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Reduced-Scale Modeling of Mobile Home Fires: A Progress Report

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

September 1981

Interim Report

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Sponsored principally by:

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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REDUCED-SCALE MODELING OF MOBILE HOME FIRES: A PROGRESS REPORT

David P. Klein

Abstract

A series of fire tests was conducted in the bedroom of a single-wide mobile home and in a quarter-scale model of that bedroom. The objectives of the tests were (1) to evaluate the relationship between fire buildup in the reduced-scale and full-scale enclosures and (2) to determine the feasibility of using a reduced-scale model test to assess the potential contribution of particular combinations of interior finish materials to fire growth in a mobile home.

The model tests simulated the phenomena of fire growth and flashover, however the time to flashover occurred later in the model than in the full-scale bedroom. Flashover was taken as the time at which the level of radiation at the center of the floor reached 2 W/cm^2. Several modifications to the model were examined but none adequately corrected the time delay to flashover. However, by monitoring the upper air temperature in the model, the occurrence or nonoccurrence of flashover for corresponding full-scale tests could be reliably predicted. Therefore, the use of a quarter-scale model was judged to be feasible.

Key words: Compartment fires; fire tests; flashover; interior finish; mobile homes; models; room fires.

1. INTRODUCTION

A research project is ongoing at the Center for Fire Research (CFR) of the National Bureau of Standards to evaluate the relationship between fire buildup in a full-scale single-wide mobile home and fire buildup in a reduced-scale enclosure. Full-scale testing has traditionally been used by CFR and other research and testing organizations as a major tool for fire research because it demonstrates realistic fire development under controlled environmental conditions. The primary efforts in full-scale testing to date can be grouped into two general classes. First, full-scale fire testing is used to provide comparative information regarding the performance of similar design constructions with different interior finish, insulation, structural members, or other features in order to assess the relative fire risk associated with these features. Second, the results of full-scale fire tests are used to identify the potential capabilities of standard laboratory fire tests to provide information on material responses which qualitatively describe performance under full-scale conditions.

Full-scale testing is normally conducted under controlled conditions in which ambient temperatures, initial ventilation, room geometry, and the size and type of ignition source are held constant. However, due to the time and expense involved with full-scale testing, it is usually not practical to conduct many additional tests under different conditions and there is no existing procedure to extend test results to cover other conditions.

It is felt that reduced-scale fire testing is a simpler, more versatile, and more economical method by which the same information may be obtained as with full-scale testing. Because of the decreased time and expense involved with reduced-scale testing, more tests can be conducted under a wider range of conditions, allowing a more realistic evaluation of different design features. A standardized reduced-scale fire test developed for laboratory use would combine the best characteristics of both standardized laboratory test methods and full-scale testing in that certain conditions could be held constant for repeatability, yet a wide range of design features could be assessed in an environment designed to examine not just a single material response, but the full range of responses including all their interactions.

The purpose of this report is to describe the progress of the CFR effort to model fire growth in a mobile home and to determine the feasibility of a reduced-scale fire test.

1.1. Objectives

This project has three overall objectives:

1. To evaluate the relationship between fire buildup in a reduced-scale and a full-scale enclosure.

2. To determine the feasibility of using a reduced-scale model test to assess the potential contribution of particular combinations of interior finish materials to fire growth and spread in a full-scale mobile home.

3. To draft a proposed test method for a standardized reduced-scale fire test if the use of a reduced-scale model is found to be feasible.

This report deals with progress toward the first two objectives. If the use of a reduced-scale model is determined to be feasible, a future report will contain details of the proposed test method.

1.2 Background

In modeling research conducted at CFR, Parker and Lee [1][1] developed scaling guidelines for designing reduced-size enclosures to model fire buildup. These guidelines are:

1. All dimensions are proportional to the scale factor except:

   a. the width of the doorway is proportional to the square root of the scale factor, and

   b. the thickness of the wall and ceiling materials remains the same as full scale.

2. Fuel content and fuel surface area are proportional to the floor area.

3. The air supply rate is proportional to the floor area.

4. Time is the same in the model as in full-scale.

Using these guidelines, a quarter-scale (i.e., scale factor equals four) model of the master bedroom was designed and constructed. The bedroom, because of its relatively small size and high fire load, was judged to be the most critical compartment in terms of fire growth in a mobile home.

2. EXPERIMENTAL DETAILS

2.1 Use of Gas Burner

During the course of previous research, a number of full-scale room fire tests were conducted in various areas of a mobile home including the bedroom [2] and living room [3,4]. One objective of these tests was to determine the role of interior finish in fire growth in these rooms. Among the items used as exposure fires to ignite the interior finish materials were 16 kg (35 lb) upholstered chairs, and 13.6, 9.1, and 6.4 kg (30, 20, and 14 lb) wood cribs. It was found during this work that for those tests where upholstered chairs were used as the exposure fire, the initial fire buildup varied considerably due to variation in the spread of flames along the surfaces of the chairs. Since the ultimate objective of this modeling

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[1] Numbers in brackets refer to literature references at the end of this report.

project is to develop a proposed standardized test, it was deemed desirable to use a more reproducible exposure fire in the quarter-scale enclosure. Although fires from the wood cribs have been demonstrated to be more reproducible than fires from the upholstered chairs [5], fires produced by diffusion gas burners provide even greater reproducibility than fires from wood cribs. A diffusion gas burner is also more flexible since the flame from a single burner can be adjusted to provide a wide range of heat production. In addition, the heat produced by a burner can be precisely adjusted, which is difficult to do with wood cribs. Finally, while wood cribs are susceptible to variability in characteristics within the species of wood from which the cribs are constructed, the variability in a gas burner is dependent only on the composition of the gas being burned and on the accuracy of the flow metering equipment. Both the composition of the gas and the accuracy of the flow meter can be ascertained and kept within acceptable limits. It was decided for these reasons to use a diffusion gas burner in the quarter-scale model to provide the exposure fire. See the appendix for the accuracy of the flow meters used with the burner.

2.2 Experimental Approach

Once the decision had been made to use a diffusion gas burner, an experimental plan was developed to test and validate various aspects of the quarter-scale model in relation to the full-scale room. This plan may be viewed as a series of steps:

Step 1: Tests had previously [2] been conducted in the full-scale bedroom using combustible interior finish materials on the walls and ceiling and using upholstered chairs to provide the exposure fires. In order to determine the burning characteristics of the exposure fires themselves (in addition to the burning characteristics of wood crib exposure fires used in other mobile home testing), tests were conducted in the full-scale bedroom using upholstered chairs and the various size wood cribs with essentially noncontributing interior finish materials on the walls and ceiling. These tests, the results of which are discussed in this report, demonstrated that maximum upper air temperatures and heat flux levels on the floor produced by a 16 kg upholstered chair were approximated by a 13.6 kg wood crib, and that the intensity of both fires was approximately the same[2]. Therefore, the 13.6 kg wood crib was selected to approximate the effects of a 16 kg upholstered chair for the purpose of developing

[2] Similar results were found in tests conducted in the living room [5].

a gas burner flame. Wood cribs weighing 9.1 and 6.4 kg were used to provide supporting data at intermediate exposure levels. Although it would have been technically easy to program the gas flow to duplicate the shape of the temperature curves measured in the upholstered chair tests, this was not considered a practical approach since the burning rates of other chairs and combustible contents are not necessarily the same and, in fact, are approximately constant in many cases.

Step 2: This step involved the development of standardized exposure fires. To accomplish this, a 305 x 305 mm (12 x 12 in) gas burner in the full-scale bedroom with noncontributing interior finish materials was used to determine the burner flows whose temperature curves matched those of the 6.4 and 9.1 kg wood cribs. These burner flows were to be used later in tests with combustible interior finish materials on the walls and ceiling.

Step 3: Next, scaled burner flows were tested in the quarter-scale model using noncontributing interior finish materials. The results showed acceptable agreement with the full-scale tests. In addition, a burner flow for the model was developed to correspond with the results of the 13.6 kg wood crib when tested in the full-scale room.

Step 4: The next step was to test the quarter-scale model using the burner flows determined in steps 2 and 3 but with combustible interior finish materials on the walls and ceiling. The materials chosen were the same or similar to those materials used in the previous full-scale testing in the bedroom.

Step 5: Finally, the materials used in the model were tested in the full-scale bedroom using burner flows corresponding to those used in the model. This step was to determine how accurately and in what ways the quarter-scale model could be used to predict fire growth in the full-scale room.

2.3 Full-Scale Test Unit

The full-scale tests were conducted in the master bedroom (bedroom #1)[3] of a conventional three-bedroom single-wide mobile home (see figures 1 and 2).

[3] Hereafter referred to as the bedroom.

The mobile home was approximately 3.7 x 18.3 m (12 x 60 ft)[4]; the bedroom was approximately 3.5 m (11 ft 4 in) wide and 2.8 m (9 ft 2 in) long, resulting in a floor area of 9.8 m^2 (105 ft^2), and had a ceiling height of 2.1 m (7 ft). The single opening into the bedroom was through a doorway 735 mm (29 in) wide and 2.0 m (6 ft 8 in) high, connecting the bedroom with the corridor. The exposure fire was located in the southeast corner of the bedroom, which is the corner diagonally opposite the doorway.

The mobile home had exterior walls constructed of 51 x 76 mm (2 x 3 in) nominal thickness wood studs, spaced 405 mm (16 in) on center, with 76 mm (3 in) of glass fiber insulation between the studs and the aluminum exterior siding. The interior walls were constructed with nominal 51 x 51 mm (2 x 2 in) studs, 405 mm (16 in) on center, with no insulation between the studs. The roof construction included aluminum exterior sheeting attached mechanically to a system of wood bow-string trusses, spaced 405 mm (16 in) on center, with 76 mm (3 in) of glass fiber insulation. The floor was constructed of 19 mm (0.75 in) thick particle board. The bedroom had two 660 x 760 mm (26 x 30 in) windows, located in the south and west walls. These windows were kept closed during testing. A detailed plan view of the mobile home is shown in figure 2.

A sprinkler system was installed with small orifice open sprinkler heads located in the center of the bedroom and in the corridor midway between the bedroom and living room. The system was available for manual activation to minimize fire spread outside the bedroom.

The interior finish materials were fastened with nails to the studs on the walls and the ceiling trusses in accordance with recommended practices. Assembly was completed at least 48 hours prior to the start of each test to allow time for all elements to reach temperature and moisture equilibrium.

2.4 Quarter-Scale Model

The 1/4-scale model of the mobile home bedroom was constructed of materials similar to the full-scale room itself. The interior dimensions of the model were 0.88 x 0.70 x 0.55 m (34-1/2 x 27-3/4 x 21-1/2 in), not including interior finish. The three exterior walls were constructed of 38 x 76 mm (1-1/2 x 3 in) wood studs, approximately 405 mm (16 in) on center where possible, with 76 mm (3 in) of glass fiber insulation and a sheet metal exterior. The wall representing an interior wall (i.e., the wall containing

[4] Values expressed in traditional units are exact. Values expressed in metric units may be approximations. Lengths over 100 mm are always rounded to the nearest 5 mm.

the doorway) was constructed with nominal 51 x 51 mm (2 x 2 in) studs with no insulation between the studs, but with a piece of 4 mm (5/32 in) lauan plywood on the exterior side to represent the adjoining interior wall. The roof consisted of a sheet metal exterior with a wooden simulated truss system (each section was cut from a single piece of wood), and 76 mm (3 in) of glass fiber insulation. As in the full-scale unit, there was an open area between the upper side of the insulation material and the sheet metal exterior skin. The interior finish materials were attached with nails to the studs of the walls and ceiling in a similar fashion to the full-scale room.

The walls and ceiling were placed on, but not permanently attached to, a portable bench. In this way the entire unit could easily be moved. The top surface of the bench, which constituted the floor of the enclosure, consisted of 13 mm (1/2 in) inorganic calcium silicate marine board over 13 mm (1/2 in) plywood. The floor area of the enclosure was 0.62 m^2 (957 in^2), approximately one sixteenth the area of the full-scale room. The doorway opening was 370 x 510 mm (14-1/2 x 20 in). As in the full-scale room, the exposure fire was located in the corner opposite the door. Figure 3 shows details of the enclosure. Figure 4 shows the wood framework of the walls and ceiling assembly during construction.

After the model had been constructed and was in use, the typical time required for one technician to reinstall the interior finish, insulation, and any damaged studding was approximately two days. Therefore, it was estimated that up to five tests could be conducted in the model every two weeks, if necessary.

2.5 Instrumentation

Diagrams illustrating the locations where test measurements were taken are shown for the full-scale room in figure 5 and for the quarter-scale model in figure 6. The limits of error for the instrumentation are listed in the appendix. Thermocouple trees, each consisting of six 0.91 mm (0.0359 in, 20 gauge) chromel and alumel wires packed in mineral insulation and enclosed in a 3.15 mm (0.124 in) diameter inconel 702 sheath with a grounded junction, were located in the center and doorway of both enclosures. The heights of the thermocouples in the center of the full-scale room were 25, 255, 815, 1220, and 1675 mm (1, 10, 32, 48, and 66 in) below the ceiling and 25 mm (1 in) above the floor. The corresponding heights in the model were 6, 64, 205, 305 and 420 mm (0.25, 2.5, 8.0, 12.0, and 16.5 in) below the ceiling and 3 mm (0.125 in) above the floor. The heights of the thermocouples in the doorway of the full-scale room were 125, 405, 710, 1015, 1420, and 1830 mm (5, 16, 28, 40, 56, and 72 in) below the lintel (i.e., below the top of the door opening). The corresponding heights for the model were 32, 100, 180, 255, 355, and 455 mm (1.25, 4.0, 7.0, 10.0, 14.0, and 18.0 in) below the lintel. A 0.05 mm (0.002 in) diameter chromel and alumel thermocouple insulated with glass fiber was located in the center of the full-scale enclosure 25 mm (1 in) below the ceiling and in the model 64 mm (2.5 in) below the ceiling.

Oxygen concentrations were sampled in the doorway of the full-scale room at distances of 125, 405, 710, 1420, and 1880 mm (5, 16, 28, 56, and 74 in) below the lintel. The distance of 1880 mm below the lintel is approximately 150 mm (6 in) above the floor. In the doorway of the model, oxygen concentrations were sampled at distances of 32, 100, and 180 mm (1.25, 4.0, and 7.0 in) below the lintel and 32 mm (1.25 in) above the floor. In addition, a sample was taken in the center of the quarter-scale enclosure at 380 mm (15 in) above the floor. All samples were filtered through glass fiber to remove soot and particulate matter, chilled through an ice bath to remove condensable vapors, then filtered through anhydrous calcium sulfate to remove additional water, and filtered through sodium hydroxide dispersed on a fiber base to remove carbon dioxide. The samples were then passed through electro chemical oxygen cells.

In both the full-scale room and in the model, calibrated, water-cooled Gardon-type heat flux transducers were used to measure total incident heat flux at the floor in the center of the enclosure and at the doorway, at the ceiling directly above the exposure fire, and on the east wall adjacent to the exposure fire at 915 and 1830 mm (3 and 6 ft) above the floor in the full-scale room and 265 and 455 mm (10.5 and 18.0 in) above the floor in the model.

In addition to the heat flux transducer located at the floor in the center of each enclosure, pieces of crumpled newsprint were placed on the floor to serve as visual ignition indicators.

During certain tests of the model, some of the lower thermocouples in the center of the enclosure were moved to different positions to monitor air temperatures at various heights. In addition, for certain tests a second 0.05 mm (0.002 in) diameter thermocouple was included 6 mm (0.25 in) below the ceiling.

2.6 Exposure Fires

The exposure fires in the full-scale room were produced using upholstered chairs, various size wood cribs, and a gas burner. The upholstered chairs weighed approximately 16 kg (35 lb) and each was constructed of a wood frame with polyurethane foam and cotton batting, and covered with rayon fabric. The removable seat cushion was also polyurethane foam covered with rayon fabric. The chairs were stored in a test building until their weight stabilized. Temperature and relative humidity in the test building were maintained at 24 ± 2.8°C (75 ± 5°F) and 35 ± 10%, respectively. They were similar to chairs used in the full-scale tests previously conducted in the bedroom. The two chairs tested were both of the same design and were produced by the same manufacturer.

The wood cribs consisted of pieces of hemlock arranged in layers, with each layer placed at a right angle to the previous one. In addition, two bottom layers of two sticks each were included to support the crib above a pan containing 150 ml of heptane. The cribs were conditioned at 21°C (70°F) and 50% relative humidity until the moisture content and the resulting change in weight had stabilized. Cribs weighing 6.4, 9.1, and 13.6 kg (14, 20, and 30 lb) were used. The cribs were designed so that after conditioning their weight would be at least as great as the weight specified. Final weight adjustments could then be made by removing one or more sticks from the top. Design specifications for the cribs are shown in table 1.

The gas burner used in the full-scale room consisted of a steel box with a 305 x 305 mm (12 x 12 in) mineral wool cover. The top surface of the burner was located approximately 305 mm above the floor. The burner used in the model was geometrically scaled down by a factor of four, so that the top surface was 76 x 76 mm (3 x 3 in) and had an area one-sixteenth that of the large burner. The top surface of the reduced-scale burner was located 76 mm above the floor. Because the scale factor was four, the ratio of corresponding heat release rates between the large and small burner was 16 to 1. That is, in order to model a particular full-scale exposure fire in the model, the small burner would be adjusted to provide one-sixteenth the heat release rate of the large burner. The gas used in the burners was methane, although a small number of comparison tests were conducted using propane.

2.7 Test Criterion

During previous research in mobile homes [2,3,4] it was determined that flashover, or full room involvement, was a critical stage in fire growth in a mobile home. Flashover is defined as a fire phenomenon in which the radiation from the heated upper walls and ceiling and from the hot gases and smoke layer in the upper part of the enclosure is sufficient to cause ignition and rapid, complete fire involvement of all combustible materials in the enclosure. Flashover occurs when the total incident heat flux at the floor exceeds approximately 2 W/cm^2. This corresponds to an upper air temperature of approximately 600°C.

During those tests in which flashover occurred in the living room or bedroom, the levels of temperature, oxygen depletion, and carbon monoxide established as limits for occupant incipient incapacitation[5] were exceeded at the opposite end of the full-scale mobile home at approximately the time of flashover. For those tests in which flashover did not occur, limiting conditions generally either did not occur, barely exceeded limiting thresholds, or exceeded limiting thresholds only after a relatively long period of time[6]. This indicated that information about life safety conditions at the far end of the mobile home could be deduced by knowing whether or not flashover occurred in the room of fire origin. In addition, flashover marked the point at which fire damage to the mobile home became severe. Therefore, the attainment of flashover was chosen as the principal test criterion.

Because the objective of the quarter-scale model is to predict fire growth in a full-scale mobile home it was anticipated that the attainment of flashover, as determined by the exceeding of a certain upper air temperature or by the exceeding of a critical heat flux on the floor, could also be used as the test criterion for the model. It remained necessary, though, to demonstrate that combinations of interior finish materials which resulted in flashover in the full-scale room also resulted in flashover in the model when tested with an equivalent scaled exposure fire, and combinations of interior finish materials that did not result in flashover in the full-scale room did not result in flashover in the model.

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[5] See reference [2] for a detailed discussion of these limits.

[6] For a summary of the times at which limiting conditions were exceeded during the previous series of bedroom tests, see figure 16 of reference [2].

