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PRESSURIZATION AS A MEANS OF CONTROLLING THE MOVEMENT OF SMOKE AND TOXIC GASES ON ESCAPE ROUTES

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SUMMARY

Tests are described which investigate the practicability of pressurization as a means of controlling the movement of smoke and toxic gases produced by fire on the escape routes from buildings.

It is concluded that a practical system can be designed and that the pressures necessary to override those produced by a fire or by adverse weather conditions can be achieved. The use of a pressurization system is shown to improve the fire-resistance of doors and the importance of the position of door gaps is discussed.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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Introduction

Smoke and toxic gases produced by fires in buildings are probably a more serious hazard to personal safety than the heat produced. Inability to pass along a corridor or down a staircase or to find an exit which leads to safety probably accounts for a high proportion of the lives lost in fires.

It is clear that great importance must be and is attached to effective measures for keeping escape routes clear of smoke, particularly in buildings in which large numbers of people work or congregate and the present very great increase in high rise office and domestic buildings has served to intensify the problem.

An escape path normally takes the form of a corridor leading from the office or flat (in which the fire could occur) to a staircase and in some circumstances a lobby is interposed between them. The purpose of the lobby is to prevent smoke passing from the corridor to the staircase and to achieve this it is common practice to ventilate it with permanent openings to the outside air. Where no lobby is provided then the staircase itself may need to be ventilated to the open air.

Such an arrangement however has several disadvantages. The occupants complain of draughts and rain penetration, the architect complains that the need to site the lobby or staircase on an external wall imposes restrictions on the design of the building, and most important the effectiveness of such openings is a strong function of weather conditions and is therefore unpredictable.

In the search for other more positive means of keeping escape routes clear it was suggested that providing an excess air pressure in the lobby or stair-

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case might prevent smoke entering. A test[1] in a new store showed that this ideas was promising and the investigation described here is designed to show the practicability of this suggestion.

Experimental arrangement

The experiments were carried out in a four-storey tower building, details of which are shown in Fig.1. The staircase, which in these tests represented the escape route, could be pressurized by the use of two fans connected to a duct system so that air could be introduced into the staircase through an input grille at each floor level. These could be used individually or both at the same time.

The maximum rate of air input into the staircase using the fans installed was 41 m^3/min (1450 ft^3/min). Each fan was driven by an electric motor of $^1/_5$ h.p. rating.

The volume of the staircase was 66 m^3 (2340 ft^3). Two doors at each of the four floors communicated with it. On the ground floor the room marked F on the plan in Fig.1 was used as the smoke chamber, smoke being generated either by a wood crib fire or by a smoke generator.

Pressure and temperature measurements could be made both in the fire chamber and at several points on the lower flight of the staircase.

When a wood crib fire was used to generate smoke, the fire load density used was 30 kg/m^2 (6.2 lb/ft^2) and the corresponding value of fire load per unit ventilation opening was 220 kg/m^2 (46 lb/ft^2)

Pressure developed in the staircase by fan installation

The pressure developed in an enclosure to which air is supplied at a steady rate and from which it is leaking at the same steady rate can be calculated using the relation:

$$F = 17.9\, A \sqrt{P}$$

where F is the rate of flow in cubic fee per minute

A is the total cross-sectional area of the leakage crack in square inches

and P is the pressure differential developed in inches water gauge.

When both fans were delivering their full output, which was monitored by air flow measurements at each input grille, the air flow into the staircase was 41 m^3/min (1450 ft^3/min), the measured excess pressure just inside the door between the staircase and the fire chamber was 5 mm (0.2 in) w.g. and using the relation above, this corresponds to a total leakage area of 1170 cm^2 (181 in^2).

Leading out of the staircase enclosure were eight doors and four windows. Assuming that a well-fitting door has a leakage area of 129 cm^2 (20 in^2) then the average leakage area per window, which were all tightly shut, was 32.2 cm^2 (5 in^2). Thus the air input per door to develop a pressure of 5 mm (0.2 in) w.g. in the staircase enclosure for these experiments was 4.6 m^3/min (160 ft^3/min).

Pressure developed by a fire

In the course of a fire test in which the staircase was not pressurized it was possible to make measurements of the pressure difference between the fire chamber and the staircase at the top of the door. At the same time temperature measurements were taken in the fire chamber.

The experimental results of pressure difference at the top crack of the door plotted against the temperature of the fire chamber are shown in Fig.2.

In a recent paper McGuire[2] has shown that the position of the neutral plane in the room (i.e. the plane for which the pressure on both sides of the door is the same) can be calculated using the relationship:

$$\frac{L_2}{L_1} = \frac{A_1^2}{A_2^2} \times \frac{T}{T_o}$$

where L_1 = distance of neutral plane from bottom of door

L_2 = " " " " " top of door

A_1 = area of crack at bottom of door

A_2 = area of crack at top of door

T = temperature in fire chamber °K

and T_o = temperature in staircase well °K.

When the position of neutral plane for each temperature has been located the pressure differential (P) at the top of the door can be determined from:

$$P = L_2 g (\rho_0 - \rho)$$

where ρ_0 = density of air at temperature T_0 °K

and ρ = " " " " " T °K

Using this method the pressure at the top of the door has been calculated for the present case and the values are shown in Fig.2.

