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Research Programme
Objective E.I.

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

THE CONTRIBUTION OF WALL LININGS TO THE GROWTH OF FIRE

by

P. H. Thomas

Summary

This paper describes experiments on the growth of fire in rooms and the effects of different wall linings. This work has led to the development of a new test for wall linings which it is thought might eventually supersede the present Spread of Flame Test. The relation between the performance of wall linings in an actual fire and their gradings on the two tests are discussed. Some preliminary test results for treated and untreated woods are given.

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Fire Research Station,
Boreham Wood,
Herts.

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Introduction

Two papers (1) (2) to previous annual Conferences have presented the work of the Joint Fire Research Station on various aspects of the fire hazard of timber. The Director of Fire Research, referred (2) to a programme of experiments in which small-scale models were to be used in investigating the development of fires in single compartments, and it is with this that the present paper is primarily concerned.

It will be useful to recapitulate the principal features of the growth of a fire. There are three stages each with its own problems.

The first is the primary ignition from a hot source. The extent to which a material is susceptible to ignition can be measured by exposing it to radiation and finding the minimum intensity required to ignite it. In the second stage the fire spreads from the point of ignition over the surface of solid combustible materials. These may be in the form of combustible material such as wall and ceiling linings, combustible floors and curtaining. The rate at which this spread occurs is an important factor since on it depends the rate of growth of the fire in that compartment. The susceptibility of a material to spread on its surface is measured in the spread of flame test(3) (B.S. 476).

In general there is an accumulation of heat in the compartment which eventually leads to all the combustibles in the compartment being involved. Towards its climax this may be a very rapid process and is rightly called flashover. At this point the temperature in the compartment rises very rapidly and from then on the structure of the compartment and neighbouring compartments is seriously endangered. This is the province of the fire resistance tests (4) whose objects are to establish the time for which a structure can withstand such conditions. This aspect of the problem, only becoming important after flashover, does not concern us here.

The fire retardant treatment of wood will delay and may even prevent ignition. Simms (1) gave data showing how the minimum intensity required to ignite a material was increased by the application of various treatments. Although this minimum intensity, both for treated and untreated woods is generally less than the intensity close to a burning ember or, say, a cigarette, it still affects the time of ignition because the higher this minimum intensity the smaller is the area where the intensity from the burning ember exceeds it. The ignition, and the onset of spread from the immediate neighbourhood of the igniting source thus takes longer to occur the higher the minimum or critical intensity for ignition.
A satisfactory fire retardant treatment will also reduce the rate at which fire spreads over the surface and this increases the time to flashover. This rate of spread of flame is measured by the standard test, but in order to assess the significance of the ratings given by the test to various materials treatments, in relation to the behaviour in actual fires, some experiments in which rooms with furniture and wall linings were ignited have been made in recent years by Hird and Fishl(5). These experiments were made with small-scale rooms, and the effects of scale were examined by using models of differe size and comparing the results with each other and with results obtained in certain full-scale tests, which are made from time to time by the Joint Fire Research Organization.

For example, some years ago the development of a fire in two similar houses, one having walls lined with untreated fibre insulating board and one having additional protection from plasterboard was studied and the times of flashover and rates of increase of temperature in these full scale fires were reproduced, for both types of lining, in models 1/10 linear scale.

The significance of flashover

The time to flashover is important because not only does the fire then involve the whole of the compartment but the other hazards associated with fire then become very much more severe. Both the oxygen content of the atmosphere and the visibility in an adjacent room decrease sharply and the carbon monoxide increases rapidly at about the time of flashover. This may be seen from Figure (1) which is based on some recent full scale tests (6).

Experimental details of model fires

The arrangement of the furniture and the model room are shown in Figure 2. 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 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 3 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 ceilings)	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 plaster-board 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 (2). 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 room 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", (3) 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. 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 average 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 of "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. ($\frac{1}{2}$-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)	Class 1	13 30	B
Fibre insulating board with surface treatment of an intumescent paint (30 g/ft^2)	Class 1	10 35	B
Asbestos paper faced fibre insulating board	Class 1	10 30	B
Fibre insulating board with surface treatment of an intumescent paint (15 g/ft^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	Boarderline 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 boards	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. In terms of a range of flash-over times Class 1 is very large. Classes 2, and 3 are very small. Class 4 has no lower limit and may therefore be in principle a large class also.

THE DEVELOPMENT OF A NEW BUILDING BOARD TEST

It was not found possible to change the criteria of the "Surface Spread of Flame Test" to make a more suitable division between gradings in the light of the results of the model experiments, so that it became necessary to develop a new test (7). This was designed to grade linings according to the flash-over times.

The apparatus used for the test is illustrated in Figure (4). It is constructed with the test panel as one side of a chamber of area $7\frac{1}{2}$ in. square. Behind the panel, $\frac{1}{2}$ in. 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 $\frac{1}{2}$-in. asbestos board. The classifications are shown diagrammatically in Figure 5 where θ denotes the flue gas temperature at any time for the incombustible board.

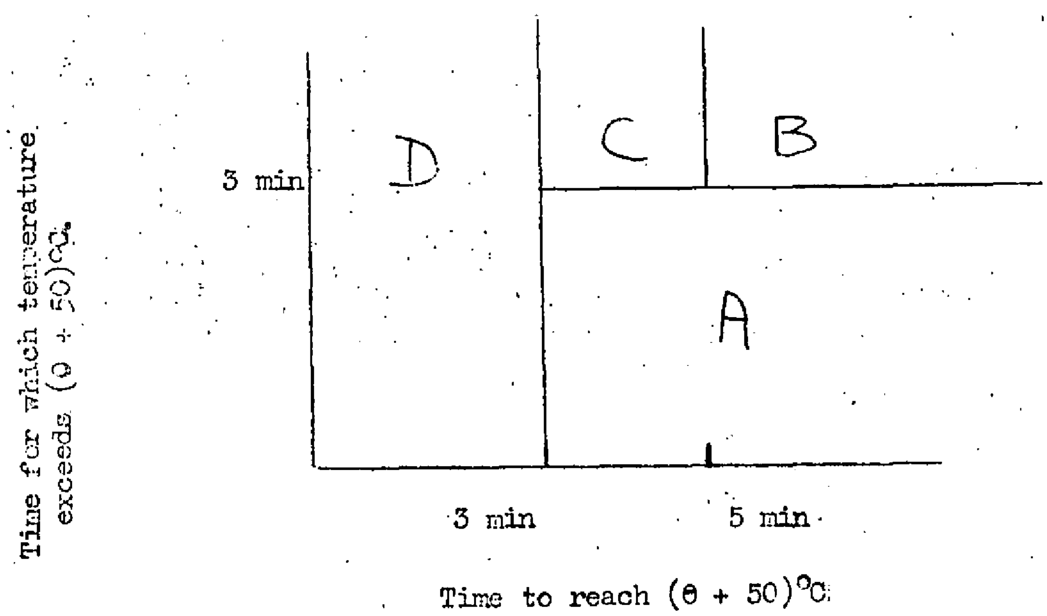

FIGURE. (5) CLASSIFICATION IN BUILDING BOARD TEST

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 $(\theta + 50)^{o}C$, 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 $(\theta + 50)^{o}C$ for less than 3 minutes, and which do not reach $(\theta + 50)^{o}C$ in less than 3 minutes are rated in the top Class - A. Materials which do not reach a temperature of $(\theta + 50)^{o}C$ in 3 minutes but reach it in less than 5 minutes and for which the time that their temperature exceeds $(\theta + 50)^{o}C$ is greater than 3 minutes are classified as Class C. The remaining Class - B includes materials for which the time that their temperature is in excess of $(\theta + 50)^{o}C$ is greater than 3 minutes.

Broadly speaking, the distinction between Classes A and B is that Class A covers materials and treatments which do not make a significant contribution to the development of fire in room even if the room is completely lined with them, while Class B covers the remaining materials and treatments previously graded Class 1. This distinction has only become possible as a result of the model experiments which were able to set a standard of the hazard from furniture and a wooden floor (untreated) by which to judge the contribution of linings. In the Surface Spread of Flame Test it appears that as a result of these experiments that Classes 2 and 3 cover a relatively small range of behaviour in a fire. In the new test these classes have, in principle, become one, i.e. Class C. It does not necessarily follow that a Class 4 material would always be graded Class D or that Class 1 materials would always be now graded A or B, but in general one would expect this to be so.

