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MOVEMENT OF SMOKE ON ESCAPE ROUTES

PART 3. EFFECT OF PERMANENT OPENINGS IN EXTERNAL WALLS

by

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Introduction

In case of occurrence of a fire in a building one of the essentials is to ensure that the occupants are able to leave the fire area to a place of safety. This entails the provision of escape routes leading either to outside the building or to designated areas within. In the case of multi-storey blocks of flats, and other buildings with similar occupancy hazards, it is customary to provide corridors leading to staircases, with limitations on the maximum distance people have to travel to reach one or other of the staircases available. In some buildings where only one staircase is provided, a lobby connects it to the corridor and to ensure that the lobby stays clear of smoke one of the measures commonly adopted is to ventilate it to the outside air. For this purpose the lobbies are usually located in the external walls and provided with permanent openings in one or more walls.

The provision of permanent openings has never been favoured by the occupants as it leads to draughts and rain penetration. Their effectiveness as a means of clearing smoke has also been questionable and there had been a lack of data on their likely behaviour in fires. This paper reports some full scale tests which have been performed in a building to determine the effectiveness of permanent openings in external walls as a means of clearing smoke.

Experimental technique

The plan of the brick building for these experiments is shown in Figure 1. It consisted essentially of two chambers connected together with an opening into which a standard door could be fitted. The fire or smoke chamber measured 2.7 x 3 m and was assumed to be the scene of fire, the smoke from which would travel to other parts of the building. The second chamber was divided into two parts, a lobby area measuring 3 x 4.5 m and a 1.5 m wide observation corridor. The division wall was provided with a single leaf firecheck door and a double leaf double swing door. The lobby which was 2.5 m high had two equal openings in the north and south walls, measuring

52 cm wide x 190 cm high provided with adjustable horizontal vent covers to enable any opening up to a maximum of 1.0 m^2 to be provided. In the opening between the lobby and the smoke chamber a single leaf hinged door, 0.76 m wide x 1.98 m high, was fitted with its timber frame having rebates 2.5 cm deep. The exact arrangement of the lobby and the smoke chamber may not be typical of many practical layouts but was considered suitable for these experiments concerned with the flow of smoke from one chamber to the other.

Four smoke meters S1 to S4 were suspended in the positions shown in Figure 1, and Plates 1 and 2, meters S1, S2 and S4 being at a height of 1.6 m representing the eye level of a person of average height whilst meter S3 was at a height of 0.9 m, simulating the eye level in a crouching position. The smoke meters were connected to recording instruments in the adjoining instrument room. It was possible to observe the conditions in the lobby from the corridor or the window to the lobby, and by providing illumination in the lobby visibility using "standard objects" could also be assessed.

A note was made of the weather conditions prevailing during the experiments by measuring the wind direction and its average speed over the period of the test. The instruments for this purpose were situated clear of the building. It was rare for the wind to blow consistently from a given direction, and it varied in most of the tests, in some cases by as much as 90 degrees over a period of 30 minutes.

For the two initial tests the fire chamber was provided with furniture and combustible linings on the walls, giving a fire load density of 23.5 kg/m^2 of the floor area. The test doors were of the $\frac{1}{2}$-hour fire check type (B.S. 459 : Part 3), a new door being required for each test. For the other tests the '2MB' smoke generator, described in Part 1, was employed. The generator was placed in the middle of the room and the window to the room was blanked with a board.

Test programme

The test programme, which consisted of 29 experiments, was divided into two parts.

Part A: The two initial tests were designed to establish the smoke conditions likely to be experienced in the lobby with actual fires. The remainder of the experiments were performed with the smoke generator, initially (Tests 3, 4, 5) a direct comparison being made with the smoke penetration through a door obtained with actual fire conditions. These were followed by experiments (Tests 6–10) in which the door was opened to simulate various conditions, and the vents in the lobby opened during the experiments to observe their effect. This enabled a standard procedure to be developed for the experiments in Part B of the investigation to determine the effect of providing various amounts of ventilation in the lobby.

Part B: Nineteen tests were carried out in this part of the programme in which the test door was a flush door with 2.5 cm rebates along the three sides and an average clearance of 5 mm at floor level. The door was opened 10 minutes after the smoke generator commenced to function, the predetermined amount of opening for ventilation having already been provided, and the total duration of a test was 30 minutes. The time for opening the door which was arbitrarily chosen from the previous experiments, ensured complete filling of the smoke chamber and rapid entry of smoke into the lobby, thus enabling a comparison to be made between the effectiveness of various ventilation conditions.

Eleven different arrangements of ventilation were used and in eight cases repeat tests were performed. Each opening was divided into two parts, referred to as top and bottom half and further identified by the wall in which they occurred; thus "top half 'N'" means that the upper half of the opening in the north wall was open. The area of opening for each half was 0.5 m^2 and represented 3.7 per cent of the floor area.

The arrangement for the tests performed is shown in Table 1 below, together with the data on average wind speed and direction during the tests.

TABLE 1

Test Data

Part A - Ad hoc and preliminary experiments

Test No.	Smoke source	Door position	Ventilation in lobby	Wind Direction	Average wind speed m/s
1	ad hoc fire	Closed	None	E-SE	2.68
2	"	"	"	N-NW	1.78
3	Smoke generator	Closed	Vents opened @ 52 min	W	4.20
4	"	"	None	N-NW	1.83
5	"	"	"	W-SW	3.80
6	"	Opened at intervals	"	N	3.93
7	"	Part open @ 10 min	"	W-NW	2.54
8	"	Opened @ 10 min	Top half 'S' @ 14 min	S-SW	3.03
9	"	"	Top half 'S' @ 21 min	N-W	3.48
10	"	"	Some during test	N-NW	2.54

Part B - Main experiments with various arrangements of ventilation

Test No.	Ventilation provided		Wind direction	Average wind speed m/s
	Vent opening	Area m^2		
11	Top half 'N'	0.5	E-SE	1.54
12	Top half 'S'	0.5	N	1.25
13	"	0.5	N-E	1.54
14	Bottom half 'N'	0.5	SW	1.21
15	"	0.5	N-E	0.98
16	Bottom half 'S'	0.5	N	1.43
17	"	0.5	W-NW	1.88
18	Full opening 'N'	1.0	N-NW	1.54
19	"	1.0	S-W	1.54
20	Fully open 'S'	1.0	N	1.52
21	Top half 'N' and 'S'	1.0	S	0.98
22	"	1.0	E-SE	1.47

(Cont'd)

Part B (Cont'd)

Test No.	Ventilation provided		Wind direction	Average wind speed m/s
	Vent opening	Area m^2		
23	Bottom half 'N' & 'S'	1.0	N-NE	0.98
24	"	1.0	W-NW	3.80
25	Top half 'N' Bottom half 'S'	1.0	W-NW	1.38
26	" "	1.0	N-NW	1.43
27	Bottom half 'N' Top half 'S'	1.0	S-SW	1.16
28	" "	1.0	W-NW	0.98
29	Full opening 'N' & 'S'	2.0	NE	1.83

Note:- Wind direction E-SE means wind variable between east and south east during the test.

Test results

Smoke density readings obtained by the meters during the tests are plotted in Figures 2 to 12. The first ten tests were of 60 minutes duration each. In the experiments with the test doors closed appreciable amounts of smoke did not enter the lobby until after 20 minutes or so. For the remainder of the tests, with the door fully opened after ten minutes, sufficient information was obtained over the next 20 minutes on the effect of ventilation and the tests were therefore terminated at 30 minutes after the start.

For the first two tests, with ad hoc fires, readings of individual smoke meters are given, together with the curve for the mean smoke density. For the remaining 17 tests, a number of curves are plotted on each graph giving the mean smoke density for all four smoke meters in each test. The main differences in the smoke readings between the high and the low measuring points was the initially slow rate at which smoke filled the lower part of the room but as the test proceeded the difference in the smoke conditions at two levels was less marked.

Part A - Ad hoc fire tests

In the first test during the initial 25 minutes very little smoke entered the lobby, the fire was slow to develop and some of the smoke was emitted from the part open window to the fire chamber (Plate 3). After 27 minutes there was some build up of smoke and then after a further 5 minutes its amount was reduced probably due to a change in wind direction. Opening the test doors for 45 seconds at 40 minutes resulted in a sudden inrush of smoke which quickly dispersed. After 46 minutes the door commenced to deform and probably char on the face exposed to fire and permitted large quantities of smoke to enter the lobby.

The fire in test No.2 (Fig.3) developed more rapidly; noticeable amounts of smoke started to enter the lobby after 15 minutes at a fairly constant rate. At 54 minutes, the vents on the south wall were fully opened resulting in some clearance of smoke. At 40 minutes the average visibility in the lobby was reduced to the length of the room, i.e. 4.5 m.

These two tests gave some indication of the smoke condition likely to be experienced with actual fire but at the same time showed the difficulties of controlling fires to follow an identical course. Each test of this nature requires a new set of furniture, a new door and a certain amount of repairs to be carried out. It was therefore decided to use the smoke generator, reported in Part 1, for further work.

Part A - Preliminary tests with smoke generator

Figure 4 shows results of 3 tests with the smoke generator in the fire chamber with the test door and the vent openings kept closed, except in the case of test No.3 when both the vents were fully opened after 50 minutes. There are considerable variations in the smoke conditions in the lobby, due mainly, it is felt, to the different wind conditions that were present. However, the mean curve for the three experiments follows closely the rate of smoke penetration into the lobby experienced in the second test with actual fire; the smoke density values at 40 minutes are almost identical. It would therefore appear a reasonable assumption that on the whole the smoke generator was producing smoke at a rate comparable with that obtainable in fires.