The difference between the two curves at the top can be accounted for by the fact that at this stage of the fire test the edge of the door was burning away at the top and consequently the top gap (A_2) was increasing, so causing the neutral plane to rise, the consequent decrease in L_2 causing the rate of increase of pressure to decrease.

The calculated value of P assumes a constant value for A_2 throughout the test.

The effect of position of opening (crackage) in door

It is clear from the relations quoted in the previous section that the lower the position of the neutral plane, the larger the value of the pressure at the top of the door which normally acts to expel the smoke from the fire chamber onto the staircase.

Among the factors which determine the position of the neutral plane are the areas of the cracks at the top and bottom of the door and an examination of the relations given earlier shows that if the gap at the top or bottom of the door is increased the neutral plane will always move towards the gap which is increased.

It follows therefore, that when the gap at the bottom of a door is increased the amount of smoke coming through the top crack of the door will also increase, since the neutral plane will move downwards (towards the increased gap) and the pressure acting to expel the smoke from the top gap will be increased.

An increase in the gap at the top of the door will decrease the pressure acting to expel the smoke but since there is now a larger gap for the smoke the total volume of smoke passing may not change appreciably.

This effect is shown diagrammatically in Fig.3 and in the course of the experiments described in this paper observations were made which confirmed the importance of the bottom gap in controlling the movement of smoke onto the staircase (Fig.4).

When pressurization is in use this effect becomes more important. If the neutral plane is defined as the horizontal plane at which the pressure in the fire compartment is equal to the pressure in the staircase enclosure, then pressurization acts to artificially raise this plane to a position above the top of the door. Under these circumstances an increase in the gap at the bottom of the door may bring the neutral plane downwards to a position below the top crack of the door and thus allow smoke to pass through this crack. A similar increase in the gap at the top would not move the neutral plane so far and consequently smoke would not pass the door even though there was a large crack at this high level.

Pressurization as a practical way of controlling smoke

We have already shown that the pressure developed at the top of a door by a fire is always below 0.75 mm (0.03 in) w.g. but in designing a pressurization system it is necessary to note the pressure differential likely to be produced in a building by adverse weather conditions.

In the course of the experiments described in this paper a variety of weather conditions was encountered but during the six months concerned (July to December) the pressure differential due to external wind never exceeded 1.25 mm (0.05 in) w.g. This agrees with the recent work of Jackman and den Ouden[3] who reported that the pressure differentials across a door between an office and corridor in a ten-storey building with a 32 km/h (20 mile/h) wind outside were of the order 0.25-0.5 mm (0.01-0.02 in) w.g.

It would seem that if pressurization to a pressure differential of 2.5 mm to 5.0 m (0.1 to 0.2 in) w.g. were achieved then this would easily override any pressures likely to be encountered due to adverse weather conditions.

Using the relation already cited and assuming that the area of crack round a normal single leaf door is 129 cm^2 (20 in^2) then an air input of 3.2 m^3/min (113 ft^3/min) per door would be needed to produce a pressure differential of 2.5 mm (0.1 in) w.g. or 4.6 m^3/min (160 ft^3/min) per door to produce a 5.0 mm (0.2 in) w.g. pressure differential. These figures assume that the only leakage path out of the pressurized enclosure is via the doors. Where windows or other leakage paths are also present, the total air input will need to be increased in order to take account of them.

In very tall buildings an additional factor which must be considered is the so called 'chimney effect' in a long vertical shaft due to the temperature difference between the inside and outside air. The pressure differential due to this effect amounts to approximately 0.24 mm (0.01 in) w.g. per storey height of 3 m (10 ft) for a 20 degC temperature difference between the inside and outside of the building.

This need not be regarded as a complication however. If the building in which it is proposed to use a pressurization system is five storeys or less then a system designed to give an excess pressure of at least 2.5 mm (0.1 in) w.g. will still override any pressure differential caused by the chimney effect. For buildings which are taller than five storeys, then the staircase enclosure can either be broken into sections of not more than 15.25 m (50 ft) height by placing a door on every fifth landing, or the smoke can be prevented from entering the staircase by the use of a pressurized lobby interposed between the staircase and the accommodation at each floor. Such smoke lobbies would, in fact, enable pressurization control to be used throughout a large building with the use of relatively small fans.

Fire tests used to test the effectiveness of pressurization

At the conclusion of the programme of work on which this paper is based, two fire tests were held to test the effectiveness of pressurization as a means of smoke control.

The fire tests were carried out in the four-storey building already described and the room marked F in Fig.1 was used as the fire chamber. In each a fire load density of 30 kg/m^2 (6.2 lb/ft^2) was used and a '$\frac{1}{2}$-hour fire-check door' was fitted between the fire chamber and the staircase, the rebates and clearances between the frame and door all being normal for this type of door.

In the first test no pressurization was used in the staircase enclosure and the fire was allowed to burn out with the door between the fire chamber and staircase shut. Smoke penetrated the staircase after a very few minutes and 11 min after the fire started it was completely smoke-logged and would have been unusable. In 18 min the door started to flame on the staircase side and in 20 min the fire had penetrated into the staircase in which the temperature rose rapidly to an untenable degree. In 25 min the door had completely collapsed.