Some results of the test are shown in Figures, (6), (7), (8) and (9). One sees in comparing Class B and C, D how the characteristic rise in temperature over that for an incombustible specimen occurs later the higher the class. Class A is different from the others in that there is a limit to how long the excess temperature can persist.

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

Quantitative basis of test

As mentioned above, the model experiments show qualitatively the comparative effects on fire behaviour of various linings and also an absolute effect compared with a standardised set of furniture and a wooden floor. The test also in principle compares the heat output and its rate of liberation with that from a standard supply. One of the objects of future model experiments will be the quantitative evaluation of the effects of different rates of heat output on the development of fire. In the meanwhile it is possible to evaluate an approximate equivalence for the test between temperatures measured in the flue and rate of heat output. One could do this by a continuous control of the supply of uel to reproduce a given curve; even this is not exact as it matters where the heat is actually liberated. A simpler but also not absolutely accurate approach is to use fixed rates of heat output, to obtain a set of temperature time curves. This is probably sufficient for our immediate needs, and so, by using different rates of gas supply to the test box an approximate equivalent has been obtained between flue gas temperature and rate of heat output.

This method is clearly most satisfactory for high rates of output from the specimen and the data for fibre insulating board are shown in Figure. (10). There is good agreement with the values obtained by measuring the rate of loss of weight while the test was in progress.

The behaviour of wood in the new test

Although no extensive work has been done yet to examine the behaviour of wood in this test, a few tests have been made for two different fire retardant treatments and they give results in line with expectations. These results are listed in Table 3. The treatments (1 and 2) concerned are mixtures of various salts, the principle one being mon-ammonium phosphate.

Timber		Treatment	Time to $\theta + 50$	Class
Yellow pine		Untreated	1 min. 35 sec.	D
Oak		Untreated	1 min. 55 sec.	D
Douglas fir		Untreated	2 min. 50 sec.	D
		"	3 min. 25 sec.	C
		"	3 min. 18 sec.	C
		"	3 min. 20 sec.	C
		"	3 min. 24 sec.	C
Douglas fir	(1)	2-3 lb/cub ft.	4 min. 10 sec.	C
		"	4 min. 50 sec.	C
Douglas fir	(1)	5-5.5 lb/cub ft.	4 min. 0 sec.	C
			4 min. 50 sec.	C
			5 min. 18 sec.	B
Douglas fir	(2)	5-6 lb/cub ft.	6 min. 24 sec.	B
			6 min. 40 sec.	B
			7 min. 36 sec.	B
Baltic redwood	(1)	1-2 lb/cub ft.	0 min. 30 sec.	D
			0 min. 50 sec.	D

Table (3)

Tests on treated and untreated woods in the new test

Some of the variation in the results is due to small variations in the level of impregnation between one sample and another. Also not all the Douglas fir was from the same batch.

The above results, scanty though they are, suggest that untreated woods are in either Class C or D, treatment by impregnation may increase the grading by an amount depending on the degree of active salt retention and, in this connexion it is of interest to note that though we do not yet have data for different levels of treatment for one species of wood the time to reach $\theta + 50$ does increase with increasing total salt retention. An estimate for the impregnated hardboard listed in Table (2) gives an approximate salt retention of about 7 lb/cub ft. and it is possible that this material has a performance of Class A, or at any rate a high performance in Class B.

Until more data are available for one particular wood treated with different levels of the same treatment one cannot make too much of the above figures but these do suggest the order of the salt retention required for various gradings. No test has yet been made where an impregnated wood has achieved Class A but there is no reason to believe this is not possible. From the point of view of growth of fire the wood would then be nearly comparable with plasterboard or wood wool. It is worth noting that one user has imposed a restriction on the use of Class 1 (spread of flame) materials. For certain uses, while not requiring incombustible materials the user specified materials inherently Class 1 and not Class 1 by virtue of a surface treatment. This in the absence of a functional criteria is recognising the relatively large range within Class 1 but clearly a functional requirement is a better one, and if this test were adopted and

Class A and B were taken as corresponding to the upper and lower halves of Class 1 it follows that it may be possible for a treated wood to be regarded as satisfactory whereas, in some instances, it is not so, at present.

It is also apparent from the above results that a treatment of less than about 2 lb cub/ft. may not raise a Class D wood to a higher grade, and although there may be some actual improvement it is not significant. There is some evidence to suggest that a low salt retention may be worse than no treatment at all (8).

Comparison with other tests

The spread of flame test, and the newly developed tests have both been compared with the flashover time in a room lined with the material tested. Since flashover time is probably the most satisfactory functional requirement at present available it would be worth while comparing the ratings given by other tests to the newly developed test which is related to flash over times. As we do not have sufficient data for this at present we intend to carry out comparative tests with other countries. We can however make a tentative comparison with the U.S. Underwriters "Tunnel Test" (9).

This consists essentially of a horizontal duct 25 ft. long of rectangular cross sections. The sides and base of the duct are incombustible and the specimen on test is made the inside surface of the top of the duct. Flames from a gas burner impinge on the specimen at one end and a classification is made of materials according to both the rate of liberation of heat and the rate of flame spread. The index is fixed according to an arbitrary scale with red oak 100 and an incombustible zero. The tentative comparison between the U.S."Tunnel" Test, and the spread of flame test, the newly developed test described above and flash over time is shown in Figure (13).

Just as the spread of flame test is more sensitive at distinguishing between the poorer materials so is the Tunnel Test. This variation of Tunnel Test index between 100 and 300 is unlikely to correspond to more than a small variation in performance in the model room. This is in line with conclusions reached by Dantuma (10) and his co-workers in Holland. They found that treatments whose efficiencies were found to be widely different on the Tunnel Test gave results that were sensibly the same on large-scale tests.

DISCUSSION

It is necessary to discuss the question of how much is it worth while treating timber. The answer to this depends on the relative proportions of treated timber and other combustible materials present. Clearly if all the combustibles are treated then the whole process of ignition and spread to flashover may be slowed down. If only a part of the material present is so treated it is a matter of probability whether the untreated material is near to the igniting source and becomes involved in fire at an early stage; the presence of a small amount of treated material is unlikely to have a significant effect. As work progresses it should become possible to answer the question how much material of such and such a class can be tolerated in a room, assembly hall, etc, the lower the grading, the less the tolerable area. For example flashover times for different percentages of area could be determined for more conditions than have been done hitherto.

It might be that the importance of the relative difference between two materials becomes less if only half, say, of the wall surface is covered. This is somewhat speculative of course but this question is important in practice and it is one of the problems which we hope to study in the work we are now doing. Having been able to represent a particular fire by a scaled model it is now necessary to explore the fundamental basis of scaling fires so that this technique can find a wider application.

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(6) Hird D. Perry M.D. and Nash P. "Experimental Fires in "Back to Back" Houses in Birmingham. Department of Scientific and Industrial Research and Fire Offices' Committee (Joint Fire Research Organization). Fire Research Note No 150/1955.

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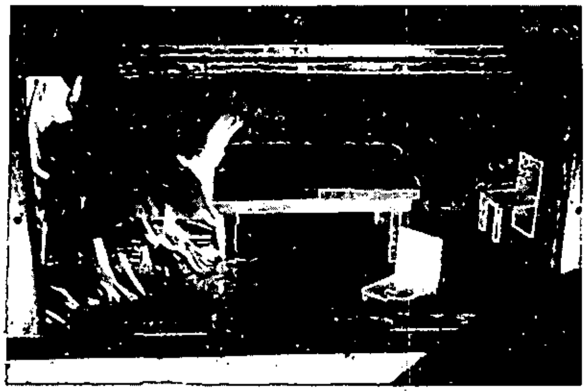
After 10min



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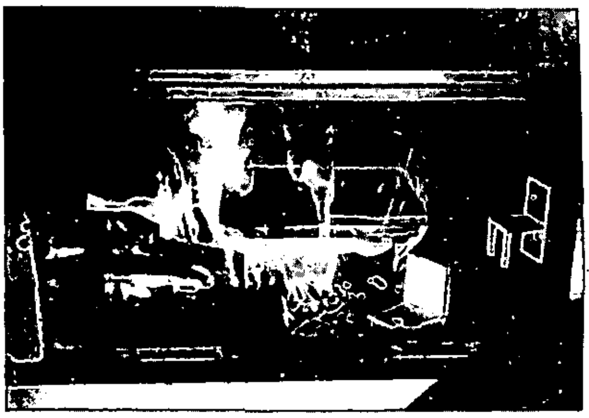

