F.R. Note No. 207/1955
Research Programme
Objective E1/1

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

This report has not been published and should be considered as confidential advance information. No reference should be made to it in any publication without the written consent of the Director of Fire Research. (Telephone: ELStree 1341 and 1797).

THE GROWTH OF FIRES IN ROOMS AND A TEST FOR INTERNAL LININGS

by

D. Hird and P. H. Thomas

SUMMARY

Experimental work on the effect of internal linings on the growth of fire in rooms is described. As a result of this work a test has been developed which will classify the fire hazard of internal linings.

August, 1955.

File No. F. 1000/17/14

Fire Research Station,
Boreham Wood,
Herts.

THE GROWTH OF FIRES IN ROOMS AND A TEST FOR INTERNAL LININGS

by

D. Hird and P. H. Thomas

INTRODUCTION

Since the last war there has been a growing tendency to avoid the use of plaster on walls and ceilings and to use instead, as internal linings, ready-made sheets of material which are included in the general term "building boards". The sales of plasterboard in this country have risen from 31 million square yards (28·3 million square metres) in 1928 to about 55 million square yards (50·3 million square metres) in 1954, and of fibre building boards from 20 million square yards (18·3 million square metres) in 1938 to about 60 million square yards (54·8 million square metres) in 1954. The per capita consumption of both types of board is therefore about 10 square feet (0·9 square metres). In the U.S.A. it is about 20 square feet (1.86 square metres) and in Sweden 60 square feet (5·6 square metres).

When large areas of combustible linings are used in a building they may contribute to the possibility of rapid spread of fire and the increasing use of such boards has been reflected in the increasing attention paid to assessing and reducing their fire hazard.

The hazard will of course vary with a number of factors, such as the nature of the occupancy, the ventilation and the position of the board. There will be some situations where the difference between types of linings is irrelevant to the growth of fire. For example, if the contents of a room or building are more easily ignited and constitute a greater fire load than any lining, it would be unnecessary to attach great importance to the lining. Again, in a room or building in which, by virtue of the restricted ventilation, no fire could develop to flash-over, it would matter little which lining was used. Between these two extremes lies a wide range of practical conditions and although special conditions may call for special recommendations or legislation, it is thought that in the first place linings should be tested for those conditions in which the extent of the fire hazard may depend primarily on the nature of the wall lining. A satisfactory test for lining materials should compare them in relation to the hazard they could present in normal use, and should also be capable of assessing the effect of paint or other protective treatments.

In Great Britain, the principal test used for this purpose is the "Surface Spread of Flame Test" described in British Standard 476 : 1953 (1). Although this test was originally developed to determine the suitability of materials for corridors it has been widely used for assessing materials, both treated and untreated for linings in general. To interpret the results of this or any other test it is necessary to know as much as possible about the relation between performance in the test and performance under practical conditions. Unfortunately there is little reliable information on the behaviour of a range of materials under similar practical fire conditions. The development of a technique whereby small-scale models can be used to investigate the growth of fire (2) has enabled the performance of many materials to be studied under reproducible fire conditions, and has given the necessary information to form the basis of a realistic grading. This paper describes an extension of experimental work to study the way in which a fire develops in a room and how it is influenced by the type of linings and ceiling provided.

EXPERIMENTS ON GROWTH OF FIRE

In 1949 an experiment was carried out to compare the development of fire in two houses, both of which were lined with fibre insulating board, but one having an additional layer of plasterboard fixed to it (3). The surfaces of the walls of both houses were covered with two coats of oil-bound distemper. The essential characteristic of the fire was that it started in the contents of the room, and the furniture was arranged in such a way that there was the high probability that, once started, a fire would develop to involve all the furniture. The aim of the experiment was to compare the contribution made by the wall linings to the rate of development of a fire.

The fire developed to flash-over within 5 minutes in the house with untreated fibre insulating board and within 23 minutes in the house with plasterboard (Table 1). After flash-over the duration of the fire was much the same in both houses. In general, the amount of combustible involved in the linings is not very large compared with that of the furniture and floor, and it is to be expected that after flash-over the nature of the linings do not greatly matter. The time to flash-over is important because it, in general, determines the time for escape. Indications from full-scale tests show that a rapid deterioration in the condition of the atmosphere in neighbouring rooms occurs just after flash-over. It is thought therefore that a test should rate materials according to this criterion. Such experiments are expensive and the possibility of using small-scale models to study fire behaviour has since been explored.

The experiments to be described were designed, in the first place, to compare the growth of fires in rooms of different size. The quantity and arrangement of furniture in the small-scale rooms and houses were made similar to those used in the full-scale tests already described so that a direct comparison could be made with a fire for which fairly comprehensive data were available. The conditions were also such as to allow a fire to develop to flash-over in traditional rooms with incombustible ceiling and linings. It is only possible to compare linings over the whole range of combustibility if the fire could develop to flash-over with incombustible linings. The size of the igniting source and the degree of ventilation were accordingly chosen both to be representative of practical conditions and also to distinguish between fibre insulating board and traditional plaster linings in the same way as in the full-scale tests. The ventilation would represent that of many modern constructions and the source of ignition was such as might occur in practice.

The results would therefore be expected to be generally valid for fires in this type of enclosure having normal fire load and ventilation and in which the nature of the lining rather than the furniture, ignition and ventilation was the critical factor.

EXPERIMENTAL DETAILS

The arrangement of the furniture and the model room are shown in Figure 1. The dimensions of the furniture were scaled linearly except that the thickness of the members was made large enough to prevent their being burnt through before flash-over. During the growth of fire to flash-over, the thickness of the members and the linings is not otherwise of great importance. The ventilation was adjusted to ensure complete development of the fire.

RESULTS OF TESTS

Table 1 gives the range of times taken for the whole room to become involved for both full scale and models for the three types of structure for which full-scale results are available. Figure 2 gives comparative temperature records for two of these tests, showing the similarity between full and small-scale tests.

It was considered from this evidence that the growth of fire could be simulated sufficiently accurately by the use of small-scale models to justify the use of this method in a comparative study of the behaviour of building boards under fire conditions.

