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

FIRST PROGRAMME OF TESTS ON EFFECT OF RESTRAINT ON FIRE RESISTANCE OF FLOORS

by

H. L. Malhotra

Summary

This note describes the first series of fire tests on concrete floors with different end conditions which are going to be performed as a part of the Co-operative Research Programme between some of the CIB/CTF delegate countries.

April 1960

Fire Research Station,
Boreham Wood,
HERTS.

FIRST PROGRAMME OF TESTS ON EFFECT OF RESTRAINT ON FIRE RESISTANCE OF FLOORS

by

H. L. Malhotra

Introduction

At the third Conference of CIB/CTF in June 1958 the effect of restraint in fire resistance tests(1) was discussed and it was decided to carry out a co-operative programme of research to study the effect of restraint on the performance of floors. Holland, France and United Kingdom agreed to participate in this investigation and it was subsequently agreed to use a common type of construction having a fire resistance of 1 - 2 hours. Floors constructed from hollow precast beams were found the most suitable and in an attempt to produce identical constructions, the beams were obtained from a factory in Holland which had already supplied similar units to the Fire Research Institute at Delft.

Scope of tests

The present series of tests consist of three 10 ft (305 cm) wide floors of a total thickness of 6.9 in. (175 mm) constructed of precast reinforced concrete beams of hollow cross section with a concrete topping. There is no transverse restraint in any of the specimens but the following end conditions are imposed.

Specimen No. 1 - Simply supported
Specimen No. 2 - Restraint mainly against longitudinal expansion
Specimen No. 3 - Restraint against longitudinal expansion and angular movement.

It is expected that the downward deflection of the restrained floors will be considerably less than that of the freely supported construction, but the end conditions should have no effect on the heat transmission through the floors if they remain intact. The occurrence of spalling on account of restraint at the ends, however, may lead to higher temperatures being attained on the top surface of the restrained specimens.

Description of specimens

The specimens have been constructed from precast hollow concrete beams (Figure 1) reinforced with 2 - $\frac{1}{2}$ in. (12 mm.) dia. bars at the bottom and 2 - $\frac{1}{4}$ in. (6 mm.) dia. bars at the top with wire netting in the lower flange. The units, with tapering sides, are 9.8 in. (250 mm.) wide at the base and when closely butted together twelve beams give a width of 10 ft. Beams of two different overall lengths have been employed in the construction of the floors, units 12 ft 9 in. (388 cm) long for specimen Nos. 1 and 2 to give a clear span of 12 ft (366 cm) and for specimen No. 3, beams 12 ft (366 cm.) long to give a clear span of 11 ft 6 in. (350 cm).

After mounting the beams in the test frame an in situ concrete topping was cast to provide an average cover of 1.18 in. (30 mm) to the top of the beams giving a floor construction of a total thickness of 6.9 in. (175 mm.). The in situ concrete was made from uncrushed river gravel, washed river sand and Portland cement in the ratio 3 : 2 : 1 by volume. The maximum size of the coarse aggregate used was $\frac{3}{4}$ in. (19 mm.). During the placing of the concrete topping 6 in. cubes were made which will be crushed to determine the strength of the concrete at 28 days and at the time of test.

Specimen Nos. 1 and 2 (Figures 2 and 3) have been constructed in the standard testing frames normally employed at Boreham Wood for testing simply supported floors. These frames are fabricated from steel joist sections with an encasement of refractory concrete giving a bearing step on the short sides. For specimen No. 2 the space between the ends of the beams and the frame was filled with concrete to provide restraint against expansion and possibly some restraint against angular movement.

For specimen No. 3 a different type of steel beam frame was used and as shown in Figure 4, encastré conditions have been provided at the two short ends which impose both longitudinal and angular restraint. L-shaped continuity reinforcement of $\frac{3}{8}$ in. (9 mm.) bars at 10 in. (254 mm.) centres together with two $\frac{1}{4}$in. (6 mm.) dia. distribution bars were used in the encastré ends, the long edges of the floor being free.

Test results

It is planned to submit these floors to fire tests at an age of 6 weeks beginning in the middle of May. The last floor specimen (No. 3) is scheduled to be tested on 1st June when the delegates to the 4th Conference of CIB/CTF will be able to witness the test in progress.

References

1. Joint Fire Research Organization. Effect of Restraint in Fire Resistance Test - CIB/CTF No. 35/UK/3, May 1958.

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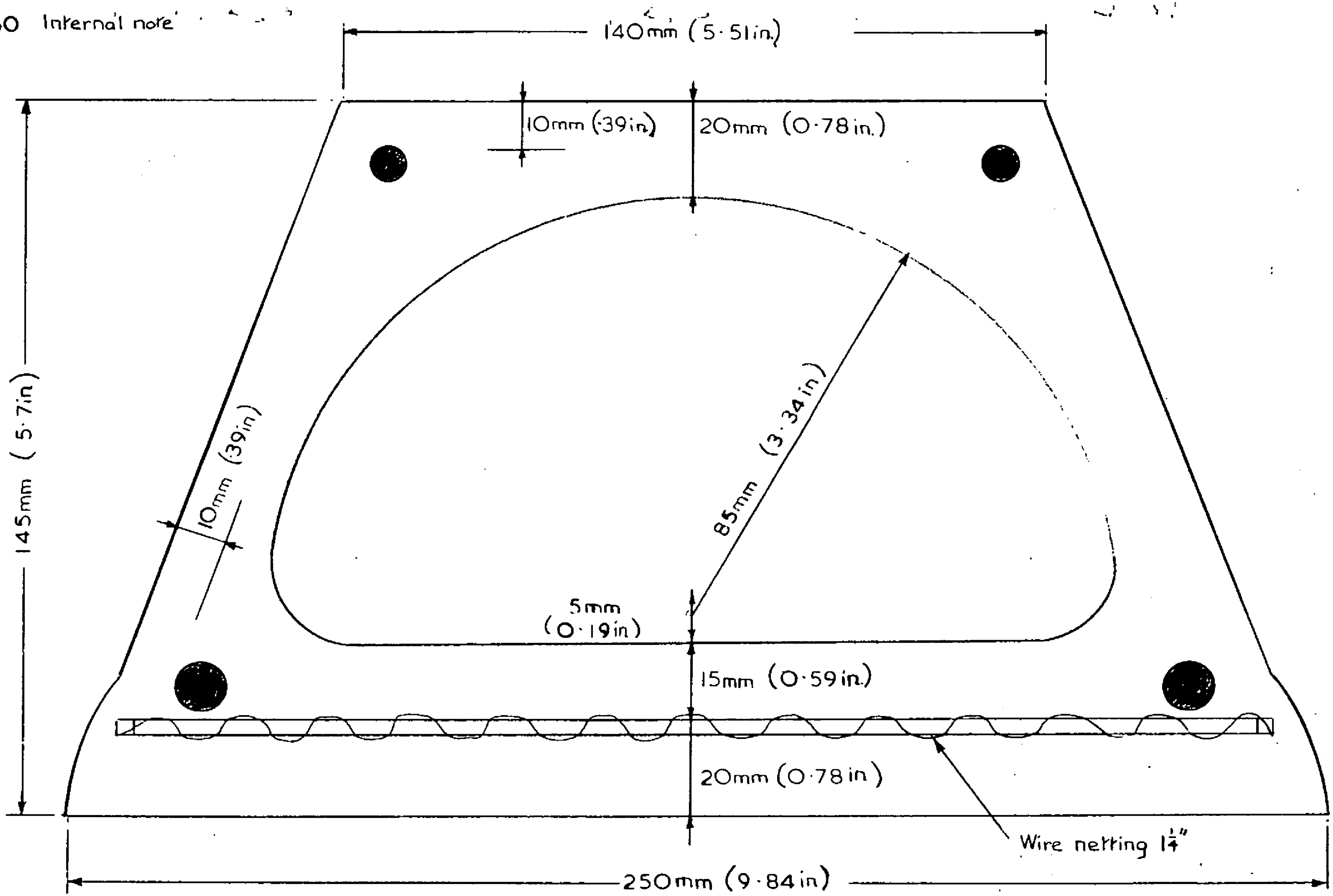