For the second test the staircase enclosure was pressurized to an excess pressure of 5 mm (0.2 in) w.g. but otherwise the same conditions as used in the first test obtained (fire load density 30 kg/m^2 (6.2 lb/ft^2) and a $\frac{1}{2}$-hour fire check door).

In this second test no smoke penetrated to the staircase during the whole of the 50 min for which the test was continued. No excessive temperatures were measured on the staircase during this period and although the edge of the door burnt away so that the crack was in fact increasing during the test, nevertheless there was no fire penetration to the staircase during this 50 min.

The temperature and smoke observations for the two tests are given in Figs 5 and 6 and Plate 1 shows the condition of the door of the fire chamber at the conclusion of test 2, i.e. when the staircase enclosure was pressurized.

Conclusions

(1) A pressurization system can be used to control smoke on escape routes and only a relatively small fan installation would be required.

(2) Such a system can override the pressures developed in a fire and those developed by adverse weather conditions.

(3) In addition to controlling smoke, a pressurization system also increased the fire-resistance time for doors. In the tests described a two-fold improvement was obtained, 25 min being increased to 50 min.

(4) Openings in the bottom of a door can increase the amount of smoke which passes through the top of it.

Acknowledgments

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(3) JACKMAN, P. J. and den OUDEN H. Ph.L. Natural ventilation of tall office buildings. Paper delivered at the Symposium of the Institution of Heating and Ventilating Engineers, Feb. 29th 1968.