In Figure 5 are shown the results of the remainder of the tests in this part of the investigation. In test No.6 the door was opened halfway at 10, 20 and 30 minutes for 10 seconds each time to simulate the passage of people.

This does not appear to have had much effect on the flow of smoke into the lobby. In test No.7 the door was opened at 30 minutes to provide a 15 cm wide gap. This resulted in some rapid increase in the smoke density in the lobby and when the door was closed at 40 minutes, there was a gradual dispersion of smoke.

In tests Nos.8, 9 and 10, the door was fully opened at 10 minutes and in each case smoke rushed into the lobby and after a few minutes reduced the visibility to less than 3 meters. In test No.8, opening of the top half vent on south side at 14 minutes led to reduction in smoke density, but a probable wind change at 35 minutes quickly cancelled the effect. In test No.9, some ventilation (top half 'S' side) was provided at 21 minutes and as in the previous case it provided some relief which was reversed later in the test. In test No.10, when the top half of the opening on the south wall was provided at 30 minutes there was very little effect, until the top half on the opposite wall was also opened 9 minutes later. Closing the vents at 45 minutes quickly increased the smoke density to its original high level. These tests showed that the smoke entry into the lobby depended upon the duration and the extent to which the test door was opened and that vent openings could clear some smoke from the lobby, if the weather conditions were favourable.

Part B - Effect of ventilation on smoke clearance

For the nineteen tests in this part a standard testing procedure was adopted with the appropriate vent opening provided at the start and the test door fully opened at 10 minutes. All tests were of 30 minutes duration and the mean smoke density curves are plotted in Figures 6 to 12. Figures 6, 7 and 8 show the smoke condition with ventilation provided on one side only. With a 0.5 m^2 opening in the bottom half of the wall the smoke conditions were hardly affected whilst with a similar opening at higher level there was a great deal of variability in the results, as was the case also with a 1.0 m^2 opening on one side. The overall level of smoke density was, however, lower when the top half of the vent was open, with or without the bottom half.

Figures 9 to 12 show the effect of providing openings in the two opposite walls and once again, openings in the bottom half of the wall seem to be least effective. With a 0.5 m^2 opening in the top half of each wall (Tests 21, 22) there was greater variability but the average smoke level was lower. With openings in the top half on one side and bottom half on the other (Tests 25-28) there was wide variability in the amount of smoke cleared from the room, presumably influenced by the prevailing weather conditions. With a 1.0 m^2 opening on each wall on opening the test door, unlike the previous tests, smoke density did not exceed 0.1, until 22 minutes when it gradually rose to a final value of just under 0.2 at the end of the test; this corresponds to a visibility of 5.6 metres.

Discussion of results

(a) Smoke from ad hoc fires

Two tests with fires have shown the difficulty of predicting accurately the rate at which smoke may be evolved in practice. They have also illustrated the effectiveness of well fitting fire check doors in preventing passage of smoke during the early stage. In one test up to 40 minutes the amount of smoke that had penetrated never reduced visibility to less than 8 metres. The presence of smoke on the other side of the door was shown when it rushed in on opening the door for only 45 seconds. In both tests it was only when the door was damaged by heat that appreciable quantities of smoke penetrated through the gaps. Ordinary doors of flush type, with similar rebates and fits, should also be able to act as effective barriers to the passage of smoke, but their usefulness would be of comparatively short duration if they were to be exposed to the heating conditions from the fire. In situations, such as in corridors or lobbies, where fires are not likely to start in the vicinity of doors, it seems reasonable to assume that well fitting flush doors with 2.5 cm rebates can provide the necessary protection and can be employed as satisfactory 'smoke-stop' doors.

(b) Use of smoke generator

Although the three tests (Tests 3, 4, 5) with the smoke generator under conditions identical with the fire tests (1 and 2), i.e. of door and vent closure, gave variable penetration of smoke, this was considered to be due mainly to the prevailing weather conditions. Even with the vents closed, wind blowing from a direction facing the openings would result in conditions of slight pressure in the lobby owing to the presence of small gaps between the vent closure slides and the wall. This would tend to retard the entry of smoke into the lobby when the test door was in a closed position. Again as the wind direction was rarely constant during the tests, its effects were correspondingly variable. On the whole, as shown in Figure 4, the average rate at which smoke entered the lobby was consistent with that obtained with the ad hoc fire in Test No.2. This was the fire test which produced the more severe smoke condition and it was therefore considered reasonable to use the smoke generators for the investigation proper.

(c) Effect of door opening

The tests have shown that the passage of smoke through a door depends upon the size of opening available and duration for which it is kept open. Opening of doors for a few seconds for passage of people is not likely to let through any appreciable quantities of smoke, on the other hand if it is ajar due to defective or inefficient self-closing mechanism then quantities of smoke can pass. With the door closed the density of smoke in the lobby increased from 0.1 to 0.2, i.e. doubled in 20 minutes on average (Fig.4), whilst with a 15 cm wide opening it took only 5 minutes (Fig.5 - test No.7) and when fully open hardly 2 minutes to achieve the same condition. This clearly illustrates how the purpose of a smoke stop door can be negated if it is open and considerably reduced if it is not properly closed. It also means that if self closing devices are specified for doors they must be of a type that can be relied upon effectively to close them in use, if they are to make any contribution to safety.

(d) Effect of weather

One of the factors over which there was no control in the experiments was the weather conditions prevailing at the time of test. Whilst every effort was made to conduct tests under light wind conditions, the velocity and direction of wind for the majority of tests varied over the test duration of 30 minutes. Whilst it may be possible to conduct tests of this nature inside a large laboratory on full or reduced scale models, it would not be possible to predict the effectiveness of any measures in practice, as the weather conditions at the time of fire could not be specified. The tests were therefore deliberately performed under natural conditions and no provision was made for windbreaks or other enclosures around the building. It has been shown beyond doubt that the original misgivings concerning a method for smoke clearance which depended upon natural ventilating effects of openings in walls were fully justified. Indeed the effect of weather on the results of this investigation has been such that it is not considered possible to provide reliable quantitative data on effectiveness of various arrangements of openings.

The dilution and clearance of smoke from the lobby depended upon the ability of the fresh air to enter through the openings to replace the smoke. Direction and velocity of wind could, under adverse conditions, force the smoke back into the lobby instead of letting it escape freely to the outside.

In the tests the situation was further complicated by the geometric shape of the building and the resultant eddies which tended to form in the re-entrant angle outside the two chambers. In practice, of course, the situation may be still more complicated by the shape of the building, the adjoining structures and different conditions likely to be encountered at different heights.

(e) Effect of opening in walls

(i) One wall only. With an opening of 0.5 m^2 in one wall, its position appeared to be critical. Low level openings were virtually ineffective whilst some smoke clearance was noticed when the openings were at a higher level and the wind was blowing from a favourable direction. Increasing the size of the opening to 1.0 m^2 and extending it from ground to nearly 2 m high showed a marginal improvement. Provision of an opening in one wall is not considered to be a satisfactory or a reliable method of smoke clearance for a room.

(ii) Openings in two walls. Openings in two opposite walls under optimum weather conditions should provide a flow of air from one side to the other which should be able to dilute the smoke laden air in the lobby. In the tests 0.5 m^2 openings in the lower part of the walls were rather ineffective whilst at high level, they needed suitable wind conditions to show any improvement in the smoke conditions. Having an alternative high and low level arrangement was no better in effect as the probability of drawing in fresh air at low level and evacuation of smoke at high level did not materialise unless the weather conditions were favourable.

The best and acceptable results were obtained when an opening of 1.0 m^2 was provided in each wall, extending to a height of 2 m as in this case either a through ventilation could be provided or in each opening fresh air could enter at low level and smoke be exhausted at high level. An opening of this type in practice is likely to meet objections on grounds of comfort for the everyday use of these areas; the presence of constant draught, loss of heat and ingress of rain and snow are not likely to find favour with the occupants of the building.

Conclusions

The present investigation was the first occasion in this country when an attempt has been made to study the movement of smoke in escape routes in any detail. A considerable amount of preparatory work was found to be necessary before the experiments could commence on the effect of ventilation on smoke clearance. Whilst detailed quantitative data on the effectiveness of permanent openings in walls on the evacuation of smoke require some further work, the investigation has provided some information on the reliability of this method and other features associated with this problem have also been highlighted.

The broad conclusions that may be drawn from the investigation are as follows:-

1. The amount and rate of smoke production in fires is not easily predictable and depends largely on the rate of development of the fire.

2. Fire check doors in suitable frames in a fully closed position can effectively prevent the passage of smoke until they become deformed and damaged by heat.

3. In positions where doors are not likely to be exposed to high temperatures, such as in corridors and lobbies, flush doors with a good fit and suitably sized rebates can be considered a suitable smoke stop measure.

4. Whilst the effectiveness of a smoke stop door depends upon its remaining closed, its opening for a few seconds for the passage of people is not likely to result in passage of appreciable amounts of smoke.

5. The evacuation or dilution of smoke from a smoke logged room by means of permanent openings in the outside walls depends upon the setting up of an air flow pattern such that fresh air is drawn into the room and the smoke laden atmosphere is exhausted outside. The rate of flow of fresh air needs to be related to the rate at which smoke is entering the room to maintain the necessary level of visibility.