TABLE 1

TIME TAKEN FOR FIRE TO INVOLVE WHOLE ROOM FOR BOTH FULL SCALE AND MODELS

Type of structure	Time taken for fire to involve the whole room	
	Full scale (min)	Models (min)
Traditional (Incombustible walls and ceiling)	14 - 20	15 - 19
Fibre insulating board walls and ceiling with two coats of distemper	5	5
Plasterboard walls and ceiling	23*	14 - 18

*Under exactly similar conditions the plasterboard room could not take longer than the traditional type room, since the paper facing of the plasterboard would make some contribution. The probable reason for the longer time taken by the full-scale plasterboard structure was that the ventilation was more restricted than with the incombustible structure.

EFFECT OF LININGS ON SPREAD OF FIRE

The manner in which development of fire is influenced by the lining of the room is of considerable interest. In all the experiments the fire was started between the cupboard and the chair as indicated in Figure 1. The mutual support given by the flames from these two pieces of furniture was sufficient to ensure the development of a substantial fire, irrespective of the surroundings.

In the traditional type of room (i.e. rooms with plastered walls and ceilings and wooden floors) the flames spread on the floor, assisted by radiation from the burning cupboard, until the table was involved. When the fire was well established in the table it spread quickly over the rest of the room (Plate 1).

In the rooms lined with building boards on wall and ceiling, once the flames from the cupboard reached the ceiling, the fire developed in an entirely different manner. With untreated fibre insulating board or compressed straw slabs, the ceiling was ignited almost immediately and the flames spread rapidly across the ceiling and down the walls, igniting the furniture before the flames had begun to spread along the floor from the cupboard. Plate 2 illustrates this point in a one-fifth scale room.

In the rooms lined with treated fibre insulating board there were slight differences depending upon the treatments used. With silicate paint, the covering cracked very quickly and the protection offered under these circumstances was small. With surface and impregnation treatments on fibre insulating board achieving higher ratings in the "Surface Spread of Flame Test", the development of the fire was similar to that for the untreated board, but the fire in the cupboard had to persist for longer before flames spread along the ceiling. With fibre insulating board protected by a 3/16-in. (½-cm) skim plaster coat, the development was similar to that in a traditional type of room.

With the impregnated and surface treated hardboards used and with plasterboard linings the mechanism of development was again more like that in the traditional room, although there was some contribution from the boards in all three cases, there being most from the hardboard with a surface treatment.

The classifications of the various boards on the "Surface Spread of Flame Test", together with the time taken for the whole room to become involved in fire when lined with the boards, are given in Table 2. These results are the averages of at least three tests in each case, the maximum deviation from the mean being about 10 per cent.

TABLE 2

PARTICULARS AND RESULTS OF BOARDS TESTED IN FULLY-LINED ROOMS

Particulars of wall and ceiling linings	Classification on "Surface Spread of Flame Test" of B.S. 476	Mean time for all room to become involved in fire min	sec	Grading on new building board test
Incombustible		17	10	A
Fibre insulating board with 3/16-in. (½-cm) skim coat	Class 1	17	45	A
Wood wool	Class 1	16	45	A
Plasterboard	Class 1	16	35	A
Hardboard impregnated with monammonium phosphate. (Retention of salt - 18 to 20 per cent by weight)	Class 1	15	45	-
Hardboard with surface treatment of an intumescent paint (30 g/ft^2)(0.032 g/cm^2)	Class 1	13	30	B
Fibre insulating board with surface treatment of an intumescent paint (30 g/ft^2)(0.032 g/cm^2)	Class 1	10	35	B
Asbestos paper faced fibre insulating board	Class 1	10	30	B

TABLE 2 (contd.)

Particulars of wall and ceiling linings	Classification on "Surface Spread of Flame Test" of B.S. 476	Mean time for all room to become involved in fire min sec		Grading on new building board test
Fibre insulating board with surface treatment of an intumescent paint (15 g/ft^2)(0·016 g/cm^2)	Class 1	9	25	B
Fibre insulating board impregnated with monammonium phosphate. (Retention of salt - 9 per cent by weight)	Class 1	9	00	-
Fibre insulating board with surface treatment of silicate paint	Borderline Class 2-3	7	45	C
Treated fibre insulating board	Class 3	6	00	C
Untreated hardboard	Class 3	6	15	D
Compressed straw slabs	Class 3	5	45	D
Untreated fibre insulating board	Class 4	5	00	D

Some tests were also carried out in which the building boards formed only the ceiling, or only the walls of the room. As would be expected, the fire took longer to develop than in the previous series of tests, but the relative merits of different boards and treatments were similar.

The pattern of the growth of fire obtained in these experiments is similar to that found in some full-scale tests undertaken by the Building Research Station in 1943, where the arrangement of furniture was essentially the same.

The results in Table 2 show that the time to flash-over varies from 9 to 18 minutes within Class 1 and from 5 to 9 minutes over the range Class 2 to 4. Clearly the classification of the "Surface Spread of Flame Test" is able to distinguish between the poorer materials in terms of flash-over time but fails to distinguish between the better materials.

THE DEVELOPMENT OF A NEW BUILDING BOARD TEST

Since it was not found possible to change the criteria of the "Surface Spread of Flame Test" in order to make the gradings agree with the results of model fires, it was necessary to develop a new test (4). This was designed to grade linings according to the flash-over times.

The apparatus used for the test is illustrated in Figure 3. It is constructed with the test panel as one side of a chamber of area $7\frac{1}{2}$ in. (19 cm) square. Behind the panel, $\frac{1}{2}$ in. (1·27 cm) of asbestos board is mounted to provide some thermal insulation. The chamber is heated by two electric elements operating at a power of 1·5 kW. Ventilation is provided by an air inlet near to the test panel and a row of gas jets act as an igniting source. The flue gases from the chamber pass through a chimney and at a point in this chimney their temperature is measured. The gas is lit and the electric power is turned on after 3 minutes.

Several materials were tested in this apparatus and it was found that if certain criteria were chosen, a classification could be obtained which would correspond to the flash-over times obtained in the model experiments described previously.

These criteria depend on the comparison of the flue gas temperature with that obtained for a standard incombustible board [½-in. (1·27-cm) asbestos board]. The classifications are shown diagrammatically in Figure 4 where θ denotes the flue gas temperature for the incombustible board. It should be noted that θ also varies with time.