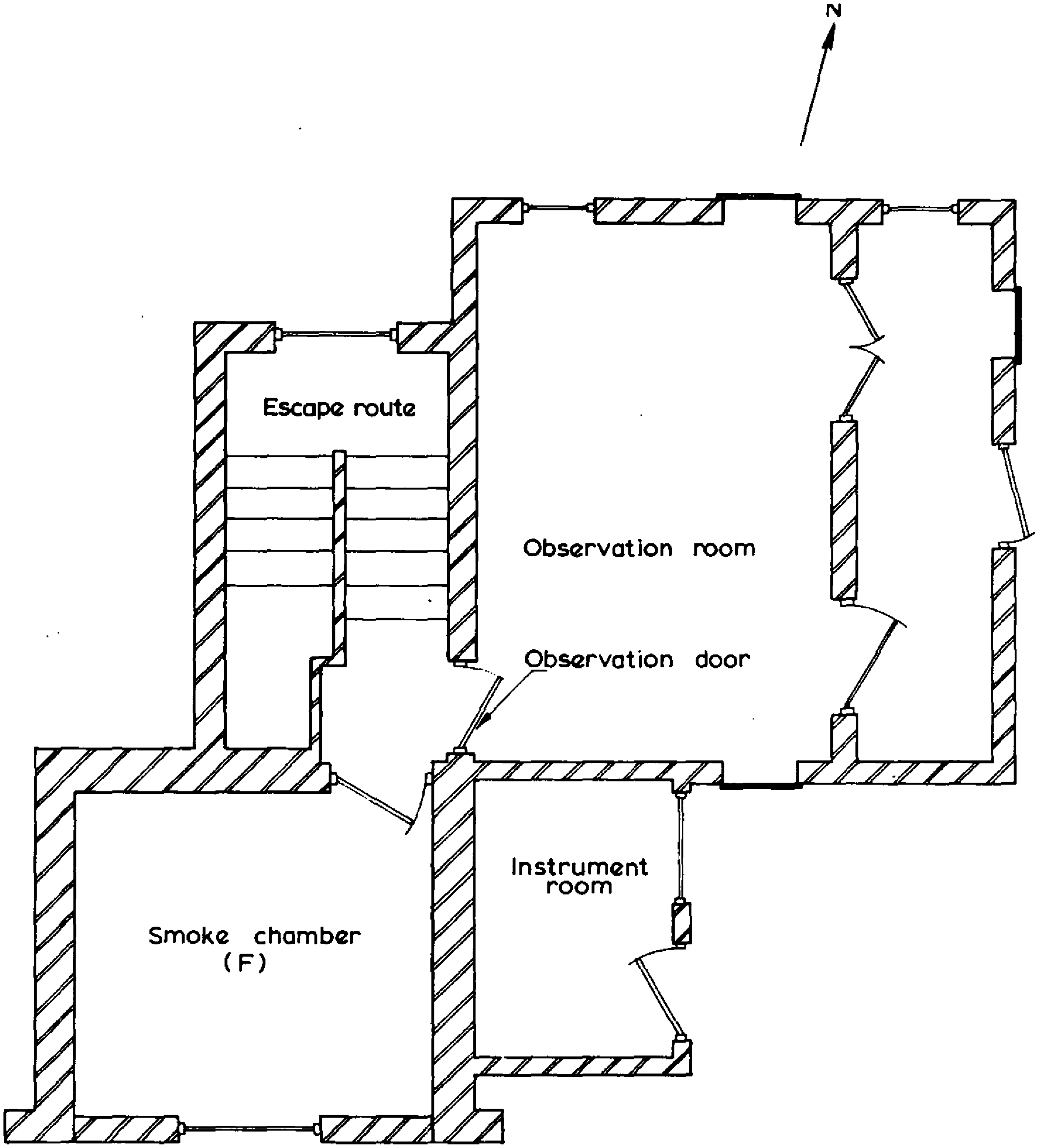

FIG. 1. GROUND FLOOR PLAN OF TEST BUILDING

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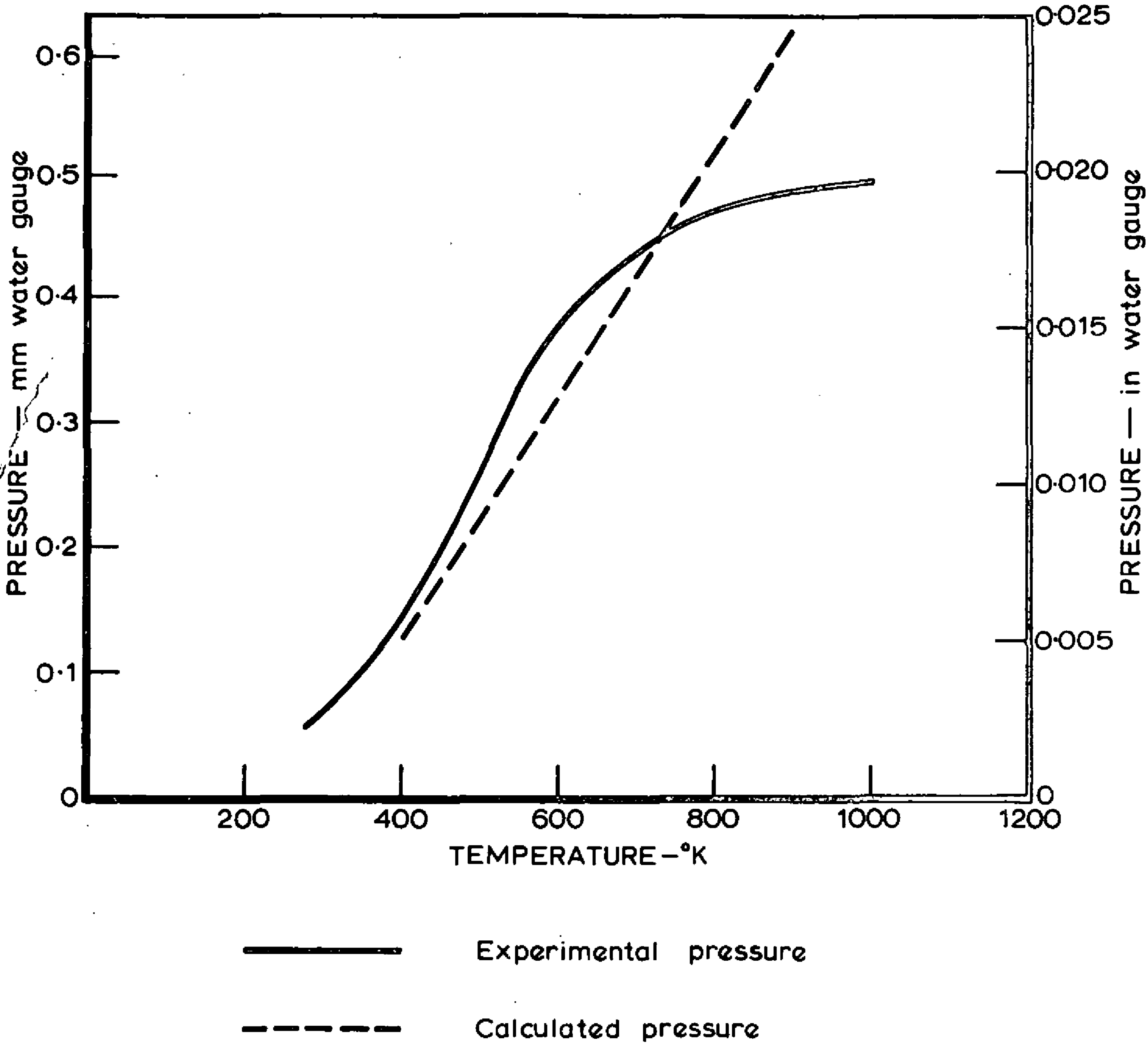