FIG.1. CROSS-SECTION OF PRECAST HOLLOW REINFORCED CONCRETE BEAMS

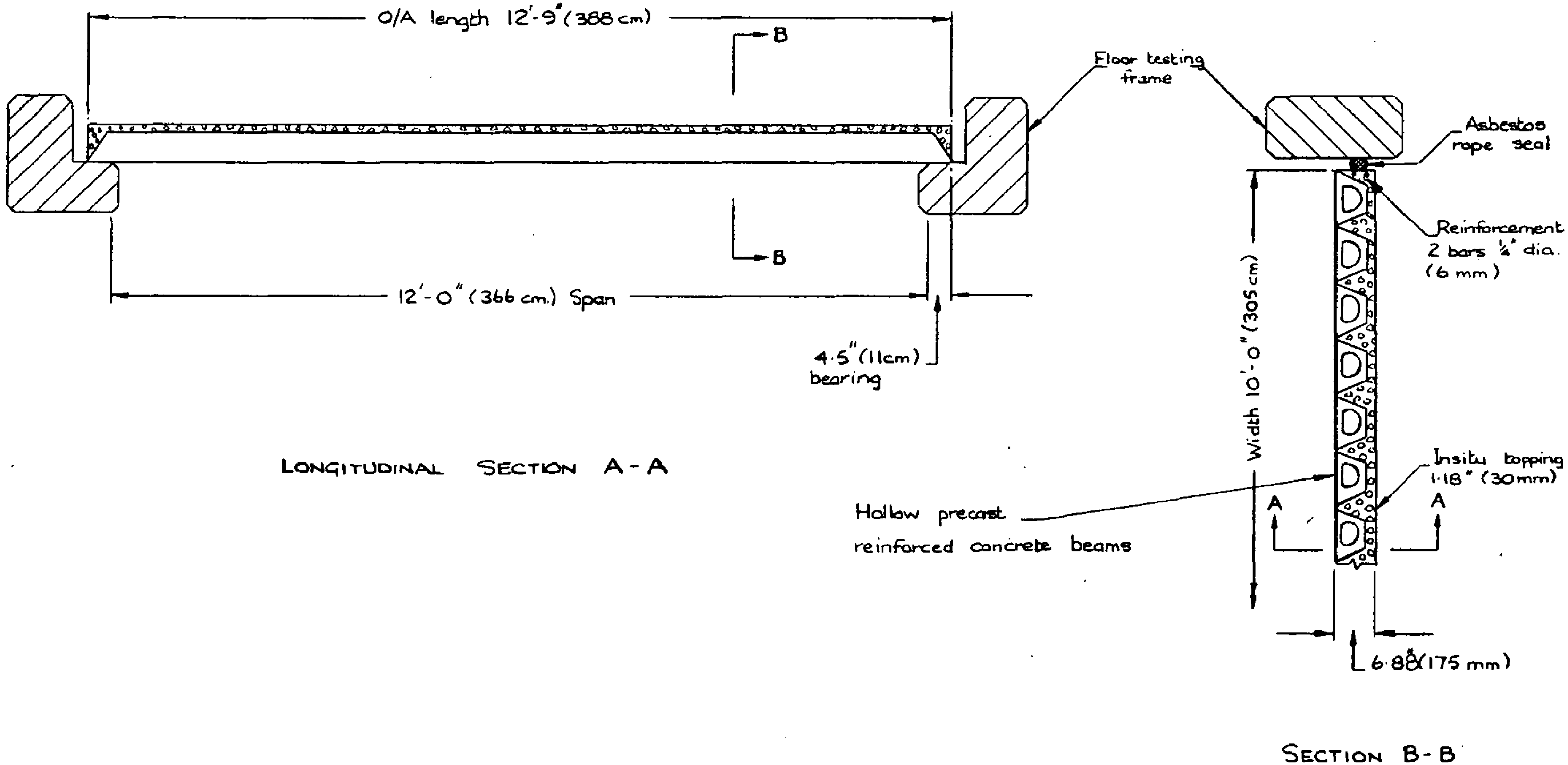

FIG. 2. SPECIMEN No I. SIMPLY SUPPORTED CONCRETE FLOOR

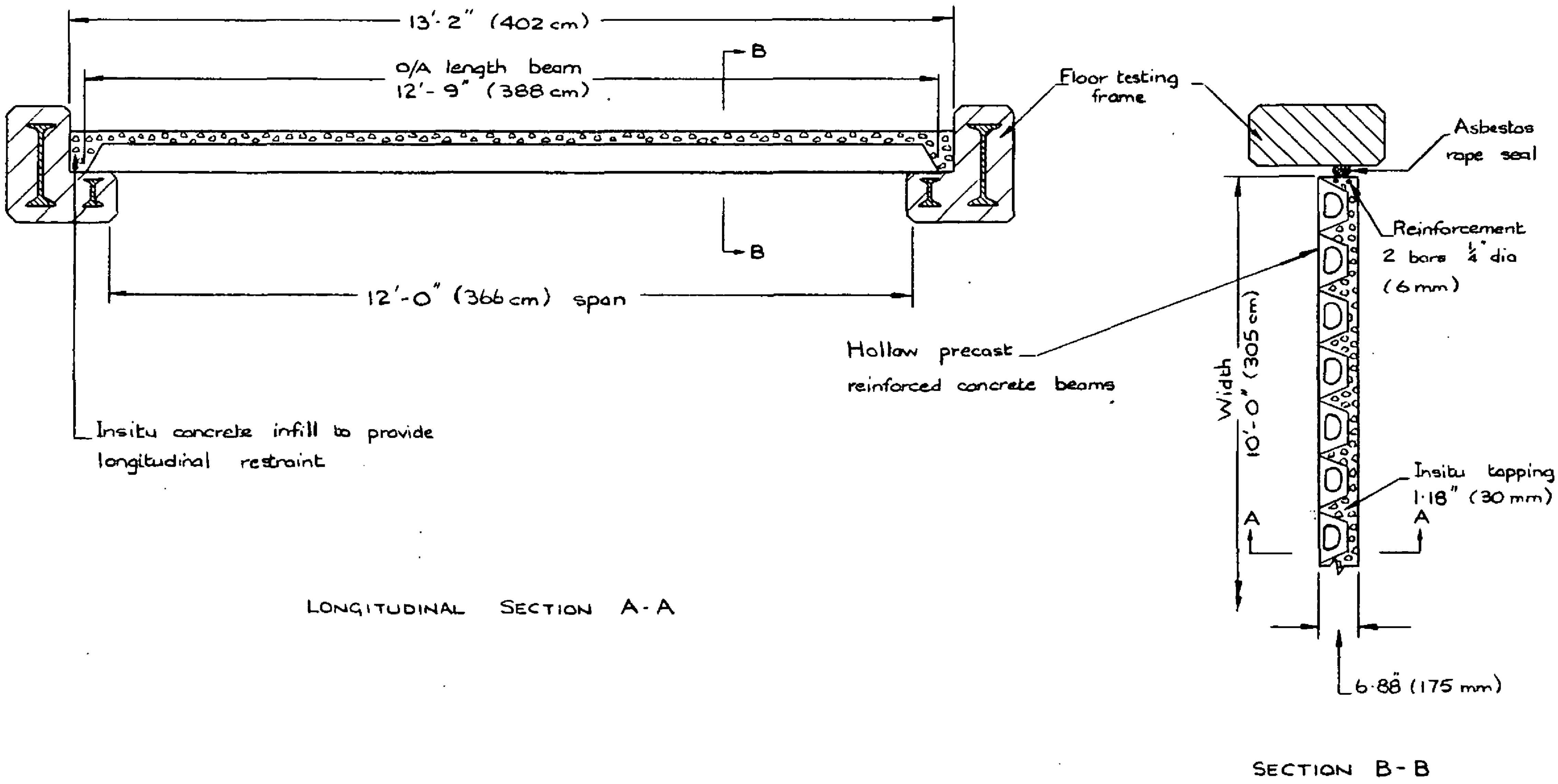

FIG. 3. SPECIMEN NO. 2. CONCRETE FLOOR WITH LONGITUDINAL RESTRAINT

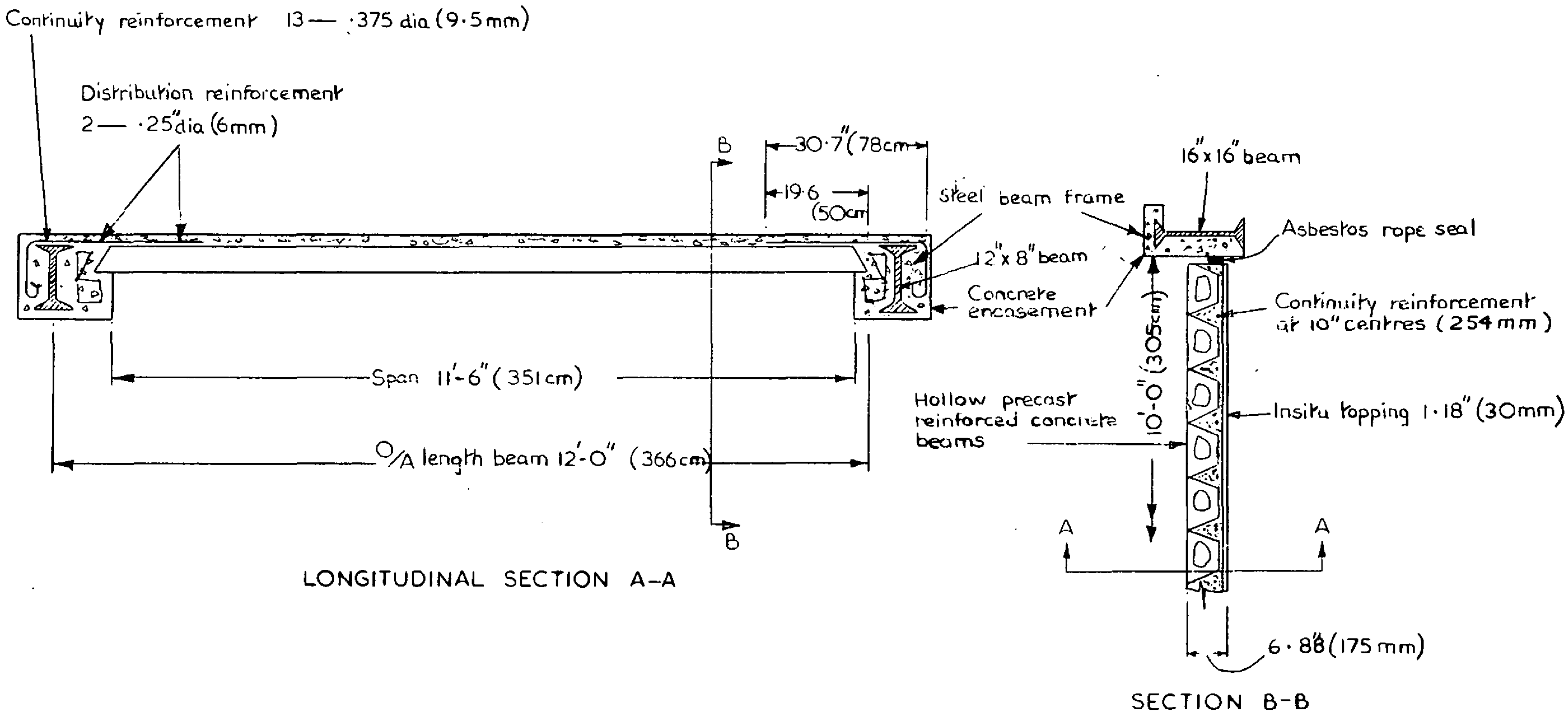

FIG. 4. SPECIMEN No. 3. CONCRETE FLOOR WITH LONGITUDINAL AND ANGULAR RESTRAINT

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EXTERNAL WALLS OF BUILDINGS - PART I

THE PROTECTION OF OPENINGS AGAINST SPREAD OF FIRE FROM STOREY TO STOREY

by

L. A. Ashton and H. L. Malhotra

1. Introduction

From the fire protection aspect, the function of the external walls of a building are primarily (1) to contain a fire within the building and give protection to fire fighters, and (2) to prevent entry of fire from an adjoining building. When a wall has windows, however, its protective value is considerably diminished, since such openings form points of weakness from both of the considerations enumerated above. Fire safety can then be achieved by proper separation of buildings from the site boundaries having regard to the dimensions of the external walls, the amount and distribution of window openings and the nature of the occupancy of the building. Methods for determining the separation of buildings have been developed(1), but they have not yet been used in building legislation.

The presence of windows in adjacent storeys of a building may introduce another hazard, that of flames issuing from the windows in one storey and spreading fire through the windows above. Some building Codes and Byelaws have attempted to reduce this hazard by including mandatory structural requirements relating to the separation between openings vertically above one another. The separation usually consists of a fire-resisting spandrel wall of specified height, or a horizontal projection.

The attention of the Joint Fire Research Organization was drawn by the Building Research Station to the need to examine the problem of protection against spread of fire from storey to storey of a building through the windows, on the grounds that the present requirements were onerous and were restrictive in the use of some forms of construction which were desirable for other reasons. An investigation was first made using models, and then experiments were made on a larger scale in a four storey tower built for the purpose. This note presents the results of the large-scale series of tests.

2. Survey of current practice

In this country measures to reduce the risk of fire spread externally in a building appeared first in Byelaws in 1952, based, it appears, on a recommendation of the Fire Grading of Buildings Committee(2). The Committee recognised that it would be onerous to ask for fire resisting glazing in buildings with average amounts of window openings and recommended for buildings of fully protected construction: "A reasonable degree of protection could be obtained by providing at least 3 ft of construction (of which at least 2 ft should be above floor level) of the same grade of fire resistance as the walls, between the lintel of the lower window and the sill of the one above". The Model Byelaws of the Ministry of Housing and Local Government(3) and of the Department of Health for Scotland(4) included this recommendation, to be applicable to all buildings other than small houses, and added, as an alternative separation, the provision of a horizontal projection extending not less than 2 ft from the wall. The London County Council By-laws(5) specify that openings above the level of the soffit of the first floor shall be limited so that their total area does not exceed one half the elevational area of the wall, and "no such opening shall extend below 2 ft 6 in. above the floor of the storey in which it is formed." It should be noted that at least one large local authority in England has not included in its Byelaws

TABLE 1

SCHEDULE OF TESTS

Test No.	Fire Load lb/ft²	Window sizes ground floor		Window sizes first floor		Under window panels ground floor		Under window panels first floor		Separation between ground and first floor windows	Remarks
		Each Window	% Opening	Each Window	% Opening	Cladding	Inner Lining	Cladding	Inner Lining		
1	5	4 ft x 6 ft	61	4 ft 4 in. x 6 ft	61	4½ in. brick wall		asbestos/cement sheeting	⅜ in. plasterboard	3 ft vertical	Other floors same as first floor
2	8	-do-	-do-	-do-	-do-	-do-		-do-	-do-	-do-	-do-
3	10	3½ ft x 5 ft	45	3½ ft x 6 ft	50	1 in. cedarboard	⅜ in. plasterboard	1 in. cedarboard	⅜ in. plasterboard	-do-	2nd floor same as first floor
4	10	3½ ft x 8 ft	71	3½ ft x 8 ft 6 in.	71	None		None		1 ft vertical	-do-
5	10	Repeat of test No. 3									
6	10	Repeat of test No. 3									2nd and 3rd floor as in test No.1
7	10	Repeat of test No. 4									2nd floor same as first floor
8	10	Repeat of test No. 4								2 ft wide horizontal balcony	2nd and 3rd floors as in test No.1
9	12½	Repeat of test No. 8									
10	12½	3½ ft x 5 ft	45	3½ ft x 6 ft	50	L.H. 1 in. cedarboard; R.H. aluminium sheet (expanded plastic in cavity)	L.H. ⅜ in. plasterboard; R.H. ⅜ in. plasterboard	L.H. 1 in. cedarboard; R.H. aluminium sheet (expanded plastic in cavity)	L.H. ⅜ in. plasterboard; R.H. ⅜ in. plastertoard	3 ft vertical	Continuous cladding of cedarboard on one half of building extending to top of first floor.
11	7	-do-	-do-	-do-	-do-	4½ in. brick wall		L.H. ½ in. wired glass; R.H. 1/16 in. glass fibre reinforced plastic	½ in. fibre insulating board; ½ in. fibre insulating board	-do-	

TABLE 2

Estimated Fire Resistance of Wall Panels

Under window panel construction		Estimated fire resistance	
Cladding	Lining	Internal fire	External fire
$4\frac{1}{2}$ in. brick wall		2 hours	2 hours
Asbestos/cement sheeting	$\frac{3}{8}$ in. plasterboard	Less than $\frac{1}{2}$ hour	Less than $\frac{1}{2}$ hour
1 in. cedar boarding	$\frac{3}{8}$ in. plasterboard	$\frac{1}{2}$ hour	$\frac{1}{2}$ hour
Aluminium sheeting (Expanded plastics in cavity)	$\frac{3}{8}$ in. plasterboard	Less than $\frac{1}{2}$ hour	Less than $\frac{1}{2}$ hour
$\frac{1}{4}$ in. wired glass	$\frac{1}{2}$ in. fibre insulating board	Less than $\frac{1}{2}$ hour	Less than $\frac{1}{2}$ hour
1/16 in. glass/ fibre plastic laminate	$\frac{1}{2}$ in. fibre insulating board	Less than $\frac{1}{2}$ hour	Less than $\frac{1}{2}$ hour

7. Test results

(1) General

The temperatures obtained in the various tests are plotted in Figures 6 to 15. Photographs of the outside of the building were taken at intervals during the tests and a selection is shown in Plates 1 to 11. The results are summarized in Table 3, and further details of the individual tests are given in the Appendix.

8. Discussion of results

The purpose of the investigation was to examine the requirements for the separation between windows in adjacent storeys of a building in order to achieve a reasonable standard of fire safety. With the means available, it was necessary to confine the experiments to one size of room of relatively small dimensions and it is not possible at this stage to predict the effect of fires in much larger buildings and having greater fire loads.

In the scope of comparatively few tests, only the more important variables could be dealt with. Since the tests were made in the open, weather conditions were a factor which it was difficult to take into account, and it was only with experience that its effect was fully appreciated. It is hoped that the other variables can be studied in work in progress on fires in rooms carried out on a model scale.

(1) Effect of conditions in fire chamber

Model experiments[10] show that the height of flames issuing from the windows of a room involved in fire increases with the rate of burning of the fuel, where the

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EXTERNAL WALLS OF BUILDINGS - PART I

THE PROTECTION OF OPENINGS AGAINST SPREAD OF FIRE FROM STOREY TO STOREY

by

L. A. Ashton and H. L. Malhotra

Summary

Building Codes and Byelaws at present generally include requirements aimed at reducing the risk of fire spreading from storey to storey through the windows. Experiments have been made both with model rooms and large scale structures to determine the protective value of these requirements and whether relaxations could be justified. This paper describes the large scale experiments on a four-storey building erected for the purpose.

July, 1960.

Fire Research Station,
Boreham Wood,
Herts.

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The attention of the Joint Fire Research Organization was drawn by the Building Research Station to the need to examine the problem of protection against spread of fire from storey to storey of a building through the windows, on the grounds that the present requirements were onerous and were restrictive in the use of some forms of construction which were desirable for other reasons. An investigation was first made using models, and then experiments were made on a larger scale in a four storey tower built for the purpose. This note presents the results of the large-scale series of tests.

2. Survey of current practice

In this country measures to reduce the risk of fire spread externally in a building appeared first in Byelaws in 1952, based, it appears, on a recommendation of the Fire Grading of Buildings Committee[2]. The Committee recognised that it would be onerous to ask for fire resisting glazing in buildings with average amounts of window openings and recommended for buildings of fully protected construction: "A reasonable degree of protection could be obtained by providing at least 3 ft of construction (of which at least 2 ft should be above floor level) of the same grade of fire resistance as the walls, between the lintel of the lower window and the sill of the one above". The Model Byelaws of the Ministry of Housing and Local Government[3] and of the Department of Health for Scotland[4] included this recommendation, to be applicable to all buildings other than small houses, and added, as an alternative separation, the provision of a horizontal projection extending not less than 2 ft from the wall. The London County Council By-laws[5] specify that openings above the level of the soffit of the first floor shall be limited so that their total area does not exceed one half the elevational area of the wall, and "no such opening shall extend below 2 ft 6 in. above the floor of the storey in which it is formed." It should be noted that at least one large local authority in England has not included in its Byelaws slabs 6 in. thick, the other floors were of normal in situ reinforced concrete 4 in. thick. The entrance to the staircase at the ground floor level was sealed to prevent the flame and the smoke entering the staircase and access to the first floor landing was arranged by means of an outside ladder and a trap door. A non-combustible door at the rear of the ground floor provided access to it and was also useful for controlling ventilation. Small observation windows were let into the back walls of the rooms and made it possible to look into the room from the balcony attached to the landings. Provision was also made for fixing thermocouples to measure temperatures in different rooms.

5. Testing technique

The first test was a preliminary trial to determine the procedure to be adopted for the rest of the experiments. Mock up furniture to give a fire load of 5 lb/ft^2 (approximately 40,000 B.T.U./ft^2) was placed in the ground floor room. After the first test it was decided to use timber cribs, three or four in number depending upon the fire load, using pieces of 2 in. x 4 in. and 1 in. x 3 in., 30 in. long rough sawn timber. A rectangular layout was used for the four cribs (see Figure 2), varying in height from 36 in. near the windows to 60 in. in the rear of the room. At the end of the second test it was also decided to line the walls and the floor with fibre insulating board to assist rapid development of fire in the room as the main interest was in the fully developed stage of the fire. Although not necessary for these experiments, the windows of the fire chamber were glazed, except for a pane at the top, in order to obtain information on the behaviour of glass in fires. As the test proceeded the glazing was broken as cracks were formed. Thermocouples projecting 3 in. below the soffit measured the temperature conditions in the fire chamber during a test.

In the first floor room, in addition to timber flooring, two pieces of mock up furniture of timber and hardboard were placed as shown in Figure 3. Surface thermocouples were attached to the side of the "cupboard" facing the window and on the top surface of the "table". Additional thermocouples were attached to the inside of underwindow panels or on the upper surface of the floor boarding, in each test. After the first four tests lightweight cotton curtains were hung at the first floor windows, and simple hardboard pelmets were fitted. Sheets of newspaper were also placed on the table.

Some temperature measurements were also made in the second and the third floor rooms in the four tests but as no significant temperature rise was observed, the measurements were subsequently discontinued.

The prevailing wind conditions were noted during each test and the average wind speed was measured with an anemometer.

6. Description of the tests

The construction data for the series of tests are summarised in Table 1 and are discussed in detail below.

(1) Fire load

The range of fire loads was from 40,000 - 1000,000 BTU/ft^2, capable of providing fires equivalent in severity of up to one hour of the standard fire resistance test(2). Experiments with models(10)(11) have shown that, under given conditions, the rate of burning of the fuel is generally independent of the fire load, which affects primarily the duration of the fire. As the fire load increases under given conditions, therefore, the greater will be the time during which flames are expected to attack the windows of the upper storeys, as long as spread of fire does not take place internally from storey to storey.

(2) Window sizes

The test series was commenced with the ground floor room having two timber framed windows, each 4 ft wide by 6 ft high and the other floors with windows of the same height and 4 ft 4 in. wide. The openings in the wall of the rooms represented by these windows were 61 per cent for all storeys. After the first two tests the width of the window was reduced to $3\frac{1}{2}$ ft and the height of the ground floor windows to 5 ft thereby reducing the percentage openings to 45 and 50 respectively for the ground and the first floors. For four of the tests the glazing was extended from ceiling to the floor level and the openings thus increased to 71 per cent of the facade.