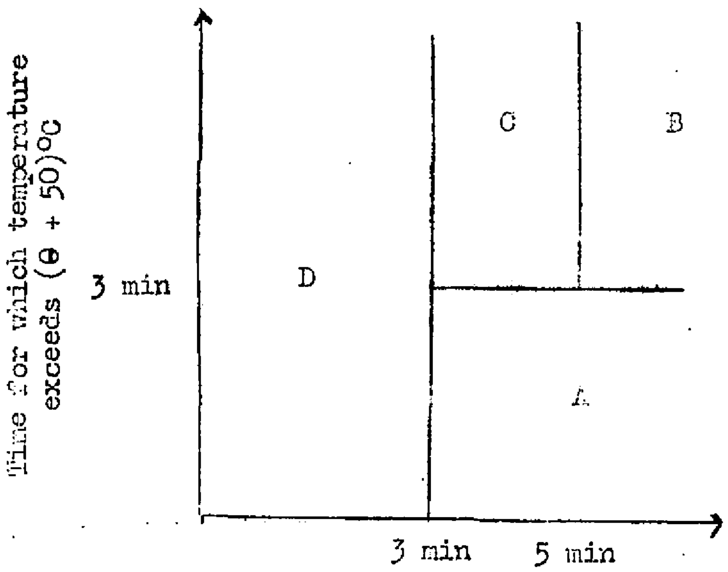


FIG. 4. CLASSIFICATION IN BUILDING BOARD TEST

If the flue gas temperature exceeds the temperature attained with an incombustible specimen by 50°C, while the only source of heat is the gas burner, the material is placed in the lowest Class - D. This implies that the material can be ignited easily and that it has a readily combustible surface. The classification with the other three gradings involves not only the time that the temperature takes to reach (θ + 50)°C, but also the time for which the temperature remains above this level. This criterion corresponds to the idea that the hazard of a lining is related not only to the ease of its ignition but also to the total amount of heat liberated. Materials for which the flue gas temperature exceeds (θ + 50)°C for less than 3 minutes, and which do not reach (θ + 50)°C in less than 3 minutes are rated in the top Class A. Materials which do not reach a temperature of (θ + 50)°C in 3 minutes but reach it in less than 5 minutes and for which the time that their temperature exceeds (θ + 50)°C is greater than 3 minutes are classified as Class C. The remaining Class B includes materials for which the flue gas temperature does not reach (θ + 50)°C in 3 minutes, but for which the time that their temperature is in excess of (θ + 50)°C is greater than 3 minutes.

Table 2 also gives the grading of various materials as given by this test.

It can be shown that the temperatures obtained using an incombustible specimen vary somewhat with the thermal properties of the specimen and the lagging. Thus the surface of a material of low conductivity will heat more quickly than one of higher conductivity and less heat will enter the material from inside the heated chamber. Flue gas temperatures will therefore be somewhat higher for the incombustible materials of lower conductivity. Some experiments were made to assess this factor and the results are shown in Figure 5. It is seen that over a considerable range of thermal conductivity, the effect on the flue gas temperatures is less than 30°C. This implies that the heat lost through the chimney is large compared with that absorbed by, and passing through, the walls of the test apparatus and the specimen and that variations of thermal properties in materials of low combustibility are of little importance.

QUANTITATIVE BASIS OF TEST

It is hoped that it will be possible in the future to use this apparatus to make an assessment of the relative importance of the furnishings and various wall linings. In order to do this it is necessary to get some idea of the rate and quantity of heat liberated by various materials. The heat liberated by the heaters is approximately equal to that which would be liberated by a burning wooden panel of the same area as the specimen and therefore the contribution of the wall lining in an actual fire may be estimated.

Some experiments have been made in which a variable gas supply to the apparatus was used as a source of heat and the results have made it possible to relate the flue gas temperature at any time in the test to the rate of heat output at that time. So far the results have only been computed for fibre insulating board and there is good agreement with the values obtained by measuring the rate of loss of weight while the test was in progress (Figure 6).

DISCUSSION

In using models for the study of fire the mechanisms of heat transfer and of ventilation change continuously throughout the fire and it may be necessary to use different models to represent different stages in the development.

For example, the growth of a fire up to flash-over and the burning of the fully-developed fire probably require different techniques for a complete study. Further experimental work is planned to study this problem. Perhaps it may become possible to relate quantitatively some, if not all, of the features of the development of a fire to the basic properties of the materials and their arrangements. For example, Hird and Fischl (5) in some of their experiments, showed that it was possible to relate approximately the distance of spread of flame along the floor of a room without furniture in it, to the threshold intensity for spread of flame as measured directly in experiments on ignition.

The ease with which a material can be ignited is related to this threshold intensity, and to the relative sizes of the igniting source and the combustible lining. The rate of spread of flame across the surface of a combustible is at present being examined theoretically as well as practically, to find the role of the thermal and chemical properties of the material. Only so far as these different lines of approach converge, will it be possible to expand our knowledge of the fundamentals of the development of a fire and to understand the relevance of the particular aspects of a special problem, but the work described in this paper is considered to provide a sufficiently firm basis for testing linings for general purposes.

REFERENCES

(1) Fire tests on building materials and structures. British Standard 476 : 1953.

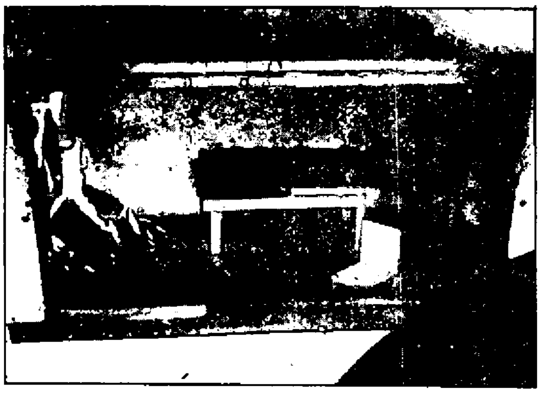
(2) HIRD, D. and FISCHL, C. F. Fire hazard of internal linings. Department of Scientific and Industrial Research and Fire Offices' Committee (Joint Fire Research Organization) National Building Studies Special Report No. 22. London, 1954. H.M. Stationery Office.

(3) Fire Research 1950. Department of Scientific and Industrial Research and Fire Offices' Committee. London, 1951. H.M. Stationery Office. p. 24.