FIG. 2. PRESSURE DEVELOPED BY A FIRE

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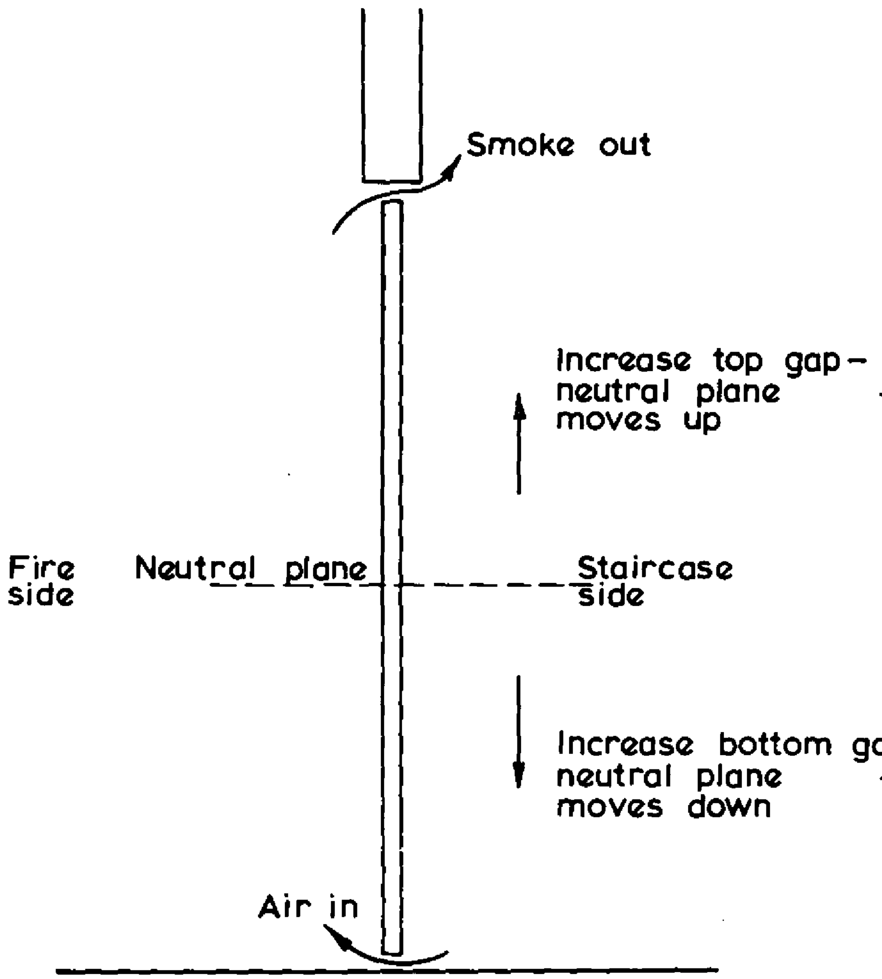
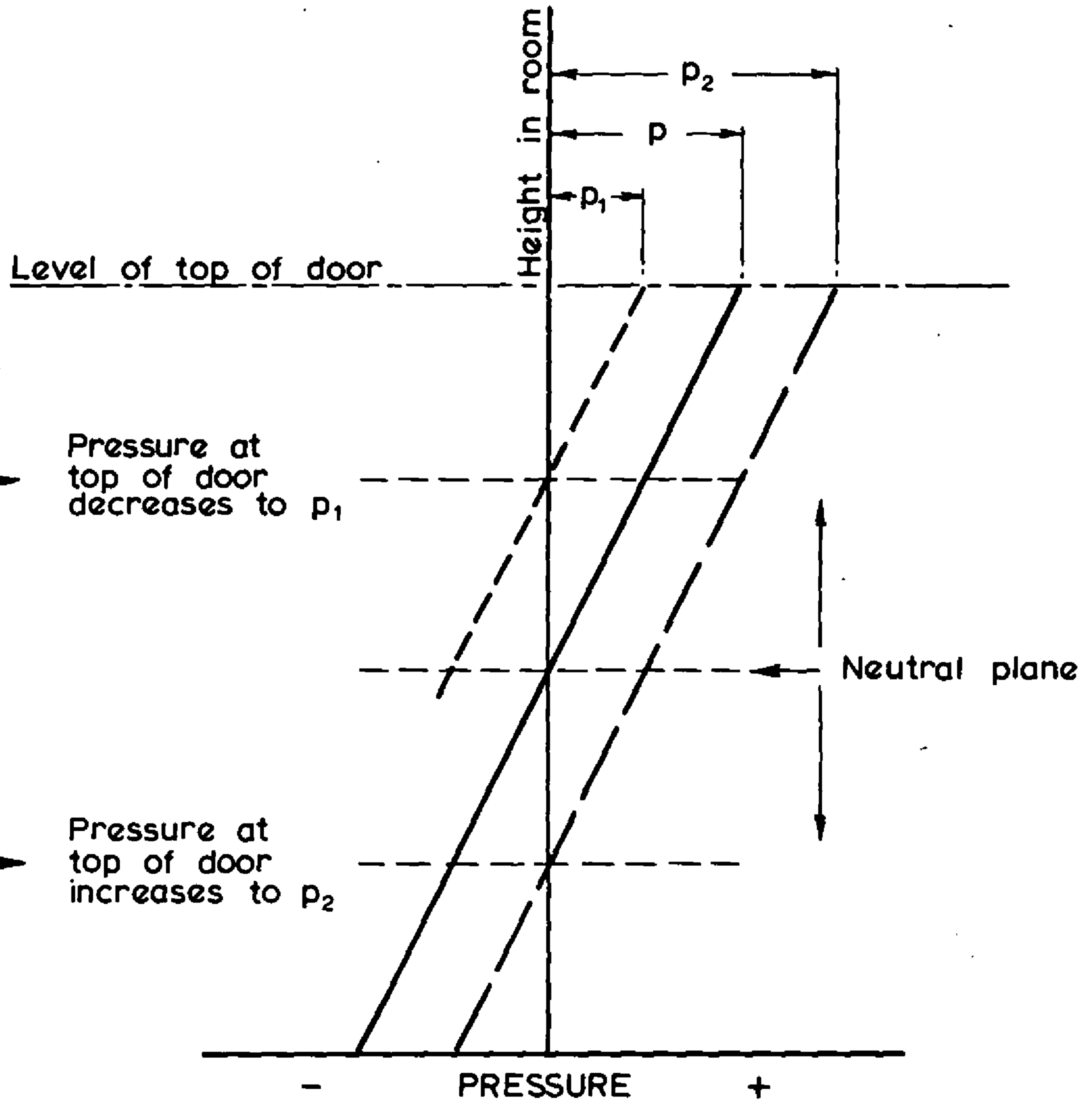