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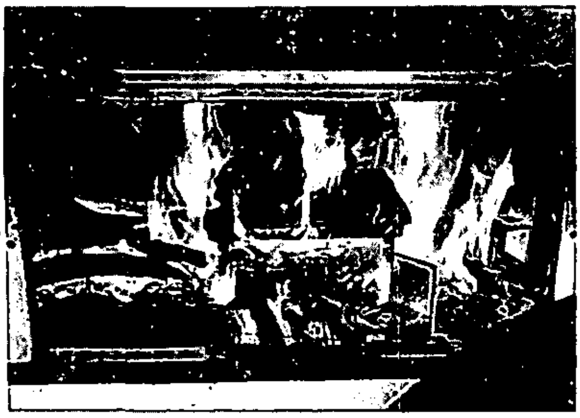
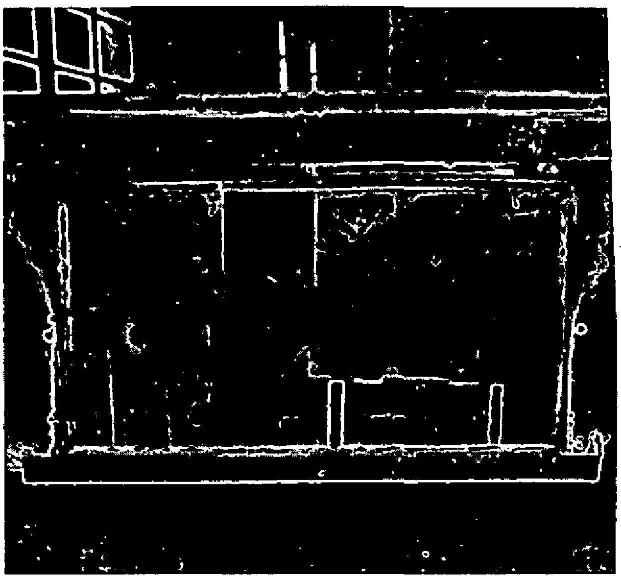


