels were tested by the radiant panel method, ASTM E 162. Since consistently low test results were obtained for melamine and vinyl-clad kitchen cabinets tested in early phases of the Operation BREAKTHROUGH Program, testing was not required for cabinets coated with these materials that were submitted in latter phases of the program. Smoke generation tests were not conducted, since the ignitability of kitchen cabinets by range fires is considered to be the primary fire safety problem associated with them.

5.1—Summary of Test Results—Wall, Side, and Ceiling Coverings

Sample Description	Specimen			Smoke Generation	
	Thickness (inches)	Density (lb/ft^2)	Flame Spread	Flaming	Smoldering
A. Glass Reinforced Polyester					
1. Glass reinforced polyester panel (approximately 20% glass and tetra bromo phthalic anhydride flame retardant in polyester resin	0.085	0.60	74	614	472
2. Glass reinforced polyester panel (with tertra bromo phthalic anhydride flame retardant in polyester resin)					
Interior Specimen	0.082	0.80	36	310	
Exterior Specimen	0.100	0.85	44	374	
3. Paper honeycomb sandwich wall panel (using glass cloth and polyester resin, having a double thickness of 5/8 inch gypsum board on one side for an interior surface, or having a single 5/8 inch gypsum board together with sand and polyester resin for an exterior surface)					
Interior Specimens	5 1/4	8.90	8	27	
Exterior Specimens			18	62	
4. Polyester resin and fiberglass composition sprayed on 3/8 inch plywood (wood stud partition filled in with two layers of foil faced glass fiber insulation sandwiched between two sheets of 3/8 inch coated plywood. The plywood was spray coated with a layer of pigmented polyester resin and fiberglass)	4 3/8	plywood & sprayed coating = 1.30	58	293	

5.1—Summary of Test Results—Wall, Side, and Ceiling Coverings

Sample Description	Specimen			Smoke Generation	
	Thickness (inches)	Density (lb/ft^2)	Flame Spread	Flaming	Smoldering
5. Laminate of gel-coated fiberglass on 3/4" plywood (smooth white finish)	13/16	3.1	90		
Front Face (smooth side)				579	
Back Face (matted surface)				443	
6. Fiber glass polyester with intumescent coating (white in color)	1/8	1.6	5	342	
7. Gel-coated fiberglass laminate on 3/4" plywood (front side, smooth white finish; rear side, a rough finish)	25/32	3.1			
Smooth Side			93	198	384
Rough Side			95	180	262
8. Polyester and chopped glass fiber interior and exterior surfacing material					
Interior	0.125	0.8	99	98.5	
Exterior	0.200	0.9	147	138	
9. Glass reinforced plastic interior panel	1/8	1.04	7	269	206
10. Glass reinforced plastic exterior panel	1.75	0.9			
White			47	190	
Beige			82	208	

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5.1—Summary of Test Results—Wall, Side, and Ceiling Coverings

Sample Description	Specimen Thickness (inches)	Specimen Density (lb/ft^2)	Specimen Flame Spread	Smoke Generation Flaming	Smoke Generation Smoldering
11. Polyester resin and fiberglass composition					
Brown, rough I	1/4	63 lb/ft^3		344	364
Brown, rough II	1/4	69 lb/ft^3		383	464
White, smooth	11/64	78 lb/ft^3		414	90
White, rough	1/4	61 lb/ft^3		315	264
12. Joint laminate 40% resin, exterior finish	.200	62.4 lb/ft^3		337	342
Joint Laminate, 41% resin, exterior finish	.200	59 lb/ft^3		319	360
Polyester skin, 31% resin, exterior finish	.175	57 lb/ft^3	70	266	244
Polyester skin, 34% resin, exterior finish	.200	62.5 lb/ft^3	80	368	319
Polyester skin, 36% resin, exterior finish	.200	64 lb/ft^3	82	298	304

5.1—Summary of Test Results—Wall, Side, and Ceiling Coverings

Sample Description	Specimen			Smoke Generation	
	Thickness (inches)	Density (lb/ft^2)	Flame Spread	Flaming	Smoldering
B. Cellulose Based					
1. White vinyl cushion wall on paper (with 3/8" plywood backing)	vinyl + paper + plywood film 1/16" + 3/8"	1.7	55	156	
2. Exterior plywood, clear grain plywood	1/2	17*	104		
3. Smooth and granular finishes on 3/8" plywood and 3/8" upsum board (smooth white finish on 3/8" plywood, and gray granular finish on 3/8" wood base fiber board and gray granular finish on 3/8" wood base fiber board)					
3/8" plywood, smooth white finish	7/16	1.2	129	187	
3/8" Plywood, gray granular finish	3/8	1.2	165	367	
3/8" wood base fiber board, smooth white finish	3/8	1.1	128	260	
3/8" wood base fiber board, gray granular finish	7/16	1.1	286	255	
4. Exterior 3/8" plywood on 1/2" gypsum board (stained light green in color)	7/8	2.9	86		

*lb/ft^3

5.1—Summary of Test Results—Wall, Side, and Ceiling Coverings

Sample Description	Specimen			Smoke Generation	
	Thickness (inches)	Density (lb/ft^2)	Flame Spread	Flaming	Smoldering
5. Particle board with vinyl wall covering (flower design)					
Particle Board Wall Covering	1 1/8 1/64	42.8	63	260	
6. Fiber board ceiling title (fiberboard with interlocking edges, white surface exposed)	1/2	0.8	32	122	333
7. 1/2" plywood ceiling panel, with 1/16" layer of fiberglass resin coating on each side	5/8	2.2	60	219	522
8. Plywood exterior wall panel (latex painted)	5/8	1.8	72	489	506
9. 3/8" rough sawn, grooved 3-ply plywood stapled to 1/2" exterior gypsum sheathing board	7/8	3.08	130**	150**	
10. Rough sawn Phillipine mahogany					
5/8" stained	5/8	1.69	80**	90**	
5/8" unstained	5/8	1.51	90**	75**	
3/8" stained	3/8	1.11	120**	125**	
3/8" unstained	3/8	1.05	105**	125**	
11. African Mohogany faced, V-grooved, coated plywood	1/4		175**	200**	
12. African Mohogany veneer faced, coated V-grooved plywood with 3/8" fire retardant particle board core	7/16		28**	115**	

** Tested in Accordance with ASTM E-84

5.1—Summary of Test Results—Wall, Side, and Ceiling Coverings

Sample Description	Specimen			Smoke Generation	
	Thickness (inches)	Density (lb/ft^2)	Flame Spread	Flaming	Smoldering
C. Miscellaneous					
1. 1/16" Formica glued to 5/8"gypsum board (light green)	11/16	2.7	18	99	
2. Interior wall partition white asbestos, laminated covering with polystyrene inner panel	4	3.75*	55	207	
Asbestos covering only			30		

*lb/ft^3

REF: Ferguson, J. B., *Summary of Flame Spread and Smoke Generation Tests Conducted for Operation* BREAKTHROUGH, NBSIR 73-228, National Bureau of Standards, Washington, D.C. 20234 (NTIS Accession No. PB-222 425)

