Fire Research Note

No. 850

SMOKE TESTS IN THE PRESSURIZED STAIRS AND LOBBIES IN A 26 STOREY OFFICE BUILDING

by

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SUMMARY

Smoke tests carried out in a 26 storey office building which had pressurization installed on its stairs and lobbies showed that the system satisfactorily prevented any smoke from entering the protected spaces.

KEY WORDS: Smoke, movement, tests, building, multi-storey, pressurization

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INTRODUCTION

Recent research[1] carried out at the Fire Research Station, Boreham Wood, has shown that pressurization is practicable as a means of protecting stairs and lobbies from invasion by smoke in circumstances where ventilation by natural means is not possible.

When the Cardiff Fire Brigade was consulted about the problem of ventilating the stairs and lobbies in the centre core of the 26 storey office block at Greyfriars they suggested that this system should be used since the building design precluded the use of natural ventilation.

After the building was completed but before it was occupied the Chief Officer of Cardiff Fire Brigade invited the Fire Research Station to participate in smoke tests that were to be carried out in order to establish that the provisions made were satisfactory.

DESCRIPTION OF THE BUILDING

The building was a 26 storey tower block which was intended mainly for office occupancy. In plan it was approximately 28 m (92 ft) square. It had a centre core which contained the services, lifts, stairs and toilets. The office accommodation completely surrounded this but was separated from it by a corridor 1½ m (5 ft) wide which ran completely round this centre part.

A photograph of the building is shown in Plate 1 and Figure 1 shows a plan of a typical floor, on each of which there is approximately 465 m^2 (5000 ft^2) of office space. The overall size of the centre core is 14.6 m (48 ft) x 11.6 m (38 ft). It contains five lifts and two staircases. One staircase opens via a small unventilated lobby 1.8 m (6 ft) x 1.2 m (4 ft) directly into the corridor serving the office accommodation. The other staircase and all five lifts open into the main lobby 10.4 m (34 ft) x 2.1 m (7 ft) wide which is placed across the centre of the core and communicates at both ends with the office corridor by single swing self-closing doors with plain centre styles. All of the doors leading on to the staircases are single swing self-closing with one leaf narrow and normally fixed in the closed position, and their centre styles are rebated.

DETAILS OF THE VENTILATION SYSTEM

Mechanical ventilation and air conditioning was arranged to serve the whole building. Openable windows were agreed on each floor level to approximately 2½ per cent of the office accommodation floor area. In order to provide a standard window frame for the contractor, a frame was designed having openable windows at high level for ventilation purposes on any floor affected by smoke These frames were then used on all windows giving openable areas in excess of the specified requirements.

In the office accommodation air is fed into the space by duct openings below each window and is extracted into ducts situated in the false ceiling of the central corridor. There is no direct air feed into the corridor but air is extracted at two grilles in the ceiling, one in each leg of the corridor which has no door to the centre lobby.

There is air extract and air feed on both the stairs and air is fed into each centre lobby via a grille at all the floor levels high up and centrally placed in this lobby. In addition there is air extract from both of the toilets and the tea room on each floor.

The position of the main air supply and extract grilles associated with the centre core are shown in the diagram of Fig.2.

The normal operating condition of the ventilating system is as follows:-

1. Office space

Warm air is supplied to the office accommodation at low level all round the external face of the building and the same amount of air is extracted at high level via the void above the false ceiling to the corridor which encircles the centre core on each floor.

2. Centre core

On each staircase the air fed into the shaft via a grille at every floor level is balanced by that extracted at the corresponding landing. The air feed and extraction is such that 4 air changes per hour is achieved.

The air feed into the central lift lobby on each floor is designed to be 350 c.f.m. which corresponds approximately to 10 air changes per hour. No air is extracted from the lobbies but the air is drawn off in each toilet room and at the two extract grilles in the ceiling of the surrounding corridor.

When smoke is detected by one of the detector heads located in the office accommodation the following conditions in the ventilating system will apply:

(1) The air supply to the office accommodation is shut off throughout the building but the air extract from the office space remains in operation.

(2) The air supply to each staircase is increased by a factor of four but the extraction remains at the figure which applies for normal operation.

(3) The air supply to the central lift lobbies continues but is not increased. The air extraction from the two grilles in the side corridors is also maintained.

(4) The extract systems for the toilets and tea rooms are closed down.

As a result of these changes in the system the excess air supplied to the stairs will keep these at a pressure in excess of that in the space on to which they open, in one case the central lift lobby and in the other in the small lobby which itself gives access to the accommodation corridor.

