

EXPERIMENTAL LARGE-SCALE FIRES: FIRE BEHAVIOR OF INTERIOR FINISH MATERIALS¹

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ABSTRACT

Large-scale fire tests are sometimes necessary to assess the validity of fire safety proposals that would restrict the use of wood products in buildings. Simulated dwelling burns in 1967 and mobile home burns in 1976 were sponsored by the Hardwood Plywood Manufacturers Association. In both series of burns, the performance of Class A and Class C flamespread wall interior finish was compared. Early limiting occupant egress conditions appeared to be primarily influenced by the combustible contents typical of and contained within the test structures.

Keywords: Plywood wall panels, decorative plywood, gypsum wall board, wood crib tests, temperature, smoke, carbon monoxide, carbon dioxide, oxygen depletion, furnishings, fuel load.

INTRODUCTION

Fire is a complex phenomenon. Perhaps sometime in the future, appropriate fire prediction equations will be developed; relationships between small-scale tests, modeling and full-scale fires may be identified; and computer simulations of projected fire scenarios might be analyzed so that the growth and result of fires can be better understood.

It appears that for the next few years we will have an extension of what has taken place in the immediate past; various laboratory or simulation tests will be used to evaluate and compare the performance of materials relative to one or more fire properties. The information derived will be used as the basis of controlling what materials may or may not be used in various types or areas of buildings.

Flamespread of products and fire endurance of assemblies are among traditional fire properties referenced in building codes. There has been recent interest in methods for assessing other fire properties including rate of heat release, the formation of toxic

and noxious combustion gases, and ease of ignition. Corner configuration tests and experimental room burns have been used to gain knowledge of fire performance of different materials, products, and assemblies.

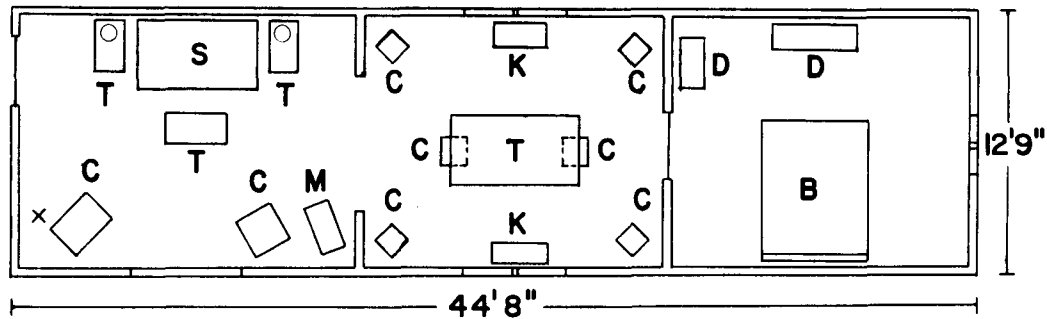
It is left to the regulator, the code official, and the inspector to sort through information provided by these available tools of the inexact science of fire property performance in setting appropriate requirements for materials and products.

The often-asked question of what a small-scale or laboratory test means relative to a real fire has become rhetorical. Most now realize that the results of an actual fire cannot be projected by a single fire property test. The quest for the ultimate small-scale fire test to govern the use of materials and products in buildings is much like flailing at windmills, which brings us full circle to the original hypothesis that structural fires are complex. This exercise in circumlocution can help to explain the necessity for conducting full-scale fire tests.

With the maze of fire property relationships as a background, frequently in the emotional atmosphere that inevitably follows a fire disaster, sometimes a proposal is made that some material or product be more rigidly controlled. On two occasions

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SWRI FLOOR PLAN OF FURNITURE PLACEMENT



- | | |
|-----------------------|---------------------------------------|
| B - DOUBLE BED | C - CHAIR, WOOD OR UPHOLSTERED |
| K - BOOK CASE | D - DRESSER OR CHEST |
| T - TABLE | M - MAGAZINE RACK |
| S - COUCH | X - IGNITION CRIB |

FIG. 1. Floor plan of furniture placement in the SwRI burns. The living room floor was covered with a nylon carpet, the dining room with vinyl asbestos tile, and the bedroom with laminated block flooring squares. Two small area rugs were placed in the bedroom.

the Hardwood Plywood Manufacturers Association (HPMA) has found it necessary to sponsor full-scale burns in multi-room structures to assess the validity of restrictive flamespread proposals.