5.2—Summary of Test Results—Floor Coverings

Sample Description	Specimen			Smoke Generation		Pill Test
	Thickness (Inches)	Density (oz/yd^2)	Flame Spread	Flaming	Smoldering	
A. Olefin Carpets						
1. Oliver gold, loop pile with jute backing (mounted on 3/8" plywood with carpet adhesive. The carpet fiber was unidentified "but may have been polypropylene")	5/16	55	295	246		
2. Continuous filament Olefin loop carpet with jute backing; mixed colors of gold, green, and yellow with rubberized hair pad underlayment			408	402		
Rug	3/16	51.3				
Jute	1/16					
Underlayment	1/2	40.0				
3. Continuous filament Olefin loop carpet with jute backing (mixed colors of gold, green, and yellow with rubberized hair pad underlayment)			528	338		Passed
Rug	3/16	51.6				
Jute	1/16					
Underlayment	3/8	44.0				
4. 100% Olefin fiber with jute 1/4 backing carpet (color-green)	1/4	60		287		Passed
5. 100% polypropylene fiber carpeting with woven jute backing (color-black and gray) or high density foam rubber backing; (color bronze and green)						
With rubber backing (no hair pad)	.375	85.3	584	361		
With jute backing (no hair pad)	.300	57.7	485	232		
With jute backing and 40 oz. hair pad underlayment			536	310		
With jute backing, adhered to 1/4" asbestos board with Carpet adhesive (no hair pad)			154			

5.2—Summary of Test Results—Floor Coverings

Sample Description	Specimen: Thickness (Inches)	Specimen: Density (oz/yd^2)	Specimen: Flame Spread	Smoke Generation: Flaming	Smoke Generation: Smoldering	Pill Test
6. Tufted carpet with polypropylene (Primary) and jute (Secondary) backing (mounted on 1/4" asbestos cement board with carpet adhesive)	1/4	56.8	60*	255*		
B. Polyamide Carpets						
1. 16 oz. 100% continuous filament nylon looped carpet with polypropylene and jute backing (color-blue and green)			439	162		Passed with & w/o pad
Rug	1/8	51.8				
Jute	3/32					
Underlayment	3/8	36.4				
2. 100% Continuous filament nylon looped carpet with polypropylene and jute backing (multicolored-green and black)			482	184		Passed with & w/o pad
Rug	1/8	51.8				
Jute	3/32					
Underlayment	3/8	36.4				
3. 100% nylon pile carpet with 3/8" jute backing, with 1/4" rubberized hair underlayment on 3/4" plywood (color-green with sculpture pattern)			180	267		Passed with & w/o pad
Rug	3/8	53.7				
Jute	1/8					
Underlayment	1/4	34.5				

*Tested in accordance with ASTM E 84

5.2—Summary of Test Results—Floor Coverings

Sample Description	Specimen			Smoke Generation		
	Thickness (Inches)	Density (oz/yd^2)	Flame Spread	Flaming	Smoldering	Pill Test
	34.5					
4. 100% nylon short loop pile carpet with polypropylene primary back and jute secondary backing (tested with and without rubberized hair pad underlayment)						Passed
Rug	5/16	55				Passed
Pad	3/8	26				Passed
With hair pad				192	302	Passed
Without hair pad				164	289	Passed
5. 100% nylon yellow shag carpet with double jute backing, (tested with and without rubberized hair pad underlayment)						
Rug	.75 to 1.0	69				Passed
Pad	3/8	26				Passed
With hair pad				260	524	Passed
Without hair pad				231	446	Passed
6. Nylon carpet, level loop polypropylene primary back, jute secondary back with latex coated felt pad underlayment						
Dark Blue (16 oz.)	1/4	62.5	222	264		Passed
Light Blue (28 oz.)	5/16	76	154	306		Passed
Underlayment	5/16	41.4				

5.2—Summary of Test Results—Floor Coverings

Sample Description	Specimen			Smoke Generation		
	Thickness (Inches)	Density (oz./yd^2)	Flame Spread	Flaming	Smoldering	Pill Test
7. 100% Nylon continous filament carpeting (orange, with 2 ply backing of 3.5 oz. polypropylene primary and 7 oz. jute secondary ply)	9/32	69	203	193	183	
8. Nylon shag carpet with 1/4" integral foam rubber backing (mounted on 3/8" plywood)		1.6** includes 3/8" ply-wood	311	518		
Shag Rubber Plywood	1 1/4 3/8					
9. 100% nylon (20 oz.) carpet with jute backing; gold in color and mounted on 5/8" plywood, on 3/8" foam underlayment			246	714		
Rug Jute Underlayment	17/32 3/32 3/8	20				
10. 100% nylon (20 oz.) carpet with high density foam backing, gold in color, 1/8" 38 oz. foam underlayment on 5/8" plywood substrate			270	658		
Rug Foam backing	17/32 1/8	20 38				
11. 100% continuous filament nylon shag carpet with 3/8" foam backing (blue and green in color)			260	325		Passed with pad
Pile Foam	1 1/4 3/8	83				

** lb/ft^2

5.2—Summary of Test Results—Floor Coverings

Sample Description	Specimen: Thickness (Inches)	Specimen: Density (oz/yd^2)	Flame Spread	Smoke Generation: Flaming	Smoke Generation: Smoldering	Pill Test
12. 28 oz. 100% continuous filament nylon looped carpet with polypropylene and jute backing (mixed colors, orange and green)			359	244		Passed with & w/o pad
Rug	5/16	59.5				
Jute backing	3/32					
Underlayment	3/8	36.4				
13. 20 oz. 100% nylon clipped loop carpet with polypropylene and jute backing (color-green)			276	351		Passed with & w/o pad
Rug	3/8	57.6				
Jute	3/32					
Underlayment	3/8	36.4				
14. Nylon (continuous filament) tufted carpet with polypropylene (primary) and jute (secondary) backings (mounted on 1/4" asbestos cement board with carpet adhesive)	7/32	59.1	70*	130*		
15. 16 oz. nylon carpet, level loop, with polypropylene (primary) and jute (secondary) backing and latex coated felted pad underlayment (mounted on 1/4" asbestos-cement board with carpet adhesive)			210*	540*		
Rug	1/4	73.8				
Underlayment	5/16	41.6				