The air being supplied to the central lift lobby will add to that leaking on to it from the stair and all of this will leak out through the single swing doors at each end into the corridor. It will then be extracted by the ducts still operating or will leak out of this corridor into the office accommodation via the doors and then out of the building by the office extract system and the window crackage.

SMOKE TESTS

Three smoke tests were carried out in order to assess the effectiveness of the pressurization system. Air flow, pressure differential, and air temperature were measured for each test in the positions indicated in Fig.2.

For all of the tests smoke was generated from standard smoke candles. In Tests 1 and 2 smoke candles were ignited at one corner of the corridor surrounding the centre core. For the third test a smoke candle was used in the central lift lobby.

The ventilation conditions used in the test were as follows:

Test 1. Fans operating as for emergency but all extract grilles on Stair 1 were sealed.

Test 2. Fans operating as for emergency but all extract grilles on both stairs operating.

Test 3. Initially all fans were switched off, then fans switched on as for emergency operation.

Tables 1-3 show the sequence of events and observations for the three tests. Table 4 and Figures 3-6 give details of the measurements made during the three tests and also during the normal operation of the ventilation system.

Table 1

Schedule of events and observations for Test 1

Ventilating fans operating as for emergency (or fire) condition.
All extract grilles on Staircase 1 covered.

Time (min)	Event or observation
0	1 Smoke candle ignited in corridor (see Fig.3).
2	Smoke filling corridor on Stair 2 side of building. No smoke discernible in either stair or lift lobby.
3	Door to corridor at Stair 1 end opened momentarily to observe smoke condition in corridor. Visibility in corridor approx. 1 metre.
4	Corridor extract shut off.
5	No Smoke reported on stairs or lift lobby.
6	Door between corridor and lift lobby at Stair 1 end opened to allow passage of two people - no sustained smoke encroachment into lobby or stair.
8	Toilet extract fans shut off.
9	Doors to corridor at both ends of lift lobby opened wide. Smoke density in corridor relatively low. (Visibility approx. 2 metres). Slight smoke encroachment into lobby - detected only by smell not by sight - no smoke on to stairs.
10½	Doors shut.
13	No smoke now detectable in lift lobby.
15	Test concluded.

Table 2

Schedule of events and observations for Test 2

Ventilating fans operating as for emergency (or fire) condition
All extract grilles on both staircases operating

Time (min)	Event or observation
0	2 Smoke candles ignited in corridor (see Fig.4)
2	Smoke spreading to corridor at both ends of lift lobby - visibility approx. 1½ metre at each lift lobby door.
3	No smoke detectable in lift lobby - no smoke reported on either stair.
4½	Door to corridor at Stair 1 end opened to allow passage of 1 person.
5	Visibility in corridor approx. 1½ metre.
5½	Door to corridor at Stair 1 end opened to allow return of same person.
6	Faint smell of smoke in lobby - no smoke visible, no smoke reported on stairs.
7½	Visibility in corridor approx. 2 metres. Doors to corridor at each end of lobby opened wide to allow smoke to enter lobby.
8	Smoke encroaching into lift lobby but visibility in lift lobby still greater than 10 metres.
9	Doors closed.
15	All trace of smoke in lift lobby gone.
16	Test concluded.

Table 3

Schedule of events and observations for Test 3

Initially all fans off - later as indicated fans operating as for emergency condition - all extracts on both staircases open

Time (min)	Event or observation
-5	1 Smoke candle lit in lift lobby - smoke density became such that visibility was approx. ½ metre. No smoke reputed on either stair even with all fans off.
0	Fans started as for emergency operation.
¾	Visibility 2 metres
4½	Visibility 5 metres
6	Visibility 6 metres
7	Window panel in door at end of lobby visible - 11 metres
8	Visibility 7 metres
10	Visibility 10 metres
11	Visibility 11 metres
12	Test concluded
	At no time during this test was any smoke reported on either staircase.
	Note: Visibility measurements relate to black figures on white background.