(3) Underwindow panels

After the first three tests it was apparent that only the underwindow panels or spandrel walls on the first floor were likely to be seriously affected since the flames were transitory at higher levels and it was therefore decided to confine attention to the performance of various constructions on the ground and the first floors. On the ground floor resistance against an internal fire was demonstrated and on the first floor the behaviour of the wall when exposed to an external fire was shown.

All the under window panels, with the exception of the ground floor in the first two tests and the last test when $4\frac{1}{2}$ in. brick wall was used, were made with 2 in. square timber framing having an external cladding and an inner lining. Five different constructions were tested, $\frac{3}{8}$ in. plasterboard forming the inner lining in three of the constructions and untreated $\frac{1}{2}$ in. fibre insulating board in the other two. Three types of non-combustible cladding were tested and two types of combustible cladding. In one test with timber cladding, the boarding was extended as a continuous finish over one half of the façade from ground level to the top of the first floor window to see if it would assist the fire to spread.

When no panels were used, i.e. the glazing extended from ceiling to floor there was a 12 in. separation formed by the floor structure between the top of the window opening in the ground floor and the bottom of the opening of the first floor. In two such tests a balcony of reinforced concrete 2 ft wide complying with the existing byelaws, was mounted between the two openings.

Further details of the various window panels tested are shown in Figures 4 and 5, and their estimated fire resistance, as defined in B.S. 476[12], is given in Table 2.

TABLE 5.

SUMMARY OF RESULTS OF TESTS

Test No.	Fire load (lb/ft²)	Separation between storeys		Wind		Maximum temperature measured on contents of 1st floor room (°C)	After flaming began from windows of ground floor room		Remarks
		Type	Nature and Fire resistance	Direction	Mean Speed (m.p.h.)		Time to break windows in first floor room (min)	Duration of attack on first floor window (min)	
1	5	3 ft wall	Non-combustible, Less than ½ hour	S.W.	4.5	20	Windows did not fall	12½	No effect on panels
2	8	-do-	-do-	W	11.2	140	1	6	Cladding shattered
3	10	-do-	Combustible cladding ½ hour	N.W.	8.0	30	2½	14½	No penetration of panels
4	10	None	Glazing to floor in upper room	S. to S.W.	6.8	100	2	16	No ignition of contents of upper room
5	10	3 ft wall	As Test No.3	S. to S.W.	9.2	100	2	13	No penetration of panels
6	10	-do-	-do-	N	3.4	100	1	15	-do-
7	10	None	As Test No.4	N	4.3	300	1	14	Charring of contents of upper room
8	10	2 ft horizontal projection	Non-combustible slab	N. to W.	4.3	20	2	9	No ignition of contents of upper room
9	12½	-do-	-do-	E	1.3	160	1½	14	Charring of contents of upper room
10	12½	3 ft wall	1) Combustible cladding 2) Non-combustible cladding Both less than ½ hour	S.E. to S.W.	6.3	40	10½	16½	No penetration of panels
11	7	-do-	1) Non-combustible cladding and combustible lining. 2) Combustible cladding and lining. Both less than ½ hour	W	5.4	140	1	11	-do-

Note: The side of the experimental building used for these tests faced S.S.E.

windows are large, and the rate of burning depends on the surface area of the combustible material. With smaller windows the rate of burning depends on the air supplied to the fire, which, apart from wind effects, is governed by the air flow factor A H, where A is the window area and H its height[11]. The tower experiments showed the effect on flame height of increasing the available surface area of the fuel and also indicated that flames from the ground floor room tended to be higher when the windows in that room were smaller, but weather conditions introduced a variable which could not be taken into account.

The fire load ranged in the tests from 5 to 12½ lb/ft^2 (40000 - 100000 BTU/ft^2 approximately). There is no marked relation between fire load and the damage sustained in the first floor room; except in Tests Nos. 8 and 9 where increasing the fire load from 10 to 12½ lb/ft^2 resulted in higher temperatures on the furniture of the upper room. On the other hand in Tests Nos.2 and 10 where the fire loads were 8 and 12½ lb/ft^2 respectively higher temperatures were recorded on the furniture in Test No.2.

(2) Effect of windows

It will be seen that, except in Test No.1, the windows of the first floor room were shattered, permitting flames, smoke and hot gases to enter the room. Where curtains and pelmets were provided, these were ignited, although in the absence of other adjacent combustible materials the fire in this room did not continue to burn. Therefore, if flames attain the height of the windows and are sustained, if only for a short period, they are likely to break the windows and ignite any readily flammable material close to them. Where flaming was most vigorous, glass was broken in the windows of the second floor.

(3) Effect of separation between windows

Current Byelaws in this country require the 3 ft separation between windows in adjacent storeys to have a fire resistance appropriate to the type of building, with a value of between ½ hour and 4 hours. For domestic buildings the fire resistance requirement may be up to one hour for a non-loadbearing panel supported in a structural frame. The tests were made with under-window panels having a fire resistance ranging from about fifteen to thirty minutes, and in no instance was a panel used having a fire resistance of one hour appropriate to the fire load of 10 - 12½ lb/ft^2. It was demonstrated that under any conditions in the tests the fire to which the panel may be exposed externally is much less severe than the fire it will have to withstand internally. In no test did actual penetration of a panel by flames occur although with the wholly combustible construction used under one window in Test No.11, penetration would probably have occurred if the flame attack had been prolonged a little longer.

Timber cladding, having a thickness of not less than ½ in. behaved well in repeated experiments, and withstood external fire exposure without being penetrated by flames. The impinging of flames on the underwindow panels was never sufficiently sustained to give continued burning of the timber, and a charred layer was built up on the surface of the cladding which was resistant to re-ignition.

Certain non-combustible materials suffered the same kind of damage when attacked by external fire as is shown when they are exposed to internal fire; asbestos/cement sheets shattered and aluminium melted. The presence in these panels of an internal lining prevented the penetration of flames to the room through the panels.

The effect of a further reduction in the fire resistance of the separation is shown by the tests (Nos.4 and 7) in which glazing extended from floor to ceiling. In neither of these tests was the furniture in the first floor room ignited, although in one of the tests (No.7) the highest temperatures for the furniture of the whole series were recorded.

The provision of a horizontal projection between the windows of the two storeys of the minimum dimensions required in the Byelaws was less effective in protecting the contents of the upper room than a 3 ft wall panel, as shown by the results of comparable tests, Nos. 9 and 10, although the wind may have contributed to the differences in the two tests.

The relative merits of the underwindow-panel, floor to ceiling glazing and the horizontal projection are shown by the three tests, Nos. 6, 7 and 8, made under similar conditions of wind direction and speed, and the same fire load. In the experiment with floor to ceiling glazing the hazard to the contents was appreciably greater than in the other two experiments, but the hazard was not great enough to lead to spread of fire to the upper room.

9. Conclusions

The following conclusions relating to structural measures which are likely to be of value in reducing the risk of fire spread externally in a building are derived from the investigation described, and from consideration of the problem in accordance with fire protection principles.

(1) The most important safeguard against spread of fire from storey to storey in a building is the provision to a compartment of fire resisting walls and floors, with all openings in these elements protected with closures of appropriate fire resistance. Fire, and the products of combustion, smoke and toxic gases, spread more readily internally than externally, and within a building are a far greater hazard to life and property.

(2) The investigation showed that ignition of the combustible structure and furniture of a room immediately above a fire would not occur readily under flame attack for as long as fifteen minutes even when the underwindow panels had no fire resistance, but the provision of separation between windows in adjacent storeys in accordance with building byelaws would not prevent ignition of flammable materials, such as curtains close to the windows of the room above a fire.

(3) The intention of the separation requirements of the Byelaws is illustrated in Figure 16. A minimum height of 2 ft above floor level is specified for the spandrel wall and this height is deemed to be sufficient to give protection to the contents against radiation from the flames or actual flame impingement (Fig. 16 a, b). In the investigation described the items of furniture were substantially shielded by the wall, but combustible material of much greater height would have been exposed to a higher risk of ignition. The indications from the tests and from model experiments were that, under suitable conditions, ignition of combustible material in the upper part of the room, for example a ceiling lining would be possible (Fig.16c). It has been suggested[8] that a vertical projection below the ceiling of a room is likely to be of greater use in protecting the windows of the storey above than a spandrel wall, on account of the different flow of the products of combustion which would result, (Fig.16d). Model experiments[9] show, however, that such a measure is unlikely to affect the flame height which has its origin virtually from the lower part of the window of the room involved, and the result is likely to be as indicated in Fig.16e.

(4) A horizontal projection or balcony is intended to deflect the flames away from the windows in the upper storey, but in order to be effective in this way a much greater distance of projection would be needed than 2 ft from the face of the wall, (Fig.16f and g).

(5) Within the conditions of the experiments it appears that a vertical separation of 3 ft or a horizontal separation of 2 ft between windows in adjacent storeys is inadequate to prevent the entry of flames from a fire in the lower storey unless fire resisting glazing is used. The extent of the increase in these separations necessary to give reasonable protection against flame penetration through the windows has not been determined. The indications are that the fire resistance required of the spandrel wall could be substantially reduced even below

½ hour, without any significant reduction in fire safety to a building or its occupants, and that no undue hazard is introduced by use of a combustible cladding of solid timber. The use of other combustible materials needs separate consideration, since they could introduce undesirable hazards.

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Acknowledgements

Mr. W. A. Morris assisted with the experimental work.

APPENDIX

Test No.1. Wind direction S.W. Average speed 4.5 m.p.h.

Although the glazing in the ground floor windows began to crack at $1\frac{1}{2}$ min. the panes remained in position for another 8 min. The fire development was more rapid than in the preliminary test, but the extent of flaming outside the windows was still small. At 16 min. some cracks in the first floor glazing occurred. The fire started to diminish at 22 min. and flaming from ground floor windows ceased. No significant damage to the first floor windows was observed.

It was decided after this test to increase the surface area of combustible material in the fire chamber by lining the walls and the floor with fibre insulating board.

Test No.2. Wind direction W. Average speed 11.2 m.p.h.

The fire load was increased to 8 lb/ft^2 of which the wall and the floor lining constituted a quarter.

The fire developed very rapidly in this test and by $4\frac{1}{2}$ min. most of the glazing had been broken in the ground floor room and the flames from the windows cracked some panes in the first floor. The wind was rather strong and, blowing across the face of the building, tended to sweep the flames to one side. Just after 5 min. one of the window panes on the first floor fell down and an asbestos/cement facing of an underwindow panel was shattered. Glazing on the first floor continued to break up and after 7 min. the second asbestos/cement facing exploded and the exposed face of plasterboard began to char. The intensity of flaming decreased after $10\frac{1}{2}$ min. and the fire was almost out at 15 min. The first floor window frames were charred, most of the glazing broken and cladding of the wall panels had disintegrated. The fire did not enter the first floor and no damage to the contents of the room was observed. With the exception of a broken window pane on the second floor, no damage occurred to the higher storeys.

Test No.3. Wind direction N.W. Average speed 8 m.p.h.

The fire load was increased to 10 lb/ft^2, the window sizes were reduced and a combustible cladding consisting of cedarboarding was used on the underwindow panels on the ground, first and second floors.

There was a rapid development of fire and by $3\frac{1}{2}$ min. the flames were issuing from the ground floor windows. The glazing on the first floor commenced to break by 6 min. and the combustible cladding and window frames were ignited. The flames issuing from the fire chamber were high enough to reach the panels on the second floor. After the initial flaming the cladding continued to burn only as long as the flames were in contact with it. By 14 min. the lower edge of the cladding had charred right through, the rest of the boarding was still intact. By 18 min. the fire penetrated through the ground floor panels and the flame intensity began to diminish. The fire was out by 28 min.

The fire did not penetrate the first floor window panels and no fire damage inside the room was observed. The second floor panels were only slightly charred.

Test No.4. Wind direction S. to S.W. Average speed 6.75 m.p.h.

Keeping the fire load the same as the previous test, the glazing on the ground, first and second floors extended from floor to ceiling. The separation between the top of the ground floor windows and the bottom of the windows of the floor above was 12 in. Four lightweight cotton curtains were hung at the first floor windows and hardboard pelmets provided.

There was a rapid build up of fire and all the glazing on the ground floor was broken by 2 min. Flames commenced to issue from the window openings and the lower part of the first floor window frames started to char at 4 min. and within the next 2 min. the glazing on this floor began to break up. The wind tended to blow the flames away from the face of the building to one side. One curtain was first ignited at $7\frac{1}{2}$ min. and subsequently two of the remaining three curtains were ignited. By 12 min. the intensity of flames began to decrease and after another 6 min. there were no flames issuing from the windows. The test was terminated at 20 min. The flames did not ignite the flooring or the furniture on the first floor, neither did the burning curtains spread the fire. There was no damage to glazing on the second and third floors.

Test No.5. Wind direction S. to S.W. Average speed 9.2 m.p.h.

Test No.6. Wind direction N. Average speed 3.4 m.p.h.

Both these tests were repeats of Test No.3 with the addition of curtaining in the first floor room and some loose newspaper placed on the table. The wind was strong and unfavourable for sustained flame attack on the first floor windows in Test No.5 but the conditions were favourable in the second test.

The fire developed rapidly in both tests, but sustained and persistent flaming occurred only with the second in which the fire was also of a slightly longer duration. In both tests the curtains were ignited but the fire did not extend elsewhere into the room. In Test No.6, the cladding of the under-window panels on the first floor was charred more extensively and temperatures in the room were on the average approximately 50°C higher than in Test No.3.

Test No.7. Wind direction N. Average speed 4.25 m.p.h.

This was a repeat of Test No.4 with wind conditions more favourable to external spread of fire. Early in the test the flames issued vigorously from the ground floor windows and at times reached the third floor. By 4 min. most of the glazing on the first floor had disintegrated, the curtains were consumed and the hardboard pelmets ignited. After 15 min. the flaming diminished and the fire was burning wholly inside the ground floor room.

The sides of the furniture facing the window on the first floor and the floor boards near the windows were charred. There was slight charring of newspapers on the top of the table where for short duration temperatures of the order of 300°C were recorded. There was no spread of fire inside the room.

Test No.8. Wind conditions N. to W. Average speed 4.25 m.p.h.

With the window sizes and the fire load as in the previous test a 2 ft wide concrete balcony was mounted between the ground and the first floor window openings.

Flames issued from the windows of the fire chamber at 6 min. The flames were observed to be deflected outwards by the balcony and once clear of it to curve inwards towards the first floor windows. By $7\frac{1}{2}$ min. some of the glazing on this floor had broken and the window frames and the curtains were ignited. Three of the curtains were burnt out by 11 min. and nearly three quarters of the glazing fallen down. By 15 min. the flaming diminished and the fire was burning inside the fire chamber only. The fire was almost out by 20 min.

No charring of furniture on the newspapers on the first floor was observed.

Test No.9. Wind direction E. Average speed 1.25 m.p.h.

This was a repeat of test No.8 with the fire load increased to 12½ lb/ft^2 and with only a slight wind.

Flames issued from the ground floor windows after 8 min. There was vigorous flaming in front of the first floor window with the flames curling back over the balcony breaking the glazing and igniting the curtains. By 14 min. almost all the glazing on this floor had fallen down and the window frames were charred for their full height. The flame intensity started to decrease by 18 min. and the fire was burning inside the fire chamber with only slight flame emission.

The furniture on the first floor suffered some charring on the sides facing the windows and some charring of the floor boarding near the windows also occurred. Transient temperatures as high as 300°C were recorded in the room. There was no spread of fire in the room.

Test No.10. Wind direction S.E. to S.W. Average speed 6.25 m.p.h.

In this test underwindow panels of two different constructions, both on the ground and the first floors, were used. On one side of the vertical centre line the panels consisted of 20G. sheet aluminium cladding with expanded plastic in the cavity and plasterboard lining. On the other side a cladding of cedarboarding was used, in addition, the whole face of the building on this side up to the top of the first floor was faced with cedarboarding to provide an unbroken combustible finish.