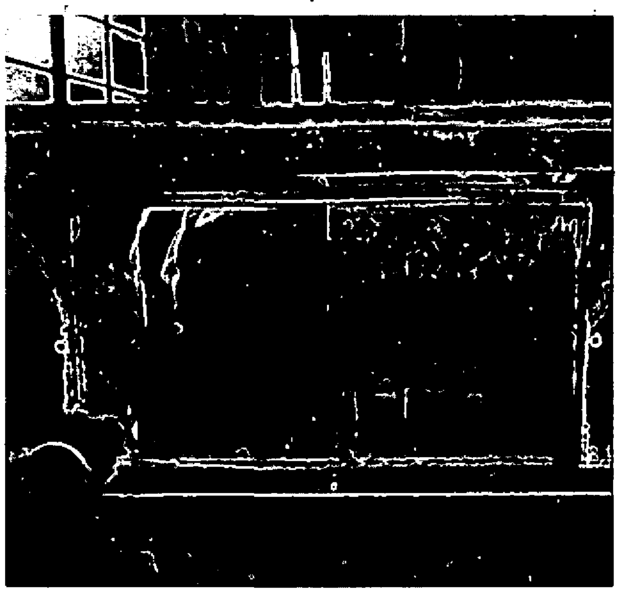
After 18 min

Flash-over
After 19 min

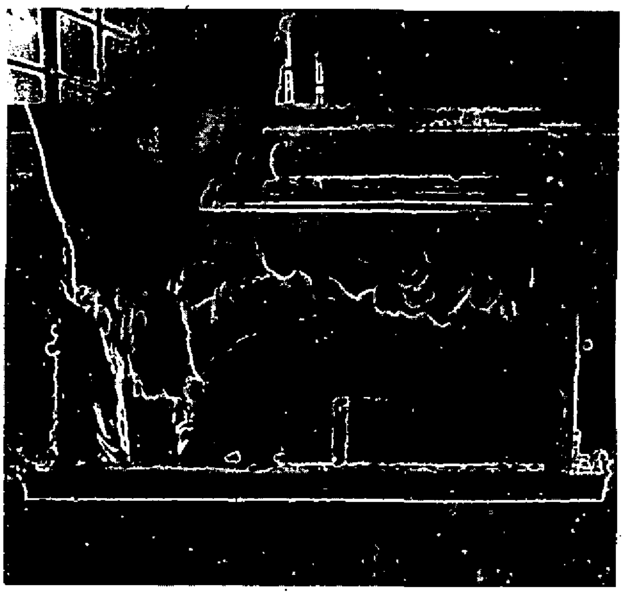
PLATE.1. DEVELOPMENT OF FIRE IN ONE-FIFTH SCALE MODEL ROOM OF TRADITIONAL TYPE



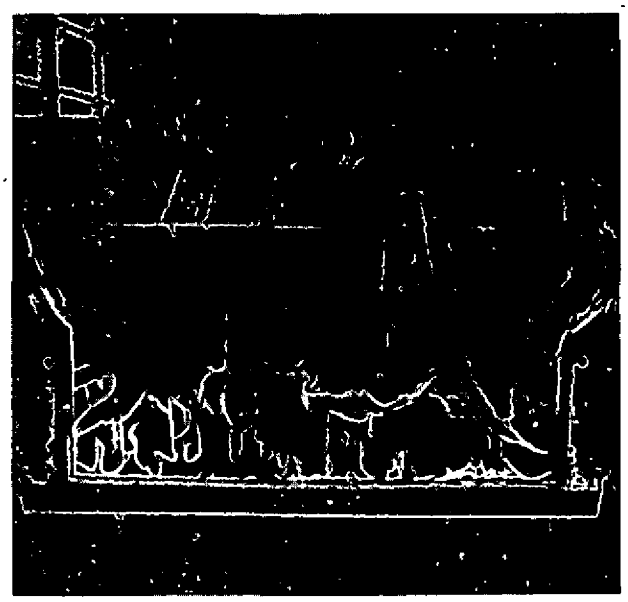
After 2min



After $4\frac{1}{2}$ min



After 5 min



After $5\frac{1}{2}$ min

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

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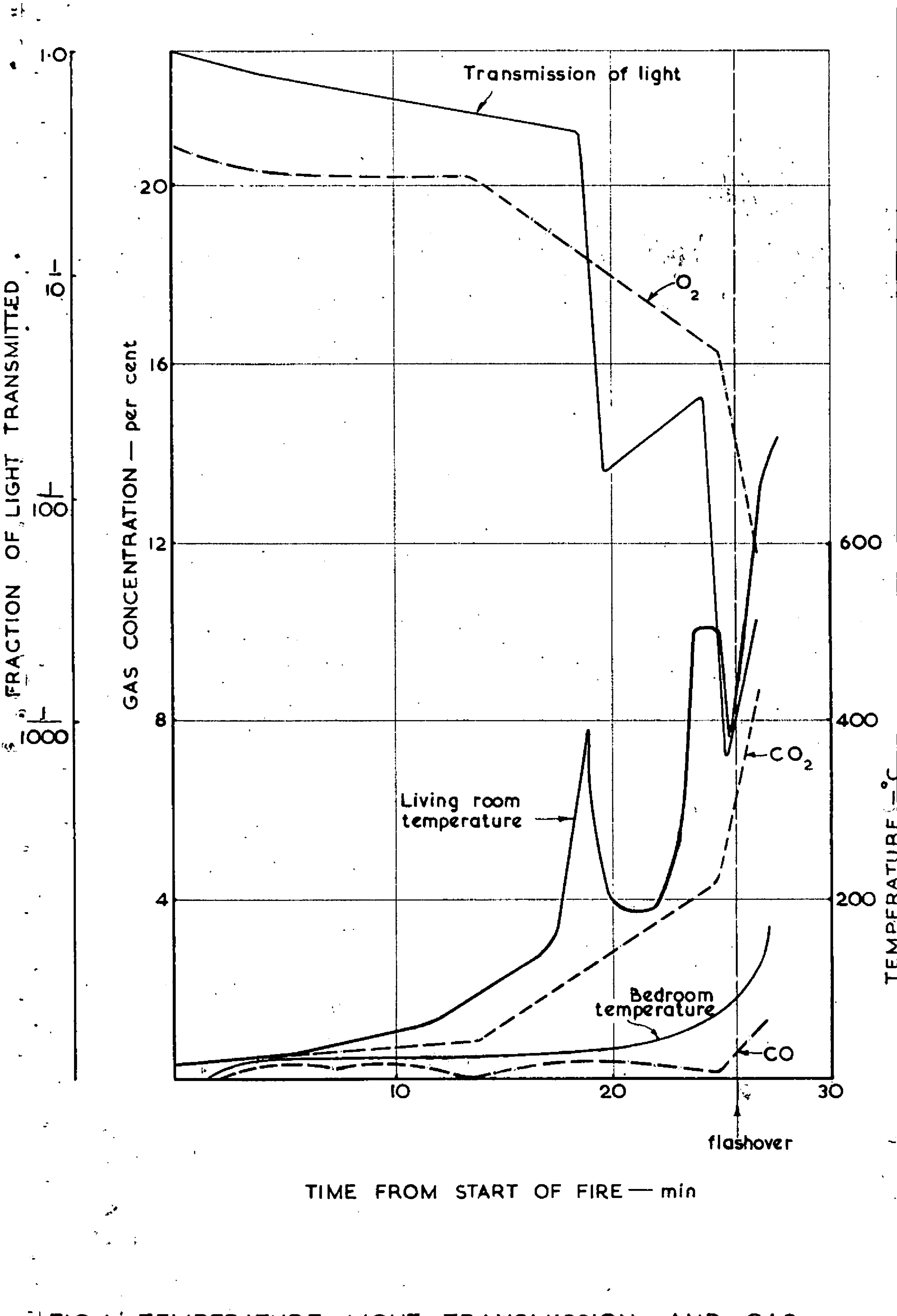
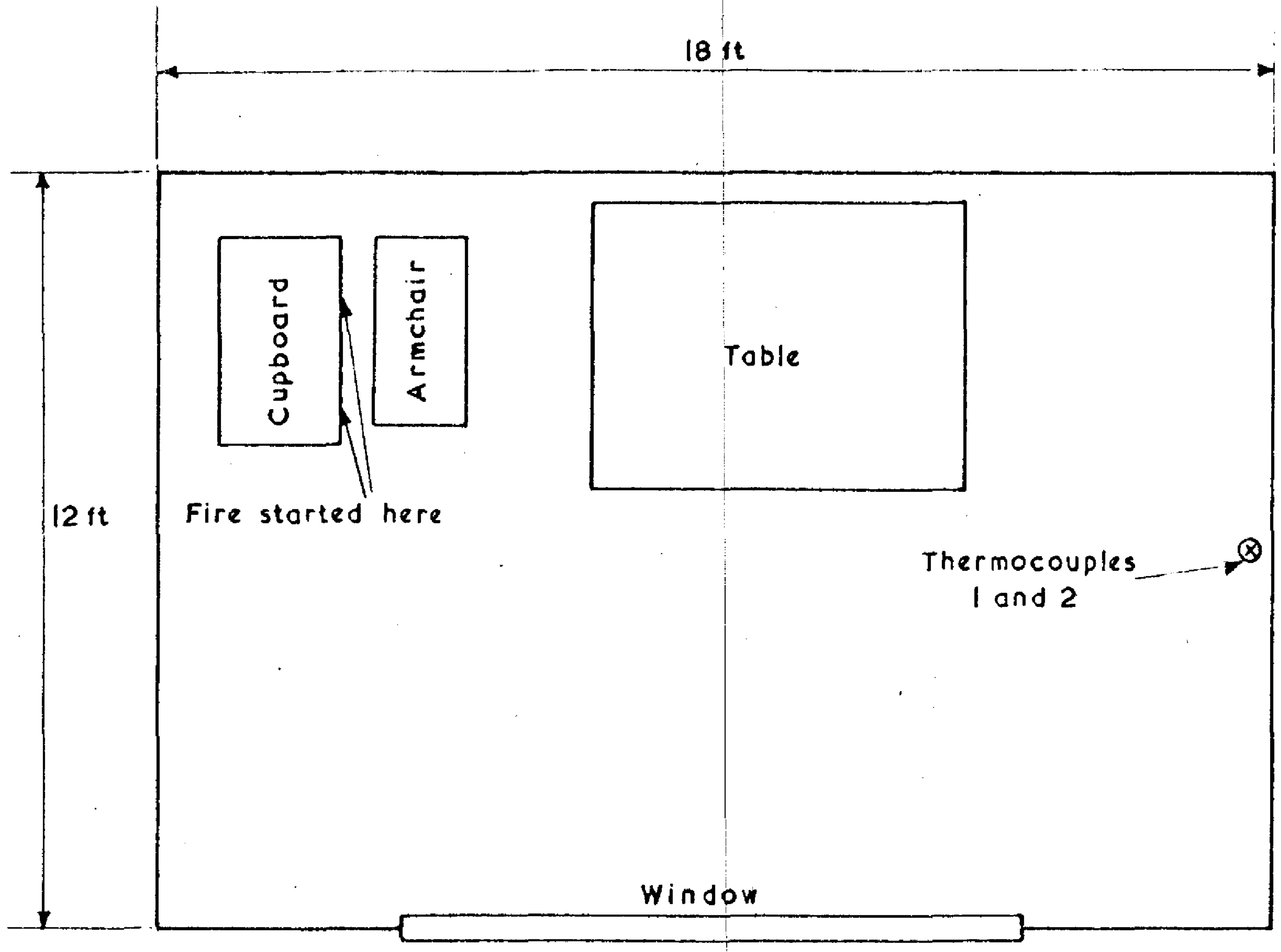
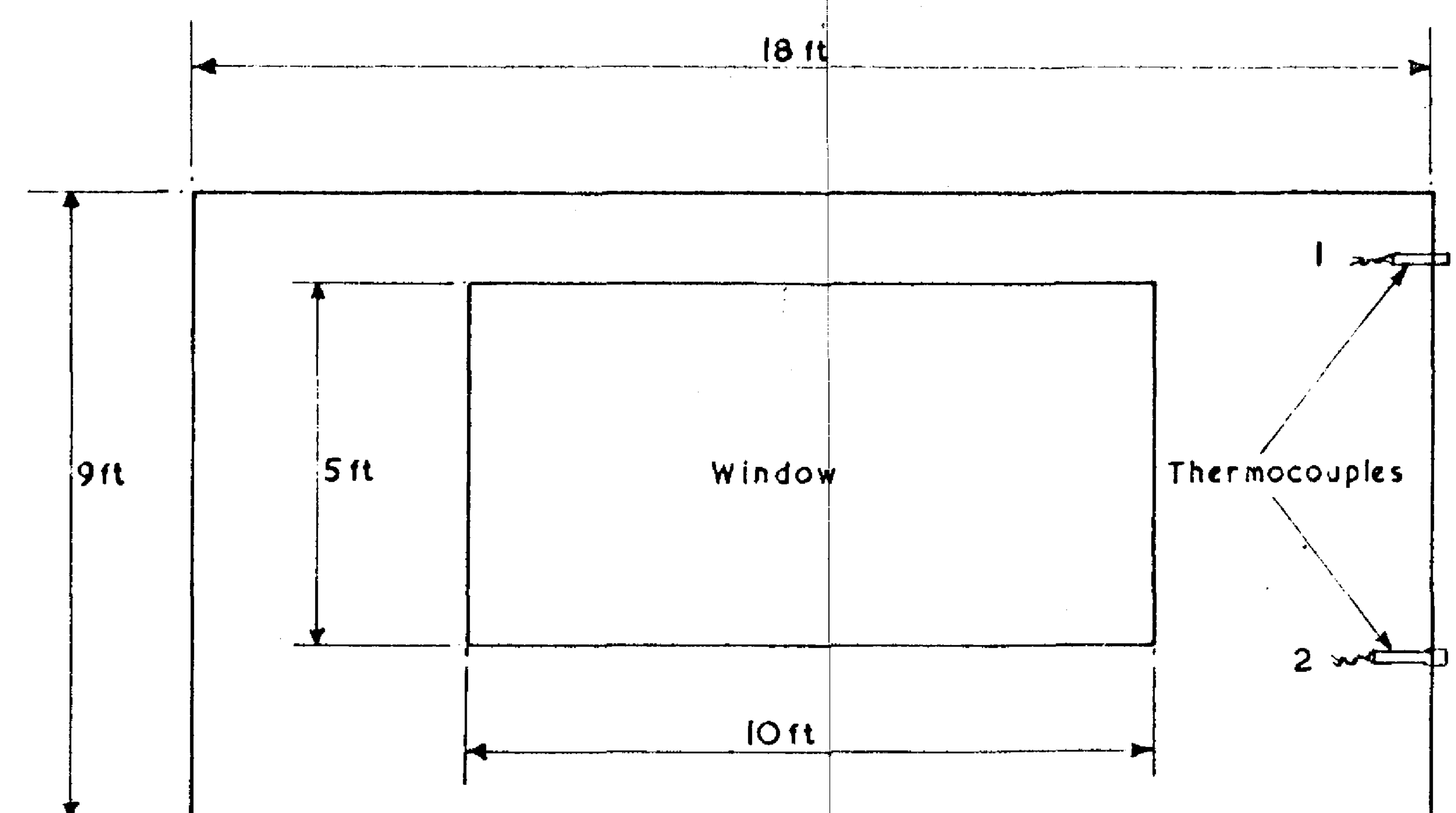