3. RESULTS AND DISCUSSION

Summary information for the full-scale and reduced-scale tests is listed in tables 2, 3, and 4. Table 2 contains information on the interior finish materials used to line the walls and ceiling of the full-scale and model enclosures. Included in this table is the surface flame spread rating for each material as determined by the ASTM E 84 Tunnel Test [6]. Table 3 summarizes information about those tests for which an upholstered chair or a wood crib was used as the exposure fire. The table lists the interior finish materials, type of exposure fire, maximum temperatures, maximum total incident heat flux, and time to flashover for each test. The temperatures were measured 255 mm (10 in) below the ceiling in the center of the room. The heat flux was measured at the floor in the center of the room. Table 4 summarizes information about those tests for which a methane gas burner was used as the exposure fire. This table includes the interior finish materials, flow rate to the burner, heat output of the burner, and time to flashover.

3.1 Modeling Exposure Fires

As mentioned previously, a series of tests was conducted in the full-scale bedroom using essentially noncontributing interior finish materials in order to gain information about the fires produced by upholstered chairs and various size wood cribs without contribution from other combustibles. For these tests the walls and ceiling of the bedroom were lined with 13 mm (0.5 in) thick unpainted, paper-faced gypsum board. In the corner with the exposure fires, additional protection was provided with 13 mm (0.5 in) thick inorganic calcium silicate marine board which extended 1.2 m (4 ft) from the corner on both walls from floor to ceiling, and covered a 3 m^2 (32 ft^2) area of the ceiling in the corner. Since none of the fires ever extended beyond the area of the corner protected by the marine board, the walls and ceiling for all practical purposes did not contribute to the fires.

This series of tests involved two 16 kg (35 lb) upholstered chairs and 6.4, 9.1, and 13.6 kg (14, 20, and 30 lb) wood cribs. Figure 7 shows the temperature histories of these five items in the full-scale bedroom. In this case the temperatures were measured 255 mm (10 in) below the ceiling in the center of the room. As can be seen, the maximum temperatures attained by the upholstered chairs were roughly approximated by the 13.6 kg (30 lb) wood crib, although the temperature curves of the upholstered chairs show significant peaks while the curves produced by the wood cribs were considerably smoother and generally higher. Maximum total incident heat flux levels (see table 3) were also similar for the 13.6 kg crib and the upholstered chairs. Results similar to these were obtained in tests involving the same types of fires conducted in the mobile home living room, which was also lined with noncontributing interior finish materials [5]. As mentioned previously, the temperature curve of the 13.6 kg wood crib rather than the curves of the upholstered chairs was used in developing the gas burner flow since the burning rates of other chairs and combustible contents may be different and in many cases are approximately constant.

The next series of full-scale tests was conducted to attempt to approximate gas burner. After some experimentation, reasonable approximations were obtained for the 6.4 and 9.1 kg (14 and 20 lb) cribs. Figure 8 illustrates these approximations.

At this point testing was begun in the quarter-scale enclosure to attempt to model the temperature histories of the wood cribs using the reduced-scale burner with scaled down methane flow rates. The area of the burner and the flow rates were both scaled down by a factor of 16 (the square of the scaling factor). Figure 9 shows a comparison of the temperature histories of the fires with the wood cribs in the full-scale bedroom and selected tests involving various gas flow rates in the quarter-scale model.

All the temperature comparisons made up to this point were measured 255 and 64 mm (10 and 2.5 in) below the ceiling for the full-scale room and model, respectively. However, later analysis suggested that, because higher temperatures existed closer to the ceiling in the full-scale room, comparisons at 25 and 6 mm (1.0 and 0.25 in) for the full-scale room and the model, respectively, might be more appropriate. Therefore, for the later tests involving combustible interior finish, the comparisons were made at those distances. However, it was necessary to confirm that the burner flows previously developed, which were based on temperature comparisons measured at 255 and 64 mm below the ceiling, were still valid when the comparisons were made for temperatures measured at 25 and 6 mm below the ceiling. Figure 10 shows a comparison of the temperature histories measured 25 and 6 mm below the ceiling for the full-scale and model tests shown in figure 9. Although the agreement was not as close for the temperatures at these distances, the agreement was judged close enough so that the development of new burner flows was not required.

3.2 Fire Growth and Interior Finish

The next phase of work involved tests which were conducted with various combinations of interior finish materials on the walls and ceiling using different exposure fires (different burner intensities). For the purpose of analysis, the tests run with two specific sets of burner intensities were studied. For the high intensity fires the methane flow was 14.06 m^3/hr (497 ft^3/hr) for the full-scale burner and 0.88 m^3/hr (31 ft^3/hr) for the quarter-scale burner. These flows produced 147.3 and 9.2 kW (8,382 and 524 Btu/min) in the full-scale room and model, respectively. For the low intensity fires the methane flow was 8.02 m^3/hr (284 ft^3/hr) full-scale and 0.50 m^3/hr (18 ft^3/hr) quarter-scale, which produced 84.1 and 5.2 kW (4,783 and 296 Btu/min) full-scale and quarter-scale, respectively. The set of high intensity fires represented a 13.6 kg (30 lb) wood crib under full-scale and quarter-scale conditions and could be related to the 16 kg (35 lb) upholstered chair. The set of low intensity fires represented a 6.4 kg (14 lb) wood crib under full-scale and quarter-scale conditions.

Figures 11, 12, and 13 show temperature histories measured 25 and 6 mm (1.0 and 0.25 in) below the ceiling in the center of the full-scale and model bedrooms for three combinations of interior finish materials with high intensity and low intensity exposure fires. The tests shown in figures 11(a) and 11(b) each involved 4 mm (5/32 in) lauan plywood walls and a 13 mm (1/2 in) wood fiber ceiling. Of the materials tested, these interior finish materials constituted the most severe combination in terms of fire growth and spread. The tests shown in figures 12(a) and 12(b) each involved 4 mm (5/32 in) lauan plywood walls with a 10 mm (3/8 in) gypsum board ceiling. And those tests shown in figures 13(a) and 13(b) each involved 13 mm (1/2 in) marine board walls and ceiling (marine board over gypsum board in the full-scale tests). Of the three combinations, this was the least severe in terms of fire growth and spread. For ease in viewing, the trends shown in figures 11, 12 and 13 have been summarized in figure 14. This figure illustrates temperature histories for one full-scale and one representative model test under low intensity and high intensity exposure fires for each of the three combinations of interior finish materials.

Flashover, as previously defined, has been shown to occur when the total incident heat flux at the floor exceeds approximately 2 W/cm^2 [2,3]. For each of the tests conducted, if a combination of interior finish materials produced flashover when tested in the full-scale room, then that same combination of materials when tested in the model with a scaled burner intensity also produced flashover. And if a particular combination did not produce flashover in the full-scale room, the combination did not produce flashover in the model with a scaled burner intensity. Thus, the most important test of the model, the ability to predict flashover in the full-scale room, appears to have been met.

It has been demonstrated that when flashover occurs in a room, the upper air temperature exceeds approximately 600°C [2,3]. However, the attainment of 600°C does not necessarily signify the beginning of flashover. As can be seen in figures 11 and 12, flashover in the quarter-scale tests occurred at some period of time after the attainment of 600°C. In fact, during several quarter-scale tests the temperature reached an initial peak greater than 600°C, fell back to a lower temperature, and later increased past 600°C again at which time flashover (as signaled by the exceeding of 2 W/cm^2 on the floor) was observed. As the severity of the wall/ceiling combination and exposure fire decreased, the length of time and range of times for flashover to occur in the model increased. Thus, while the times to 2 W/cm^2 were relatively close between the model and the full-scale room for the severe condition of plywood walls, wood fiber ceiling, and high burner intensity; under the condition of plywood walls, gypsum board ceiling, and low burner intensity the time to 2 W/cm^2 was 151 sec for the full-scale test but ranged from 460 sec to 972 sec for the model.

The wide range of times to the attainment of 2 W/cm^2 on the floor and the phenomenon of an initial peak temperature followed by a decrease or plateau indicated that the interior finish materials in the model did not always provide enough fuel to lead to rapid flashover. Rather, it appeared that the time of the initial peak temperature indicated when most of the easily consumed fuel became exhausted, after which the fires died back until the walls and ceiling had dried out enough to become further involved. This theory is supported by the apparently significant influence of relative humidity on the times required to reach flashover (see section 3.4). In addition, the greater heat loss by convection in the model and the differences in stoichiometry and mixing between the full-scale and the model may have contributed to the difference in performance between the full-scale and the model.

This performance indicated that the model provided a less severe test than the full-scale room and that the model performed better when the conditions being tested (i.e., interior finish materials and exposure fire) were more severe. This also indicated that, if the attainment of 2 W/cm^2 heat flux on the floor was taken to be the indication of flashover, then some conditions which might be considered "border-line cases" might require an exceedingly lengthy period of time to reach flashover in the model (or might never reach flashover under high humidity conditions) but might attain flashover in a full-scale test. For this reason it was decided to make use of the initial peak temperature which occurred in those tests which attained a delayed flashover.

Tables 5 and 6 summarize peak temperatures, times to peak temperatures, times to the attainment of 2 W/cm^2 on the floor, and times to ignition of the first newsprint indicator for all tests having high and low burner intensities, respectively. In every test of the model which involved a high burner intensity and in which a delayed flashover was attained, the initial peak temperature 6 mm (0.25 in) below the ceiling in the center of the room reached at least 515°C. In those tests which involved a high burner intensity and in which flashover was not attained, there was generally no pronounced initial peak temperature and, regardless of the occurrence of a peak, the temperature 6 mm (0.25 in) below the ceiling did not exceed 431°C[7]. This indicated that the initial peak temperature could be used to predict the potential for flashover given the proper environmental conditions, and that a temperature greater than 431°C but less than 515°C could be chosen as a criterion for those tests using a high burner intensity. The temperature of 500°C was chosen as a temperature which would likely be exceeded during tests which would eventually attain flashover but which would likely not be exceeded during tests which would not eventually attain flashover. For those tests involving a low burner intensity 375°C was chosen to be a reasonable criterion. It can be seen in figures 11, 12, and 13 that, of the interior finish combinations tested, only the combinations of gypsum board or marine board on the walls and ceiling did not exceed 500°C and 375°C for high-intensity and low-intensity tests, respectively.

Table 7 summarizes information from tables 4, 5, and 6. This information provides a comparison between the time to reach flashover (2 W/cm^2) for a full-scale test and the times to reach 500°C or 375°C for corresponding reduced-scale tests. Table 7 shows that the times to reach 500°C and 375°C in the model are much closer to the time to flashover in the full-scale than the times to actually reach flashover in the model. Table 7 also shows that the time to reach flashover is subject to some variability. Relying on the flash-

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[7] In two tests (tests M4B 43 and 47) involving nonstandard interior finish (gypsum board walls and a wood fiber ceiling), the initial peak temperature was 520 and 569°C, respectively. In both tests the upper air temperature exceeded 600°C and although the incident heat flux on the floor was noticeably higher (0.89 and 1.40 W/cm^2, respectively) than usually occurs in non flashover tests, it never reached 2 W/cm^2. These tests were judged to have reached flashover based on the upper air temperatures exceeding 600°C.

over time for a single test may be misleading. The performance of the newsprint flashover indicators is illustrated in tables 5 and 6. These tables show that in most cases the time to ignition of the first newsprint indicator was very close to the time to attain 2 W/cm^2 on the floor, indicating that generally the newsprint provided a good indication of the occurrence of flashover.

3.3 Modifications

Several modifications to the model were examined in an effort to reduce the time to delayed flashover in the model and to bring temperature histories in the model closer to their corresponding temperature histories for full-scale tests. The modifications to the model included (1) the use of propane, rather than methane, as the burner fuel, (2) the use of a burner designed to increase the flame exposure to the walls, and (3) the use of a lower, wider door opening. In addition, the use of temperatures measured at a distance other than 6 mm below the ceiling was investigated.

The first modification which was tested was the use of propane, rather than methane, as the burner fuel. Because propane has a more radiant flame, it might be expected to cause the combustible interior finish materials to become involved sooner. Although a propane flame would also affect fire growth in the full-scale room, it was thought that its use might bring the time to flashover in the model closer to the time to flashover in the full-scale room, particularly for less flammable interior finish and lower burner intensities. Figure 15 illustrates temperature histories for a full-scale test and four quarter-scale tests all involving the same lauan plywood walls and gypsum board ceiling and each with a low-intensity (5.2 kW) exposure fire. Test M4B 50 involved a propane flame, methane was used for the other tests. The propane flame produced somewhat higher temperatures than the methane flames in the other quarter-scale tests and resulted in flashover in the shortest time. However the results were not a dramatic improvement and the shortened time may have been influenced by the lower ambient relative humidity.

The next modification examined was the use of a redesigned burner. The full-scale and reduced-scale burners were both designed with square burning surfaces since the wood cribs had square burning surfaces (refer to section 2.6). As a means of involving more surface area of the walls in the model a burner was designed whose burning surface contained the same area as the quarter-scale burner but whose burning surface was in the shape of a right isosceles triangle (see figure 16). Since the burner area and gas flow rate were not changed the exit velocity remained the same. However, because the exposed wall area was increased and because the flame stayed closer to the wall surfaces and therefore provided improved heat transfer, it was thought that a shorter time to flashover might result. Figure 17 illustrates temperature histories for a full-scale test and three quarter-scale tests, all involving the same lauan plywood walls and gypsum board ceiling. One of the quarter-scale tests (test M4B 53) used the triangular burner, the other two used the square burner. Test M4B 53 experienced a lower initial peak temperature than the other two model tests but reached flashover first. However, because of the lower ambient relative humidity for that test, it is not clear that the more rapid time to flashover was primarily the result of the triangular burner. In addition, the burner did not eliminate the phenomenon of the initial peak temperature followed by a decline.

In order to trap more hot gases in the upper part of the room the top of the door opening (the lintel) was lowered for several tests. To maintain a constant ventilation parameter[8] the width of the opening was increased. The dimensions of the experimental door opening were 430 mm (17 in) wide by 455 mm (18 in) high. The dimensions of the original opening were 370 mm (14.5 in) wide by 510 mm (20 in) high. Figures 18(a) and 18(b) illustrate temperature histories for tests with the high burner intensity and involving lauan plywood walls with gypsum board and wood fiber ceilings, respectively. With the exception of test M4B 57, the quarter-scale tests in each group which had the experimental door opening experienced slightly lower temperatures during the initial buildup phase and had a lower initial peak temperature than the other quarter-scale tests. In addition, the experimental door opening did not appear to decrease the time to delayed flashover.

For test M4B 58 the experimental burner and experimental door opening were used together. Figure 19 illustrates temperature histories for this test and other tests using similar interior finish materials and the high burner intensity. For test M4B 58 the plateau temperature remained relatively high compared with the temperatures produced in the other model tests. However, the time to flashover was still not significantly improved.

Beginning with test M4B 50, temperatures in the center of the model enclosure were measured at 13 and 25 mm (0.5 and 1 in) below the ceiling in addition to 6 mm (0.25 in) below the ceiling. This was done to determine whether the temperatures being measured 6 mm down were actually the peak temperatures. Figure 20 shows temperature histories at these three elevations

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[8] The ventilation parameter for open doorways is proportional to $wh^{3/2}$ where w and h are the width and height of the doorway, respectively. See reference [1] for a further discussion.

from two typical tests. Table 8 provides more detailed information on temperatures measured at the three distances for tests M4B 50 through 60. In 8 of the 11 tests examined, the highest average[9] temperature occurred 25 mm below the ceiling (shown as "Position C" in table 8). This occurred in 3 of the 5 tests using the original door opening and in 5 of the 6 tests using the experimental opening. The peak temperature monitored inside the enclosure was measured at 25 mm below the ceiling in 9 of the 11 tests. This occurred in 4 of the 5 tests using the original door opening and in 5 of the 6 tests using the experimental opening. In those cases where the peak measured temperature or peak measured average temperature did not occur at 25 mm below the ceiling, the peaks occurred at 13 mm down. The temperatures measured 6 mm below the ceiling were always the lowest of the three, due to heat losses to the ceiling or outgassing. Table 8 indicates that, although the height at which the true peak temperature actually occurs may vary, the true peak is more likely to be measured at 25 mm than 13 mm and much more likely to be measured at either 25 or 13 mm than at 6 mm.

3.4 Relative Humidity and Repeatability

Figures 21, 22, and 23 illustrate the relationship between ambient relative humidity and the time to reach ignition of flashover indicators in the model for three combinations of interior finish materials and exposure fires. Figure 21 involves tests with lauan plywood walls, a gypsum board ceiling, and a low intensity (5.2 kW) exposure fire. Figure 22 involves the same lauan plywood walls and gypsum board ceiling but with a high intensity (9.2 kW) exposure fire. This represents a more severe test condition. The general trend in these two figures of increased ignition times with increased ambient relative humidity suggests that the humidity has an effect on the time to reach ignition of the indicators. Figure 23 involves tests with lauan plywood walls, a wood fiber ceiling, and a high intensity burner. This represents the most severe test condition of the three. For these tests any effect due to relative humidity appears to be imperceptible.

If curves were to be fit to these sets of points the curves would provide a basis for defining the repeatability of the model, at least in terms of time to flashover, by the scatter of the points around the curves. And by experimentally collecting points at the extreme ends of the curves, limiting conditions might be extrapolated (e.g., the minimum time to flashover for a "no humidity" condition and the humidity level, if one exists, at which flashover will not occur for a given combination of interior finish materials and exposure fire).

[9] The average temperature for each location is determined by summing the temperature values read every 10 seconds and then dividing by the number of values read.

3.5 Single Room vs Entire Structure

Several questions arise in regard to using a model of one room as opposed to a model of the entire structure. One question concerns the adequacy of using a single-room model to test interior finish materials which may be used throughout the mobile home. Another question concerns which room should be chosen to be modeled.

In regard to the first question, the use of a single-room model is valid if it can be shown that test results using this model will predict full-scale test results using the entire structure. As discussed in section 2.7 and references [2,3, and 4], the attainment of flashover in the fire room can be used to deduce information relating to both the life safety conditions at the far end of the full-scale mobile home and the fire damage to the mobile home. It is for this reason that the attainment of flashover in the fire room was selected as the test criterion for the full-scale tests referenced above and for use in this modeling work. But since the attainment of flashover is all that is required, data and observations from other parts of the full-scale mobile home are not necessary. This means that it only needs to be shown that test results (i.e., whether or not combinations of interior finish materials attain flashover with particular exposure fires) in the model will predict test results in the full-scale room. And in section 3.2 it was shown that, for the tests conducted to date, the use of 500°C and 375°C as test criteria for model tests using high-intensity and low-intensity exposure fires, respectively, will predict the attainment of flashover in the full-scale bedroom.