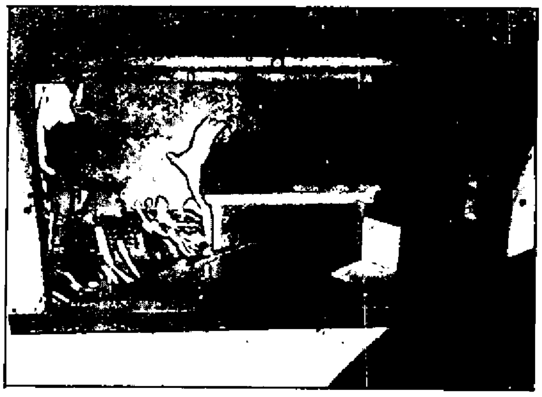
(4) HIRD, D. and KARAS, G. C. A method for classifying the fire hazard of internal linings and their treatments. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization F.R. Note No. 166/1955.

(5) HIRD, D. and FISCHL, C. F. Fires in model rooms. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization F.R. Note No. 12/1952.

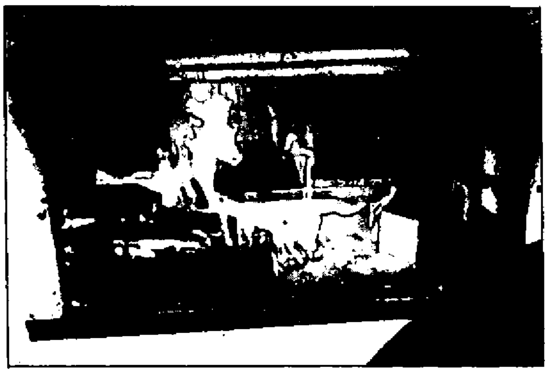
PC.