FIRE TESTS

Southwest Research Institute Burns

During the late 1960's, a requirement was proposed as a result of a number of fires in San Francisco that all interior wood paneling $\frac{1}{2}$ inch or less in thickness be backed by a noncombustible material. As a response to this proposal, the Hardwood Plywood Manufacturers Association sponsored three tests conducted by Pryor (1968) of Southwest Research Institute. A building approximately 13 ft wide by 44 ft long was constructed within which the tests were conducted. The structure contained three rooms simulating a living room, din-

ing room, and bedroom. Identical furnishings were placed in the building for each of three burnouts, as illustrated in Fig. 1. The structure was rebuilt after each burn. The design variable was interior wall finish with flamespread determined by the Steiner tunnel using ASTM E-84 (ASTM 1976):

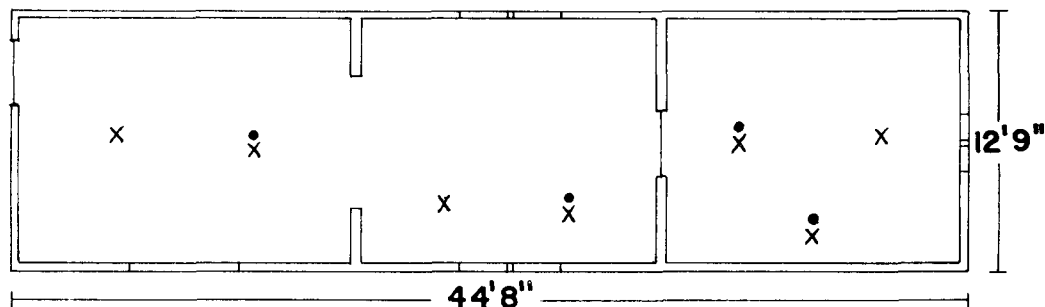
Test 1, gypsum wallboard, $\frac{1}{2}$ -inch thick—flamespread of 15 (Class A).

Test 2, cherry plywood, $\frac{1}{4}$ -inch thick—flamespread of 148 (Class C)—applied over $\frac{1}{2}$ -inch gypsum wallboard (Class A).

Test 3, cherry plywood $\frac{1}{4}$ -inch thick—flamespread of 148 (Class C)—applied directly to studs.

Each room in the structure was about 12 \times 14 ft. There was an open archway, approximately 6 ft wide, between the living room and the dining room. Between the

SWRI INSTRUMENTATION LAYOUT



• - GAS PROBE AT ONE OR MORE ELEVATION

X - THERMOCOUPLE AT ONE OR MORE ELEVATION

FIG. 2. Location of thermocouples and gas probes in the SwRI burn structure.

dining room and bedroom, there was a closed wood hollowcore flush door. Furnishings were selected by Southwest Research Institute to be typical of the Southwest region.

The fire was initiated in the corner of the living room by a 9 $\frac{3}{4}$ -lb crib placed equal distance from the wall surface and an upholstered chair. Temperature and carbon monoxide (CO), carbon dioxide (CO₂), and oxygen (O₂) levels were measured at various elevations and locations in the living room, dining room, and the bedroom, as shown on Fig. 2. Life safety or occupant egress was the primary factor investigated.

Results of these tests were that limiting life conditions occurred rapidly in all three tests in the living room and dining room at about 6 to 8 min. Temperature was found to be the critical factor: the temperature level cited by Southwest Research Institute was 300 F.

In the bedroom, limiting conditions were never reached in the structure that had gypsum walls. This test was terminated after 60 min. In the burns that had ply-

wood over gypsum board and plywood applied directly to studs, limiting conditions were reached in the bedroom in about 26 to 28 min. The closed hollowcore bedroom door kept hot gases from entering the bedroom from the primary fire area of the living and dining rooms. This closed door would have kept the bedroom occupant safe from fire in all three burns for a relatively long period of time.

Two of the conclusions stated by Southwest Research Institute were:

In terms of the relative times to reach limiting temperature conditions in the living room and dining room areas of each test, there did not appear to be any significant difference as indicated by the conditions at the 5-ft level.

The major combustible sources contributing to the early limiting conditions in the living room and dining room areas appear to be the contents as evidenced by the lack of any significant change (noted in conclusion above) when the different interior finish assemblies were used.

TABLE 1. Comparison of test structures and test conditions.

