DASA 1886

IITRI

DETERMINATION OF FIRE CONDITIONS SUPPORTING ROOM FLASHOVER

Contract No. DA 49-146-XZ-475

IITRI Project M6131

for

Defense Atomic Support Agency
Washington, D. C.

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DETERMINATION OF FIRE CONDITIONS SUPPORTING ROOM FLASHOVER

Thomas E. Waterman

Final Report
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FOREWORD

This is the final report of Contract No. DA-49-146-XZ-475, IITRI Project M6131, conducted for the Defense Atomic Support Agency during the period September 1966 to September 1967. The work was carried out under the guidance of Mr. John Snyder, DASA project technical monitor. Contributors to the program include the following personnel of the Heat and Mass Transfer Section of the Mechanics Research Division: Thomas E. Waterman, project engineer, Frederick Salzberg, and Frank Vodvarka.

Respectfully submitted,

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ABSTRACT

This is the first annual report of a continuing program to investigate fire behavior in rooms during the ignition-to-flashover period. The objectives of the program are to quantitatively evaluate time histories of temperature, gas composition, and heat flux in ignited rooms, and to determine the conditions necessary for the occurrence of flashover. The approach being used is to study a series of room fires involving contents typical of actual occupancies, develop simple, reproducible fuel arrays which duplicate the essential features of these fires, and then establish procedures for small scale simulations of room fires using the simplified fuel arrays. Experiments at the smallest feasible scale will then be used to evaluate effects of such parameters as room size, ceiling height, location and size of ventilation openings, combustibility of wall and ceiling covering and insulating quality of wall and ceiling material. This report contains the results of the studies of full scale room fires using both real and simplified fuel arrays.

Experiments were conducted in an instrumented test chamber 12 x 12 x 8 ft high. Time histories of temperature, gas composition, and heat flux (radiative and convective) were determined for real content fires corresponding to living-room, bedroom and storage area configurations with various degrees of ventilation. Similar experiments were performed for simple fuel arrays involving both wood and propane fuels to simulate the real room fires. A number of conclusions were drawn concerning the mechanism of room flashover and conditions existing during fire buildup. Fires with both wood and propane fuels were found to be capable of simulating real room fires. Propane fuel was chosen for future work because of the ease with which its burning rate may be controlled.

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I. INTRODUCTION

The usefulness of fire as a weapon of destruction was clearly demonstrated by the incendiary and nuclear attacks of World War II. Since that time, the development of weapons with yields in the megaton range has produced a fire potential that dwarfs all past experiences. Recognizing the need for assessing the incendiary consequences of nuclear warfare, the Defense Atomic Support Agency, in 1959, engaged IIT Research Institute to develop a computer model for predicting the fire damage to an urban area from a nuclear burst. This multiphase task, subsequently monitored by the National Military Command Systems Support Center, appears to be the first coordinated treatment of all stages of fire development. Due to the lack of detail in records of past fires, statistical use of data from those records was impractical, and the model was developed using expressions describing the physical phenomena involved. Where required information was lacking, simplifications or approximations, consistant with the state of the art, were introduced to make the program usable. Awareness of these limitations, combined with a study of results produced by the model, has effectively pointed to those significant areas of fire behavior that are inadequately defined. The areas generally are those concerned with fire development in a room, non-radiative fire spread between structures, and mass-fire phenomenology. The mechanisms governing the initial stages of fire development were found to be of particular importance.

Early in 1965, a Fire Phenomenology Workshop sponsored jointly by DASA and OCD was convened to identify parameters of fundamental importance to fire phenomena, to discuss the measurement of variables in laboratory and field experimentation, and to consider the possibility of standardization of data collection. This conference directed further emphasis to the build-up stage of room fires. It, and follow-up communications have led to the formulation of a comprehensive program, coordinated by NRDL, designed to upgrade knowledge of the less-understood aspects of fire behavior. The objectives have been stated[1] as follows:

"The primary objective is a generalized data base from which estimates of established fires in urban structures can be made - such estimates being sufficiently detailed to provide a high-reliability assessment of fire damage to at least the point in the post-attack fire history when interunit spread and coalescence effects begin to dominate."

"Secondary objectives include (a) determining the importance and understanding the role of fire brands in fire-spread processes, (b) evaluating the effect of fire interaction (e.g. coalescence) on fire behavior and (c) developing an advanced fire initiation-buildup-spread model employing the results of the experimental parts of the subtask."

To achieve these objectives the program has been subdivided into eight problem areas. These are:

(1) Fire initiation in fuel arrays.

(2) Item to item propagation.

(3) Conditions of buildup and flashover.

(4) Generalization of buildup behavior.

(5) Fire spread and mass fire modelling.

(6) Fire-brand formation and transport.

(7) Interaction and coalescence.

(8) Computer code for initiation, buildup, and spread.

This report is concerned with problem area 3, conditicns of buildup and flashover, and it covers IITRI's efforts on this task from September 1, 1965 to August 31, 1966. The specific goal of the work is to determine the conditions necessary for the occurrence of flashover during fire buildup in a room. This information (criteria for occurrence and time required) can be combined with results of studies of item-to-item fire spread, ignition of fuel complexes, and frequency of occurrence and location of room combustibles to assess the relation between total ignitions and the number of resultant significant fires (capable of spreading) from nuclear weapon.

II. DISCUSSION

Fire buildup in a room following ignition of some portion of its contents can proceed by several paths. The fire may spread along connected fuel elements and/or propagate to other disconnected elements. Due to the bounds imposed by the room itself, behavior will differ from that of fires in the open. This will be true particularly when the volume of active fire becomes a significant portion of the room volume. When this occurs, a stage of rapid development often follows in which all uninvolved combustibles suddenly ignite. This occurrence usually coincides with the onset of active flaming of the originating fire and quite often is preceded by flaming across the room ceiling. The term "flashover" is employed to describe this stage of fire development. The occurrence of flashover is of importance since it signifies the beginning of that period in which the fire appreciably affects its surroundings, both by attacking the integrity of the barriers confining it and by exposing nearby structures or combustibles to thermal radiation.

A. Factors Affecting Fire Buildup in a Fuel Item

A number of factors influence the buildup of fire in an ignited fuel item. These can be outlined as follows:

(1) Type of ignition.

(2) Location and size of ignited area.

(3) Physical characteristics of item.

- a. size
- b. material(s) (heat content, combustibility, insulative quality, etc.)
- c. construction or configuration

(4) Local environment.

- a. reflection and reinforcement of radiation
- b. local convection pattern and velocity

c. composition of air reaching item

d. temperature of air reaching item

The following examples point up the manner in which some of these factors influence the fire buildup in a burning fuel item. Flames spread more rapidly over furniture padded with foam rubber than over furniture padded with fibrous material. Similarly, fire builds up in an innerspring mattress to a much more intense level than in a solid cotton mattress because of differences in construction and configuration. Ignition of the lower portion of a fuel item usually results in faster buildup than occurs after ignition of an upper portion of an identical item. Fire buildup after a glowing ignition is slower than that following a flaming ignition even though the flaming ignition may be followed by a period where only glow persists. The presence of a wall can considerably enhance the buildup of fire in a fuel item even when the wall is non-combustible.

B. Effects of Fire Buildup in a Fuel Item

A burning item produces two outputs, heat and unburned fuel, which further the spread of fire. Heat may be released as radiant energy from the flames or hot surfaces of the item or in the form of hot gases. These gases will consist of the products of combustion, unburned combustibles, oxygen and nitrogen. The quantity of each output of the fire and the location of each output determine the ability of the burning item to ignite other items (including unburned portions of the ignited item), whether they be in direct contact or separated from the burning item.

C. Ignition of a Second Item

For a second item to ignite, it must absorb sufficient energy; the energy required is related to the rate at which energy is deposited and the physical characteristics of the material. The energy may be received by radiant or convective means or both. Pilot ignition may occur since the presence of a small flame or spark may result in a local hot spot which is sufficient to trigger the burning of a larger area receiving energy at a rate below that necessary for spontaneous ignition.

D. Interaction of Multiple Burning Items

When two or more items in a room are burning, the output of each fire will influence the local environment of the other(s). These influences take the form of radiant reinforcement, increased and redirected air motion (and perhaps flame locations) increased temperatures, and decreased oxygen.

E. Flashover Phenomena

Throughout the fire-buildup stages described above, hot fire gases containing unburned combustibles accumulate in the upper portion of the room. The ceiling, walls, and upper portions of much of the room contents are heated by these gases, as well as by direct radiation. It was previously thought that flashover comes about when the unburned gases suddenly ignite, causing flaming across the ceiling, a large increase in radiant and convective heating, and rapid ignition of preheated combustibles. Later sections of this report will show that flaming across the ceiling is indeed the mechanism which usually triggers flashover, but that this flaming is not caused by burnoff of accumulated combustible gases. Rather, the ceiling flames are merely extensions of the flames from the burning item caused by impingement against the ceiling. The energy released by this "flashover" adds to that already received by the remaining unignited room combustibles causing some or all of them to ignite. The degree of ignition of the remaining fuel at flashover has been described by the following terminology:

(1) Flashover - full involvement of combustible room contents

(2) Partial Flashover - full involvement of all combustibles within only a distinct portion of the room. This occurrence is common in large rooms.

(3) False Flashover - a momentary flaming over the ceiling which produces few if any new ignitions. The items do, however, approach ignition temperature after this exposure and a false flashover is normally followed by full or partial flashover within a short period of time. Apparently the first ceiling flaming is caused by the start of flame

impingement which is momentarily reinforced by combustion of the ceiling covering or trapped gases, or both. After these combustibles are consumed, the flames recede for a short period until the fire intensity increases and the flames spread over the ceiling due to impingement alone.

1. Full Involvement

After full involvement of room combustibles, the burning behavior is influenced by the relative values of fuel-surface area, window-opening area, and room volume. With high ventilation and low fuel surface the burning is said to be fuel-surface controlled and the individual fuel items burn with limited interaction. As the ratio of fuel surfaces to ventilation increases, the apparent interaction increases until fully coalesced burning is achieved. In a completely ventilation controlled fire, it is impossible to associate any portion of the flames with any one fuel item. As the degree of ventilation is further reduced, a state is reached where flaming essentially ceases and a smouldering fire results.

2. Partial Involvement

Each condition described above can occur with just a portion of the room space burning. The restriction of the fire to a segment of the room can come about because of the amounts and distributions of fuel and vent openings.

III. PROBLEM APPROACH

One approach to generalizing the "conditions" for flashover, in order to eventually predict its occurrence and the time required, would be to accumulate statistical data by burning many combinations of room contents in all sizes and shapes of rooms with various coverings, ventilation conditions, etc. but this is time consuming and thus undesirable. It was practical in past experiments at IITRI(2) to accumulate such statistical data on real rooms since the kinds of items ignited, the room size, and the ventilation conditions were such that flashover always occurred very soon after the onset of active burning of the ignited item. In reality, measurements were made of the time needed to reach the active burning stage for the types of burning items being considered. No information was gathered to indicate the effect of less intense fires or larger room spaces on the probability or time of occurrence of flashover.

The approach developed and being used for this study is to study a limited series of real room fires, duplicate these fires with simplified fuel arrays, and then establish reduced scale simulations using the simplified fuels. Several "standard" fires selected in the process will then be used at the smallest possible scale to evaluate the effect of changing parameters such as room size, ceiling height, location and size of ventilation openings, combustibility of wall and ceiling covering, and insulative quality of walls and ceiling. The present report covers the full scale fires with both real and simplified fuel arrays. It is anticipated that scaling studies will be completed during the second year's effort and that studies in the third year will concentrate on parametric variations at reduced scale.

IV. EXPERIMENTS

A. Experimental Facility

The full-scale room fires were conducted in an instrumented test chamber selected to represent a typical residential room size. (See Fig. 1) The chamber is 12 ft x 12 ft x 8 ft high of wood joist framing. Aluminum sheets are attached to the inside of the frame and, in turn, their inner surfaces are covered with a silica-asbestos board.(3) The resulting structure withstands successive fire buildups quite well with only occasional repairs. The room is located against one end of a laboratory space 25 ft x 100 ft x 18 ft high such that the window openings from the experimental room can be made to the laboratory interior and/or to the outside. Thus, the laboratory space can be used to provide a large quiescent air volume when desired. Each window opening is 4 ft wide and extends from the floor to within 18 in. of the ceiling. Various inserts provide reduced opening sizes or complete closure of either window.

Instrumentation locations are shown in Fig. 2. TC 1 - 20 are Chromel-Alumel thermocouples to measure approximate gas temperatures. These thermocouples were not shielded

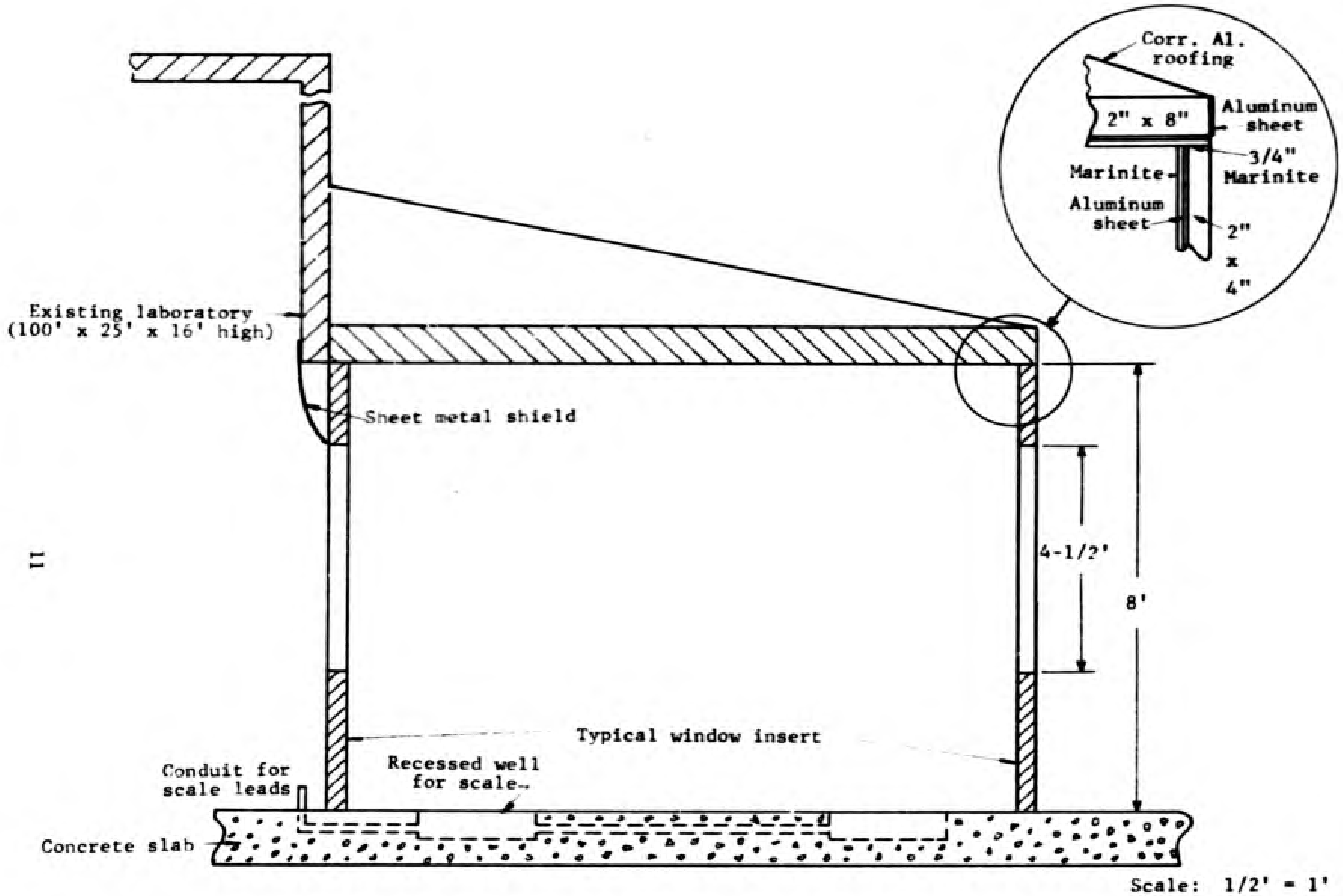


Fig. 1 SCHEMATIC OF DASA TEST CELL

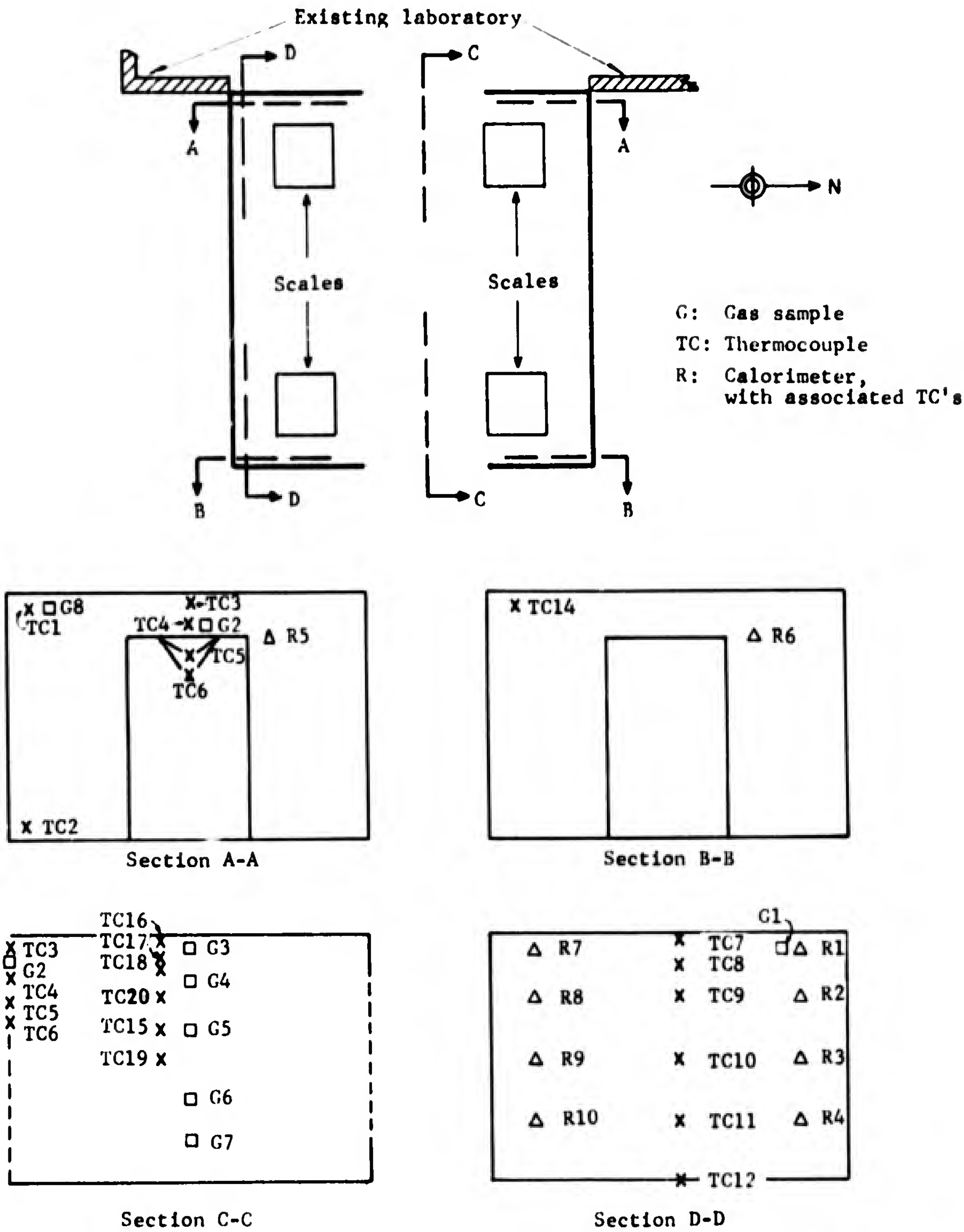


Fig. 2 INSTRUMENTATION, DASA TEST CELL

and thus are subject to some radiation errors. They serve to describe horizontal temperature profiles near the ceiling and vertical profiles near the wall and near room center. Some comparisons of horizontal temperature profiles are obtained at other heights.

Other thermocouples were placed in pairs near each calorimeter location within the room. The first of each pair was cemented to a groove in the wall surface, and the second thermocouple monitored gas temperature about two inches from the wall. These served to indicate the time lag between the temperature rise of the walls and that of the room gases, and provided a means of relating the convective heating indicated by the calorimeter to the convective heat actually being picked up by the walls.

R1 through R10 denote calorimeter locations. These units were developed in the course of the program and measure both radiant and convective heat flux. A detailed description of their construction and operation is given as Appendix A.

G1 through G8 indicate the points at which gas samples were drawn from the room. These samples were sequentially passed through a set of continuous analyzers where O_2, CO, and CO_2 contents were measured. Occasional samples were collected and analyzed for other combustibles on a batch basis.

Recesses were provided in the floor of the room to accommodate weight-measuring devices. These were small industrial scales in which the rotating dial was removed and replaced with a low-torque potentiometer. This permitted remote recording of the weight of burning combustibles in the room.

In addition, 16 mm color photographic records were taken of the active portions of the fires. This was usually done with two cameras, one directed toward the ignition source and the second directed toward the far side of the room. A clock was included in the pictures to relate them to the other records.

B. Schedule

The experiments generally fall into two categories: those involving real room contents, and those involving simplified fuel arrays (synthetic fires). For a complete listing of experiments see Appendix B.

In the first series, each experiment used a single chair or a single crib in the room. This series served to establish the adequacy of instrumentation for describing the spatial variation of conditions within the room. Following these experiments, some modifications and additions of instrumentation were made, resulting in the system described earlier and shown in Fig. 2.

Fully-loaded, real-room fires were then undertaken. These involved living room, bedroom, and storage-area configurations.

(1) Living Room

Figure 3 shows typical living room arrangements for couches placed at rear or side walls with respect to the open window. A third arrangement was used in which the couch was placed beneath the window opening. In each case, the couch was placed on a weighing platform and served as the ignited item. Couches padded with either cotton batting (conventional) or with foam rubber were used. These two categories were considered since past experience has shown a marked difference in their rates of fire buildup. Several burns were also included in which two chairs were placed on the platform with a small table between them.

Four ventilation areas were used. These consisted of window openings 4 ft wide x 4-1/2 ft high, 2 ft x 4-1/2 ft, 4 ft x 3 ft and 4 ft x 1 ft. In all cases, the bottom of the opening was 6 ft below the ceiling.

(2) Bedrooms

An example of a bedroom furniture layout is shown in Figure 4. Due to their ready availability, T.V. cabinets were substituted for dressers and chests. All beds were assembled with wooden head and foot boards, and all had box springs and mattresses. Bedclothes consisted of a sheet, blanket and bed spread which were the ignited items. The four ventilation areas listed previously were used.

(3) Storage Areas

The storage areas were designed to represent a

(Note - Miscellaneous clothing and newspapers placed on coffee table, TV cabinets, and chairs. Wood trim and mouldings added to corners of room).

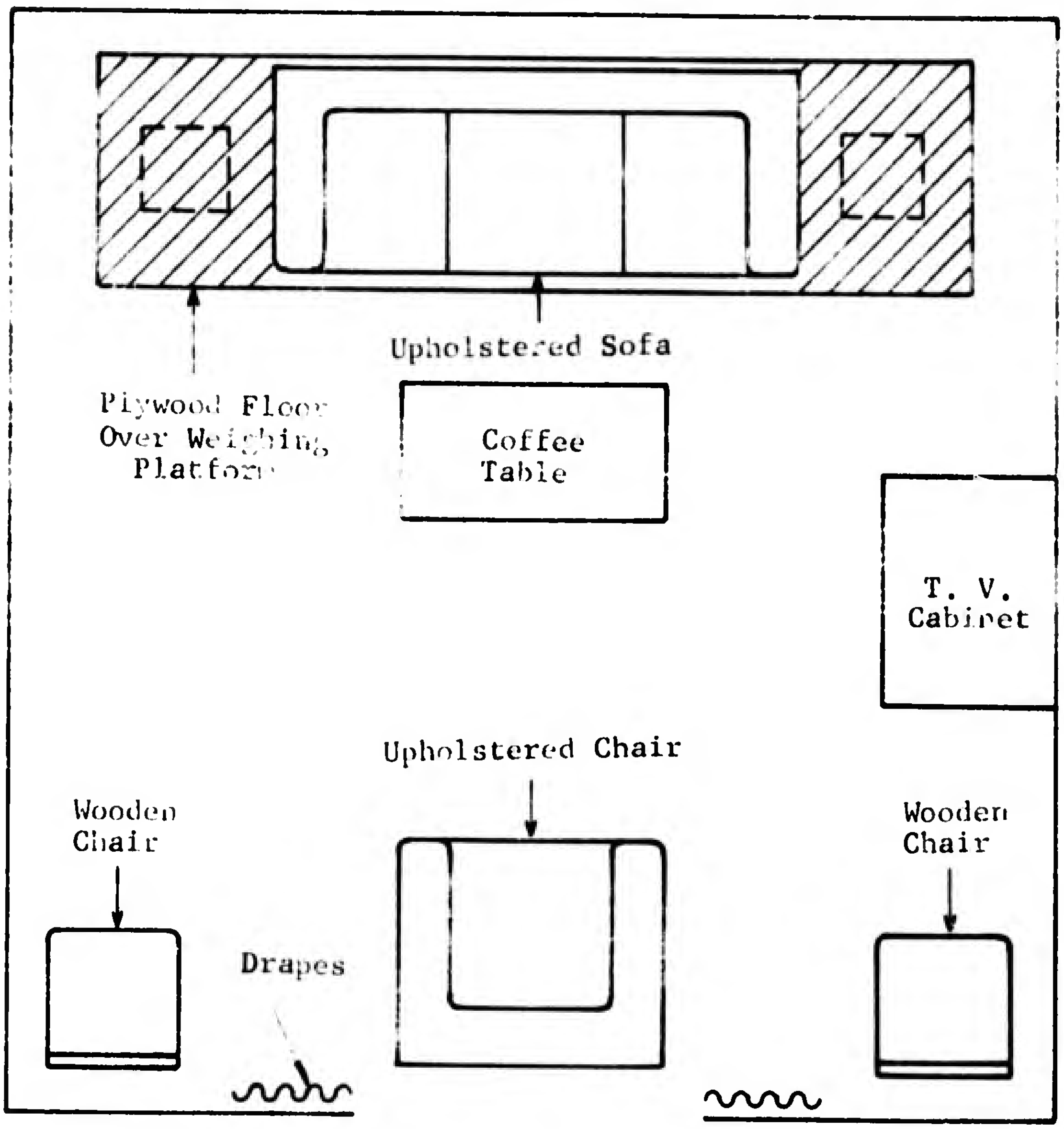


Fig. 3A TYPICAL FURNITURE ARRANGEMENT FOR LIVING ROOM - COUCH AT REAR

(Note: Miscellaneous clothing and newspapers placed on coffee ·able, T.V. cabinet and chairs. Wood trim and mouldings added to corners of room.)

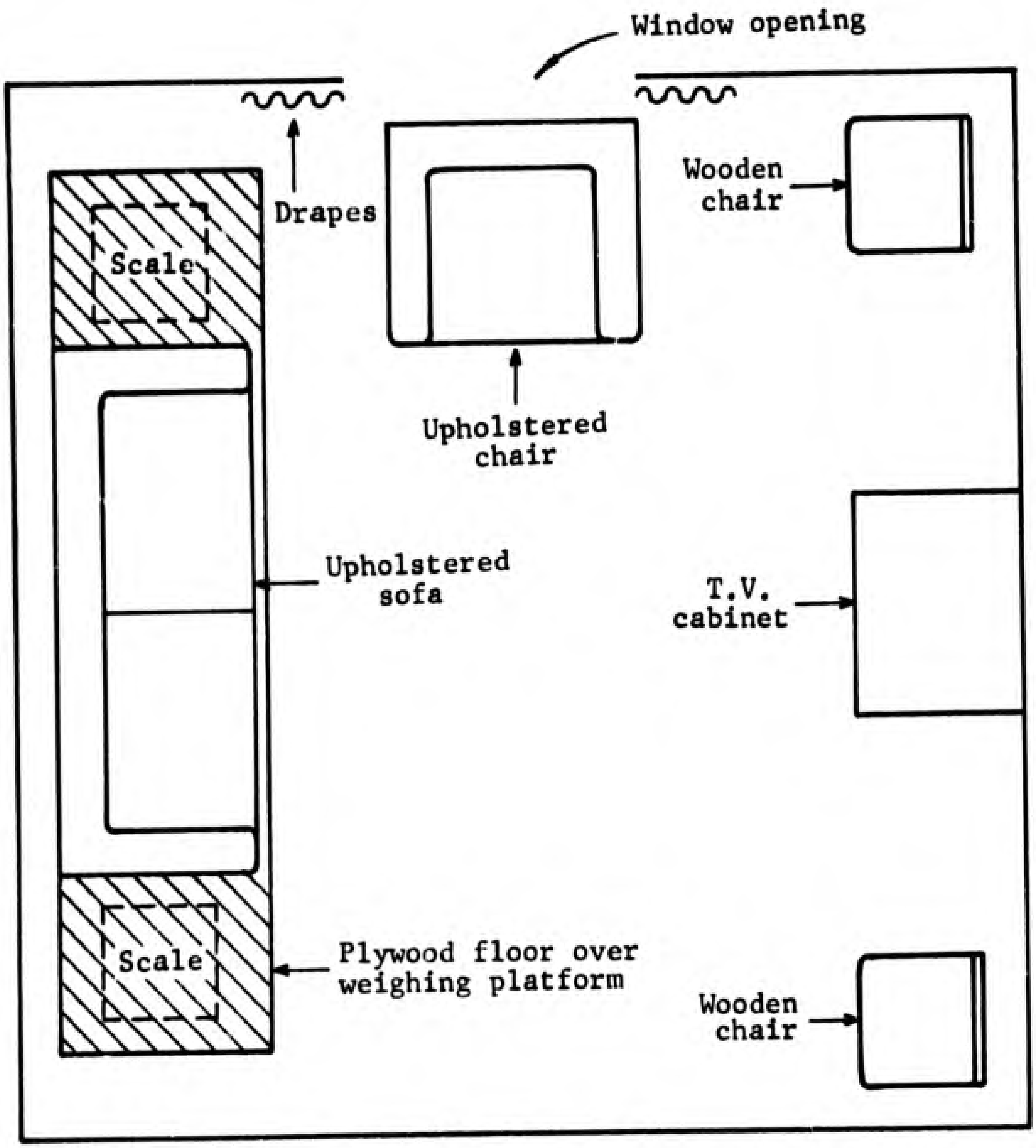


Fig. 3B TYPICAL FURNITURE ARRANGEMENT FOR LIVING ROOM, COUCH AT SIDE

(Note: Miscellaneous clothing and newspapers on chairs.
Wood trim and mouldings added to corners of room.)