Table 4

Details of measurements made

	Fans as for emergency operation Test 1		Fans as for emergency operation Tests 2 & 3		Fans operating normally		No fans operating	
PRESSURES	mm w.g.	in w.g.	mm w.g.	in w.g.	mm w.g.	in w.g.	mm w.g.	in w.g.
P1	1.02	0.04	0.76	0.03	0.25	0.01	0.127	0.005
P2	0.635	0.025	0.51	0.02	0.10	0.004	0.127	0.005
P3	0.635	0.025	0.38	0.015	0.25	0.01	0.178	0.007
P4	0.51	0.02	0.51	0.02	0	0	0	0
AIR FLOWS	m^3/min	c.f.m.	m^3/min	c.f.m.	m^3/min	c.f.m.	m^3/min	c.f.m.
Stair 1 input	6.8	240	6.8	240	1.9	67	0	0
" extract	-	-	3.0	107	3.0	107	0	0
Stair 2 input	7.9	280	7.9	280	0.8	27	0	0
" extract	1.9	67	1.9	67	1.9	67	0	0
Lift lobby input	5.9	210	5.9	210	5.9	210	0	0
Corridor extract	3.4	120	3.4	120	3.4	120	0	0
Stair 1 side Stair 2 side	3.4	120	3.4	120	3.4	120	0	0
Toilet extract	0	0	0	0	1.70	60	0	0
Stair 1 side Stair 2 side	0	0	0	0	0.85	30	0	0
TEMPERATURES	°C		°C		°C		°C	
T1	20		20		12		12	
T2	13		13		13		13	
T3	8		10		9		9	
T4	7		8		8		8	
T5	7		7		7		7	
T6	10		11		10		10	
T7	12		12		12		12	
T8	14		14		14		14	

DISCUSSION OF RESULTS

The results of the measurements for the various conditions used in the tests are shown in Table 4 and Figs 3-6. The measurements of pressure differential are made across the doors in the positions indicated and therefore in certain circumstances these figures are additive, for example in Test 1 the pressure difference between the corridor and stair 1 would be 1.65 mm (0.065 in) w.g. and in Test 2 this pressure difference was 1.27 mm (0.05 in) w.g.

The purpose of Tests 1 and 2 was to demonstrate that pressurizing the stairs and lift lobby would prevent smoke from entering these vital parts of the escape route if a fire occurred anywhere in the office accommodation.

The pressure difference measurements made showed that the lobby of the central core was maintained at a pressure above that in the corridor and office accommodation during the normal operation of the ventilation system, the excess being 0.25 mm (0.01 in) w.g. but the pressure difference across the doors to the stairs was smaller (0.1 mm (0.004 in) w.g. for stair 1 and zero for stair 2) due to the fact that the extract system on these stairs was removing as much air as was being supplied by the air input system.

When the fans were operated as for the emergency condition the pressure excess in the two stairs rose to 0.5 mm (0.02 in) w.g. and this value for stair 1 adds to that of the lift lobby to give a pressure difference between stair 1 and corridor of 1.27 mm (0.05) w.g.

The smoke tests carried out demonstrated quite clearly that this pressure excess was adequate to prevent smoke entering the centre core with the doors closed. Even when the doors to the corridor were opened the smoke penetration was relatively small and that this was quickly cleared by the air being supplied to the core.

The difference between tests 1 and 2 was that in the first the extract system on stair 1 was not working, but a comparison between the result of the two tests does not show positively whether there is any merit in including this feature in a pressurization system.

The argument in favour of including an extract system is that if smoke should encroach on to the stair then the extract will allow it to be removed. On the other hand the extraction of air lessens the total available for pressurization and therefore reduces the excess pressure developed. However, the tests did show quite conclusively that a pressurization system will act to clear smoke without the help of extraction, the lift lobby was so cleared after the doors to the corridor were opened.

There is no doubt however that an extract system has a part to play in a pressurized building, particularly, in one which is almost completely sealed. The provision of extracts in the corridor in this building served to reduce the pressure in this area and at the same time form a necessary leakage path for the pressurizing air. It could perhaps be argued that the increased use of extraction in this part of the building would have been preferable to supplying extract on the stairs.

The purpose of Test 3 was to simulate the extreme situation in which the central lift lobby on one floor became badly smoke logged presumably because the doors were held or fixed open.

The test showed that when the doors were closed again the pressurizing air supply acted to clear the smoke comparatively rapidly and visibility initially less than $\frac{1}{2}$ metre was raised to 2 metres in $\frac{3}{4}$ minute and to 5 metres in under 5 minutes.

The test also showed that even when the lift lobby was completely smoke logged the pressurization system prevented any smoke encroachment on to the stairs.

During the period covered by the three tests the external wind conditions were very variable.

At the start of the tests the wind direction was SW and the speed was 26 km/h (16 mph) but by the end of the tests the speed had increased to 48 km/h (30 mph) and it had veered to the NW.

However the air flow and pressure measurements made during this period were quite steady and it is therefore clear that the extreme weather conditions were

having little effect on the pressurization arrangements made inside the building.