FIG. 1. TEMPERATURE, LIGHT TRANSMISSION AND GAS CONCENTRATION IN GROWTH OF FIRE



PLAN OF ROOM WITH FURNITURE



FRONT ELEVATION OF ROOM

FIG. 2. DIAGRAM OF ROOM

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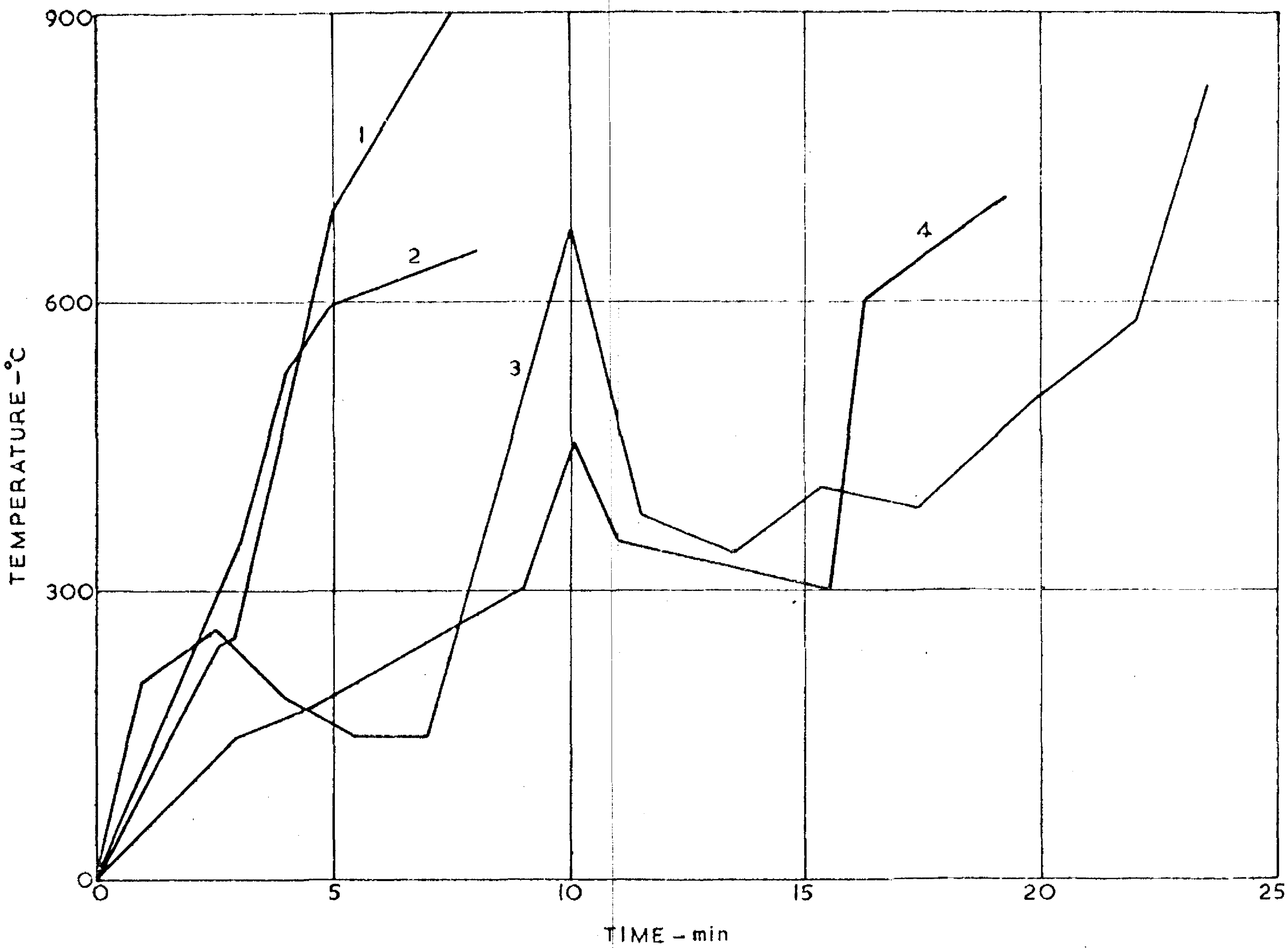

1. Full-scale room lined with fibre insulating board
2. Model room lined with fibre insulating board
3. Full-scale room lined with plasterboard
4. Model room lined with plasterboard