*Tested in accordance with ASTM E 84

5.2—Summary of Test Results—Floor Coverings

Sample Description	Specimen			Smoke Generation		
	Thickness (Inches)	Density (oz/yd^2)	Flame Spread	Flaming	Smoldering	Pill Test
16. 28 oz. nylon carpet, level loop, with polypropylene (primary) and jute (secondary) backings and latex coated felted pad underlayment (mounted on 1/4" asbestos-cement board with carpet adhesive)			210*	595*		
Rug	5/16	81.1				
Underlayment	5/16	41.6				
C. Miscellaneous						
1. Gold hi-lo carpet, rubber backing	1/2	68.4				
With 5/8" plywood backing				311		
Without 5/8" plywood backing				361		
2. Vinyl floor covering on 3/4" plywood (1/64" vinyl backed with 1/16" cardboard; color-light brown and green with rough surface)	57/64	3**	70	181		
3. Vinyl floor covering, color yellow, green, and brown	0.065	42	350	185		
4. Vinyl Sheet Flooring						
Brand X	0.075	37		529		
Brand Y	0.075	35.9		244		
5. Vinyl floor covering 1/16" thick, underlayment-3/8" flakeboard	7/16	1.7**	72	767		
6. Vinyl floor covering (mounted on 1/4" asbestos board with adhesive)	0.150	75	137	617	545	

* Tested in accordance with ASTM E 84
**lb/ft^2

REF: Ferguson, J. B., *Summary of Flame Spread and Smoke Generation Tests Conducted for Operation* BREAKTHROUGH, NBSIR 73-228, National Bureau of Standards, Washington, D. C. 20234 (NTIS Accession No. PB-222 425)

5.3—Summary of Test Results —Kitchen Cabinets

Sample Description	Specimen Thickness (inches)	Specimen Density (lb/ft^2)	Flame Spread
1. Kitchen cabinet doors with plastic outer finish and paper honeycomb interior (brown in color)	3/4	1.2	93
Outer Plastic	1/16		
Honeycomb paper	5/8		
2. Kitchen cabinet end panels with plastic and lacquer finish on 1/8" poplar with 1 1/2" x 3/4" white pine batten (brown in color)	7/8	0.5	985
Panel	1/8		
3. Particle board core door and end panels; doors with polyester laminate overlap and panels with birch veneers			
Doors	1/2	52**	114
End Panels	1/2	46**	117
4. Simulated woodgrain kitchen cabinet doors and end panels (color brown)			
End Panels	1/8	57.6**	216
Town house doors (end panels)	7/16	75**	66
Scandinavian doors (doors)	7/16	74.6**	107

**lb/ft^3

5.3—Summary of Test Results—Kitchen Cabinets

Sample Description	Specimen		Flame Spread
	Thickness (inches)	Density (lb/ft^2)	
5. Plywood Kitchen cabinet doors and end panels (door panels plywood, with dark brown wood grain veneer-lacquer finish; end panels, plywood with dark brown wood grain veneer).			
Door panel	3/4	2	477
End panel	3/4	2.2	70
6. Plywood kitchen cabinet door and end panels (rerun of number 5 above)			
Doors	3/4	1.8	417
End panels	3/4	2.0	262
7. 3/16" mohogany plywood kitchen cabinets, and end panels with Melamine woodgrain veneer on one side.	3/16	0.75	14
8. 3/4" plywood kitchen cabinet door panel (color-light brown finish).	3/4	2	72
9. Composition wood door panel for kitchen cabinets with 1/32" wood grain veneer on both sides (color-dark stained finish).	7/16	2.2	91
10. Particle board with vinyl clad walnut wood grain finish kitchen cabinet doors (5/8") and end (3/8") panels			
Door panels	5/8	2.6	93
End panels	3/8	2.0	70
11. Particle board kitchen cabinet doors and end panels (door panel 3/8" wood grain finish on both sides; end panel 1/2" varnish on both sides, wood grain on exterior).			
Door panels	3/8	2.6	75
End panels	1/2	2.2	109

REF: Ferguson, J. B., *Summary of Flame Spread and Smoke Generation Tests Conducted for Operation* BREAKTHROUGH, NBSIR 73-228, National Bureau of Standards, Washington, D. C. 20234 (NTIS Accession No. PB-222 425)

6.

OTHER TESTS

6. OTHER TESTS

Several additional tests were conducted to answer questions that arose about specific Operation BREAKTHROUGH systems.

A glass fiber reinforced polyester resin roofing system was tested to determine its ability to meet the requirements for a UL class "C" fire resistance rating. To determine ease of ignition of an exterior wall by fire emerging from a window, a mockup of a typical reentrant corner commonly found in townhouses and garden apartments was tested. The effectiveness of a pressurized system for keeping smoke out of a stairwell in a high-rise apartment building was determined by measuring the rate of infusion of a tracer gas into the stairwell. Questions about the fire safety of an exterior wall panel system were answered by measuring its potential heat, ease of ignition and rate of heat release.

6.1 Fire Resistance of Roof Covering Materials

Many fires are spread by means of burning embers blown onto a roof from nearby fires. For this reason, most building codes require that roofing materials possess a certain degree of fire resistance. Fire resistant roof covering systems are grouped into three different classes: Class A (resistant to severe fire exposure), Class B (resistant to moderate fire exposures), and Class C (resistant to light fire exposures), on the basis of their performance when subjected to the three separate tests described in detail in ASTM E 108 and UL 790. Class C ratings are generally required for single family dwelling roofs in areas covered by building codes; however, codes covering high fire risk in congested residential areas frequently have more stringent requirements.

Since one of the Operation BREAKTHROUGH single family housing systems incorporated a glass fiber reinforced polyester resin roof assembly whose fire resistance was not known, tests were conducted to determine its ability to meet the requirements for a Class C rating.

The roof panel construction is described in detail in Section 3.2.1 of this publication. The Class C test conditions specified in ASTM E 108 for (1) intermittent flame exposure, (2) spread of flame, and (3) exposure to burning brands were used.

The basic fire-test apparatus is shown in Figure 6.1a. It consists of a test deck to which the roof covering is applied, a framework on which the test deck is mounted at the prescribed incline, a gas burner, and a variable-speed blower and air duct for producing the requisite wind conditions. Additional equipment consists of gas burners for igniting burning brands, a velometer for measuring wind velocity, a draft gauge for measuring gas pressure and a stop watch for measuring the duration of the test.

In the *Intermittent Flame Exposure Test,* the roof covering materials are mounted on a 4 1/3-ft long roof deck at an angle in a 12±0.5 mph uniform air current flowing parallel to the sides of the deck. Built-up roofs are mounted on the maximum slope recommended by the manufacturer; for shingles and roll roofing products, the test deck is set at a slope of 5 inches of rise per horizontal foot. After the blower is adjusted to produce the specified 12 mph air current, the test roof deck is subjected to

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a sheet of gas flame extending the length of the deck and having a width approximately the same as that of the deck at its bottom edge (see Figure 6.1a). Systems are rated as Class A, B or C, respectively, if they can sustain exposure for the requisite number of cycles listed in Table 6.1.

The air current is maintained at the 12 mph rate after the last application of flame until all evidence of glow, flame and smoke has disappeared, or until failure occurs. Criteria for failure are: (1) the appearance of sustained flame on the underside of the roof deck, (2) the production of flying, flaming, or glowing brands that leave the deck, or (3) the displacement of portions of roofing on the deck, resulting in deck exposure.