A related issue is whether the enclosed nature of a mobile home results in an air supply to the fire which, after a period of time, contains significantly less oxygen resulting in a decrease in fire severity in the full-scale home. If this were the case, the fact that the air supply to the model always contains the normal ambient concentration of oxygen would tend to increase the relative severity of the model since the fire in the model would always have an ample supply of oxygen. This issue is actually not a problem since the overall objective of predicting full-scale flashover using the model appears to be possible. However, tables 9 and 10 show that the depletion of oxygen in the return air entering the fire room in full-scale tests is generally not great. Table 9 shows oxygen concentrations for air at the floor level entering the bedroom door and table 10 shows similar concentrations for tests conducted in the living room under a previous series of tests (see reference [3]). For the bedroom under non-flashover conditions, even after 10 min (600 sec) the concentration never fell below 19.8%. In those tests which reached flashover, the minimum pre-flashover concentration never fell below 19.5%. For the living room under non-flashover conditions the concentration never fell below 19.1%. In those tests which reached flashover, the minimum pre-flashover oxygen concentration in 3 of the 4 tests was 20.9%; in the other test the minimum was 15.9%. It should be noted, however, that any increase in fire severity in the model due to increased oxygen in the air supply relative to the full-scale mobile home is beneficial since, as mentioned previously, the model is inherently less severe than the full-scale test.

The second question regarding a single-room model concerns which room of the mobile home should be modeled. This question has no one correct answer. There is no reason to believe that the modeling techniques used here for the bedroom could not also be used to model fire buildup in other areas of a mobile home such as the living room or corridor. It should be noted that as the size of the room increases, the relative severity of fire growth in that room decreases. That is, a fire initiated by a 9.2 kW source in the living room will be less severe than a fire initiated by the same source burning in the bedroom. In this work the bedroom was modeled because its smaller volume presented a more severe test for interior finish materials.

4. SUMMARY

This report details results from a number of tests conducted as part of an effort to model fire growth in a mobile home and to determine the feasibility of a reduced-scale model room fire test. The objectives of this modeling project are: 1) to evaluate the relationship between fire buildup in a reduced-scale and full-scale enclosure, 2) to determine the feasibility of using a reduced-scale model to assess the potential contribution of combinations of interior finish materials to fire growth and spread in a full-scale mobile home, and 3) if the use of a reduced-scale model is found to be feasible, to draft a proposed test method for a standardized reduced-scale fire test. This report deals with progress toward the first two objectives.

Full-scale fire tests were conducted in the bedroom of an actual single-wide mobile home. Reduced-scale fire tests were conducted in a quarter-scale model of that bedroom. The first phase of testing involved noncontributing interior finish materials. The purpose of this testing was to calibrate a full-size and quarter-scale methane diffusion burner for the full-size room and model, respectively, to simulate the burning of 16 kg (35 lb) upholstered chairs and 13.6, 9.1, and 6.4 kg (30, 20, and 14 lb) wood cribs. The second phase of testing involved using the burners at specific methane flows with various combinations of combustible interior finish materials on the walls and ceiling to evaluate the relationship between fire buildup in the quarter-scale and full-size rooms. The attainment of flashover was selected as the test criterion for previous full-scale mobile home tests and for these full-scale tests since flashover is a critical stage in fire development and deductions about conditions at other locations in the mobile home can be made by knowing whether or not flashover has occurred in the fire room.

Based on the results of the tests conducted so far, it appears that the quarter-scale model can be used to predict flashover in the full-scale bedroom by the monitoring of upper air temperatures in the model. For quarter-scale tests using an exposure fire which produced 9.2 kW (524 Btu/min) and full-scale tests using an exposure fire which produced 16 times as much heat (corresponding to the square of the scaling factor 4), when the air temperature 6 mm (0.25 in) below the ceiling in the model exceeded 500°C, flashover occurred in the corresponding full-scale test. If the temperature in the model did not exceed 500°C, flashover did not occur in the corresponding full-scale test. Similar results occurred when the exposure fire in the model produced 5.2 kW (296 Btu/min), the full-scale exposure fire produced 16 times as much heat, and the temperature of 375°C was used. Thus the flashover prediction temperatures of 500 and 375°C in the model can be used as test criteria for tests using 9.2 and 5.2 kW exposure fires, respectively.

The model was shown to simulate the basic phenomena of fire growth and flashover. However flashover, as determined by the attainment of 2 W/cm^2 on the floor, occurred after a longer period of time in the model. Three modifications to the model were tested in an effort to reduce the time delay to flashover. These modifications were: 1) the use of propane, rather than methane, as the burner fuel, 2) the use of a burner designed to increase the flame exposure to the walls, and 3) the use of a lower, wider door opening to trap more heated gas in the upper part of the enclosure. None of the modifications provided enough improvement to justify making it a permanent part of the model. However, the delayed time to flashover (or even the possibility of no flashover) in the model does not affect the accurac of the test since the attainment of a particular flashover prediction temperature in the model and not the attainment of flashover itself is the test criterion.

An examination of air temperatures at different heights in the model indicated that temperatures measured at 13 and 25 mm (0.5 and 1 in) below the ceiling were generally higher than the temperature at 6 mm (0.25 in) below the ceiling. If temperatures were to be monitored at 13 or 25 mm rather than 6 mm, the flashover prediction temperatures of 500 and 375°C would require upward adjustment. This will be examined in a future report.

Ambient relative humidity apparently causes a delay in the time to reach flashover in the model, particularly for less combustible interior finish combinations and lower burner flows. A curve which is fit to the data points would provide a basis for defining the repeatability of the model at least in terms of time to reach flashover, and limiting conditions for the model might be determined by extrapolating such a curve.

The technique of using a model of a single room to test interior finish materials which may be used throughout an entire mobile home is valid since it can be demonstrated that test results using the model will predict full-scale test results using the entire structure. There is no reason to believe that the modeling techniques used here for the bedroom can not be applied to any room of a mobile home. In this case the bedroom was selected since its smaller volume makes the model a more severe test of interior finish materials than if a larger volume room such as the living room were used.

In conclusion, it does appear to be feasible to assess the potential contribution of interior finish materials to fire growth and spread in a full-scale mobile home through the use of a reduced-scale model. Therefore, a proposed standardized test method developed around the quarter-scale model described in this report will be drafted. Details of this proposed test method and results from further testing will be included in a future report.

5. ACKNOWLEDGMENTS

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[6] Standard Test Method for Surface Burning Characteristics of Building Materials, 1979 Annual Book of ASTM Standards, Part 18, American Society for Testing and Materials, Philadelphia (1979).

Figure 1. Photograph of single-wide mobile home used in conducting full-scale fire tests.

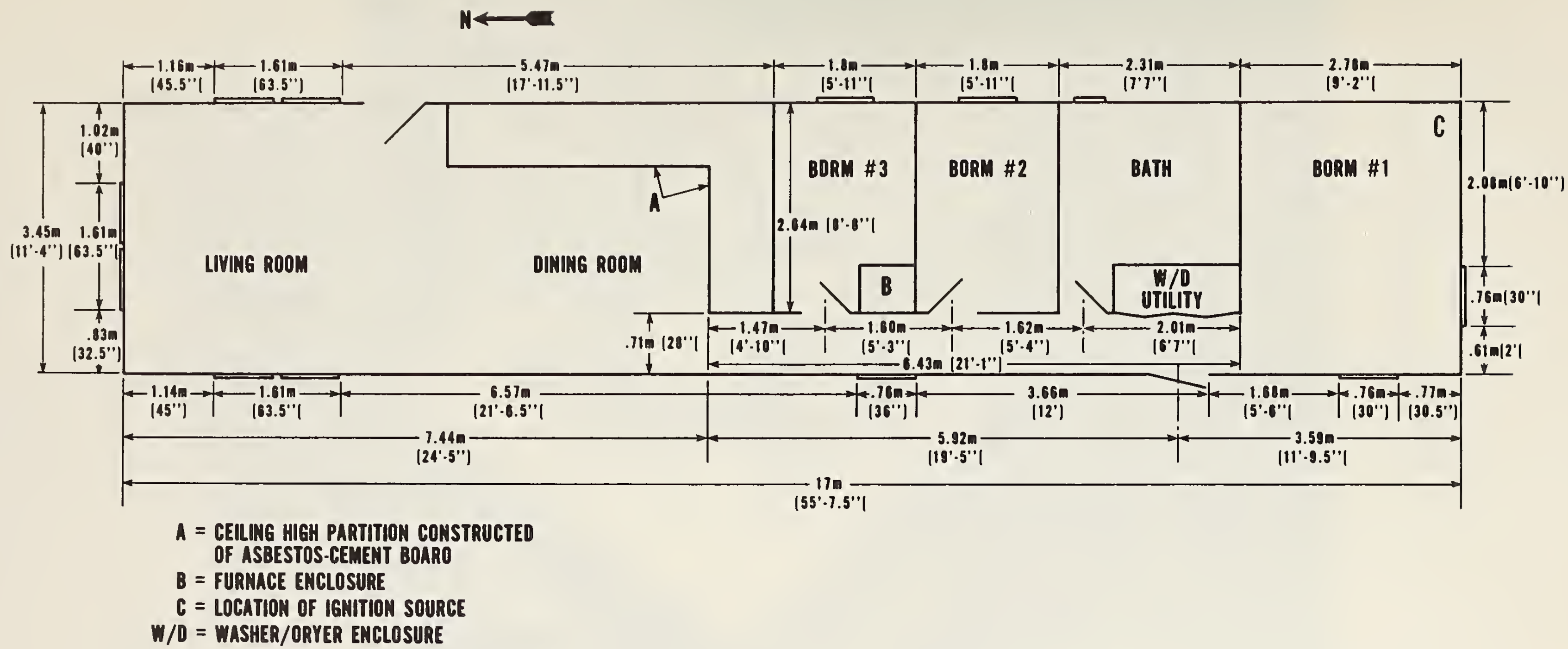


Figure 2. Plan view of full-scale mobile home.

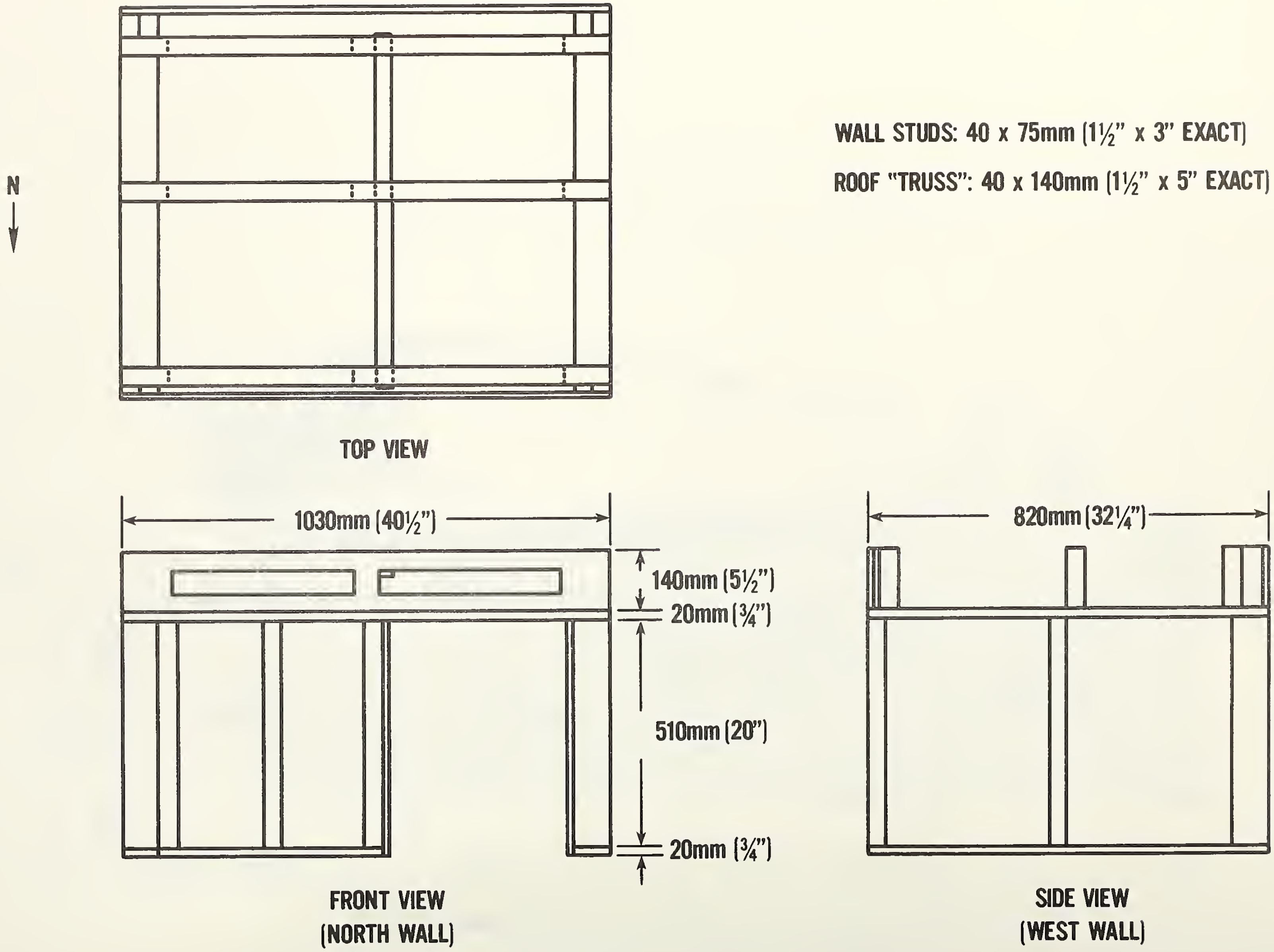


Figure 3. Drawing of wood wall and ceiling assembly of quarter-scale enclosure showing key dimensions. Interior finish materials, insulation, and exterior skin not shown.

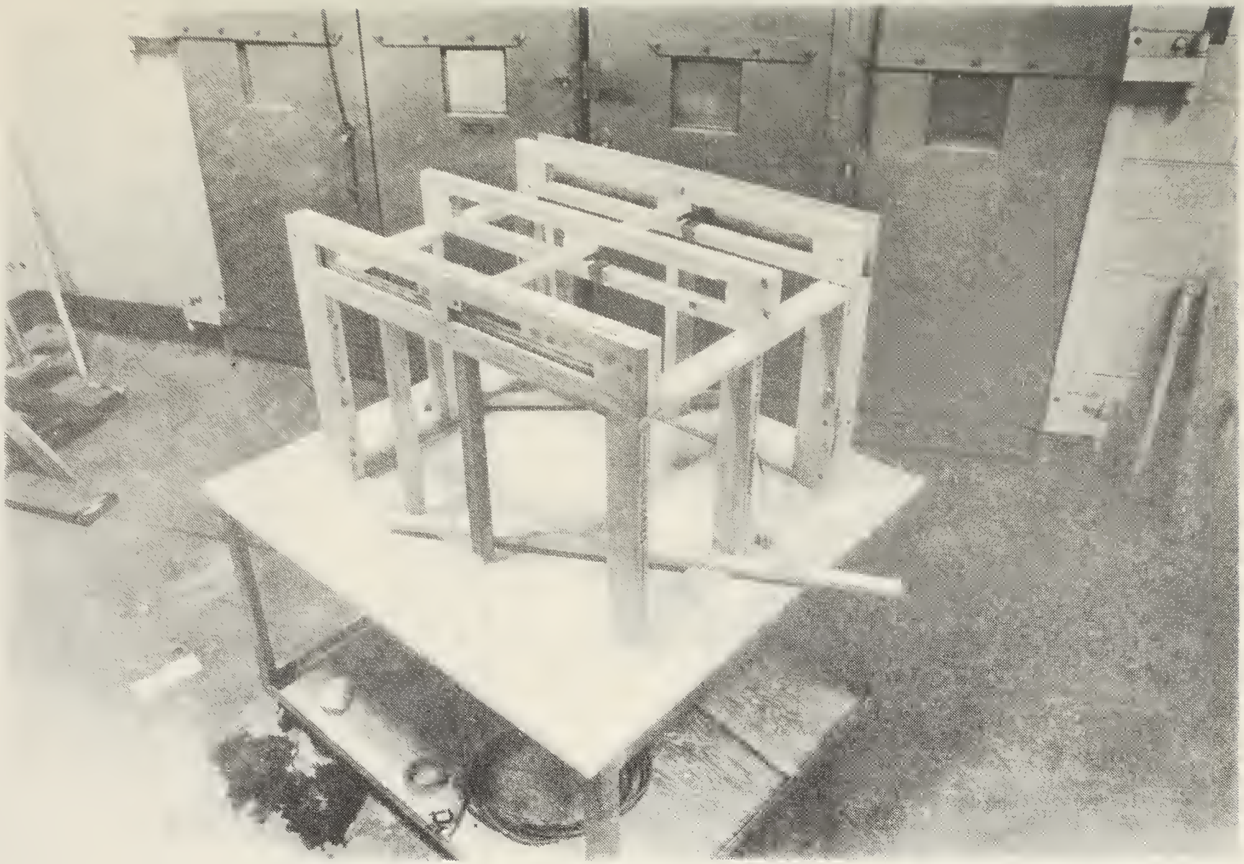
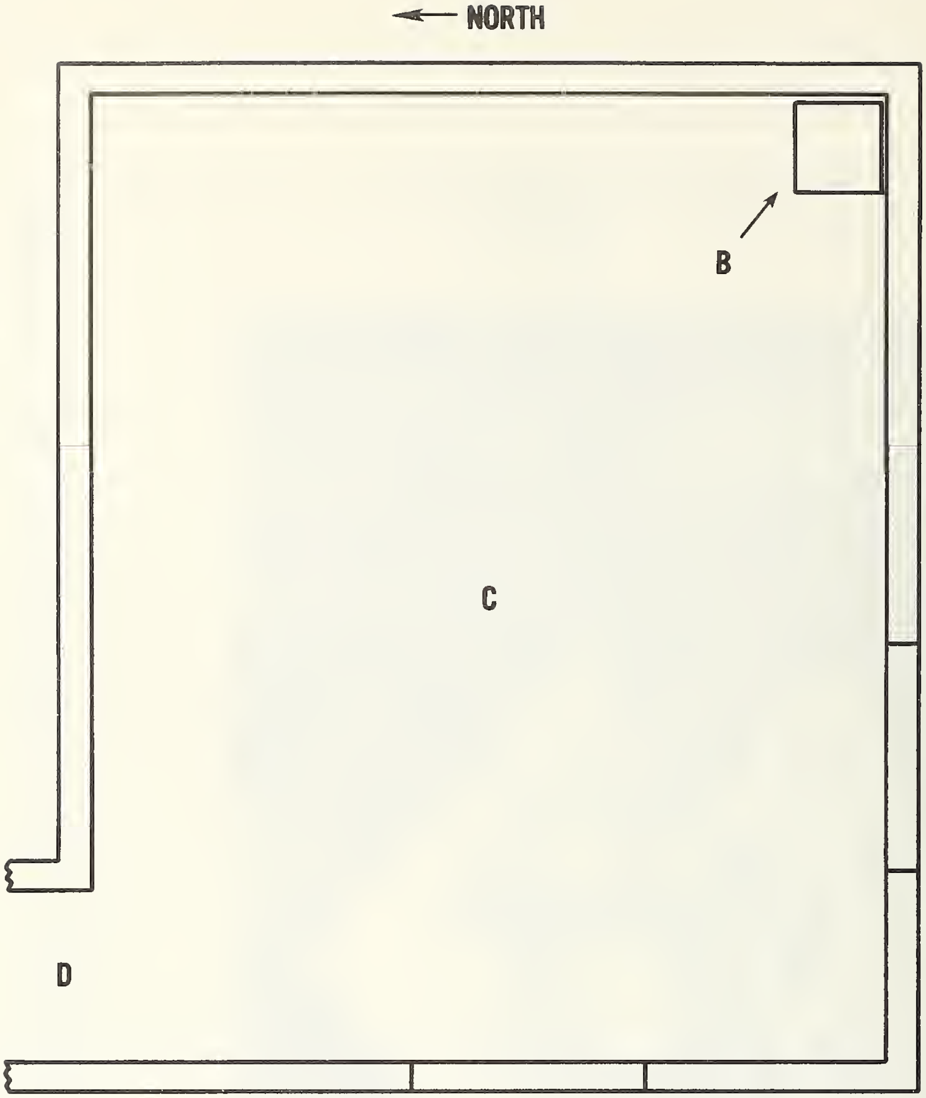


Figure 4. Photograph illustrating wood wall and ceiling assembly of quarter-scale enclosure. Northwest corner is closest to camera.