FIG. 3. COMPARATIVE TEMPERATURE RECORDS OF FULL-SCALE AND MODEL ROOMS

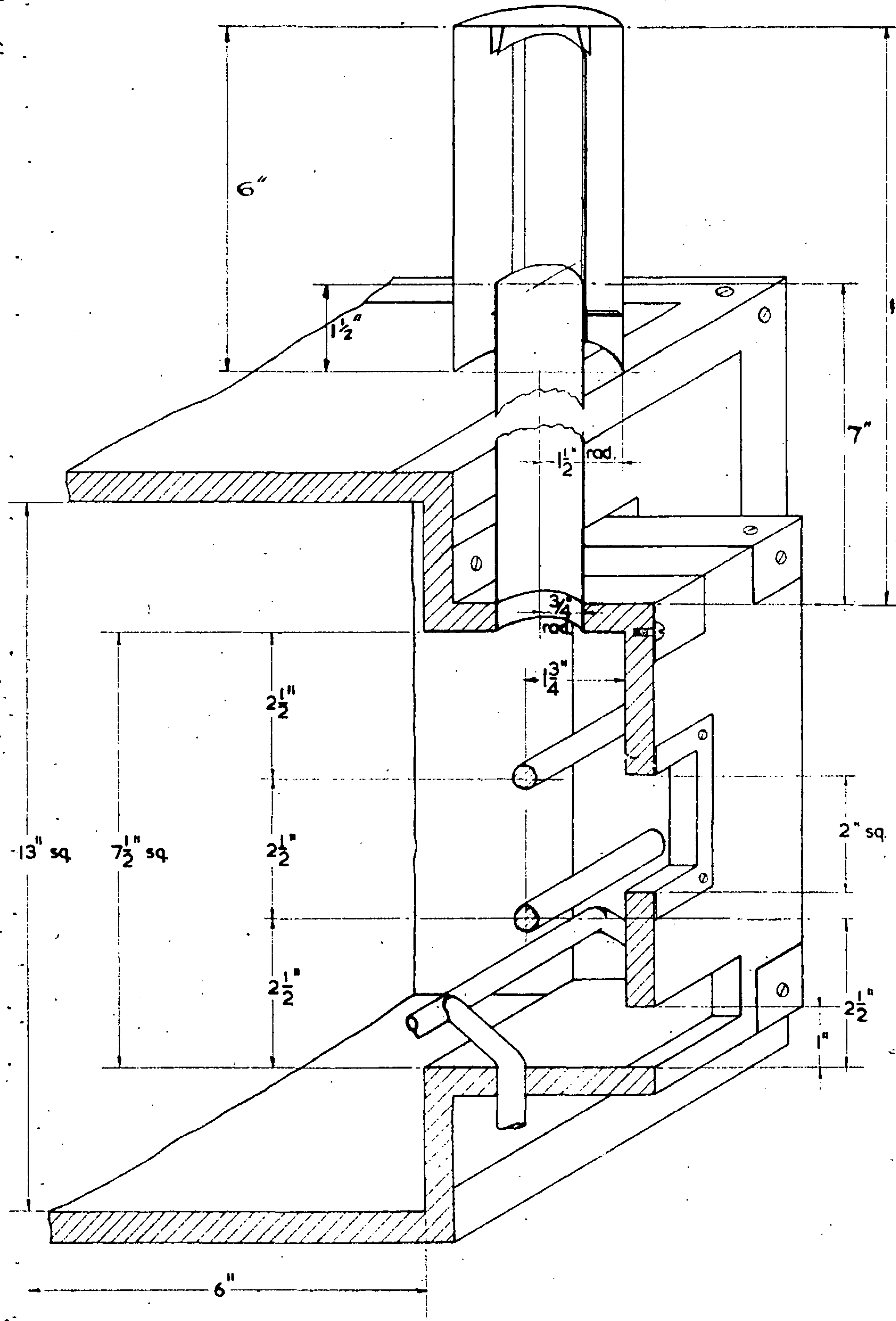

FIG. 4. APPARATUS FOR TESTING BUILDING BOARDS (SECTION)

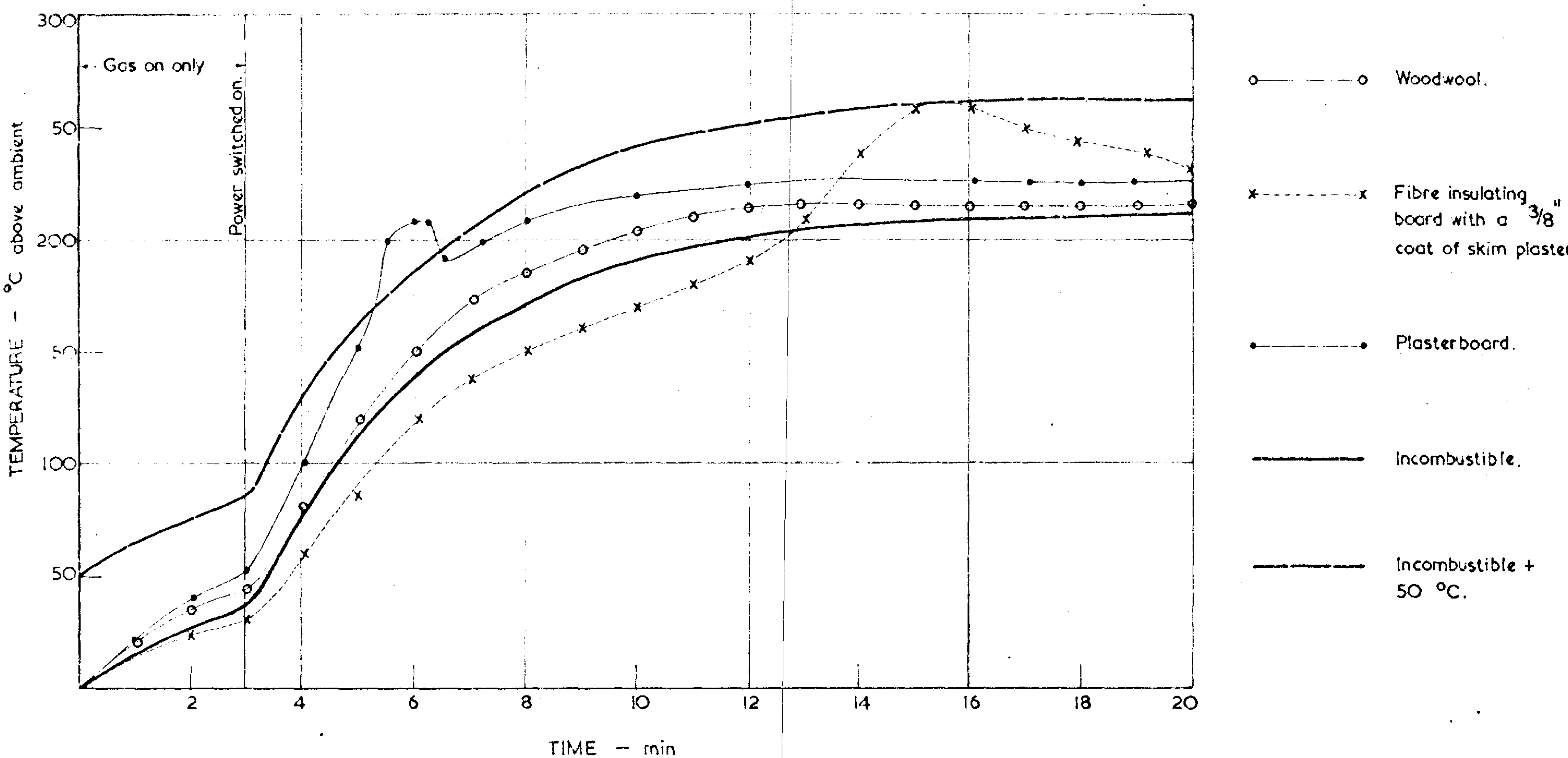

FIG. 6. REPRESENTATIVE CURVES FOR PROPOSED CLASS A.

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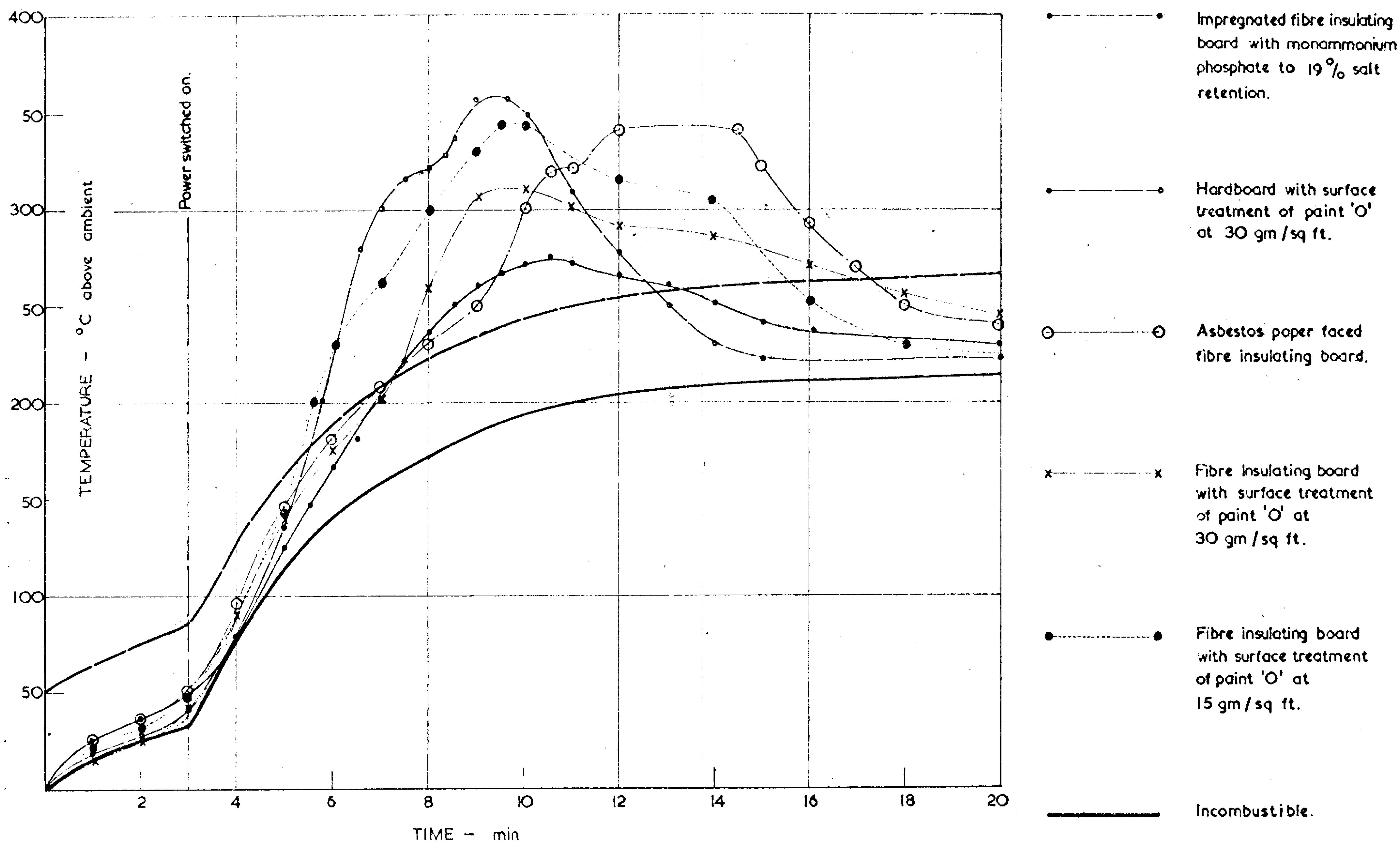

FIG. 7. REPRESENTATIVE CURVES FOR PROPOSED CLASS B.