6. It follows from above that the rate of smoke evacuation is dependent upon the size of the opening.

7. The role played by weather conditions in the setting up of this air flow pattern is so critical that the effectiveness of permanent openings as a means of evacuating smoke is not predictable and could not be relied upon with any degree of certainty unless the openings were so arranged as to produce continuous through draughts.

8. Provision of openings in opposite walls to provide cross-ventilation is more effective than openings in one wall alone.

9. Even with cross-ventilation unless the openings are large enough their effectiveness would be in doubt. To deal with smoke entering through one open door, the size of each opening for cross-ventilation should be of a size similar to the door.

10. Openings at high level are more effective than those at low level.

11. The size of openings which were shown to be effective in this investigation are not likely to prove acceptable to the occupants of the building on grounds of comfort. An acceptable alternative might be the provision of mechanically operated openings linked with a smoke detection mechanism.

Acknowledgment

Grateful thanks are due to Mr. L. A. Ashton for his guidance and to Messrs. W. A. Morris and G. Bedford for undertaking much of the experimental work.

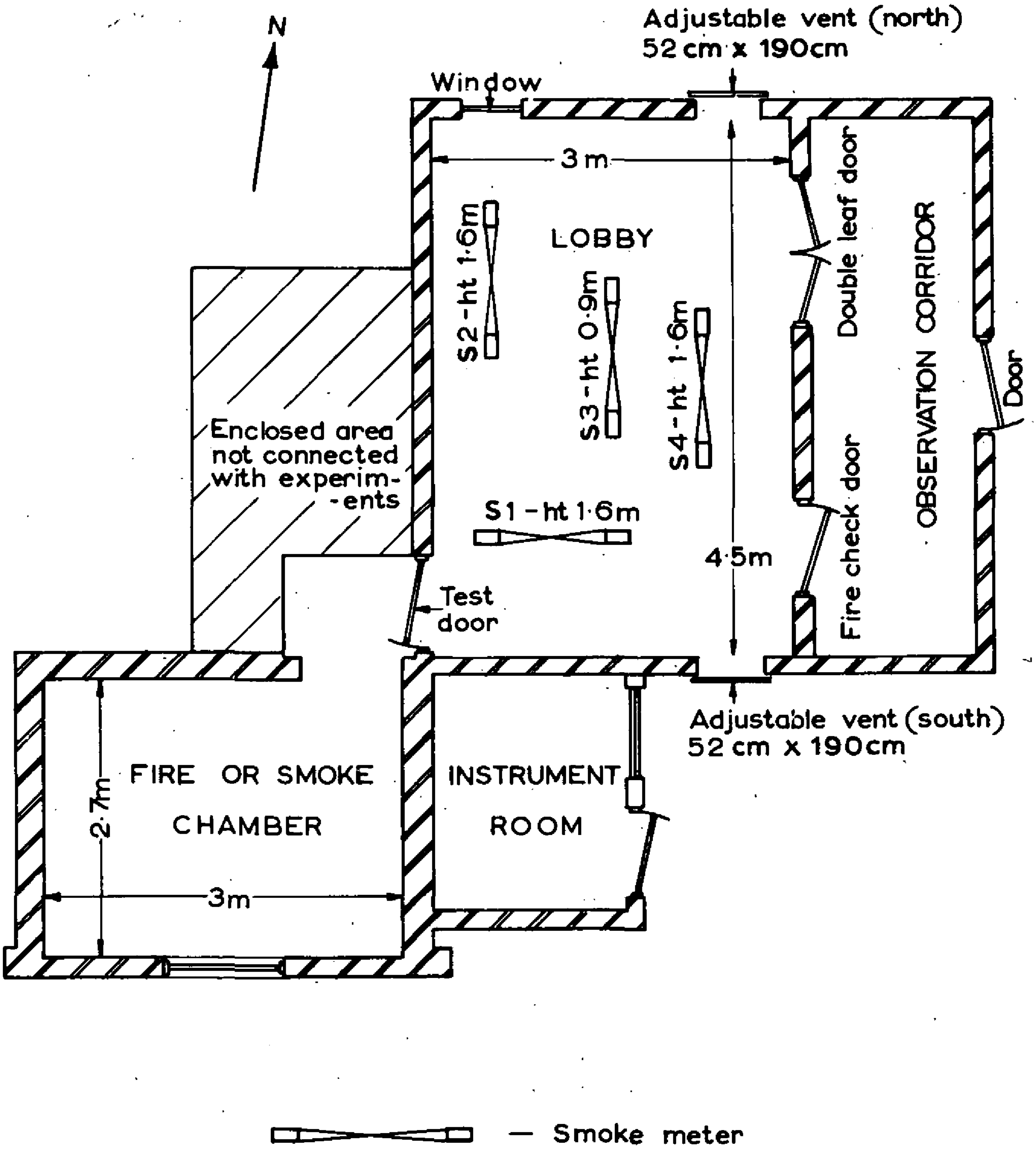

FIG. 1. PLAN OF BUILDING FOR TESTS ON MOVEMENT OF SMOKE

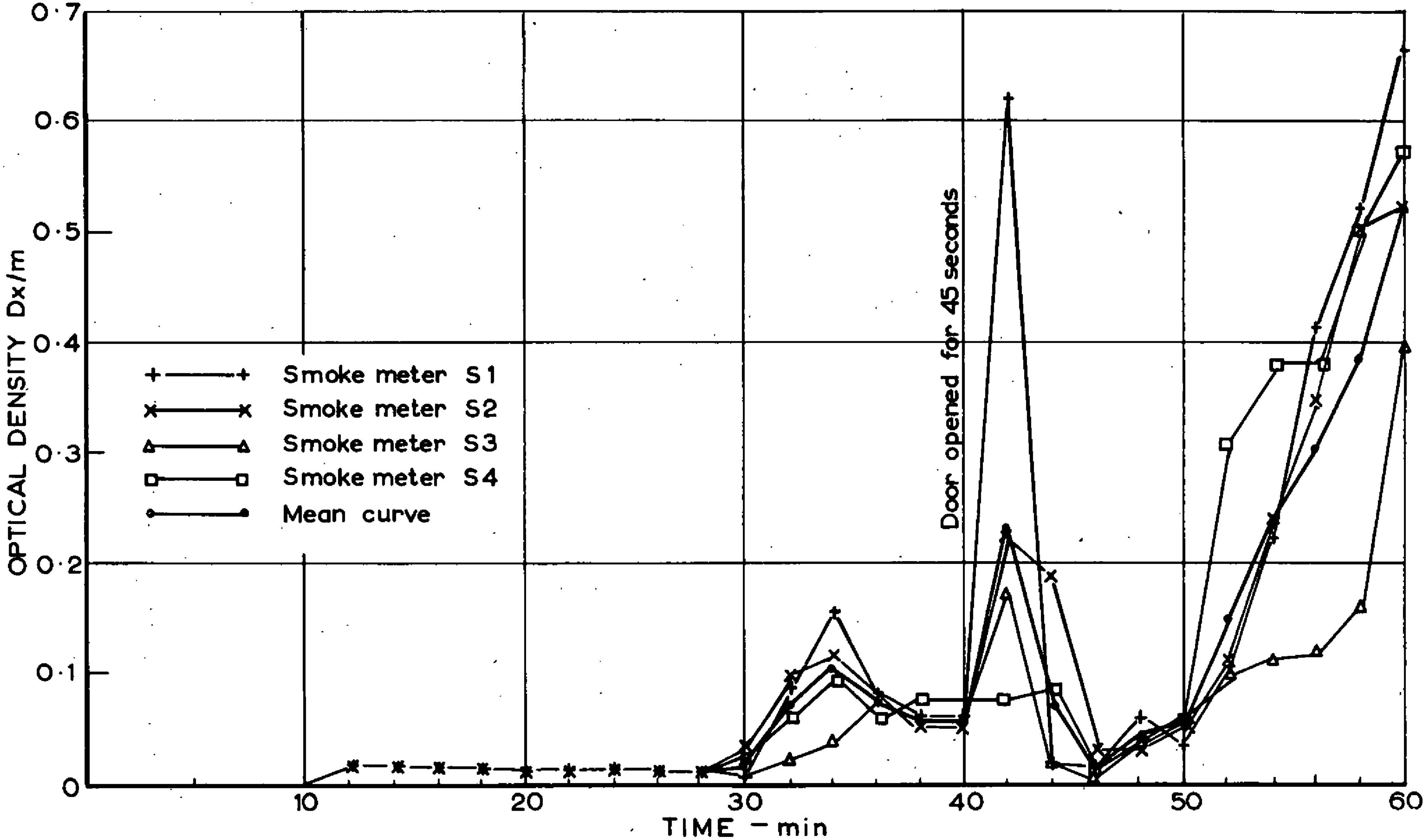

FIG. 2. SMOKE DENSITY CURVES – AD HOC FIRE TEST No. 1