The fire was slow to develop and the first flames issued from the windows at 13 min. and ignited the combustible cladding. One of the curtains was ignited at 15½ min. and by 18 min. some of the boarding adjacent to the window was also flaming. At 19 min. the aluminium panel on the first floor softened and exposed the plastic insulation which started to burn. There was no continued burning of the cedarboard cladding, flaming occurring only when the flames were in contact with it. At 24 min. the plasterboard behind the aluminium facing became visible and its surface began to char. By 29½ min. the fire on the ground floor penetrated through the aluminium-faced panel and through the cedarboarding within a further half a minute. At this stage there was very little flaming outside the windows.

The fire did not penetrate the underwindow panels on the first floor, there was no charring of furniture or newspaper, and one curtain and the pelmets were intact at the end of the test.

Test No.11. Wind direction W. Average speed 5.4 m.p.h.

The fire load was decreased to 7 lb/ft^2 and two different constructions for underwindow panels employed on the first floor. A 4½ in. brick was used under the windows on the ground floor. A fibre insulating board internal lining was used for underwindow panels on the first floor with an exterior cladding of ¼ in. wired glass for one panel and a corrugated sheet of fibreglass/polyester resin laminate for the other.

The fire developed fairly rapidly and the flames ignited the plastic sheeting in just under 2 min. The glazing on the first floor started to break at 3 min. and one of the curtains was ignited. The wired glass panel cracked but remained in position and by 6 min. the plastic sheeting had finished burning. The flaming began to diminish at 10 min. Between 15 and 16 min. the internal lining of fibreboard ignited in the two panels. The fire in the ground floor was nearly out at 20 min.

The fire did not penetrate the first floor room by the end of the test althoug the panel linings gave temperature readings of 600 to 700°C on the inside after 15 min. and would have ignited if the flaming had been of slightly longer duration.

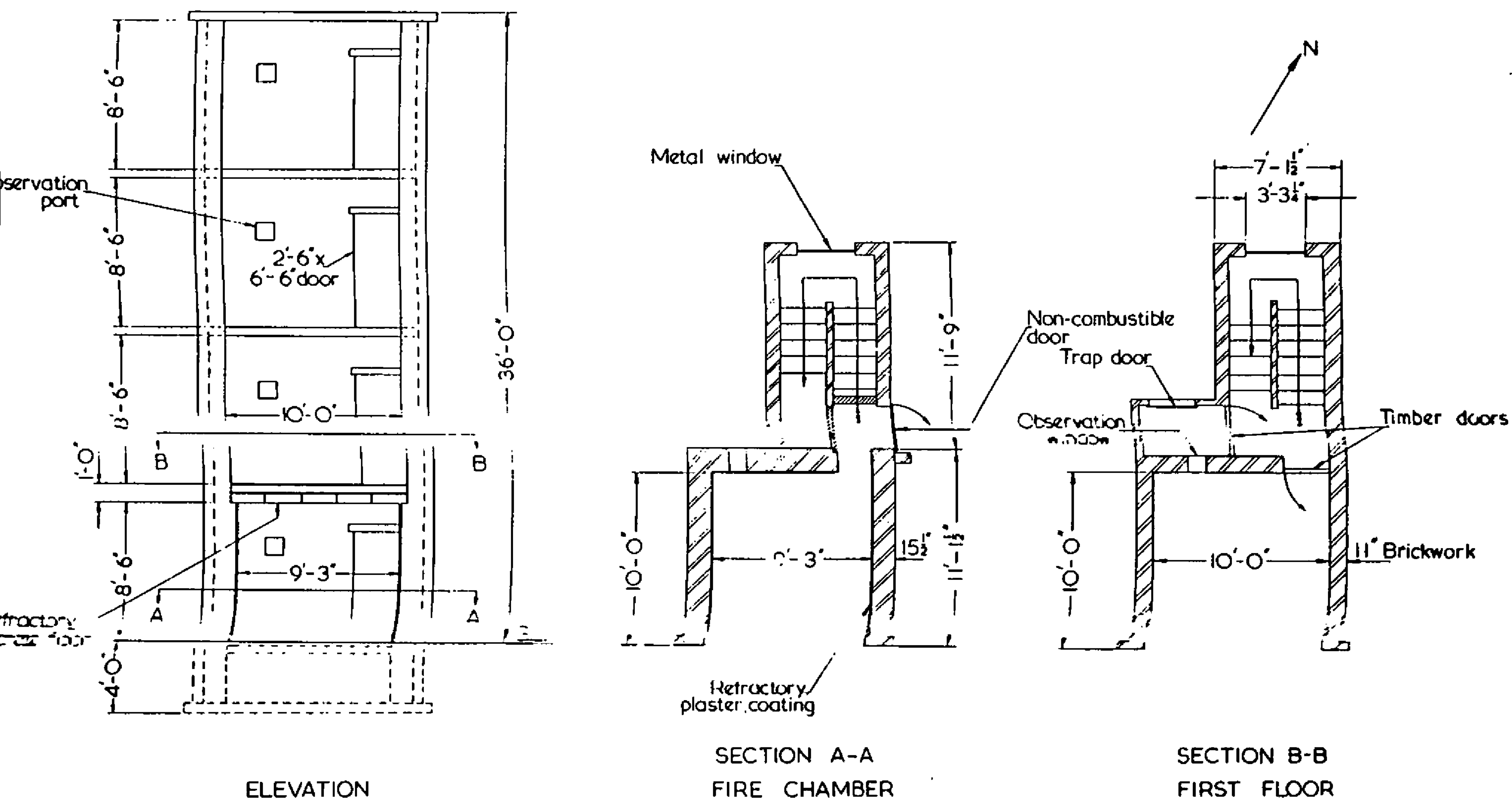
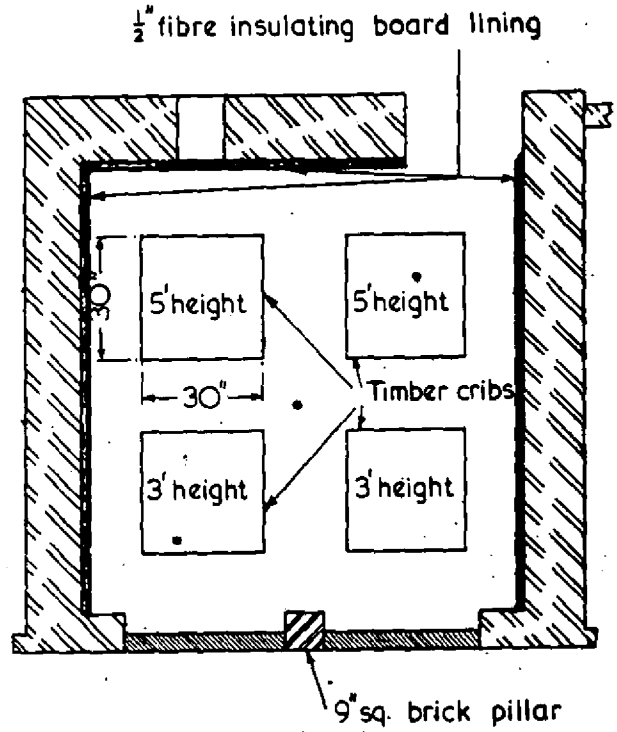