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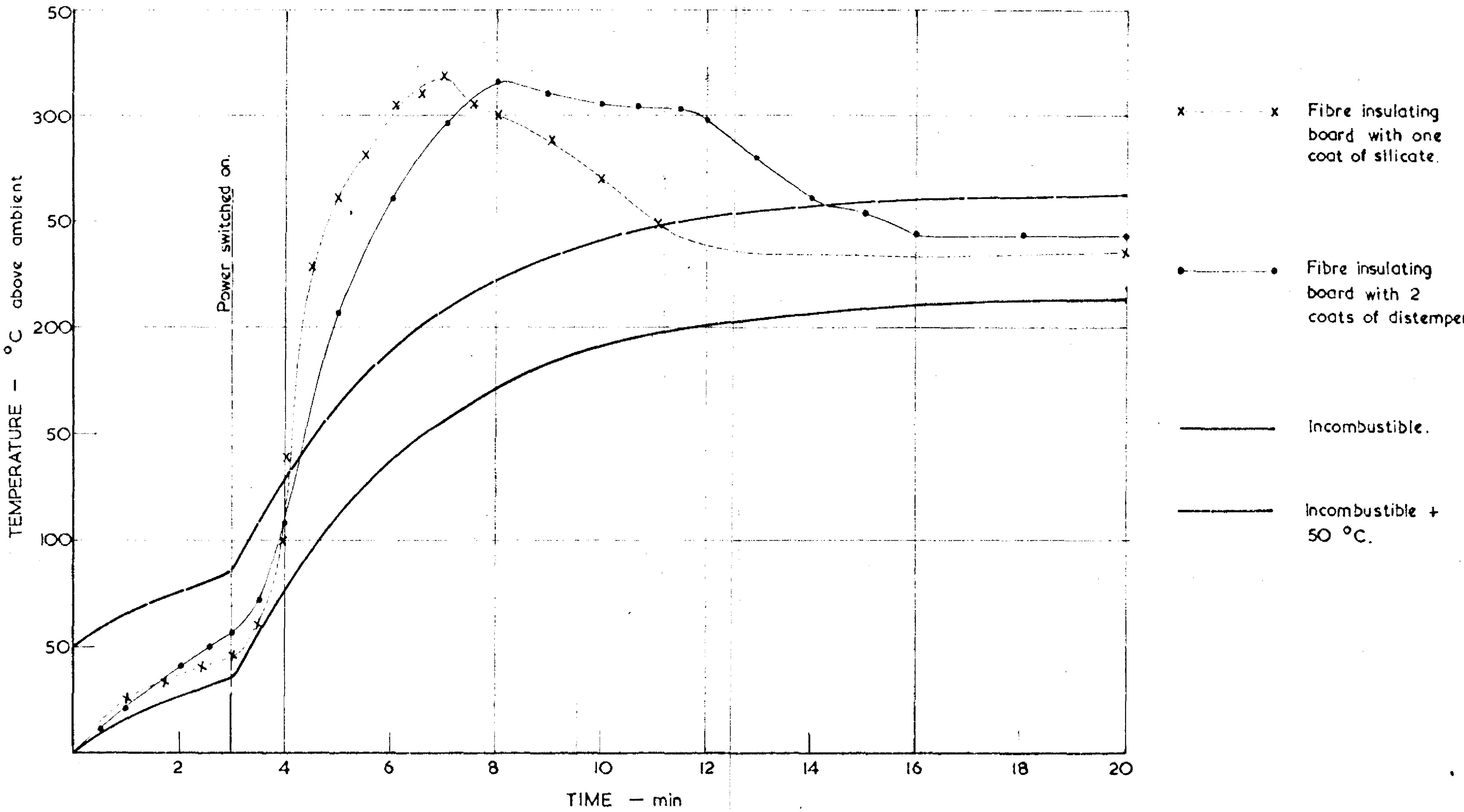

FIG. **8.** REPRESENTATIVE CURVES FOR PROPOSED CLASS C.