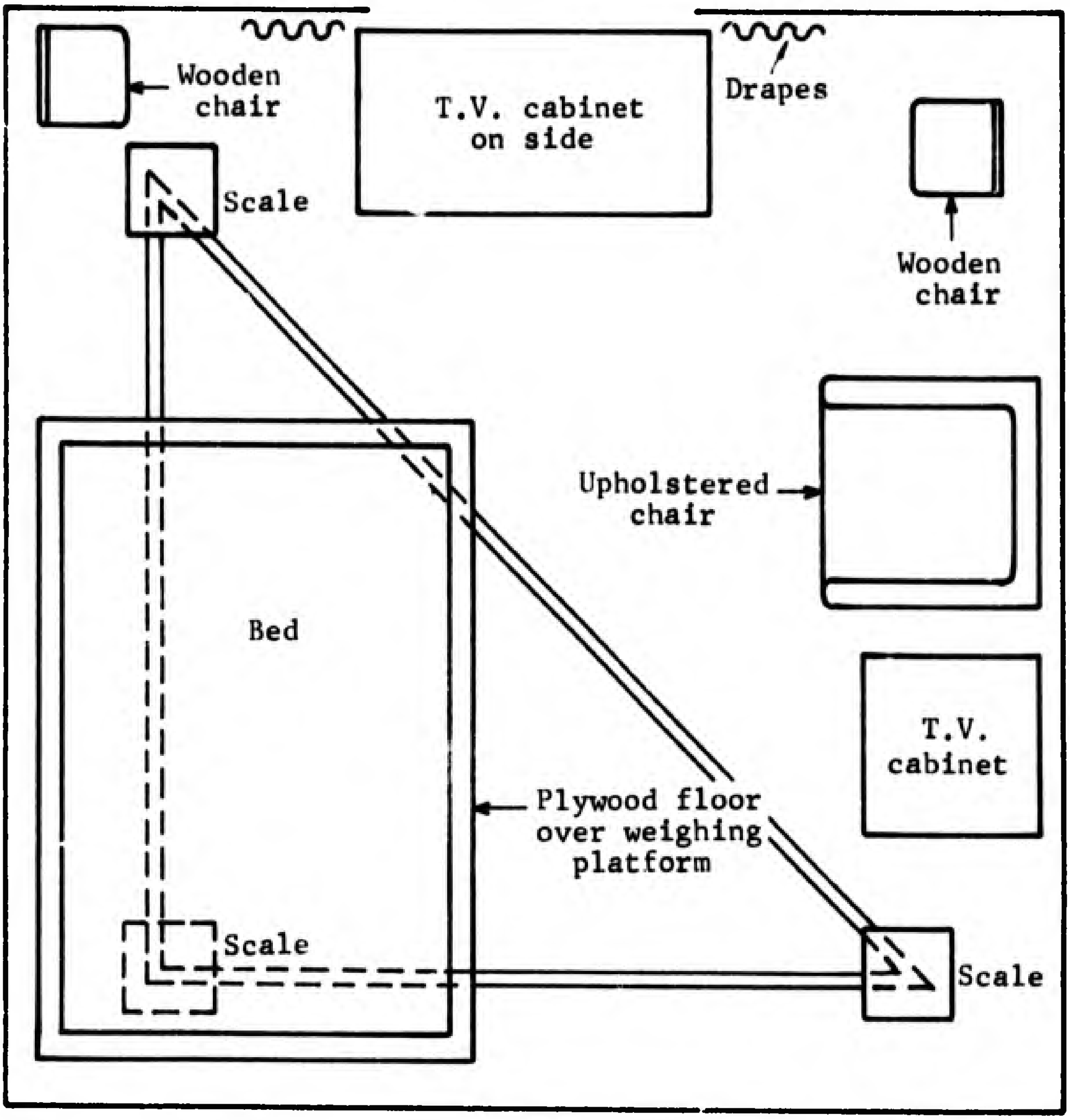


Fig. 4 TYPICAL FURNITURE ARRANGEMENT FOR BEDROOM

mixture of combustible and non combustible materials placed in cardboard cartons having varying amounts of combustible packing and stored on shelves. As shown in Figure 5, only the initially-ignited row of shelves was completely loaded. Those shelf areas which were to ignite at or near flashover were duplicated only as to the exposed fuel surface and no attempt was made to provide a long burning fuel supply at these locations.

(4) <u>Crib Fires</u>

These fires duplicated the fuel arrangement of a living room except that the couch was replaced by a crib. They provided a gradual, fairly-constant rate of fire buildup to a controllable (by selecting crib size) maximum.

Most of the real room fires progressed to flashover. As flashover was reached, conditions were often changing quite rapidly indicating a flashover capability of many of the ignited items much in excess of that required for the test room. To obtain a more complete picture of this capability, a third series of fires was conducted involving individual items of furniture in the room. These included chairs, couches, beds, storage shelves, and cribs. Small sections of newsprint were attached to the far walls of the room. Flaming ignition of these sheets indicated when flash-over would have occurred but did not appreciably disturb the conditions of the room so that the outputs of the burning item could be monitored beyond the flashover point. The crib fires, included in this series, also served as a first step in develop-

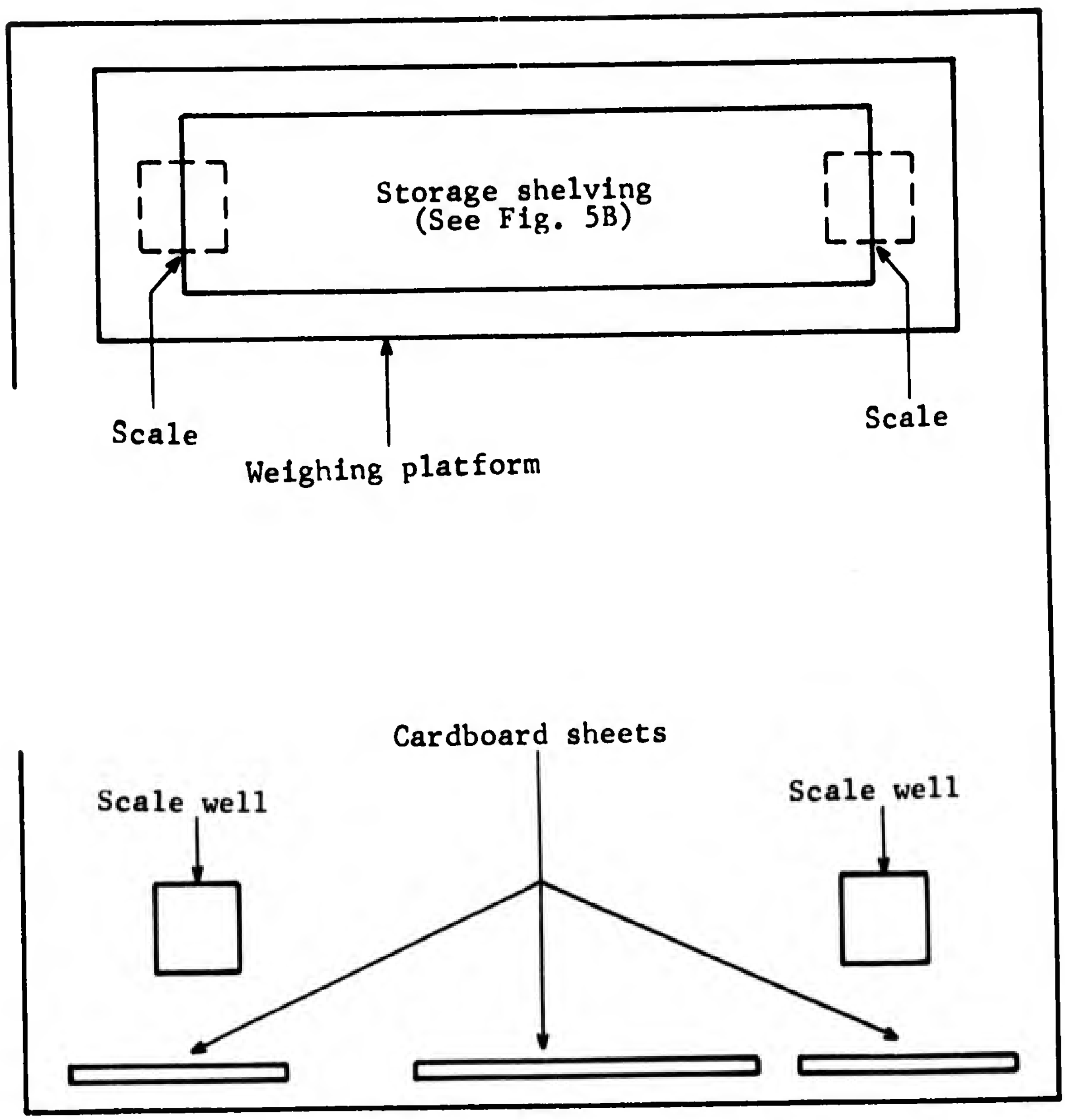


Fig. 5A TYPICAL ARRANGEMENT FOR STORAGE SPACE

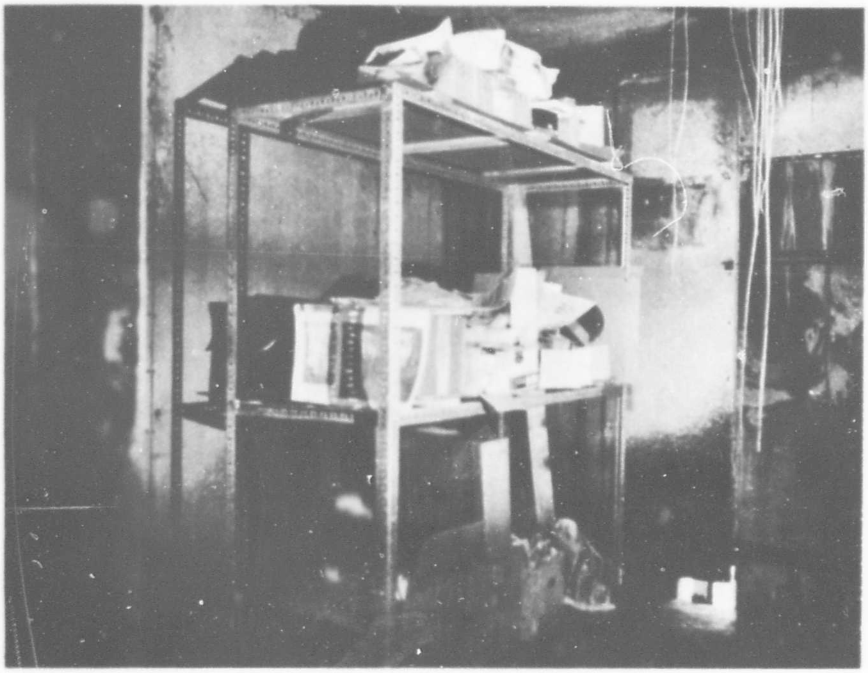


Fig. 5B PHOTOGRAPH OF STORAGE SHELVING
(INITIATED ON LOWEST SHELF)

ing the simplified fuel array.

Although the crib fires showed promise of matching the outputs of the real furniture fires, gas burners were investigated before studies of the effects of crib height, stacking, density, etc. were completed. The use of a gaseous fuel offered full control over the burning rate and was thus considered more desirable. Several burner designs were tried involving various nozzle sizes and flame spreaders. A simple system of six-1/2 inch pipes was selected for further investigation. Experiments were performed at various total gas flow rates through one, two, three, or six burners.

Experiments were then performed in which the burners were controlled to duplicate the total heat fluxes received by calorimeters across the room from several of the real furniture fires. It was found that radiant and convective heating from real furniture fires could be duplicated simultaneous by the gas burners. To compare the outputs of several real furniture items to the gas burners without the influence of the room confinement, several fires of each type were conducted in the center of the main laboratory (25 x 100 x 18' high) where the hot combustion products would not significantly heat the structure.

The final series of experiments was performed to obtain detailed records of the room conditions for various gas flow rates. From these experiments, the reference or standard fires were selected for the scaling studies to be conducted during the second year of the program.

V. RESULTS

The experimental schedule given in Chapter IV is a chronological summary of the experiments and their specific purposes as defined at the time they were conducted. This is elaborated in Appendix B, which is a descriptive listing of the experiments along with a limited selection of the measured results. Due to the enormous quantity of data generated by the experiments, simplified means of data handling and reduction were employed and, where possible, the raw data were examined directly as recorded. A complete reproduction of all data acquired is not given here. Instead, representative samplings are presented of the real-room conditions, along with portions of the results that led to specific conclusions. Finally, this chapter will show the conditions generated with the LP gas burners, from which the "standard" fires were selected for use in the future scaling studies.

A. Fire Buildup In Real Furnishings

In many of the fires involving real furniture items, the early part of the buildup period produces little heating or combustion products in the room. Only after the interior of the ignited item is actively involved does the fire seriously affects its surroundings (remaining room contents, walls, ceiling, etc.). At this time, the fire often becomes significantly larger than the minimum required for flashover with the result that the interior conditions change very rapidly up through room flashover. While resulting in a sharply defined flashover time, this type of behavior makes the establishment of room conditions at flashover difficult to assess, since instrumentation limitations require that the bulk of the data be taken sequentially. Where buildup was less rapid, this difficulty decreased; and for those cases where flashover was not quite reached, the time period for recording data was well extended.

1. Gas and Temperature Profiles

Figure 6 shows the changes with time of spatial concentration and temperature profiles in the gas, for a fire involving a couch. In this case, buildup was gradual near the flashover level and, in fact, the remaining room combustibles ignited over a period of several minutes. Figures 7, 8, and 9 are profiles for couch burns taken shortly before flashover. The effects of reduced ventilation are easily seen in Figure 9. Similar plots for a crib fire and a bed fire are shown in Figures 10 and 11. In each case, a general homogeneity can be noted in the upper part of the room with a rather sharp change in magnitude at the neutral density plane (near midheight). In several of the records a slight increase in CO and decrease in O_2 can be noted near midheight. This was caused by the warm distillation products rising through the cooler lower air to the neutral density plane where they tended to spread out. This phenomenon could be observed visually in storage area fires which built up rapidly.

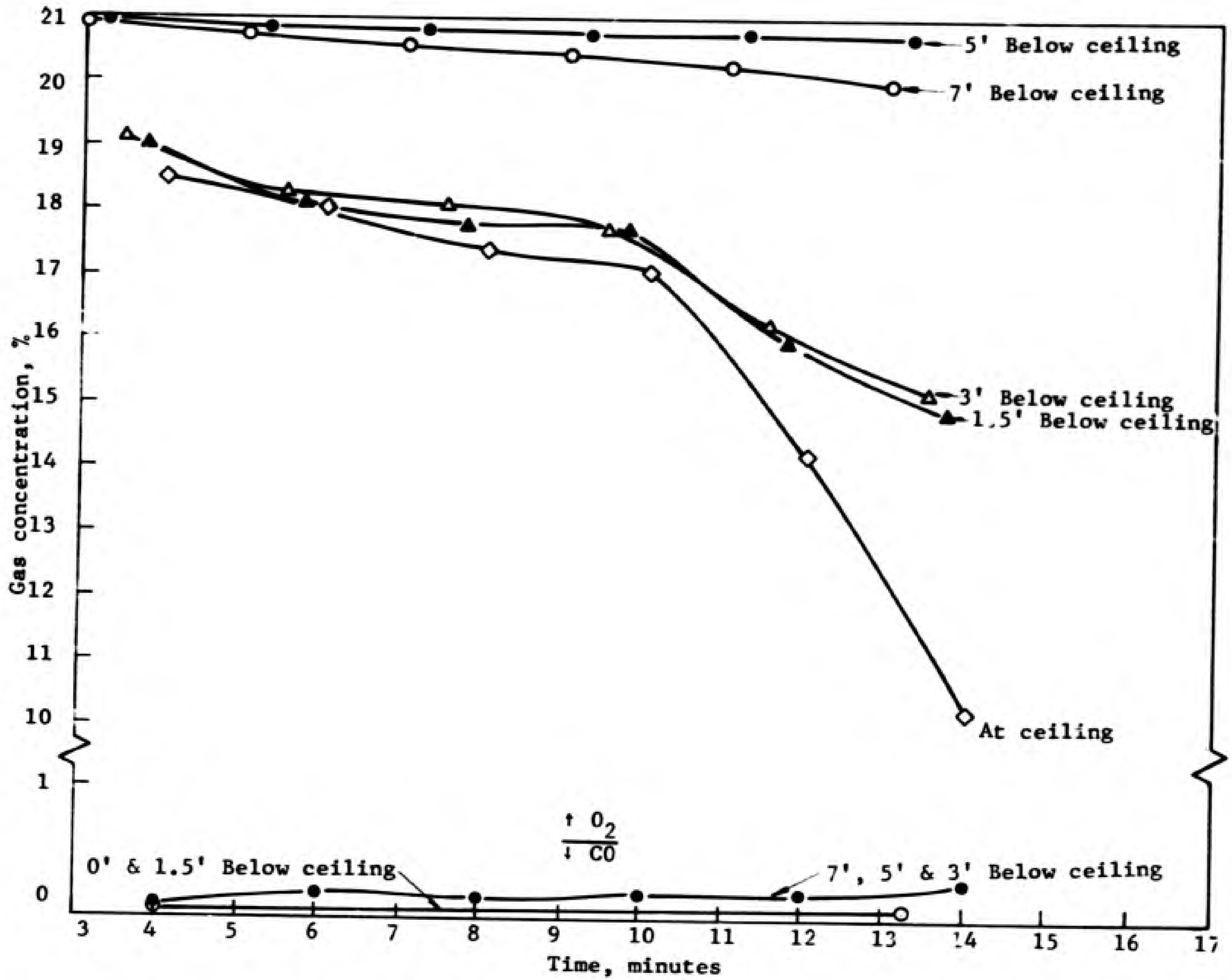


Fig. 6A TEMPORAL AND SPATIAL VARIATION IN GAS CONCENTRATION AT ROOM CENTER FOR A COUCH FIRE (DASA-019)

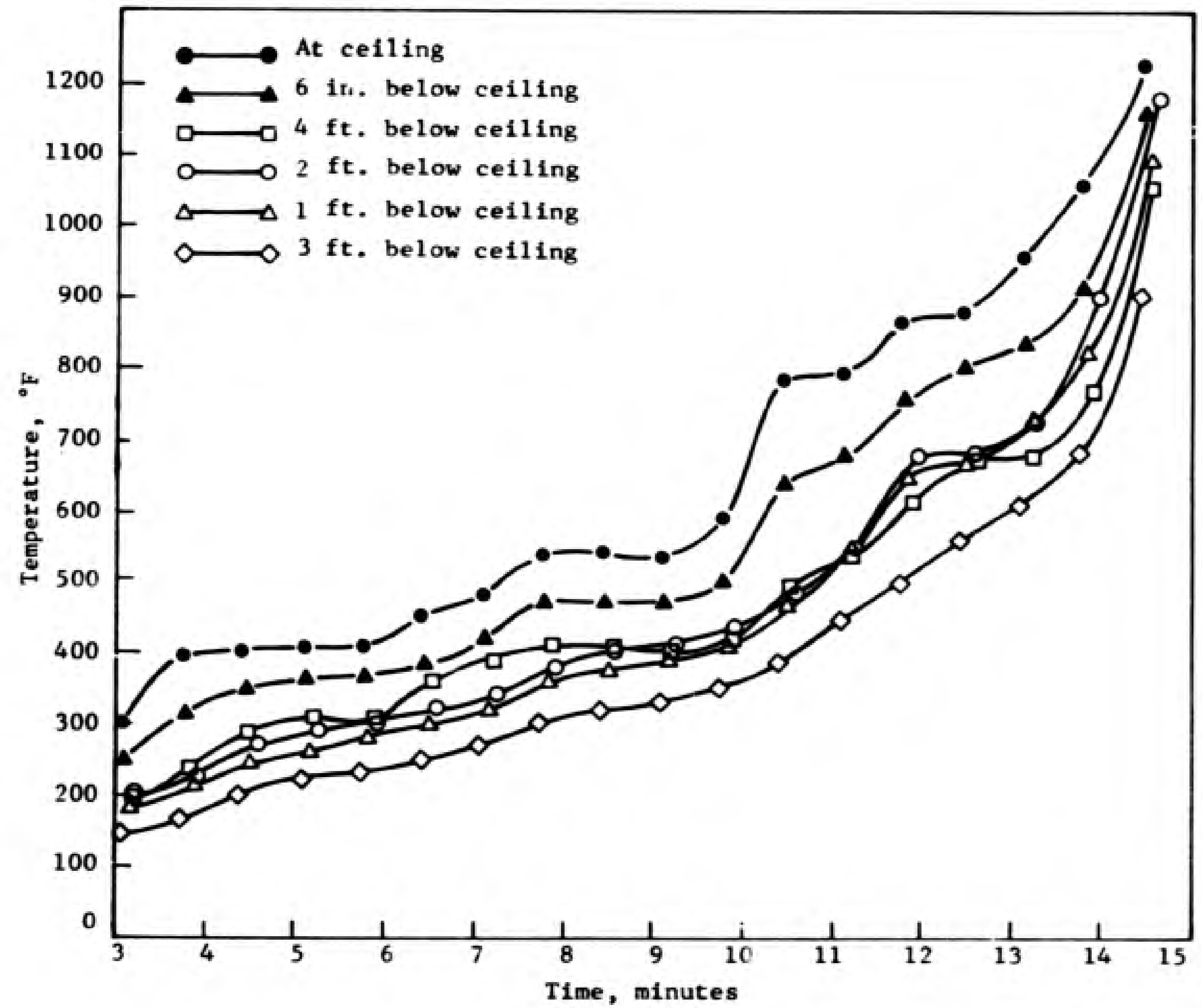


Fig. 6B TEMPORAL AND SPATIAL VARIATION IN TEMPERATURE AT ROOM CENTER FOR A COUCH FIRE (DASA-019)

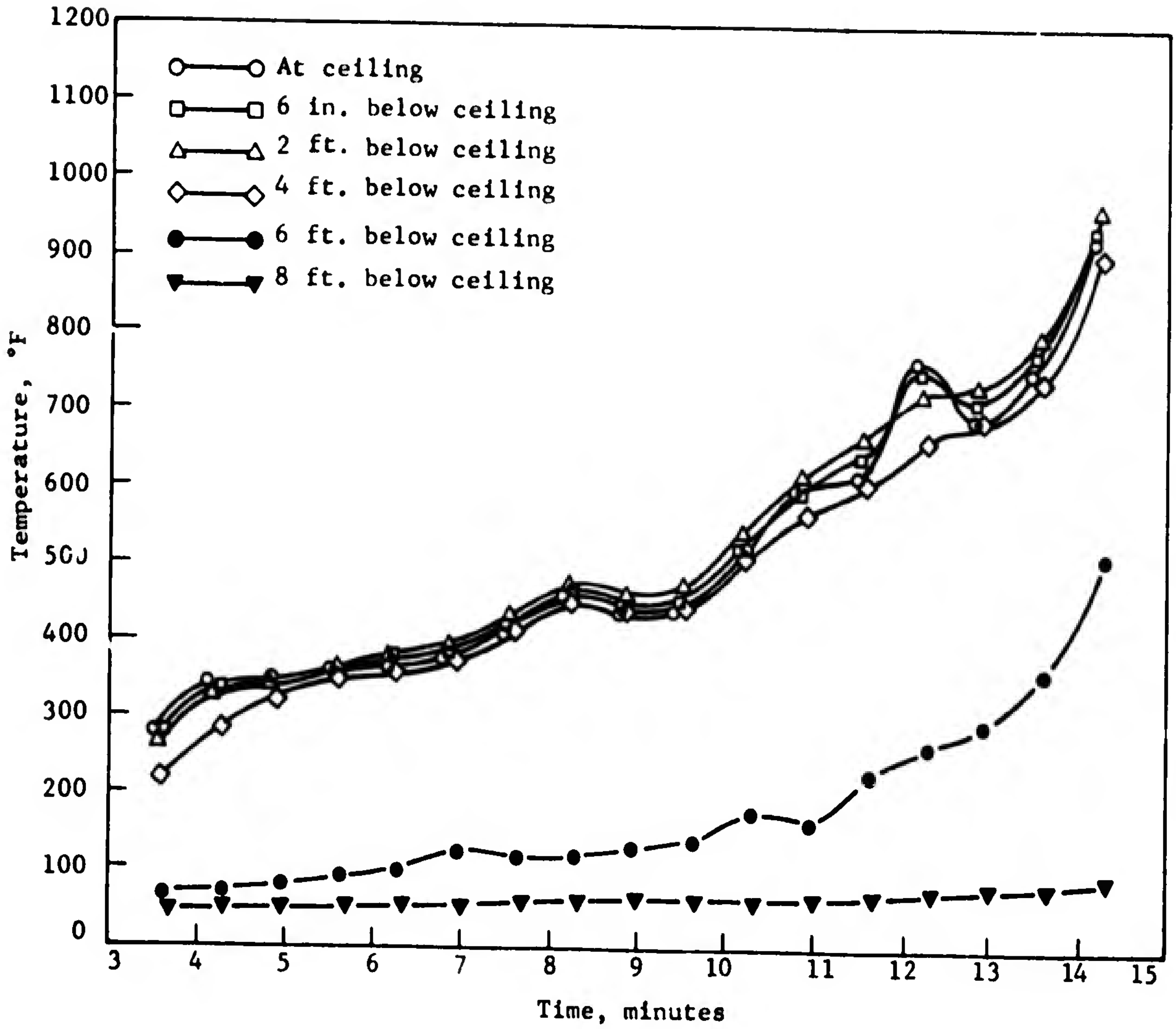
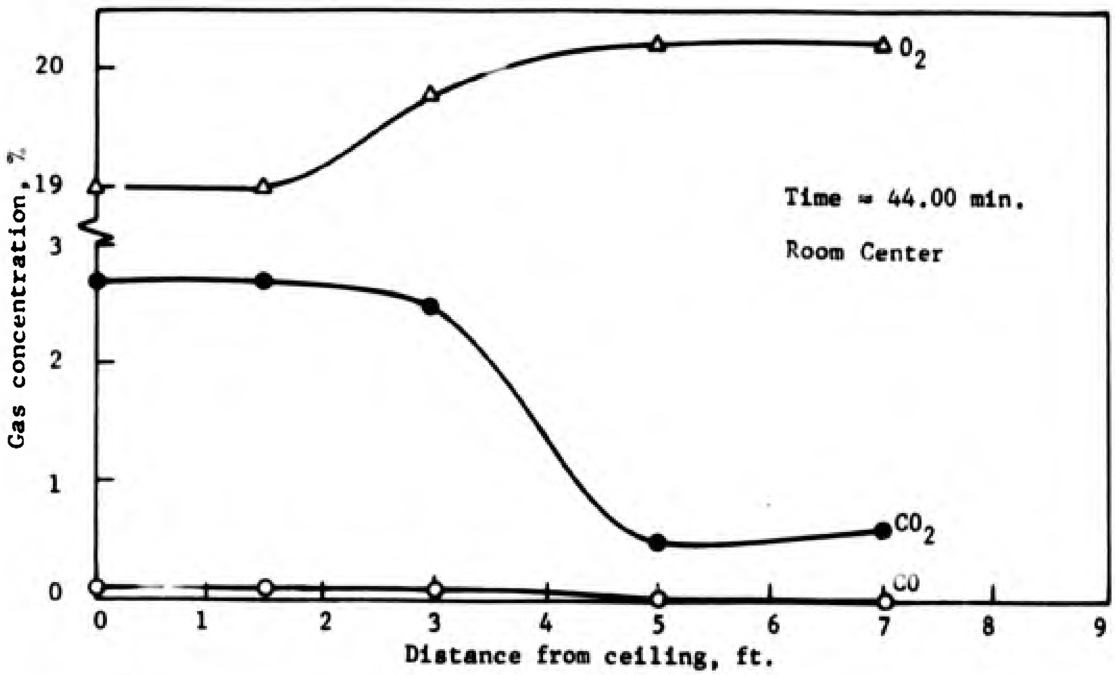


Fig. 6C TEMPORAL AND SPATIAL VARIATION IN TEMPERATURE ACROSS ROOM FROM A COUCH FIRE (DASA-019)