FIG. 1. FOUR STOREY BUILDING FOR FIRE TESTS



• Position of thermocouples 3in. below ceiling

FIG.2. LAYOUT OF TIMBER CRIBS IN THE FIRE CHAMBER

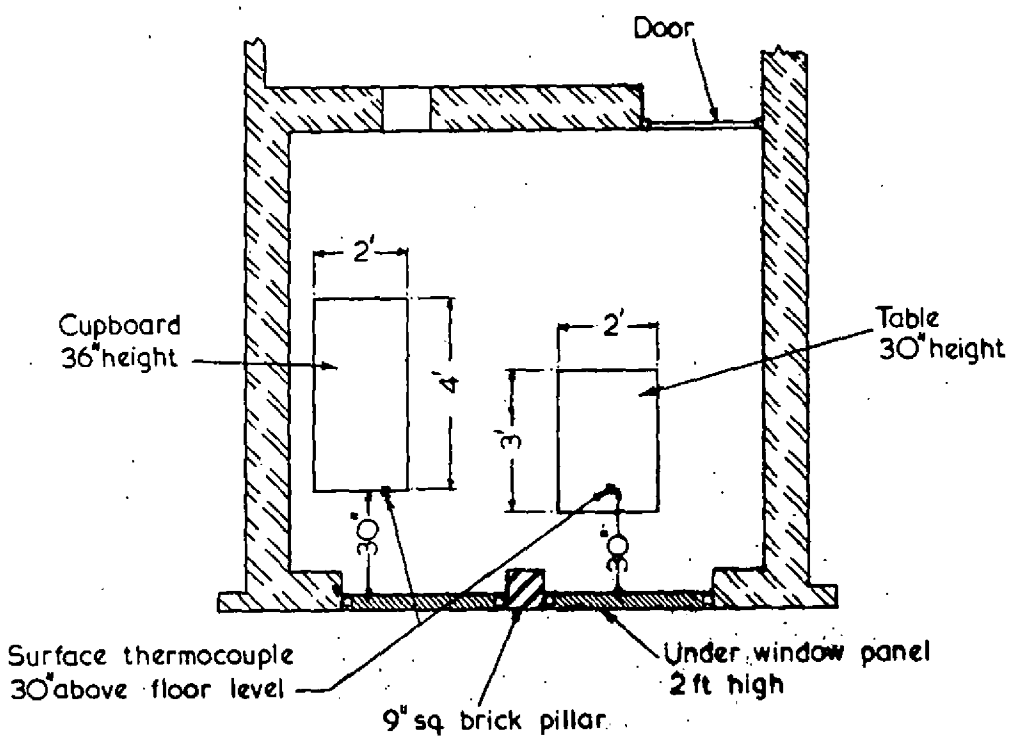


FIG.3. ARRANGEMENT OF FURNITURE AND THERMOCOUPLES IN FIRST FLOOR ROOM

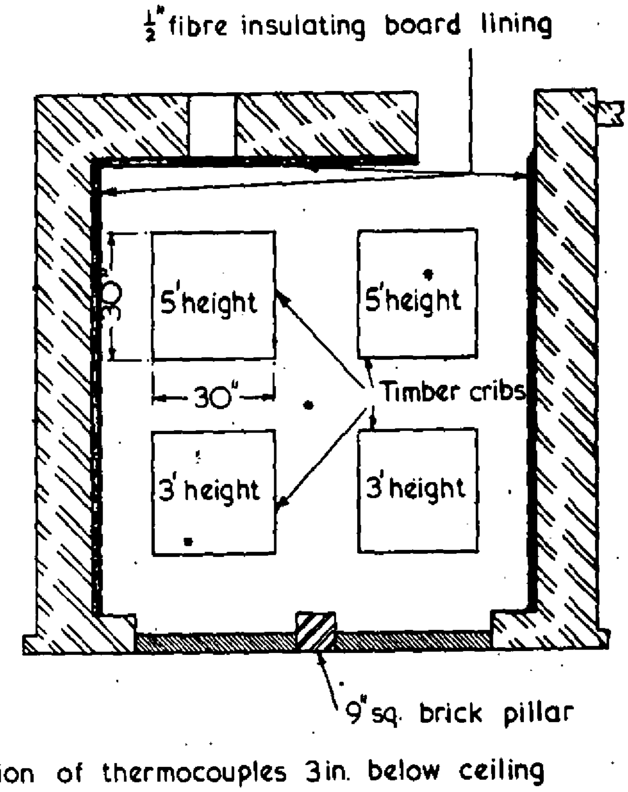


FIG.2. LAYOUT OF TIMBER CRIBS IN THE FIRE CHAMBER

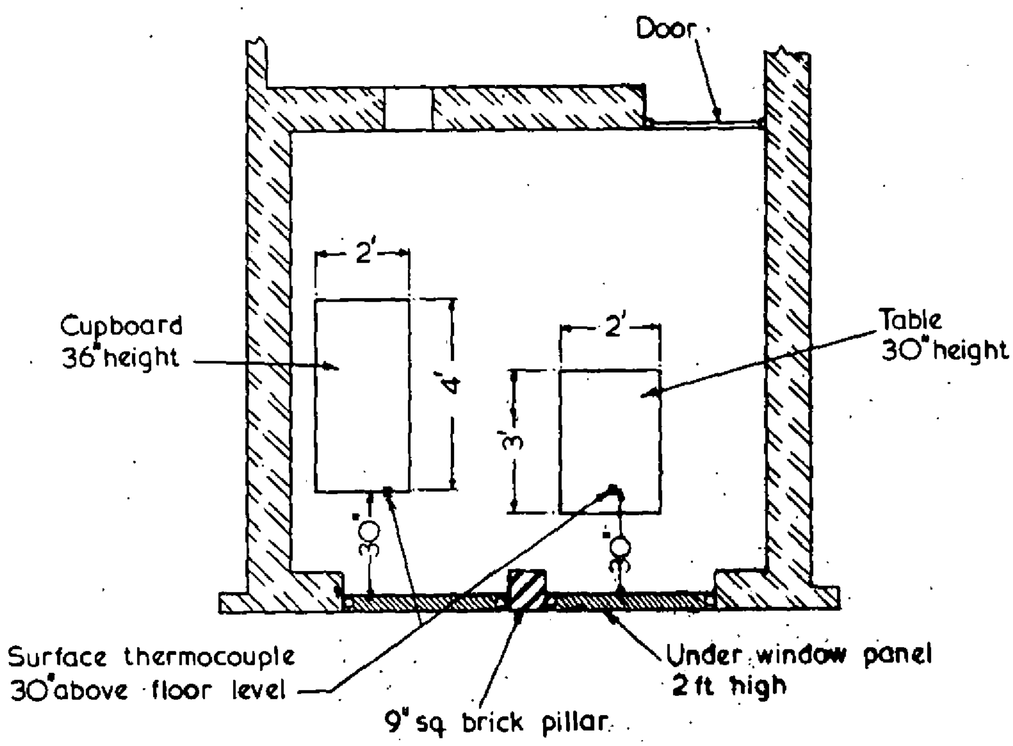


FIG.3. ARRANGEMENT OF FURNITURE AND THERMOCOUPLES IN FIRST FLOOR ROOM

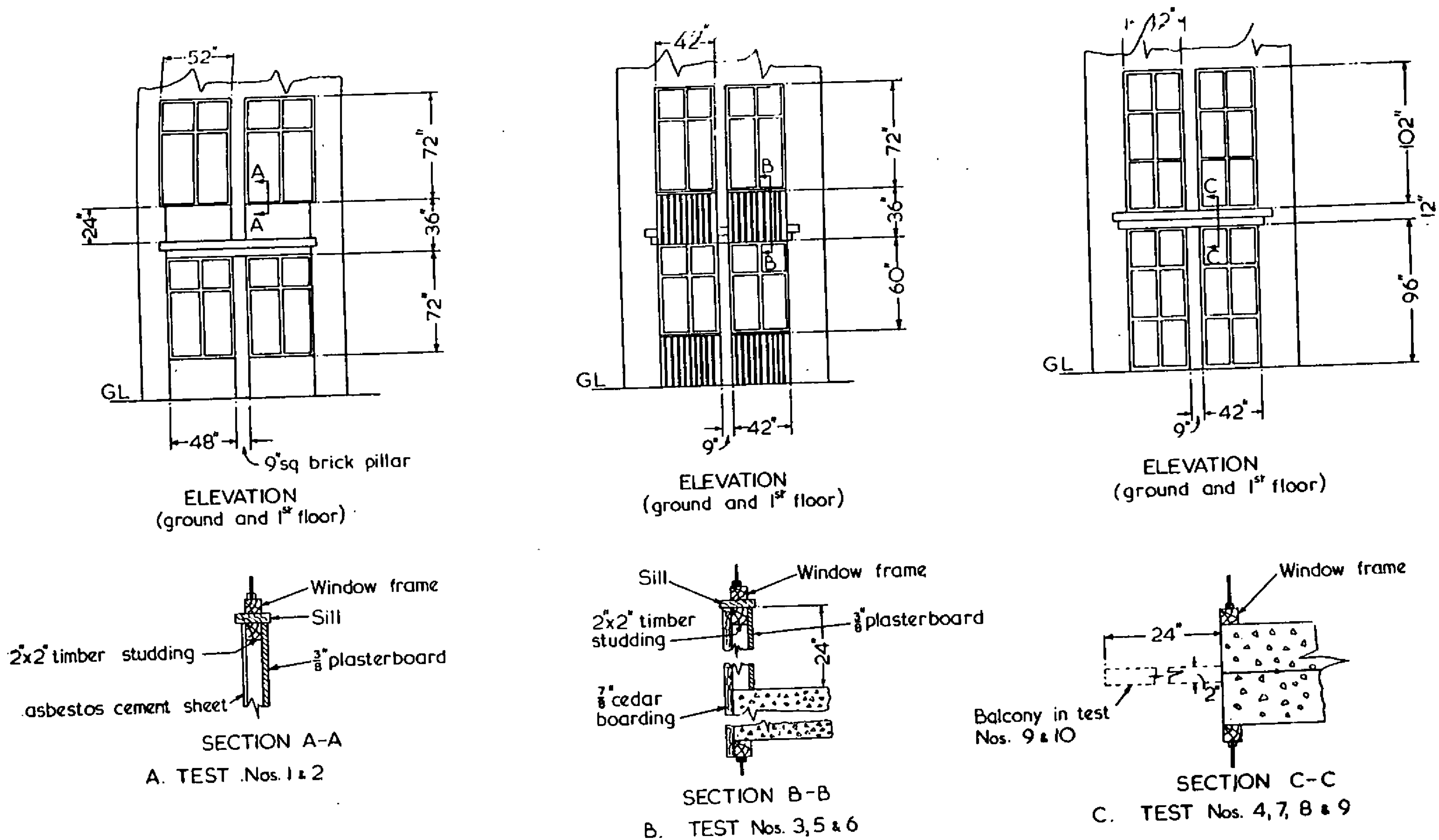


FIG. 4. ARRANGEMENT OF WINDOWS & UNDER WINDOW PANELS — TESTS 1-9

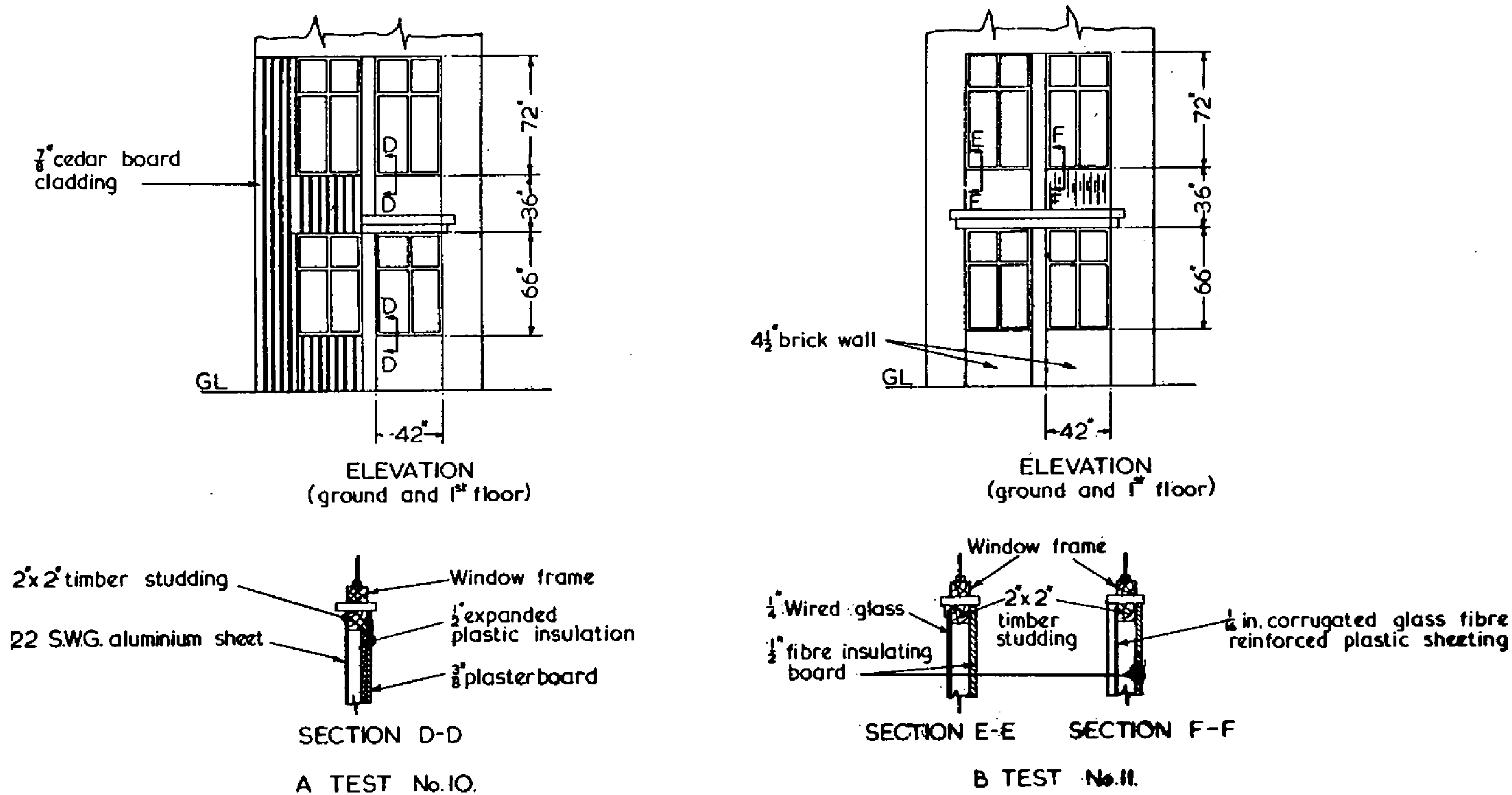


FIG.5. ARRANGEMENT OF WINDOWS & UNDER WINDOW PANELS — TESTS 10 & 11

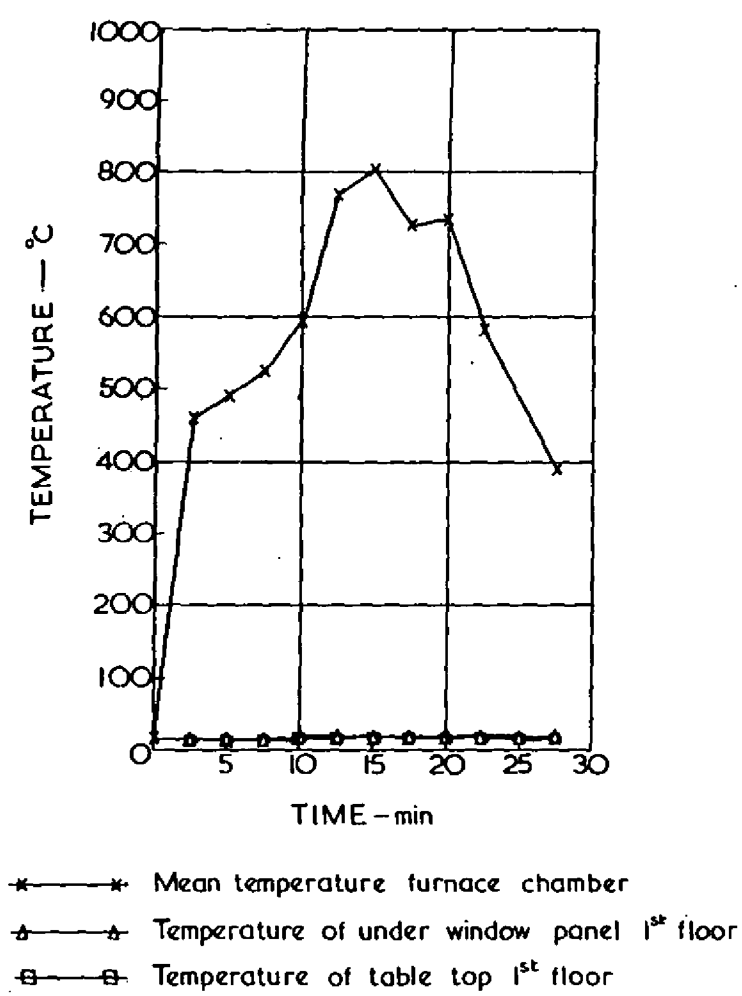


FIG. 6. TEMPERATURE CURVES TEST No. 1.

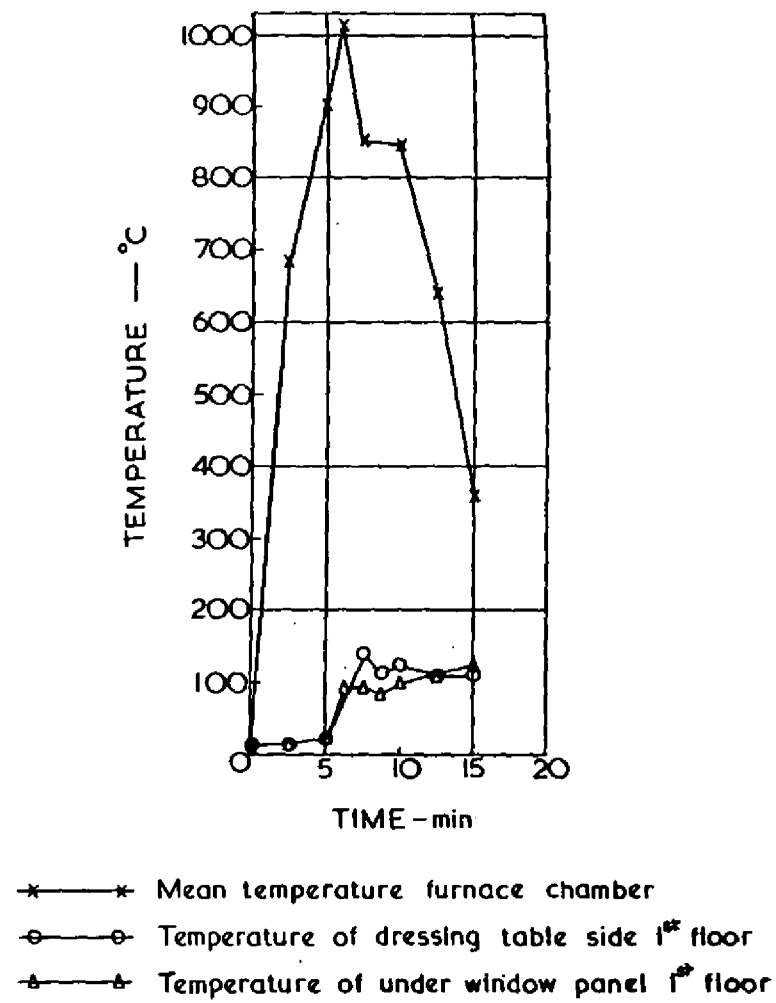


FIG. 7. TEMPERATURE CURVES TEST No. 2.

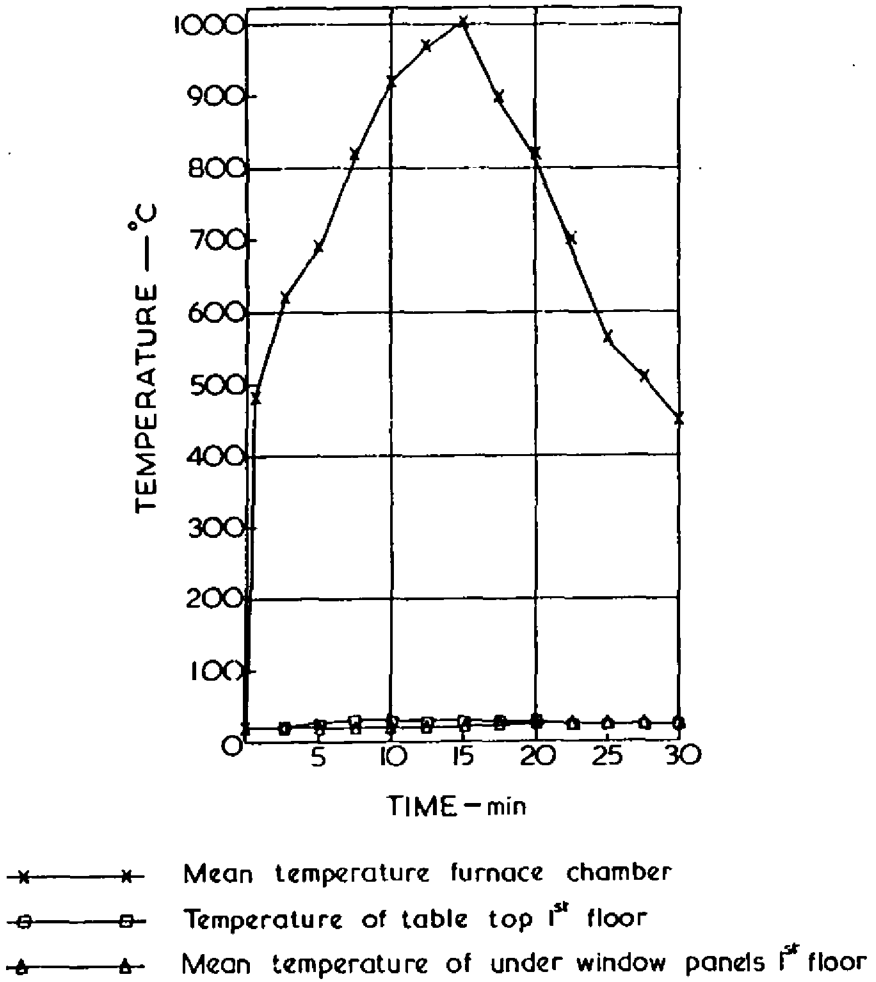


FIG. 8. TEMPERATURE CURVES TEST No. 3.