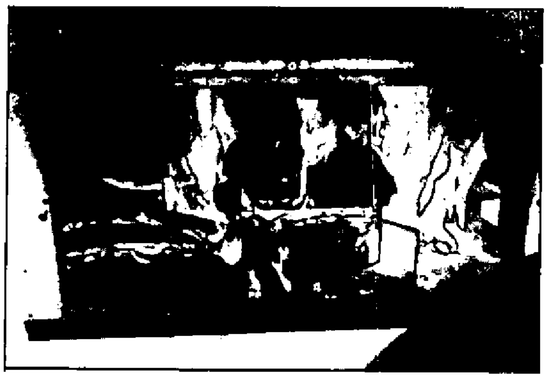
After 10 min



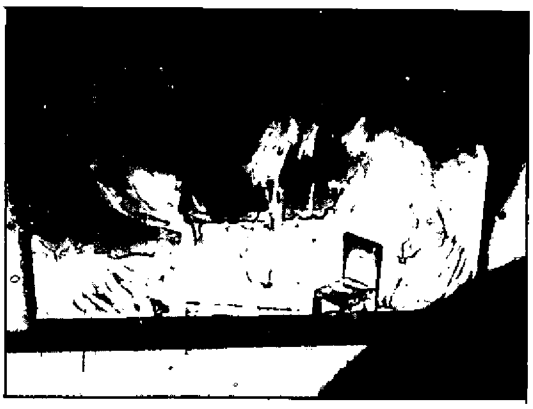
After 12 min



After 16 min

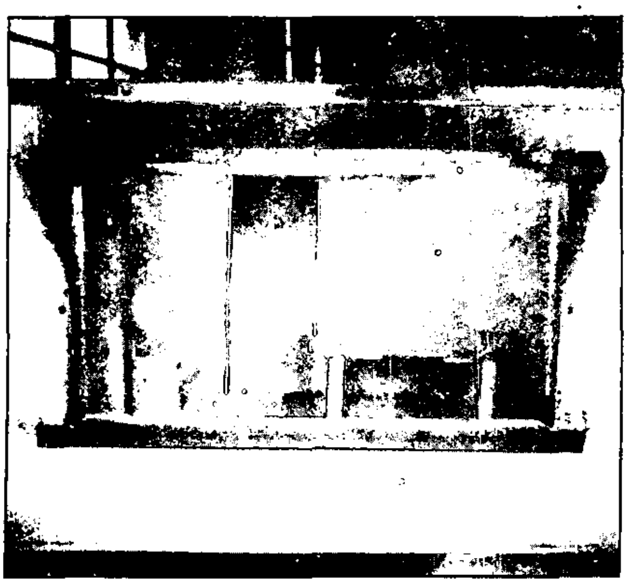


After 18 min



Flash-over
After 19 min

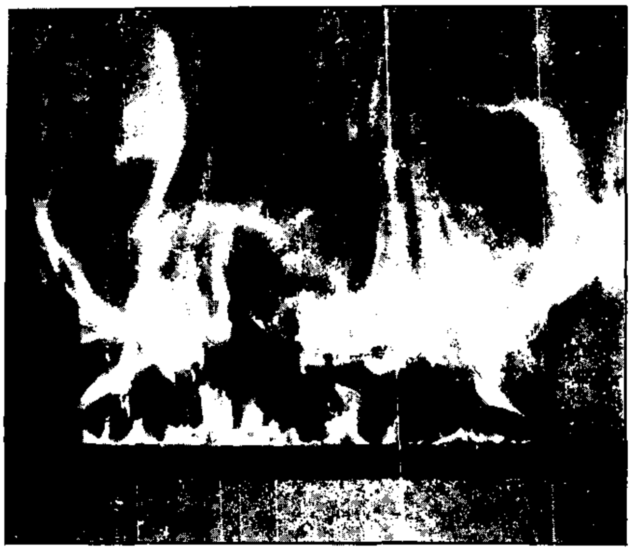
PLATE.1. DEVELOPMENT OF FIRE IN ONE-FIFTH SCALE MODEL ROOM OF TRADITIONAL TYPE



After 2 min

After 4½ min

After 5 min



After 5½ min

PLATE.2. DEVELOPMENT OF FIRE IN MODEL ROOM LINED WITH UNTREATED FIBRE INSULATING BOARD

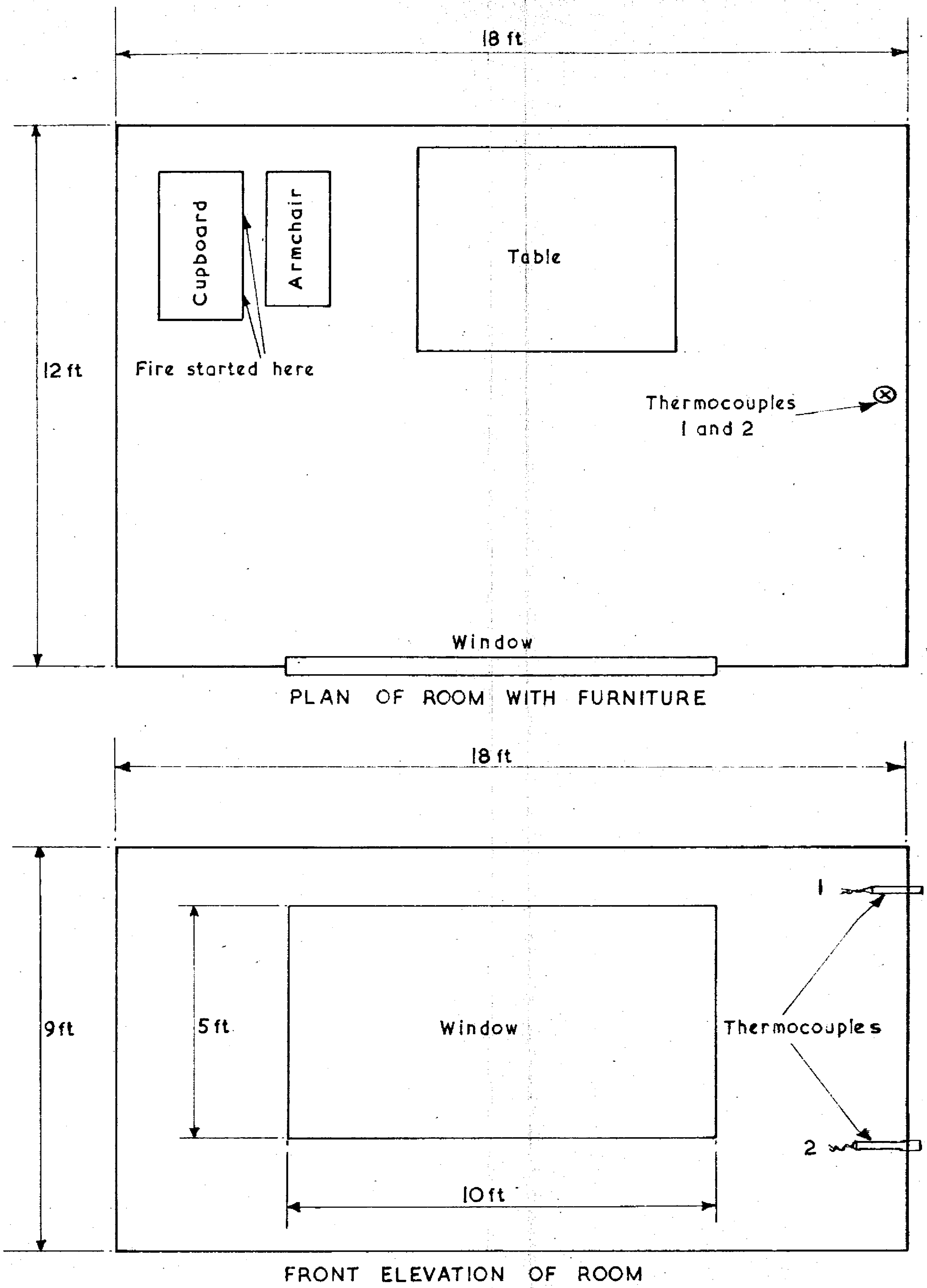


FIG. 1. DIAGRAM OF ROOM

We had a rare opportunity to perform a full scale fire test on a building which was to be demolished. The building (one floor 1300 m^2) is a four story with a basement constructed by the reinforced concrete. We did two series of tests; a basement fire and room fires. I would like to inform you briefly on a room fire.

The test room (7 m x 19 m x 3 m) having ten windows and five doors is in second floor. The ceiling is covered with the accustic fiber tile. The lumber woods is piled up about 40 cm hight on the floor as the fuel, except the area around the starting point. The detail is shown in Fig. 4-1.1 and 4-2.

All windows are opened, all doors are closed, and the fire is set at one end of the room.

1:00	the flame reaches at the ceiling
1:30	the ceiling catches fire, the flame begin spreading
2:05	the spreading flame reaches at 10 m from the starting point
2: ?	the whole fuel on the floor suddenly catches fire at the same time
2:40	the spreading flame reaches at the opposite end of the ceiling, then the room flashes over
4:30	the window frames (wood) in the third floor catches fire and the window glass in the fourth floor fall down
6:00	the fire brigade starts the fighting against the fire

The growth of fire is shown in Fig. 4-3 and the temperature measurement in Fig. 4-5.