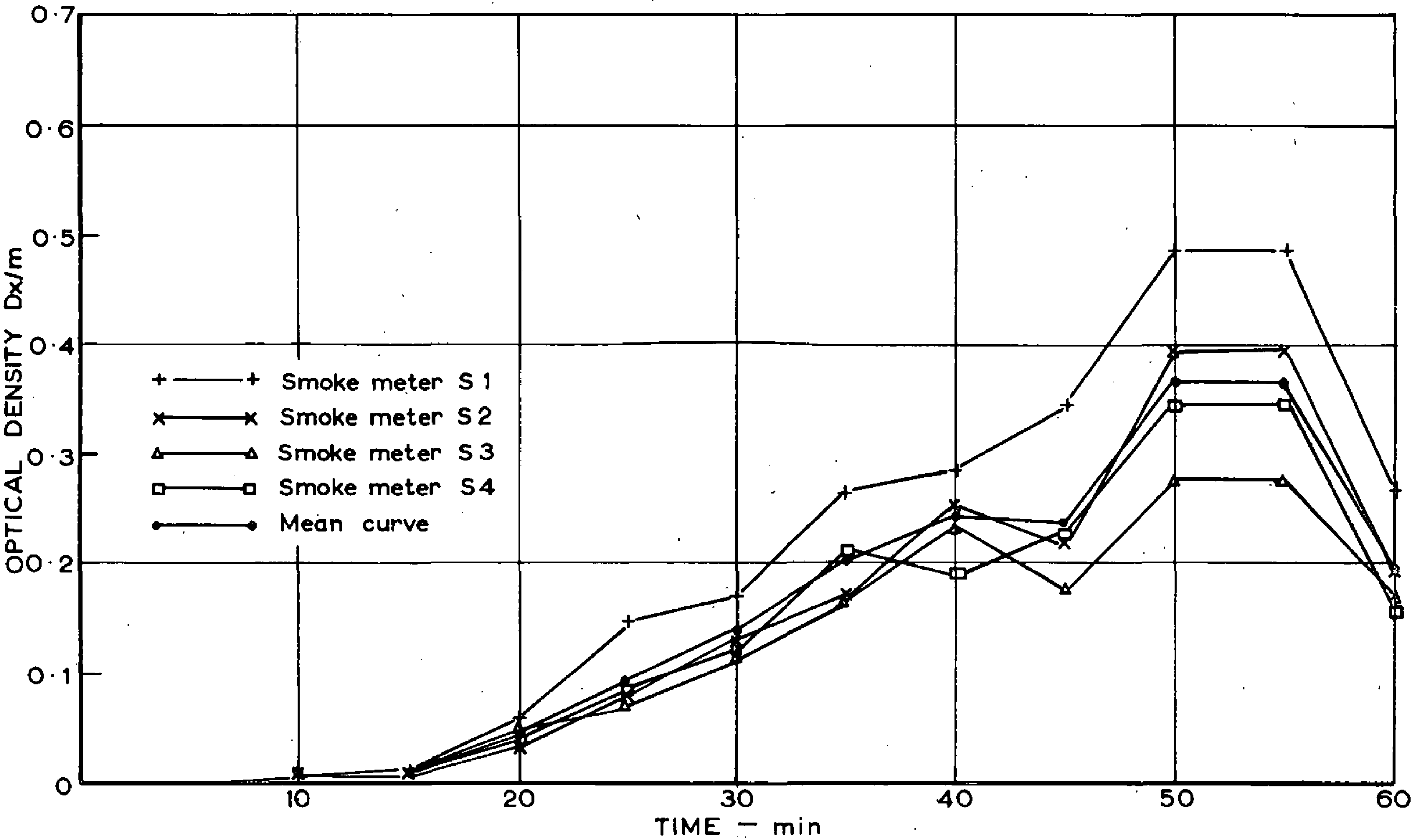

FIG. 3. SMOKE DENSITY CURVES — AD HOC FIRE TEST No. 2

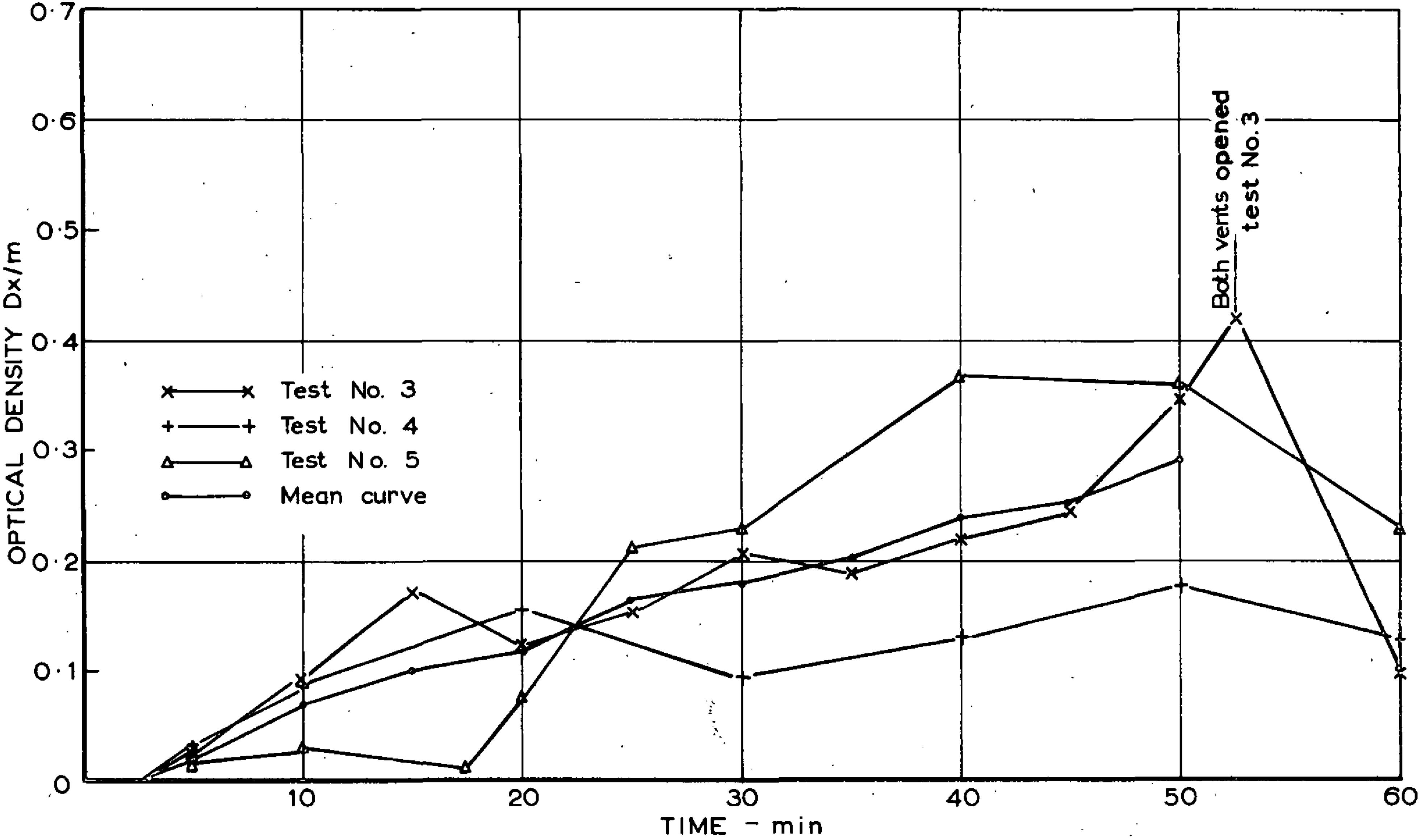

FIG. 4. MEAN SMOKE DENSITY WITH DOOR CLOSED–TEST Nos. 3,4 & 5

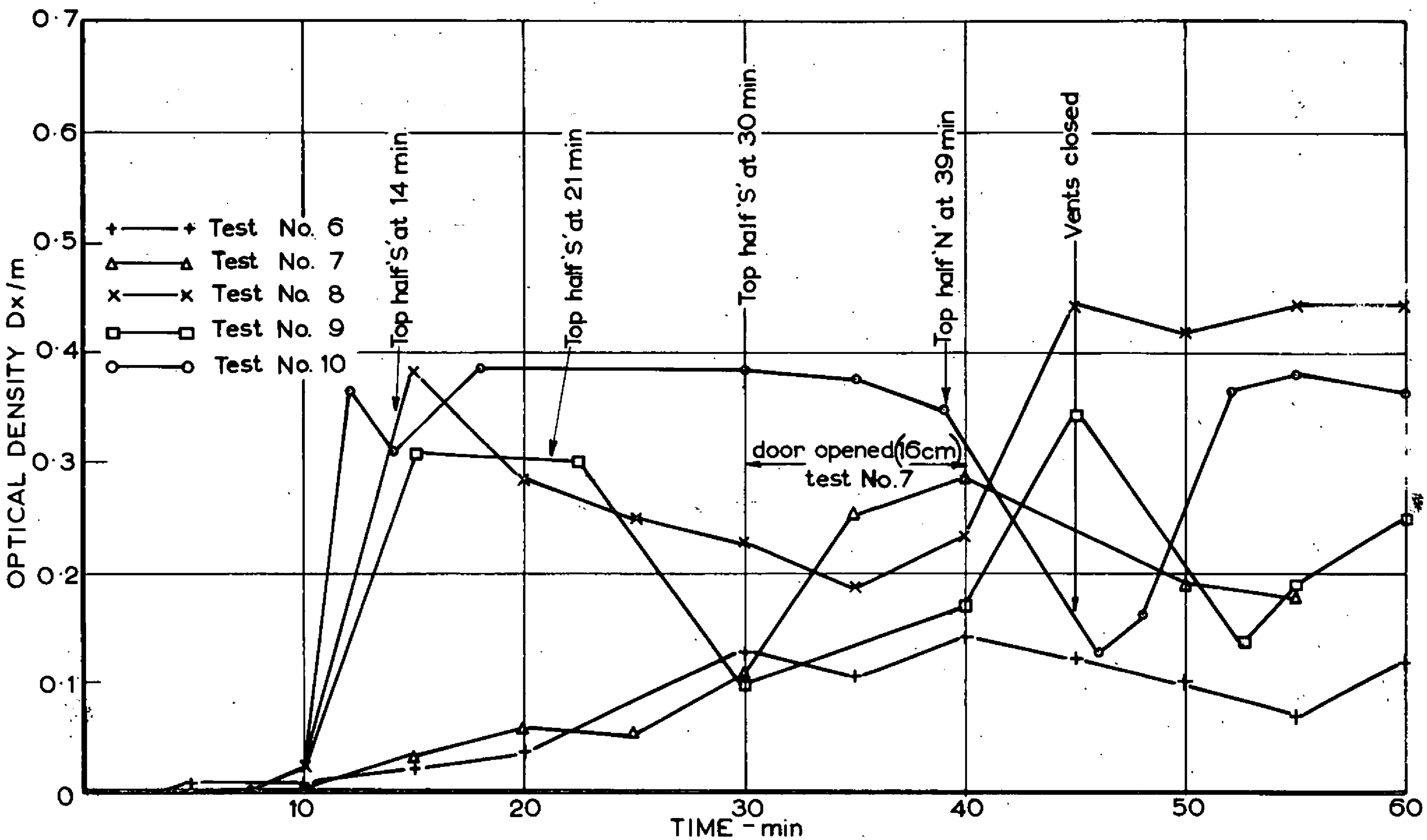

FIG. 5. MEAN SMOKE DENSITY CURVES—TEST Nos. 6, 7, 8, 9 & 10

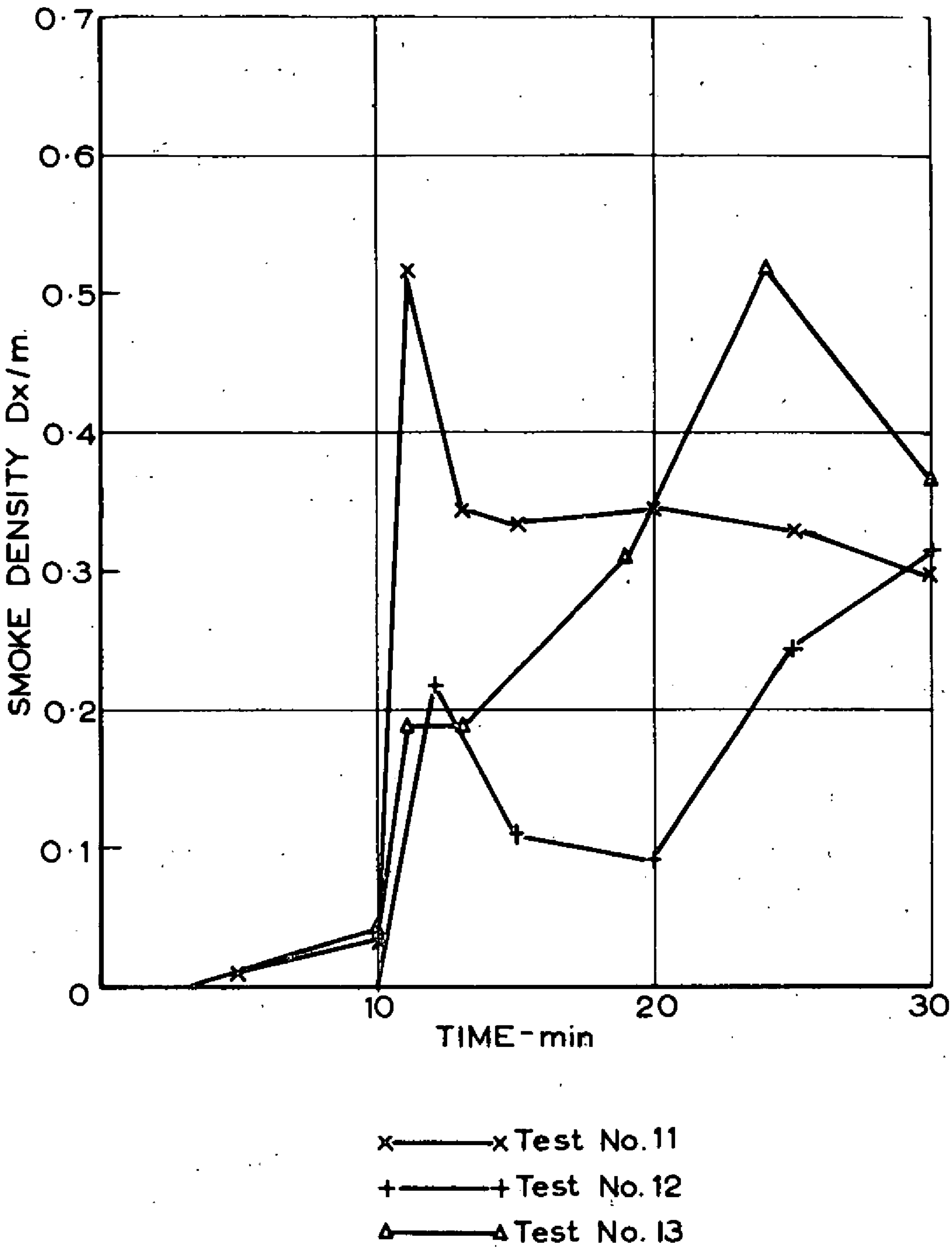

FIG. 6. MEAN SMOKE DENSITY CURVES—TEST Nos. 11, 12, & 13

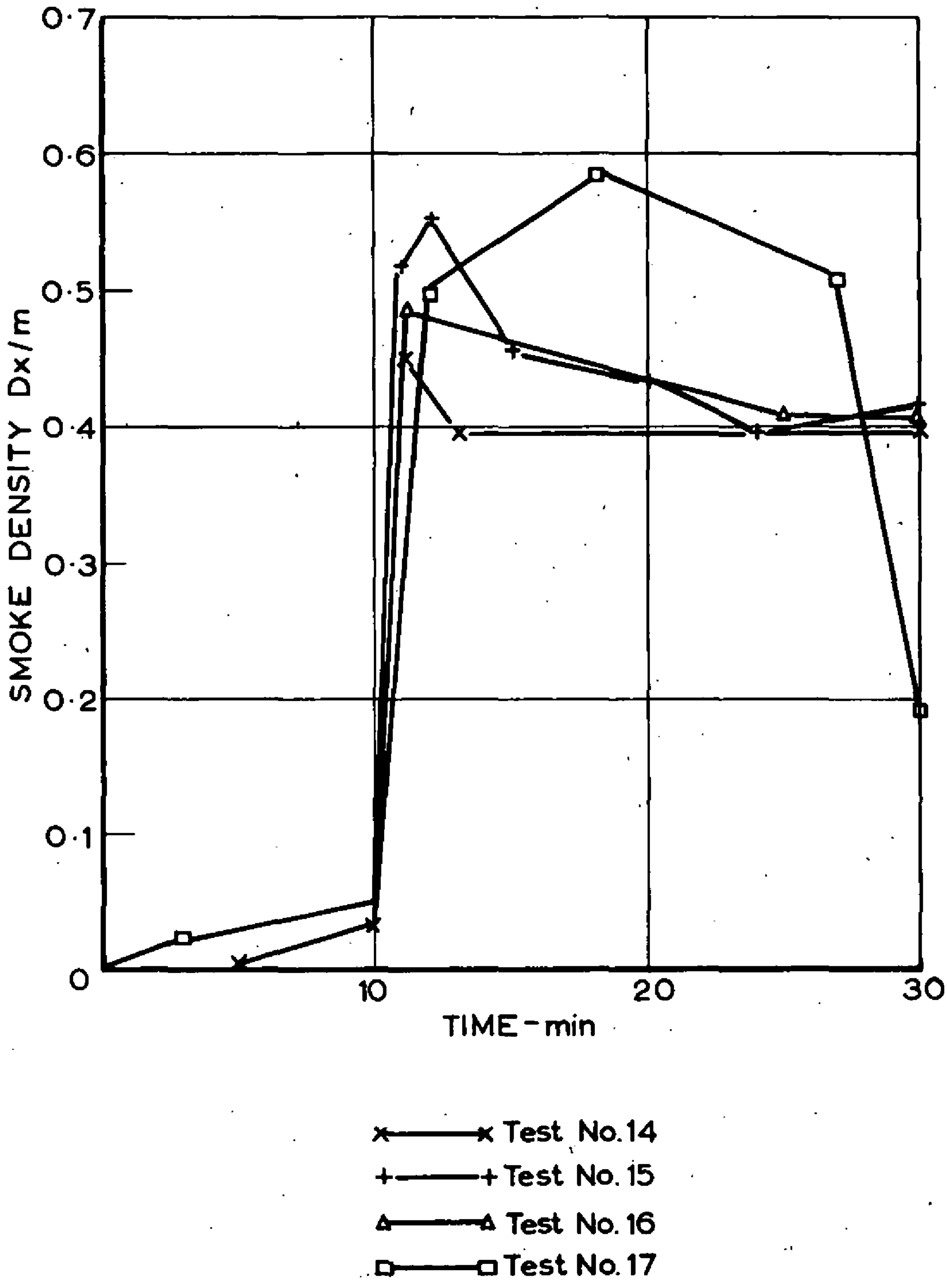

FIG. 7. MEAN SMOKE DENSITY CURVES - TEST Nos. 14, 15, 16 & 17