Location B (Burner)

Heat flux transducers:
East wall, 915 and 1830 mm above floor, horizontal view
Ceiling, centered over burner, downward view

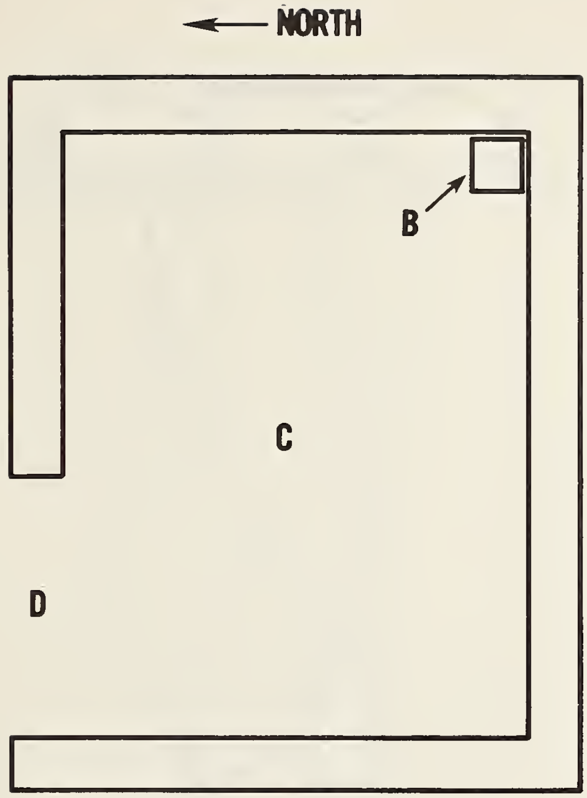
Location C (Center)

Thermocouples: 25, 255, 815, 1220, and 1675 mm below ceiling, 25 mm above floor
Heat flux transducer: floor level, upward view

Location D (Door)

Thermocouples: 125, 405, 710, 1015, 1420, and 1830 mm below lintel
Heat flux transducer: floor level, upward view
Oxygen probes: 125, 405, 710, 1420, and 1880 mm below lintel

Figure 5. Plan view of full-scale bedroom illustrating sampling locations for test measurements.



Location B (Burner)

Heat flux transducers:
East wall, 265 and 455 mm above floor, horizontal view
Ceiling, centered over burner, downward view

Location C (Center)

Thermocouples: 6, 64, 205, 305, 420 mm below ceiling,
3 mm above floor
Heat flux transducer: floor level, upward view
Oxygen probe: 380 mm above floor

Location D (Door)

Thermocouples: 32, 100, 180, 255, 355, and
455 mm below lintel
Heat flux transducer: floor level, upward view
Oxygen probes: 32, 100, 180 mm below lintel,
32 mm above floor

Figure 6. Plan view of quarter-scale enclosure illustrating sampling locations for test measurements.

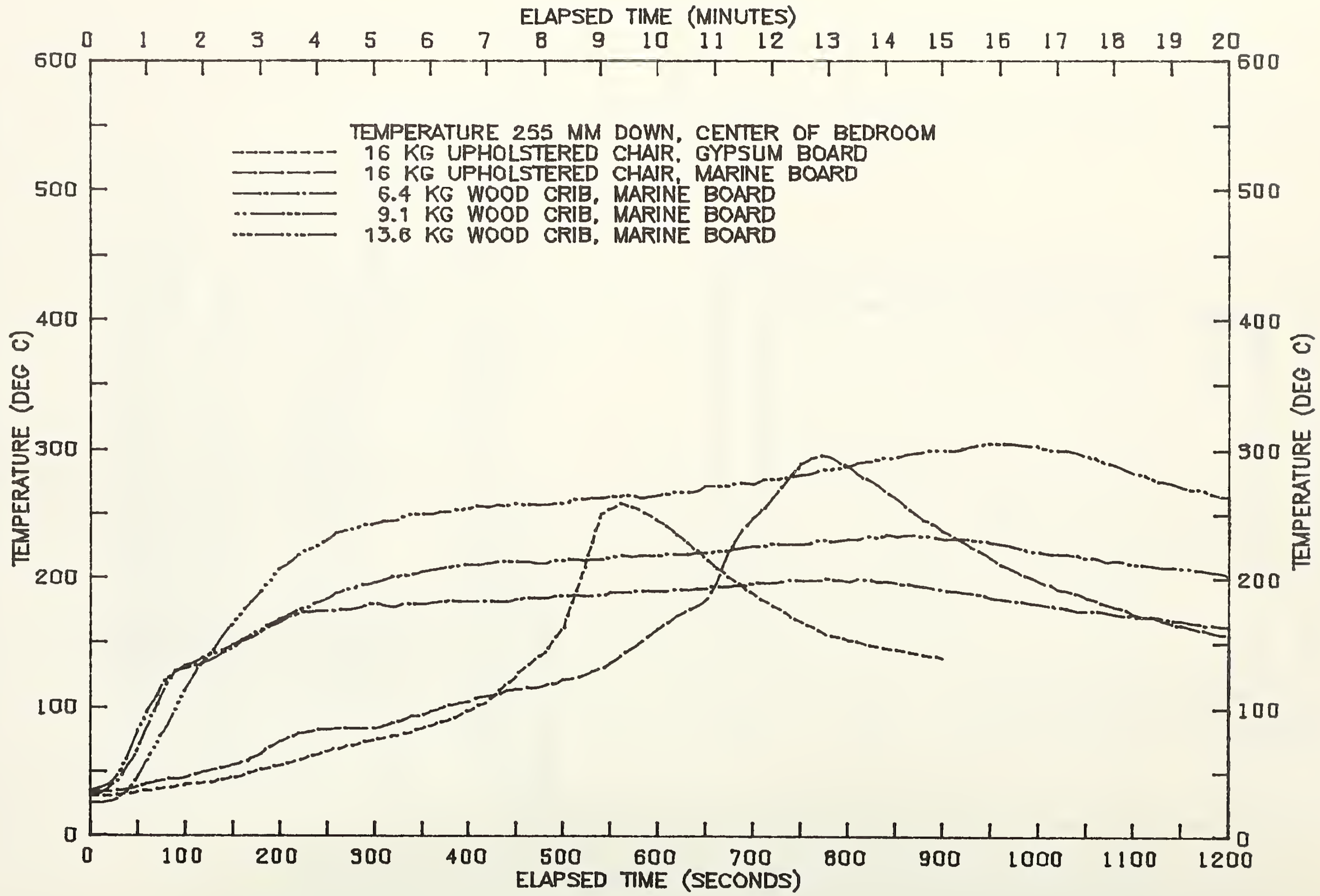


Figure 7. Temperature histories for two upholstered chairs and three wood cribs of different sizes in the full-scale bedroom.

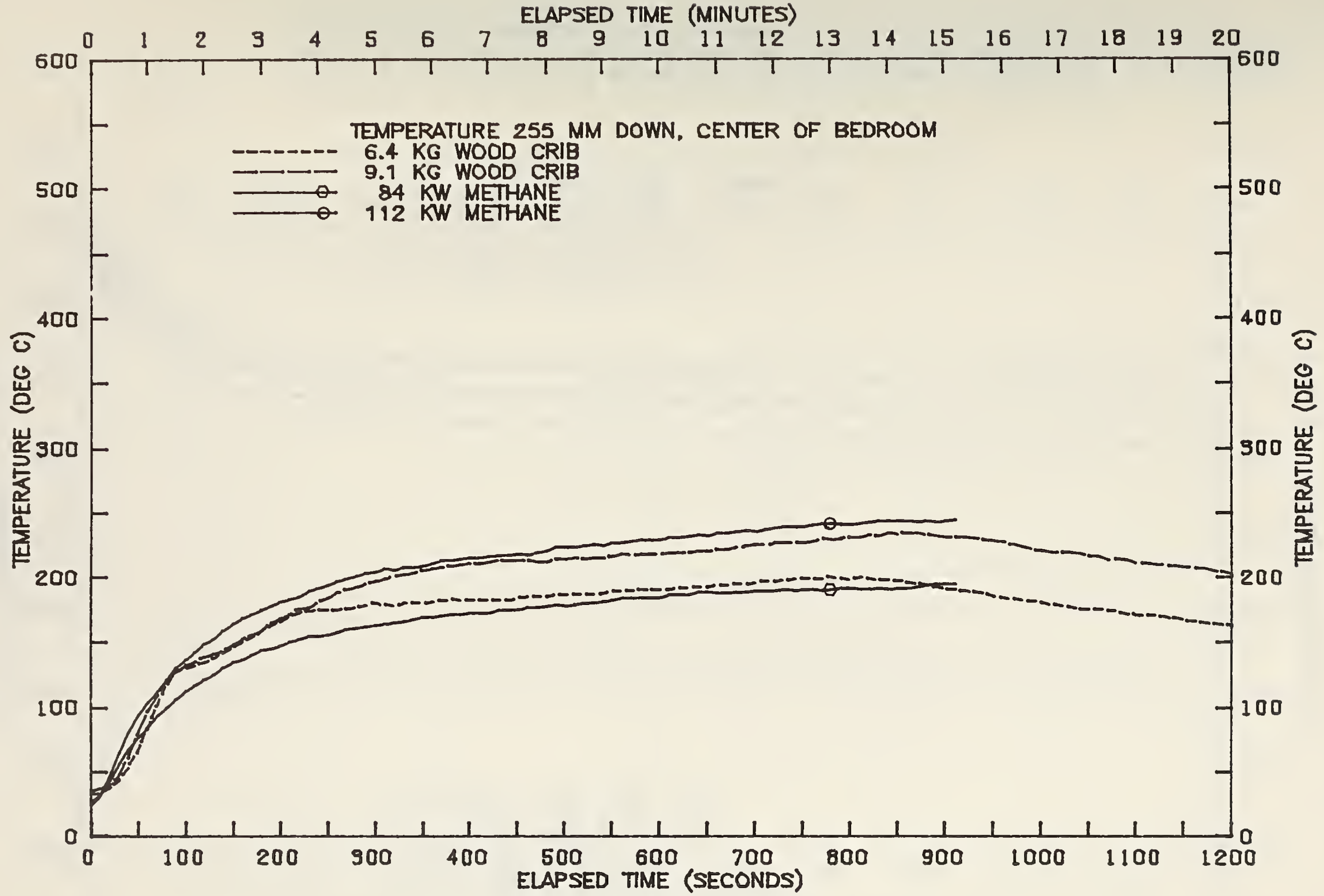


Figure 8. Temperature histories for two wood cribs and a methane burner at two flow rates in the full-scale bedroom.

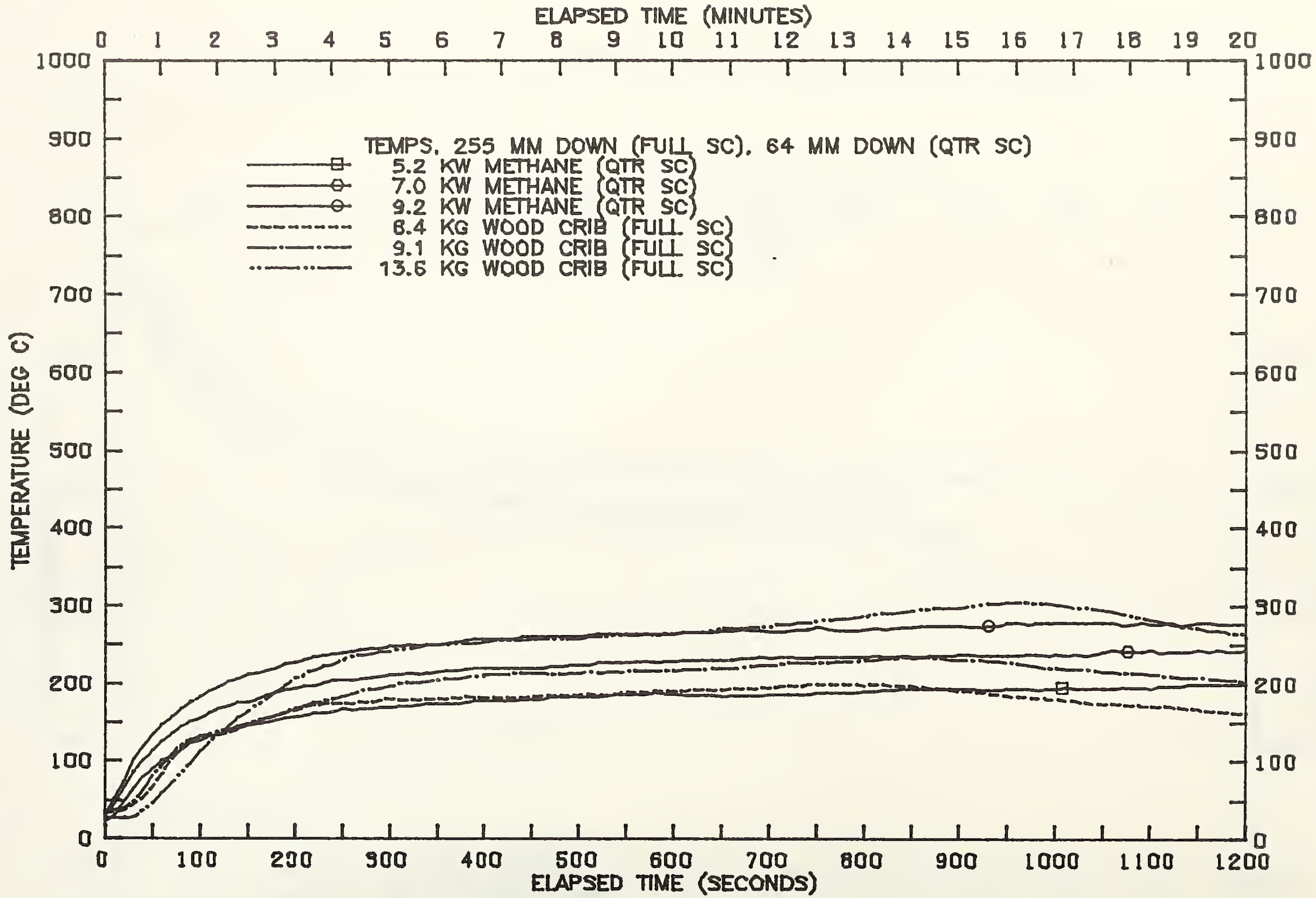


Figure 9. Comparison of temperature histories sampled at 255 mm (full-scale) and 64 mm (quarter-scale) below the ceiling for tests involving wood cribs in the full-scale bedroom and tests with a methane burner in the quarter-scale bedroom. All tests used noncontributing interior finish materials.

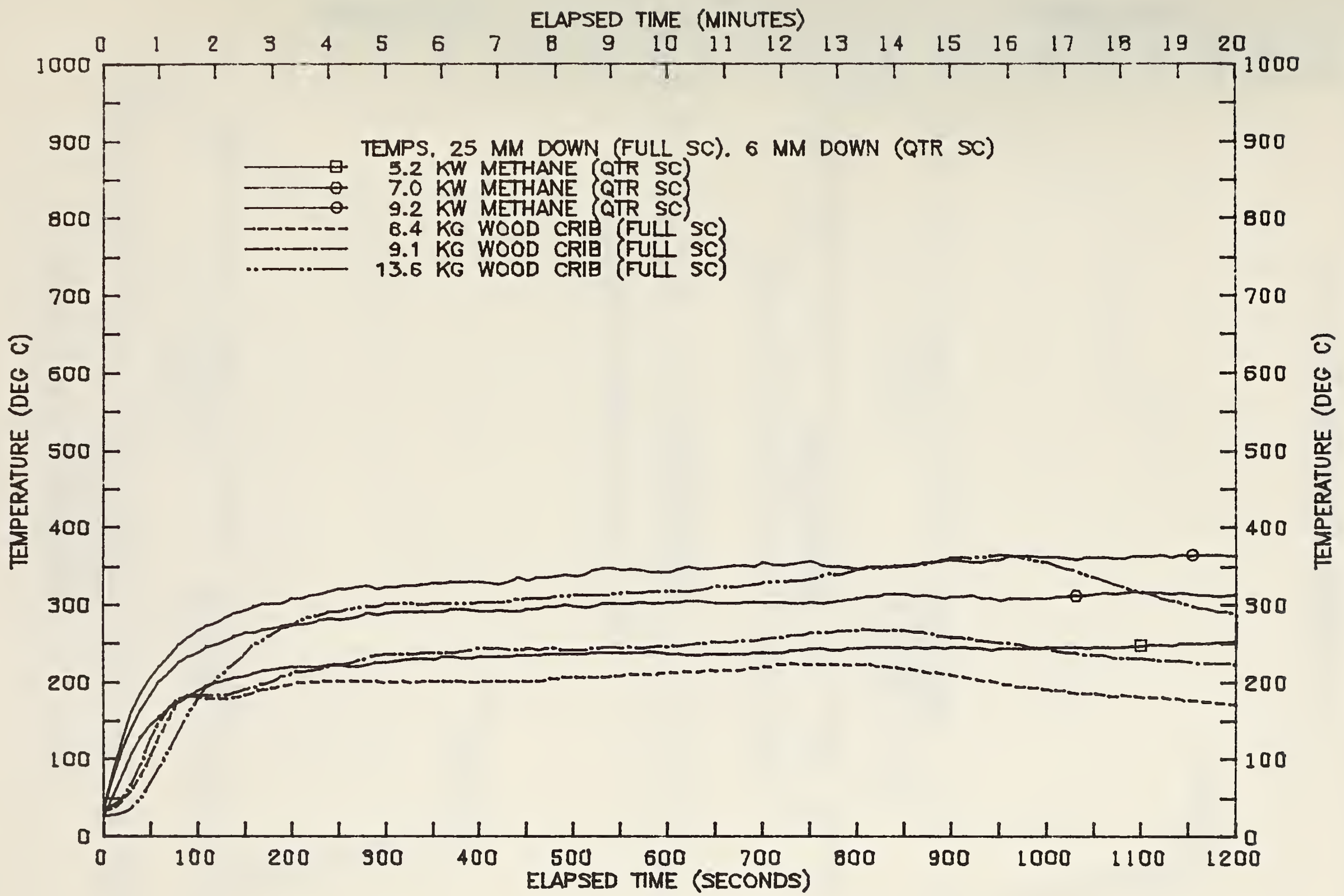


Figure 10. Comparison of temperature histories sampled at 25 mm (full-scale) and 6 mm (quarter-scale) below the ceiling for tests involving wood cribs in the full-scale bedroom and tests with a methane burner in the quarter-scale bedroom. All tests used noncontributing interior finish materials.