	Southwest Research Institute	Underwriters' Laboratories
Structure Dimensions	12'9" x 44'8"	13'9" x 66'9"
Approx. Volume Living Area	4130 ft ³	6140 ft ³
Approx. Volume Primary Fire Area	2750 ft ³	3140 ft ³
Ceiling Finish	Gypsum Wallboard 15 FS	Cellulose Fiberboard 75 FS
Fuel Load Overall	2.35 lb/ft ²	1.17 lb/ft ² *
Fuel Load Primary Fire Area	1.73 lb/ft ²	1.83 lb/ft ² *
Ventilation	Semi-closed 2 dining room windows open 3" 1 bedroom window open 6"	Closed No windows open No internal fans on
Ignition Crib Description	52 pieces Douglas-fir 3/4" x 3/4" x 18"	50 pieces Douglas-fir 3/4" x 3/4" x 6.7"
Ignition Crib Weight	9.75 lbs	3.3 lbs
Ignition Crib Position	Equidistance from chair and wall - 3" to 4" from each	1" and parallel to chair; 1" from wall one point
Ignitor	3 oz methyl alcohol in pan	0.19 oz ethyl alcohol in pan
Room of Fire Origin	Living room corner	Living room corner
Number of Bedrooms	1	2

* Does not include kitchen cabinets

termine the appropriate crib size to be used as an ignition source. Criteria used in selecting the crib included that it be sufficiently large that both the wall and the upholstered chair would have an opportunity to ignite, and be sufficiently large that the fire in its initial stage would be similar in both mobile homes. The crib would have to be sufficiently small so it would not represent a significant factor in producing limiting conditions or to be a significant factor in the fuel load. The crib was used primarily as an ignitor. After a number of tests had been conducted on four different crib sizes, a size of 3.3 lb (1,500 g) was found to be appropriate. A crib of this size might simulate something like a small magazine rack or a medium to large

trash container filled with various items of trash and paper. The crib in each full-scale fire test was placed between the wall surface and a chair in one corner of the living room as shown in Fig. 3.

Certain factors that might affect occupant egress were studied. Temperature measurements, carbon monoxide (CO), carbon dioxide (CO₂), oxygen (O₂) and smoke levels were continuously monitored in the bedroom and at various other locations in the mobile home, including the corridor and kitchen-living area, as shown in Fig. 4.

The mobile home had two bedrooms. The door to the master bedroom, which was located at the opposite end of the mobile home from the living room, was wired open

TABLE 2. Comparison of test observations.

Test number	Southwest Research Institute			Underwriter's Laboratories	
	1	2	3	1	2
Flamespread class	A-A	C(A)-A	C-A	A-B	C-B
Conditions					
Temperature	64°F	72°F	72°F	57°F	68°F
Relative Humidity	87%	98%	42%	55%	37%
Wind Speed	7mph	8mph	8mph	10 to 12	5 to 11
Approx. time to 212°F					
5 feet elevation					
Living room	6:08	3:56	5:00	6:12	5:15
Adjacent room	6:39	4:29	5:21	7:47	6:03
3 feet elevation					
Bedroom-open door	-	-	-	8:43	6:56
Bedroom-closed door	NR	26:56	26:10	NR	NR
Approx. time to 300°F					
5 feet elevation					
Living room	7:26	5:50	6:22	6:28	5:22
Adjacent room	8:18	6:42	8:04	7:58	6:07
3 feet elevation					
Bedroom-open door	-	-	-	NR	14:20
Bedroom-closed door	NR	28:36	27:32	NR	NR
Maximum temperature at					
5 feet elevation					
Living room	1240°F	1990°F	1910°F	1420°F	1510°F
Adjacent room	600°F	1990°F	1850°F	990°F	1060°F
3 feet elevation					
Bedroom-open door	-	-	-	285°F	320°F
Bedroom-closed door	85°F(A)	600°F	1210°F	90°F	70°F(A)
Duration of test (minutes)	60	30	30	45	15

- No small bedroom
NR Not reached
(A) No rise in inside temperature

during each test. The second bedroom was off the corridor and the door to this bedroom remained closed during each test.

The mobile homes were constructed with building products normally used by the manufacturer. Lauan hardwood plywood, 1/4-inch thick, with a flame spread of 190 was used as the primary wall finish and 1/2-inch cellulose fiberboard with a flame-spread of 75 was used as a ceiling finish in one home. The second home was identical to the first except that 5/16-inch gypsum board wall panels with a flame spread of 20 represented the primary wall finish. The mobile homes bore the seal of an in-

spection agency indicating that each met federal standards.

High temperatures were reached in both mobile homes quite rapidly. In the living room and kitchen, 100 C occurred in the plywood home in about 5 min, and in the gypsum board home at about 6 3/4 min. In the bedroom, this temperature in the plywood home occurred at about 6 1/2 min and in the gypsum home at about 8 1/2 min.