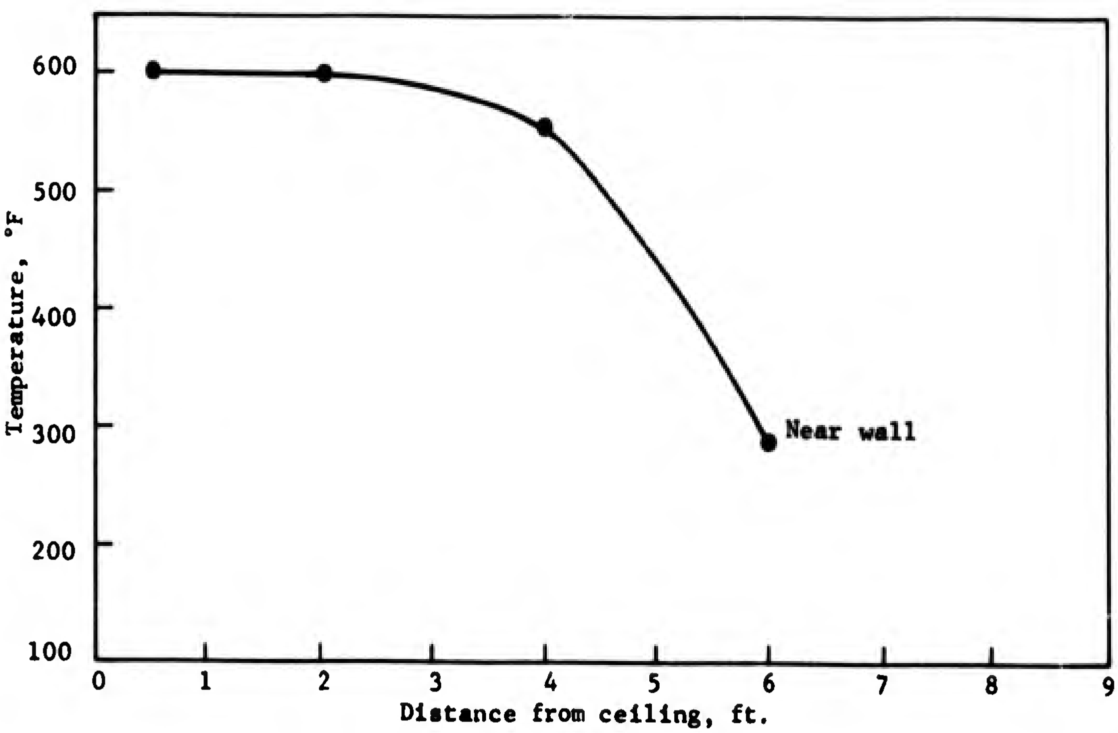


Fig. 7 VERTICAL PROFILES OF GAS CONCENTRATION AND TEMPERATURE SHORTLY BEFORE FLASHOVER, DASA-071 (COUCH), 4-1/2 FT. WINDOW OPENING

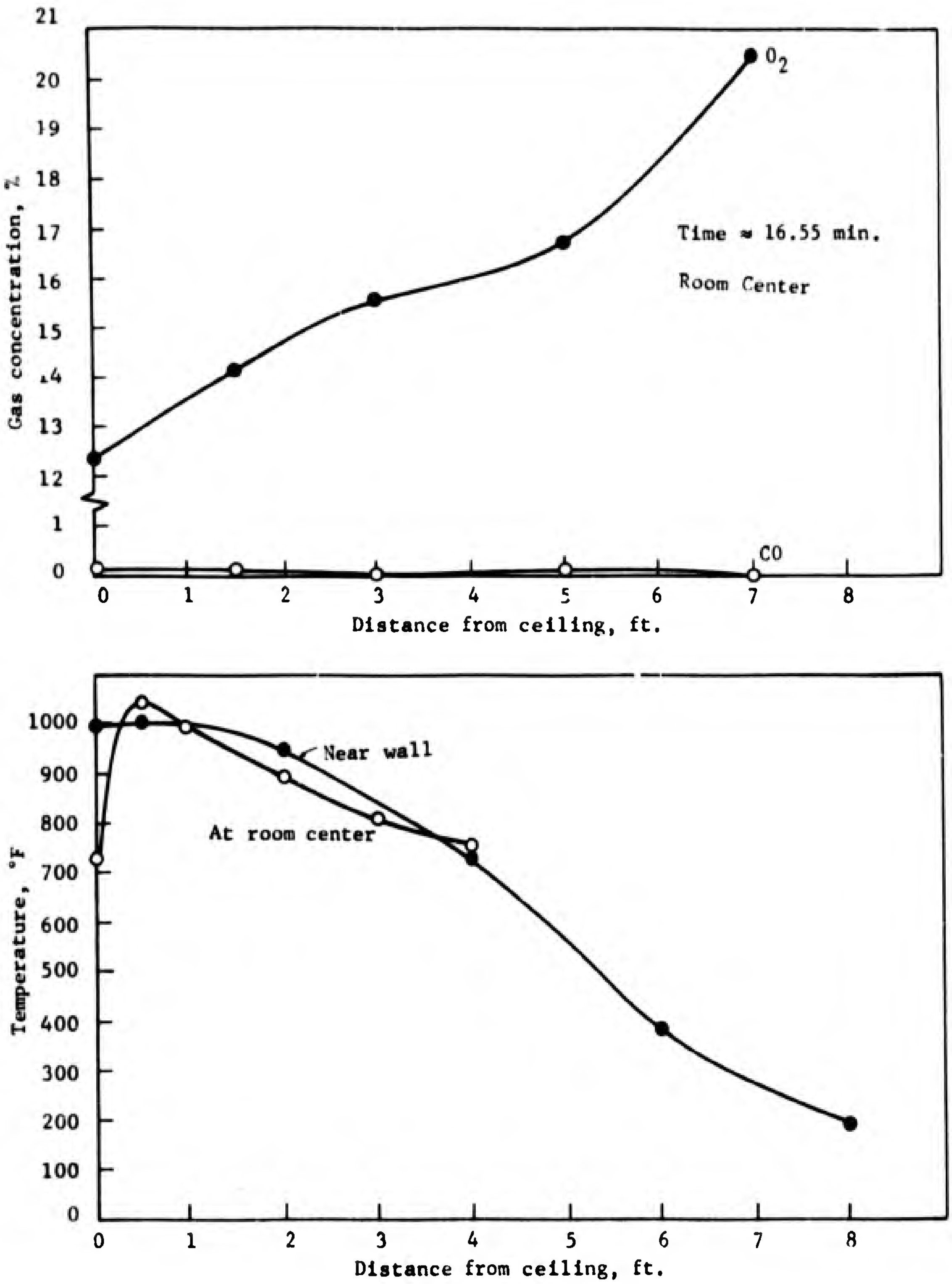


Fig. 8 VERTICAL PROFILES OF GAS CONCENTRATION AND TEMPERATURE SHORTLY BEFORE FLASHOVER, DASA-030 (COUCH), 3 FT. WINDOW OPENING

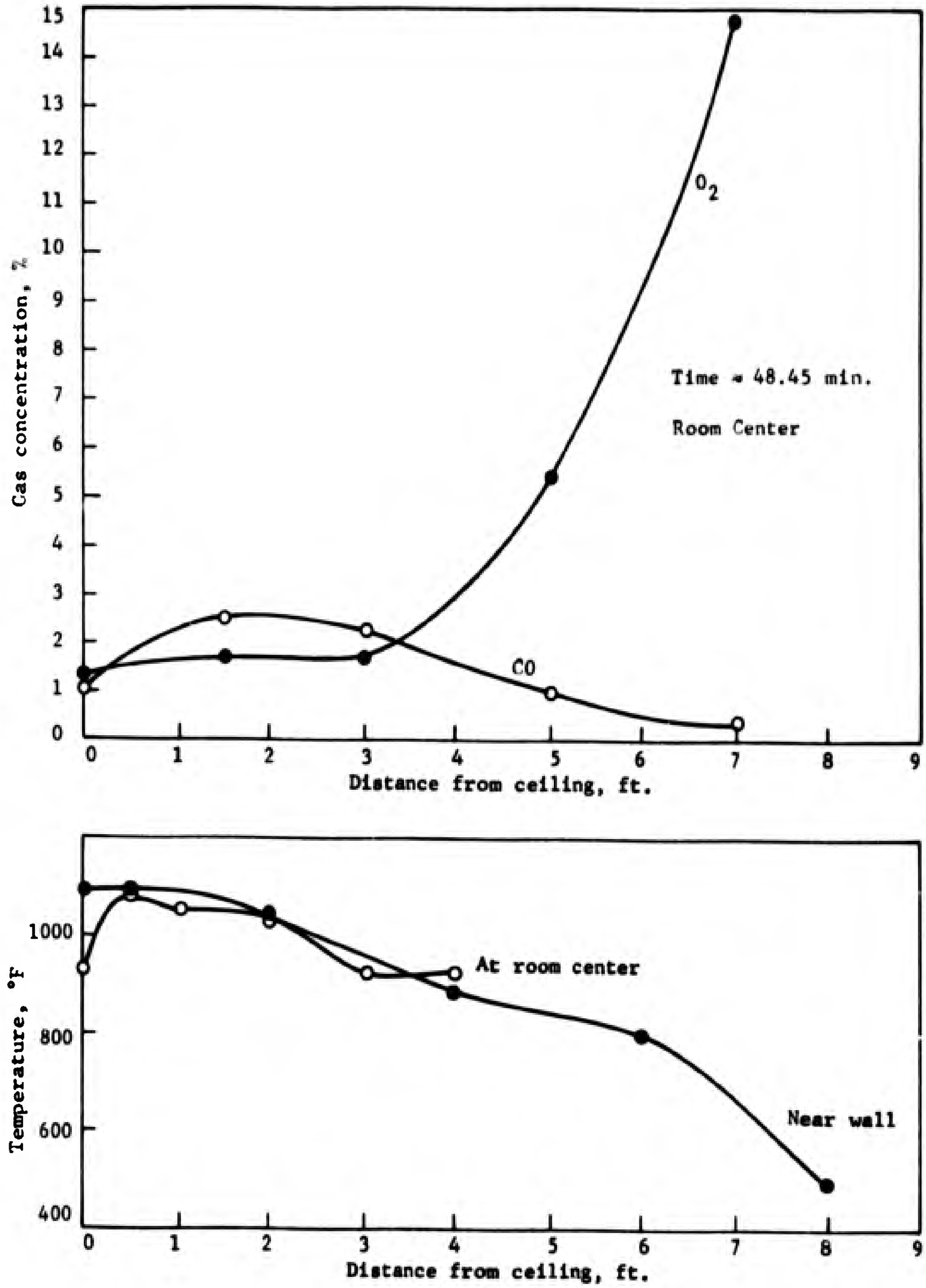


Fig. 9 VERTICAL PROFILES OF GAS CONCENTRATION AND TEMPERATURE SHORTLY BEFORE FLASHOVER, DASA-033 (COUCH), 1 FT. WINDOW OPENING

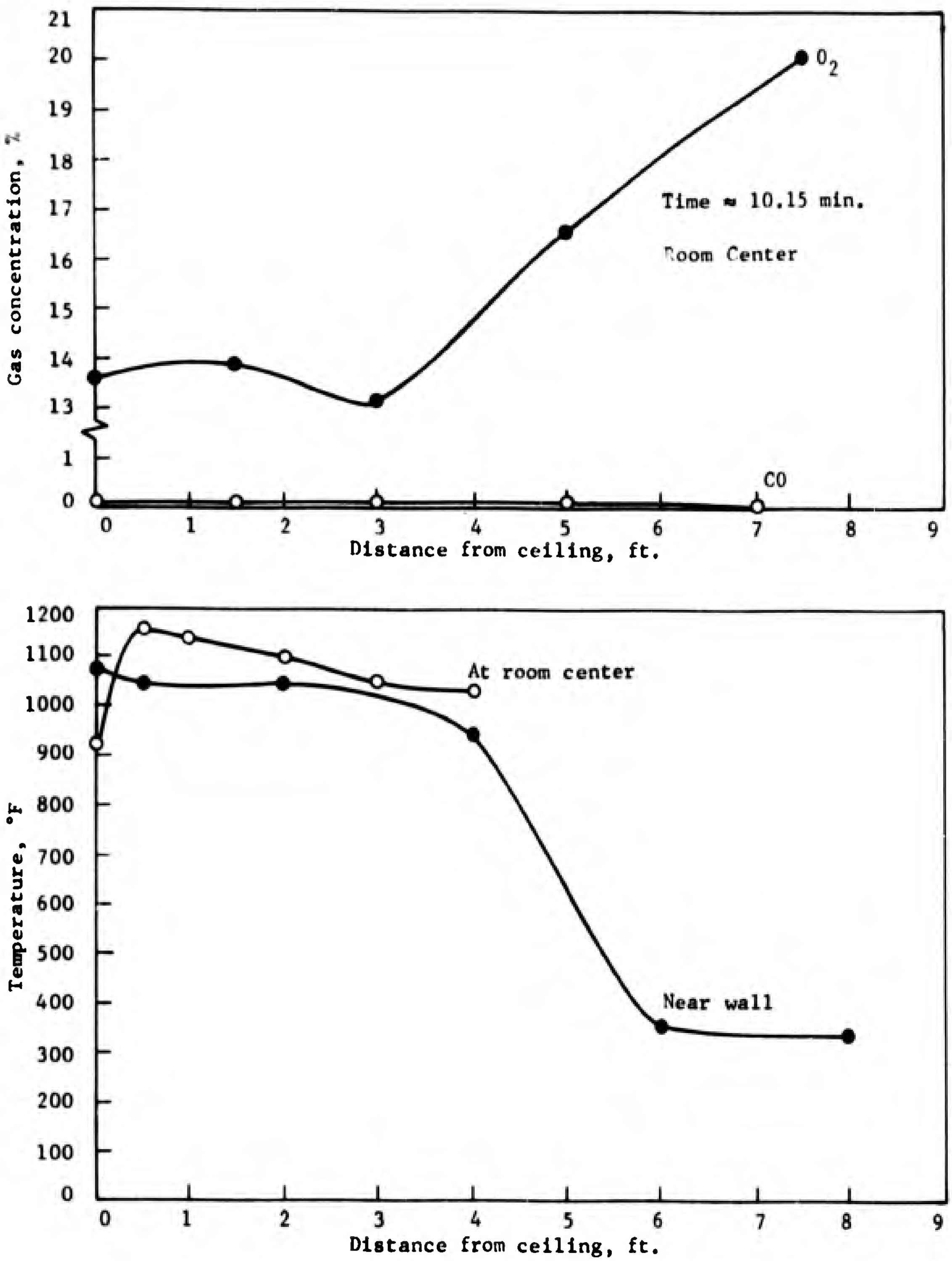


Fig. 10 VERTICAL PROFILES OF GAS CONCENTRATION AND TEMPERATURE SHORTLY BEFORE FLASHOVER, DASA-038 (CRIB), 4-1/2 FT. WINDOW OPENING

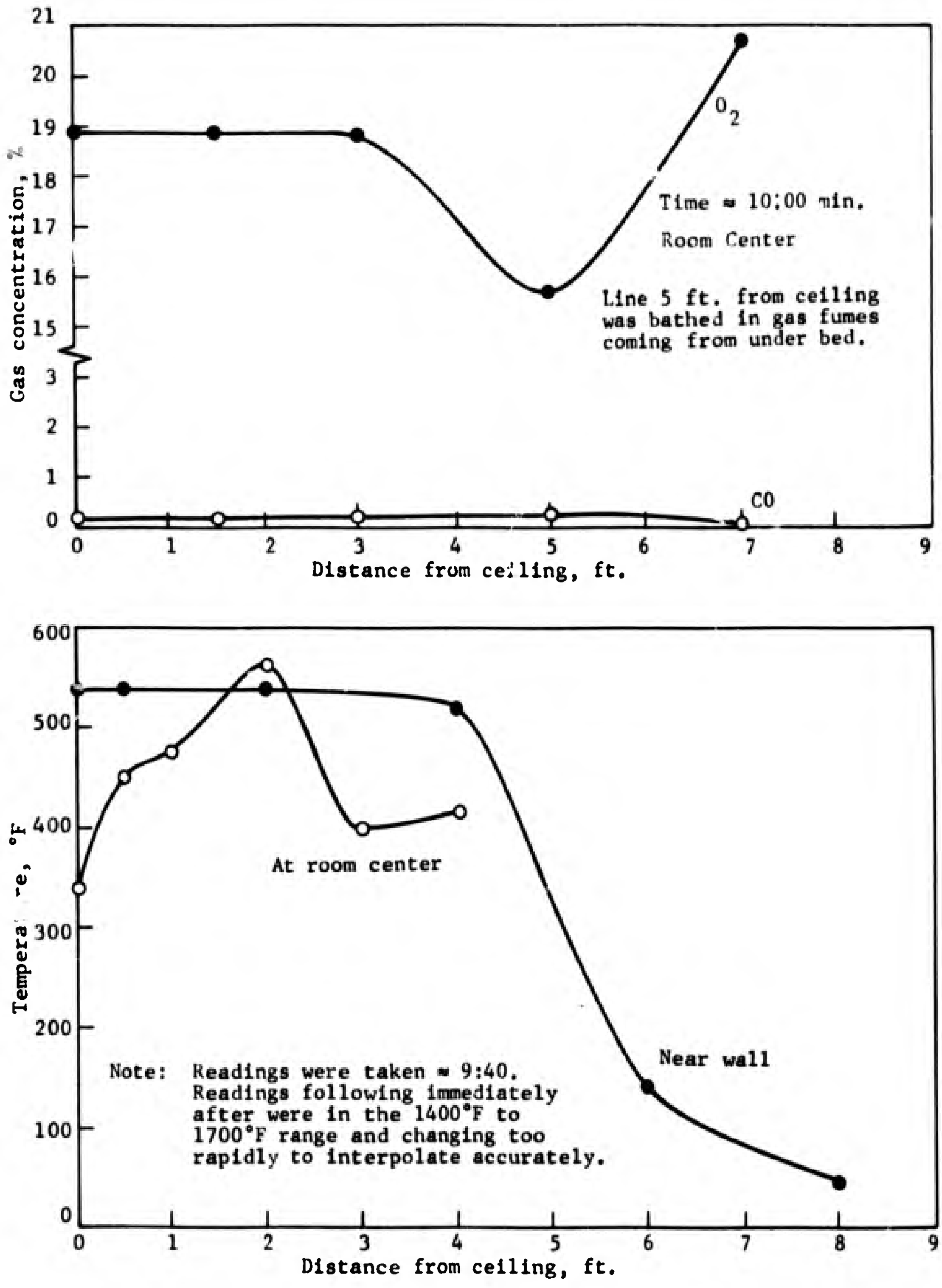


Fig. 11 VERTICAL PROFILE OF GAS CONCENTRATION AND TEMPERATURE SHORTLY BEFORE FLASHOVER, DASA-041 (BED), 4-1/2 FT. WINDOW OPENING

For several fires, gas concentration was monitored continuously at room center near the ceiling. Figures 12, 13 and 14 are examples of these records for couch and bed fires. Temperature records are also shown. Figure 14 (bed) shows rather rapid buildup after one false start and die-back period.

2. Calorimetry

Rapid buildup of the fires after an extended period of low intensity is most evident in the calorimeter records. Figures 15 through 18 are examples of the radiant and convective heat fluxes received across the room from burning conventional couches, foam-padded couches, beds, and storage shelves, respectively. As might be expected, the convective heat flux is smallest in the lower portion of the room. Also, as the total heat flux increases with time, the radiant flux becomes a higher proportion of the total. On each figure, the time of ignition of several thicknesses of newsprint placed adjacent to the calorimeter located 2 ft below the ceiling is noted. In these burns and in most others, the radiant flux exceeded the convective flux when ignition of the newsprint occurred. The total flux level for newsprint ignition is fairly high for these burns where fire buildup is quite rapid. Examination of records for slower fire buildup (Figure 19) shows that a long exposure at lower flux level will also cause ignition. Detailed quantitative study of this phenomenon is being done elsewhere[(4)]. Further examples of heat-flux levels 2 ft below the room ceiling are shown in Figures 20 through 24. Figure 20

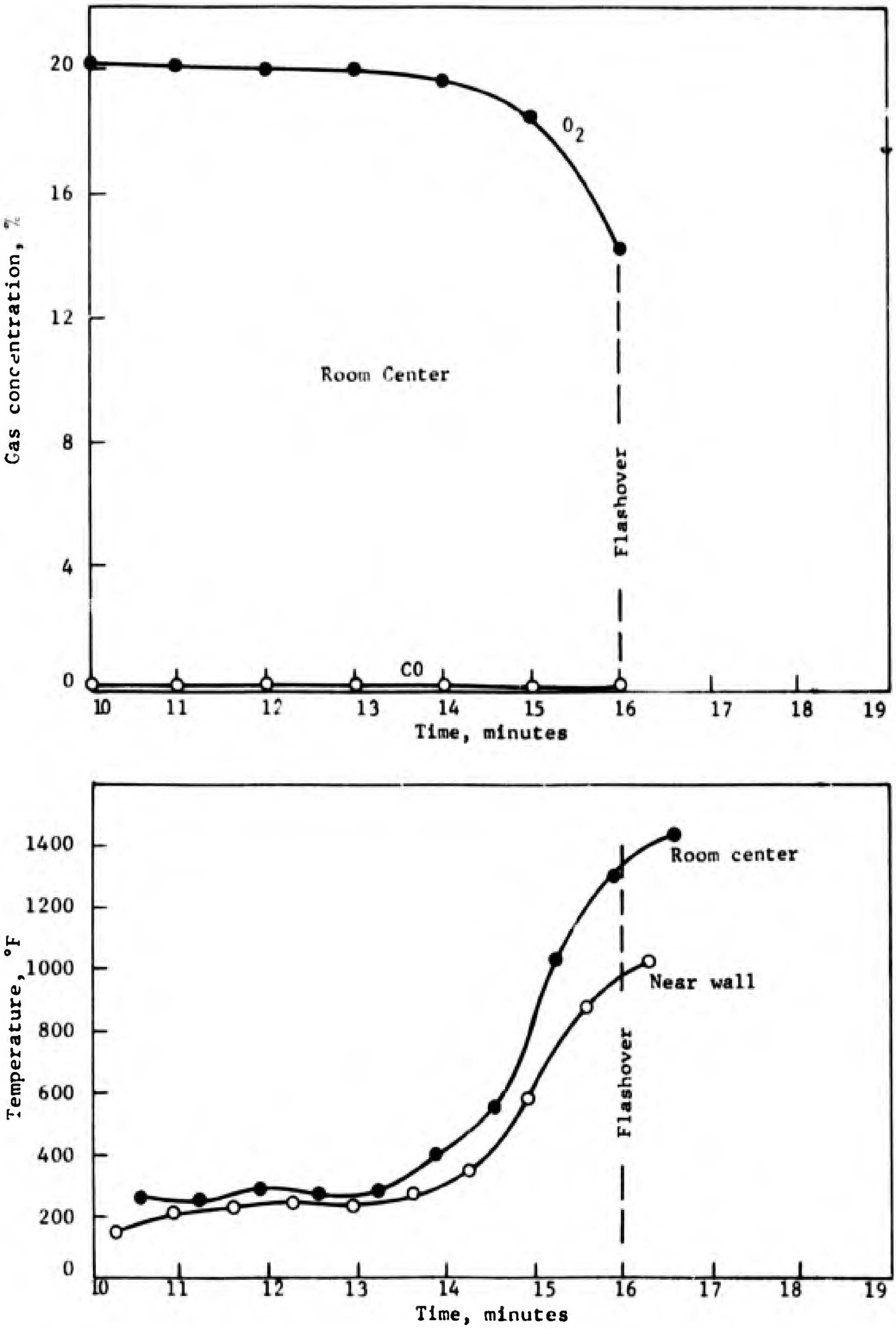


Fig. 12 TEMPORAL VARIATION IN GAS CONCENTRATION AND TEMPERATURE NEAR ROOM CEILING, DASA-015 (COUCH), 4-1/2 FT. WINDOW OPENING

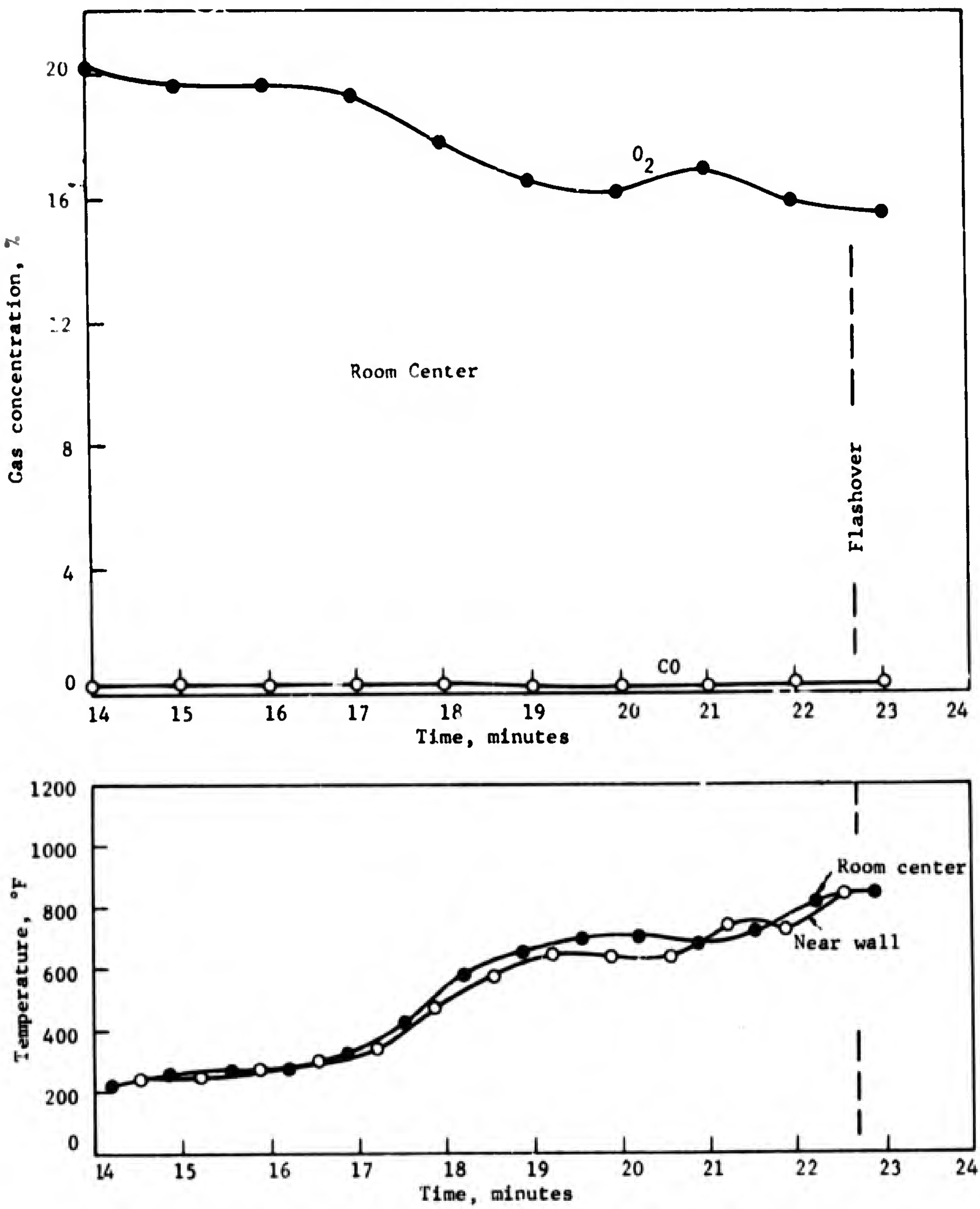


Fig. 13 TEMPORAL VARIATION IN GAS CONCENTRATION AND TEMPERATURE NEAR ROOM CEILING, DASA-020 (COUCH), 3 FT. WINDOW OPENING