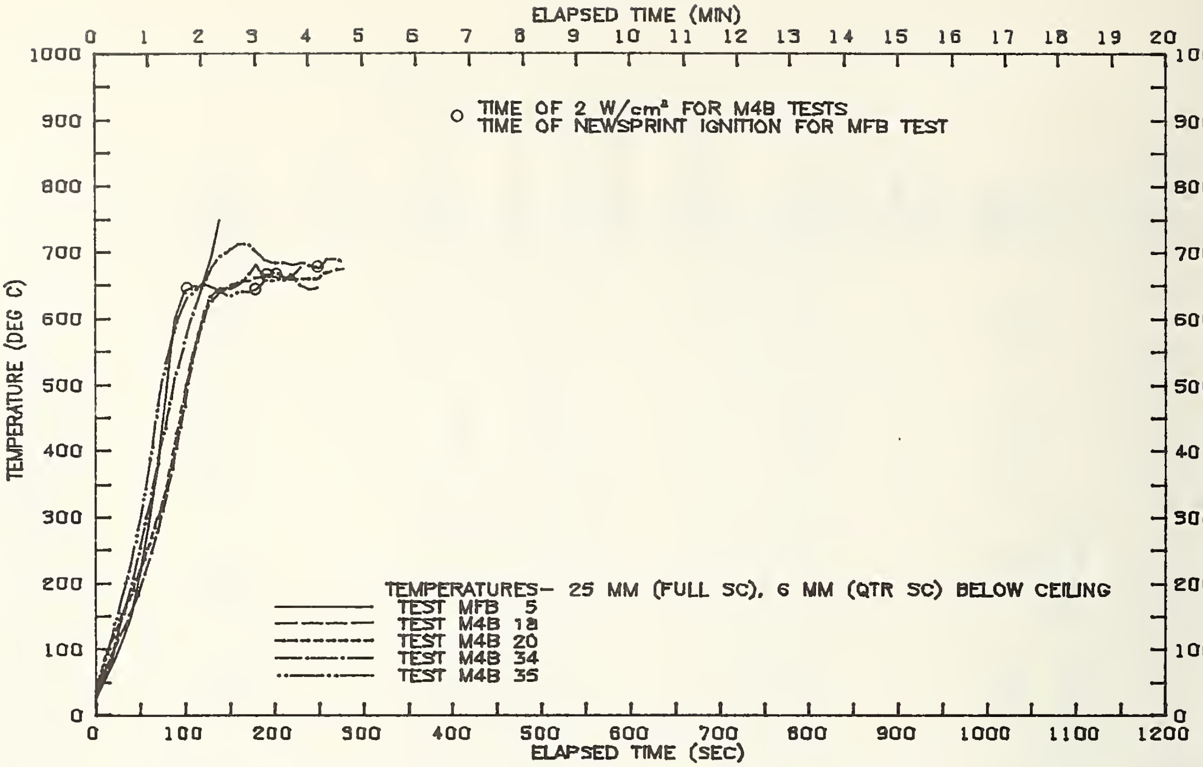


Figure 11a. High intensity exposure fire.

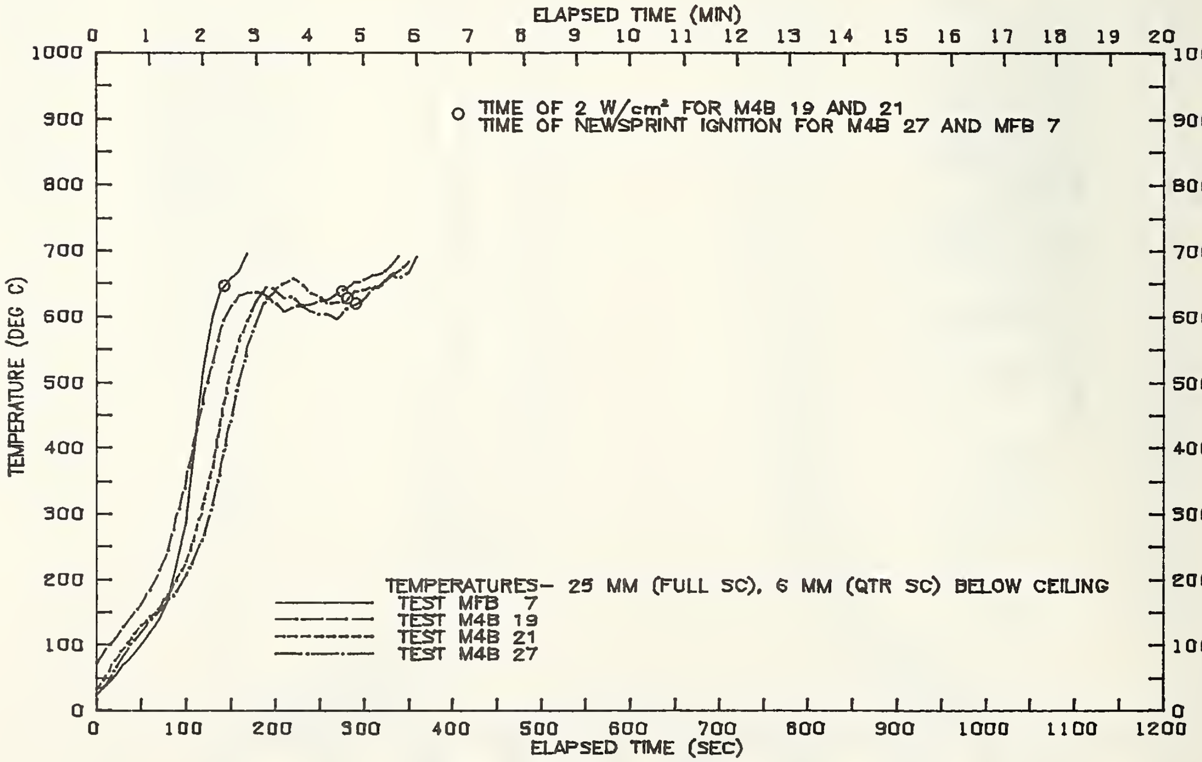


Figure 11b. Low intensity exposure fire.

Figure 11. Temperature histories measured at 25 and 6 mm below the ceiling in the center of the full-scale and model bedrooms, respectively, for tests involving lauan plywood walls and wood fiber ceilings.

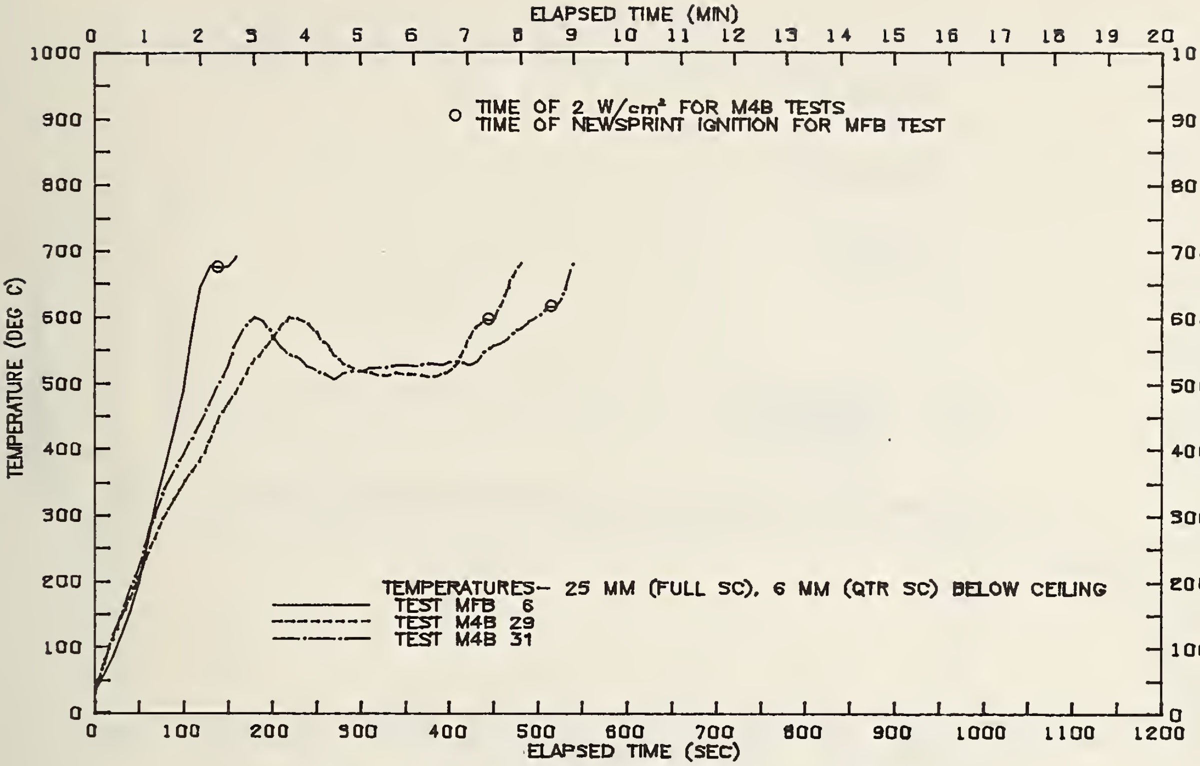


Figure 12a. High intensity exposure fire.

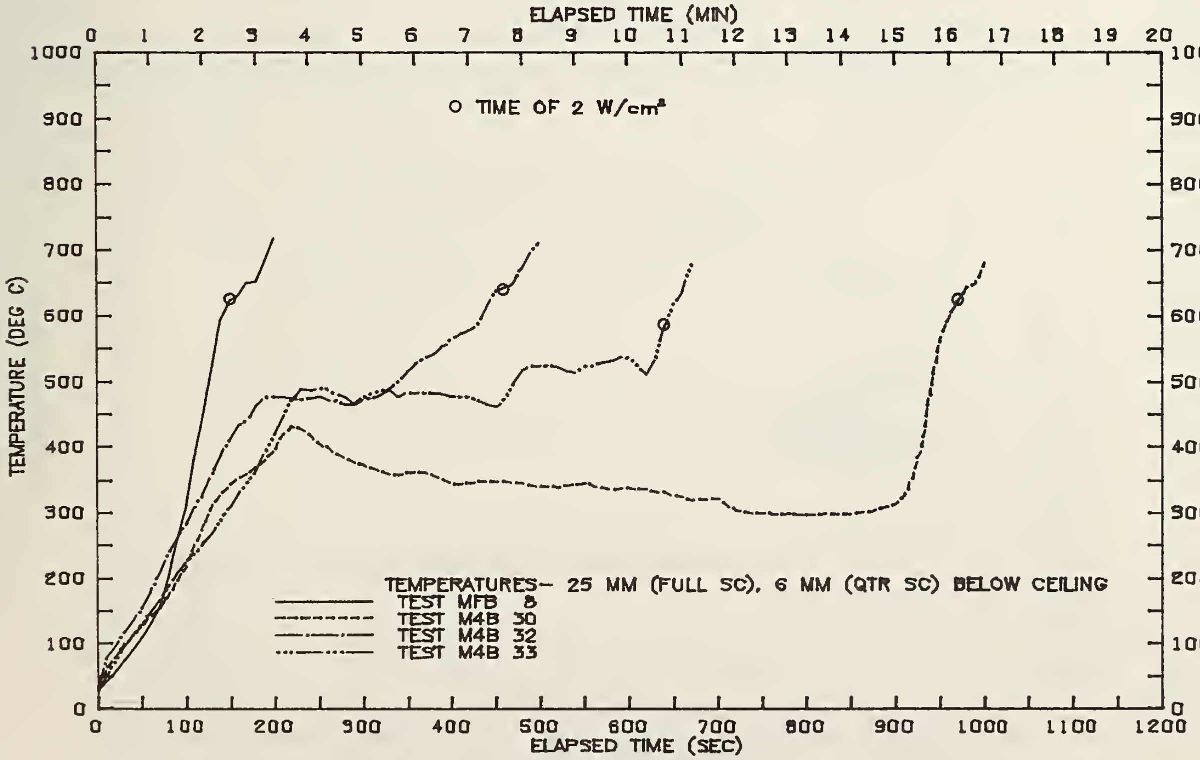


Figure 12b. Low intensity exposure fire.

Figure 12. Temperature histories measured at 25 and 6 mm below the ceiling in the center of the full-scale and model bedrooms, respectively, for tests involving lauan plywood walls and gypsum board ceilings.

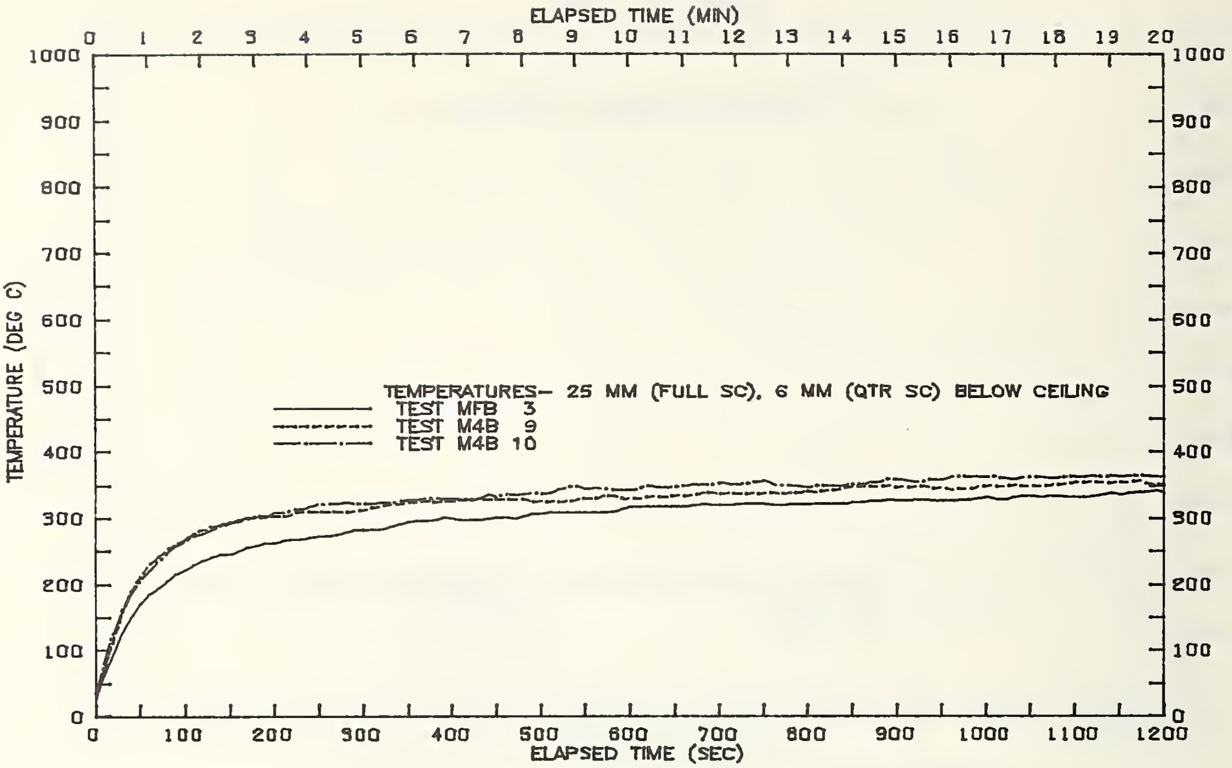


Figure 13a. High intensity exposure fire.

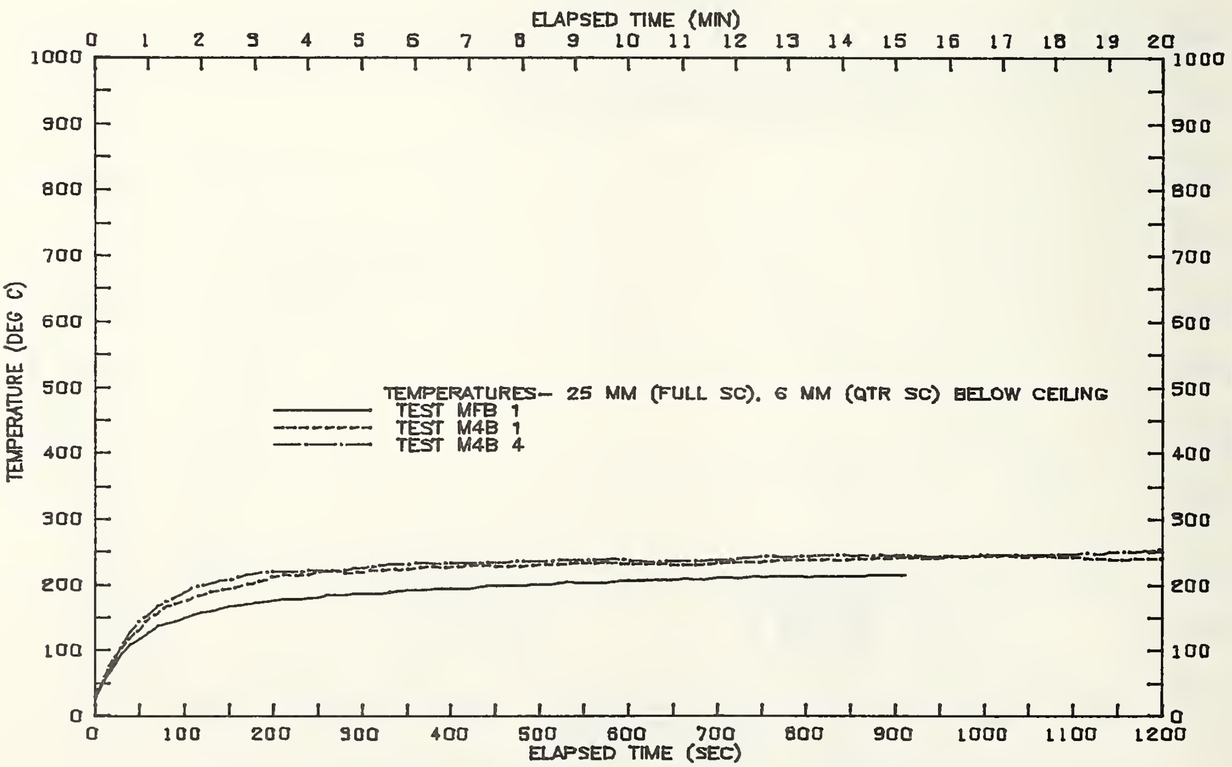


Figure 13b. Low intensity exposure fire.

Figure 13. Temperature histories measured at 25 and 6 mm below the ceiling in the center of the full-scale and model bedrooms, respectively, for tests involving noncontributing interior finish materials.