Both homes contained labeled smoke detectors meeting applicable standards which were located as required by the federal standards. The alarm of the smoke detector in the plywood home sounded continuously

National Bureau of Standards Tests

Budnick (1976) of the National Bureau of Standards conducted a series of nine corridor tests as described in an Interim Report, NBSIR 76-1021. Each test was of a different combination of wall and ceiling materials as applied in a mobile home corridor. Included were $\frac{3}{4}$ -inch lauan wall paneling (flamespread 194) and $\frac{1}{2}$ -inch fiberboard ceiling (flamespread 122) in one test, and gypsum wallboard (flamespread 24) and mineral fiberboard ceiling (flamespread 19) in another. In addition to the Class C-Class C (wall-ceiling) test and the Class A-Class A test, seven other burns having various Class A (0-25), Class B (26-75) and Class C (76-200) wall and ceiling finish combinations were also conducted. The experimental design of this NBS study was such that the fire spread was restricted to the corridor area. A 14-lb wood crib and the materials used for wall and ceiling represented the primary fuel load in this series of tests.

As a result of this study, one stated conclusion was, "Based on these tests the use of Class A wall and ceiling materials in the corridor could significantly increase the fire safety for occupants and reduce the property losses from fires. For a fire starting in the living room, this could represent the difference between the fire burning into the bedroom or not." Although this came from an interim report, preliminary to a final report on mobile home fire safety, some interests seized this conclusion as a basis for proposing changes in flamespread requirements in the Federal Mobile Home Construction and Safety Standards (HUD 1975).

It is estimated that hardwood plywood represents 80 to 90% of wall finish in mobile homes. Thus, it became apparent that an experiment should be sponsored by the hardwood plywood industry to evaluate comparative fire performance of Class A and Class C wall finish as it related to occupant egress in typically furnished mobile homes. It was decided that two mobile homes would be constructed, both meeting the Federal Mobile Home Construction and

Safety Standards (effective 15 June 1976). It was determined that the size of the unit must be representative of typical single-wide mobile homes; thus, a 14-ft-wide by 67-ft-long unit was selected.

Underwriters' Laboratories Inc. burns

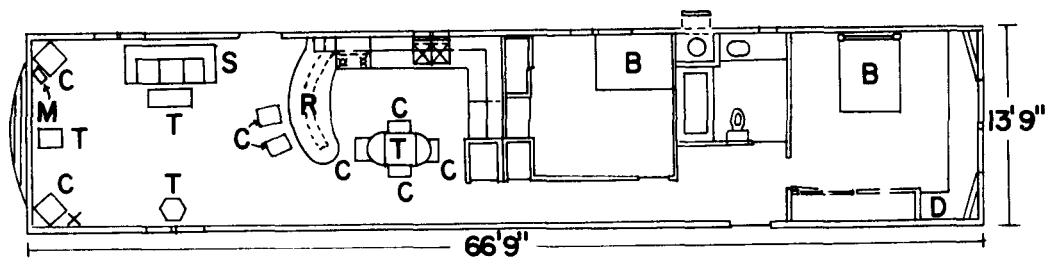
Two burns were conducted by Underwriters' Laboratories on September 21 and 22, 1976. A *Fact-Finding Report on Comparative Fire Testing of Two Mobile Home Units with Representative Interior Finish Materials and Furnishings* was prepared for the Hardwood Plywood Manufacturers Association by Underwriters' Laboratories (1977).

The sponsoring organization, HPMA, decided on the following various design details. It was felt that the mobile homes should be evaluated as an entire system; that is, as they might be bought and lived in by occupants. The mobile homes contained the most common furnishing package provided by the manufacturer, plus a few additional items to reflect a more lived-in condition. Mobile homes are normally sold furnished containing carpets, drapes and items of furniture in the living room, dining room, and bedrooms. The placement of furniture in the mobile homes is shown in Fig. 3.

The living room had been previously selected by HPMA as the room of fire origin because a National Fire Protection Association study (1975) indicated the living room and kitchen to be fairly similar as locations in which fires are most likely to start in mobile homes. The choice of the living room by HPMA was made because various fire safety kitchen requirements had been incorporated in the federal mobile home standards. These requirements included 50 flamespread material behind the kitchen range and other protection to the kitchen cabinets above the stove and in the vicinity surrounding the stove. It was reasoned that when the effect of these measures is assessed by fire experience statistics, the incidence of kitchen fires would decrease relative to living room fires.