TABLE 6.1

TEST CONDITIONS

Class Rating	Flame Temperature °F	Flame On, Minimum	Flame Off, Minimum	No. of Test Cycles Minimum
Class A	1400 ± 50	2	2	15
Class B	1400 ± 50	2	2	8
Class C	1300 ± 50	1	2	3

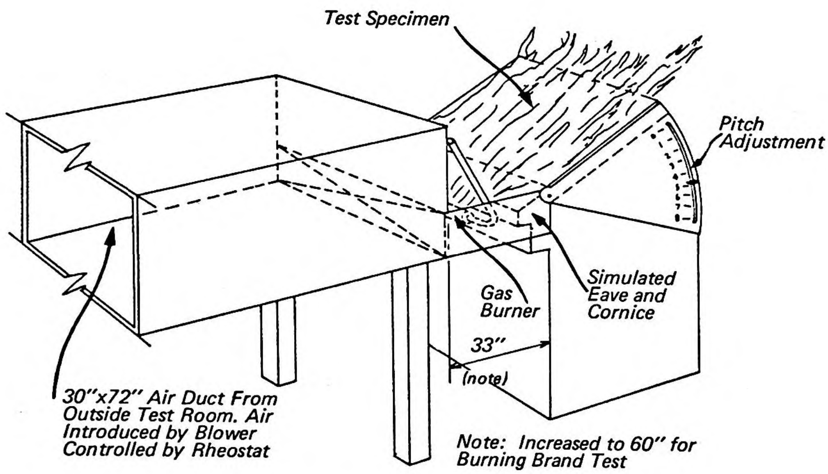

FIGURE 6.1a
Schematic of Fire Test Apparatus

In the *Spread of Flame Test*, a 13-ft long test roof deck is mounted in the equipment used for the intermittent flame test at the same slope. The 12 mph air velocity and the flame adjustments are also the same as those specified for the intermittent test. For Class A and B systems, the gas flame is applied continuously for 10 min, or until the flame (actual ignition of the test deck surface) has spread to the top of the deck, or until the flame has begun to recede from the point of maximum spread, whichever is the shorter. For Class C systems, the gas flame is applied for a period of 4 min and then removed. Criteria for failure are: (1) the production of flying, flaming, or glowing brands that leave the deck, (2) the displacement of portions of roofing on the deck resulting in deck exposure, or (3) the spread of flaming beyond 6 ft for Class A systems, beyond 8 ft for Class B systems and beyond 13 ft (the length of the deck) for Class C systems.

In the *Burning Brand Test* a 4 1/3-ft long test deck is mounted in the same manner as described for the intermittent flame test, except that the framework is 60-in from the air duct outlet instead of the 33-in specified for the intermittent flame test, and the gas piping and burner are removed so as not to obstruct the air flow. Pine or fir brands differing in size and construction details for each class of test (see Figure 6.1b for brand construction details) are placed on the test roof deck in specified locations and then fanned with a 12±0.5 mph wind. One brand is placed at the location considered most vulnerable for class A tests; for Class B, one brand is placed at each of the two locations considered most vulnerable, and for Class C, 25 brands are placed on the deck at 1 or 2-min time intervals. Each individual test is continued either until the brand is consumed and until all evidence of flame, glow and smoke has disappeared from both the exposed surface of the material being tested and the underside of the test deck, or until failure occurs. Criteria for failure are: (1) the appearance of sustained flame on the underside of the test roof deck for Classes A and B; for Class C tests there may be sustained flaming on the underside of the deck for not more than 5 of the 25 brands, (2) the production of flying, flaming or glowing brands that leave the deck, or (3) the displacement of portions of roofing on the deck resulting in deck exposure.

From the results of the three types of tests conducted, it was concluded that the roofing system met the requirements for Class C rating. During the intermittent flame test neither of the specimens tested indicated smoking or deep char penetration of the material; only minor surface blistering was observed. In addition, the undersides of both test decks remained intact, and there was no sensation of warmth at any time during the test. During the spread of flame tests, surface blistering was observed; however, the spread of flame did not exceed 5 ft, and there was no smoking, fall-off, breaking, or production of flying brands from the roof material itself. Observations made during the burning brand tests showed the absence of any flaming on the underside of the test deck, or fall-off or fire brand activity from the roofing material itself.

REF: Williamson, R. B. and Kwan, Q., *Structural Research Laboratory Report* No. 72-10, University of California, Berkeley, California, August 1972. (Unpublished)

Standard Methods of Fire Tests of Roof Coverings, E-108-58, *ASTM Book of Standards,* Part 18.

Tests for Fire Resistance of Roof Covering Materials, UL 790, Underwriter's Laboratories, Inc.

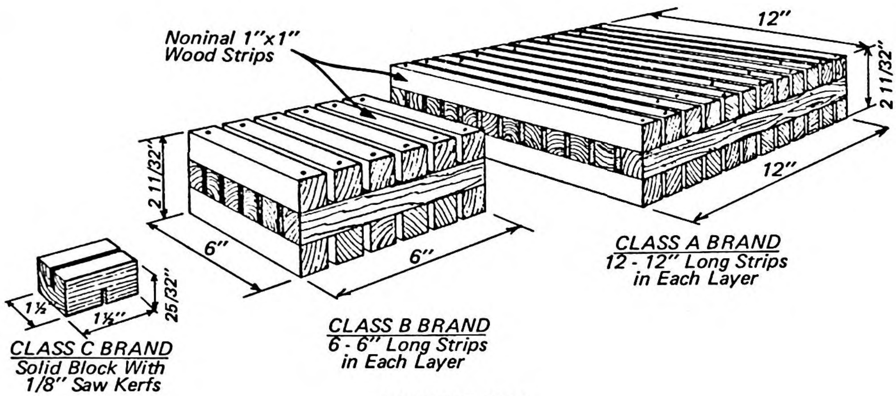

FIGURE 6.1b
Fire Brands for Classes
A, B, and C Tests

6.2 Flame Propagation from a Room to Exterior Surfaces

In buildings such as townhouses and garden apartments, exterior walls are frequently erected perpendicular to a wall containing a window opening near the reentrant corner. When exterior walls in this configuration are composed of combustible material, it is possible for fire to spread from an interior room to the adjacent combustible exterior walls through the windows. The two full-scale fire tests described in this section were conducted to evaluate Operation BREAKTHROUGH criteria dealing with the problem of reentrant wall corners.

The basic reentrant corner test assembly, which is shown in Figure 6.2, consisted of a burn room in which wood cribs were ignited to simulate the radiation and convection conditions that would occur in an actual fire, and two exterior wall specimens erected perpendicular to a wall containing a window leading into the burn room. The walls and ceiling of the burn room were lined with one layer of 5/8-in thick type X gypsum wall board sprayed with vermiculite plaster and secured with 3/8-in bolts.