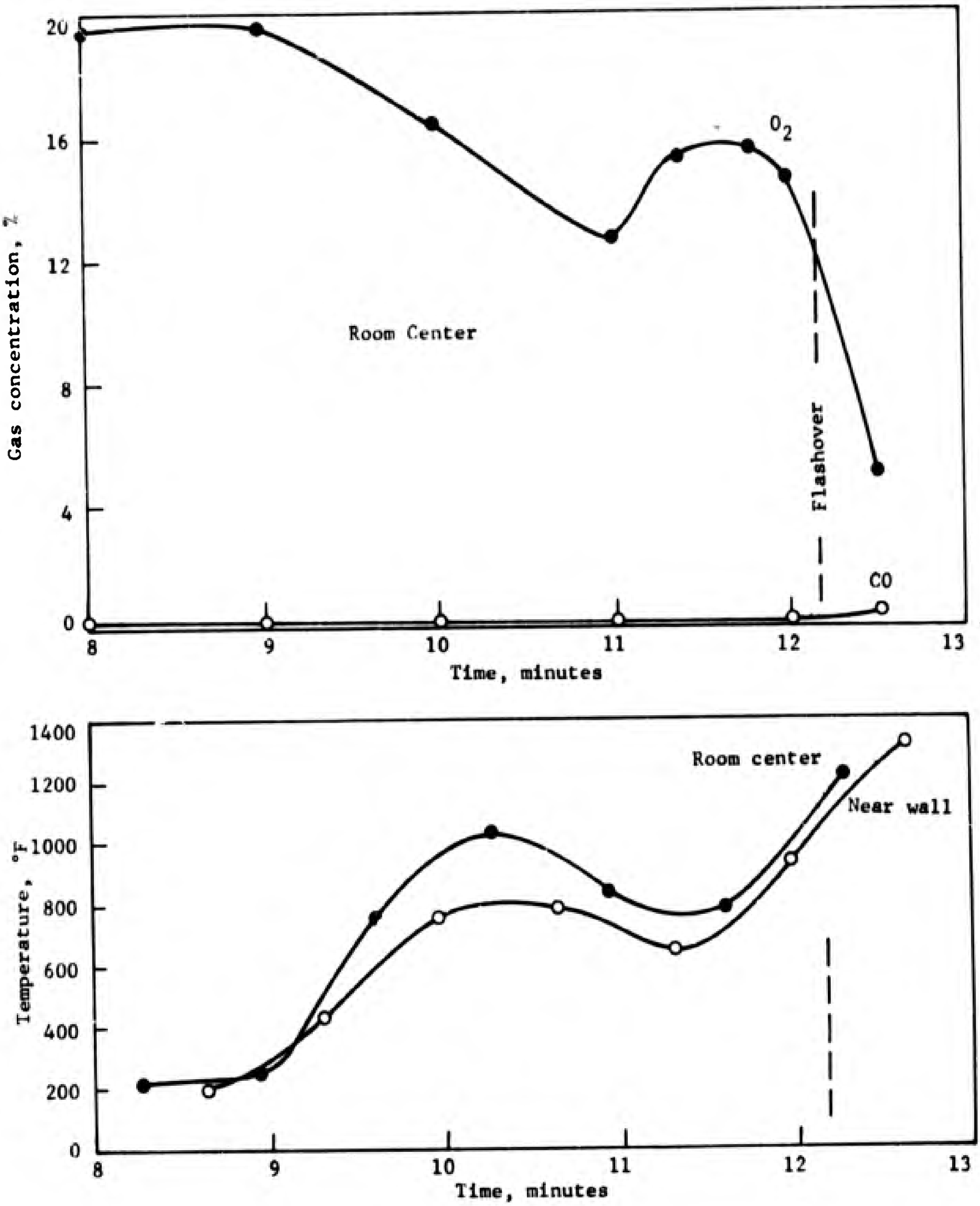


Fig. 14 TEMPORAL VARIATION IN GAS CONCENTRATION AND TEMPERATURE NEAR ROOM CEILING, DASA-043 (BED), 4-1/2 FT. WINDOW OPENING

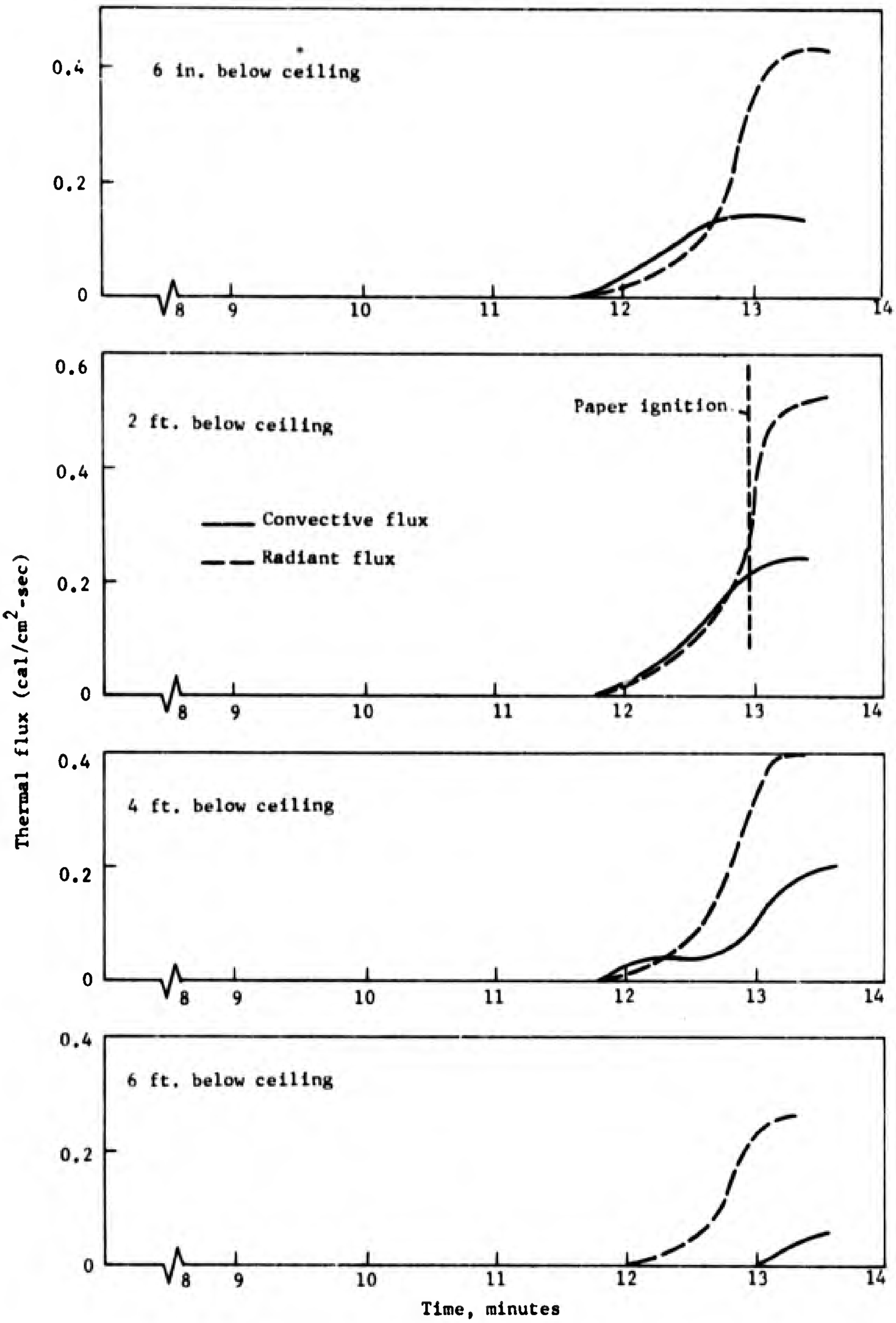


Fig. 15 HEAT FLUX RECEIVED ACROSS ROOM FROM A COUCH FIRE (CONVENTIONAL PADDING), (DASA-049)

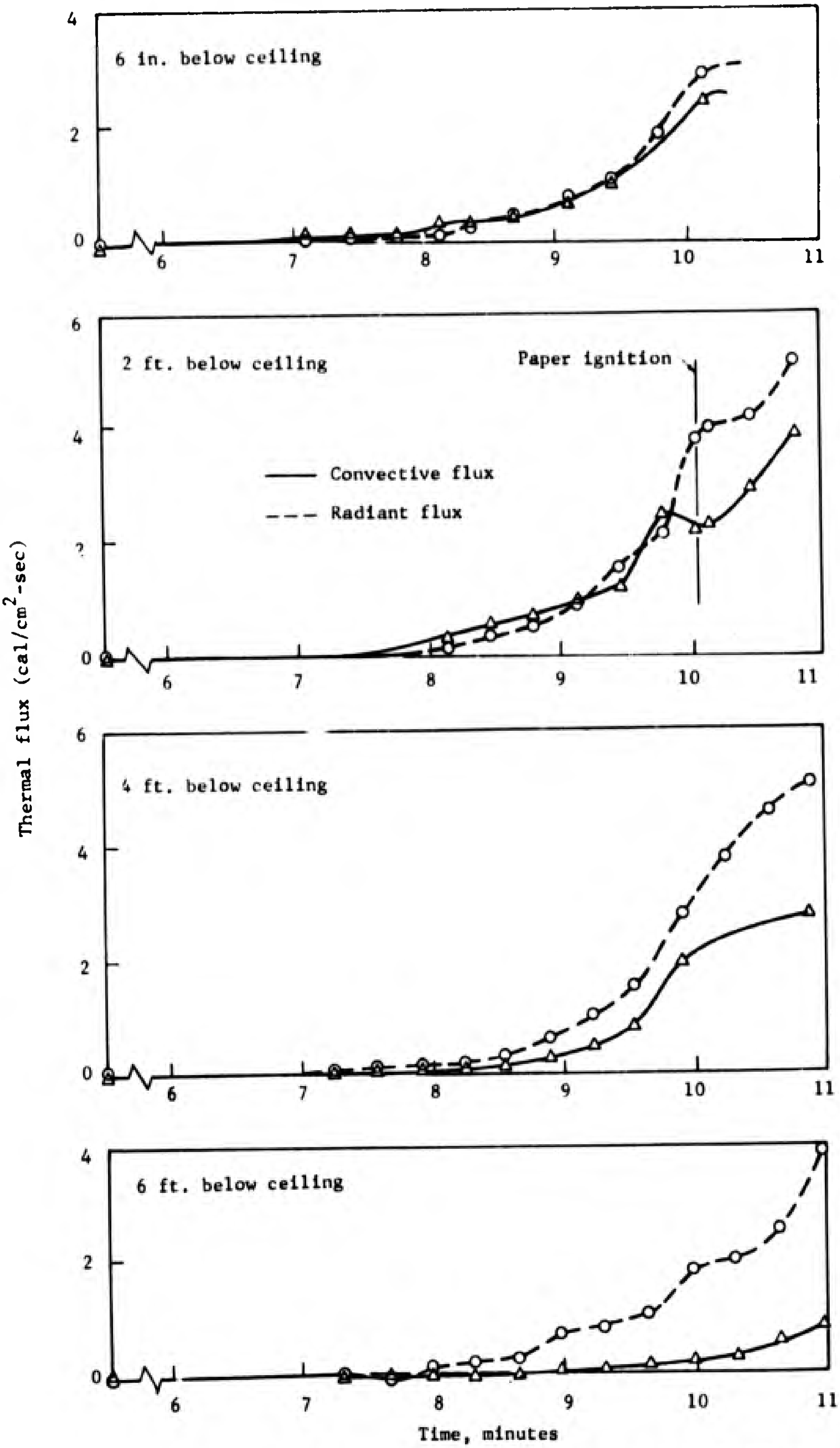


Fig. 16 HEAT FLUX RECEIVED ACROSS ROOM FROM A COUCH FIRE (FOAM RUBBER PADDING), (DASA-050)

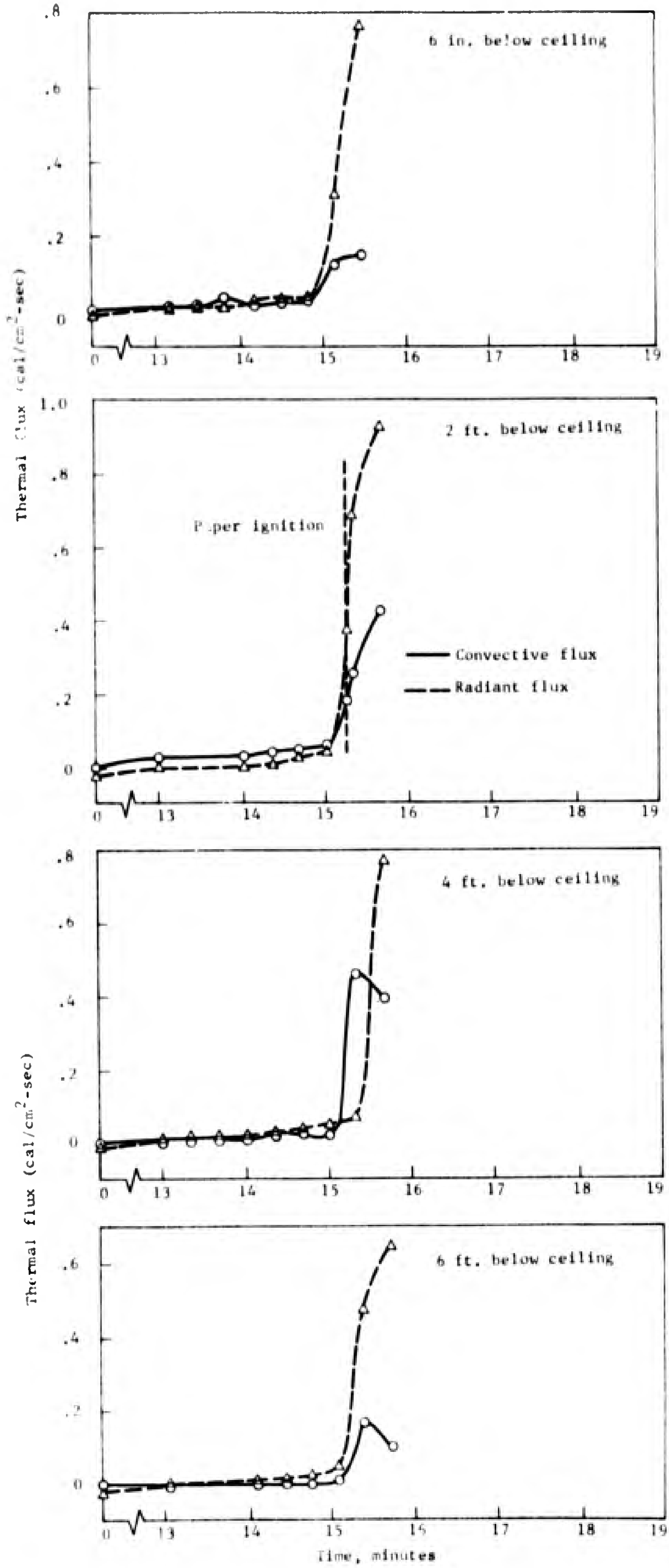


Fig. 17 HEAT FLUX RECEIVED ACROSS ROOM FROM A BED FIRE (DASA-045)

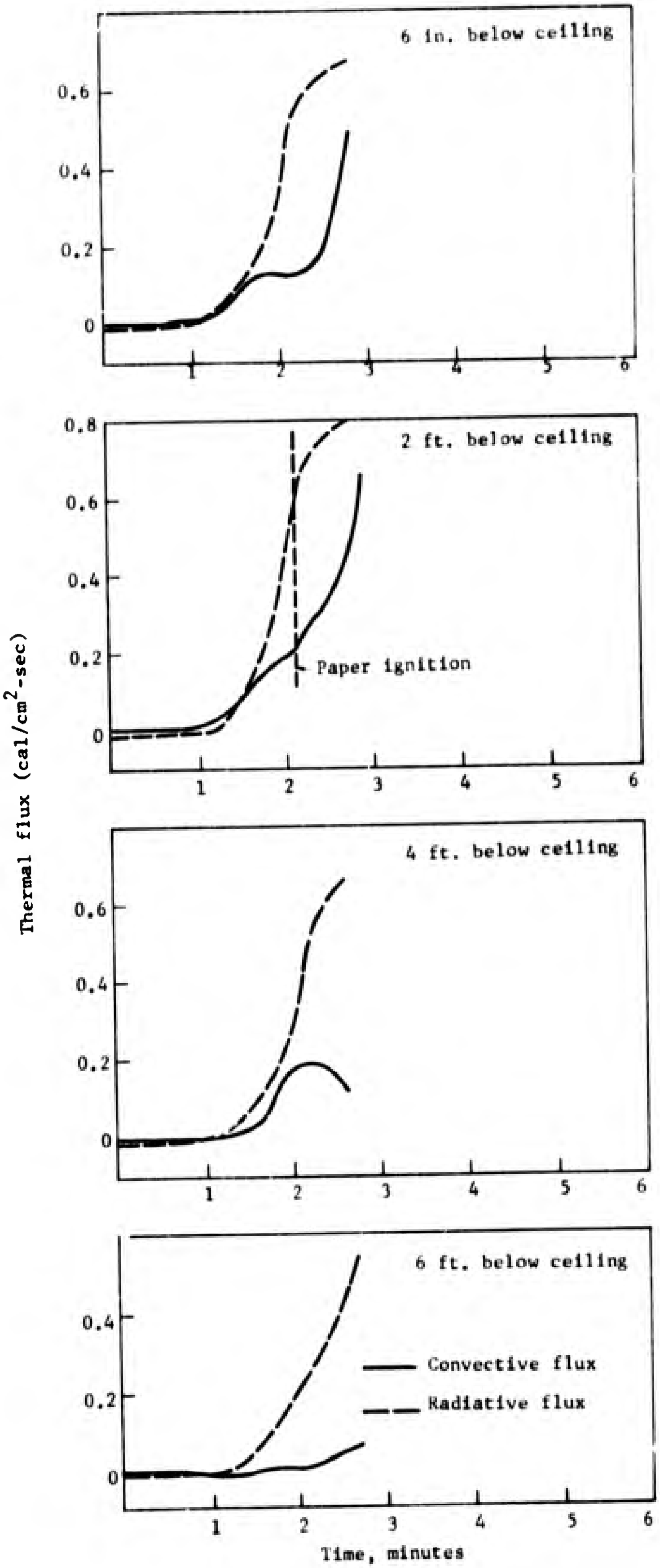


Fig. 18 HEAT FLUX RECEIVED ACROSS ROOM FROM BURNING STORAGE SHELVES (DASA-047)

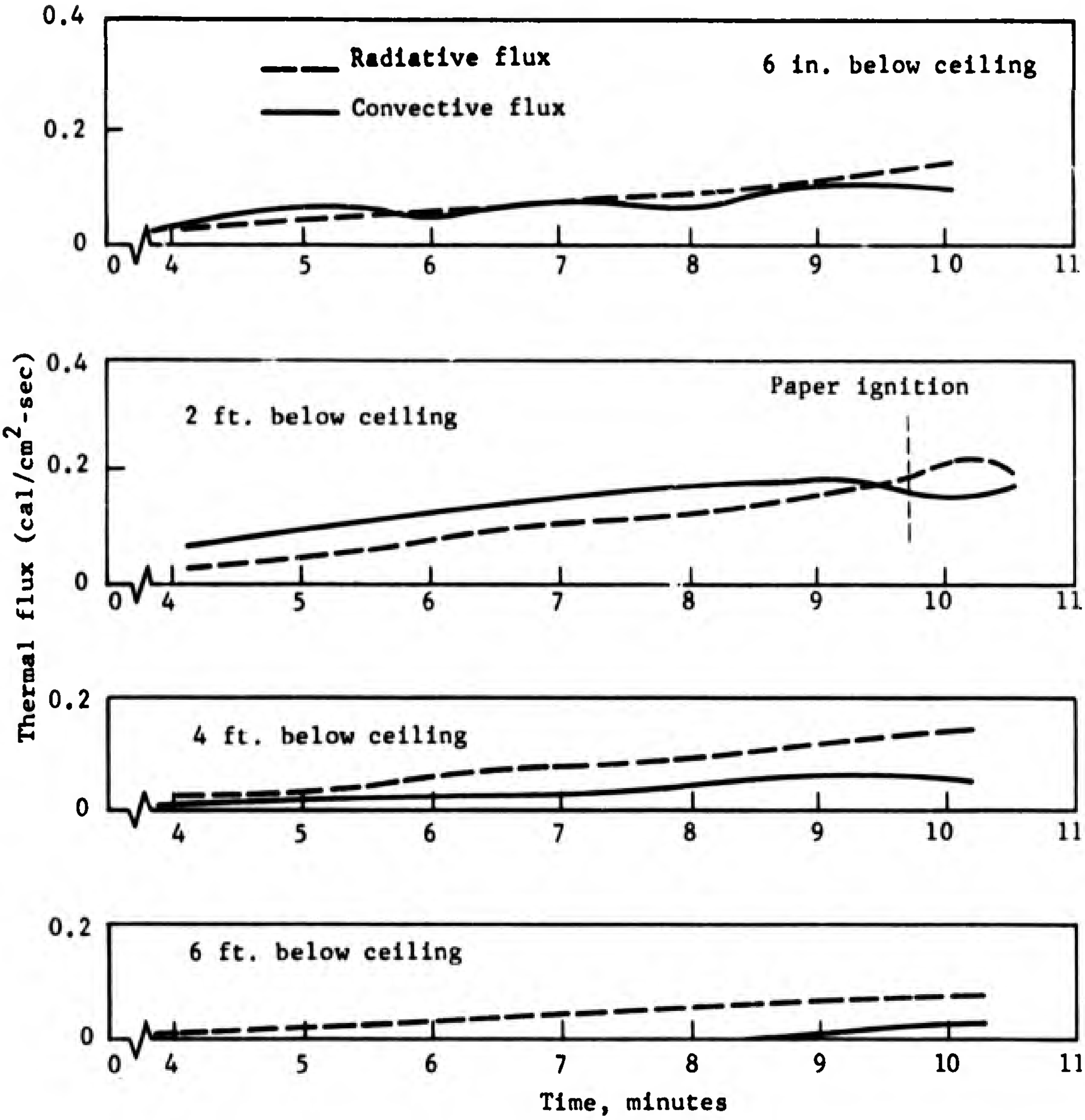


Fig. 19 HEAT FLUX RECEIVED ACROSS ROOM FROM A CRIB FIRE (DASA-054)

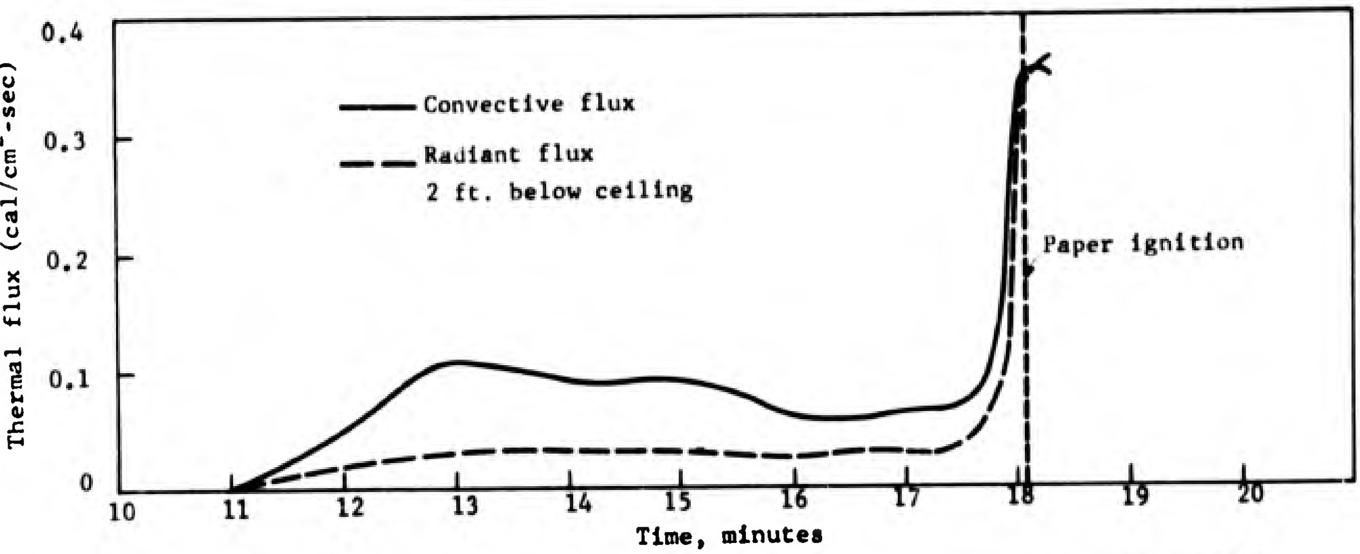


Fig. 20 HEAT FLUX RECEIVED ACROSS ROOM FROM A COUCH (CONVENTIONAL PADDING)FIRE (DASA-052)

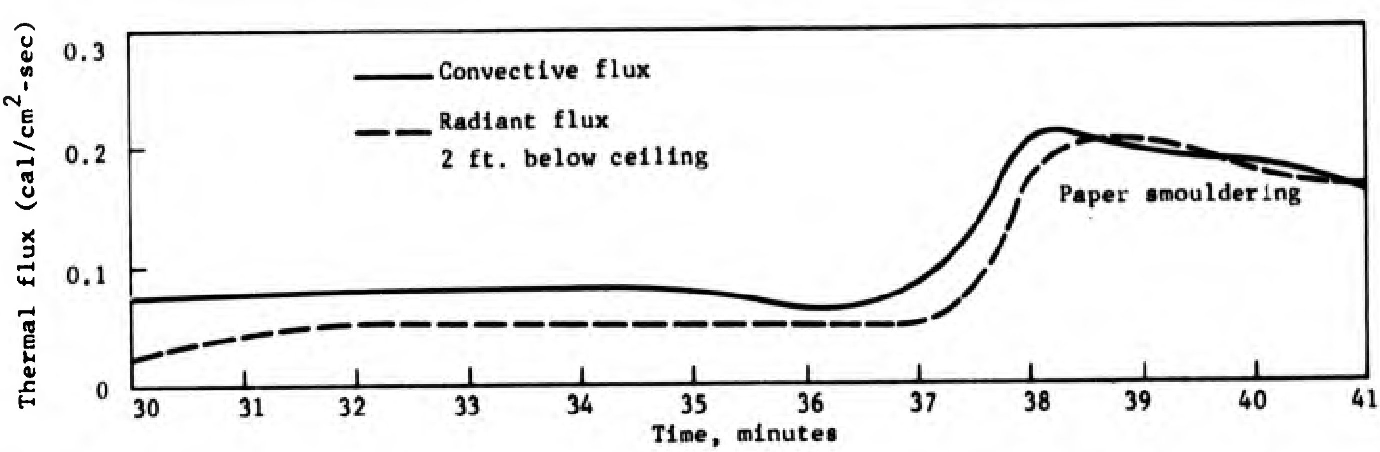


Fig. 21 HEAT FLUX RECEIVED ACROSS ROOM FROM A CHAIR FIRE (DASA-068)

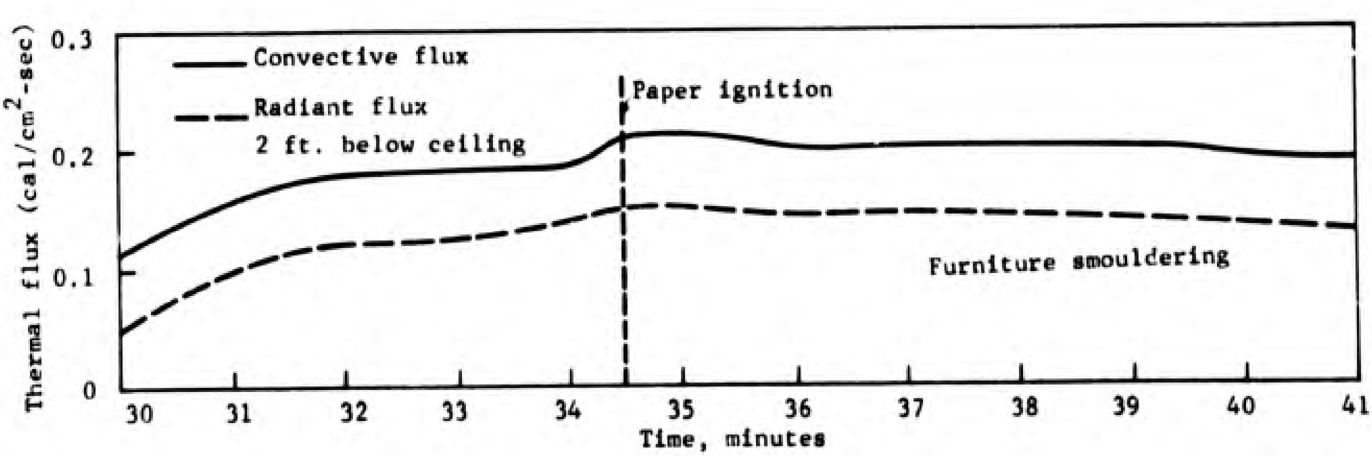


Fig. 22 HEAT FLUX RECEIVED ACROSS ROOM FROM A COUCH (CONVENTIONAL PADDING) FIRE (DASA-071)

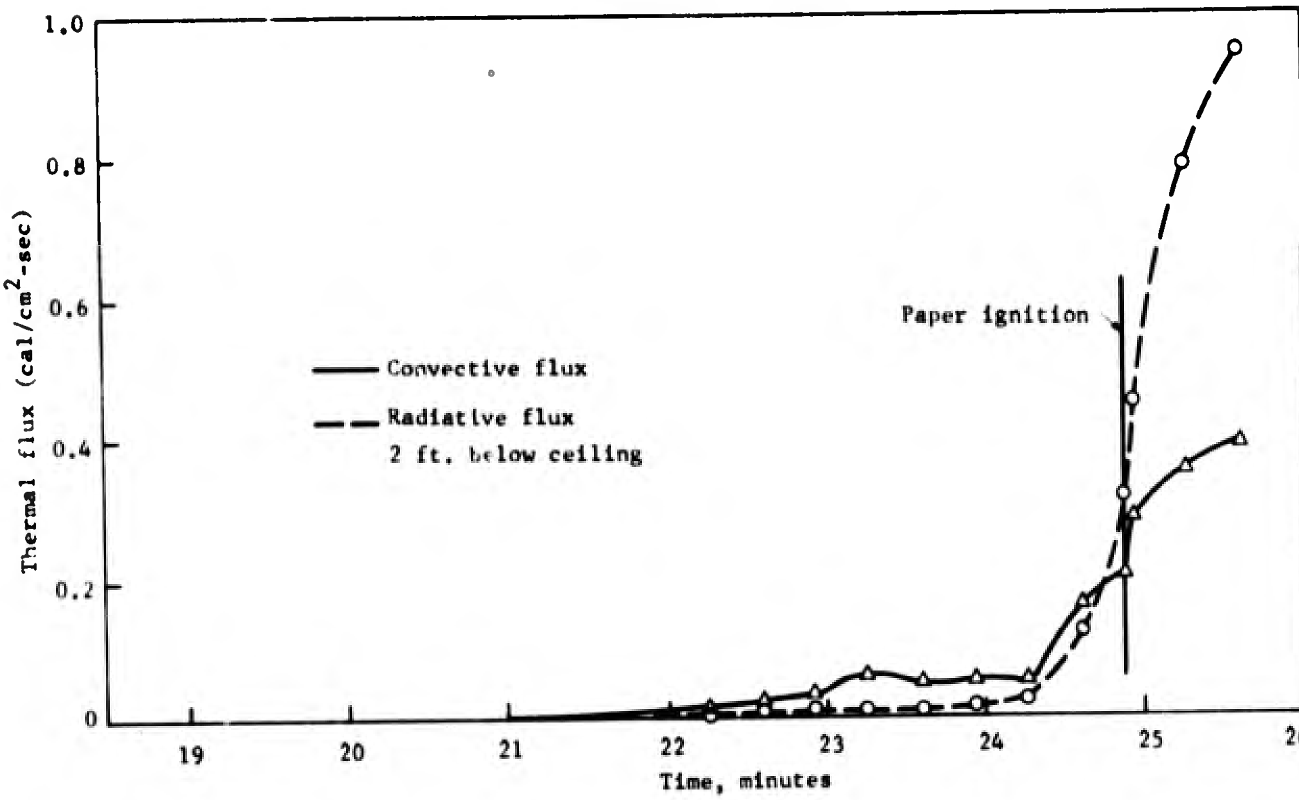


Fig. 23 HEAT FLUX RECEIVED ACROSS ROOM FROM BED FIRES (DASA-044)