Considerable work was conducted to de-

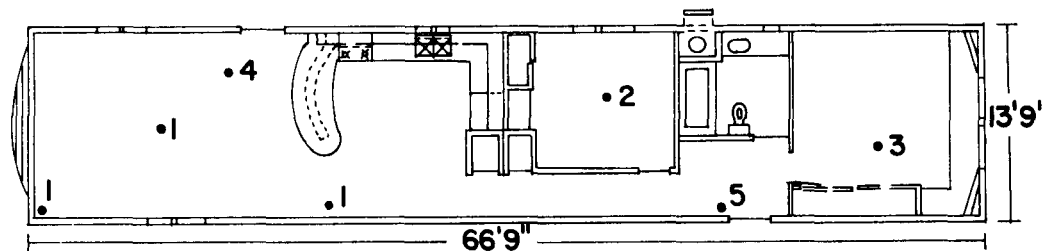
UL FLOOR PLAN OF FURNITURE PLACEMENT



- | | |
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FIG. 3. Floor plan of furniture placement in the UL burns. Sculptured shag carpeting with pad was on the living room floor, and corridor floor and level loop shag carpeting with pad on the floor of the large bedroom. Vinyl roll goods were used for floor coverings in the kitchen, small bedroom, and bathroom.

UL INSTRUMENTATION LAYOUT



- | | |
|--------------------------------------|---|
| 1 - TEMP. | 4 - TEMP + CO + O₂ + SMOKE |
| 2 - TEMP + CO | 5 - TEMP + CO + O₂ + SMOKE + CO₂ |
| 3 - TEMP + CO + O₂ | |

FIG. 4. Location of thermocouples, gas probes, and smoke measuring devices in UL tests in mobile homes.

TEMPERATURES (60" ABOVE FLOOR)

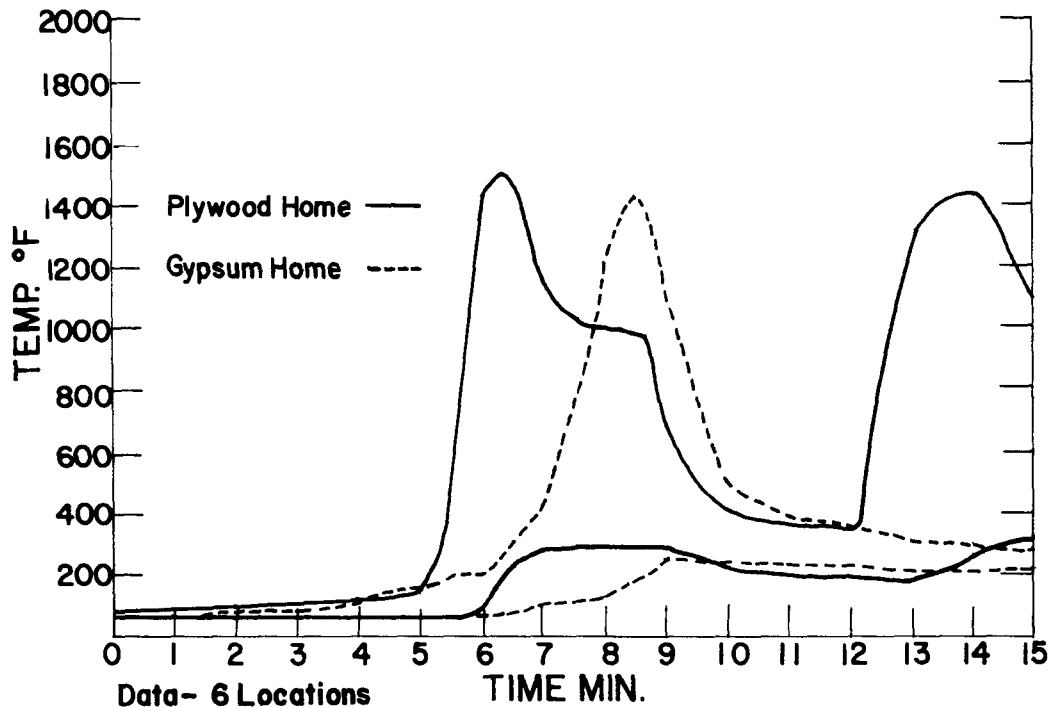


FIG. 5. Temperature profiles in the UL burns at 60 in above floor elevation. Each profile includes temperature measurements taken at six locations within the mobile home. Temperature profiles do not show measurements in small bedroom within which there was little or no temperature rising during the tests. The slope of the temperature lines at 5 min (plywood home) and at 7 min (gypsum home) is reasonably similar to the slope of temperature plottings occurring shortly thereafter at other locations within the mobile homes.

at 5 min and 20 sec and in the gypsum board home at 4 min and 15 sec.