Since some damage occurred to the concrete burn room floor during the first test, the floor was covered with refractory sand over which fire brick were placed for the second test. The two exterior wall specimens were erected on each side of the window opening, which was 24 in by 38 in in the first test, and 32 in by 38 in in the second test. One wall was located 1 ft to one side of the window opening for both tests, and the other wall was 5 ft away from the other side of the window opening for the first test and 4 ft 4 in away for the second test. Each wall was 12 ft long and 16 ft high and composed of single layer of 1/2-in thick A-C grade exterior plywood in 4 by 8 ft sheets installed over a layer of gypsum board backing. The plywood, which was selected as being representative of a typical exterior wall finish material, had a flame spread index of 103, as measured by the radiant panel test method described in Section 5.1.1.2. Instrumentation consisted of 32 thermocouples placed on the wall closest to the window opening, 12 thermocouples located on the other wall, 4 thermocouples located in the burn room, and 2 radiometers and a radiation pyrometer, whose locations are shown in Figure 6.2.

The burn room was loaded with 15 wood cribs representing the fire load of combustible contents. Each crib was made of multiple layers of nominal 2 by 2 by 14-in kiln-dried wood sticks nailed into a lattice arrangement. For the first test, the cribs were 5 layers high and weighed approximately 18 lb each; for the second test, the cribs were 7 layers high and weighed approximately 24 lb each. The 4.4 and 6.3 lb/ft^2 of fire load produced by the cribs used for tests 1 and 2, respectively, are representative of the combustibles found in a typical residential room. Liquid heptane was used to ignite the wood cribs, and a controlled amount of air was supplied to the burn room during the test.

Ignition of the exterior plywood panels located 1-ft from the edge of the window in a reentrant corner did not occur, due to the burning of a room fire load of 4.4 lb/ft^2 of floor area. However, surface charring did occur, and peak surface temperatures of 350°C (660°F) were measured. When the fire load was increased to 6.3 lb/ft^2, and air was continuously introduced into the burn room surface ignition took place at 9 min on the plywood in the vicinity of the window opening. The incident irradiance and the total amount of heat energy absorbed at the exposed surface of the plywood wall prior to ignition were estimated to be approximately 1.0 W/cm^2 and 175 J/cm^2, respectively. No ignition was observed for the wall located farther away from the window (4 1/2 ft to 5 ft).

On the basis of this testing, it was concluded that the choice of a limiting flame spread index of 75 for exterior wall surface materials in a reentrant wall corner configuration was reasonable.

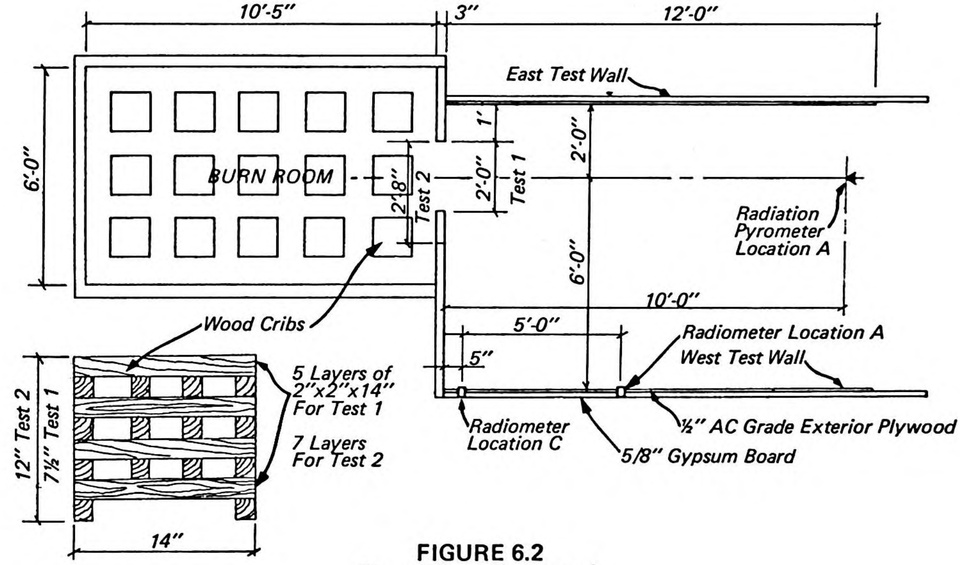

FIGURE 6.2
Plan of Burn Room and Test Wall Layout

REF: Son, B. C. and Fang, J. B., *Fire Spread on Exterior Walls Due to Flames Emerging from a Window in Close Proximity to a Reentrant Wall Corner,* NBSIR 73-266, National Bureau of Standards, Washington, D. C. (NTIS Accession No. PB-225 286/4WB).

6.3 Evaluation of a Pressurized Stairwell Smoke Control System

In the case of a fire in a conventional high rise building, the combination of buoyancy forces due to the fire and stack effects due to weather conditions can cause air and smoke to travel upwards in stairways, elevator shafts and vertical utility shafts. The presence of large amounts of smoke in the escape paths of a building prevents safe evacuation from a building fire, and hampers fire fighting. One of the methods proposed for keeping exitways smoke-free in the event of a fire is by the pressurization of the stairwells in a building.

On-site smoke infiltration tests were conducted in a 12-story building constructed by one of the Operation BREAKTHROUGH Housing System Producers (HSP's) to determine the effectiveness of a pressurized smoke-proof smoke control system. The HSP elected to use a modification of NRC Method III, *Pressurized Vertical Shafts.* In this method, the following conditions apply:

1. The stair enclosure chosen to be the smoke-proof enclosure shall have equipment capable of providing a mechanical air supply into the shaft at the upper end of not less than 15,000 cfm, plus:

    a. 100 cfm for each door (having a perimeter of not more than 20 ft) that is equipped with a tight-fitting weatherstripping, or

    b. 200 cfm for every other door (having a perimeter of not more than 20 ft) into the stairshaft.

2. Each stairshaft shall have a vent at street level, opening either directly outside or into a vestibule or corridor that has similar opening to outside, having an opening of not less than 0.5 sq ft for every door that opens into the shairshaft, other than doors at street level, but in any case not less than 20 sq ft.

3. The vent at the bottom of the stairshaft may be provided with a window, shutter or door, which shall open automatically, unless there is a central control facility from which the window, shutter or door may be open manually, and shall be designed to remain in the open position during the fire emergency.

4. Manual or automatic operation of a fire alarm box on any floor shall initiate the mechanical air supply to the smoke-proof stair enclosure, as provided in (1) above and shall cause the window, shutter, or door to open as provided in (3) above.

For the 12-story building in which the tests were conducted, the basic air supply to the smoke-proof stair enclosure was set at 10,000 cfm instead of the 15,000 cfm stipulated above. Weatherstripped doors were used on the smoke-proof stair enclosure, thereby reducing additional air supply needed for door leakage from 200 cfm to 100 cfm per door. As a result, the total air supply provided by the HSP was approximately 11,200 cfm, made up of 10,000 cfm plus 1,200 cfm for door leakage.

The air supply fan for the smoke-proof stair enclosure was placed on the roof over the stairtower (see Figure 6.3a). Both this fan and an automatic-opening device on the grade-level door to the outside were connected to the building fire alarm system. Operation of the building fire alarm system starts the fan and opens the grade-level exit door.