It was accepted when the tests were being planned that it was not practicable to use hot smoke and that it would be necessary to use the standard smoke canisters. The temperature measurements made at the point of smoke generation (T_1 in Table 4) indicate that 20°C was the order of the temperature of the smoke used.

It is recognized then that the tests described here do not reproduce the pressures developed in a fire situation. Nevertheless the results were so positive and the measured pressure differences were in general greater than those reported from measurements made in a fire test[1] that the authors have no doubts as to the effectiveness of the system under real fire conditions.

Owing to limitations in the availability of the building the tests had to be carried out before the final adjustments to the ventilation system had been completed.

For this reason the measured air flows and consequently the pressures developed are somewhat lower than those specified by the Design Engineers and agreed by Cardiff Fire Brigade.

The assurance was however given that when the necessary adjustments had been made the specified air flows would be achieved. Consequently when the building is occupied greater pressures than those measured in the test will be available to prevent smoke from encroaching on to the vital escape routes.

CONCLUSIONS

1. The pressurizing system installed acted as a positive smoke control and no smoke penetrated into the protected spaces. Even with doors open the smoke penetration was minimal.
2. Although cold smoke was necessarily used in the tests the measurements showed that the pressure differences developed would have been adequate to control smoke from a fire. Additionally greater pressure differences will be produced when the ventilator system is finally adjusted thus increasing the measure of control available.
3. All of the tests demonstrated that pressurization has a definite smoke clearance action, and one test measured this for a case of very severe smoke logging.

4. The external variable weather conditions did not disturb the pressurizing system in any way.

ACKNOWLEDGMENTS

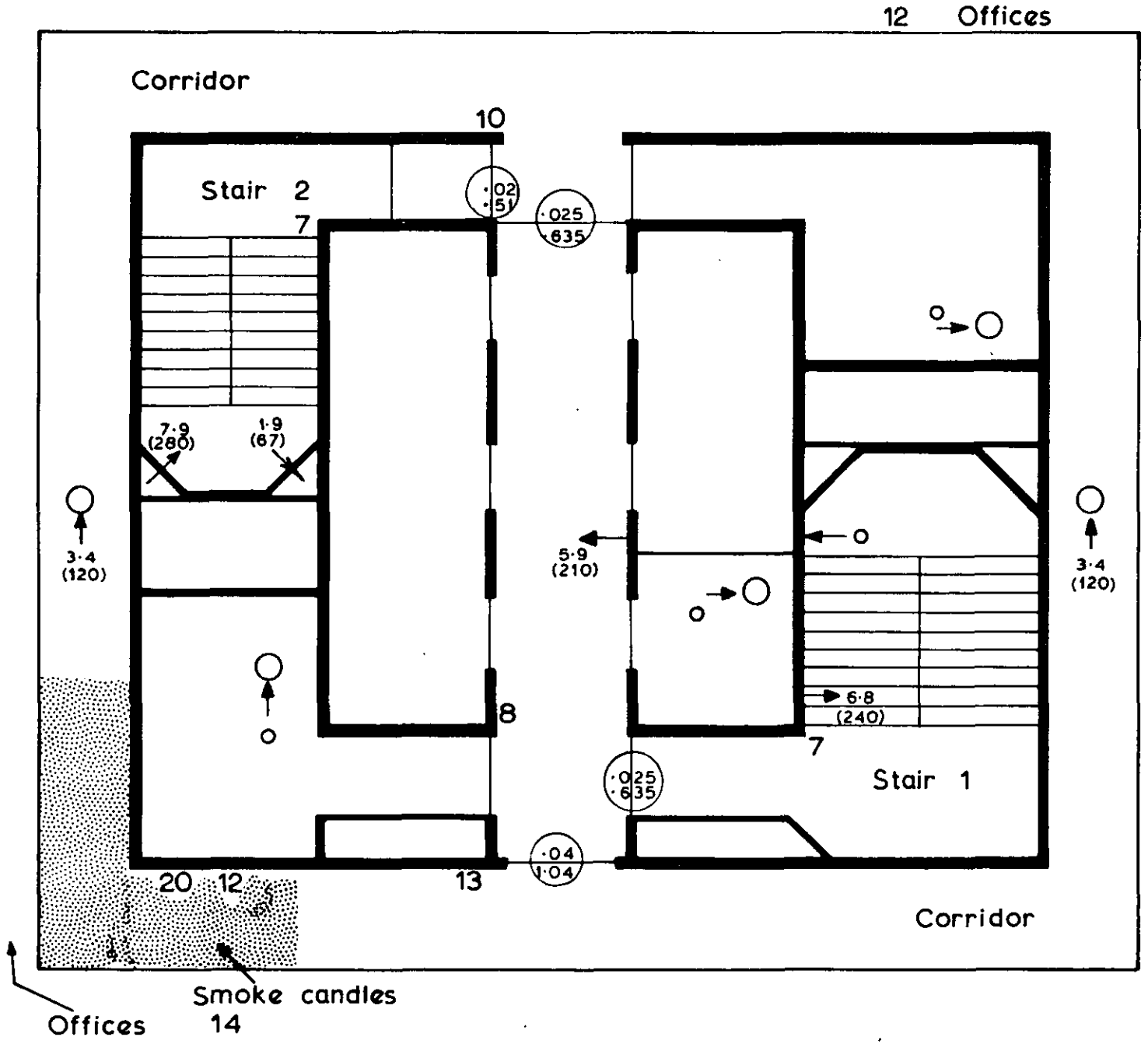
The authors wish to thank Mr. M. J. Mace, the Chief Officer of Cardiff Fire Service for his encouragement and for providing facilities and help without which it would not have been possible to carry out the tests.