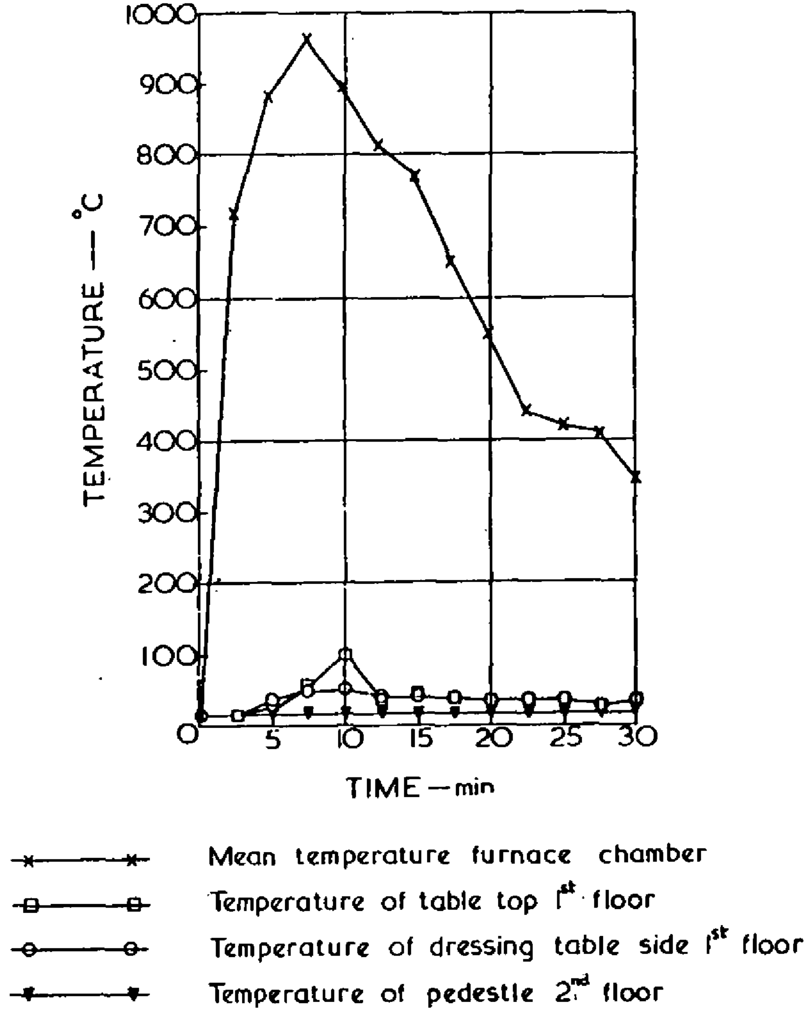
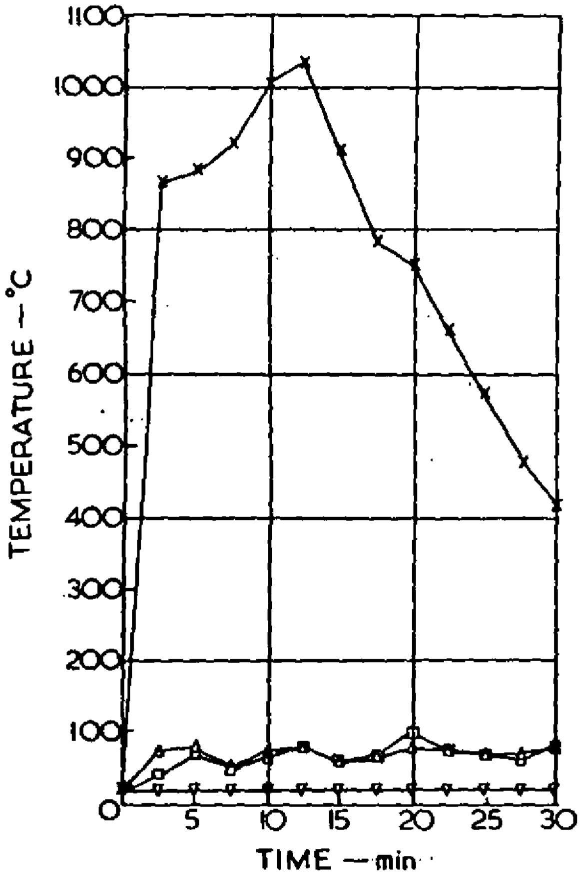


FIG. 9. TEMPERATURE CURVES TEST No. 4.



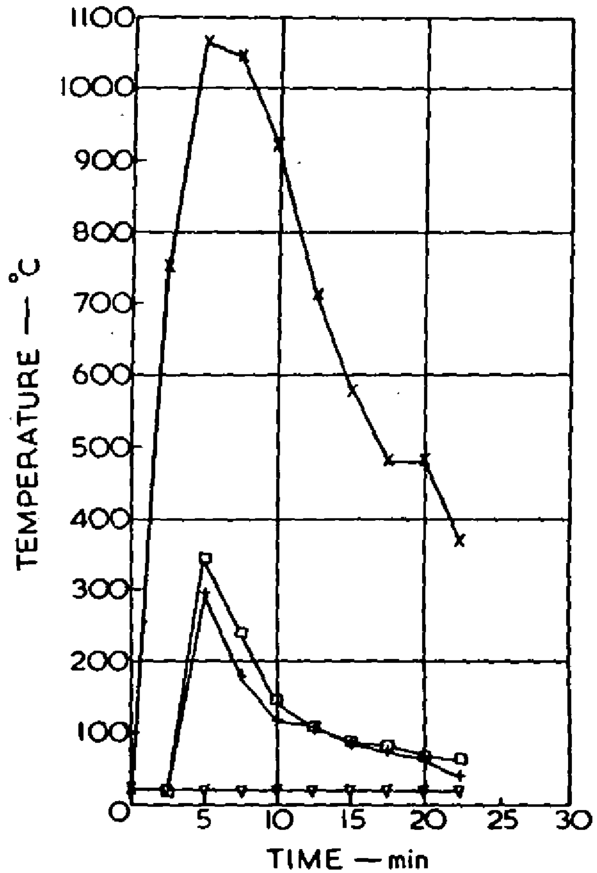
Mean temperature furnace chamber

Temperature of table top 1st floor

Temperature of inside face of under window panel 1st floor

Temperature of dressing table side 1st floor

FIG. 10. TEMPERATURE CURVES TEST No. 5 & 6



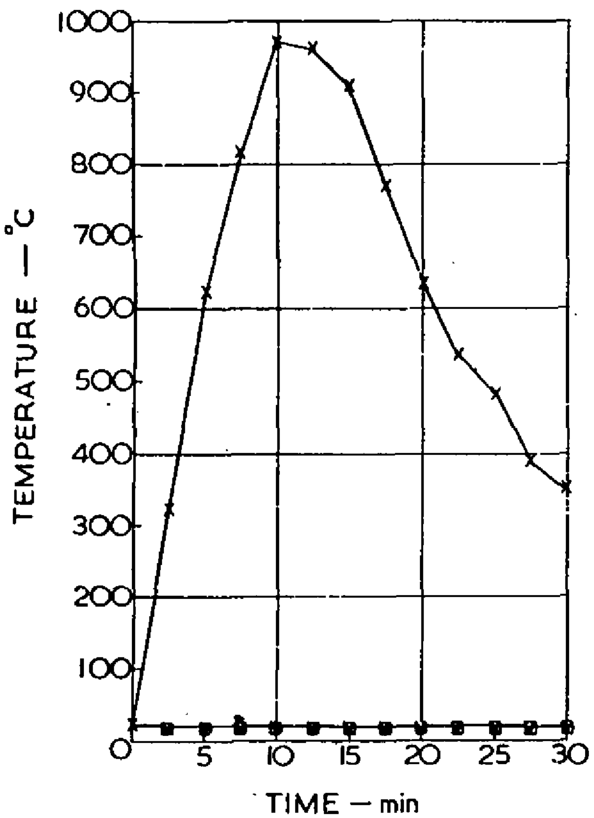
Mean temperature furnace chamber

Temperature of table top 1st floor

Temperature of timber floor 12" from window

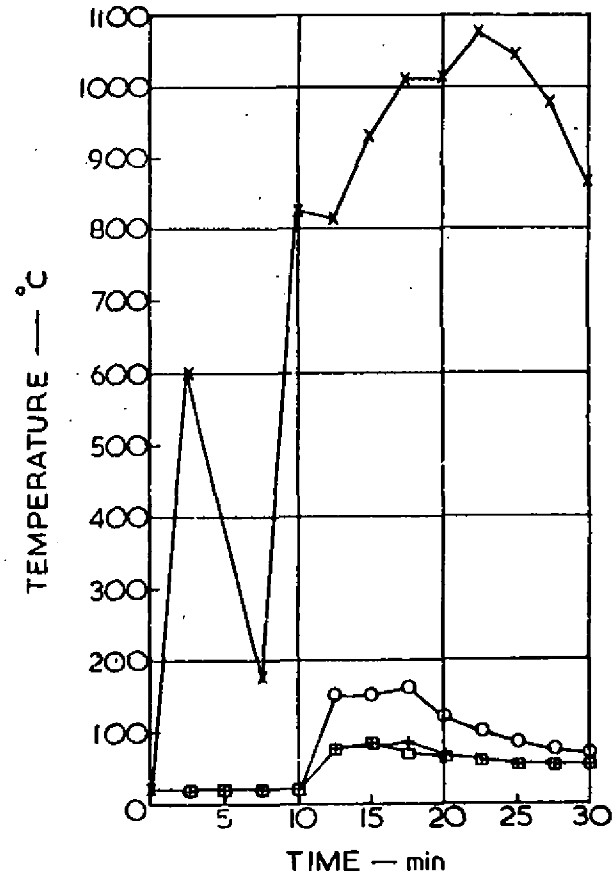
Temperature of dressing table side 1st floor

FIG. 11. TEMPERATURE CURVES TEST No. 7



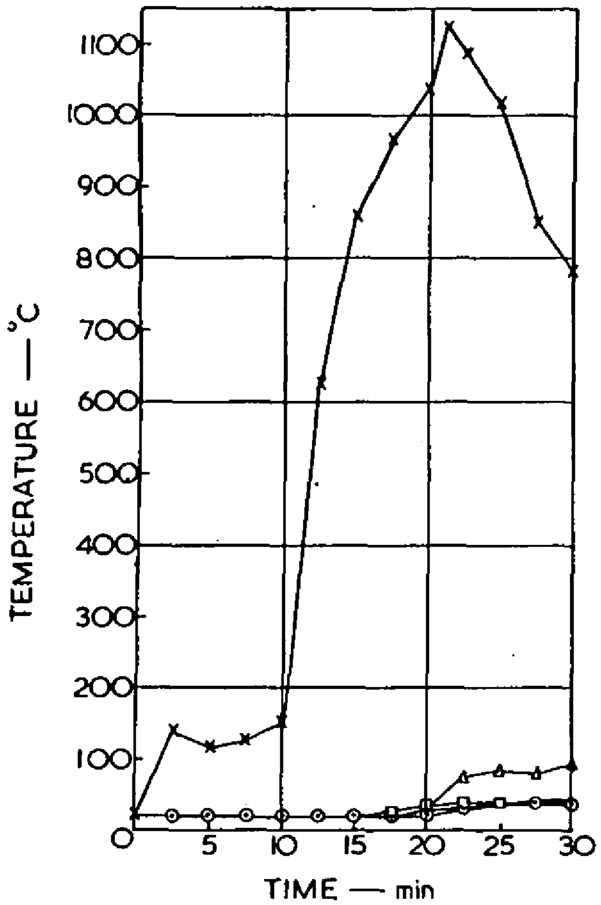
- ×——× Mean temperature furnace chamber
- ⊟——⊟ Temperature of table top 1st floor
- +——+ Temperature of timber floor 12" from window
- ▽——▽ Temperature of dressing table side 1st floor

FIG. 12 TEMPERATURE CURVES TEST No. 8.



- ×——× Mean temperature furnace chamber
- ⊖——⊖ Temperature of dressing table side 1st floor
- ⊟——⊟ Temperature of table top 1st floor
- +——+ Temperature of timber floor 12" from window

FIG. 13. TEMPERATURE CURVES TEST No. 9



Mean temperature furnace chamber

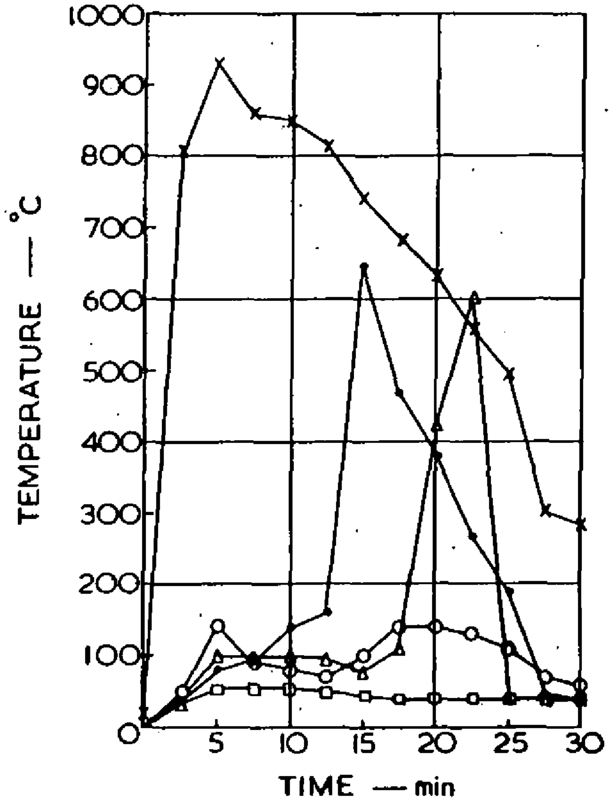
Temperature of inside face of under window panel 1st floor (aluminium faced panel)

Temperature of inside face of under window panel 1st floor (timber faced)

Temperature of table top 1st floor

Temperature of dressing table side 1st floor

FIG.14. TEMPERATURE CURVES TEST No.10.



Mean temperature furnace chamber

Temperature of inside face of under window panel 1st floor (plastic sheeting)

Temperature of inside face of under window panel 1st floor (wired glass)

Temperature of table top 1st floor

Temperature of dressing table side 1st floor

FIG.15. TEMPERATURE CURVES TEST No.11.

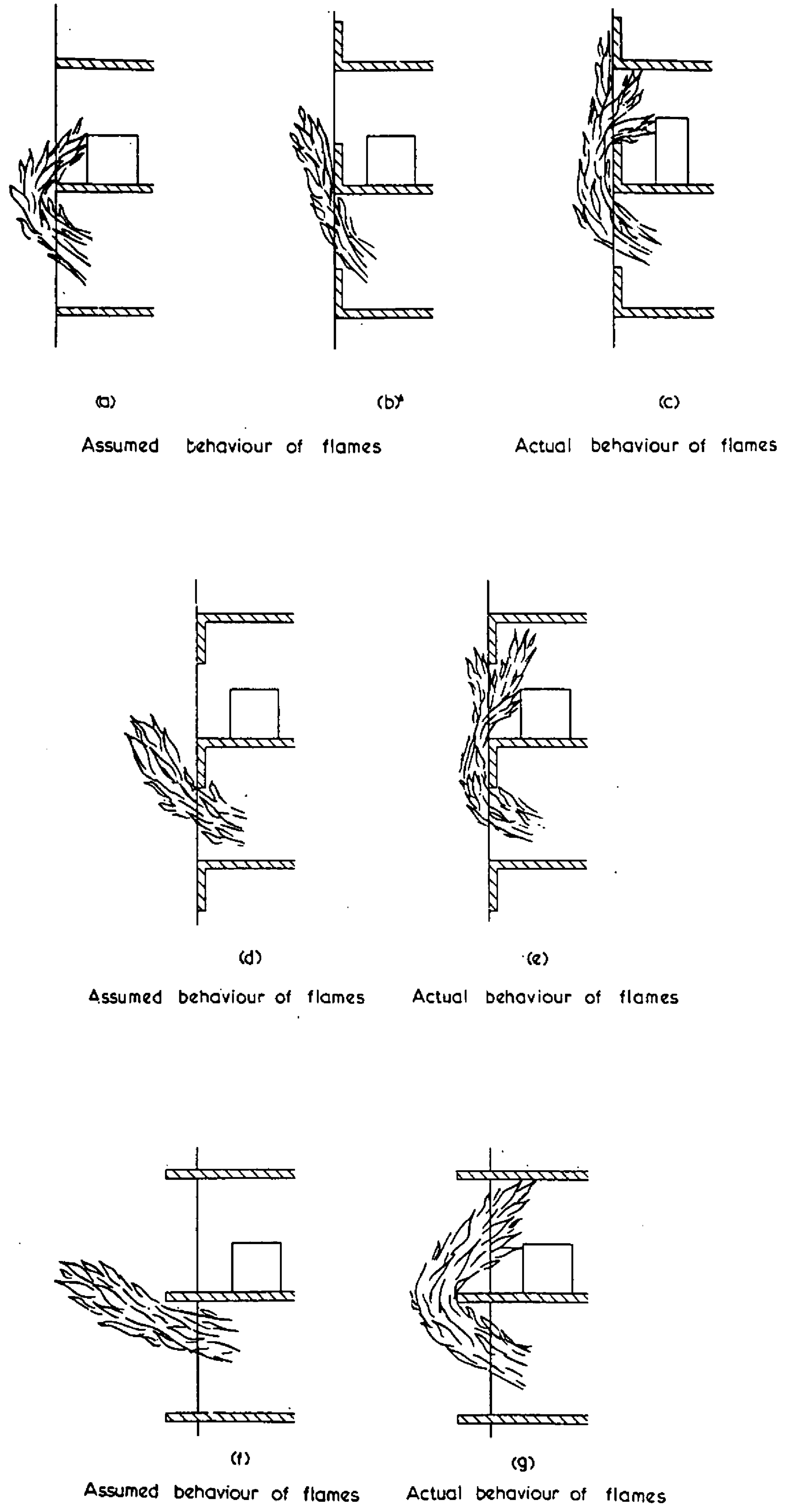
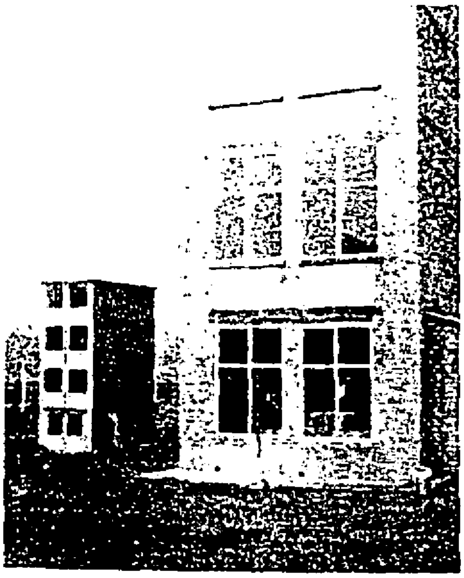