The rate of spread of smoke into the pressurized stairwell of the 12-story building was evaluated by introducing a controlled amount of SF_6 tracer gas into an 1800 cfm air flow emanating from a room chosen to represent the site where a fire is occurring. The SF_6 was chosen as a tracer gas since its electron capture property makes it easy to detect, and it is odorless, colorless, harmless and stable. After the SF_6 was introduced into the burn room, its concentration was measured at the second, fifth, ninth and eleventh floor levels of the pressurized stairwell at time intervals of 5, 15 and 25 min after the introduction of the SF_6 gas.

The test was first performed with a simulated fire on the second floor (see Figure 6.3b for floor plan details) and then with a simulated fire on the ninth floor, whose layout was quite similar. In addition to determining the smoke infiltration rate with the

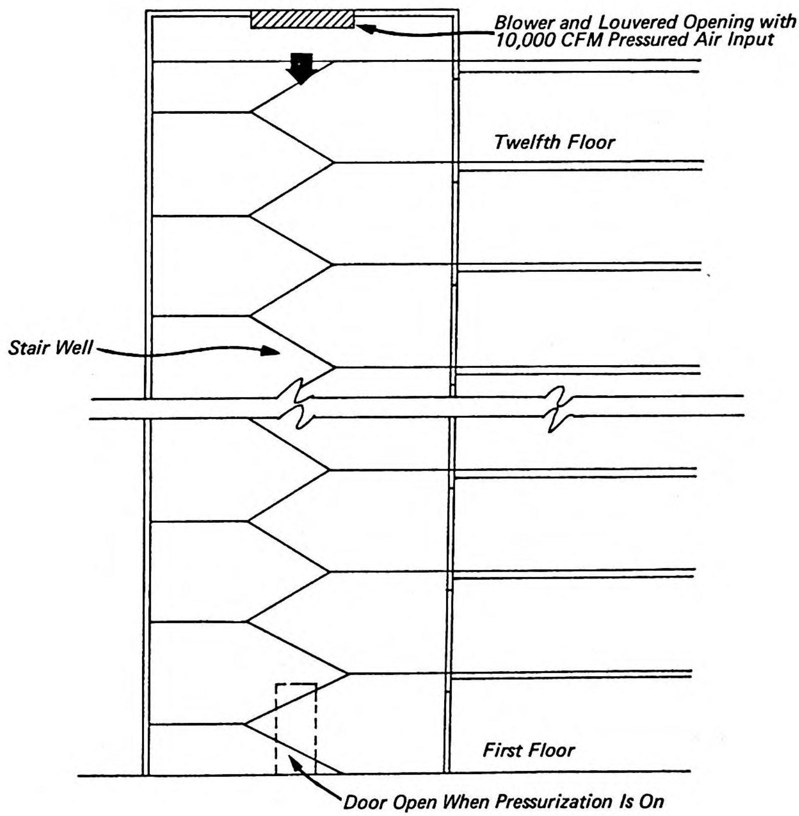

FIGURE 6.3a
Pressurization Flow
Supply and Vent

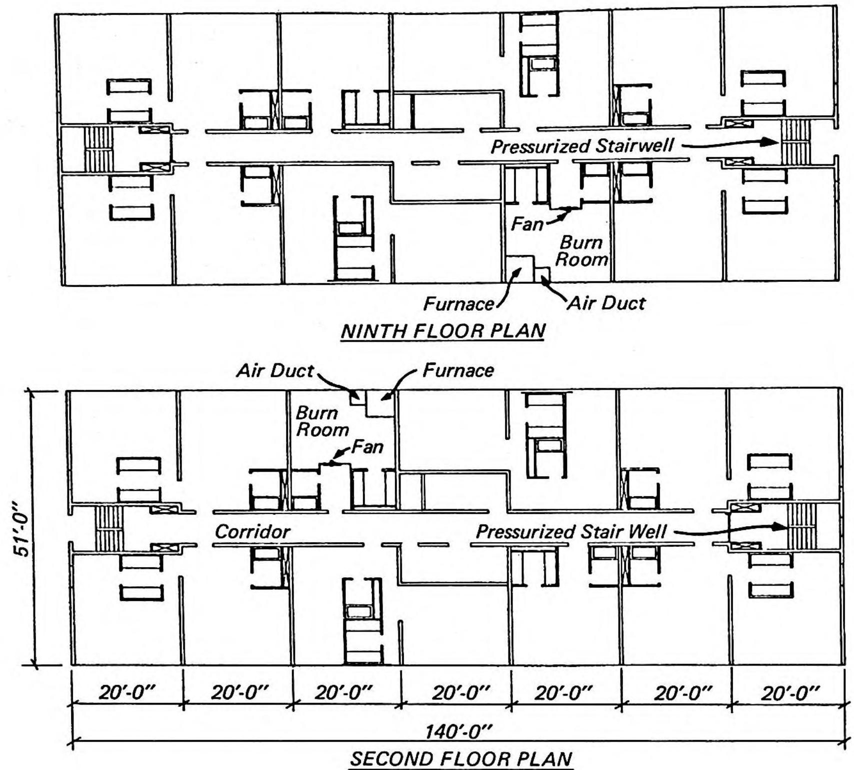

FIGURE 6.3b
Floor Plans of Test Building

stairwell pressurized and all of the exit doors closed, the effects of leaving doors open were determined.

Smoke levels of less than 0.1% were found in the stairwell in all of the tests conducted with the pressurization system on. This included a test in which doors on second, ninth and eleventh floors were left open. A good idea of the effectiveness of the smoke control system can be obtained by comparing the test results found for two tests. In one test, a fire was simulated on the second floor; the stairwell door on this floor was left open, and the pressurization system was left on. In the second test, all test conditions were the same, except the pressurization system was shut down. The simulated smoke levels in the stairwell during the first test were less than 0.1%; in the second test, they ranged from 4 to 70%.

On the basis of these tests, it was concluded that the stairwell pressurization system used was very effective in preventing smoke from entering stairwells, even with several doors open.

REF: Fung, F. C. W., *Evaluation of a Pressurized Stairwell Smoke Control System for a 12-Story Apartment Building,* NBSIR 73-277, National Bureau of Standards, Washington, D. C. (NTIS Accession No. PB-225 278/IWB)

6.4 Potential Heat

Potential heat, which is a measure of the extent to which materials contribute heat to support active combustion when they are ignited, is one of several factors that should be considered when evaluating the fire safety of building elements.

A two-step process is generally involved in utilizing potential heat data. First, the amount of heat given off by the individual materials that make up a building element is experimentally determined on a weight basis. Then the contributions of the individual components that make up a building element are calculated on a square foot basis.