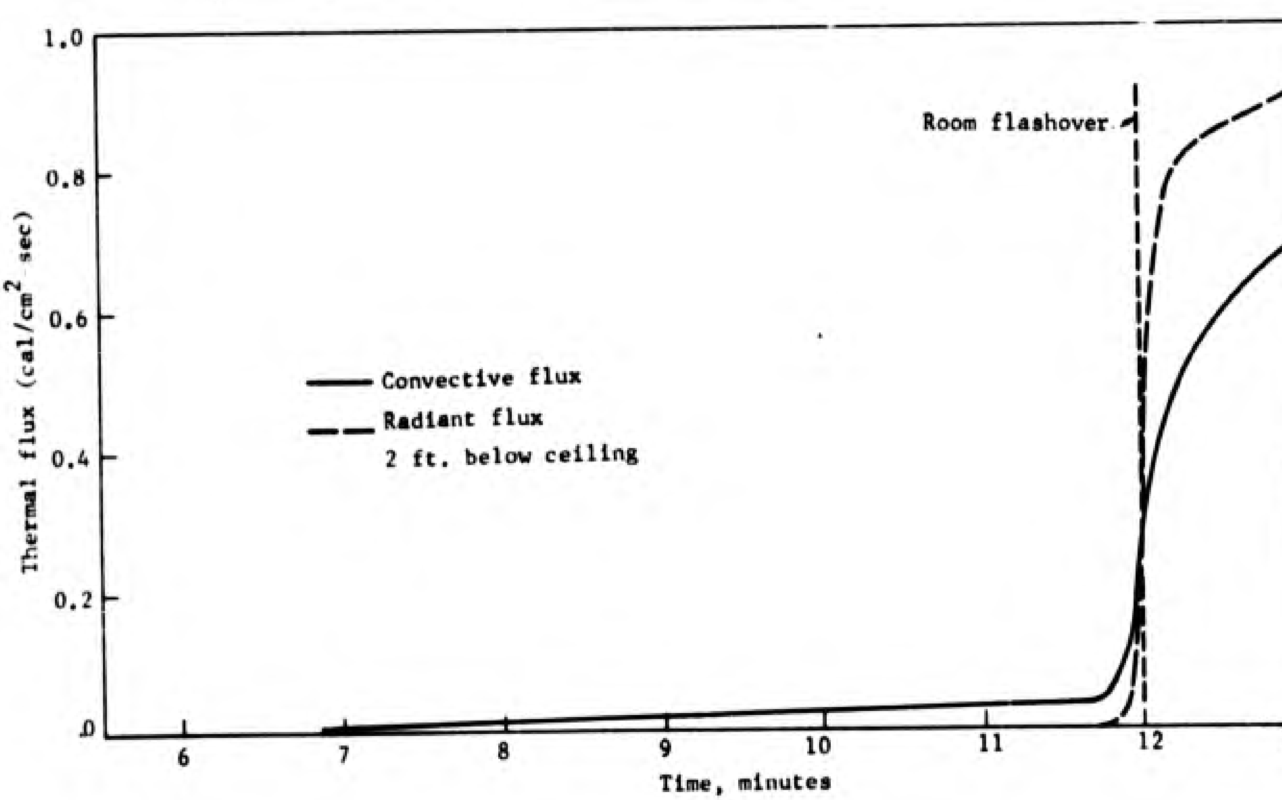


Fig. 24 HEAT FLUX RECEIVED ACROSS ROOM FROM BED FIRES (DASA-070)

illustrates a fairly typical couch fire which produced flashover. Figure 21 shows heat fluxes from burning a medium-sized upholstered chair, which resulted in only smouldering ignition of the paper placed near the calorimeter. This fire was somewhat below the intensity required for room flashover. Figure 22 shows data for a couch burn in which the paper ignited in flames but the room did not flash over. The remaining upholstered contents did undergo smouldering ignition and also burst into flames after they were removed from the room. Since the heat-flux level remained almost constant for some time after ignition of the paper (and particularly, did not increase) this burn can be considered to represent an exposure very near the threshold for flashover.

Figures 23 and 24, bed burns, both show very rapid change in flux intensity near flashover. Figure 24, for a fully loaded room, illustrates quite well the uncertainty in defining a flux level at flashover for burns which involve full contents and which buildup very rapidly.

B. <u>Simplified Fuel Arrays</u>

1. Crib Fires

The crib fire is a more reproducible initiating fire than that from a real furniture item. Some data from crib fires were shown in Figure 19. Additional histories of radiant and convective flux are included here as Figures 25 through 27. By changing the crib size and shape, varied intensities and buildup rates were obtained. This effect and

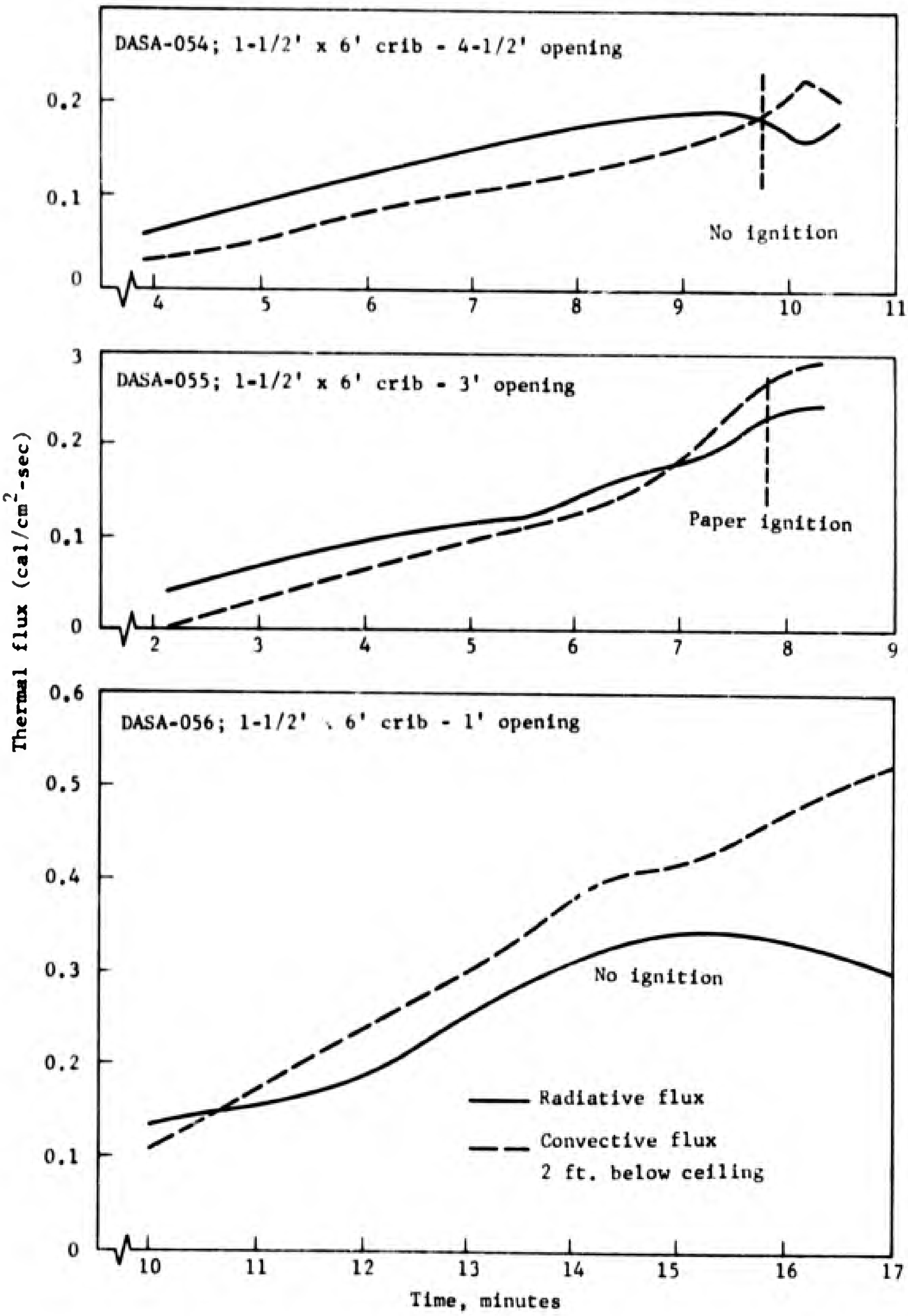


Fig. 25 HEAT FLUX RECEIVED ACROSS ROOM FROM CRIB FIRES

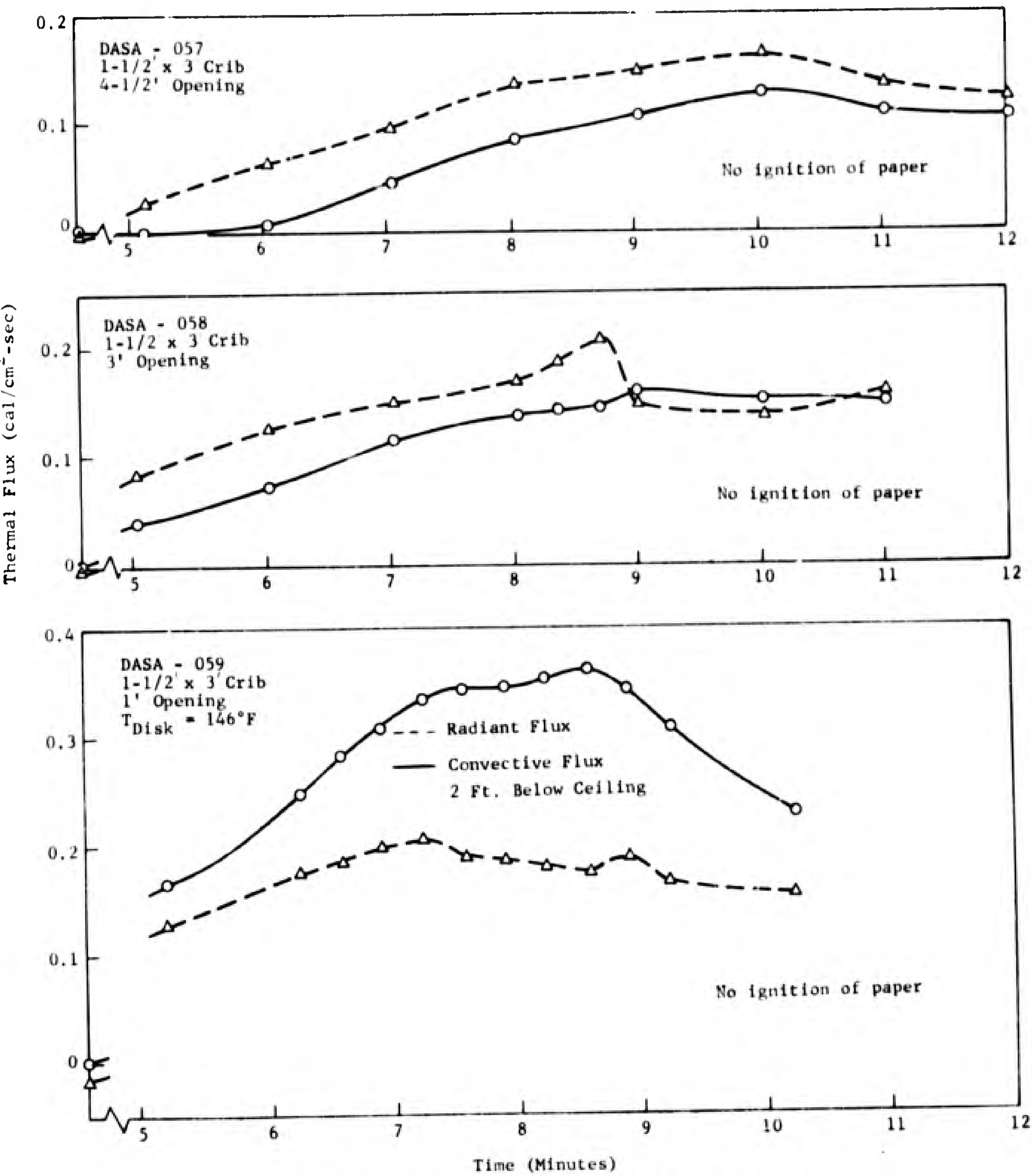


Fig. 26 HEAT FLUX RECEIVED ACROSS ROOM FROM CRIB FIRES

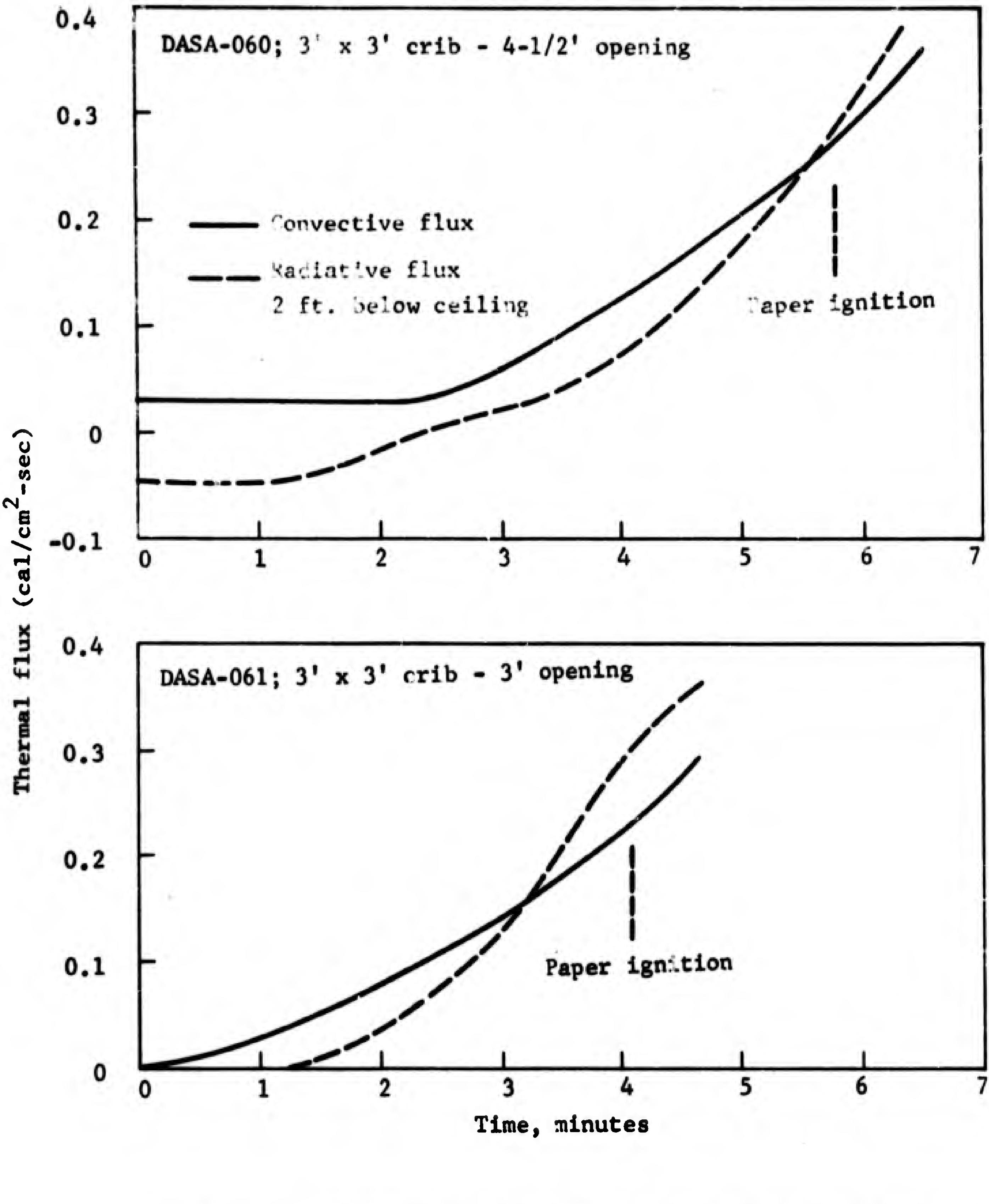


Fig. 27 HEAT FLUX RECEIVED ACROSS ROOM FROM CRIB FIRES

that of ventilation are shown by the figures. In Figure 28 the results for a 1-1/2 ft x 6 ft crib are compared with those for a couch. The ventilation areas were different, nevertheless they were both quite large and the burning rates just prior to flashover were almost identical. Although the couch burned for about 51 minutes before ignition of the paper, while the crib burned for only about 10 minutes, the fires were quite similar during the 6-7 minutes prior to paper ignition. This indicates that the couch fire contributed very little toward flashover during the 45 or so minutes that it burned at low intensity.

2. Gas Fires

The use of gas burners allows maximum control over the time history of the fire output. The ability of the gas flame to adequately simulate a real furniture item is evident from Figure 29. The reason for this ability became apparent when several couches were burned in the center of the main laboratory where negligible wall or ceiling effects existed. Under those circumstances a maximum radiation level of 0.035 cal/cm^2-sec was received by a calorimeter equivalent to those located across the test room from the fire and 2 ft below the ceiling. At that location within the test room, radiant flux levels from couch burns were between 0.15 and 0.5 cal/cm^2-sec. Thus, the radiant flux measured within the room was primarily from the hot walls and ceiling. Under these circumstances, the simulating fire need only place the heat at the proper location within the room, but need not have exactly

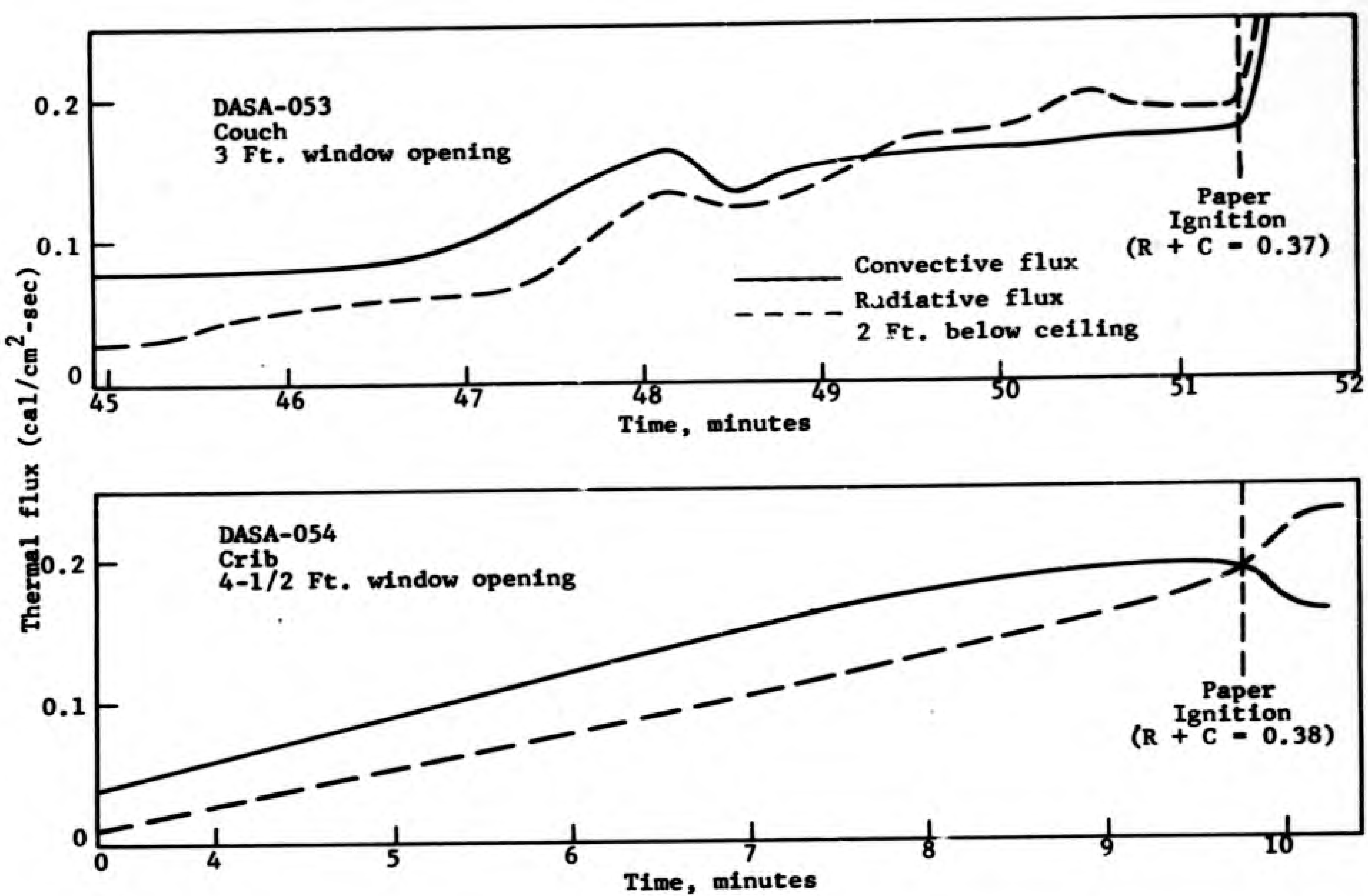


Fig. 28 A COMPARISON OF HEAT FLUX LEVELS FROM A CRIB FIRE AND A COUCH FIRE

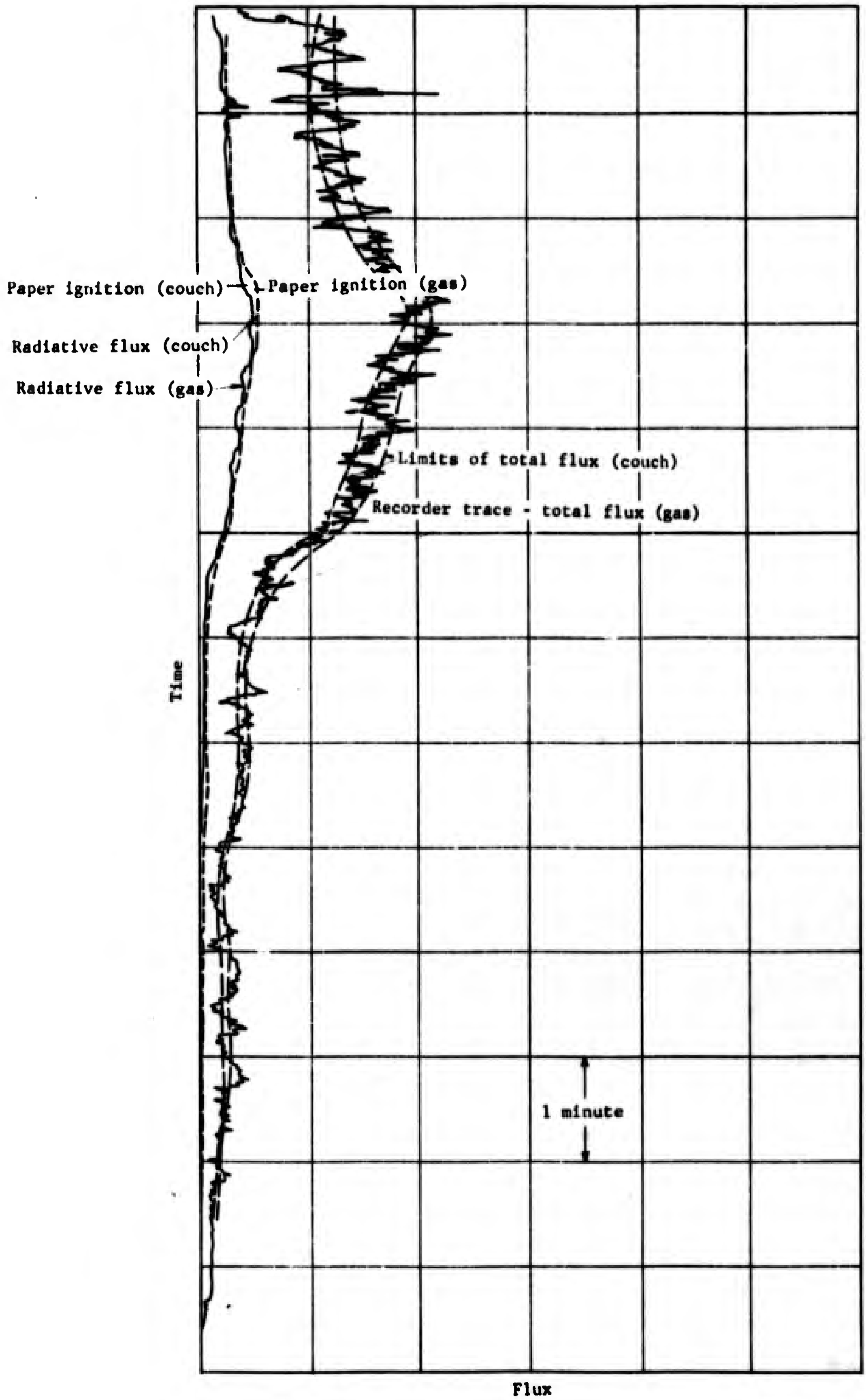
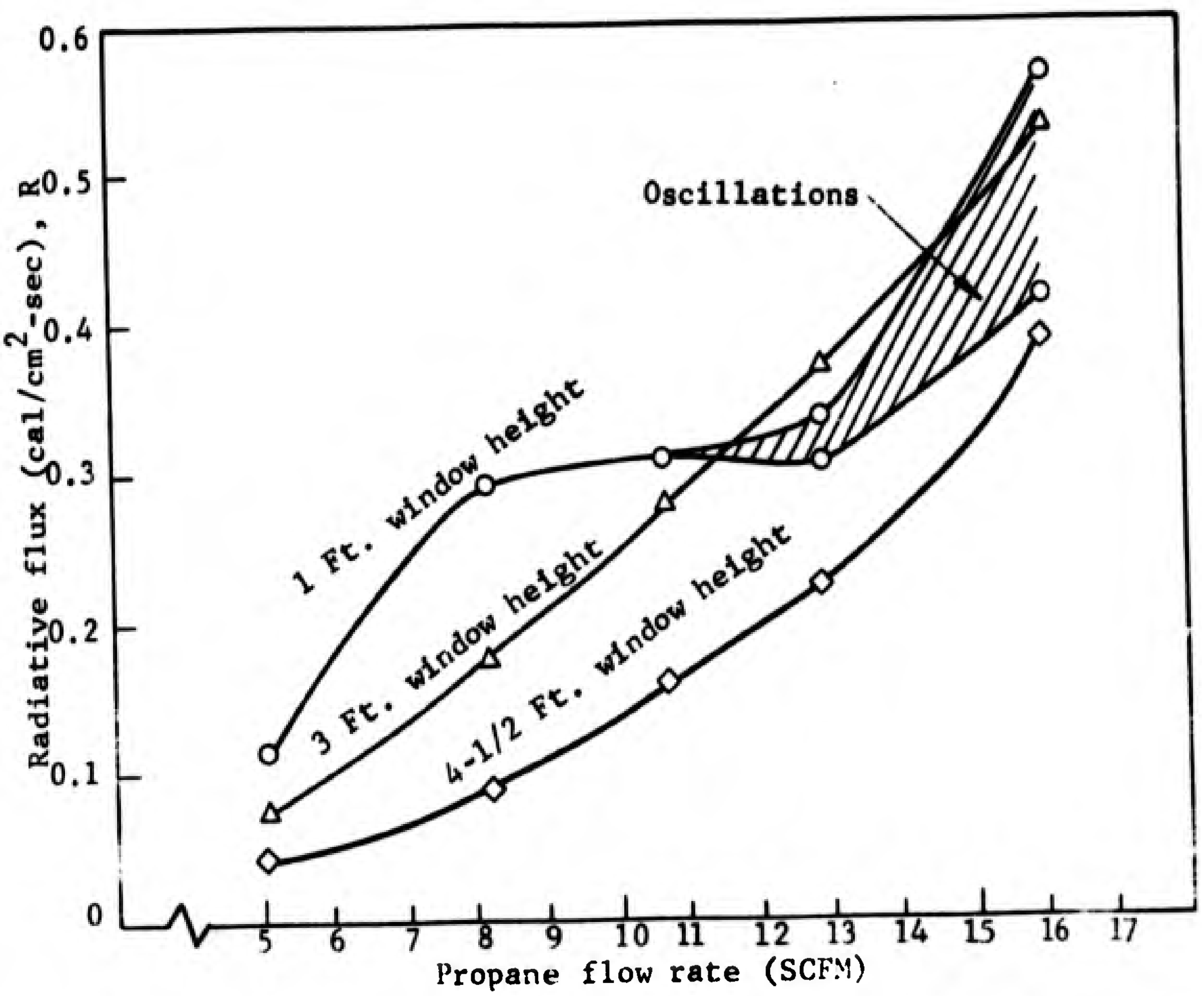


Fig. 29 SIMULATION OF THERMAL FLUX FROM COUCH FIRE (DASA-062) WITH L.P. GAS BURNERS (DASA-156)

the same radiant and convective outputs as the real fire.