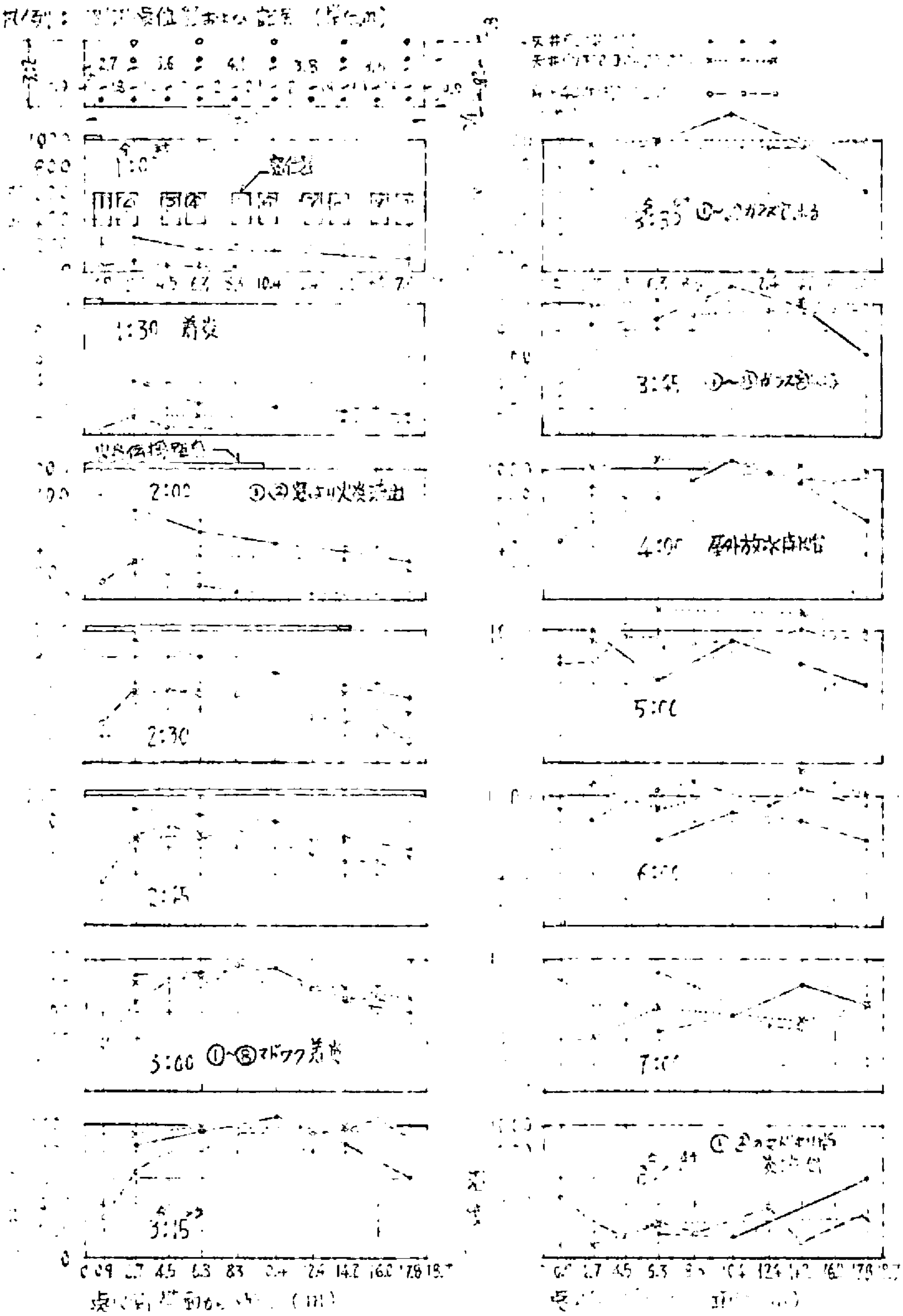
The flame spread across the ceiling of 18 m length takes only 70 second. Observers are surprised how fast the flame spreads. The mean rate of spread is 26 cm/sec.

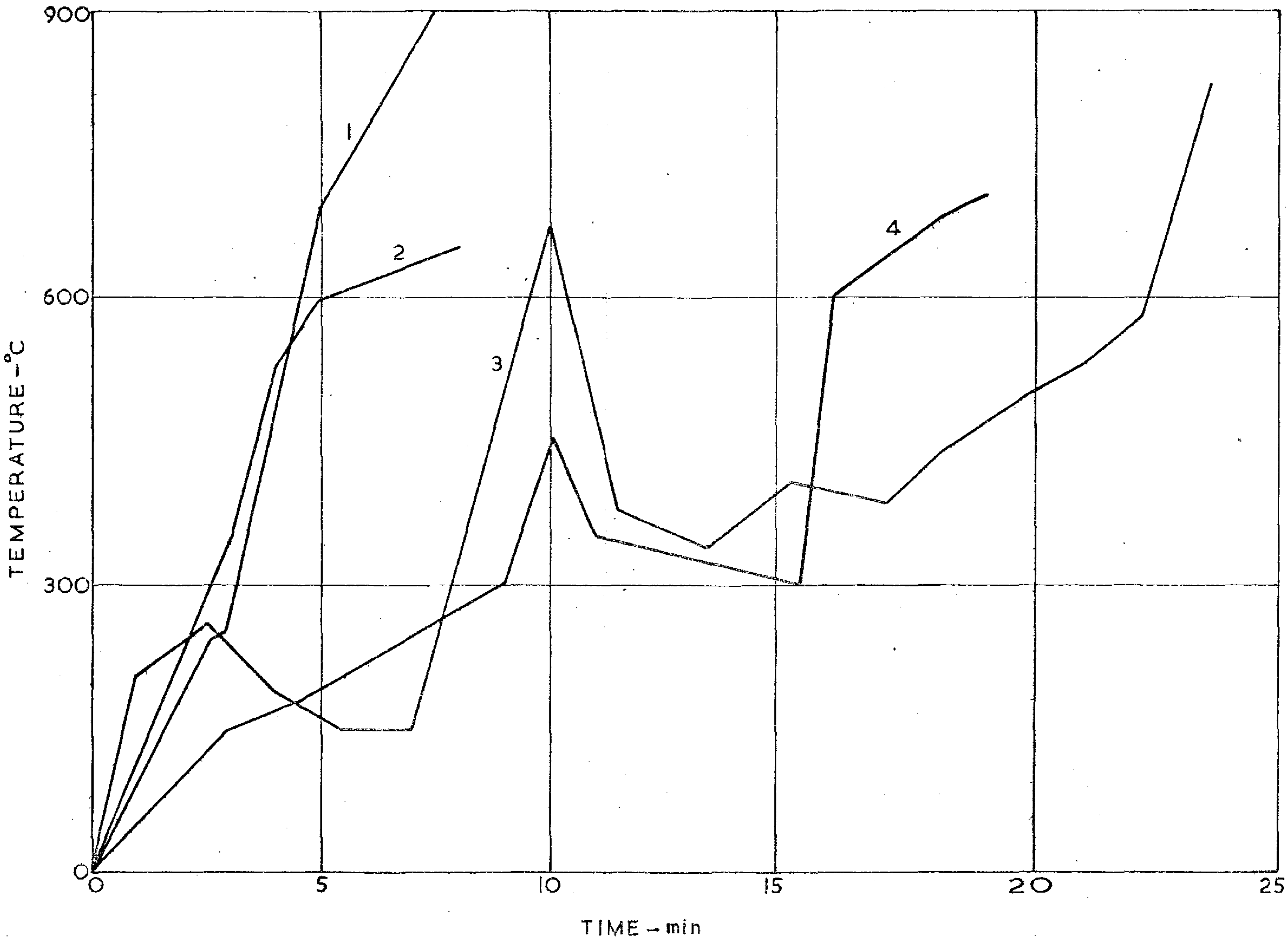
We also measures the pressure difference between the inside and outside at a window around the center of the room, from which we can estimate the gas velocity spouting from the window as shown in Fig. 4-7 and 4-8. Two minuteslater the gas velocity at the ceiling level reaches already about 4 m/sec.