The potential heat method was used in the Operation BREAKTHROUGH Program on a window wall system, proposed by one of the Housing System Producers to be installed on a medium rise building. The window wall was of steel stud construction, with a 1/2-in gypsum board facing on the building interior side and aluminum clad plywood panels on the exterior side. The 5/16-in thick exterior grade Douglas Fir plywood exterior panels were faced with acrylic enamel coated 10 mil aluminum sheets on their weather exposed (building exterior) surfaces and with 2 mil aluminum foil on their unexposed surfaces. Spaces between the studs were filled with full-thickness glass fiber insulation.

A schematic flow diagram of the test method, Figure 6.4, shows the steps involved in determining the potential heat of a material. Two samples are removed from the material to be tested. One of these is pulverized, pelleted and then burned in a high pressure oxygen bomb, yielding a measure of the gross heat of combustion. The other sample is ashed in a muffle furnace at 750°C, and the residue is ground or pulverized. A portion of the ash corresponding to a known weight of the original material is mixed with a combustion promoter, pelleted and burned in the combustion bomb. After correcting for the heat produced by the combustion promoter, the difference in heating values of the two specimens is reported as the potential heat.

Using the data obtained by measurements of this type, the potential heat of the proposed exterior window wall was determined. Values of 8,320 Btu/ft^2 for the aluminum faced plywood panelling, 630 Btu/ft^2 for the insulation and 1,380 Btu/ft^2 for the gypsum wall board were calculated, yielding a total potential heat value of 10,330 Btu/ft^2 for the window wall system.

Since this value was higher than the value recommended for exterior walls in the Operation BREAKTHROUGH Guide Criteria, the ease of ignition and rate of heat release measurements described in Sections 6.5 and 6.6, respectively, were investigated before a decision was made as to the relative fire safety of the wall system.

REF: Bright, R. G., National Bureau of Standards, Washington, D. C. (Unpublished communication), July 13, 1971.

Loftus, J. J., Gross, D., and Robertson, A. F., *POTENTIAL HEAT—A method for Measuring the Heat Release of Materials in Building Fires,* Proceedings of the American Society for Testing and Materials, *61,* 1336. (1961)

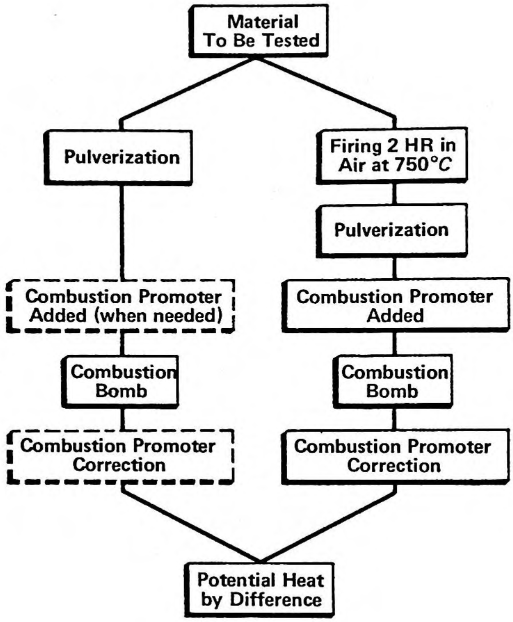

FIGURE 6.4
Schematic Flow Diagram for
Potential Measurements

6.5 Ease of Ignition

The ease with which a material can be ignited is dependent on factors such as its dimensions, the incident heat flux and environmental conditions such as air composition, air temperature and air velocity. The test described in this section was designed to evaluate building materials in contact with flames from incidental or low-energy fires, such as might be expected when a wall is exposed to the flames from a wastebasket fire adjacent to it.

The test was used in combination with potential heat and rate of heat release determinations (see Sections 6.4 and 6.6) to ascertain the acceptability of an exterior wall-cladding material proposed by one of the Operation BREAKTHROUGH Housing System Producers.

The basic test apparatus is shown in Figure 6.5 a. Two 6 by 6-in specimens, each clamped to a backup asbestos-cement board 9 in high by 6 in wide and 3/4 in thick, face each other with a 3/4-in gap between them. The lower edge of each specimen is flush with another asbestos-cement board having the same thickness as the test specimen, which serves as a noncombustible extension of the specimen surface.

A specially designed burner supplied with city gas at a flow rate of 15 ft^3/ min is located 3 in below the lower edge of the specimens. When the gas-air mixture is ignited, a flame passes between the specimens and about 6 in above them.

The test begins by electrically igniting the gas-air mixture and simultaneously starting a stop watch. The object of the test is to determine the minimum flame exposure time required to produce sustained flaming of at least one of the two specimens. This minimum flame exposure time is called the ignition time. Flaming is considered to be sustained if it persists anywhere on the test specimen for at least one minute after the exposure flame has been stopped by cutting off the gas-air mixture. Some typical ignition times obtained for three glass fiber reinforced polyester panels, both with and without flame retardent treatment, wood fiber insulating board, plus oak, pine, redwood and fir and marine plywood boards are shown in Figure 6.5 b.

The exterior face of the wall siding panels being evaluated had an ignition time of between 3 and 4 min. At that point in time, the aluminum sheet separated from the plywood, and the wood was no longer protected. For the interior face, the aluminum foil did not separate from the plywood, and no ignition was observed during the test.