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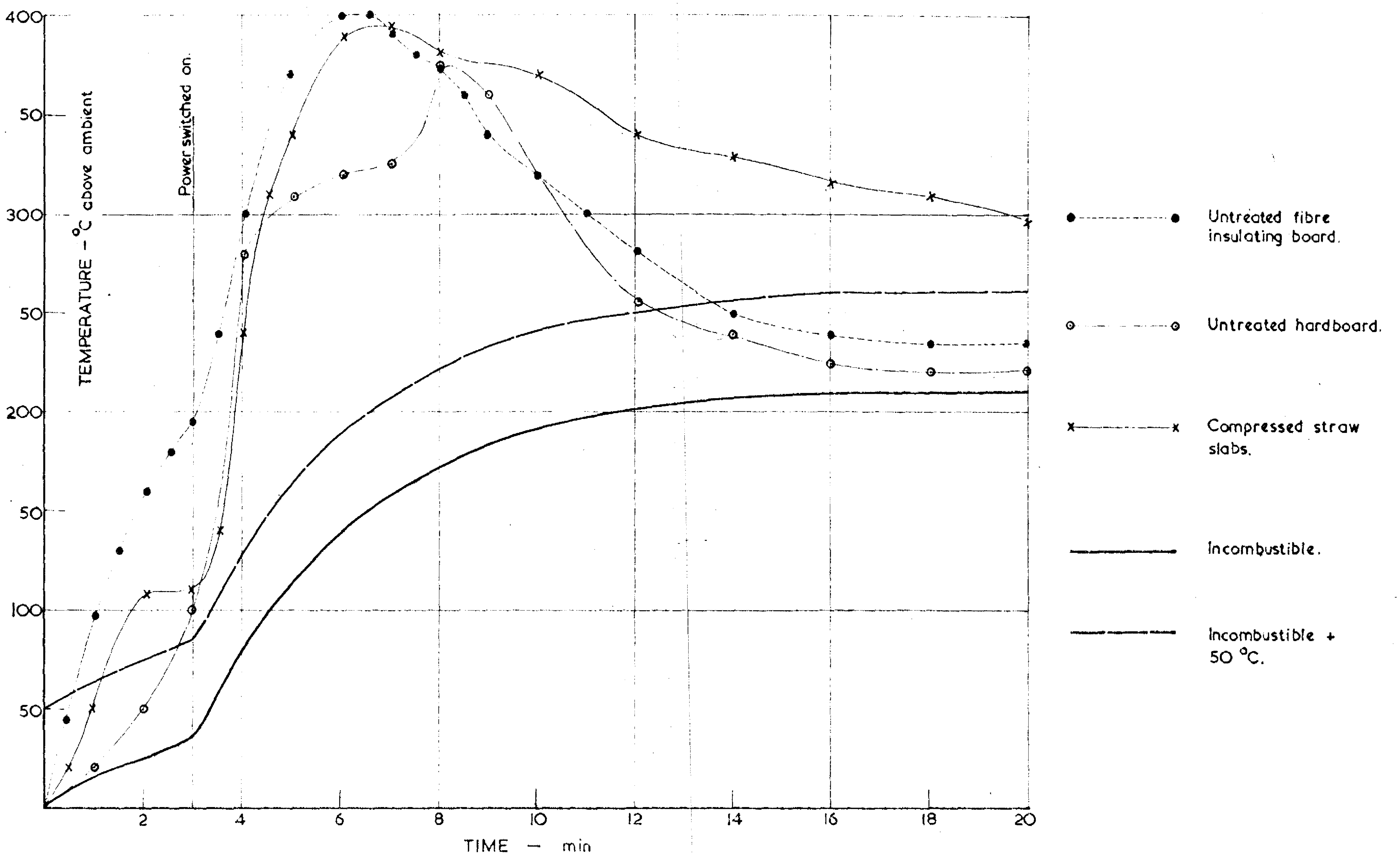
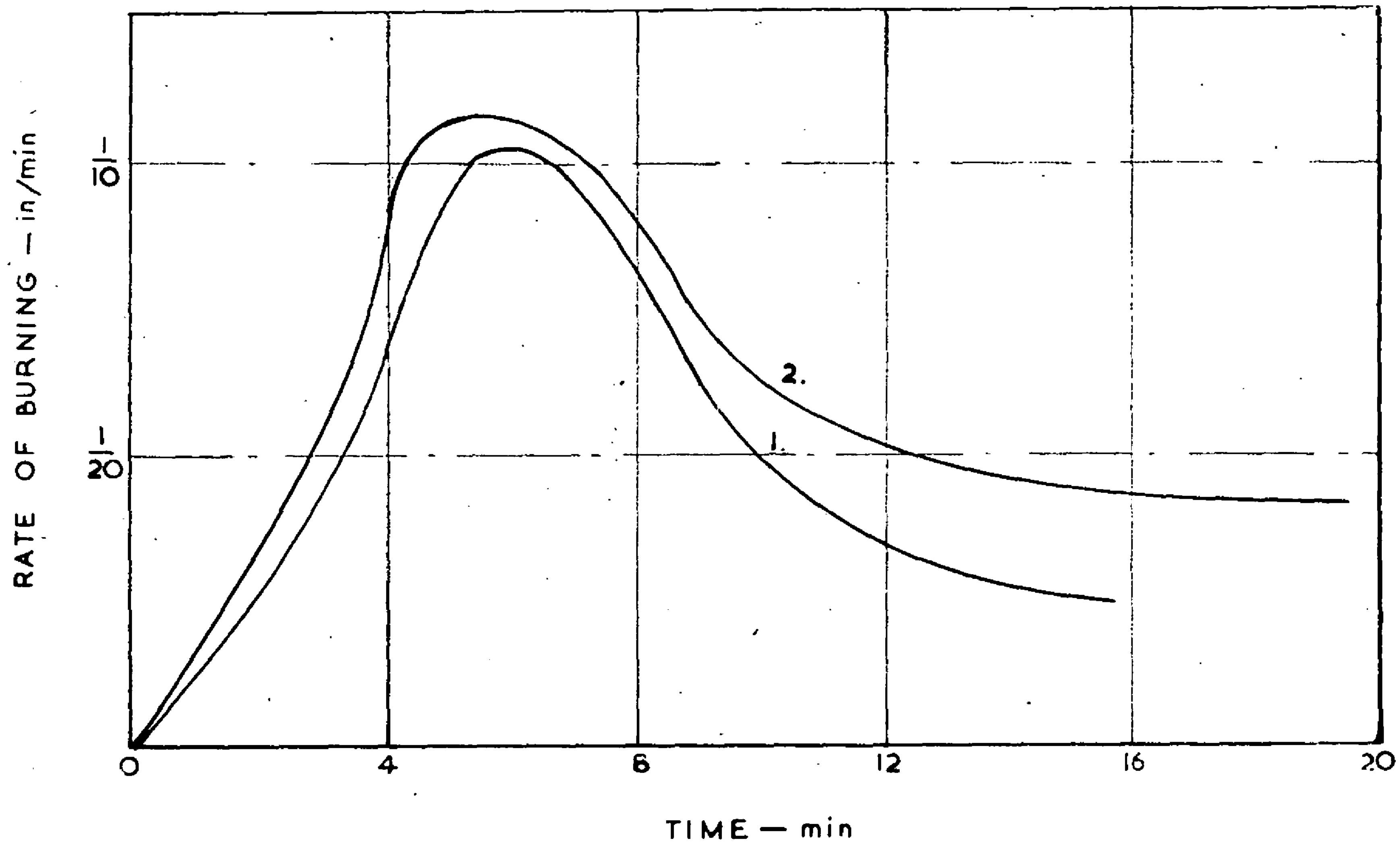


FIG. 9. REPRESENTATIVE CURVES FOR PROPOSED CLASS D.



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

FIG. 10 RATE OF BURNING OF FIBRE INSULATING BOARD

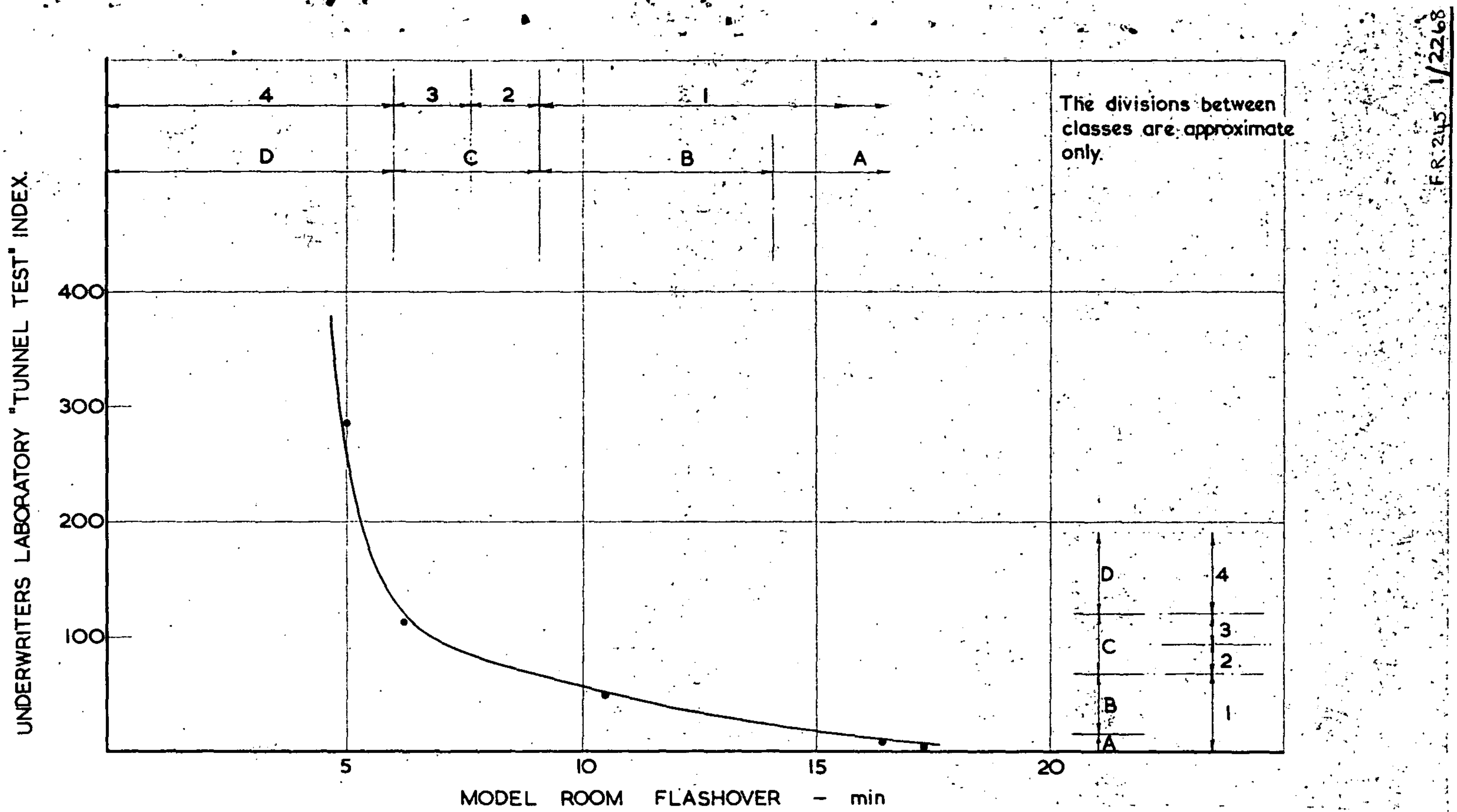


FIG. 11. ESTIMATED RELATIONSHIP BETWEEN "TUNNEL TEST" INDEX, FLASHOVER TIMES AND TEST GRADINGS.