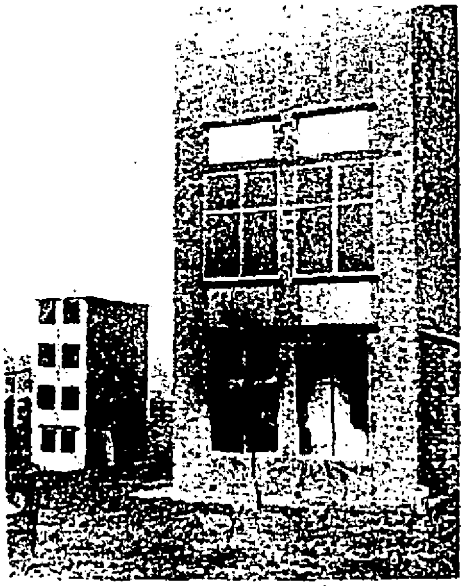
FIG. 16 ASSUMED AND ACTUAL SHAPES OF FLAMES

1/3680 F.R. 436

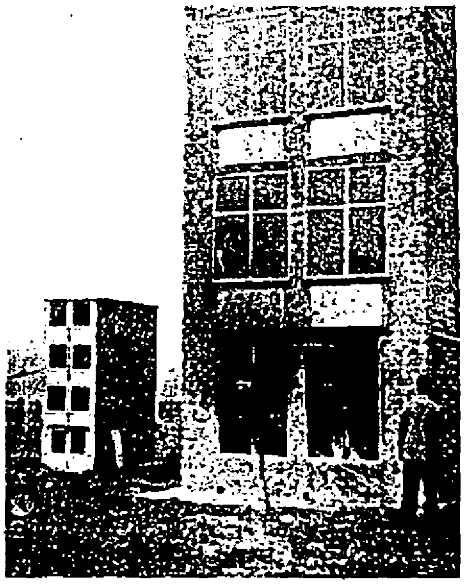


a. Start of fire

b. Emission of flames from ground floor room (12 min.)

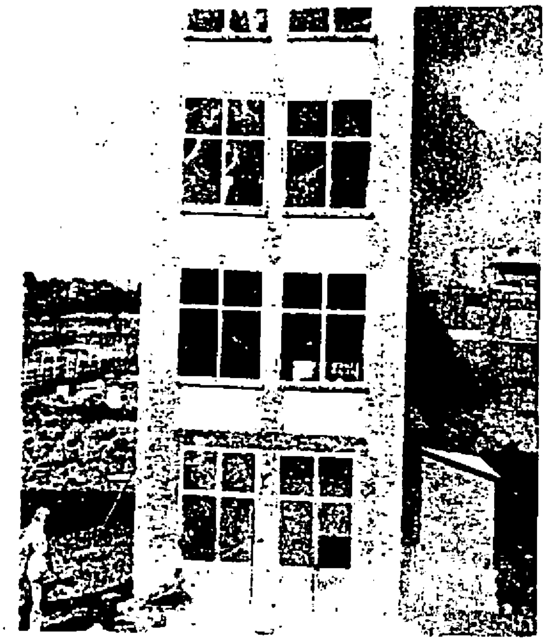


c. Fire burning in fire chamber (20 min.)



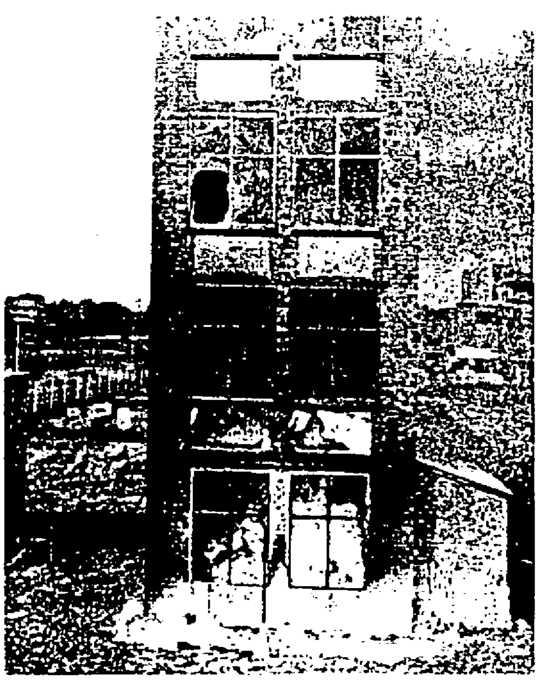
d. End of test (25 min.)

TEST N^o^. 1. A/C SHEETING AND PLASTERBOARD PANELS

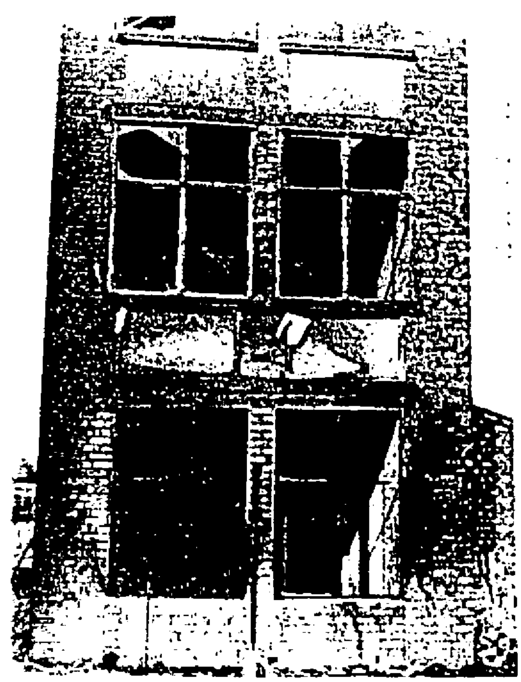


a. Start of fire

b. Wind fanning flame across face of building (7 min.)

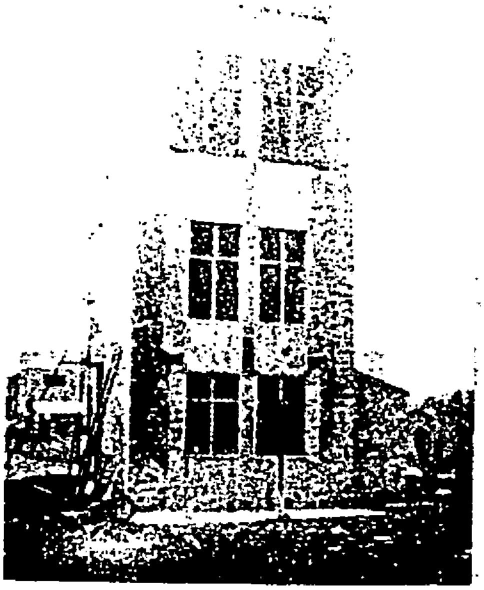


c. Near the end of fire (15min.)

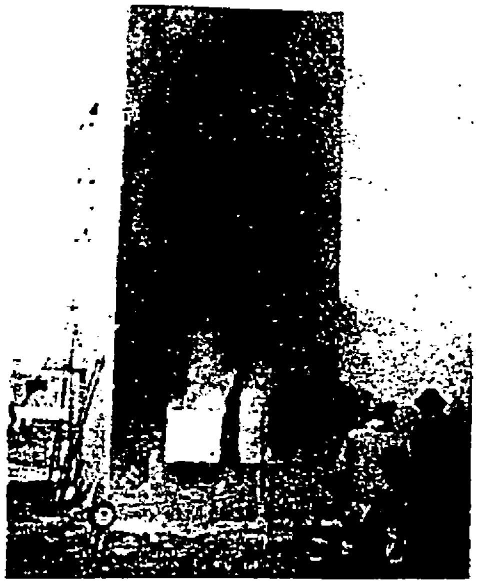


d. Close up of ground and first floor after the fire

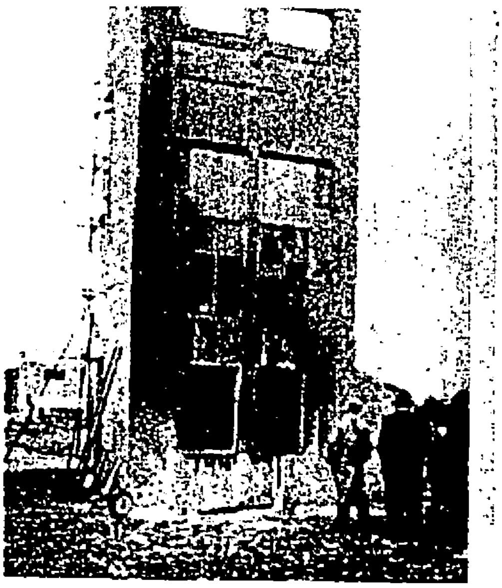
TEST N^{O}. 2. REPEAT OF TEST N^{O}. 1.



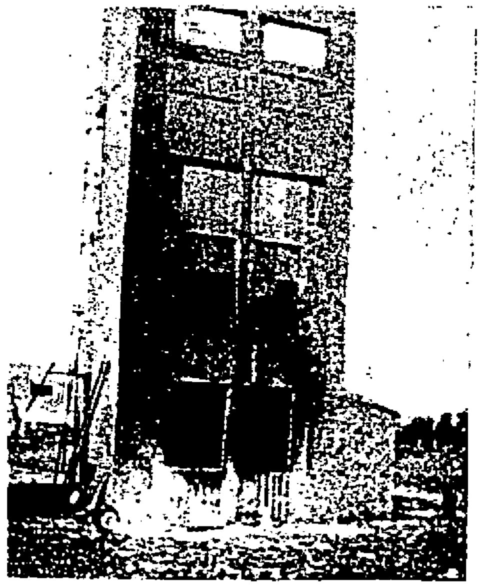
a. Start of fire



b. Flames issuing from the windows (10 min.)

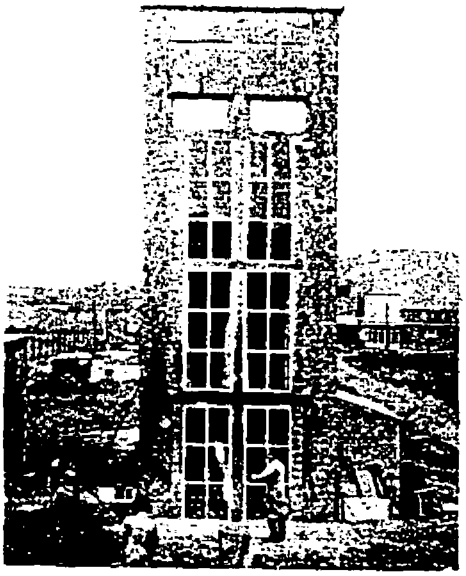


c. Penetration of fire through ground floor panels (18 min.)



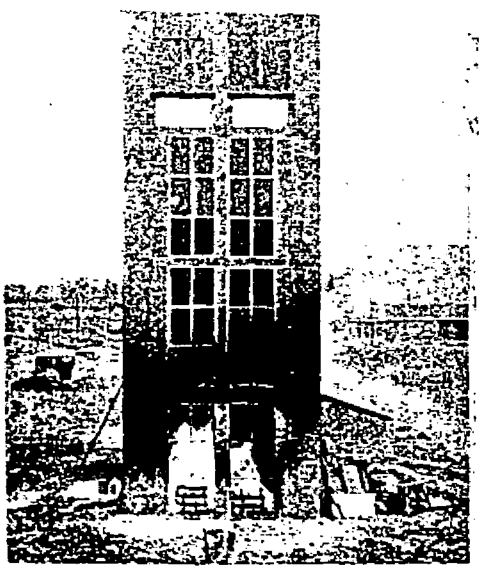
End of test (28 min.)

TEST N°. 3. TIMBER FACED PANELS

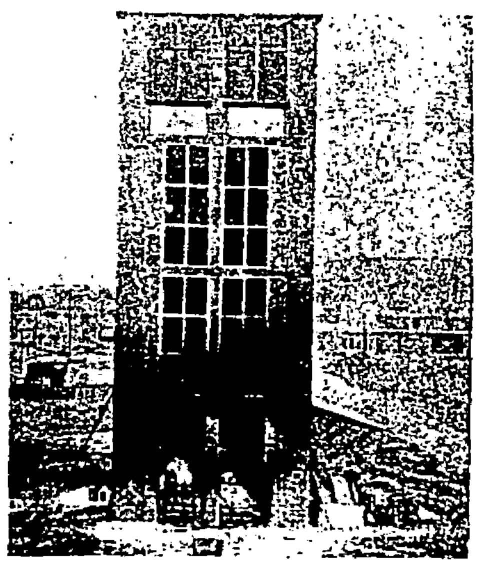


a. Start of fire

b. Effect of side wind on flames (5 min.)



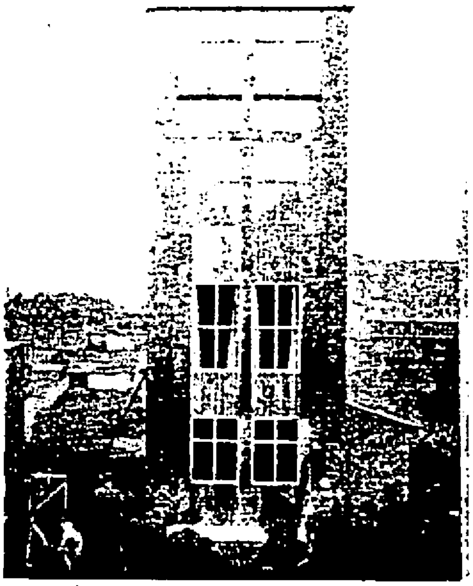
c. Fire burning inside the fire chamber (18 min.)



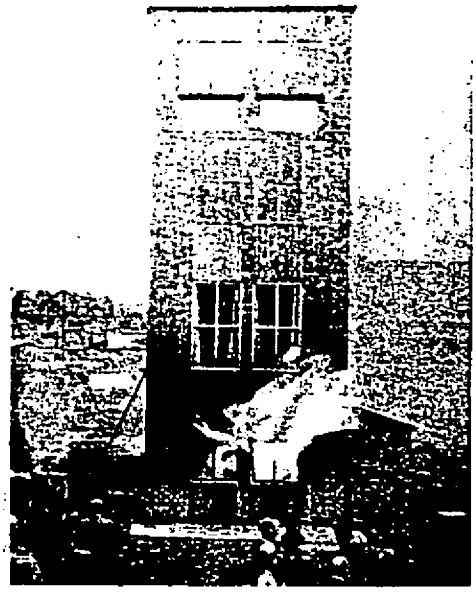
d. Near the end of test (20 min.)