The tests were conducted with the homes in the winter (or closed) condition: heating units were off and the windows and outside doors were shut.

GENERAL DISCUSSION

NBS tests confined ignition and burning primarily to a 14-lb crib and to what other combustibles there may have been in the corridor, although the NBS interim report indicates that tenability of test criteria was studied as it related to the event of a fire originating in the living room or kitchen area of a mobile home. Temperatures of

100 C and greater were not reached in the bedroom when Class A walls and ceiling materials were used.

In the HPMA-sponsored tests, the fire location was considered to be representative of certain actual fire experience situations, and the mobile home was tested as a system including ordinary and typical furnishings as well as the structure. Temperature conditions of 100 C were reached in all rooms of each mobile home except in the small bedroom. The door from the corridor to this bedroom was closed during each test.

Both the SwRI and the UL burns were conducted to assess the response to fire of Class A and Class C wall finishes in an environment where furnishings and contents

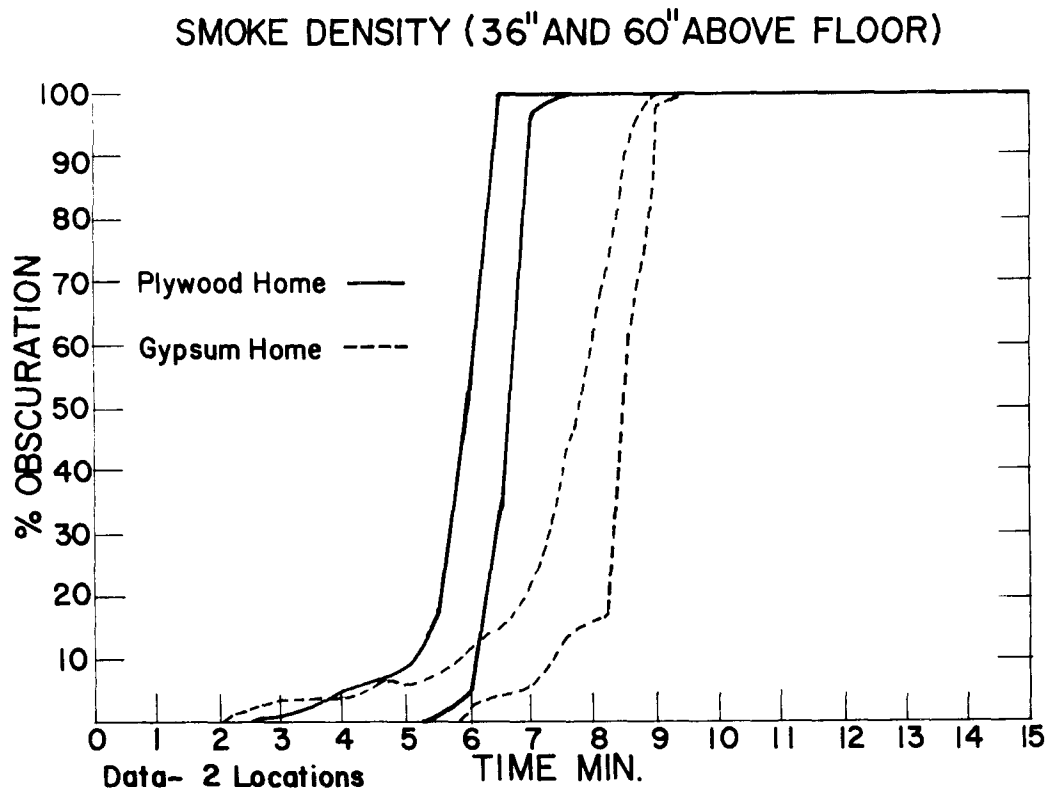


FIG. 6. Smoke density profiles taken at two elevations (36 inches and 60 inches above floor) at two different locations during the UL burns.

are normally present. The SwRI burns were conducted in a structure to simulate a living room, dining room, and bedroom in a dwelling. The UL burns were conducted in two mobile homes built on a typical construction line. In both test series, an ignition wood crib was placed equal distance from the wall and an upholstered chair.

In the study of these two series of tests, there are differences in the SwRI and the UL burns. Class A flamespread ceiling material was used in the SwRI tests, while Class B was used in the mobile homes. Some ventilation was provided by open windows in the SwRI tests; a closed or "winter" condition existed in the UL tests. Similarities of note include the approximate volume of the primary fire area, fuel load in the primary fire area, and location of

fire origin. Table 1 provides a comparison of the two test structures.