(a) Section through door between fire and staircase



(b) Diagram of pressure distribution up face of door on fire side for three positions of neutral plane

FIG. 3. DIAGRAM SHOWING EFFECT OF DOOR GAP POSITION

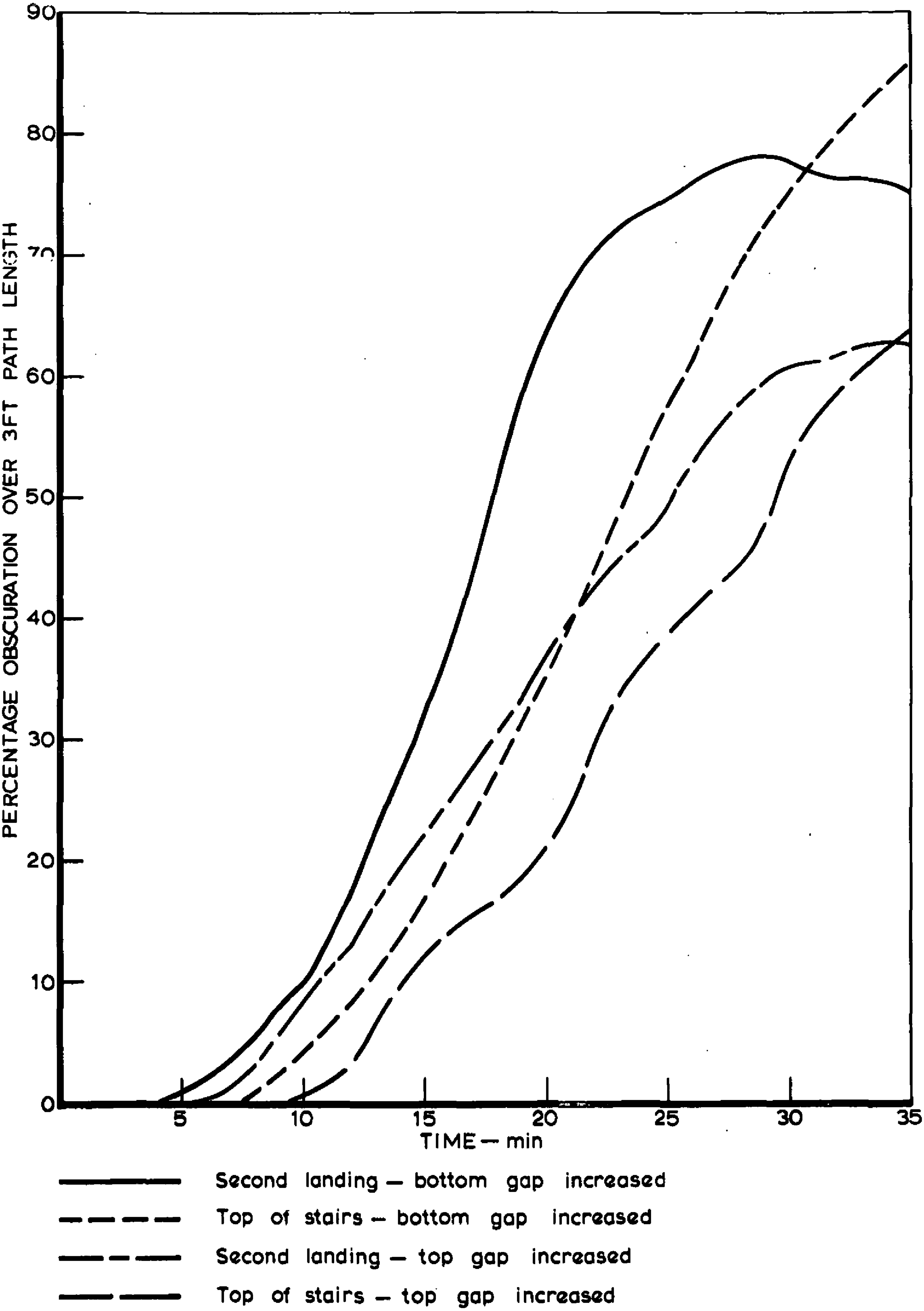