TEST N°. 4. ROOM HEIGHT GLAZED WINDOWS

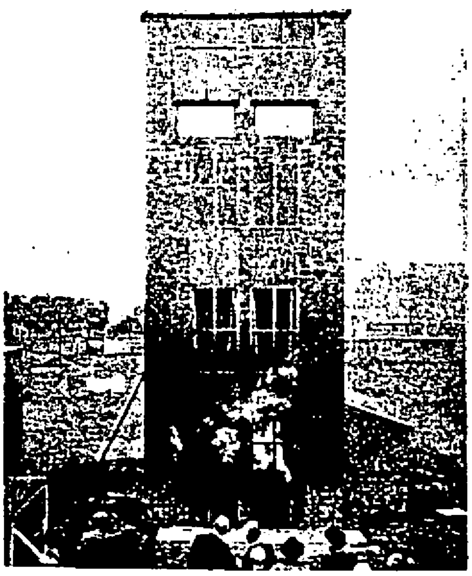
PLATE 4



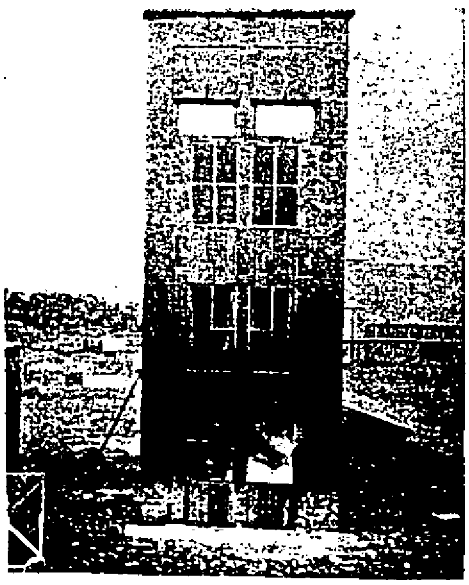
a. Start of test



b. Effect of cross-wind on the flames (5 min.)



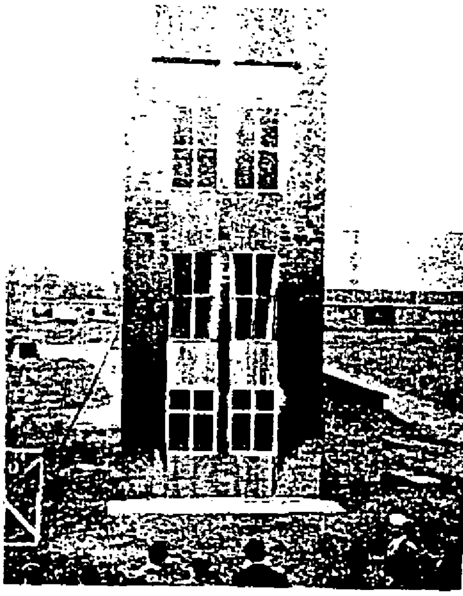
c. Ignition of cedar boarding with flames impinging on its surface (10 min.)



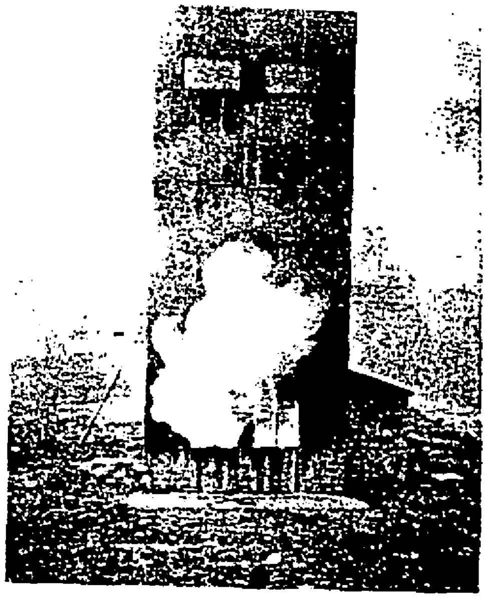
d. Fire penetrated ground floor panels (17 min.)

TEST N°. 5. REPEAT OF TEST N°. 3.

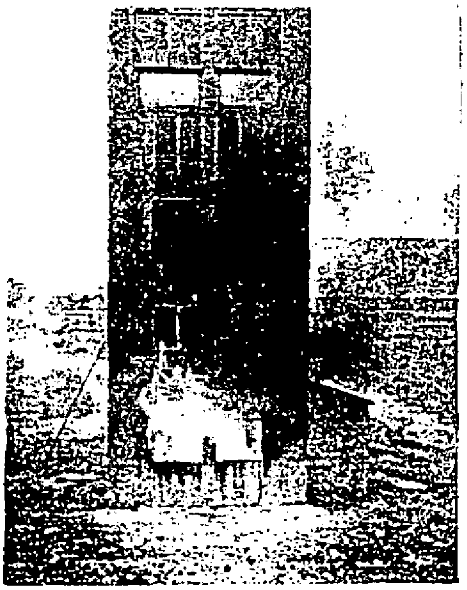
PLATE 5



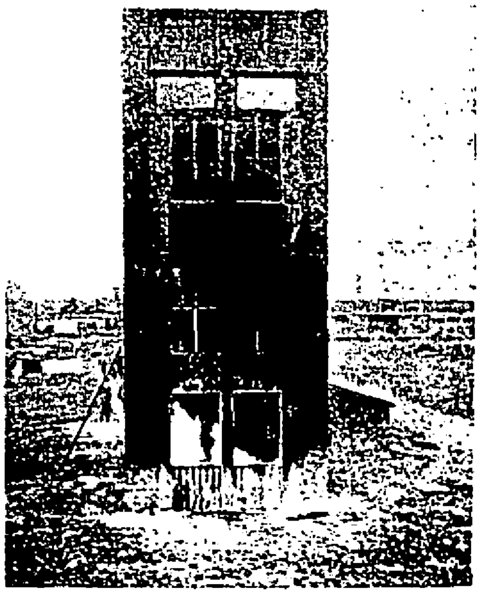
a. Start of fire



b. Flames covering first floor facade (5 min.)

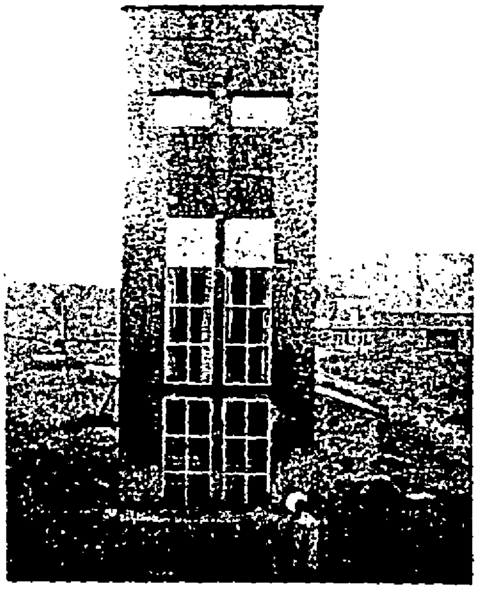


c. Ignition of a curtain (10 min.)



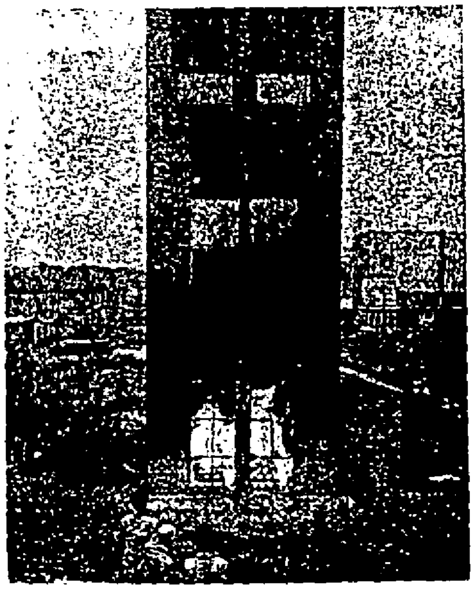
d. End of test (20 min.)

TEST No. 6. REPEAT OF TEST No. 3.



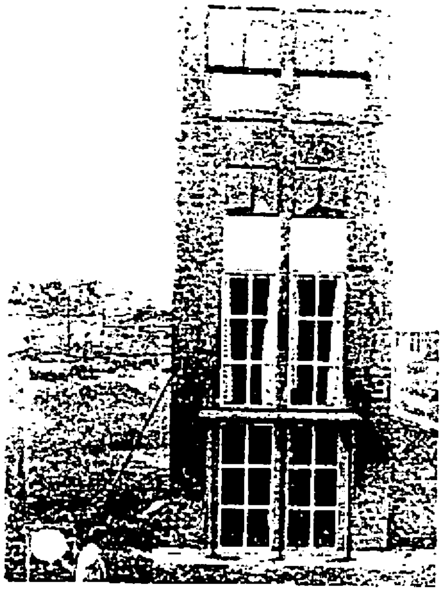
a. Before start of fire

b. Flames reach the 2nd floor level (4 min.)

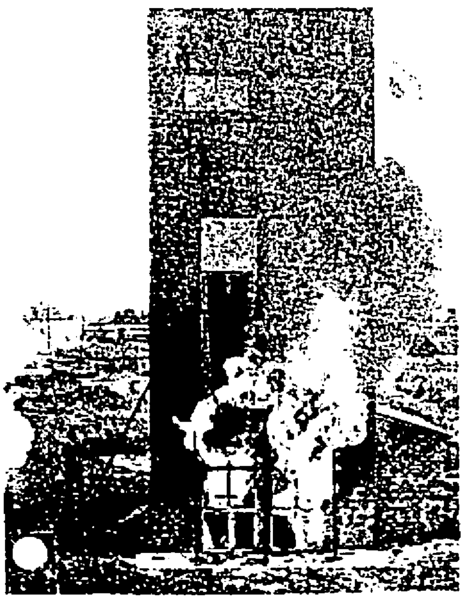


c. Fire burning inside the fire chamber (15 min.)

TEST No. 7. REPEAT OF TEST No. 4.

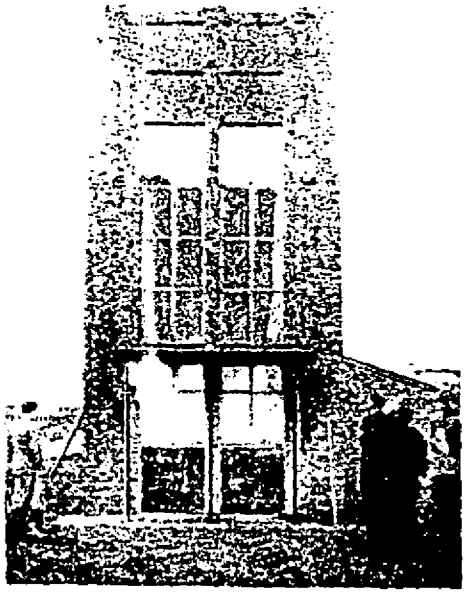


a. Before start of fire



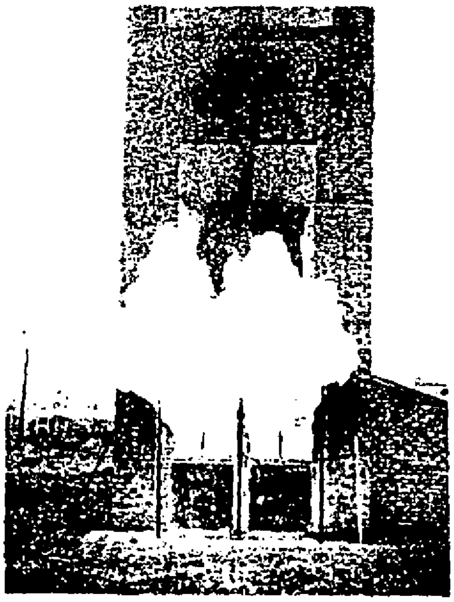
b. Flames issuing from ground floor (8 min.)

c. Side view showing curling of flames over balcony

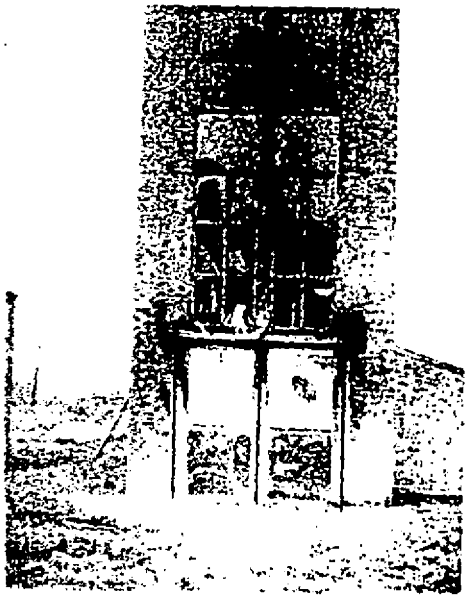


a. Flames commence to issue from ground floor (8 min.)

b. Flames covering first floor facade over the balcony (10 min.)

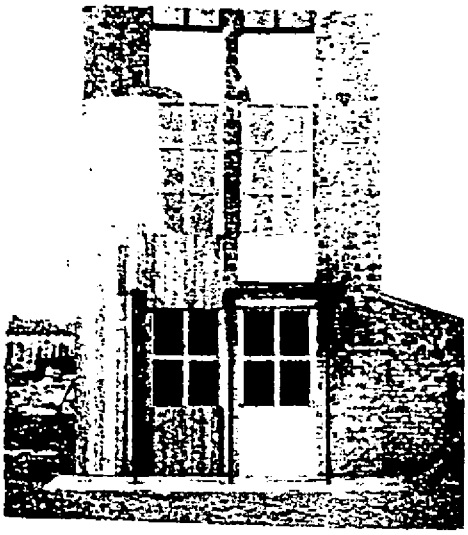


c. Ignition of a curtain (13 min.)



d. Near the end of fire (18 min.)

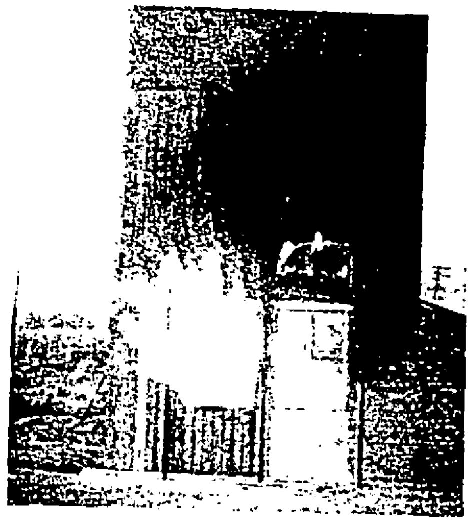
TEST N°. 9. REPEAT OF ...



a. Start of fire

b. Flames issuing from ground floor (13 min.)

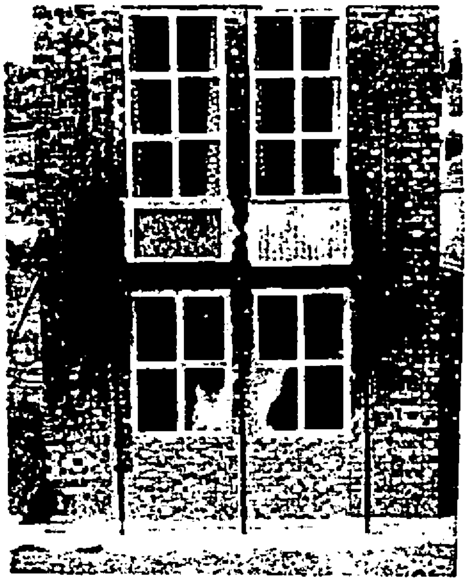
c. Impinging flames ignite cedar boarding (18 min.)



d. Aluminium facing on first floor melts (24 min.)

e. Penetration of fire on ground floor through aluminium face panel (29½ min.)

f. Penetration of fire on ground floor through timber clad panel



a. Start of fire

b. Ignition of plastic faced panel (2 min.)

c. Plastic facing continues to burn without assistance from fire (4 min.)

d. Near the end of test (12 min.)

TEST NO. 11 [illegible]