They are grateful to the Pearl Assurance Company Ltd, for making the building available for the experiments.

The photograph of the building is reproduced by courtesy of the Western Mail and Echo.

REFERENCE

1. BUTCHER, E. G., FARDELL, P. J. and CLARKE, J. J. Pressurization as a means of controlling the movement of smoke and toxic gases on escape routes. F.R. Note 704, 1968.



TEST 1
STAIR FANS ON BOOST EXTRACT
ON STAIR 1 COVERED (all floors)

→ 1·9(67) Airflow measured in m^3/min and ft^3/min

(·02 ·51) Pressure difference measured in millimetres and inches water gauge

10 Temperature °C

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FIG. 3. MEASUREMENT AND AIR FLOW CONDITIONS FOR TEST 1

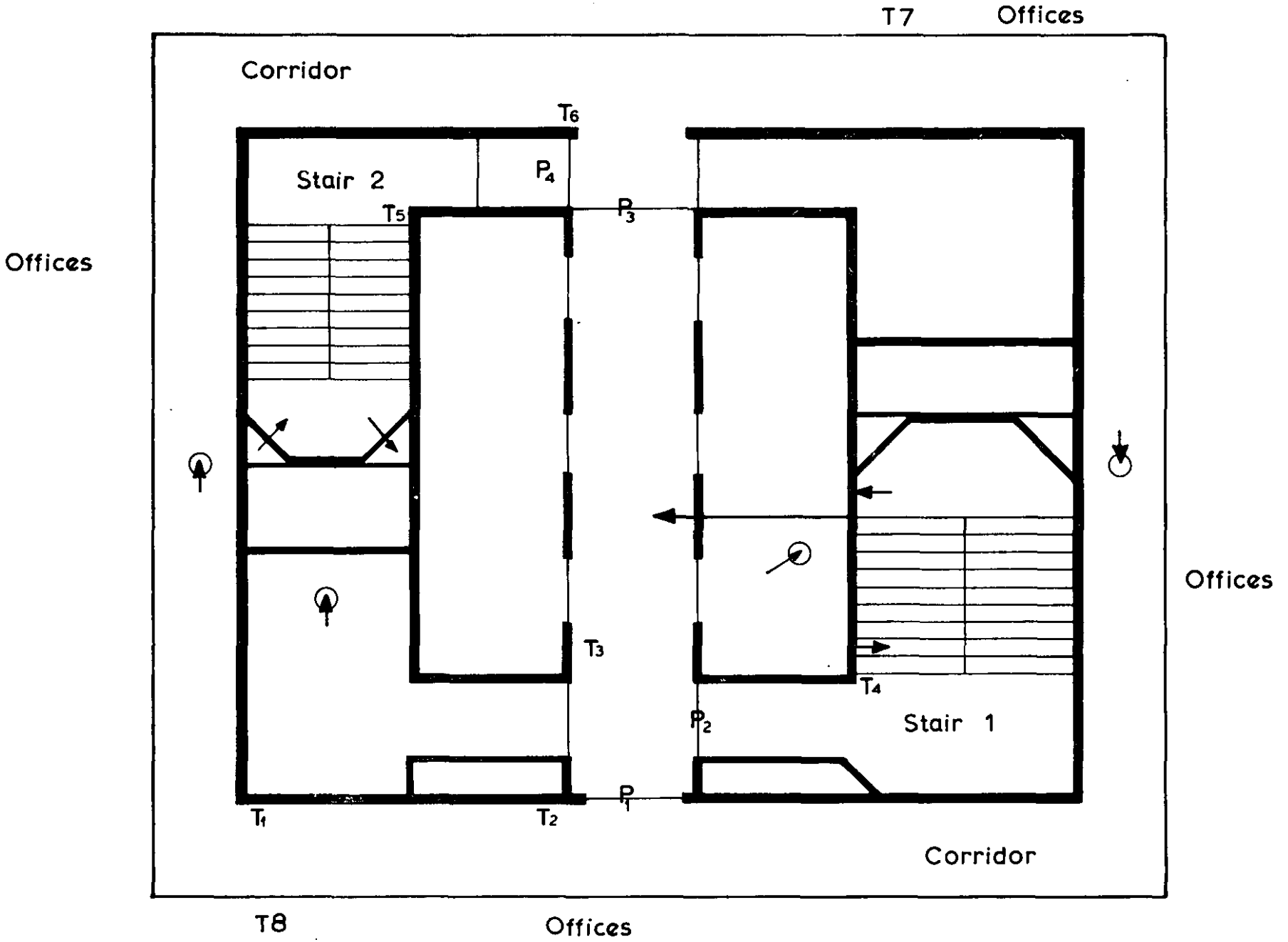


FIG. 2. AIR INPUT AND EXTRACT IN CENTRE CORE AND MEASURING POSITIONS USED

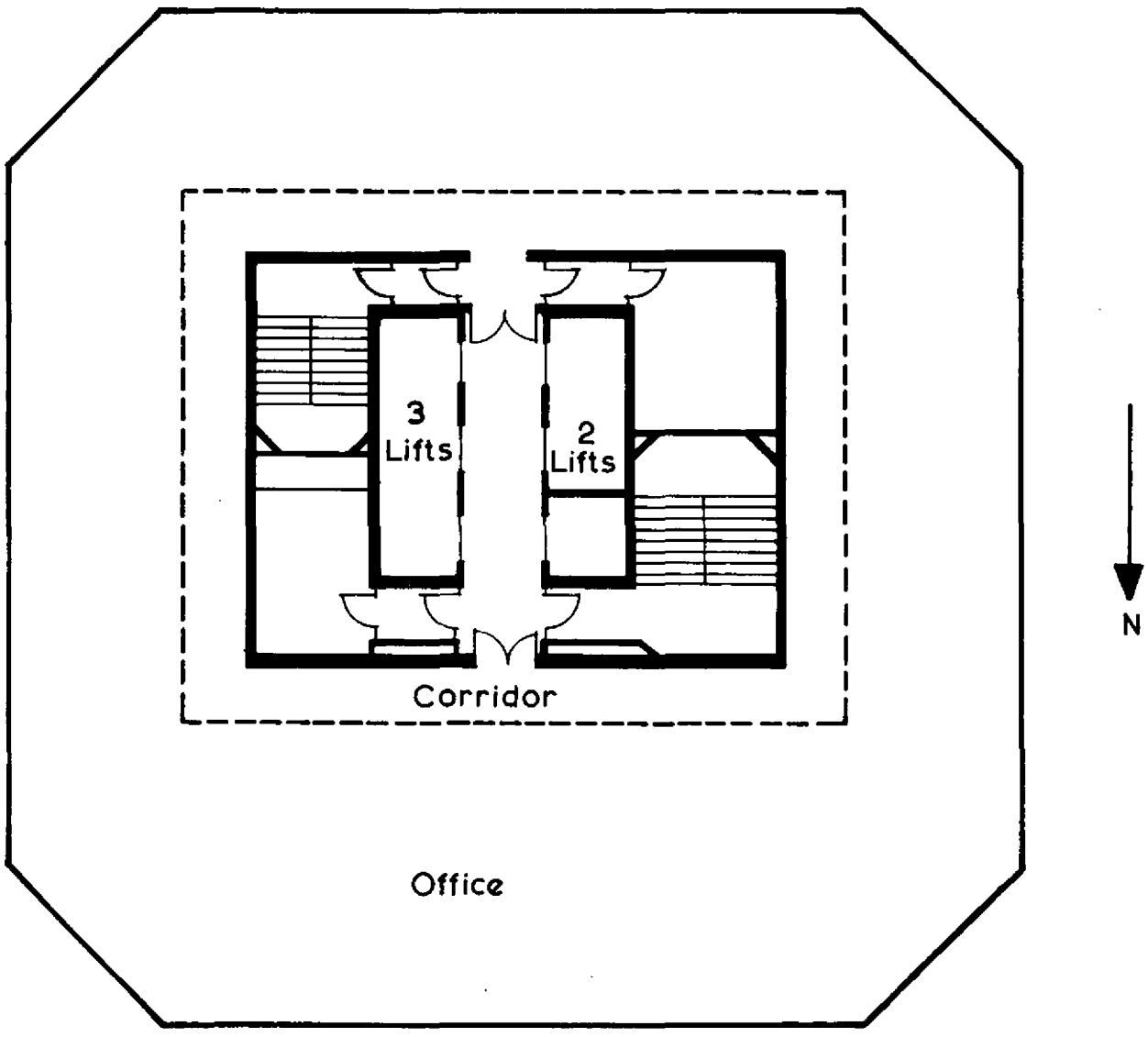
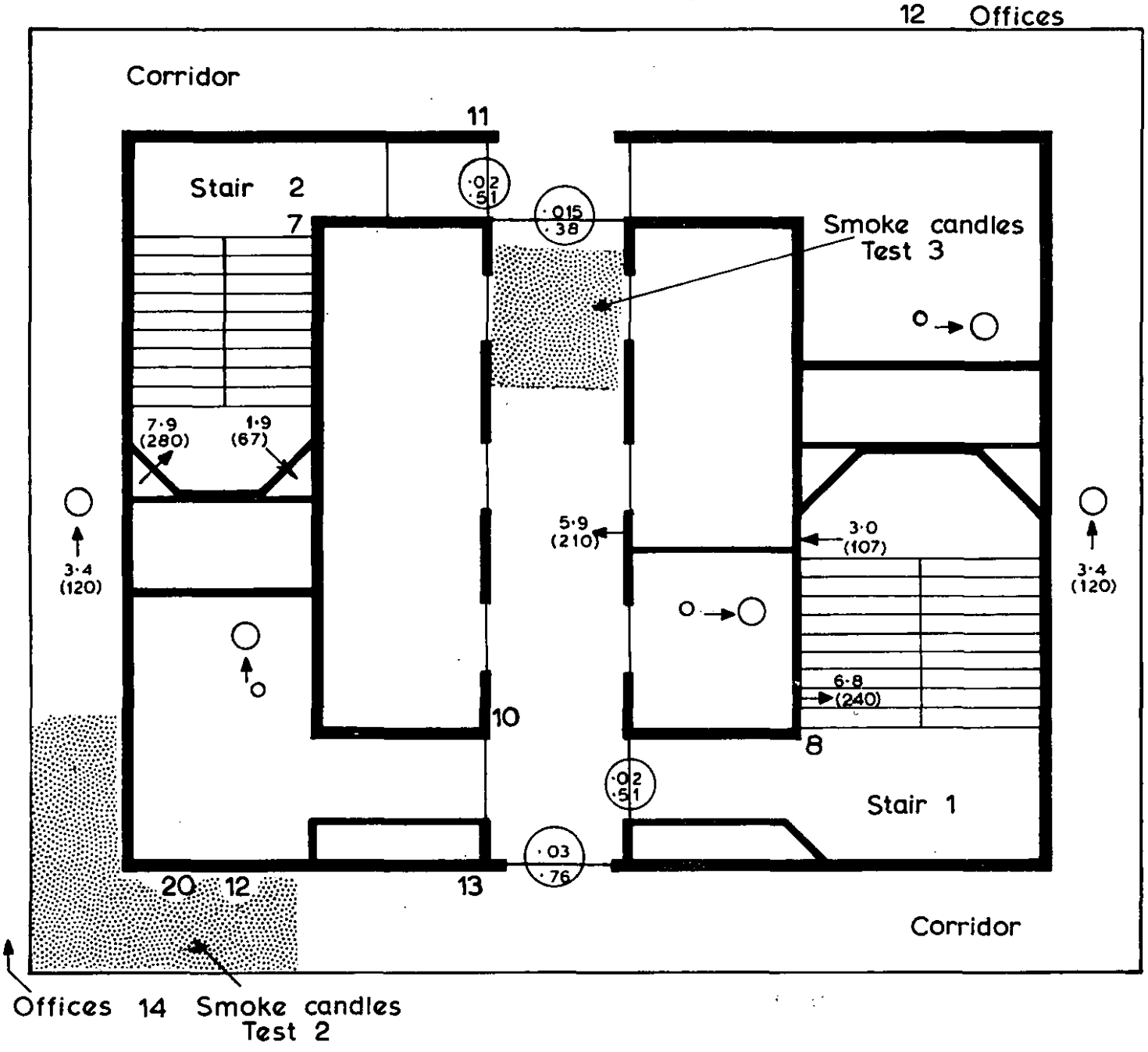