FIG. 4. EFFECT OF POSITION OF DOOR GAP ON SMOKE DENSITY IN STAIRCASE

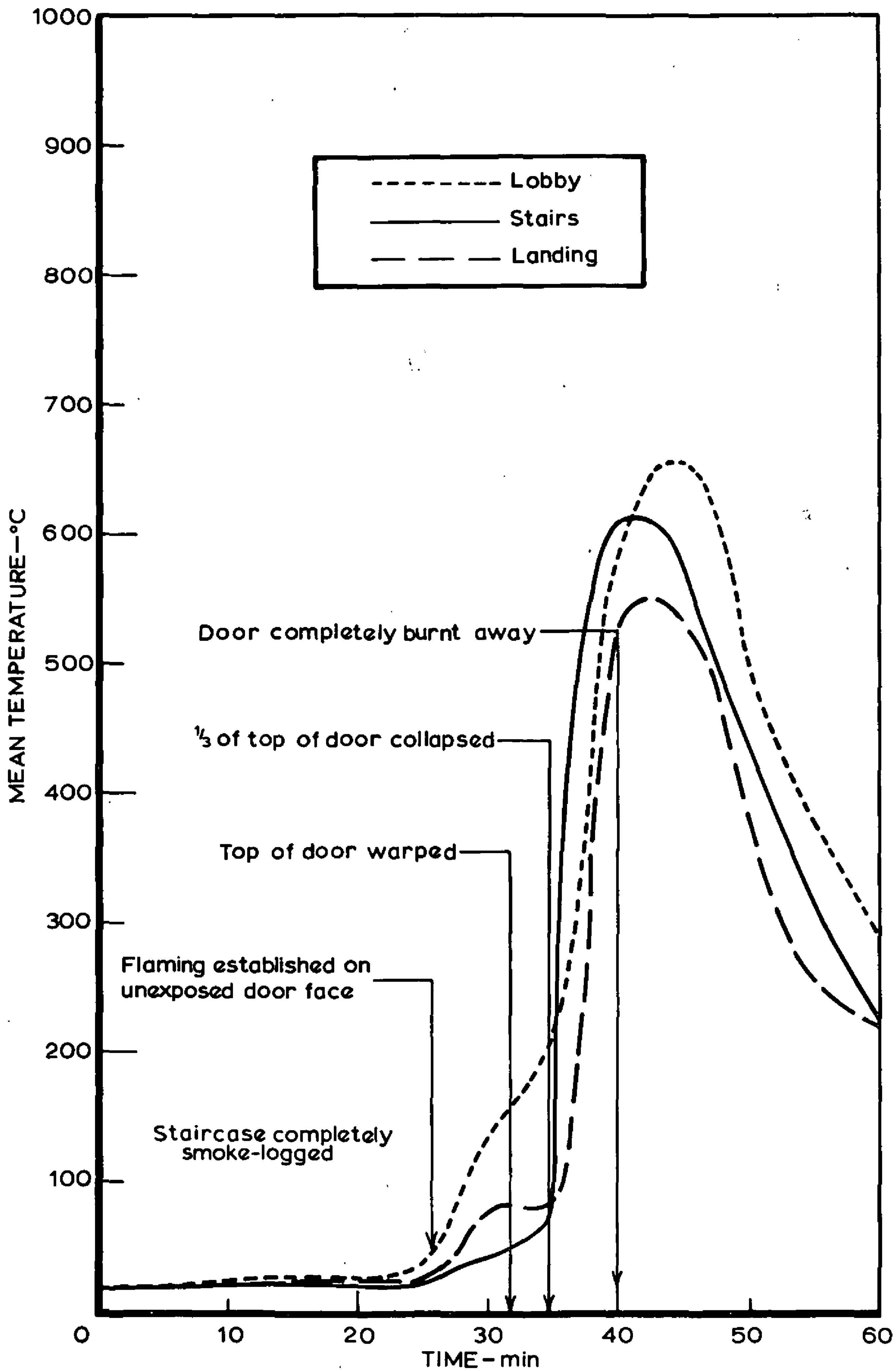


FIG.5. CONDITIONS IN STAIRCASE DURING FIRE TEST — NO PRESSURIZATION

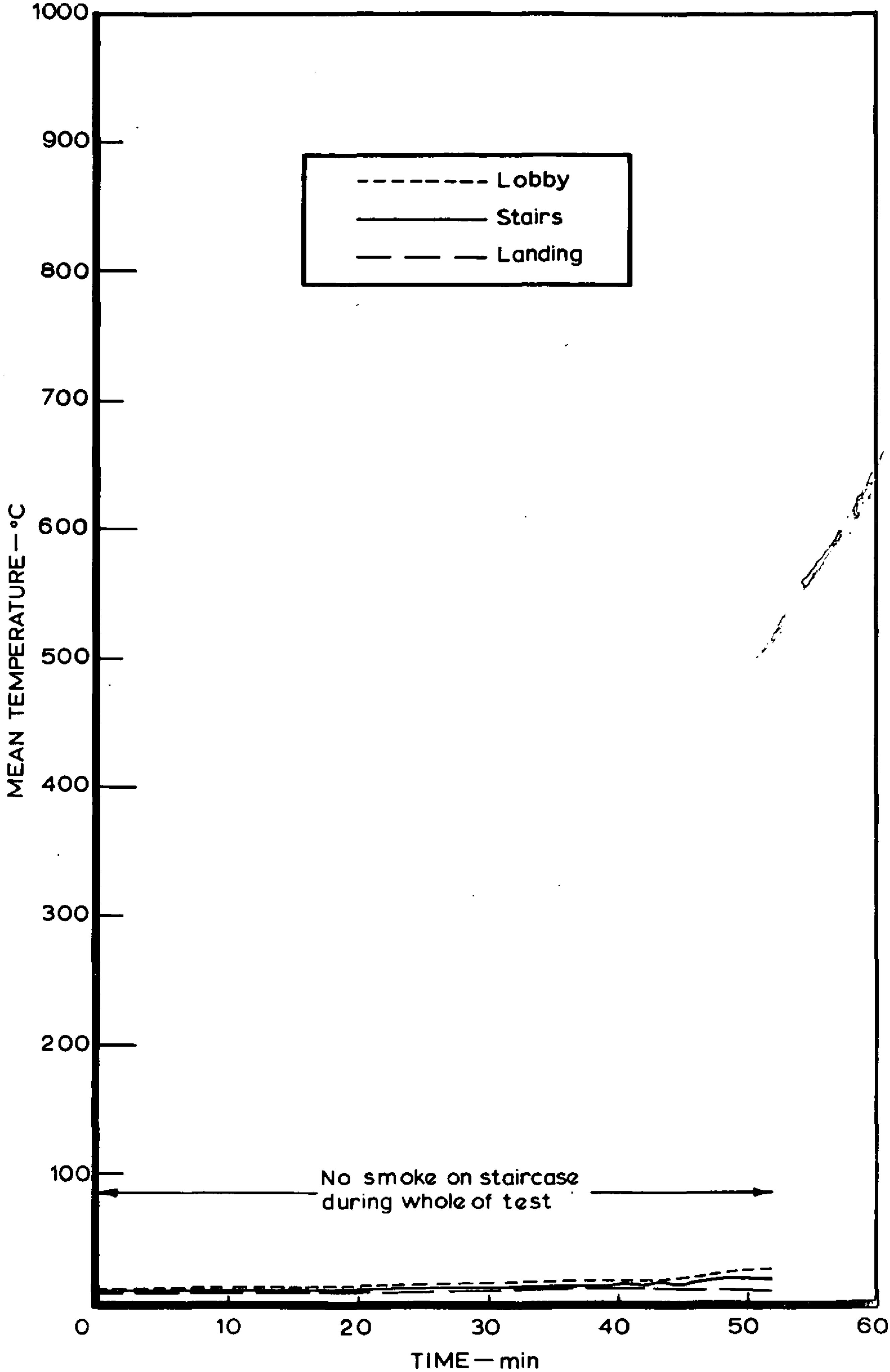