In this test the source of fire is rather big and ventilation is enough, so that flame spreading speed along the ceiling may be faster than usual fires. However the fire source being able to impinge on the ceiling should be, at least, more than 3 m hight of flame and then, when the ceiling catches fire, the fire source may, we assume, take a considerable value of burning rate. Accordingly the speed of hot gas running along the ceiling may also increase considerably. It, therefore, is expected that flame spread drawn by the hot gas will take much higher value than one of usual testing method.

In any way we realize from this test that the burning rate of fire source effects much to the flame spreading along the ceiling.

別図－7. A室長 [illegible] 天井面 [illegible]





1. Full-scale room lined with fibre insulating board
2. Model room lined with fibre insulating board
3. Full-scale room lined with plasterboard
4. Model room lined with plasterboard

FIG. 2. COMPARATIVE TEMPERATURE RECORDS OF FULL-SCALE AND MODEL ROOMS

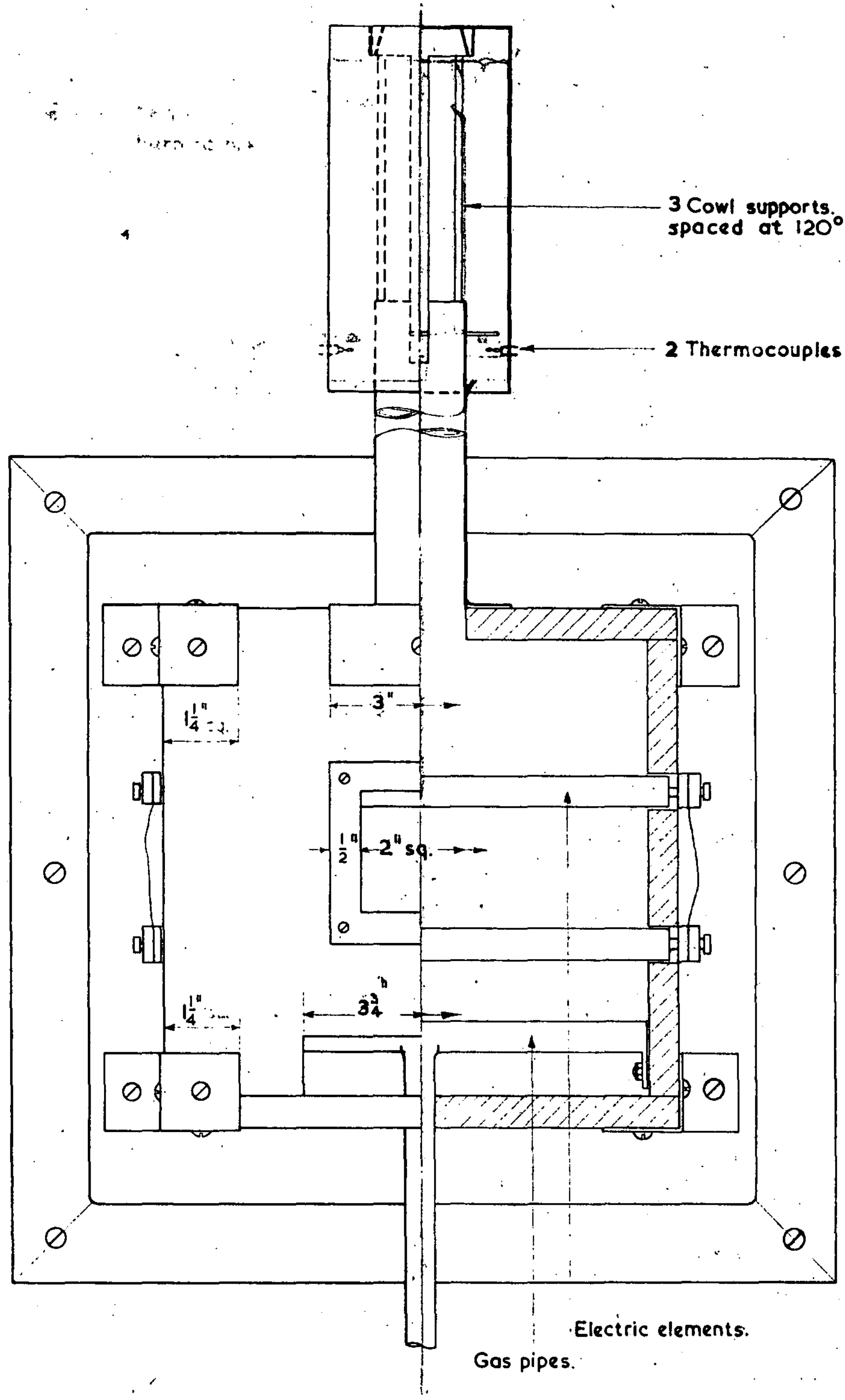


FIG. 3A. APPARATUS FOR TESTING BUILDING BOARDS (FRONT VIEW.)