C. Reference Fires

For developing reference fires for use in the scaling studies, experiments were performed with the bank of six 1/2-in. pipes operated at various gas flow rates and room ventilations. The results of these experiments are shown in Figures 30-34. Figure 30 shows the maximum flux levels received in the upper room across from the fire for various gas-flow rates and window openings. As shown by the figure, reduction of the window height from 4-1/2 ft to 3 ft increased the flux levels at all gas flow rates, while reduction from 3 ft to 1 ft increased flux levels only at the lower gas flow rates. With the 1 ft high window the effect of limited air supply strongly affects the combustion at gas flow rates of 8 cfm and above. At the larger gas flows a periodic fluctuation developed in the calorimeter records which is shown by the shaded area on the figure. This pulsing, at about one cycle per minute, seemed quite regular in frequency, and was found to correspond to a visible burn off of accumulated gases within the room space. The conditions giving rise to oscillations correspond to fuel release rates which would not normally occur in real room fires under restricted ventilation, and are thus of only minor interest to this study. No attempt was made to study the pulsation to determine its exact cause. For scaling purposes, the reference fires are tentatively selected at 5,



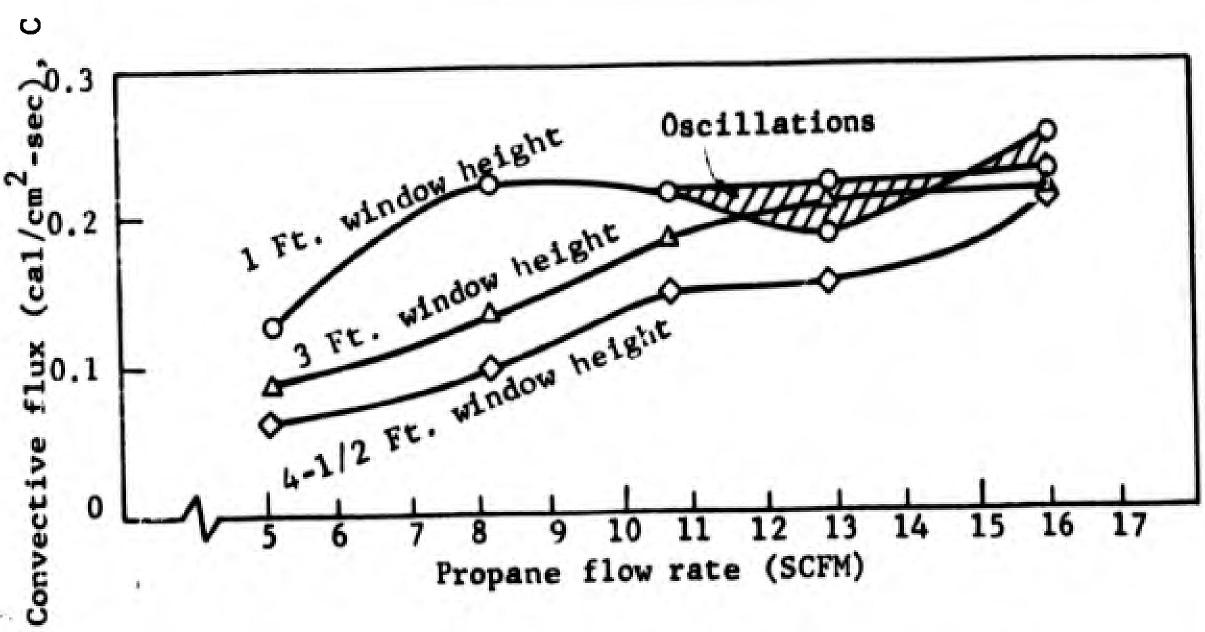


Fig. 30A HEAT FLUX ACROSS ROOM FROM PROPANE GAS FIRES (EQUILIBRIUM VALUES)

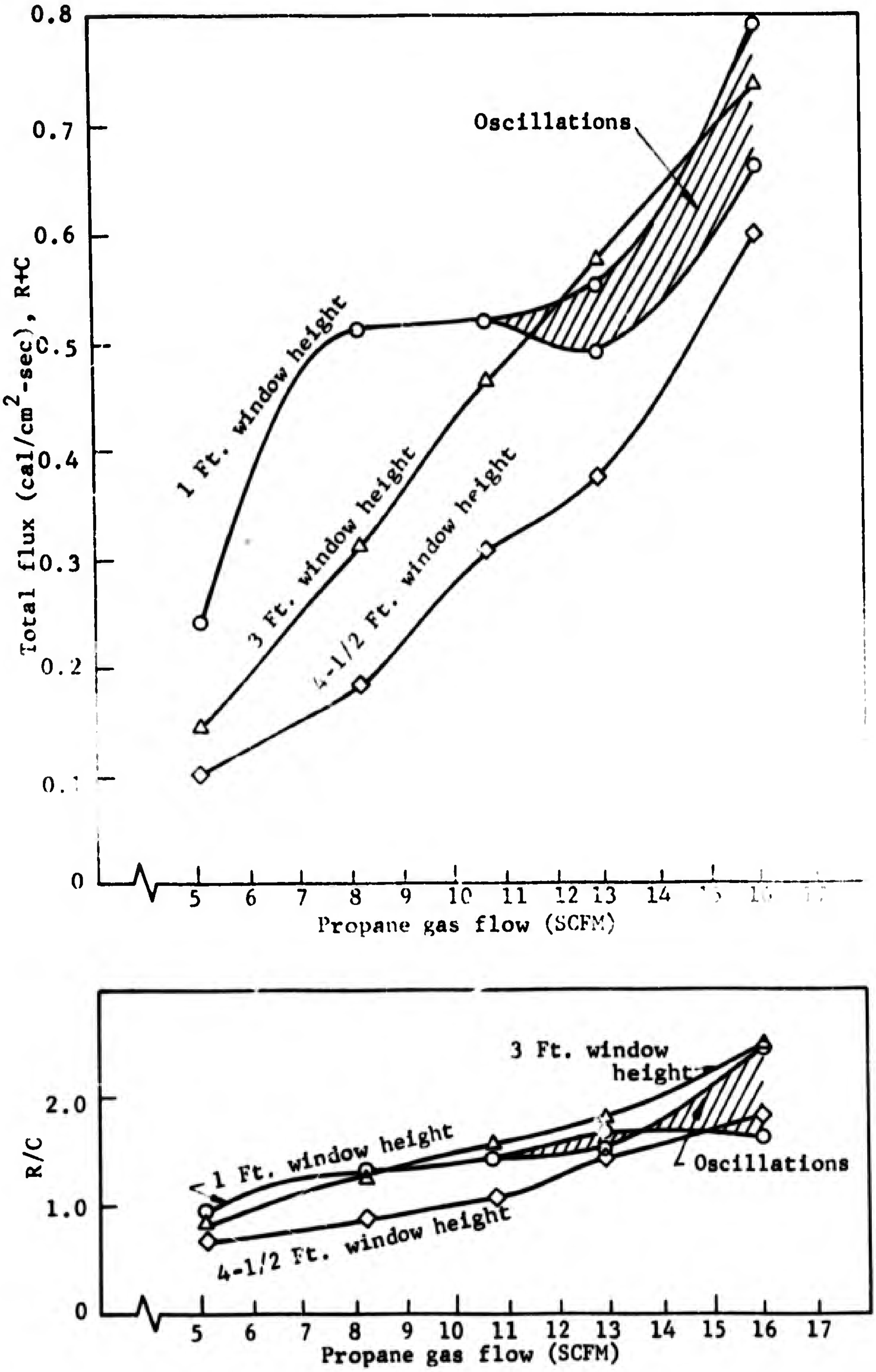


Fig. 30B HEAT FLUX ACROSS ROOM FROM PROPANE GAS FIRES (EQUILIBRIUM VALUES)

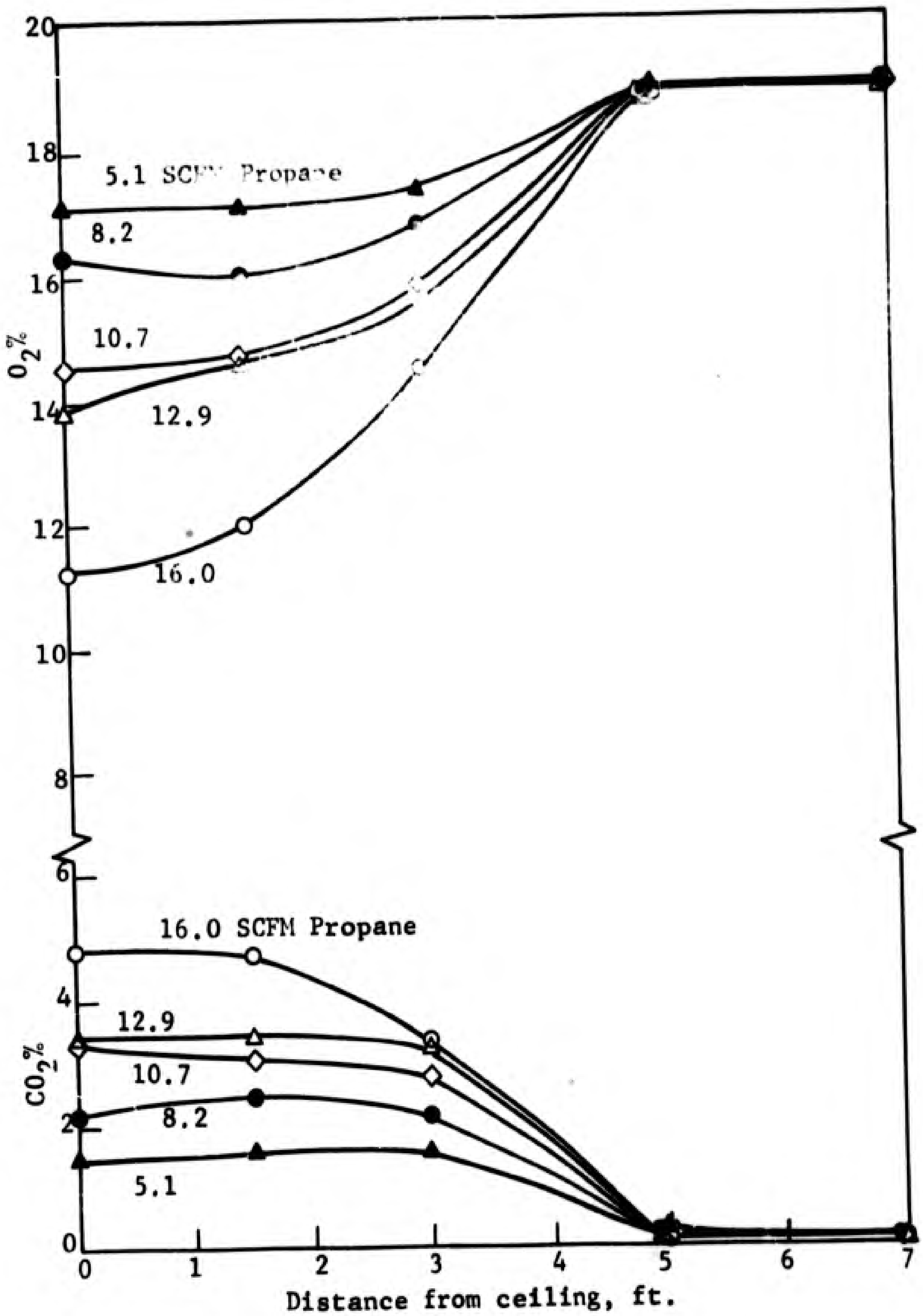


Fig. 31A VERTICAL GAS PROFILES - PROPANE FIRES (4-1/2 FT. WINDOW HEIGHT)

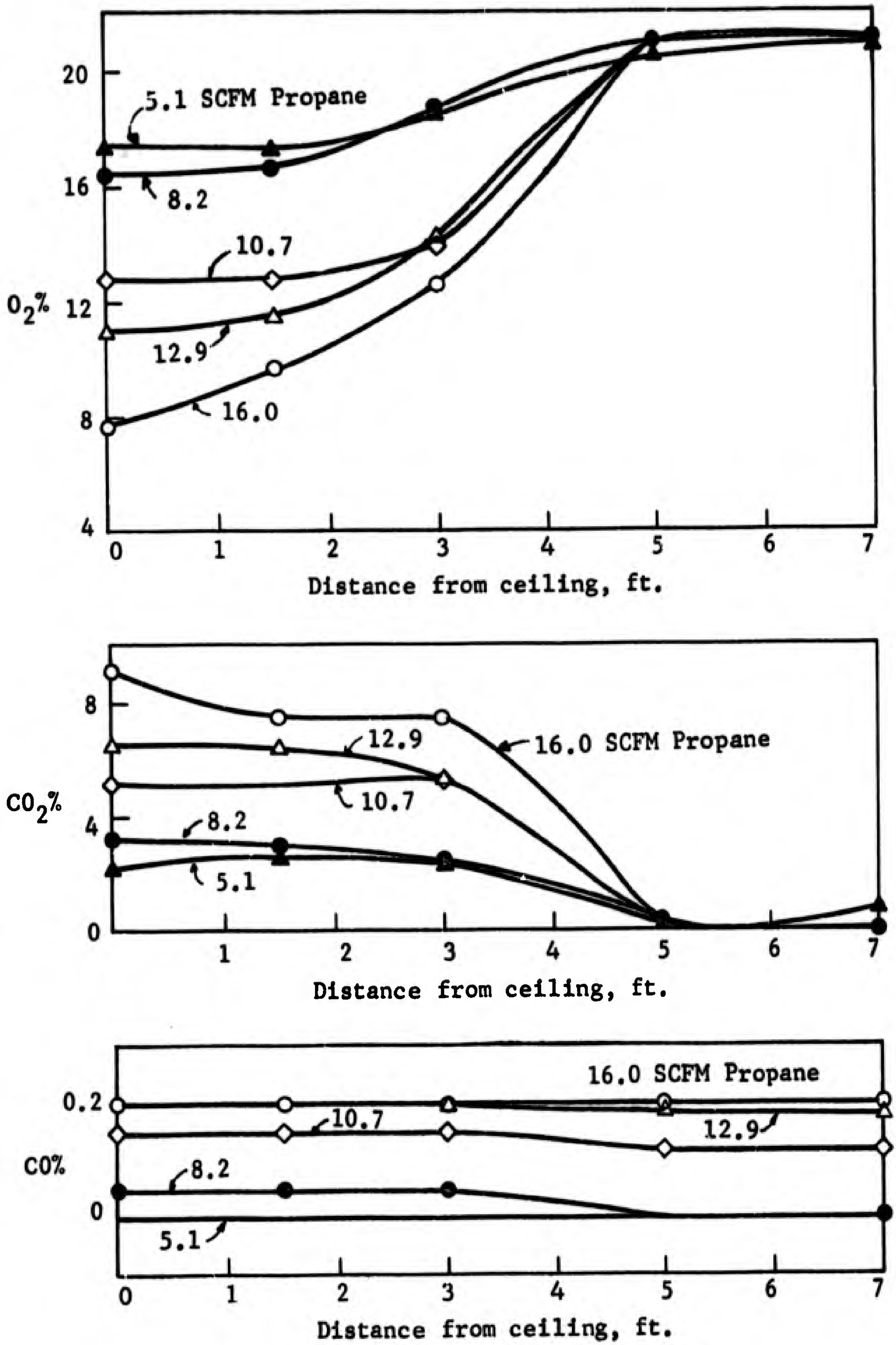


Fig. 31B VERTICAL GAS PROFILES - PROPANE FIRES (3 FT. WINDOW HEIGHT)

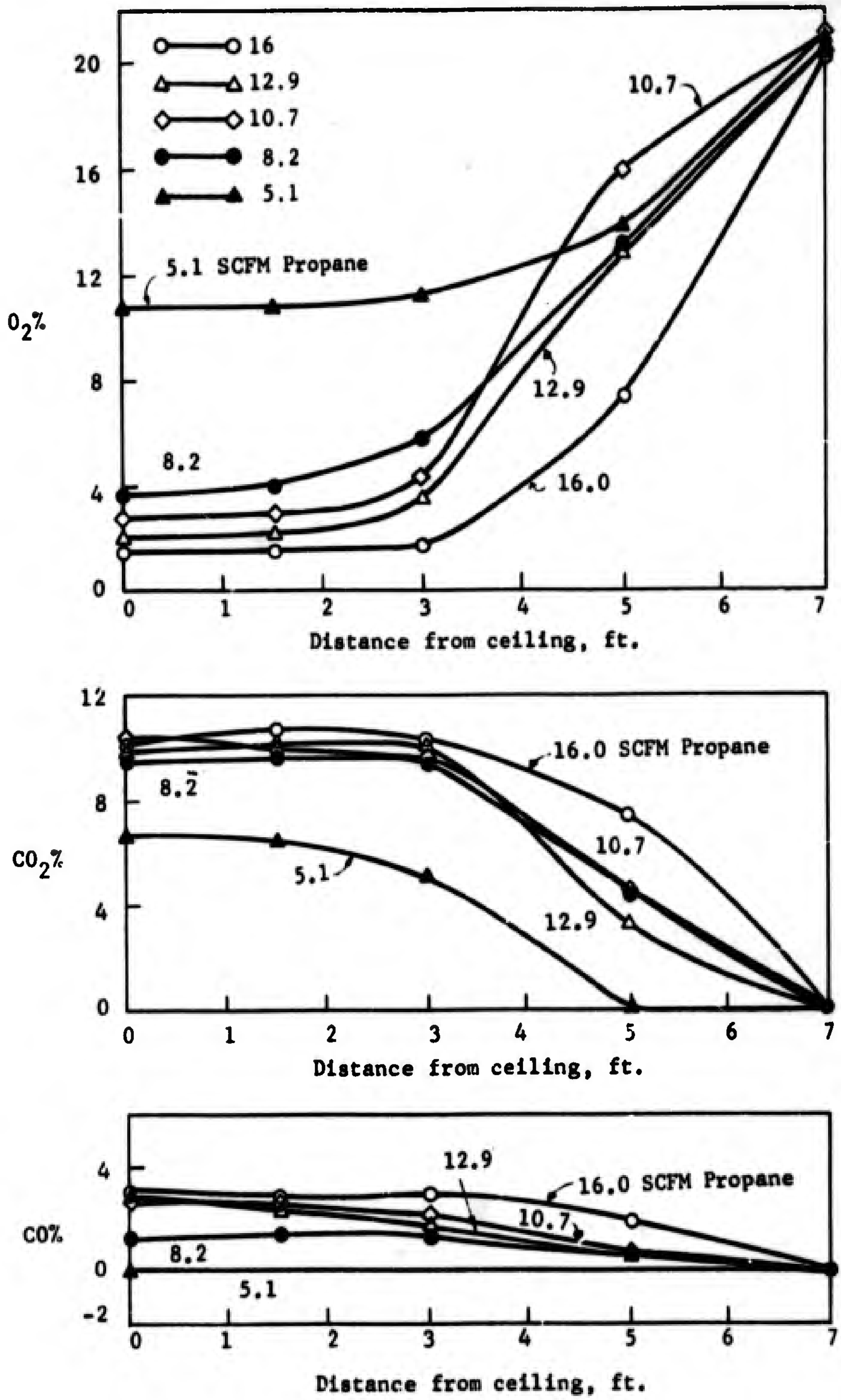


Fig. 31C VERTICAL GAS PROFILES - PROPANE FIRES (1 FT. WINDOW HEIGHT)

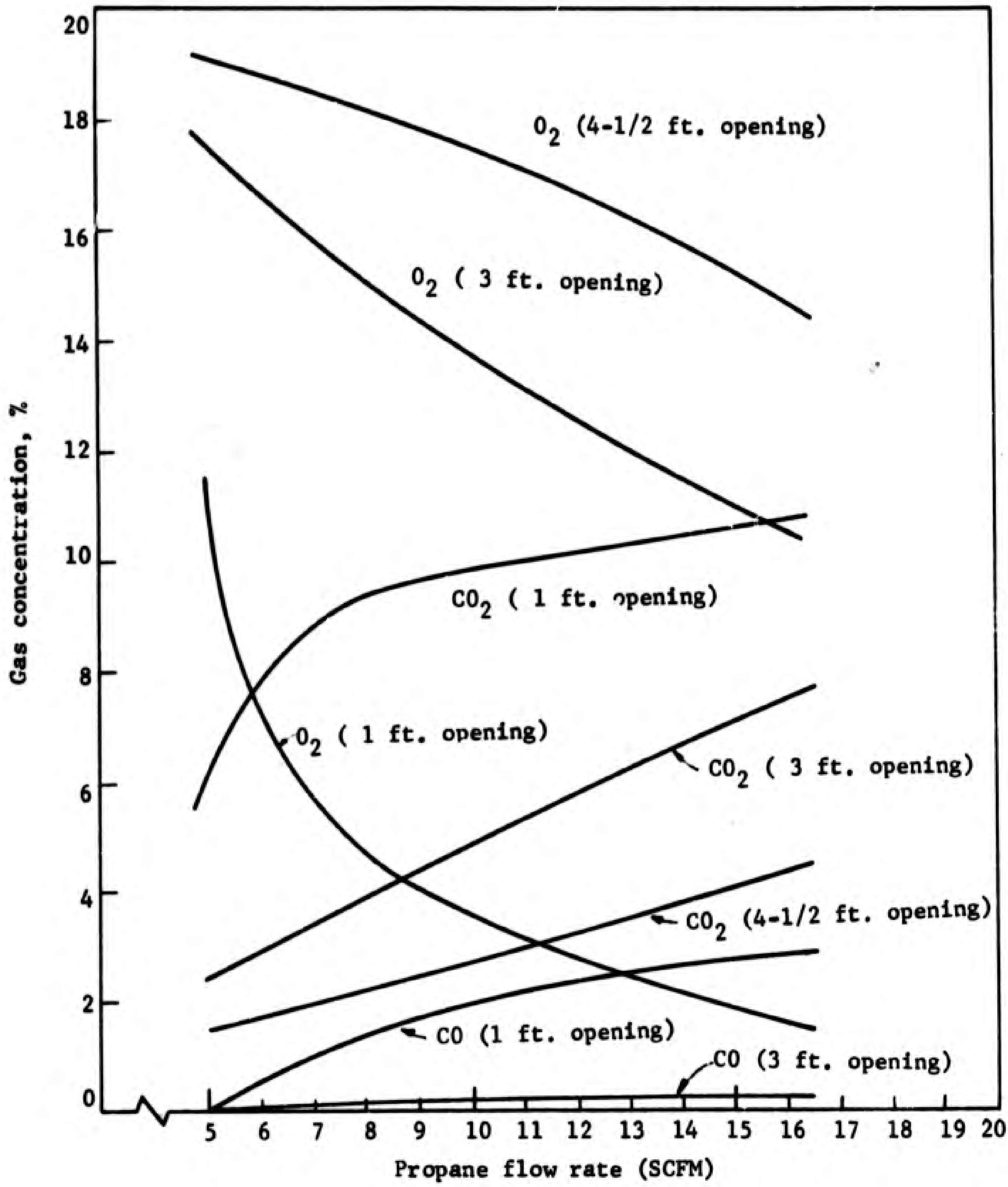


Fig. 32 EFFECT OF FUEL SUPPLY ON GAS CONCENTRATION (2 FT. BELOW CEILING) - PROPANE GAS FIRES

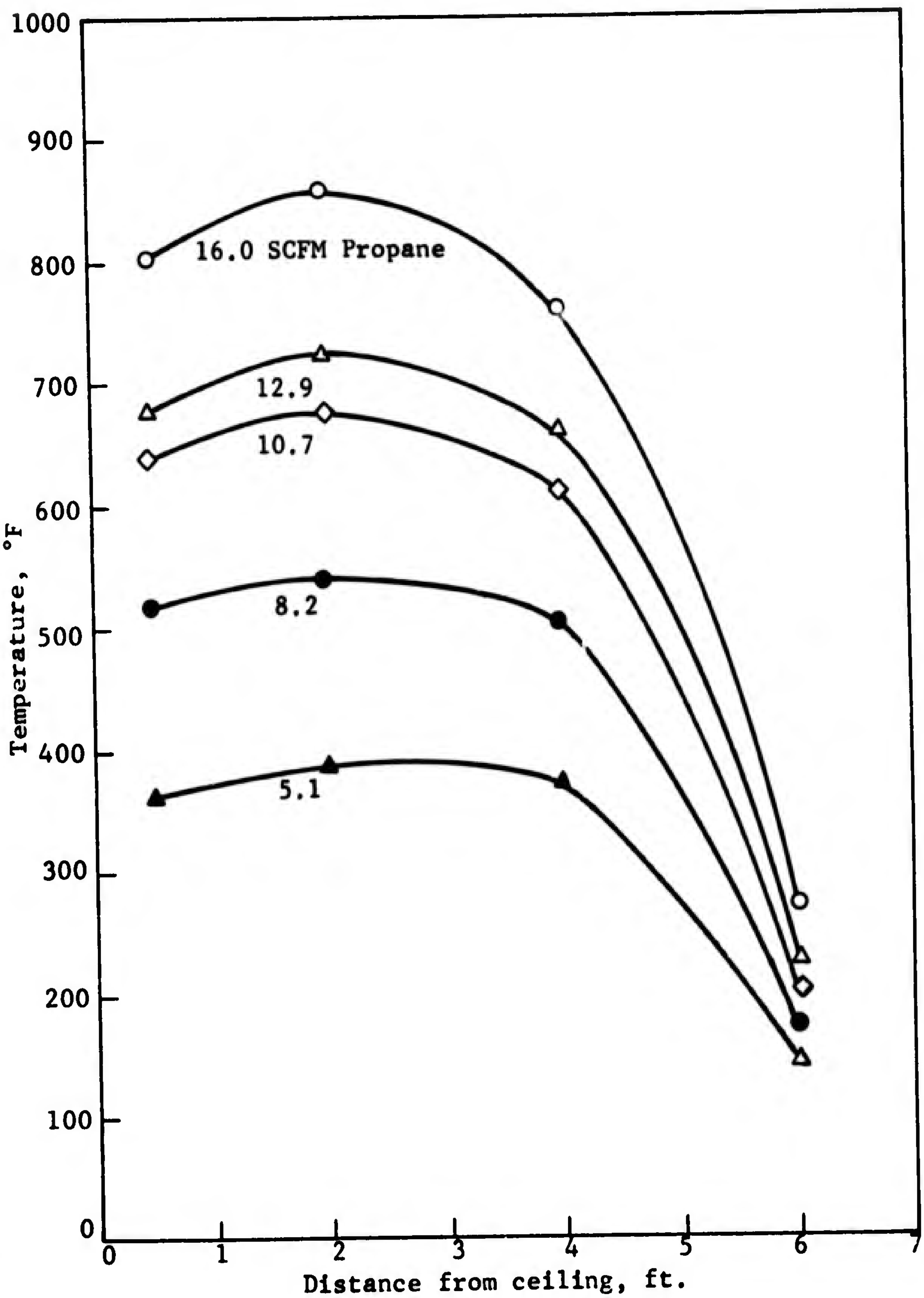


Fig. 33A VERTICAL TEMPERATURE PROFILES NEAR THE WALL FOR PROPANE GAS FIRES (4-1/2 FT. WINDOW HEIGHT)