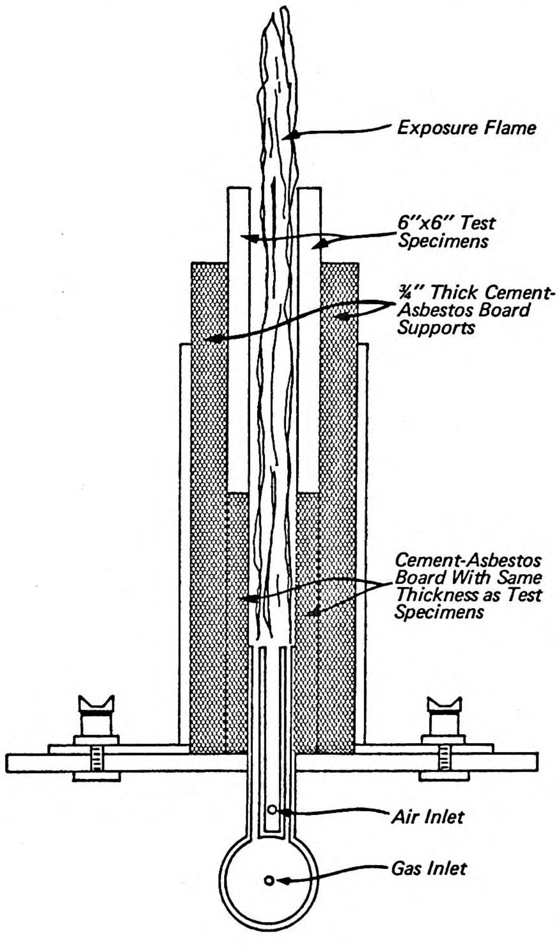

FIGURE 6.5a
Test Apparatus for Ease of Ignition Test

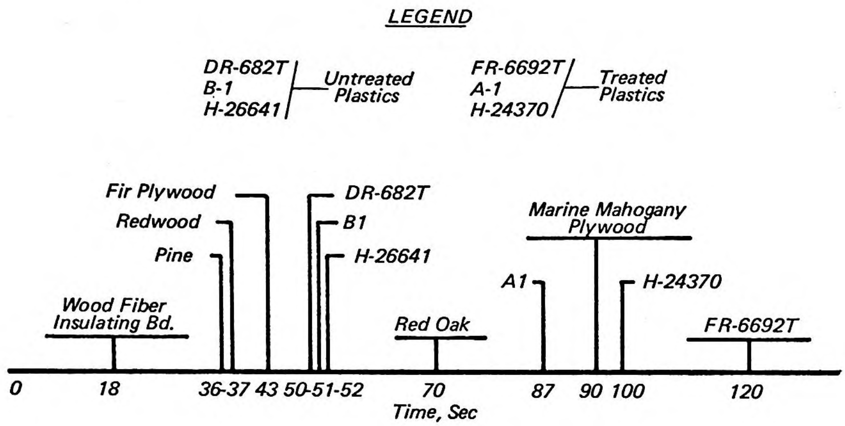

FIGURE 6.5b
Exposure Time Required for Sustained Ignition

REF: Bright, R. G., National Bureau of Standards, Washington, D.C. (Unpublished Communication), July 13, 1972.

Parker, W. J., *The Development of a Test for Ease of Ignition by Flame Impingement,* NBS Report 10468, National Bureau of Standards, Washington, D.C.

6.6 Rate of Heat Release

The rate at which a burning material releases heat in a fire environment is an important characteristic of that material and should be considered when specifying its use in a particular construction. In a room fire, a large portion of the heat released is absorbed in the walls and ceiling. The attendant rise in temperature creates radiation levels which serve to increase flame-spread rates, produce new ignitions, and further increase the rate of heat release of the burning materials. This phenomenon is commonly referred to as flashover. In order to properly evaluate the performance of a combustible material in a fire environment, the rate of heat release as a function of both the time and environmental conditions, including the irradiance level, the air velocity past the surface, the air temperature, and the chemical composition of the air must be known.

The rate of heat release calorimeter test described in this section was used in combination with potential heat and ignition time determinations (see Sections 6.4 and 6.5) to ascertain the acceptability of an exterior wall-cladding material proposed by one of the Operation BREAKTHROUGH Housing System Producers.

The heat release rate calorimeter shown in Figure 6.6 determines the amount of heat given off by a test specimen by measuring the decrease in the amount of fuel of known heat value required to maintain a constant temperature at a fixed location in the test apparatus. The calorimeter consists of three sections: (1) a combustion chamber, (2) a control chamber, and (3) mixing chamber.

The combustion chamber is lined on three sides with gas-fired, porous ceramic radiant panels. The fourth side of the combustion chamber contains the door through which the specimen is admitted. The combustion chamber is open at the top, allowing the hot combustion gases to pass freely into the control chamber.

The side walls of the control chamber consist of porous ceramic panels of the same type used in the combustion chamber. A controlled constant flow of excess air is admitted through the porous plates into the control chamber to reduce the temperature of the stack gases to a manageable level, and to minimize the errors associated with combustion products of various enthalpies. The high velocity air passing into the chamber through the porous plates also serves to block out heat transfer through the side walls of the chamber. The gas flow to an auxiliary burner located near the center of the control chamber is automatically controlled so that the average temperature of the gases passing up into the mixing chamber remains constant. By this means, the amount of heat produced by the burning specimen is exactly compensated for by a reduction in the amount of heat produced by the burner. The rate of heat release of the specimen is measured by recording the reduction in gas flow to this burner.

A 4 1/2 by 6-in asbestos-cement board reference blank is inserted into the specimen holder and oriented vertically in the center of the combuustion chamber, and a stable base line is thus established prior to inserting a test specimen of the same size.

A peak heat release rate of 9 to 10 Watts/cm^2 was observed when the exterior face of the test specimen was exposed to a heat flux of 6 Watts/cm^2. This corresponds to a fire temperature of 730°C (1346°F). There was an initial delay in ignition, but after separation of the aluminum sheet from the plywood, the heat release rate from the escaping gases was comparable to unprotected wood. The aluminum foil protecting the interior face of the plywood did not delaminate during the test, and no heat release was observed.

These values can be compared to values of 7-8 W/cm^2 for 1/2-in insulating fiber board, 10.3 W/cm^2 for 3/4-in pine, 10.7 W/cm^2 for 3/4-in plywood, 12.5 W/cm^2 for 3/4-in oak and 15.2 W/cm^2 for 3/8-in particle board.

REF: Bright, R. G., National Bureau of Standards, Washington, D. C. (Unpublished Communication), July 13, 1972.

Parker, W. J. and Long, M. E., *Development of a Heat Release Rate Calorimeter at NBS,* NBS Report 10462, National Bureau of Standards Washington, D. C.

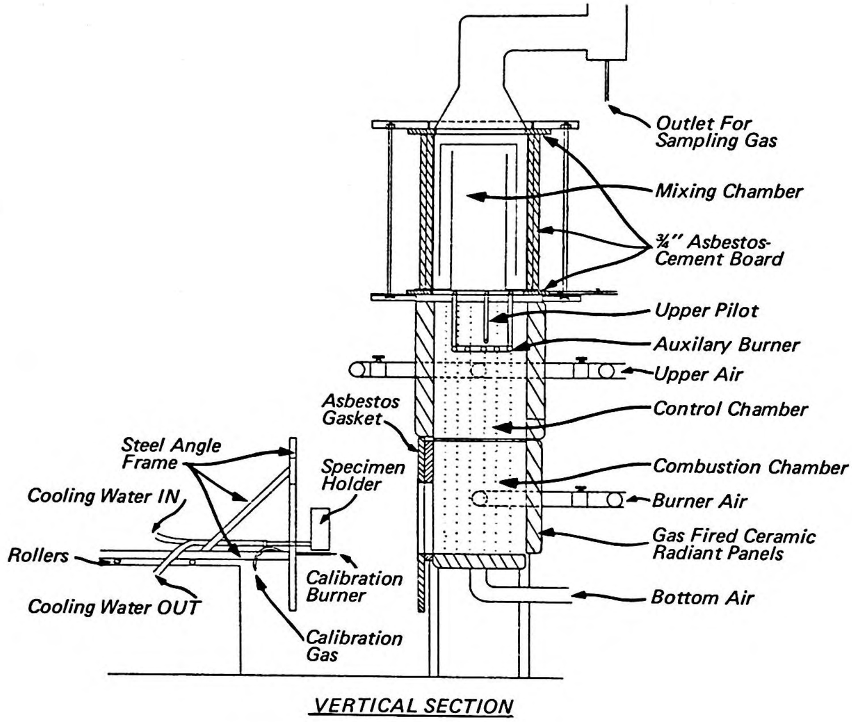

FIGURE 6.6
NBS Heat Release
Rate Calorimeter

acknowledgments

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