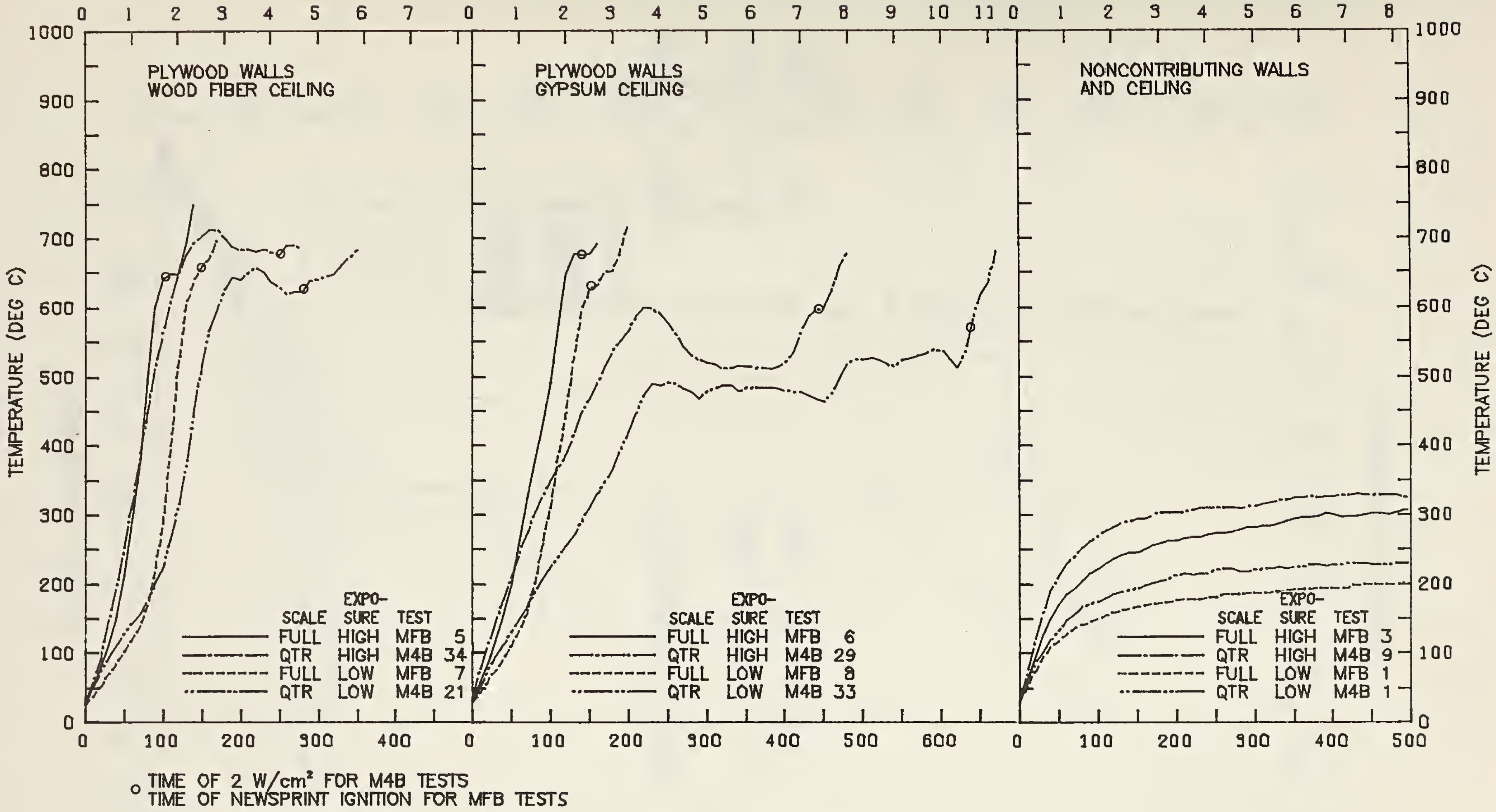


Figure 14. Summary plot illustrating temperature histories measured at 25 and 6 mm below the ceiling in the center of the full-scale and model bedrooms, respectively, for selected tests.

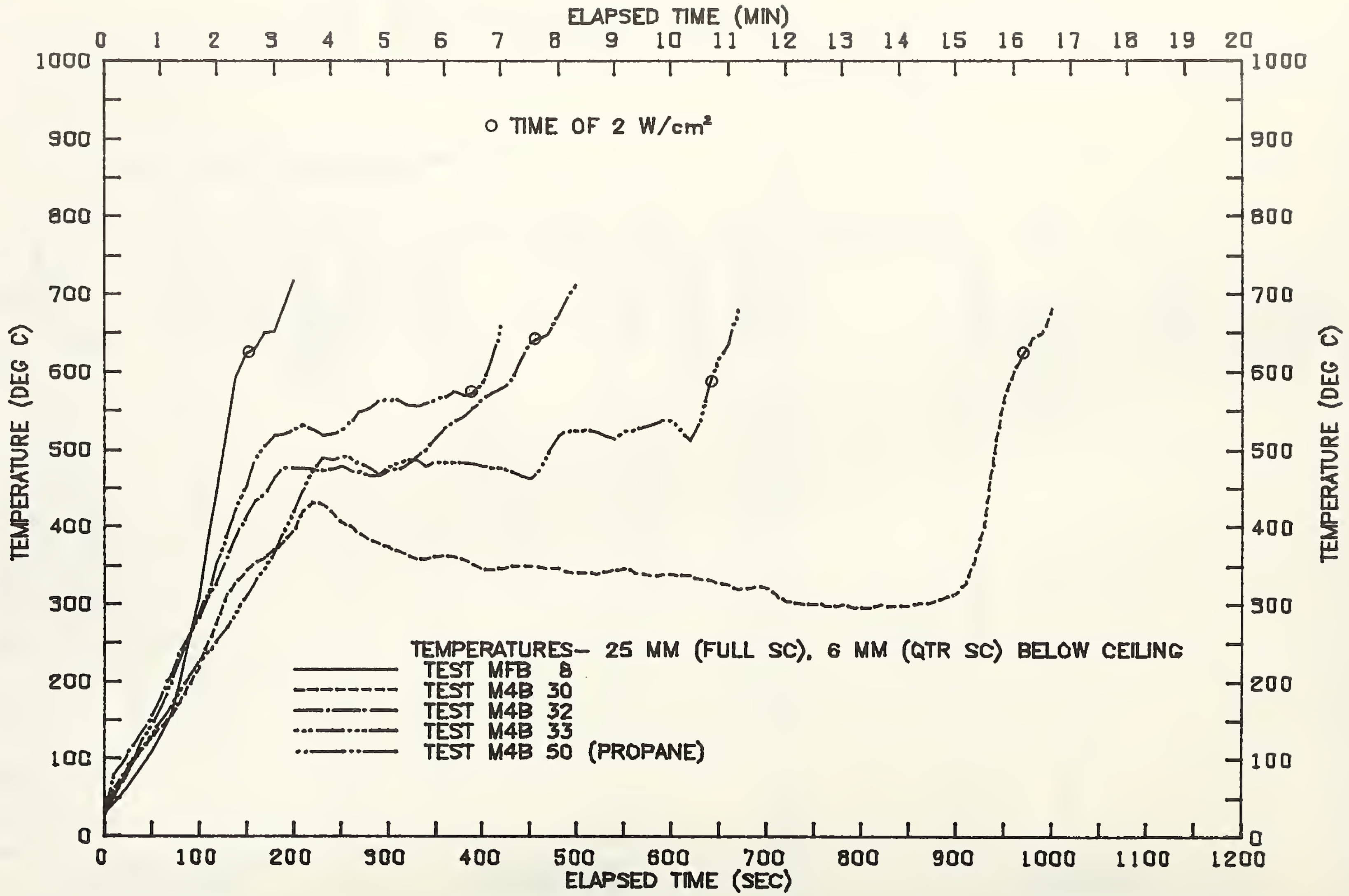
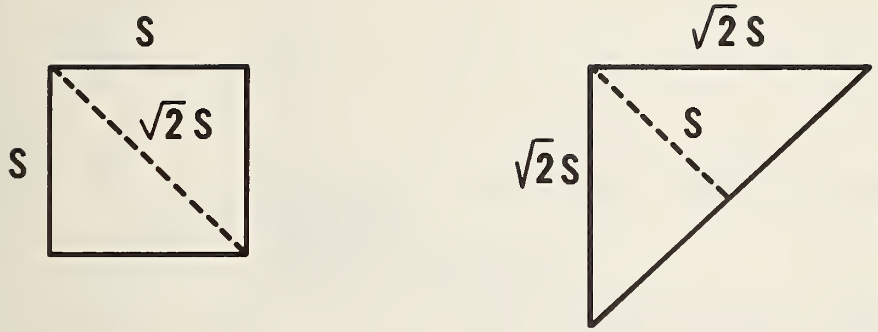


Figure 15. Temperature histories for tests with lauan plywood walls and gypsum board ceilings. A propane exposure fire was used for test M4B 50. For the other tests methane was used.



SIDE = S = 3in

AREA = S^2 = 9in

ORIGINAL BURNER

SIDE = $\sqrt{2}\,S \approx 4\frac{1}{4}$in

AREA = $\frac{1}{2}(\sqrt{2}\,S)^2 = S^2$

EXPERIMENTAL BURNER

Figure 16. Plan view of the original square burner and the experimental triangular burner used in the model.

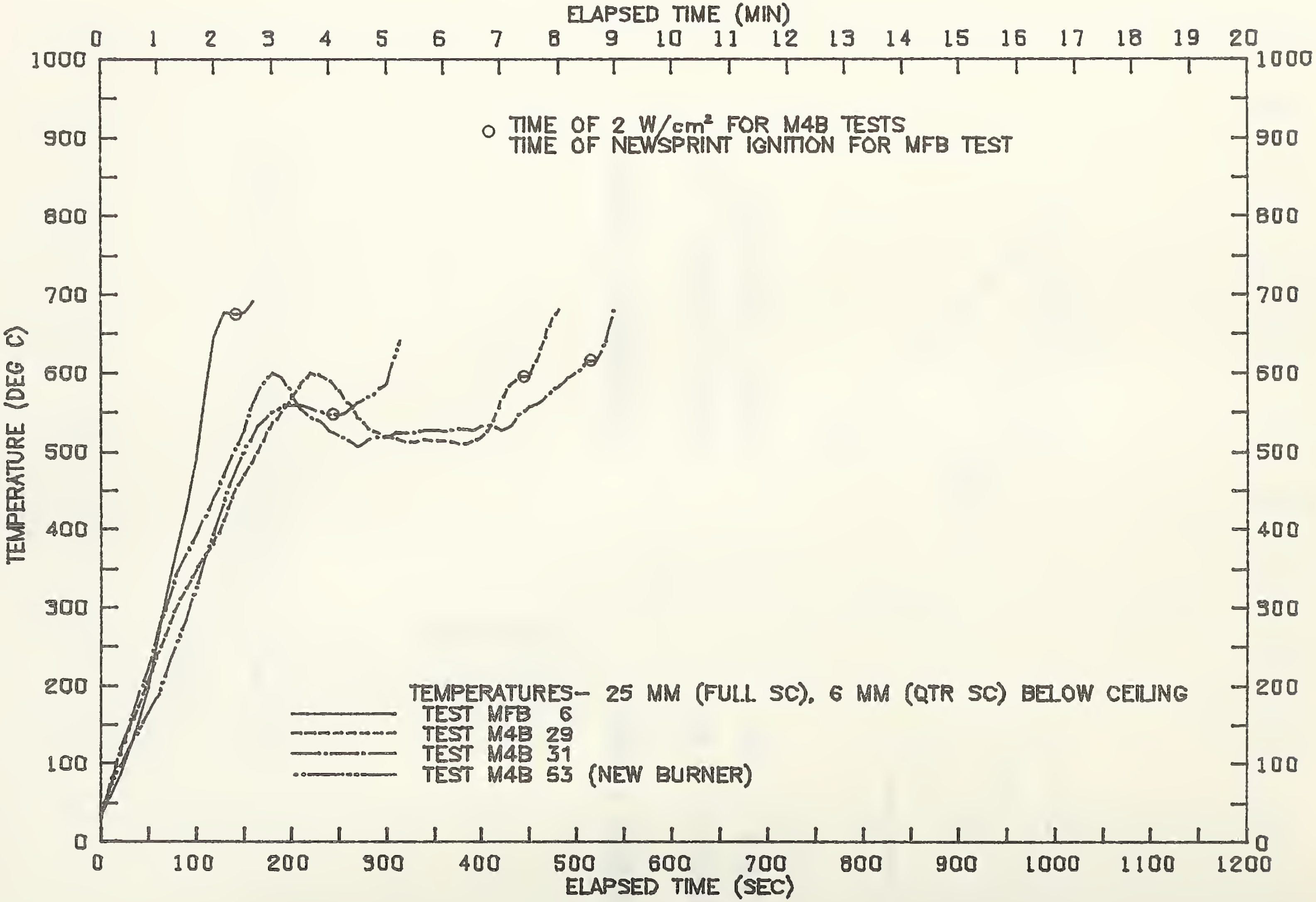


Figure 17. Temperature histories for tests with lauan plywood walls and gypsum board ceilings. The triangular burner was used for test M4B 53. For the other tests a square burner was used.

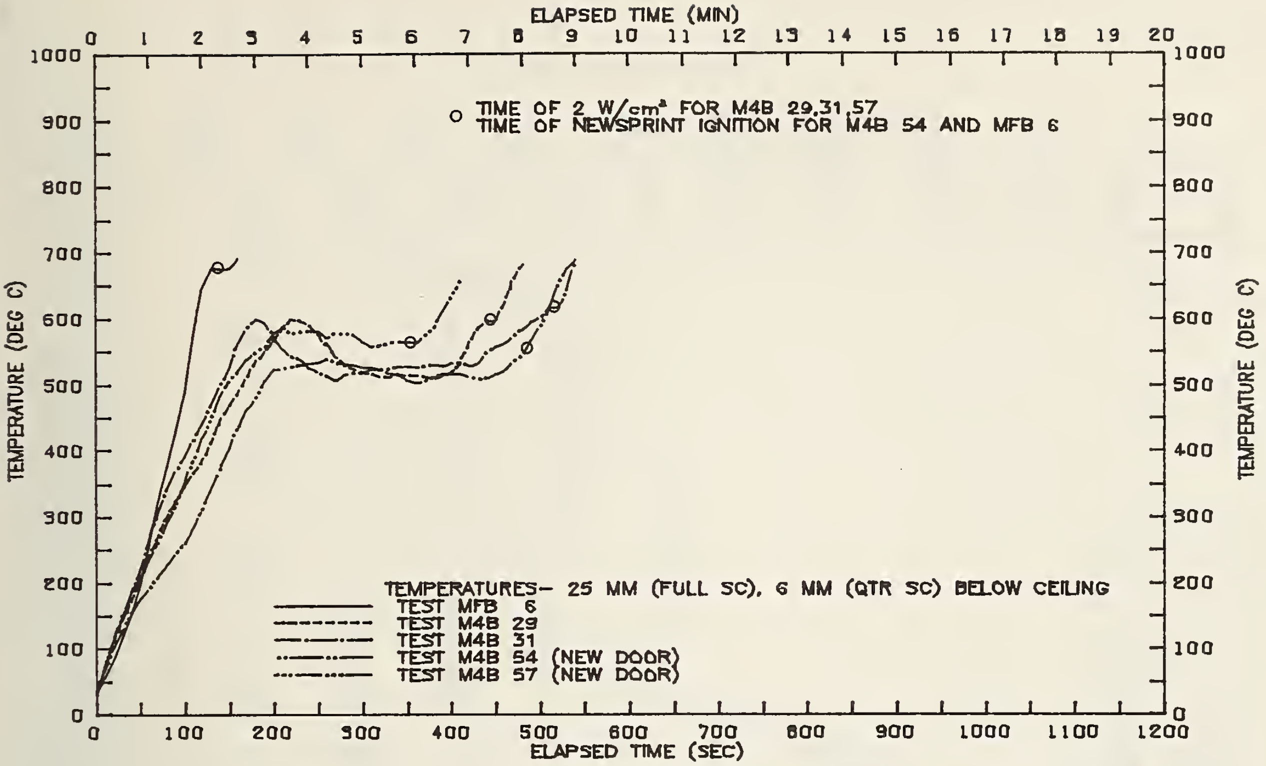


Figure 18a. Lauan plywood walls and gypsum board ceilings.

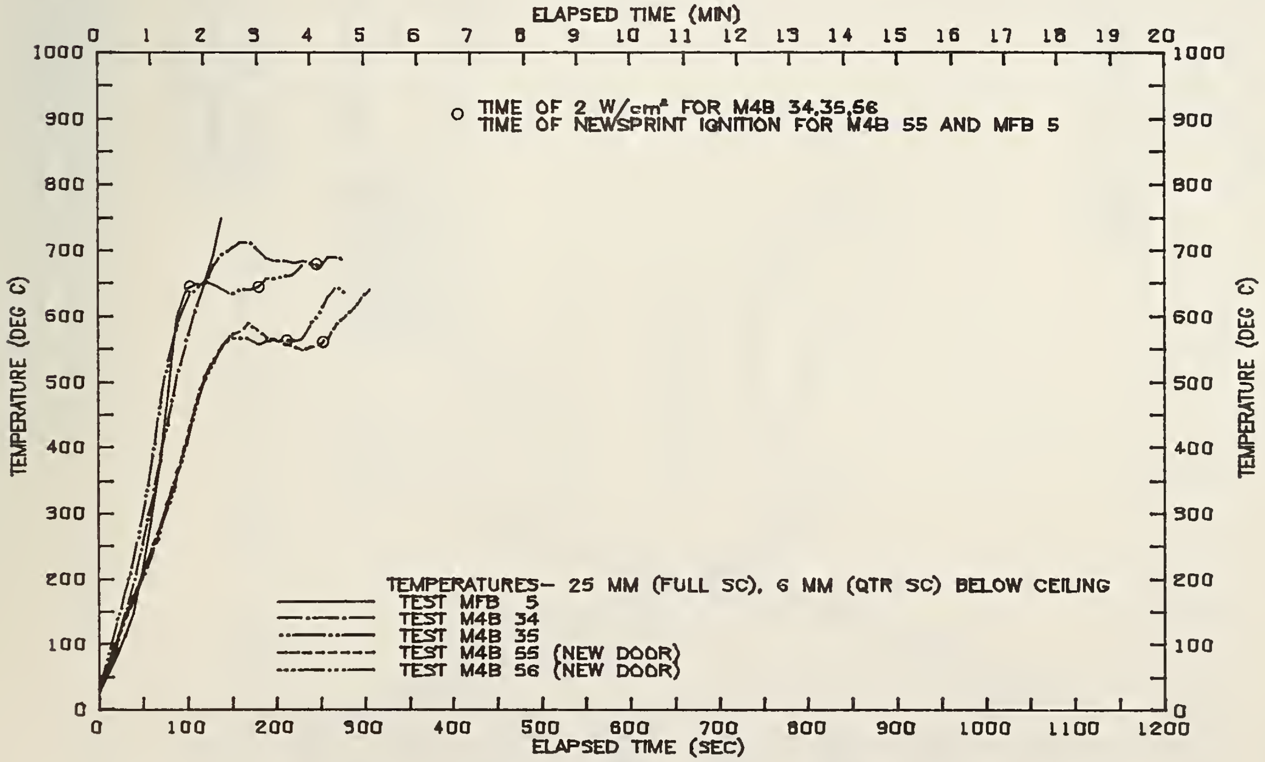


Figure 18b. Lauan plywood walls and wood fiber board ceilings.

Figure 18. Temperature histories illustrating the effect of the experimental door opening for two combinations of interior finish materials.