The atmospheric conditions at which the tests were conducted and various time-temperature observations in the five burns are outlined in Table 2. The temperature values are approximate as they have been taken from curves, or tables in which some interpolation was sometimes necessary. Time-temperature values were taken from the location within the room where the measured temperature occurred first.

In comparing the Table 2 temperature profiles of the SwRI burns with the UL burns, the rate of temperature buildup was slower in the SwRI burns. The time differential between the occurrence of 212 F and 300 F in the living room and in the adjacent dining room was from 1:18 (Test

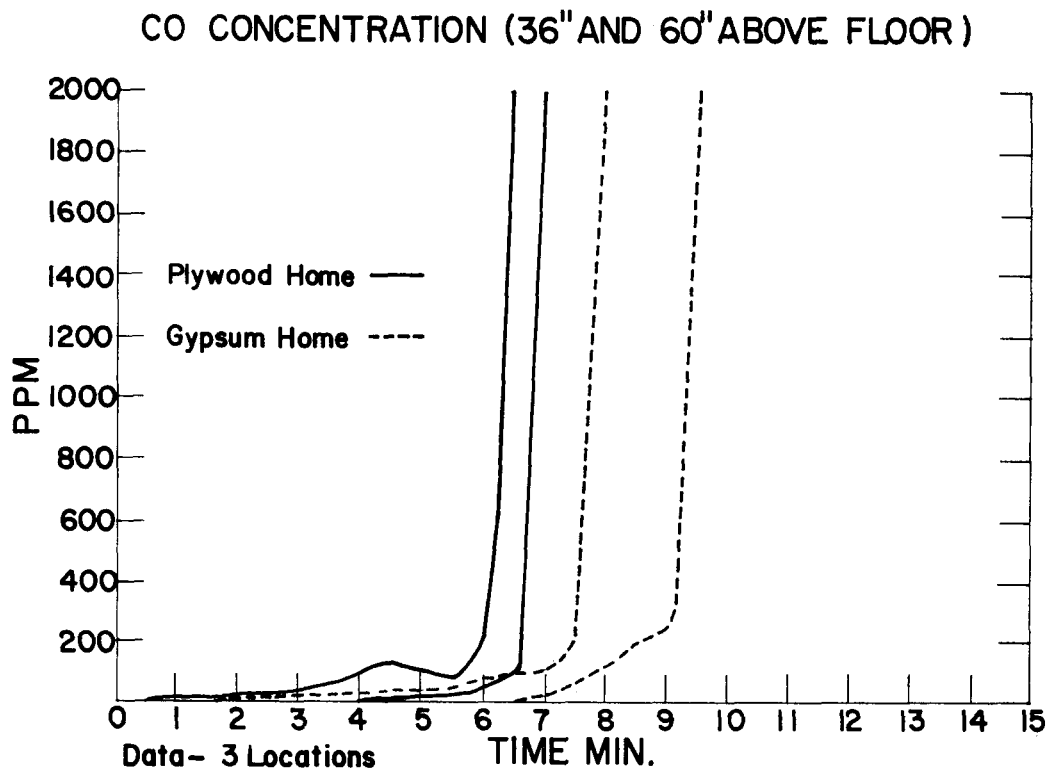


FIG. 7. CO concentration profiles taken at three locations at 36-inch elevation except in rear corridor of plywood wall paneling home (60-inch elevation) during the UL burns. Profiles for CO do not show concentration changes in the small bedroom, which exhibited a different and displaced pattern relative to the plywood and gypsum homes.

1) to 2:43 (Test 3). In the UL burns, the time differential between 212 F and 300 F in the living room and in the kitchen area was from 4 to 16 sec.

Data from the two UL test burns are quite similar in many respects. Low to moderate increases in temperature and combustion products took place early during each test. At 5 to 6 min in the plywood-wall-finish mobile home and at about 7 to 8 min in the gypsum-wall-finish mobile home, the nature of fire involvement changed. The temperature (Fig. 5) in both homes rose rapidly, and almost simultaneously heavy development of smoke (Fig. 6) occurred. Shortly thereafter, within about 1 min, CO concentration (Fig. 7) increased and O₂ concentration (Fig. 8) decreased quite rapidly. This suggests that in

certain fires where no outside ventilation is provided a number of events can occur almost at the same time, acting to prevent the escape of trapped occupants.