FIG.6. CONDITIONS IN STAIRCASE DURING FIRE TEST WITH PRESSURIZATION

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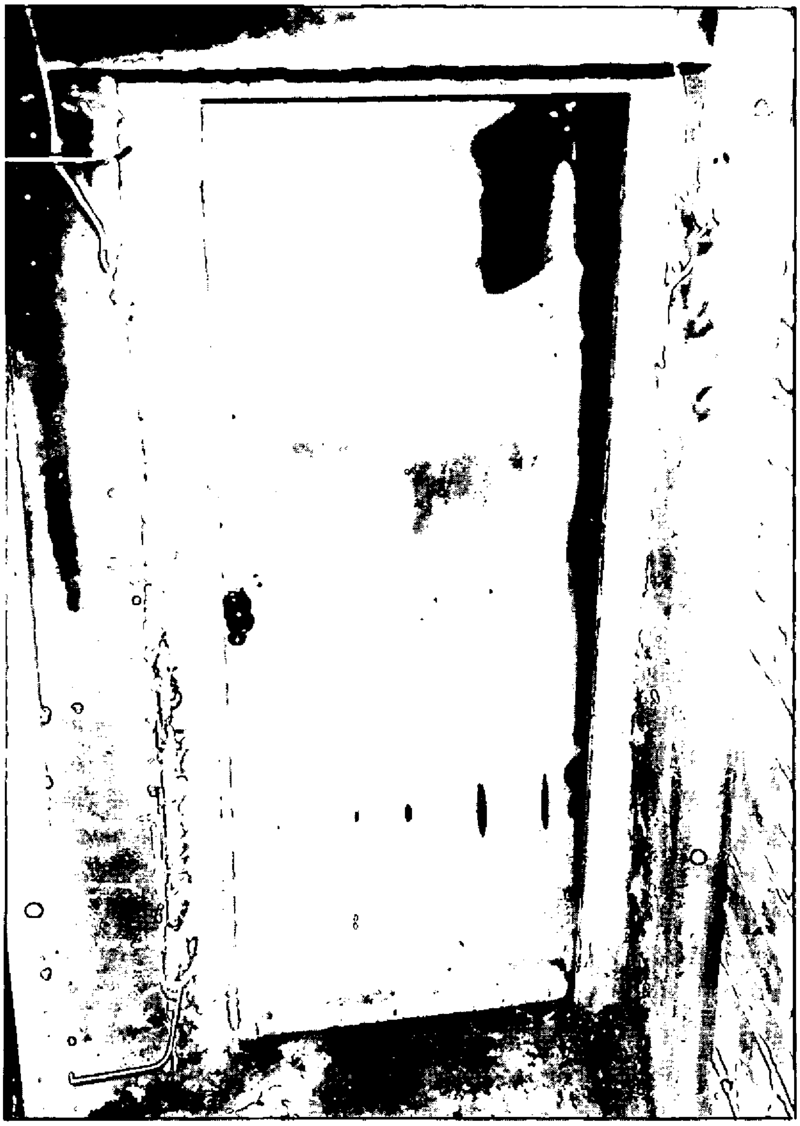

PLATE 1. CONDITION OF DOOR OF FIRE CHAMBER AT END OF PRESSURIZED FIRE TEST