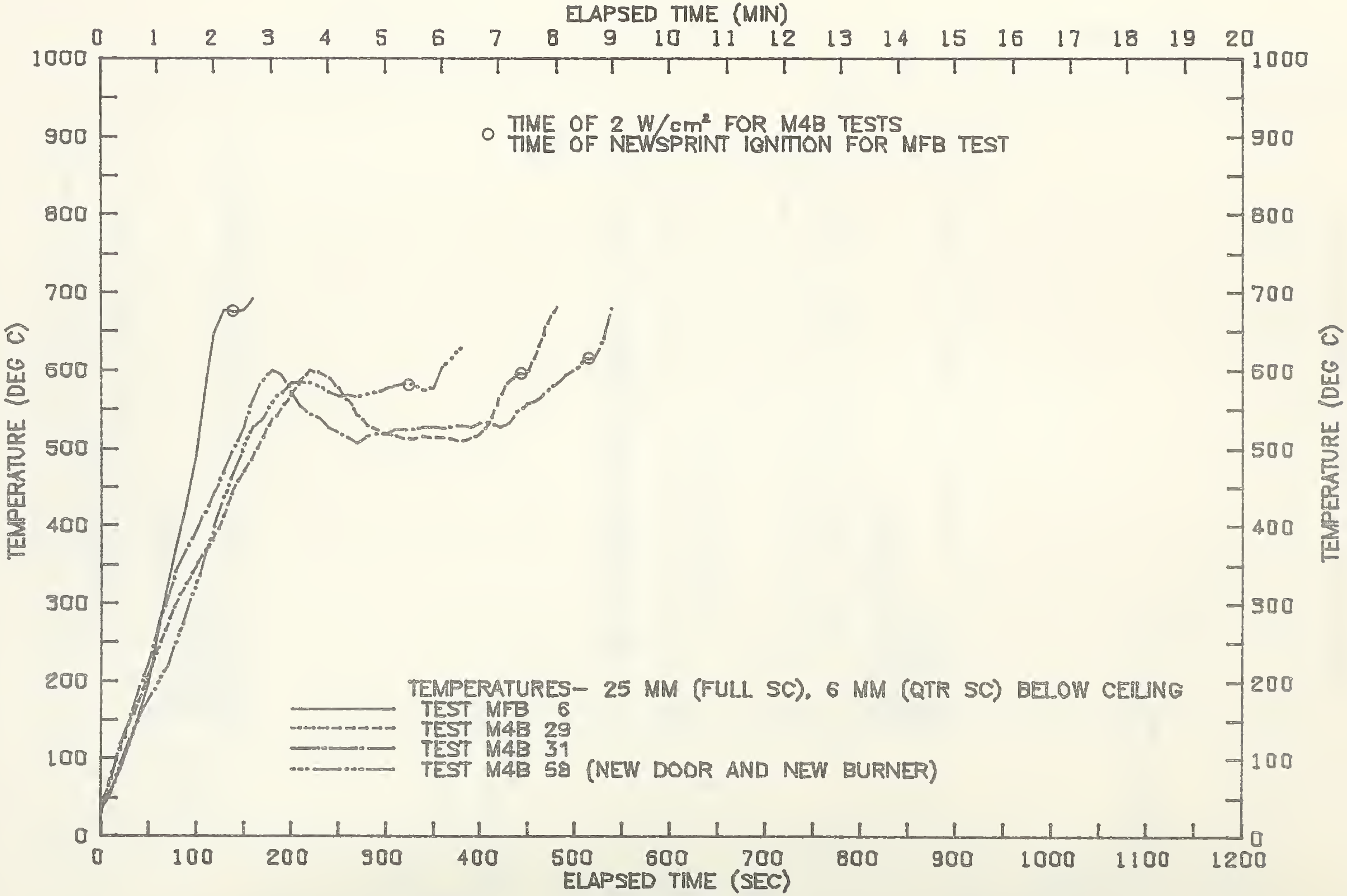


Figure 19. Temperature histories for tests with lauan plywood walls and gypsum board ceilings. For test M4B 58 the experimental door opening and triangular burner were used. For the other tests the original door opening and square burner were used.

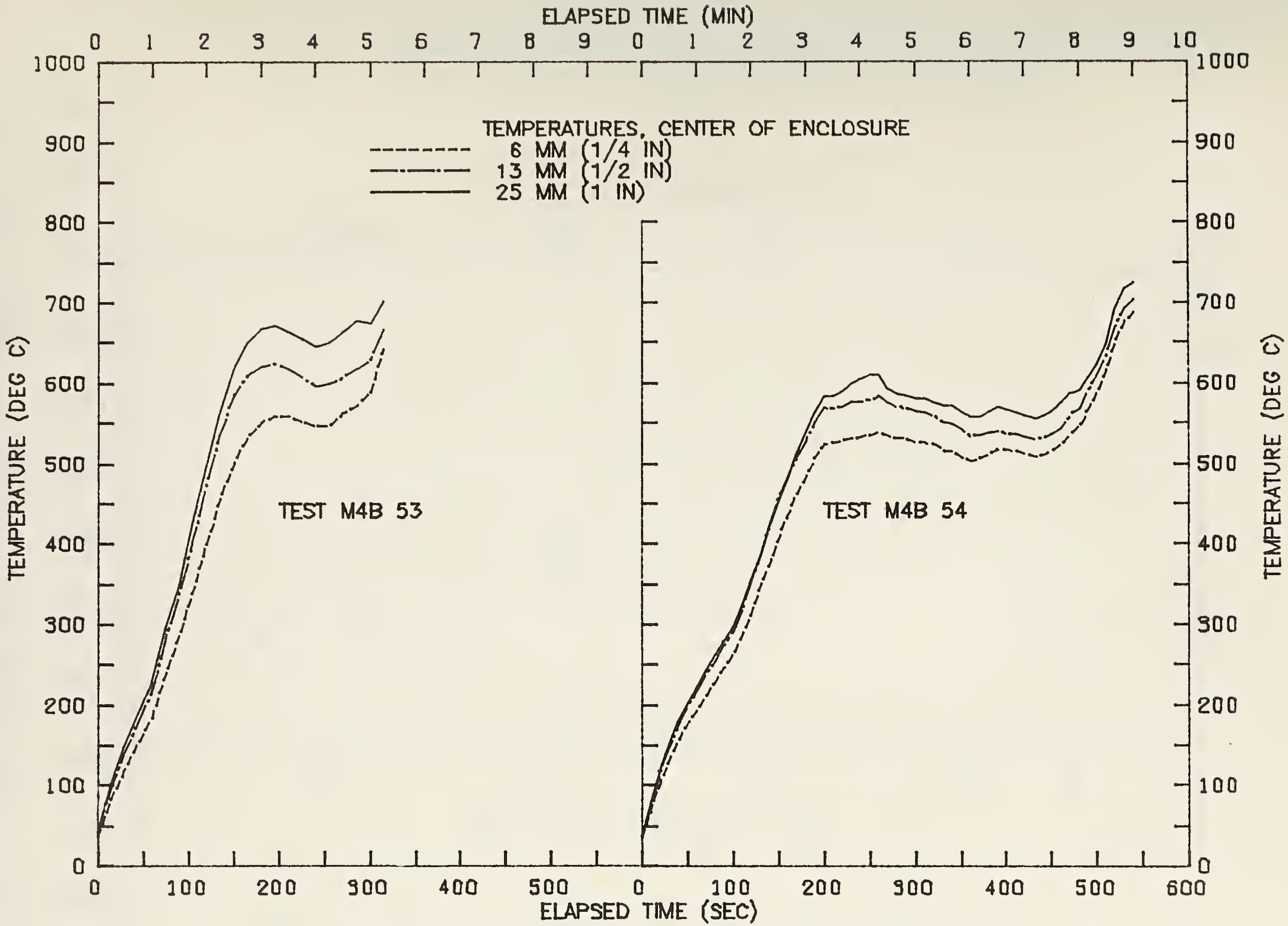


Figure 20. Temperature histories for two quarter-scale tests.

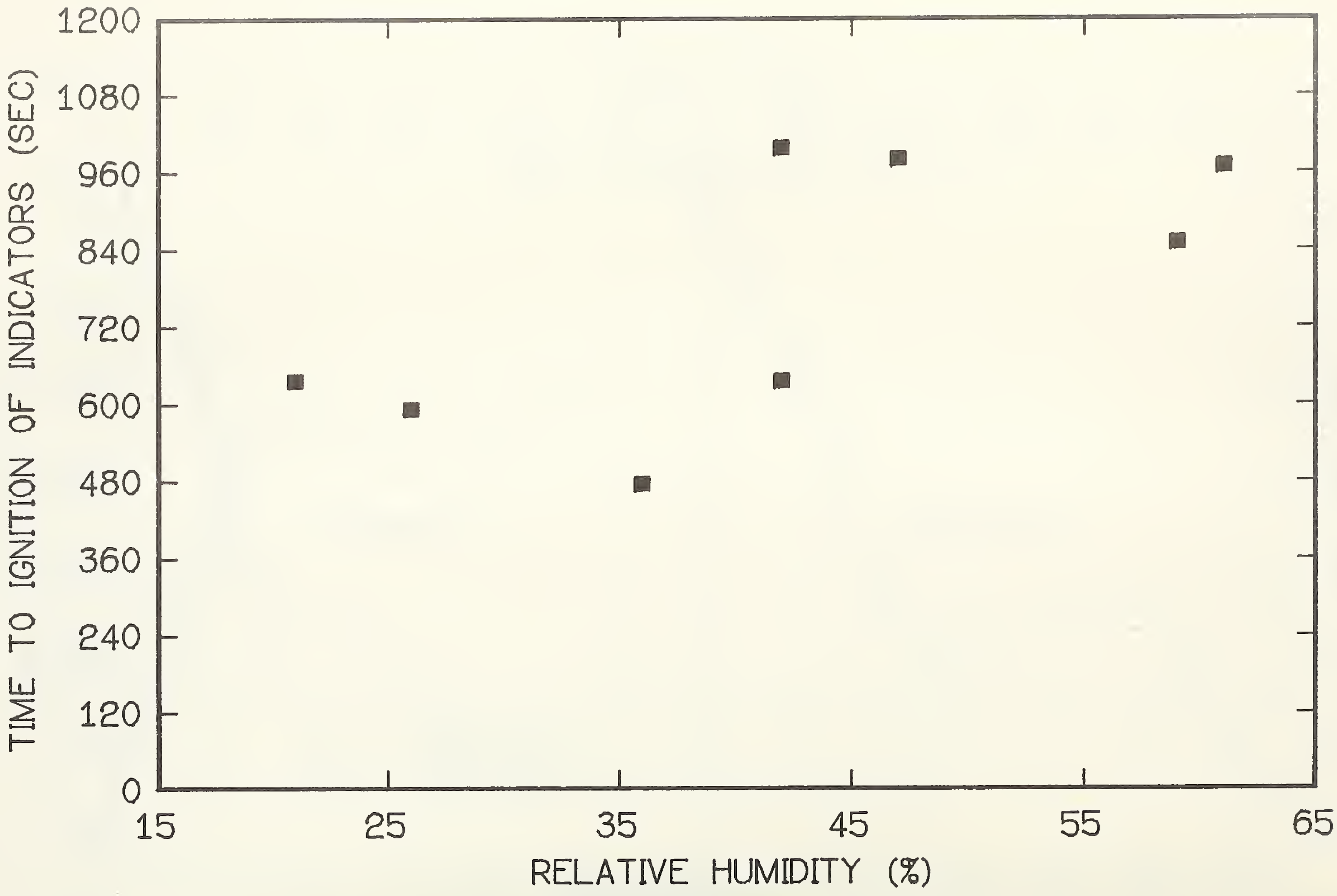


Figure 21. Time to ignition of flashover indicators versus ambient relative humidity for tests involving lauan plywood walls, gypsum board ceilings, and low intensity exposure fires.

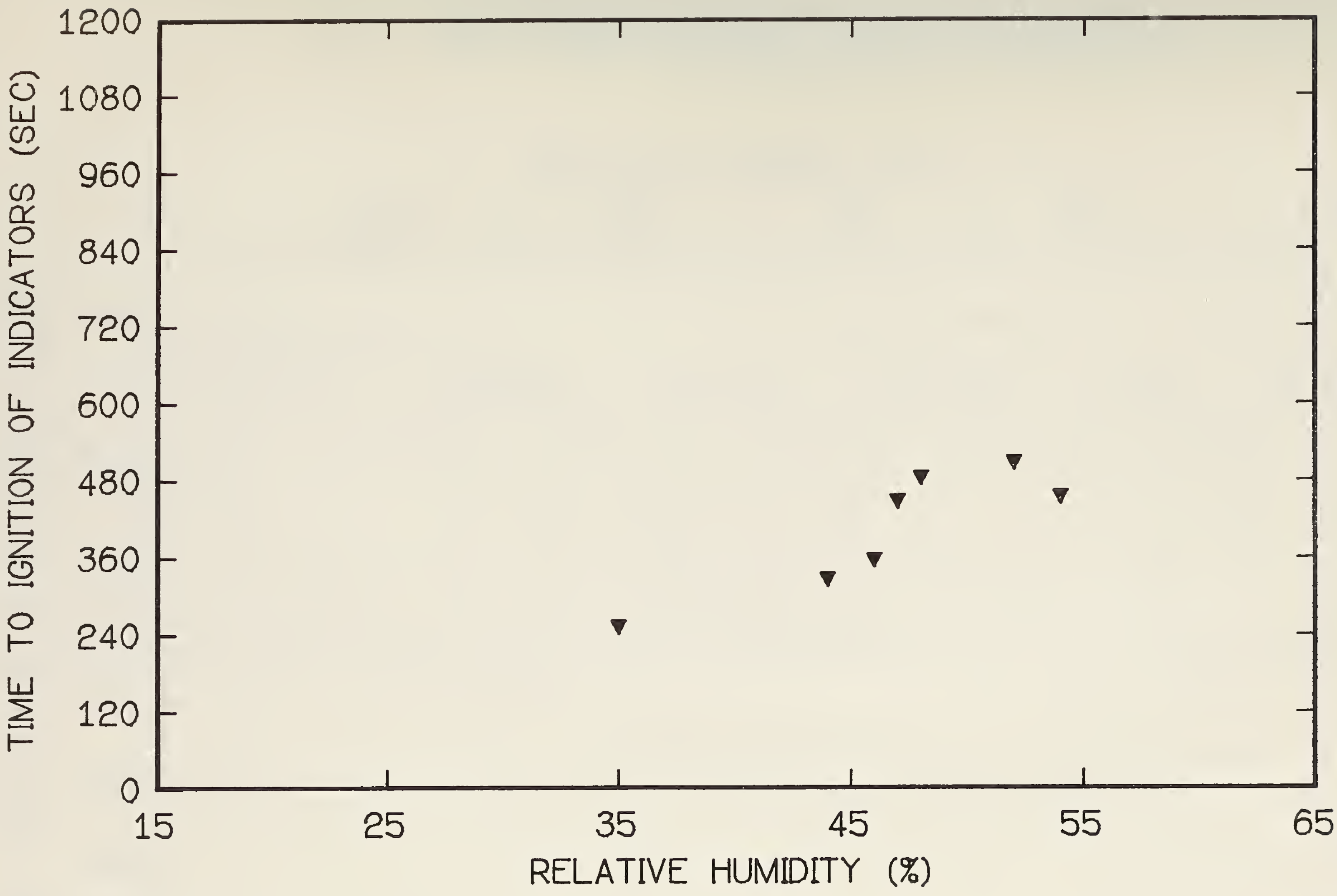


Figure 22. Time to ignition of flashover indicators versus ambient relative humidity for tests involving lauan plywood walls, gypsum board ceilings, and high intensity exposure fires.

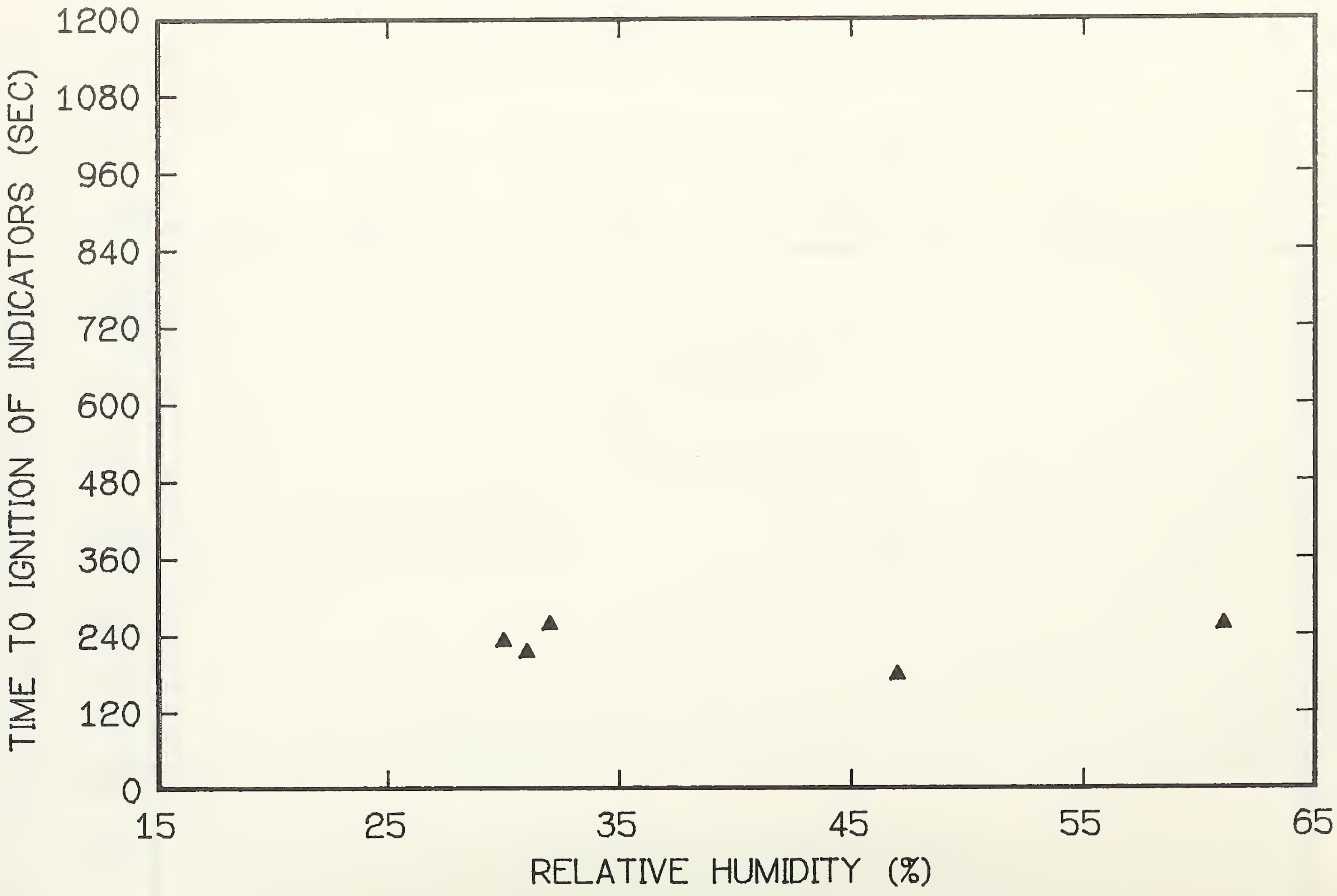


Figure 23. Time to ignition of flashover indicators versus ambient relative humidity for tests involving lauan plywood walls, wood fiber ceilings, and high intensity exposure fires.