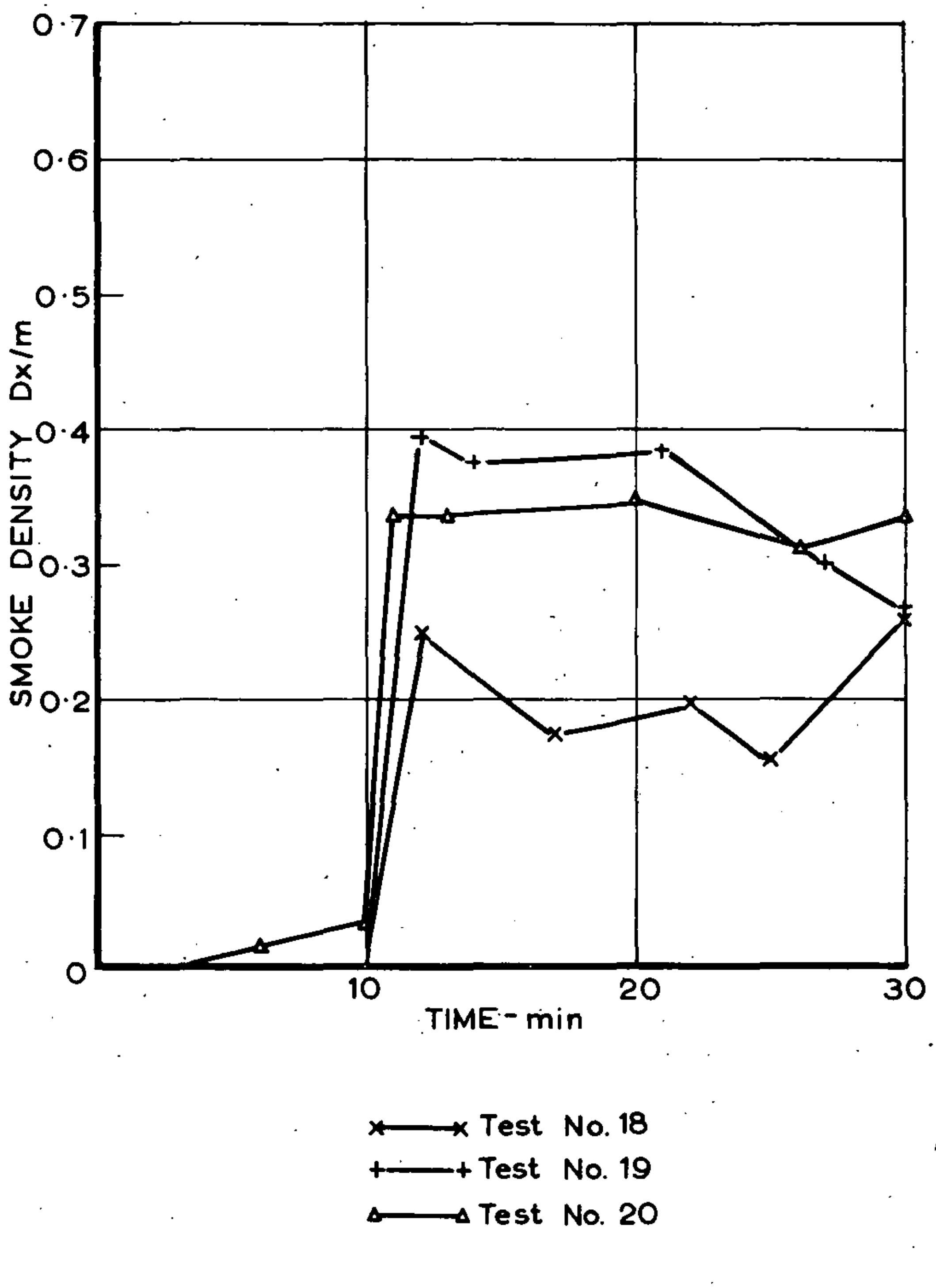

FIG. 8. MEAN SMOKE DENSITY CURVES - TEST Nos. 18, 19 & 20

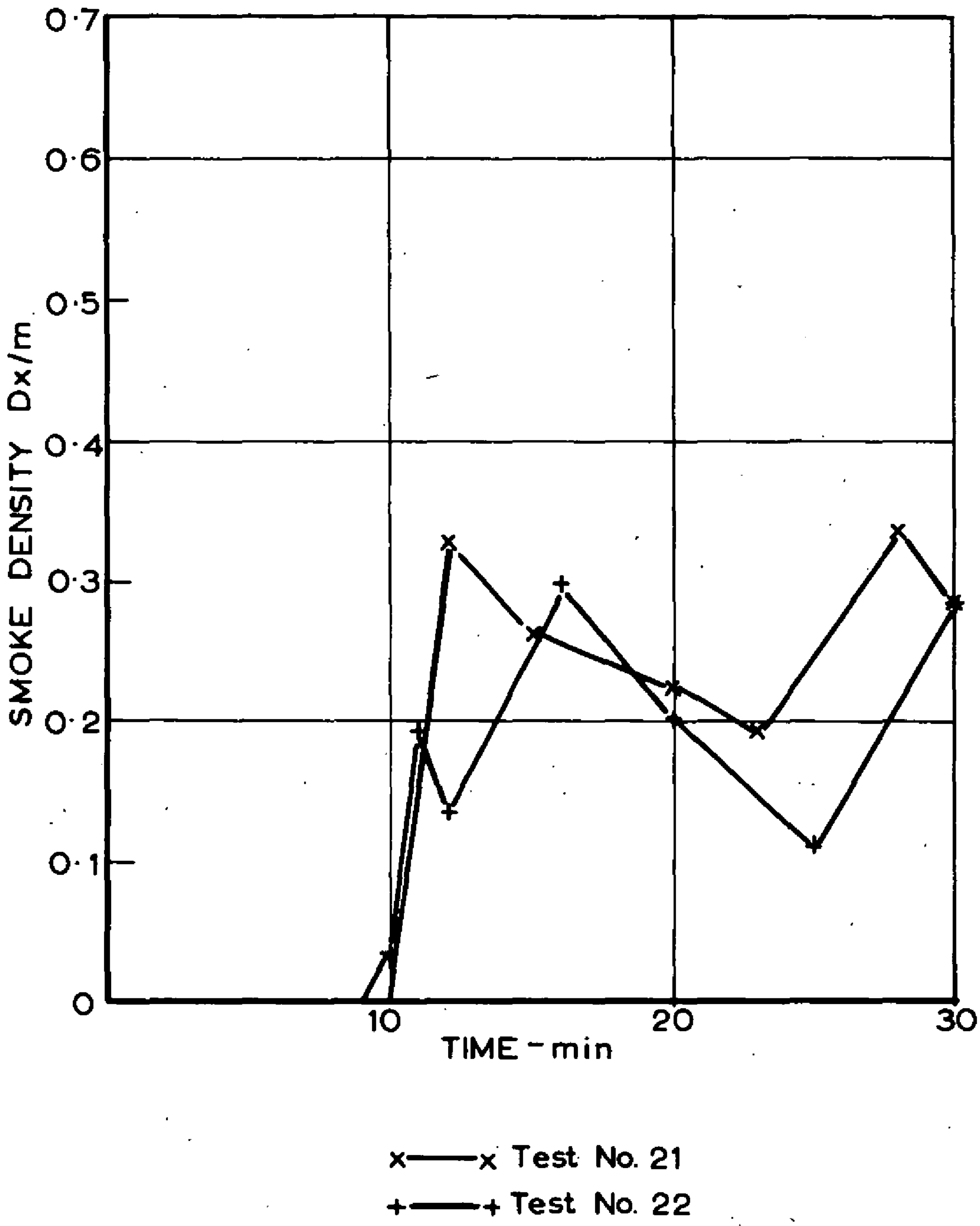

FIG. 9. MEAN SMOKE DENSITY CURVES - TEST Nos. 21 & 22

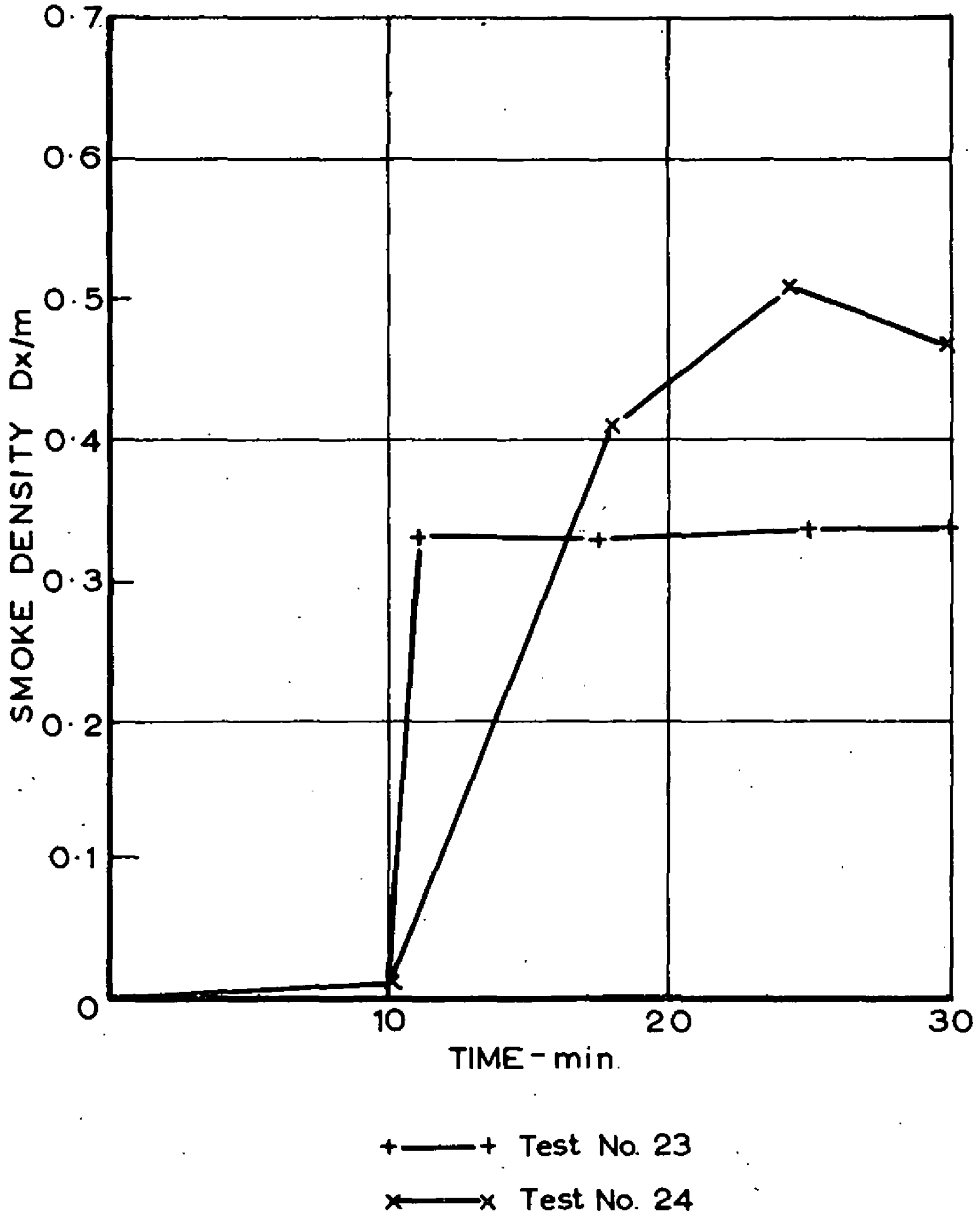

FIG. 10. MEAN SMOKE DENSITY CURVES - TEST Nos. 23 & 24

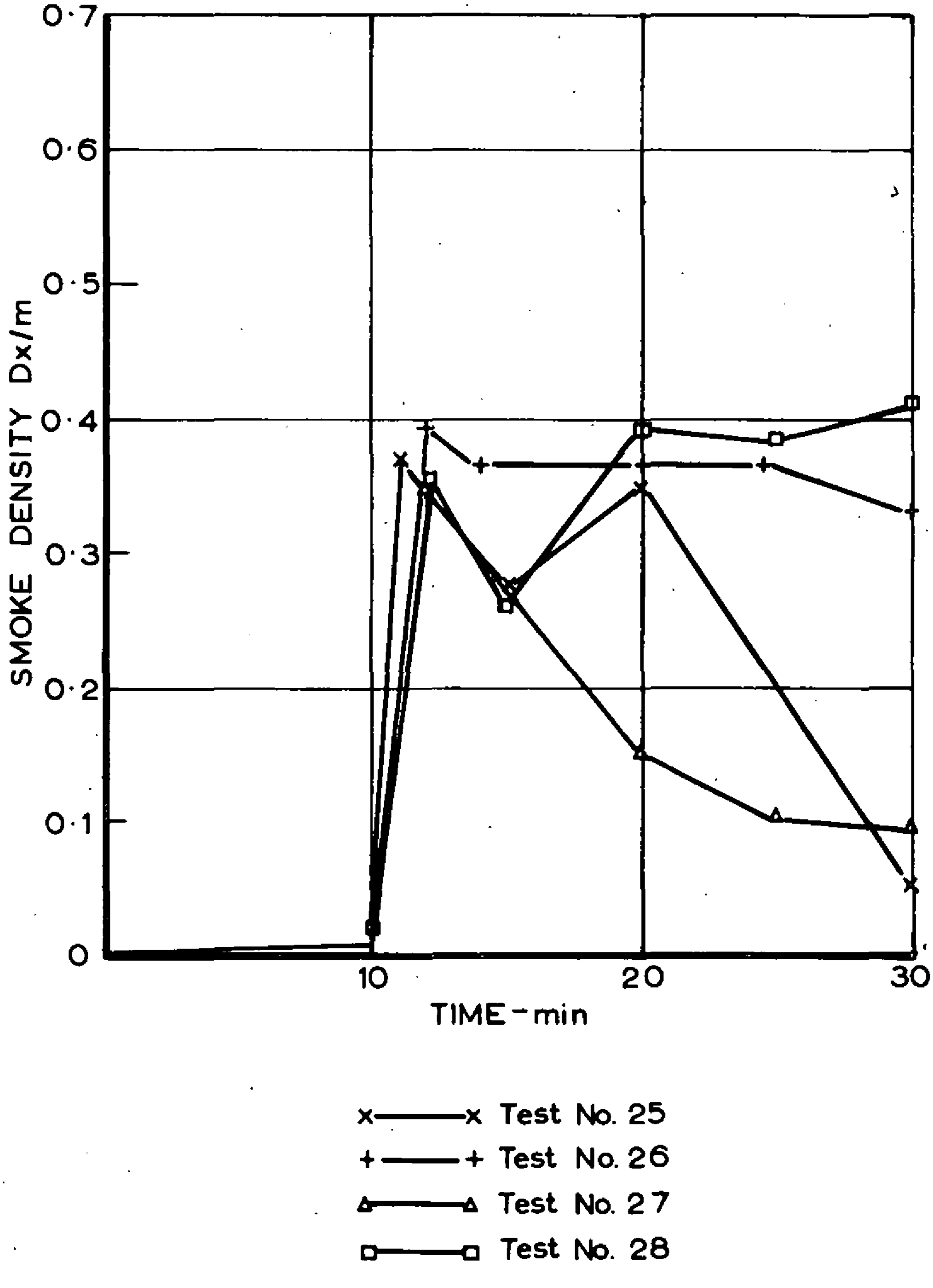

FIG. 11. MEAN SMOKE DENSITY CURVES – TEST Nos. 25, 26, 27 & 28

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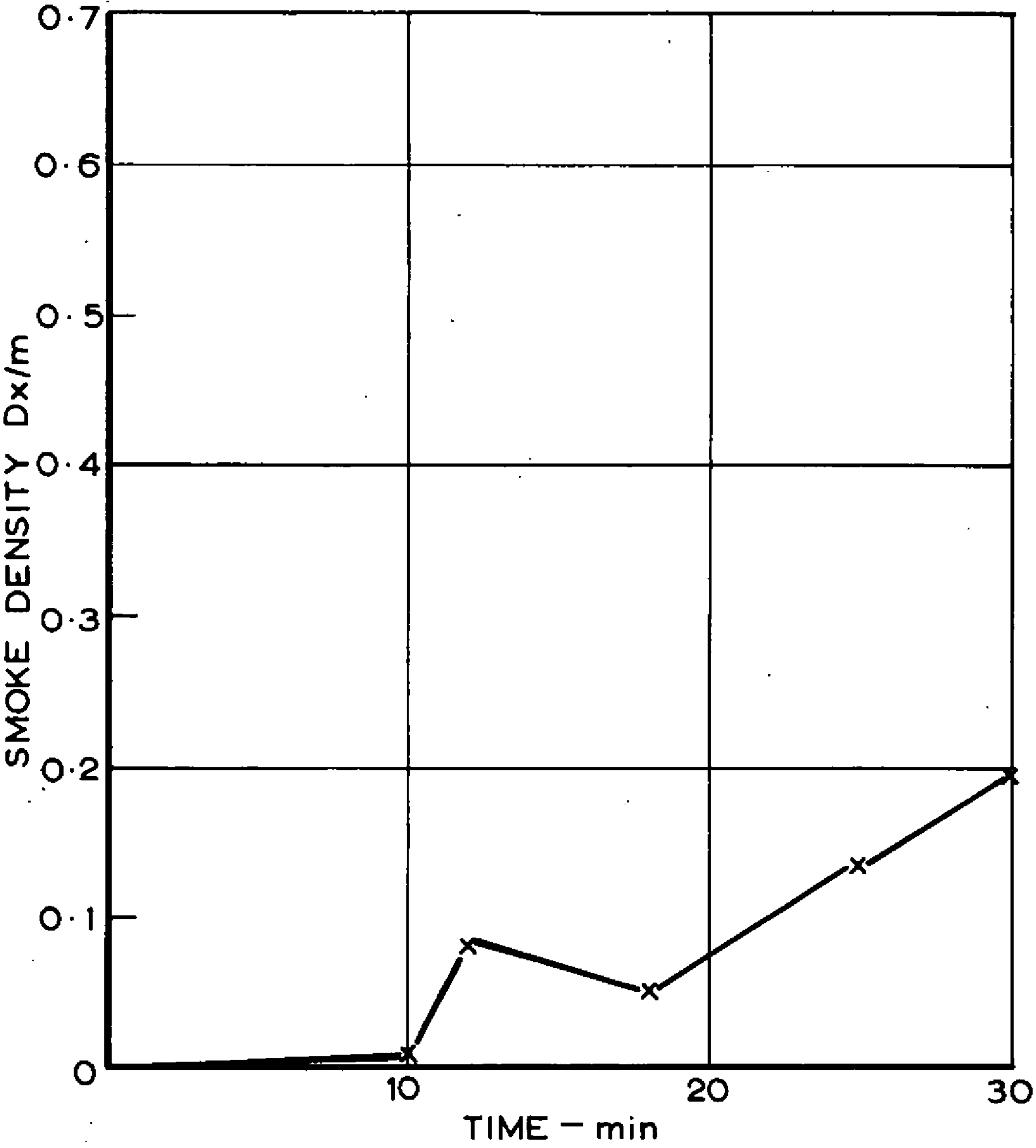