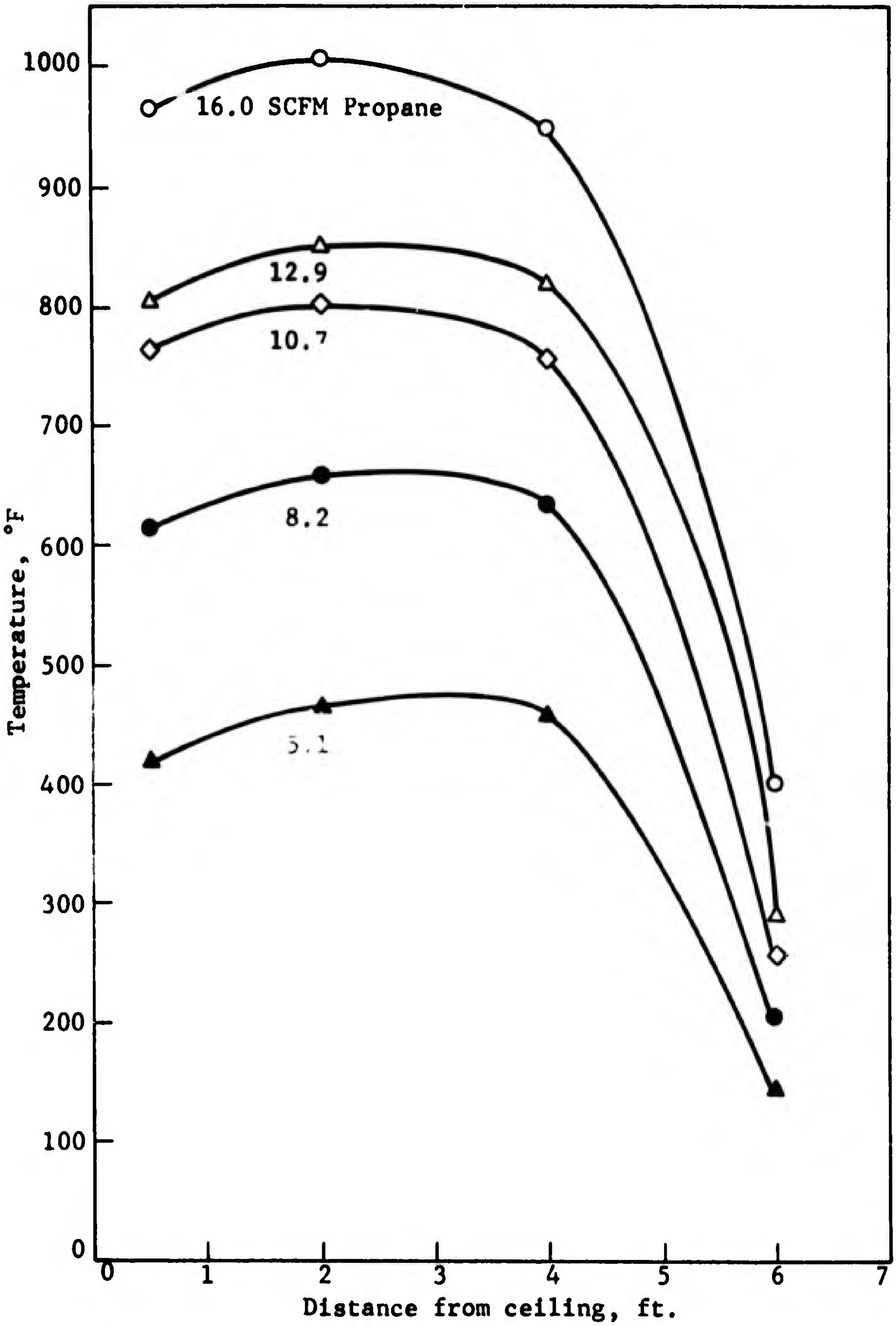


Fig. 33B VERTICAL TEMPERATURE PROFILES NEAR WALL FOR PROPANE GAS FIRES (3 FT. WINDOW HEIGHT)

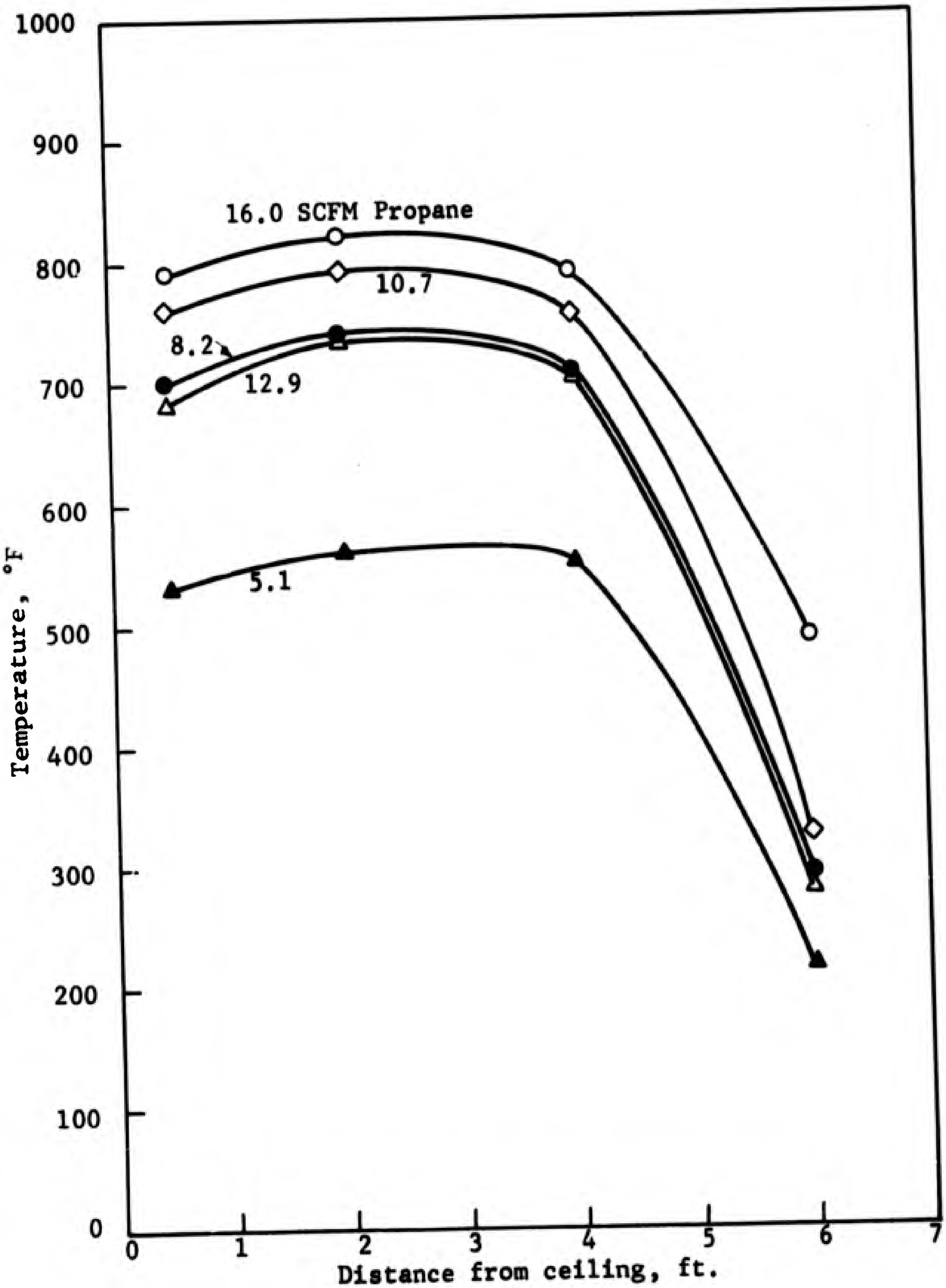


Fig. 33C VERTICAL TEMPERATURE PROFILES NEAR WALL FOR PROPANE GAS FIRES (1 FT. WINDOW HEIGHT)

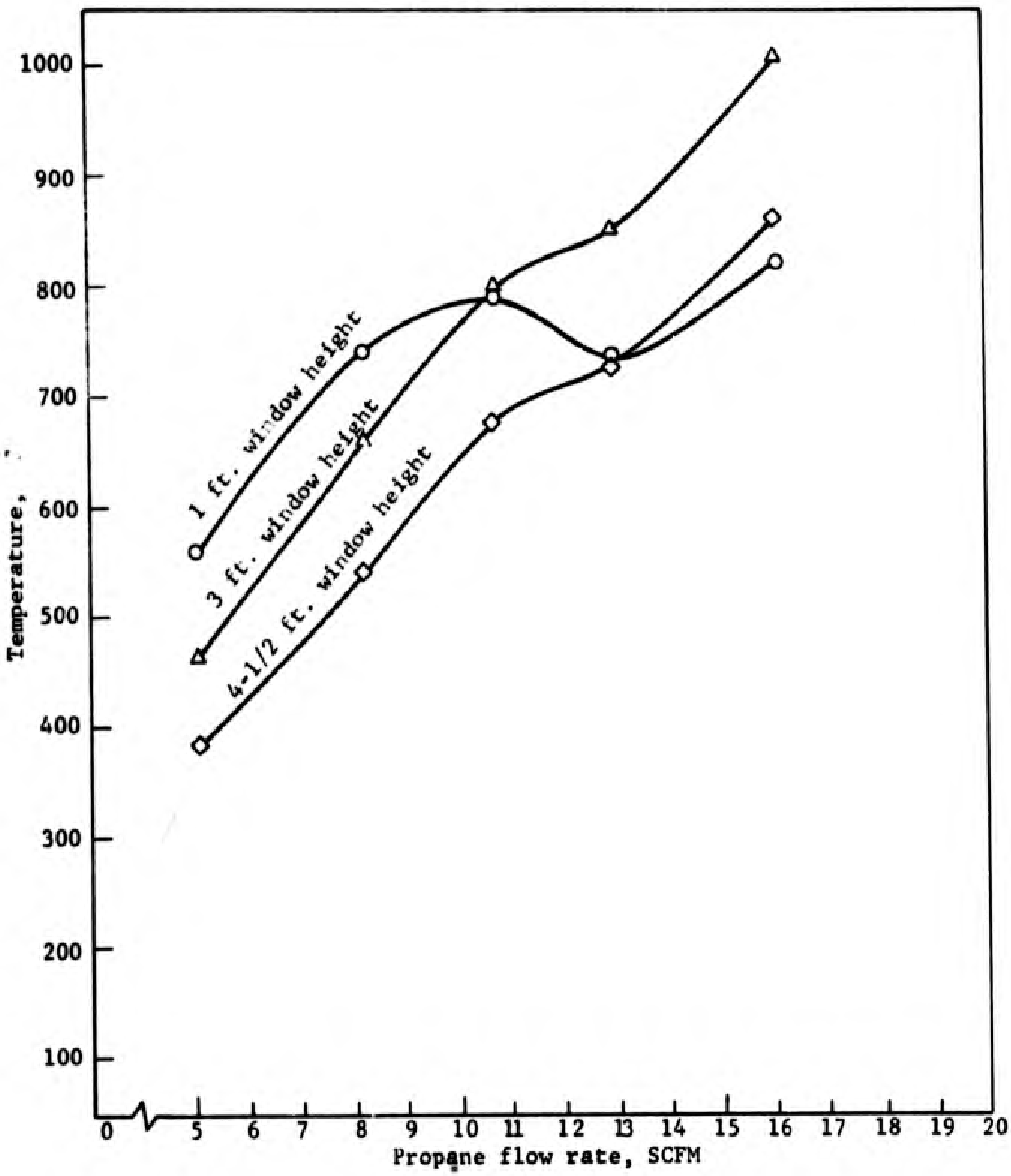


Fig. 34 EFFECT OF FUEL SUPPLY ON TEMPERATURE (2 FT. BELOW CEILING) - PROPANE GAS FIRES

8, 11, 14 and 16 cfm propane gas flow for window sizes of 4 ft x 4-1/2 ft high and 4 ft x 3 ft high.

Figure 31 shows the vertical distributions of maximum concentrations of CO, CO_2, and minimum concentrations of O_2 measured at room center. In Figure 32, the gas concentrations 2 ft below the ceiling at room center are plotted against propane gas flow. Figure 33 gives vertical temperature profiles of the maximum temperatures near the wall. The values measured 2 ft below the ceiling are replotted against propane gas flow as Figure 34.

As mentioned earlier, the results illustrated by Figures 30-34 will serve as the reference fires for scaling studies. That is to say, proper scaling will have been achieved when the model room results duplicate the conditions established by the reference fire at full scale.

VI. CONCLUSIONS

A number of conclusions can be drawn from the experiments concerning the cause or definition of flashover, the general room conditions at flashover, and the ability of simplified fuel arrays to synthesize fire buildup and flashover conditions for real furniture. The more significant conclusions are listed below:

(1) Room flashover is the rapid involvement of the many items of combustible room contents due to their ignition energies being exceeded almost simultaneously.

(2) These minimum ignition energies depend on rate of heating and composition of available air (mainly O_2 content).

(3) The fact that all minimum ignition energies are exceeded almost simultaneously is due to the room confinement. This confinement does not, however, trap high concentrations of unburned combustible gases near the ceiling (measured concentrations were well below flammability limits). Flaming over the ceiling (often observed just prior to flashover) is due primarily to the constraining effect of the ceiling on the flames rising from the initiating item. The small amounts of combustible gases present could enhance these flames somewhat.

(4) Combustible gases distilled from unignited items within the room tend to rise only to the neutral density plane and there spread and blow out of the window. Only under extremely-fast fire buildup in the initiating item were these gases observed to aid fire spread by igniting within the room.

(5) Except in the space immediately above the initiating item, a residential size room (with noncombustible and moderately insulating walls and ceiling) contains two rather distinct

homogeneous layers during fire buildup. These layers are separated by a horizontal plane which corresponds with the neutral-density plane of the opening (air moves into the room below this plane and gases move out above the plane). Temperatures and gas concentrations are relatively constant within each layer, and change rapidly in the immediate vicinity of the separating plane. This generalization is probably not valid for spaces with large floor areas and relatively low ceilings, where significant horizontal gradients probably exist.

(6) For conditions near flashover in the room studied, convective heating in the upper portion of the room is of the same order of magnitude as radiation. Below the neutral plane, convection is minor. Thus, except where restricted ventilation and rapid fire buildup in the initiating item produce low O_2 concentrations, the upper portion of the room provides for more rapid ignition. The upper portions of most furniture items extend slightly into this region in most real room situations.

(7) Oxygen and CO_2 concentrations within the room are quite dependent on the ratio of ventilation opening to burning rate. CO concentrations do

not exhibit significant increases until ventilation is quite restricted.

(8) Because the room has zones which are heated quite uniformly, a rather small combustible surface, such as vertical strips of several layers of newspaper, on the wall opposite the initiating fire gives a good indication of the time when flashover of the room space would have occurred. Such strips, placed in fully-loaded rooms usually ignite just prior to flashover because ignition of the newsprint requires slightly less energy than do ignition of most fabrics or wood.

(9) Major furniture items (beds, large upholstered chairs and couches) usually initiated room flashover in the room size studied. When flashover did not occur, the initiating item, due to its particular internal construction, had never become totally involved in active fire but had burned in stages.

(10) Radiant transfer measured at various room locations is not primarily from the flames. Its source is the hot upper walls and ceiling of the room. The flames above the initiating item are quite transparent and thus the hot

gases must heat the walls and ceiling convectively which, in turn, radiate the heat within the room.

(11) Because of items 3 and 10, simulation of the initiating fire is simplified and fires in either wood cribs or gaseous fuels can be used. The use of propane offers the maximum control over the time-rate of burning and is considered the most desirable. The fuel should be introduced at relatively low velocity, however, so as not to markedly increase the general mixing or turbulence within the room.

(12) Measurements of the relative radiant and convective contributions to total heat flux can be made in room fires with a twin-disk calorimeter developed in the course of the program.

VII. RECOMMENDATIONS

The purpose of this program has been to develop means to synthesize real room fires using simple fuels such as wood, liquid hydrocarbons, or gas. Propane gas has been successfully used for this synthesis, so that convective and radiative heating within the test room caused by fire buildup in real furniture can be duplicated by the flames from propane gas burners. The ability to simulate real fires with gas flames is particularly fortunate in that, of the several possible simulants, gas lends itself most readily to accurate measure and control of burning rate.

It is recommended that the second years effort, briefly described in Chapter III, now be undertaken. The goal of this effort would be to establish the minimum model size that can be related (scaled) to full size room conditions. This scaling would utilize the "standard" fires described in Chapter V. The approach would be to investigate 1/2 scale rooms (for which we feel confident that successful scaling can be achieved) and to follow this to the smallest scale that produces meaningful results. Preliminary indication of successful scaling will be duplication of the full scale radiative and convective heating above the neutral density plane. Final verification will involve duplicating the full scale flux, temperature, and O_2 concentration profiles at the reduced scale.

1. One-Half Scale Experiments

A room would be built that has all horizontal dimensions equal to 1/2 those of the present structure with ceiling height and window height adjustable. The first series of experiments will be run with the ceiling at 1/2 full height and the window height scaled to $(1/2)^{2/3}$ full height. Thus the 12' x 12' x 8' room with a 4' wide x 5' high window would be scaled to a 6' x 6' x 4' room with a 2' wide x 3.1' high window. The gas flow (fire size) would be reduced to 1/4 that of full scale. Scaling of window height in this manner follows the assumption that in ventilation-controlled burning, gases flow through the opening in proportion to $Wh^{3/2}$ where W is the window width and h is the window height. This also implies that the major portion of the convective output of the fire is lost through the opening. It is expected that 20 to 25 experiments would be required to establish the preliminary indication of successful scaling. These would use the five intensity levels and two ventilation conditions mentioned earlier.

Should scaling agreement not be reached in the first series of experiments, a second series with ceiling and/or window height modified (on the basis of the first series) would be conducted. Again, 20 to 25 experiments can be anticipated. Since past experience with fully involved rooms indicates that simulation at 1/2 scale should be possible, it is assumed that this step will be successfully completed.

2. 1/4 Scale Experiments

Following the 1/2-scale experiments, a room would be built at 1/4 scale (3' x 3' x 2' high). The procedure used at 1/2 scale will be repeated for these burns. Successful scaling will depend on the effects of this size reduction on the turbulence of the flames and gas movements. There is some reason to suspect that problems will be encountered since fully developed room fires do not behave predictably at this scale. It may be that during the buildup stage, full turbulence is not required, however. In any case, verification would involve some 20-25 experiments.

3. Minimum Scale Size

Following the 1/4-scale burns, and depending on their results, a series of experiments at either 1/8 or 1/3 scale would be conducted, again involving a similar series of 20-25 experiments. At the completion of these experiments, the minimum scale which produced satisfactory scaling would be investigated fully to confirm that matching of profiles of temperature, flux, and gas concentration had been achieved. This would require 20 to 25 additional experiments. Thus, development of the minimum size synthetic room fire that can be related to full scale results would require 100 to 150 scaled experiments.

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2. Vodvarka, F. J., and T. E. Waterman, "Fire Behavior Ignition to Flashover", Final Report OCD Work Unit 2536-C, Multi-Task Contract No. OCD-PS-64-50, June 1965.

3. Maranite, Johns Manville, a silica asbestos board having a density of 36 lb ft^3.

4. Alvares, N. J., "The Effect of Pressure on Ignition by Thermal Radiation", 66 - Spring Meeting Western State Section, Combustion Institute.

5. "Fire Research - 1964", Department of Scientific and Industrial Research and Fire Offices' Committee, Joint Fire Research Organization, London, 1965.

6. Trademark - Eastman Kodak Company.

APPENDIX A

A TWIN DISK CALORIMETER FOR SEPARATING RADIATIVE AND CONVECTIVE HEAT FLUX

Several devices for measuring radiant or convective contributions to heat transfer have been discussed in recent years. Most recently, the British J.F.R.O.(5) described an instrument using two slug calorimeters one having a polished face and the other a blackened face, in which the rate of temperature rise indicates the heat flux. Both calorimeters absorb the same convective flux, but different portions of the radiative flux due to their different emittances. Use of this type of instrument is complicated by the necessity for cooling of the unit between successive measurements. In addition, elaborate corrections must be applied to the results.

The first device used in the present work also utilized one polished and one blackened disk. However, the calorimeter was of the asymptotic type in which the temperature level of each disk indicated heat flux. It was expected that this device would be suitable for continuous measurements. However, two problems were encountered with this unit. First, the unit showed abnormal sensitivity to heat flux under purely radiant exposure. This was attributed to natural convection set up by the hot sensor disks. This effect could be only partially eliminated by selection of the calibrating flux level. Second, frequent recalibrations were needed because the emittance of the polished disk changed rapidly during exposure to fire gases.

The second device, which was used in all of the experiments, was designed to measure total flux and radiant flux separately, so that convection would be obtained by difference. Construction details of the dual element calorimeter are shown in Figure 35. The blackened disks are 0.001 in. thick constantan foil soldered over the end of 1/4 in. copper tubes. 0.003 in. thick copper leads are silver soldered to the foil at the center and edge of each disk, and form a differential thermocouple to measure the temperature rise at the center of the disk. Provision is made to attach these fine wires to more rugged extension leads in the rear portion of each tube. The tubes containing the disks are epoxy cemented into a stainless steel housing to form the completed unit. The front half of the housing is water cooled. The rear half merely serves to protect the side openings in the 1/4 inch copper tubes where the extension leads are attached to the 0.003 inch lead wires. Water at 140°F is used for cooling. The use of colder water results in excessive soot and moisture accumulation from the fire gases. As shown in Figure 35, an Irtran 2[6] window is attached to the unit by a collar so that all convection to the one disk is blocked. The window is placed rather close to the disk to maintain a wide view angle.

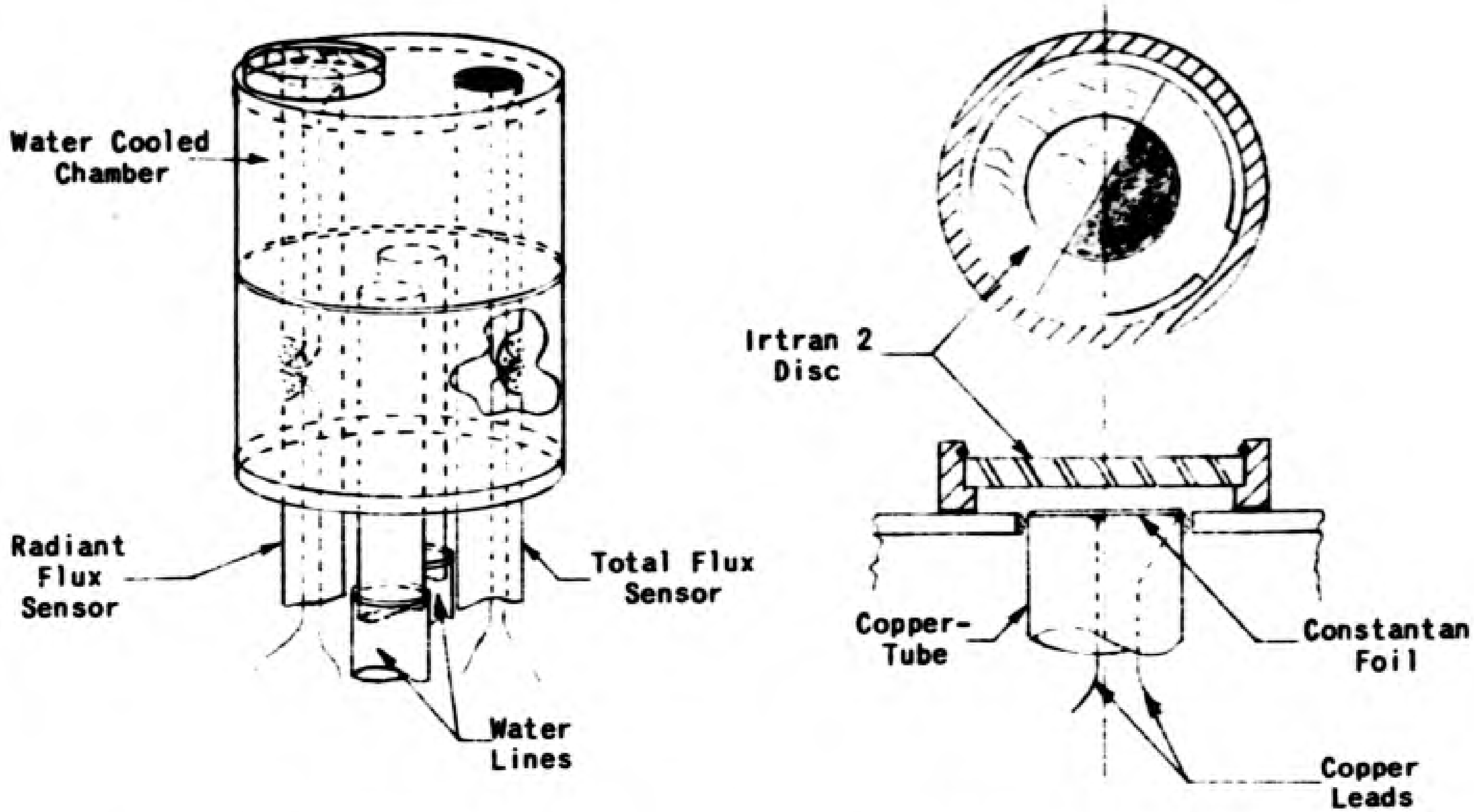

Fig. 35 CONSTRUCTION DETAILS OF DUAL ELEMENT CALORIMETER

In the room fires, radiation is emitted by the heated walls as well as by the flames and hot surfaces associated with the burning items. Consequently, the significant radiation will contain a wide range of wavelengths, and the window covering the radiation calorimeter must have a wide band of transparency. Irtran 2 satisfies this requirement very well, as shown by its transmittance curve in Figure 36. Since it transmits radiation at wavelengths up to about 12 microns, the Irtran 2 window is useful for measuring radiation from sources at temperature as low as about 400°F. Figure 37 shows how the source temperature and cut-off wavelength of the window affect the fraction of total energy emitted by a black-body source that is transmitted to the radiation calorimeter.

Figure 38 shows typical calorimeter outputs recorded during fire buildup. As indicated in the figure, the unit was removed at regular intervals for window cleaning. No flashover is shown in this record since the room contained only one burning item.

The relation between the heat fluxes and the records obtained are shown below.

For the blackened disk ($\varepsilon = 0.92$):

$$0.92\ R + C = BE_B \qquad \text{(A-1)}$$

where R = radiant flux absorbed

C = convective flux

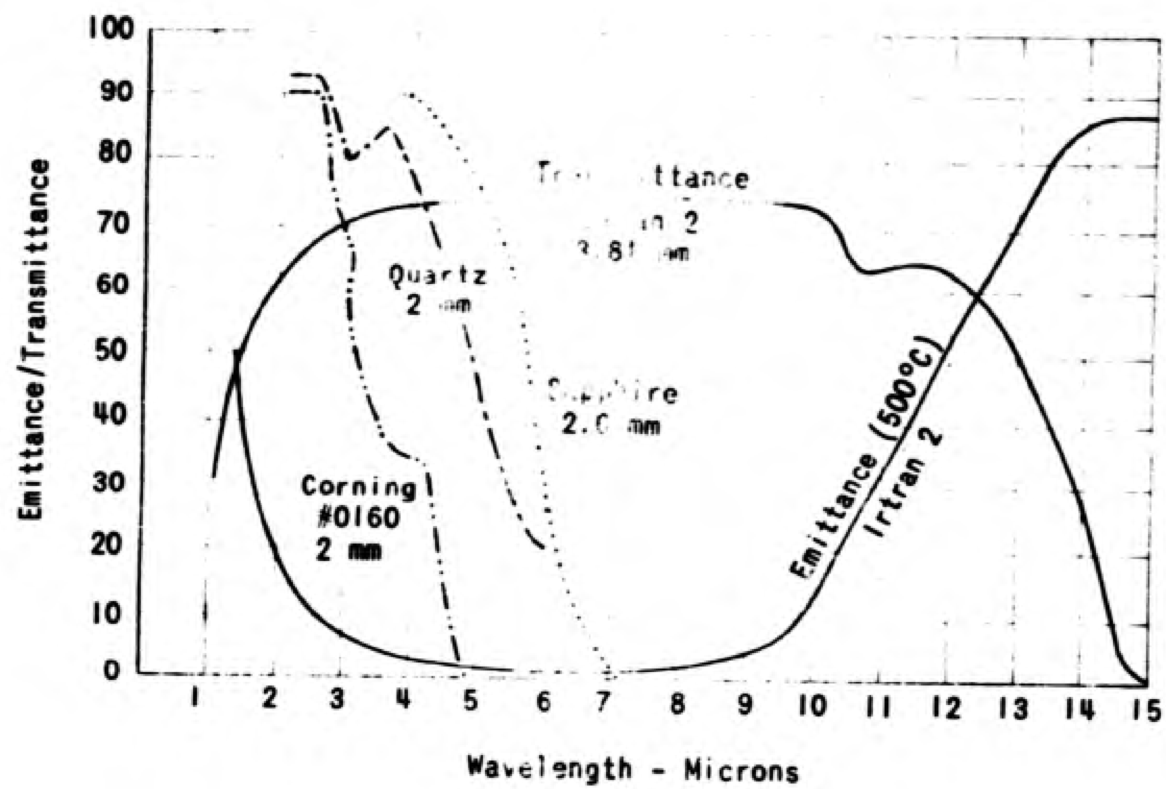

Fig. 36 INFRA-RED TRANSMITTING PROPERTIES OF SELECTED MATERIALS

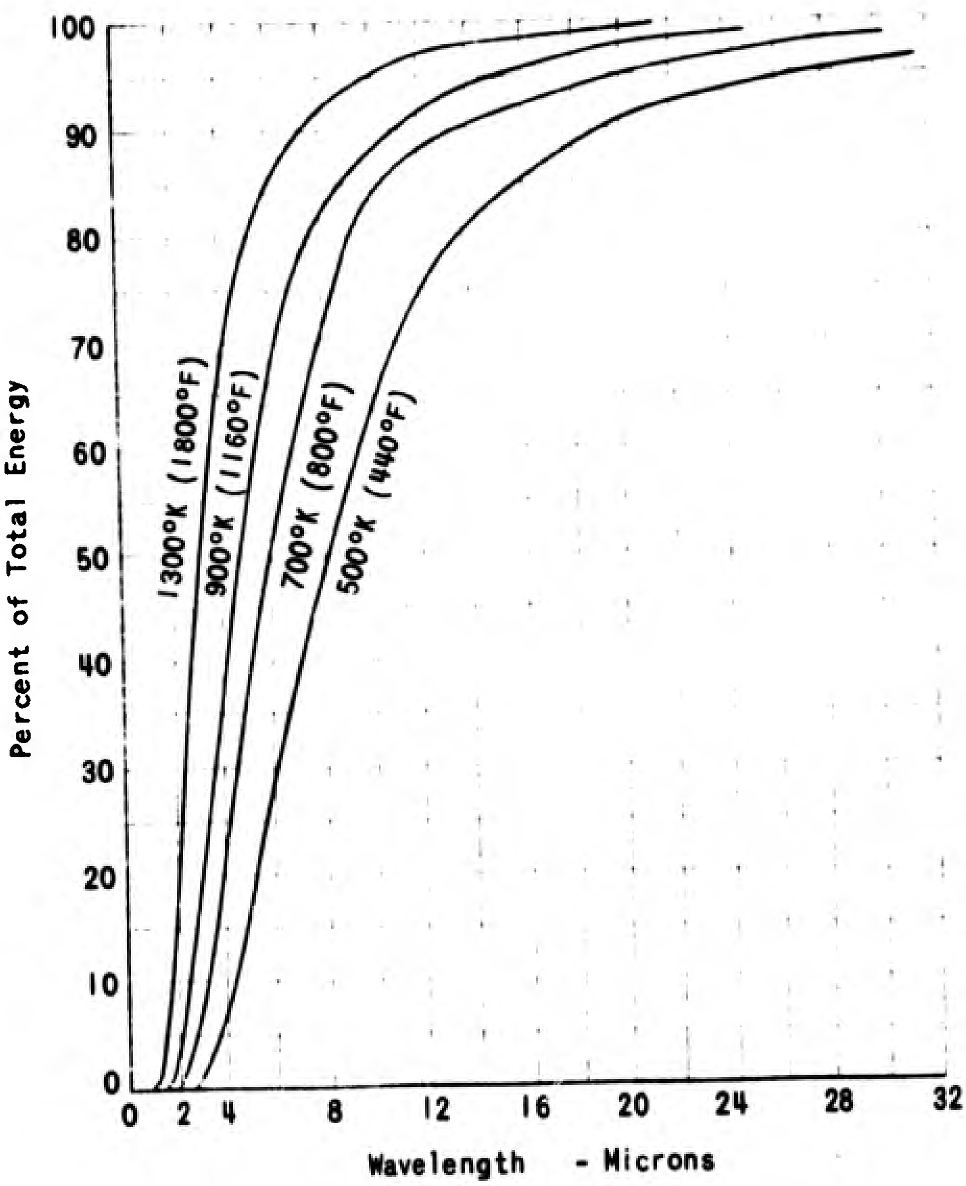

Fig. 37 EFFECT OF RADIATING BODY TEMPERATURE ON THE PERCENT OF TOTAL RADIATIVE ENERGY EMITTED BELOW INDICATED WAVELENGTHS