1/171/9

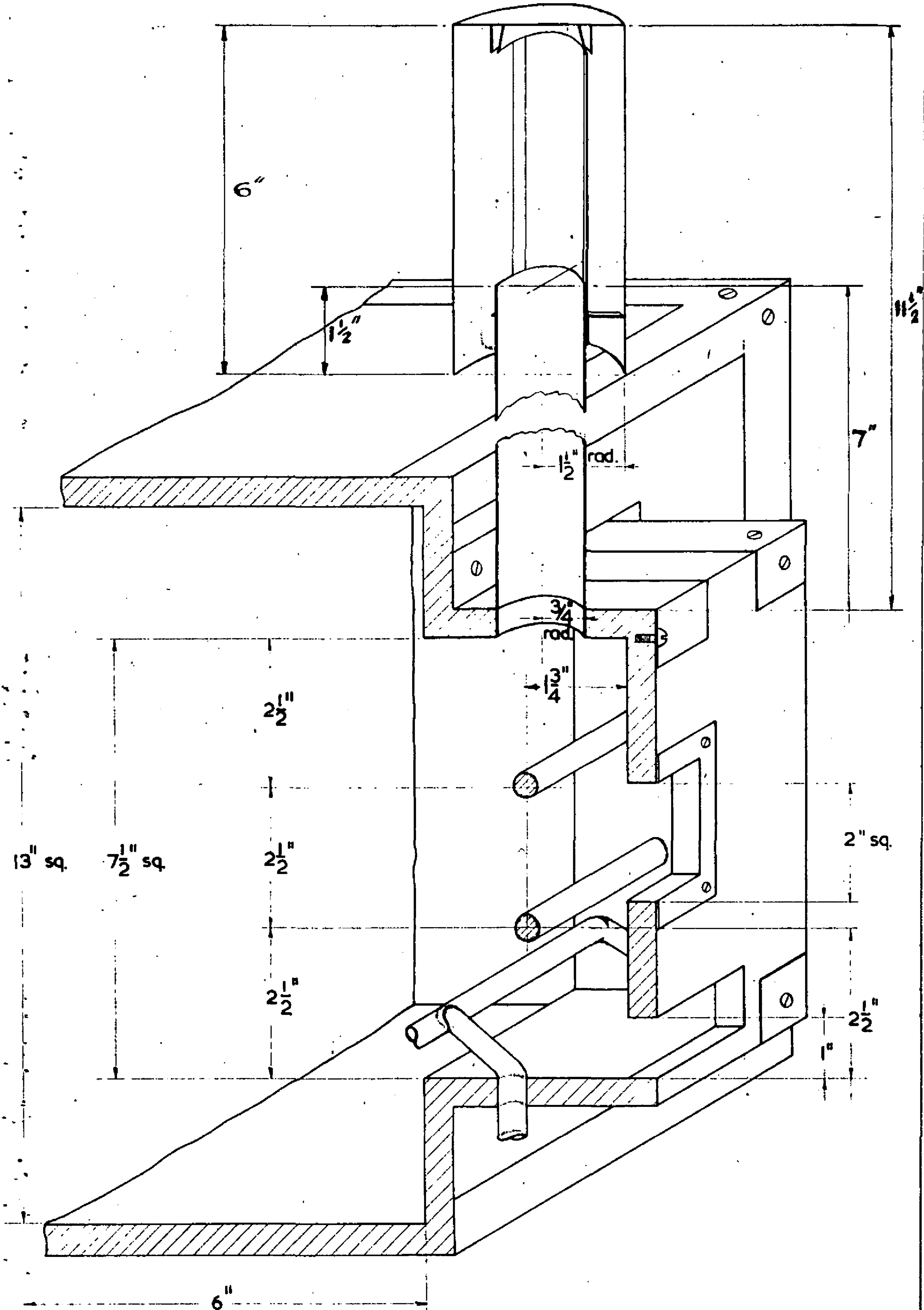
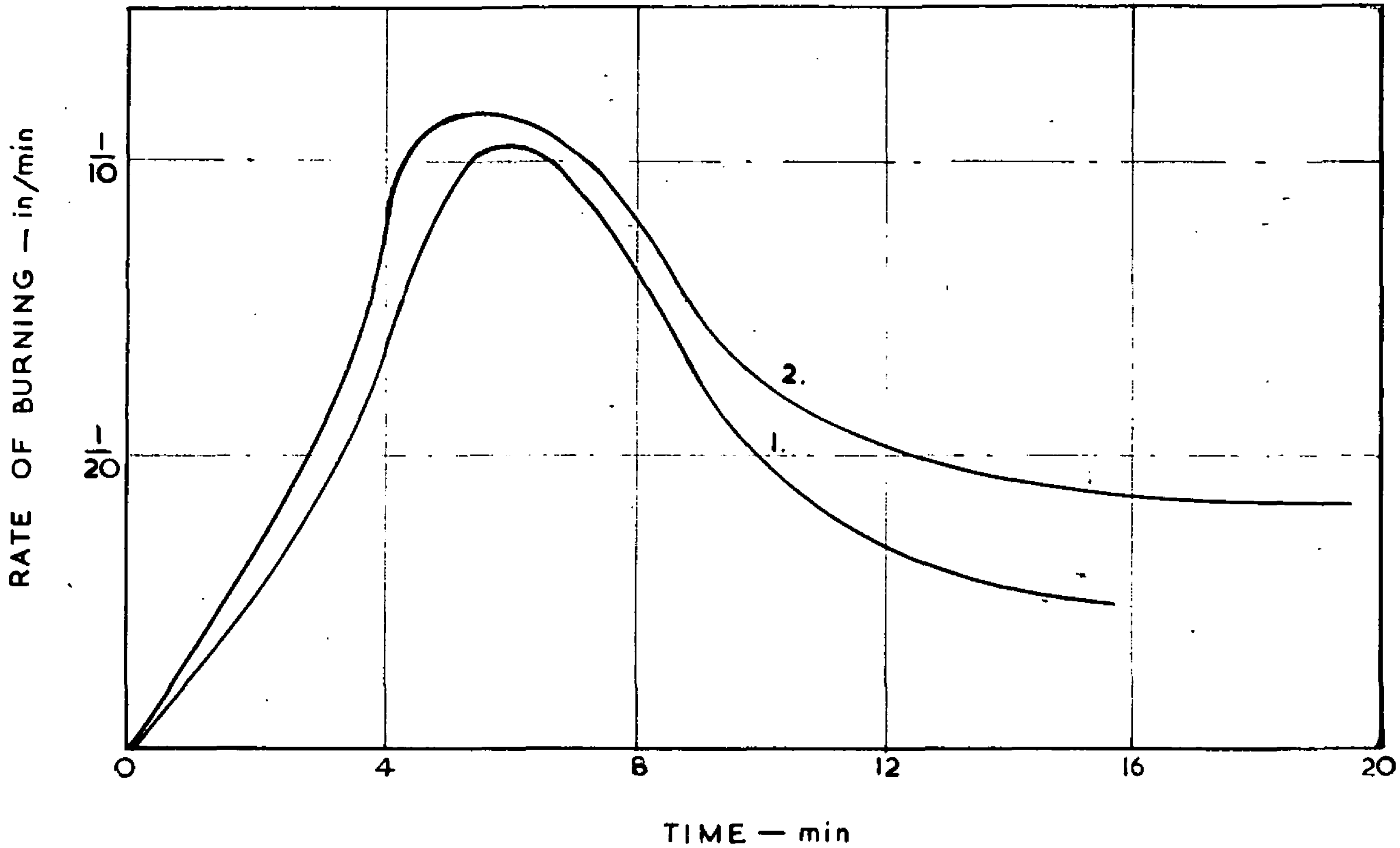


FIG. 3 B. APPARATUS FOR TESTING BUILDING BOARDS (SECTION)

1/1719



1. Calculated from flue gas temperature
2. Measured by weighing

FIG. 6. RATE OF BURNING OF FIBRE INSULATING BOARD