Table 1. Design Specifications for the Wood Cribs.

Crib Weight		Width and Depth of Square Cross Section of Each Stick		Separation Distance Between Sticks		Length of Each Stick		Number of Sticks Per Layer	Number of Layers	Amount of Heptane Ignitor
kg	lbs	mm	in	mm	in	mm	in			ml
6.4	14	38	1.5	69	2.7	355	14	4	6	150
9.1	20	38	1.5	48	1.9	380	15	5	6	150
13.6	30	38	1.5	48	1.9	380	15	5	10	150

Table 2. Description of Interior Finish Materials Used in Testing.

NBS I.D. Code	Description	ASTM E84 Flame Spread
W-5	4 mm (5/32 in) printed, prefinished, grooved lauan plywood paneling.	182
W-12	4 mm (5/32 in) printed, prefinished, grooved lauan plywood paneling.	171
W-16	13 mm (1/2 in) calcium silicate structural insulation paneling (marine board).	0
W-16a	All walls lined with material W-19. Additional layer of W-16 installed in corner containing exposure fire.	0*
W-19	10 mm (3/8 in) paper-faced gypsum board, taped and spackled.	15
W-22	4 mm (5/32 in) printed, paper-overlayed, grooved lauan plywood paneling.	300**
C-5	13 mm (1/2 in) prefinished, low-density wood fiberboard ceiling paneling.	73
C-9	10 mm (3/8 in) paper-faced gypsum board, taped and spackled.	15
C-13	13 mm (1/2 in) calcium silicate structural insulation paneling (marine board).	0
C-13a	Entire ceiling lined with material C-9. Additional layer of C-13 installed in corner containing exposure fire.	0*

* Under the condition that fire never extends past the marine board.

** Material is labeled as meeting Class C requirement (flame spread 76-200).

Table 3. Summary Information for Tests Using an Upholstered Chair or Wood Crib as the Exposure Fire.

Test No	Interior Finish Materials NBS Identification Code		Exposure Fire	Maximum Temperature		Maximum Heat Flux	Flashover Time as Determined	
	Walls	Ceiling		25 mm Deg C	255 mm Deg C	W/cm^2	by 2 W/cm^2 min:sec	by Indicators min:sec
MHBED 8	W-16a	C-13a	16 kg (35 lb) Upholstered Chair	372	295	0.21	NR	NR*
MHBED 9	W-16a	C-13a		380	287	0.23	NR	NR
MHBED 10	W-16a	C-13a	6.4 kg (14 lb) Wood Crib	224	200	NC**	NR	NR
MHBED 11	W-16a	C-13a	9.1 kg (20 lb) Wood Crib	268	234	0.11	NR	NR
MHBED 12	W-16a	C-13a	13.6 kg (30 lb) Wood Crib	365	305	0.20	NR	NR

* NR = Not reached

** NC = Essentially no change from ambient condition

Notes
1) All tests full scale.
2) Interior finish materials used on walls and ceiling for all tests: marine board (in corner) over gypsum board (throughout).

Table 4. Summary Information for Selected Tests Using a Methane Burner as the Exposure Fire.

Test Number	Enclosure Scale F=Full R=Reduced	Interior Finish Materials NBS Identification Code: Walls	Ceiling	Relative Humidity %	Temperature °C	Time to Flashover** min:sec
Walls: Marine Board; Ceiling: Marine Board — Burner Intensity: Low						
MFB 1	F	W-16a	C-13a			NR***
M4B 1	R	W-16	C-13	31*	21*	NR
4	R	W-16	C-13	40*	22*	NR
Walls: Marine Board; Ceiling: Marine Board — Burner Intensity: Moderate						
MFB 2	F	W-16a	C-13a			NR
M4B 5	R	W-16	C-13	60*	22*	NR
6	R	W-16	C-13	46*	24*	NR
Walls: Marine Board; Ceiling: Marine Board — Burner Intensity: High						
MFB 3	F	W-16a	C-13a	66	19	NR
M4B 9	R	W-16	C-13	40*	22*	NR
10	R	W-16	C-13	33*	21*	NR
Walls: Gypsum Board; Ceiling: Gypsum Board — Burner Intensity: High						
MFB 9	F	W-19	C-9	40	18	NR
M4B 51	R	W-19	C-9	24	24	NR
64	R	W-19	C-9	39	26	NR
Walls: Lauan Plywood; Ceiling: Gypsum Board — Burner Intensity: Low						
MFB 8	F	W-22	C-9	30	17	2:31†
M4B 15	R	W-12	C-9	46*	24*	8:00
16	R	W-12	C-9	32*	23*	6:40
30	R	W-22	C-9	47	24	16:20
32	R	W-22	C-9	36	26	7:55
33	R	W-22	C-9	42	26	10:35
50††	R	W-22	C-9	31	27	6:38
Walls: Lauan Plywood; Ceiling: Gypsum Board — Burner Intensity: High						
MFB 6	F	W-22	C-9	40	24	2:19
M4B 13	R	W-12	C-9	35*	26*	4:30
14	R	W-12	C-9			5:15
29	R	W-22	C-9	47	24	7:30
31	R	W-22	C-9	52	26	8:30
53	R	W-22	C-9	35	26	4:15
54	R	W-22	C-9	48	28	8:06
57	R	W-22	C-9	46	28	5:59
58	R	W-22	C-9	44	26	5:29
63	R	W-22	C-9	54	27	7:37

Table 4. Summary Information for Selected Tests
Using a Methane Burner as the Exposure Fire (continued).

Test Number	Enclosure Scale F=Full R=Reduced	Interior Finish Materials NBS Identification Code Walls	Ceiling	Relative Humidity %	Temperature °C	Time to Flashover** min:sec

Walls: Lauan Plywood
Ceiling: Wood Fiberboard
Burner Intensity: Low

Test Number	Scale	Walls	Ceiling	Relative Humidity %	Temperature °C	Time to Flashover** min:sec
MFB 7	F	W-22	C-5	42	11	2:24
M4B 19	R	W-12	C-5	34*	26*	4:55
21	R	W-5	C-5	46	25	4:45
27	R	W-5	C-5	40	24	4:53
61	R	W-22	C-5	56	28	5:48

Walls: Lauan Plywood
Ceiling: Wood Fiberboard
Burner Intensity: High

Test Number	Scale	Walls	Ceiling	Relative Humidity %	Temperature °C	Time to Flashover** min:sec
MFB 5	F	W-22	C-5	55	11	1:46
M4B 18	R	W-12	C-5	54*	24*	3:30
20	R	W-5	C-5	50	23	3:20
34	R	W-22	C-5	61	24	4:15
35	R	W-22	C-5	47	24	2:57
55	R	W-22	C-5	32	27	4:16
56	R	W-22	C-5	30	26	3:50
60	R	W-22	C-5	31	27	3:33

INDEX TO METHANE BURNER EXPOSURE FIRES

Exposure Fire	Scale	Flow m^3/hr	Flow ft^3/hr	Heat Production kW	Heat Production Btu/min
Low	Full	8.02	284	84.1	4,783
	Quarter	0.50	18	5.2	296
Moderate	Full	10.70	378	112.1	6,378
	Quarter	0.69	24	7.0	399
High	Full	14.06	497	147.3	8,382
	Quarter	0.88	31	9.2	524

* Approximate
** Flashover as determined by ignition of newsprint indicator.
*** NR = Not Reached
† Newsprint ignition at 2:05 for test MFB 8 may have occurred early due to debris burning nearby. Flashover was judged to have occurred at 2:31 based on heat flux on floor and upper air temperature.
†† For test M4B 50 propane gas was used.

Table 5. Information on Peak Temperatures, Heat Flux Levels, and Flashover Times for Tests Using a High Intensity Exposure Fire.

	Initial Peak Temperature 6 mm Down	Overall Peak 6 mm Down		Maximum Heat Flux at Floor if Less Than 2 W/cm^2	Flashover Time as Determined		Time to Reach 500°C 6 mm Down
		Temperature	Time		By 2 W/cm^2	By Indicators	
Test	Deg C	Deg C	min:sec	W/cm^2	min:sec	min:sec	min:sec
M4B 9	330	356	19:30	0.38	NR*	NR	NR
M4B 10	330	366	19:30	0.48	NR	NR	NR
M4B 13	641	641	3:20		4:38	4:30	2:26
M4B 14	657	692	6:10		5:15	5:15	2:35
M4B 18	681	681	3:00		3:27	3:30	1:44
M4B 20	669	675	4:40		3:15	3:20	1:42
M4B 29	599	680	8:00		7:25	7:30	2:45
M4B 31	600	687	9:00		8:35	8:30	2:20
M4B 34	713	713	2:40		4:08	4:15	1:28
M4B 35	653	678	3:50		3:02	2:57	1:15
M4B 43	520	629	15:00	0.89	NR	16:00**	2:40
M4B 47	569	623	16:00	1.40	NR	19:10**	2:29
M4B 51	325	358	20:10	0.33	NR	NR	NR
M4B 52	514	684	10:20		9:23	9:30	3:38
M4B 53	560	642	5:15		4:06	4:15	2:30
M4B 54	539	687	9:00		UD***	8:06	3:08
M4B 55	589	644	5:10		UD	4:16	1:58
M4B 56	567	644	4:30		3:33	3:50	1:59
M4B 57	588	657	6:50		5:56	5:59	2:27
M4B 58	585	630	6:20		5:24	5:29	2:30
M4B 60	628	628	4:50		3:37	3:33	2:09
M4B 62	616	666	5:20		4:05	4:08	1:58
M4B 63	543	647	8:40		7:56	7:37	2:55
M4B 64	306	329	18:30	0.43	NR	NR	NR
M4B 66	431	431	5:50	0.23	NR	NR	NR
M4B 67	620	678	12:10		10:50	10:42	3:18
M4B 68	615	616	15:20		14:45	14:44	2:23
M4B 69	602	682	4:30		3:42	3:49	1:44
M4B 70	596	608	5:00		4:16	4:17	2:05

*NR = Not Reached
**Only first indicator ignited and may have been influenced by debris burning on floor nearby.
***UD = Unreliable Data

Table 6. Information on Peak Temperatures, Heat Flux Levels, and Flashover Times for Tests Using a Low Intensity Exposure Fire.

Test	Initial Peak Temperature 6 mm Down	Overall Peak 6 mm Down		Maximum Heat Flux at Floor if Less Than 2 W/cm^2	Flashover Time as Determined		Time to Reach 375°C 6 mm Down
		Temperature	Time		By 2 W/cm^2	By Indicators	
	Deg C	Deg C	min:sec	W/cm^2	min:sec	min:sec	min:sec
M4B 1	223	245	17:00	UD*	UD	NR**	NR
M4B 4	240	255	20:00	0.25	NR	NR	NR
M4B 15	690	711	8:30		7:54	8:00	3:26
M4B 16	621	689	8:10		7:06	6:40	3:20
M4B 17	608	669	8:30		7:51	7:55	2:49
M4B 19	637	692	5:40		4:33	4:55	1:44
M4B 21	644	682	5:50		4:46	4:45	2:11
M4B 27	638	692	6:00		UD	4:53	2:20
M4B 30	432	681	16:40		16:12	16:20	3:04
M4B 32	477	713	8:20		7:40	7:55	2:15
M4B 33	490	680	11:10		10:41	10:35	3:03
M4B 36	226	226	19:40	0.15	NR	NR	NR
M4B 44	229	340	19:10	0.38	NR	NR	NR
M4B 49	237	241	16:20	0.28	NR	NR	NR
M4B 50***	532	659	7:00		6:31	6:38	2:06
M4B 61	583	716	7:10		5:43	5:48	2:52
M4B 65	502	663	17:00		16:23	16:37	3:50

*UD = Unreliable Data
**NR = Not Reached
***For test 50 propane was used. For all other tests methane was used.

Table 7. Summary of Time to Reach Flashover in Full-Scale and Time to Reach 500°C or 375°C in Model.

Walls/Ceiling:	Plywood/Wood Fiberboard		Plywood/Gypsum Board	
	Test Number	Time* (min:sec)	Test Number	Time* (min:sec)
High Intensity	MFB 5	1:46	MFB 6	2:19
	M4B 18	1:44	M4B 13	2:26
	M4B 20	1:42	M4B 14	2:35
	M4B 34	1:28	M4B 29	2:45
	M4B 35	1:15	M4B 31	2:20
	M4B Average	1:32	M4B Average	2:32
Low Intensity	MFB 7	2:24	MFB 8	2:31**
	M4B 19	1:44	M4B 30	3:04
	M4B 21	2:11	M4B 32	2:15
	M4B 27	2:20	M4B 33	3:03
	M4B Average	2:05	M4B Average	2:47

* Time to ignition of flashover indicators for full-scale (MFB) tests, time to reach 500°C for model (M4B) tests at high intensity, time to reach 375°C for model (M4B) tests at low intensity.

** Adjusted flashover time. See Table 4.

Table 8. Average and Peak Temperatures Measured at Different Heights in the Model for Selected Tests.

Test Number	Door Opening	Burner Shape S=Square T=Triangle	Burner Output (kW)	Avg Temperature* (Deg C) at Position** A	B	C	Rank Order	Peak Temperature*** (Deg C)	Occurred at Position
M4B 50	original	S	5.2****	430	465	447	B,C,A	705	C
M4B 51	original	S	9.2	319	342	334	B,C,A	383	B
M4B 52	original	S	9.2	441	491	493	C,B,A	729	C
M4B 53	original	T	9.2	409	458	490	C,B,A	702	C
M4B 54	experimental	S	9.2	442	473	489	C,B,A	725	C
M4B 55	experimental	S	9.2	447	474	496	C,B,A	676	C
M4B 56	experimental	S	9.2	432	455	476	C,B,A	686	C
M4B 57	experimental	S	9.2	463	496	505	C,B,A	703	C
M4B 58	experimental	T	9.2	445	474	497	C,B,A	689	C
M4B 59	experimental	S	11.4	490	527	525	B,C,A	677	B
M4B 60	original	S	9.2	425	469	489	C,B,A	687	C

* The average temperature for each location is determined by summing the temperature values read every 10 seconds, then dividing that sum by the number of values read.

** Thermocouple positions are in the center of the enclosure
A = 6 mm (1/4 in) below ceiling
B = 13 mm (1/2 in) below ceiling
C = 25 mm (1 in) below ceiling

*** Peak temperature is not necessarily an indication of the severity of a test since some fires were extinguished just after flashover while others were allowed to burn longer and therefore become hotter.

**** For test 50 propane was used. For tests 51 - 60 methane was used.

Table 9. Minimum Oxygen Concentrations in Bedroom Doorway at Floor Level.

Test Number	Exposure Fire	Wall Material	Ceiling Material	Minimum O_2 Concentration for Non-Flashover Tests at 300 sec	Minimum O_2 Concentration for Non-Flashover Tests at 600 sec	Minimum Pre-Flashover O_2 Concentration for Flashover Tests
MHBED 8	Upholstered Chair	Marine Board over Gypsum Board	Marine Board over Gypsum Board	20.9	20.2	
MHBED 9	Upholstered Chair	Marine Board over Gypsum Board	Marine Board over Gypsum Board	20.9	20.4	
MHBED 10	14 lb Crib	Marine Board over Gypsum Board	Marine Board over Gypsum Board	20.8	19.9	
MHBED 11	20 lb Crib	Marine Board over Gypsum Board	Marine Board over Gypsum Board	20.7	20.2	
MHBED 12	30 lb Crib	Marine Board over Gypsum Board	Marine Board over Gypsum Board	20.4	19.8	
MFB 1	8.4 kW	Marine Board over Gypsum Board	Marine Board over Gypsum Board	20.8	20.4	
MFB 2	112.1 kW	Marine Board over Gypsum Board	Marine Board over Gypsum Board	20.7	19.9	
MFB 3	147.3 kW	Marine Board over Gypsum Board	Marine Board over Gypsum Board	NR*	NR	
MFB 4	175.7 kW	Marine Board over Gypsum Board	Marine Board over Gypsum Board	NR	NR	
MFB 10	84.1 kW	Gypsum Board	Gypsum Board	20.8	20.4	
MFB 9	147.3 kW	Gypsum Board	Gypsum Board	20.6	19.9	
MFB 8	84.1 kW	Lauan Plywood	Gypsum Board			20.7
MFB 6	147.3 kW	Lauan Plywood	Gypsum Board			19.5
MFB 7	84.1 kW	Lauan Plywood	Wood Fiber			20.6
MFB 5	147.3 kW	Lauan Plywood	Wood Fiber			NC**

* NR = Data not recorded.

** NC = Essentially unchanged from ambient concentration.

Notes
1) Ambient O_2 concentration = 21.0% for MHBED tests and MFB 1,2.
= 20.9% for MFB 5 and subsequent MFB tests.
2) Pre-flashover times allow a 40-second lag time between the time of sampling and the time the sample is analyzed.

Table 10. Minimum Oxygen Concentrations in Living Room Doorway at Floor Level.

Test Number	Exposure Fire	Wall Material	Ceiling Material	Minimum O_2 Concentration for Non-Flashover Tests	Minimum Pre-Flashover O_2 Concentration for Flashover Tests
MHLIV 17	Chair	lauan plywood	gypsum board		20.9
MHLIV 18	Sofa	gypsum board	gypsum board	20.6	
MHLIV 19	Sofa	gypsum board	wood fiberboard	20.4	
MHLIV 20	Chair	gypsum board	wood fiberboard		20.9
MHLIV 21	Chair	intumescent lauan	wood fiberboard		20.9
MHLIV 22	Chair	gypsum board	wood fiberboard	20.6	
MHLIV 23	Chair	intumescent lauan	wood fiberboard		15.9
MHLIV 24	Chair	intumescent lauan	gypsum board	19.1	

Note

All O_2 readings based on ambient O_2 concentration of 21.0%

APPENDIX. LIMITS OF ERROR FOR INSTRUMENTATION.

Type of Instrument	Limits of Error
Thermocouple (Type K)	
0 - 277°C	±2.2°C
277 - 1260°C	±0.75% of reading
Heat Flux Transducer	±10% of reading
Oxygen Gas Analyzer	±1% of reading
Flow Meter	
0 - 25 SCFH*	±3% of reading
5 - 50 SCFH**	±4% of reading

* For low and moderate intensity fires.
** For high intensity fires.

NBS-114A (REV. 2-80)

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David P. Klein

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

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Office of Policy Development and Research
U. S. Department of Housing and Urban Development
Washington, DC 20410

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A series of fire tests was conducted in the bedroom of a single-wide mobile home and in a quarter-scale model of that bedroom. The objectives of the tests were (1) to evaluate the relationship between fire buildup in the reduced-scale and full-scale enclosures and (2) to determine the feasibility of using a reduced-scale model test to assess the potential contribution of particular combinations of interior finish materials to fire growth in a mobile home.

The model tests simulated the phenomena of fire growth and flashover; however, the time to flashover occurred later in the model than in the full-scale bedroom. Flashover was taken as the time at which the level of radiation at the center of the floor reached 2 W/cm^2. Several modifications to the model were examined but none adequately corrected the time delay to flashover. However, by monitoring the upper air temperature in the model, the occurrence or nonoccurrence of flashover for corresponding full-scale tests could be reliably predicted. Therefore, the use of a quarter-scale model was judged to be feasible.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Compartment fires; fire tests; flashover; interior finish; mobile homes; models; room fires

13. AVAILABILITY

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