SUMMARY OBSERVATIONS

1. Full-scale fire tests conducted under as realistic conditions as possible are sometimes necessary to assess the validity of fire safety proposals.
2. The results of various large-scale fire test experiments should be considered by taking account of the experimental design under which the tests are conducted.
3. Early limiting egress conditions of various one-story residential structure and furnishing fires appear to be caused primarily by the building contents, based

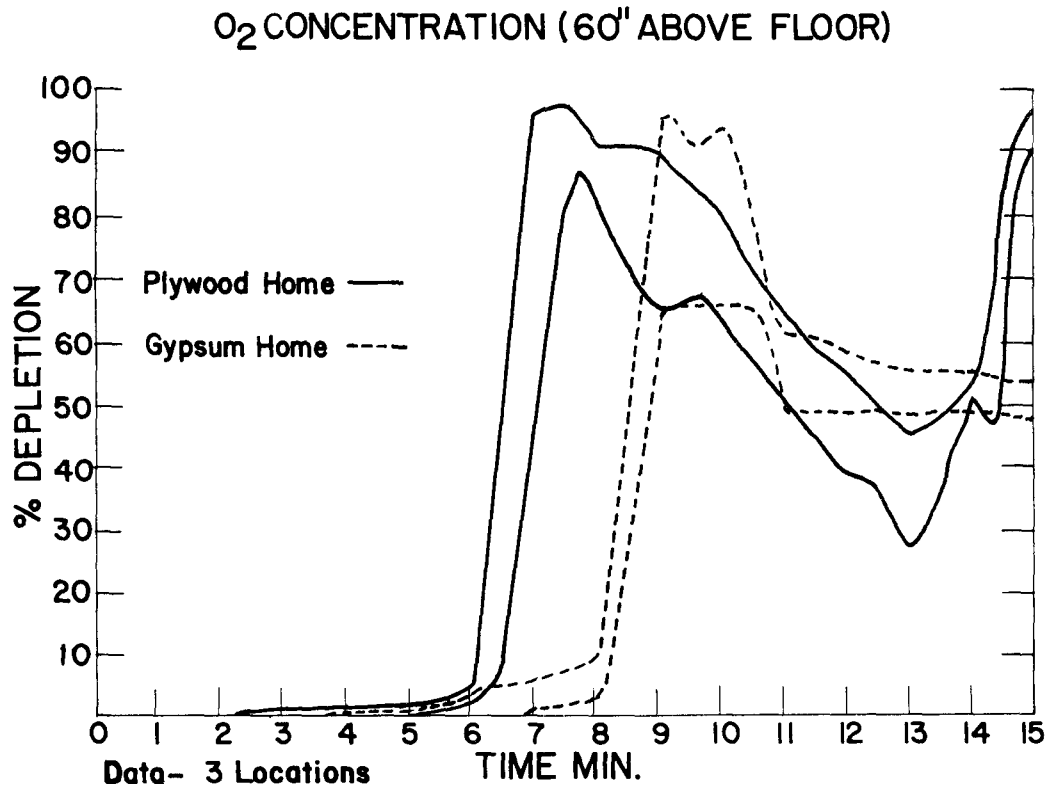


FIG. 8. O₂ concentration profiles taken at three locations at 60-inch elevation during the UL burns.

on similarities of fire test data and on the small time differential of 2 min and less limiting egress conditions when Class A and Class C flamespread interior wall finishes were evaluated in the two HPMA-sponsored test series.

4. Closed interior doors reduce the movement of heated gases and combustion products between rooms. Hollowcore wood doors may provide significant escape time when a fire originates in another room.
5. Temperature appears to be the most important limiting egress factor in the test series described.
6. The UL burns, conducted under closed ventilation conditions, exhibited extremely rapid temperature change at 5 and 7 min with corresponding rapid changes in smoke development. Following shortly thereafter were similar rapid

increases in CO and decreases in O₂ levels.

REFERENCES

- ASTM. 1976. Standard method of test for surface burning characteristics of building materials. ASTM E 84-76a. Am. Soc. Test. Mater. Philadelphia, Pa.
- BUDNICK, EDWARD K. 1976. Fire spread along a mobile home corridor. NBSIR 76-1021. USDC Nat. Bur. Stand. 51 pp.
- HUD. 1975. Mobile home construction and safety standards. Federal Register Vol. 40, No. 244—Thursday December 18, 1975. Pp. 58752.
- NFPA. 1975. A study of mobile home fires. No. FR75-2. Nat. Fire Protect. Assoc., Boston, Mass. 15 pp.
- PRYOR, A. J. 1968. Full-scale evaluation of the fire hazard of interior wall finishes. Southwest Research Inst. San Antonio, Texas. 79 pp.
- UL. 1977. Fact-finding report on comparative fire testing of two mobile home units with representative interior finish materials and furnishings. Underwriters' Laboratories, Northbrook, Ill. 88 pp.