FIG. 12. MEAN SMOKE DENSITY CURVE - TEST No. 29

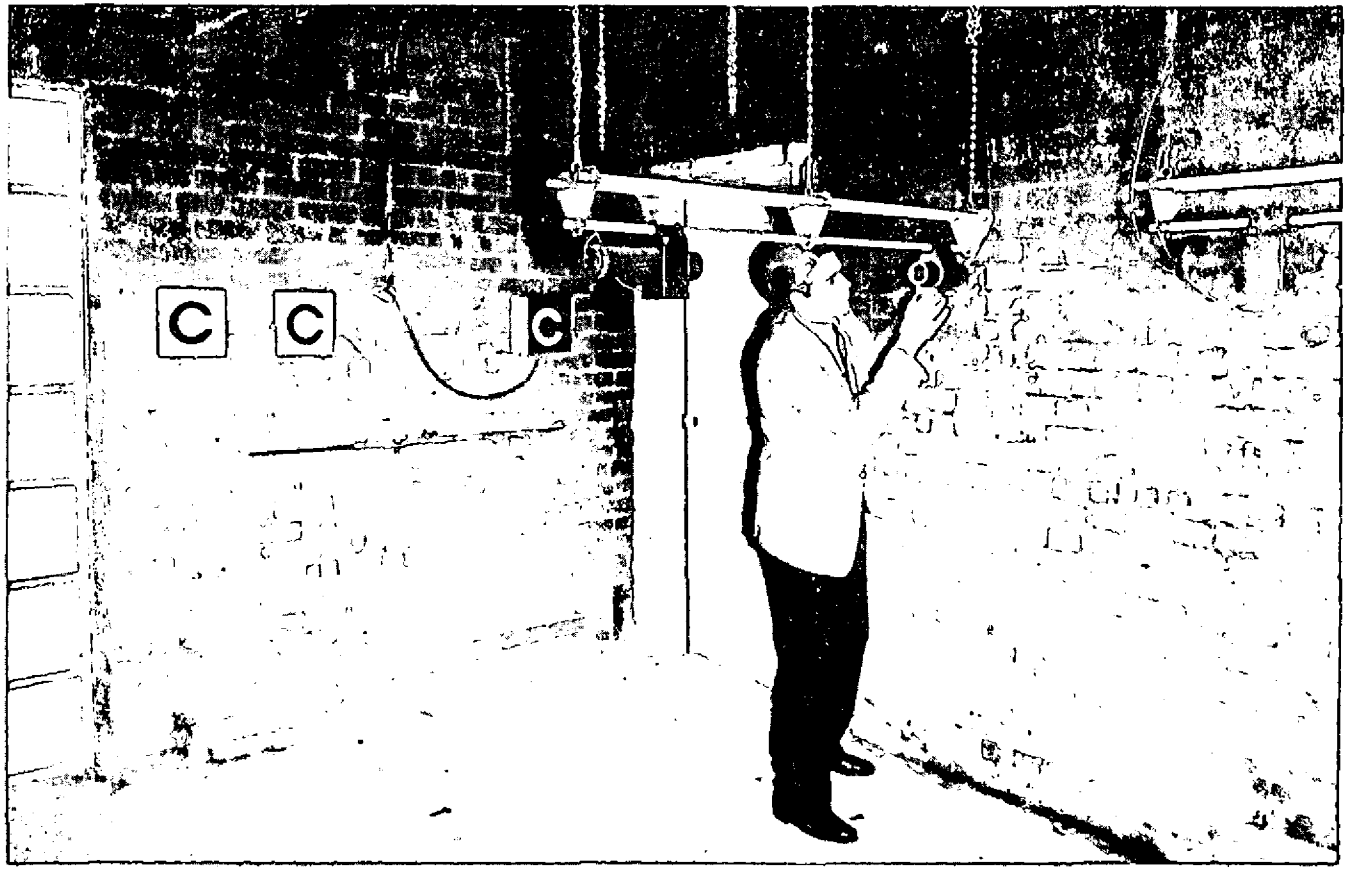

PLATE 1 FIXING AND SETTING OF SMOKE METERS IN LOBBY
IN BACKGROUND VISIBILITY TARGETS AND ON LEFT
ADJUSTABLE VENTS

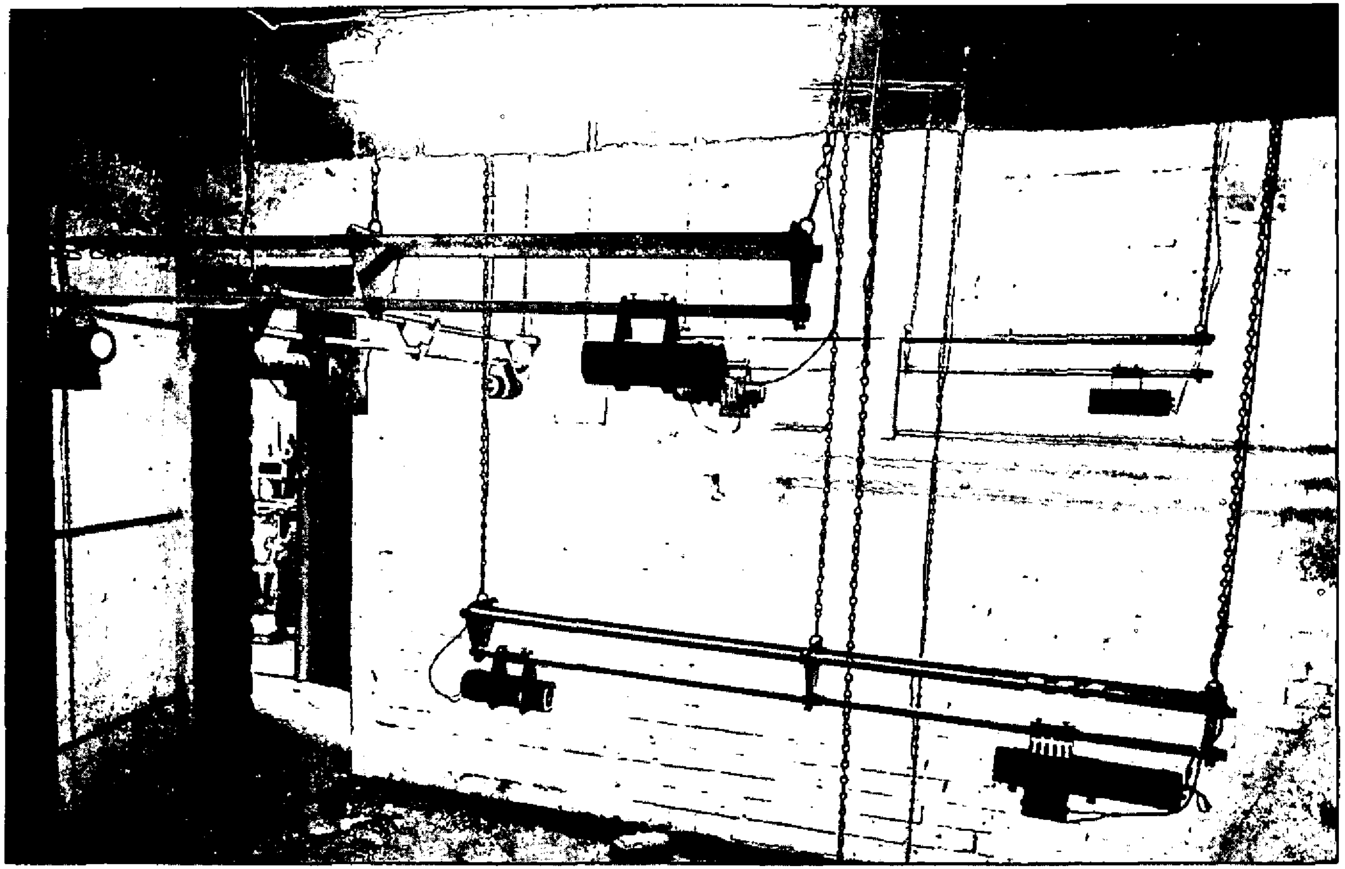

PLATE 2 DISTRIBUTION AND LOCATION OF SMOKE METERS IN LOBBY

PLATE 3 EMISSION OF SMOKE FROM WINDOW OF FIRE CHAMBER IN AN AD HOC TEST

PLATE 4 AN EXPLORATORY EXPERIMENT SHOWING TENDENCY OF SMOKE TO STRATIFY