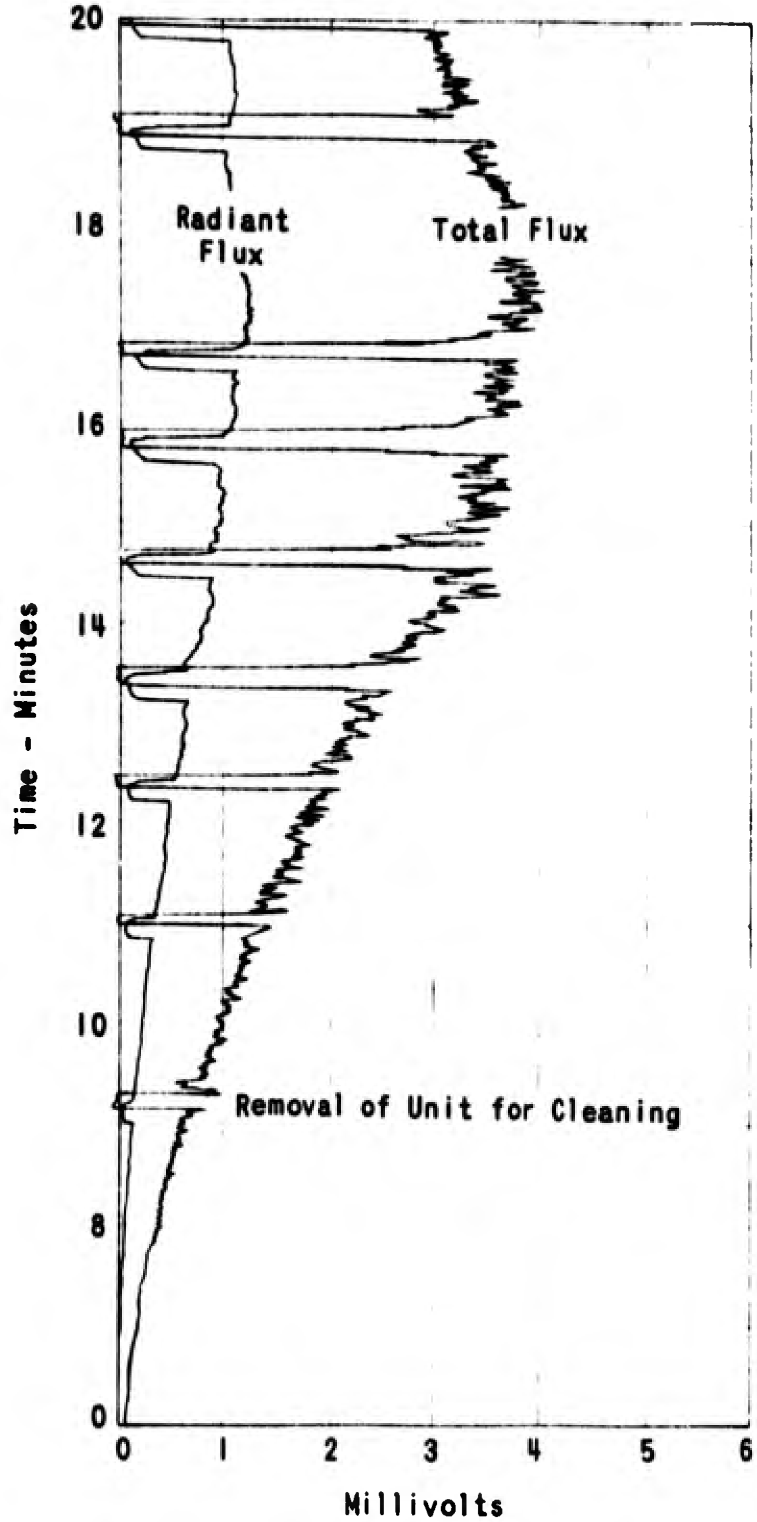

Fig. 38 TYPICAL MILLIVOLT OUTPUT FROM DUAL UNIT CALORIMETER

B = calibration constant involving disk thickness, diameter, thermocouple location, losses, etc.

E_B = millivolt signal generated

ε = emittance of the disk

For the disk covered by the window:

$$DR = AE_A \tag{A-2}$$

where D = factor involving transmission of window and emittance (0.92) of the disk

A = calibration constant for disk (similar to B)

E_A = millivolt signal generated

For calibration with a radiant source,

C = 0 and

$$B = \frac{0.92\ R_c}{E_{B,c}} \tag{A-3}$$

$$A = \frac{DR_c}{E_{A,c}} \tag{A-4}$$

where subscript c indicates calibration values.

Substitution of Equations A-3 and A-4 into Equations A-1 and A-2 yields

$$0.92\ R + C = \frac{0.92\ R_c}{E_{B,c}} E_B \qquad \text{(A-5)}$$

$$R = \frac{R_c}{E_{A,c}} E_A \qquad \text{(A-6)}$$

From Equations A-5 and A-6,

$$C = 0.92\ \left(\frac{R_c}{E_{B,c}}\ E_B - \frac{R_c}{E_{A,c}}\ E_A\right) \qquad \text{(A-7)}$$

Performance of the calorimeters was evaluated with purely radiative heating, purely convective heating, and combinations of the two. The results have shown that the calorimeter adequately measures total heating and radiant heating for the conditions which occur in actual room fires.

APPENDIX B

TABULATED DATA

TABLE B-1c

SUMMARY OF EXPERIMENTS

DASA EXP. NO.	INITIATING ITEM	REMAINING CONTENTS	WINDOW OPENING WIDTH FEET	WINDOW OPENING HEIGHT FEET	LOCATION OF FIRE RELATIVE TO OPENING	BEFORE FLASHOVER AT ROOM CENTER MIN O_2 %	BEFORE FLASHOVER AT ROOM CENTER MAX CO %	PEAK BURNING RATE* AT OR BEFORE FLASHOVER LBS/MIN	TIME TO FLASHOVER MIN-SEC	R (CAL $CM^{-2}SEC^{-1}$)	C (CAL $CM^{-2}SEC^{-1}$)	R&C** (CAL $CM^{-2}SEC^{-1}$)
001	MED UPH CHAIR	NONE	4	4-1/2	REAR CORNER	19.3	< 0.1	3.3				
002	MED UPH CHAIR	NONE	4	4-1/2	REAR CORNER			5.5				
003	MED UPH CHAIR	NONE	4	4-1/2	REAR CORNER	21	0.06	2.5				
004	MED UPH CHAIR	NONE	4	4-1/2	REAR CORNER			5.2				
005	MED UPH CHAIR	NONE	4	4-1/2	REAR CORNER			5.9				
006	MED UPH CHAIR	NONE	4	4-1/2	REAR CORNER			5.2				
007	CRIB - 3' X 3'@	CHAIR	4	4-1/2	REAR CORNER			10.1				
008	CRIB - 3' X 3'	CHAIR	4	4-1/2	REAR CORNER			13.4				
009	CRIB	NONE	CALORIMETER EVALUATION: 50°F WATER									
010	CRIB	NONE	CALORIMETER EVALUATION: 130°F WATER									
011	CRIB	NONE	CALORIMETER EVALUATION: MICA WINDOW									
012	CRIB	NONE	CALORIMETER EVALUATION: MICA WINDOW									
013	COUCH	LIVING ROOM	4	4-1/2	SIDE	11.1	0.1	9.9	NONE			
014	COUCH	LIVING ROOM	4	4-1/2	SIDE	17.0	0.15	8.8	NONE			.24
015	SECTIONAL COUCH	LIVING ROOM	4	4-1/2	SIDE	14.2	0.1	11.7	16-00			.73
016	SECTIONAL COUCH	LIVING ROOM	4	4-1/2	SIDE	16.8	0.15	~ 7	17-15			.41
017	COUCH	LIVING ROOM	2	4-1/2	SIDE	7.8	0.1	7.4	15-15			.79
018	COUCH	LIVING ROOM	2	4-1/2	SIDE	11.7	0.3	5.5	39-50			.47
019	SECTIONAL COUCH	LIVING ROOM	2	4-1/2	SIDE	10.8	0.25	5.3	13-45			.49
020	COUCH	LIVING ROOM	4	3	SIDE	15.6	0.2	4.2	22-40			.37
021	COUCH	LIVING ROOM	4	3	SIDE	11.0	0.15	7.8	18-10			.69
022	COUCH	LIVING ROOM	2	3	SIDE	2.0	1.8	7.0	24-10			.88
023	COUCH	LIVING ROOM	4	4-1/2	REAR	7.5	0.2	8.7	19-50			.50
024	2 MED FOAM CHAIRS	LIVING ROOM	4	4-1/2	REAR	1.4	1.4	14	15-55			1.64
025	COUCH	LIVING ROOM	4	4-1/2	REAR	14.25	0.15	6.3	18-00			.44
026	2 MED FOAM CHAIRS	LIVING ROOM	4	4-1/2	REAR	2.9	1.4	3.8	6-00			1.01
027	SECTIONAL COUCH	LIVING ROOM	4	4-1/2	REAR	10.1	0.5	8.9	14-30			.83
028	2 MED FOAM TOPPED CHAIRS	LIVING ROOM	4	4-1/2	REAR	18.0	0.18	1.2	NONE			.098
029	FOAM COUCH & CUSHION	LIVING ROOM	4	4-1/2	REAR	1.0	4.5	-	4-30			.60

c FOR REMARKS SEE TABLE B-2

* WEIGHT LOSS OF FUEL

@ ALL CRIBS ARE 1 X 2 LUMBER ON 3" CENTERS, 6 ROWS HIGH

** RADIANT (R), CONVECTIVE (C) FLUX (CAL/CM^2-SEC) AT FLASHOVER FOR FULLY LOADED ROOMS. FOR ROOMS WITH NO CONTENTS, VALUES TAKEN WHEN NEWSPRINT IGNITES. IF NO IGNITION, MAXIMUM VALUES RECORDED.

TABLE B-1

SUMMARY OF EXPERIMENTS

DASA EXP. NO.	INITIATING ITEM	REMAINING CONTENTS	WINDOW OPENING WIDTH FEET	WINDOW OPENING HEIGHT FEET	LOCATION OF FIRE RELATIVE TO OPENING	BEFORE FLASHOVER AT ROOM CENTER MIN O_2 %	BEFORE FLASHOVER AT ROOM CENTER MAX CO %	PEAK BURNING RATE* AT OR BEFORE FLASHOVER LBS/MIN	TIME TO FLASHOVER MIN-SEC	R (CAL $CM^{-2}SEC^{-1}$)	C (CAL $CM^{-2}SEC^{-1}$)	R&C** (CAL $CM^{-2}SEC^{-1}$)
030	SECTIONAL COUCH	LIVING ROOM	4	3	REAR	12.4	0.12	7.4	†			.64
031	2 MED FOAM CHAIRS	LIVING ROOM	4	3	REAR	10.5	0.5	†	12-30			.71
032	COUCH	LIVING ROOM	4	1	REAR	3.9	2.8	9.5	16-10			.49
033	COUCH	LIVING ROOM	4	1	REAR	1.3	2.5	3.3	49-00			.67
034	FOAM COUCH	LIVING ROOM	4	1	REAR	1.25	3.7	5.5	NONE			.31
035	COUCH	LIVING ROOM	4	4-1/2	FRONT	12.5	0.2	7.7	NONE			.24
036	COUCH	LIVING ROOM	4	4-1/2	FRONT	16.2	0.15	4.0	NONE			.12
037	CRIB - 1.5' X 6'	LIVING ROOM	4	4-1/2	REAR	11.0	0.2	5.7	15-40			.57
038	CRIB - 1.5' X 6'	LIVING ROOM	4	4-1/2	REAR	13.1	0.1	4.2	10-30			.57
039	CARTONS - SHELVES	STORAGE	4	4-1/2	SIDE	11.25	0.1	11	4-30			1.52
040	CARTONS - SHELVES	STORAGE	4	4-1/2	SIDE	3.75	2.8	10.5	2-30			3.1
041	BED	BEDROOM	4	4-1/2	REAR CORNER	15.7	0.2	†	10-20			2.5
042	BED	BEDROOM	4	4-1/2	REAR CORNER	17.8	0.25	9.6	11-40			2.6
043	BED	BEDROOM	4	4-1/2	REAR CORNER	12.8	0.25	8.3	12-10			2.3
044	BED	NONE	4	4-1/2	REAR CORNER			18	24-53***	.32	.21	.53
045	BED	NONE	4	4-1/2	REAR CORNER			12†	15-15	.38	.18	.56
046	BED	NONE	4	3	REAR CORNER			10.9	8-30	.42	.30	.72
047	CARTON - SHELVES	NONE	4	4-1/2	SIDE			†	2-05	.57	.21	.78
048	COUCH (FOLD DOWN SLEEPER)	NONE	4	3	SIDE			6.4	11-20			
049	COUCH (FOLD DOWN SLEEPER)	NONE	4	4-1/2	SIDE			11.3	12-57	.30	.22	.52
050	FOAM COUCH	NONE	4	4-1/2	SIDE				10-02	.38	.22	.60
051	FOAM COUCH	NONE	4	4-1/2	REAR			10.8	12-45	.13	.49	.62
052	SECTIONAL COUCH	NONE	4	4-1/2	REAR			11.9	18-05	.35	.35	.70
053	COUCH	NONE	4	3	REAR			8.77	51-20	.19	.17	.36
054	CRIB - 1.5' X 6'	NONE	4	4-1/2	REAR			8.75	9-45	.18	.17	.35
055	CRIB - 1.5' X 6'	NONE	4	3	REAR			8.4	7-49	.27	.23	.50
056	CRIB - 1.5' X 6'	NONE	4	1	REAR			5.2	NONE	> .5	> .3	> .8
057	CRIB - 1.5' X 3'	NONE	4	4-1/2	REAR			5.4	NONE	.13	.16	.29

† FOR REMARKS SEE TABLE B-2

* WEIGHT LOSS OF FUEL

** RADIANT (R), CONVECTIVE (C) FLUX (CAL/CM^2-SEC) AT FLASHOVER FOR FULLY LOADED ROOMS. FOR ROOMS WITH NO CONTENTS, VALUES TAKEN WHEN NEWSPRINT IGNITES. IF NO IGNITION, MAXIMUM VALUES RECORDED

***FOR ROOMS WITH NO LOADING, FLASHOVER IS APPROXIMATED BY IGNITION OF SECTION OF NEWSPRINT 2 FT BELOW CEILING.

TABLE B-1●

SUMMARY OF EXPERIMENTS

DASA EXP. NO.	INITIATING ITEM	REMAINING CONTENTS	WINDOW OPENING WIDTH FEET	WINDOW OPENING HEIGHT FEET	LOCATION OF FIRE RELATIVE TO OPENING	BEFORE FLASHOVER AT ROOM CENTER MIN O_2 %	BEFORE FLASHOVER AT ROOM CENTER MAX CO %	PEAK BURNING RATE* AT OR BEFORE FLASHOVER LBS/MIN	TIME TO FLASHOVER MIN-SEC	R CAL $CM^{-2}SEC^{-1}$	C CAL $CM^{-2}SEC^{-1}$	R&C**
058	CRIB - 1.5' X 3'	NONE	4	3	REAR			6.8	NONE	.16	.20	.36
059	CRIB - 1.5' X 3'	NONE	4	1	REAR			6.4	NONE	.36	.20	.56
060	CRIB - 3' X 3'	NONE	4	4-1/2	REAR			11.1	5-46	.29	.28	.57
061	CRIB - 3' X 3'	NONE	4	3	REAR			7.2	4-05	.31	.23	.54
062	CHAIR	NONE	4	4-1/2	REAR CORNER			6.1	39-40	.24	.20	.44
063	CHAIR	NONE	4	4-1/2	REAR CORNER			3.4	NONE			
064	CHAIR	NONE	4	4-1/2	REAR CORNER			6.5	11-52			
065	CHAIR	NONE	4	3	REAR CORNER			7.3	36-23			
066	CHAIR	NONE	4	3	REAR CORNER			1.1	NONE	0	0	0
067	CHAIR	NONE	4	3	REAR CORNER			2.5	NONE	.05	.10	.15
068	CHAIR	NONE	4	1	REAR CORNER			3.8	●	.19	.21	.40
069	CANCELLED											
070	BED	BEDROOM	4	4-1/2	REAR CORNER			●	12-00	●	●	●
071	COUCH	LIVING ROOM	4	4-1/2	REAR	19	0.1	11.7	34-28	.15	.21	.36
072	CRIB - 2' X 2'	NONE	4	4-1/2	REAR CORNER			4.9	NONE	.10	.17	.27
073	CRIB - 2' X 2'	NONE	4	3	REAR CORNER			3.4	NONE	.11	.19	.30
074	CRIB - 2' X .'	NONE	4	1	REAR CORNER			3.8	NONE	.17	.20	.37
075	CRIB - 2' X 2' (12 ROWS HIGH)	NONE	4	4-1/2	REAR CORNER			8.1	MISSED			
076	CRIB - 2' X 2' (12 ROWS HIGH)	NONE	4	4-1/2	REAR CORNER			6.6	3-50	.33	.31	.64
077	CRIB - 2' X 2' (12 ROWS HIGH)	NONE	4	3	REAR CORNER			6.9	MISSED			
078	CRIB - 2' X 2' (12 ROWS HIGH)	NONE	4	1	REAR CORNER			6.4	NONE			.68
079 THRU 096	LP GAS 1, 3 OR 6 BURNERS, 1/8 IN PIPE WITH FLAME SPREADERS	NONE	4 4	4-1/2 1	SIDE					See Figs. 30-34		
097 THRU 107	LP GAS, 1, 3 OR 6 BURNERS, 1/2 IN PIPE	NONE	4	4-1/2	SIDE							

● FOR REMARKS SEE TABLE B-2

* WEIGHT LOSS OF FUEL

** RADIANT (R), CONVECTIVE (C) FLUX (CAL/CM^2-SEC) AT FLASHOVER FOR FULLY LOADED ROOMS. FOR ROOMS WITH NO CONTENTS, VALUES TAKEN WHEN NEWSPRINT IGNITES. IF NO IGNITION, MAXIMUM VALUES RECORDED.

TABLE B-I

SUMMARY OF EXPERIMENTS

DASA EXP. NO.	INITIATING ITEM	REMAINING CONTENTS	WINDOW OPENING WIDTH FEET	WINDOW OPENING HEIGHT FEET	LOCATION OF FIRE RELATIVE TO OPENING	BEFORE FLASHOVER AT ROOM CENTER MIN O_2 %	BEFORE FLASHOVER AT ROOM CENTER MAX CO %	PEAK BURNING RATE* AT OR BEFORE FLASHOVER LBS/MIN	TIME TO FLASHOVER MIN-SEC	R CAL $CM^{-2}SEC^{-1}$	C CAL $CM^{-2}SEC^{-1}$	R&C**
109 THRU 129	LP GAS, 1, 2, 3 OR 6 BURNERS, 1/2 IN PIPE	NONE	4	4-1/2	SIDE							
130 THRU 149	LP GAS, 1, 2, 3 OR 6 BURNERS, 1/2 IN PIPE	SEE REMARKS										
150 THRU 152	RECONFIRM 125, 7, 9											
153	COUCH	SEE REMARKS										
154	COUCH	SEE REMARKS										
155	LP GAS, 3-1/2 IN PIPES	NONE	4	4-1/2	REAR CORNER					See Figs. 30-34		
156	LP GAS, 3-1/2 IN PIPES	NONE	4	4-1/2	REAR CORNER							
157	LP GAS, 1-1/2 IN PIPE	NONE	4	4-1/2	REAR CORNER							
158	LP GAS, 3-1/2 IN PIPES	NONE	4	4-1/2	REAR							
159	LP GAS, 6-1/2 IN PIPES	NONE	4	4-1/2	REAR							
160 THRU 201	LP GAS, 6-1/2 IN PIPES	NONE	4 4 4	4-1/2 3 1	SIDE	SEE FIG. 31 & 32 FOR GAS CONCENTRATIONS						

† FOR REMARKS SEE TABLE B-I

* WEIGHT LOSS OF FUEL

** RADIANT (R), CONVECTIVE (C) FLUX (CAL/$CM^{-2}SEC^{-1}$) AT FLASHOVER FOR FULLY LOADED ROOMS. FOR ROOMS WITH NO CONTENTS, VALUES TAKEN WHEN NEWSPRINT IGNITES. IF NO IGNITION, MAXIMUM VALUES RECORDED.

TABLE B-2

REMARKS FOR TABLE B-I

DASA EXP. NO.	REMARKS
001-012	NONE
013	DRAPE IGN AT 12 MIN 20 SEC (MARGINAL FLASHOVER CONDITION)
014	DRAPE IGN AT 15 MIN 30 SEC (MARGINAL FLASHOVER CONDITION)
015	DRAPES IGNITED ~ 40 SEC EARLIER
016	DRAPE IGNITED AT 16 MIN
017	TOTAL FLUX AT MIDWALL = 0.6 AT FLASHOVER, RISES RAPIDLY TO ~ 1.1 CAL/CM^2-SEC
018	NONE
019	NOT SHARP FLASHOVER, SEVERAL IGNITIONS BETWEEN 12-14 MIN
020	NONE
021	NO MAJOR COMBUSTIBLES IN GAS SAMPLE EXCEPT CO
022	TOTAL FLUX AT MIDWALL = 0.5 CAL/CM^2-SEC AT IGN, RISES RAPIDLY TO ~ 0.9 CAL/CM^2- SEC
023	NONE
024	DRAPES IGN AT 13 MIN 50 SEC
025	DRAPES IGN 12 SEC EARLIER
026-028	NONE
029	BURN RATE ROSE RAPIDLY FROM 0 TO ~ 10 LBS/MIN STARTING AT ABOUT 4 MIN
030	NOT SHARPLY DEFINED, 18-19 MIN
031	BURN RATE 1.7 LBS/MIN FROM 9-12 MIN, RISING RAPIDLY AT FLASHOVER
032	NONE
033	NOT SHARPLY DEFINED, 42 MIN 30 SEC DRAPE IGNITION
034	HEAVY SMOKE, TEMPERATURES HIGH BUT NO O_2
035	CURTAINS SMOULDERING AT 32 MIN, (ON THE BRINK OF FLASHOVER)
036	NONE
037	CRIB IGNITED AT ONE END
038	CRIB IGNITED AT ONE END
039	STARTS AT NEUTRAL DENSITY PLANE AND MOVES RAPIDLY UP

TABLE B-2

REMARKS FOR TABLE B-I

DASA EXP. NO.	REMARKS
040	FIRE BUILDS UP MORE RAPIDLY THAN 039, DISTILLATION PRODUCTS VISIBLY COLLECT AT NEUTRAL DENSITY PLANE, THEN BURN OFF AT FLASHOVER
041	BURN RATE CHANGING RAPIDLY AT FLASHOVER, AVERAGED 3 LBS/MIN FROM 9-10 MIN, 17-1/2 LBS/MIN FROM 10-10 MIN 30 SEC (MINIMUM O_2, PROBABLY A LOCAL CONDITION)
042-044	NONE
045	BURN RATE RISING VERY RAPIDLY AT FLASHOVER, AVERAGED $\sim$ 24 LBS/MIN FROM 15 TO 16 MIN
046	NONE
047	BURN RATE RISING VERY RAPIDLY, AVERAGED 6 LBS/MIN 1 MIN→2 MIN, 29 LBS/MIN 2 MIN→3 MIN
048-050	NONE
051	HEAVY SMOKE APPARENTLY BLOCKED RADIATION
052-055	NONE
056	O_2 STARVED
057-058	NONE
059	O_2 STARVED
060-065	NONE
066	NO ACTIVE BURNING PERIOD
067	NONE
068	PAPER SUFFERED SMOULDERING IGNITION ONLY
069	NONE
070	IMPOSSIBLE TO ACCURATELY MEASURE R, C AND BURN RATE AT FLASHOVER, IN 20 SEC PERIOD R WENT 0→.62 CAL/CM^2-SEC, C WENT .04→.38 CAL/CM^2-SEC, AND BURN RATE 2.5→30.4 LBS/MIN
071	PAPER IGNITION ONLY, SMOULDERING IGNITION OF REMAINING COMBUSTIBLES (MARGINAL FLASHOVER)
072	NONE
073	IGNITION OF PAPER AT OTHER REAR CORNER AT 4 MIN 46 SEC
074	NONE
075	IGNITION OF PAPER AT OTHER REAR CORNER AT 2 MIN 44 SEC, MAX R = .36, MAX C = .34
076	IGNITION OF PAPER AT OTHER REAR CORNER AT 2 MIN 25 SEC, MAX R = .38, MAX C = .35

TABLE B-2

REMARKS FOR TABLE B-I

DASA EXP. NO.	REMARKS
077	MAX R = .41, MAX C = .37
078	O_2 STARVED
079-096	PRELIMINARY GAS BURNER EVALUATION, NO ACCURATE FLOW MEASUREMENTS (REPRODUCED PRESSURE AT VALVE FOR CONTROL) EXAMINED R & C
097-107	PRELIMINARY GAS BURNER EVALUATION, NO ACCURATE FLOW MEASUREMENTS (REPRODUCED PRESSURE AT VALVE FOR CONTROL) EXAMINED R & C
108-129	MEASURED FLOW RATES, R, C, FLAME HT (AND CEILING LAY OVER) EFFECT OF NO. OF BURNERS ON CONDITIONS MINOR UNLESS ROOM MIXING LARGE
130-149	BURNERS PLACED IN CENTER OF MAIN LAB, FLAME HEIGHT, R, FLOW RATE (RADIATION VERY LOW)
150-152	NONE
153	BURNED IN MAIN LAB, RADIATION VERY SMALL
154	FALSE WALL BEHIND COUCH TO CHANNEL FLAMES UPWARD, RADIATION STILL VERY SMALL
155	SIMULATION OF CHAIR BURN, 062
156	SIMULATION OF CHAIR BURN, 062
157	SIMULATION OF CHAIR BURN, 062
158	SIMULATION OF COUCH BURN, 052
159	SIMULATION OF COUCH BURN, 052
160-201	GENERATION OF GAS CONCENTRATION, TEMPERATURE, RADIANT AND CONVECTIVE FLUX PROFILES AS A FUNCTION OF FUEL SUPPLY RATE (SELECTION OF REFERENCE OR "STANDARD" FIRES) FOR USE IN SCALING STUDIES

Unclassified

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13 ABSTRACT

This is the first annual report of a continuous program to investigate fire behavior in rooms during the ignition-to-flashover period. The objectives of the program are to quantitatively evaluate time histories of temperatures, gas composition, and heat flux in ignited rooms, and to determine the conditions necessary for the occurrence of flashover. The approach being used is to study a series of room fires involving contents typical of actual occupancies, develop simple, reproducible fuel arrays which duplicate the essential features of these fires, and then establish procedures for small scale simulations of room fires using the simplified fuel arrays. Experiments at the smallest feasible scale will then be used to evaluate effects of such parameters as room size, ceiling height, location and size of ventilation openings, combustibility of wall and ceiling covering, and insulative quality of wall and ceiling material. This report contains the results of the studies of full scale room fires using both real and simplified fuel arrays.

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Security Classification

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fire Buildup						
Flashover						
Fire Propagation						

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