FIG. 1. TYPICAL FLOOR PLAN



TEST 2 and 3
STAIR FANS ON BOOST
STAIR EXTRACTS OPEN

→1·9 (67) Airflow measured in m^3/min and ft^3/min

(·02 / ·51) Pressure difference measured in millimetres and inches water gauge

10 Temperature °C

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FIG. 4. MEASUREMENT AND AIR FLOW CONDITIONS FOR TEST 2 AND 3

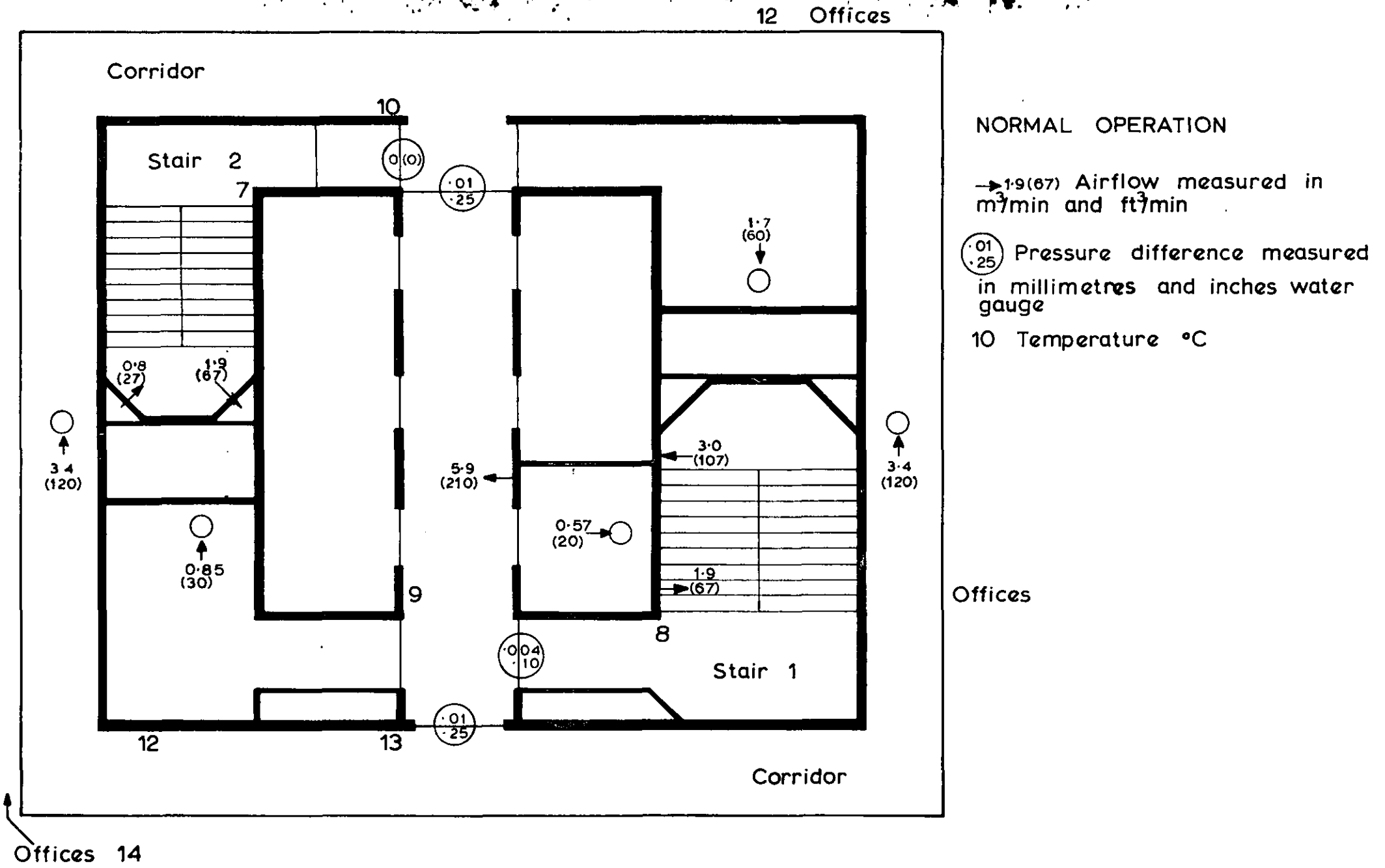


FIG. 5. MEASUREMENTS AND AIR FLOW CONDITIONS FOR NORMAL OPERATION OF FANS

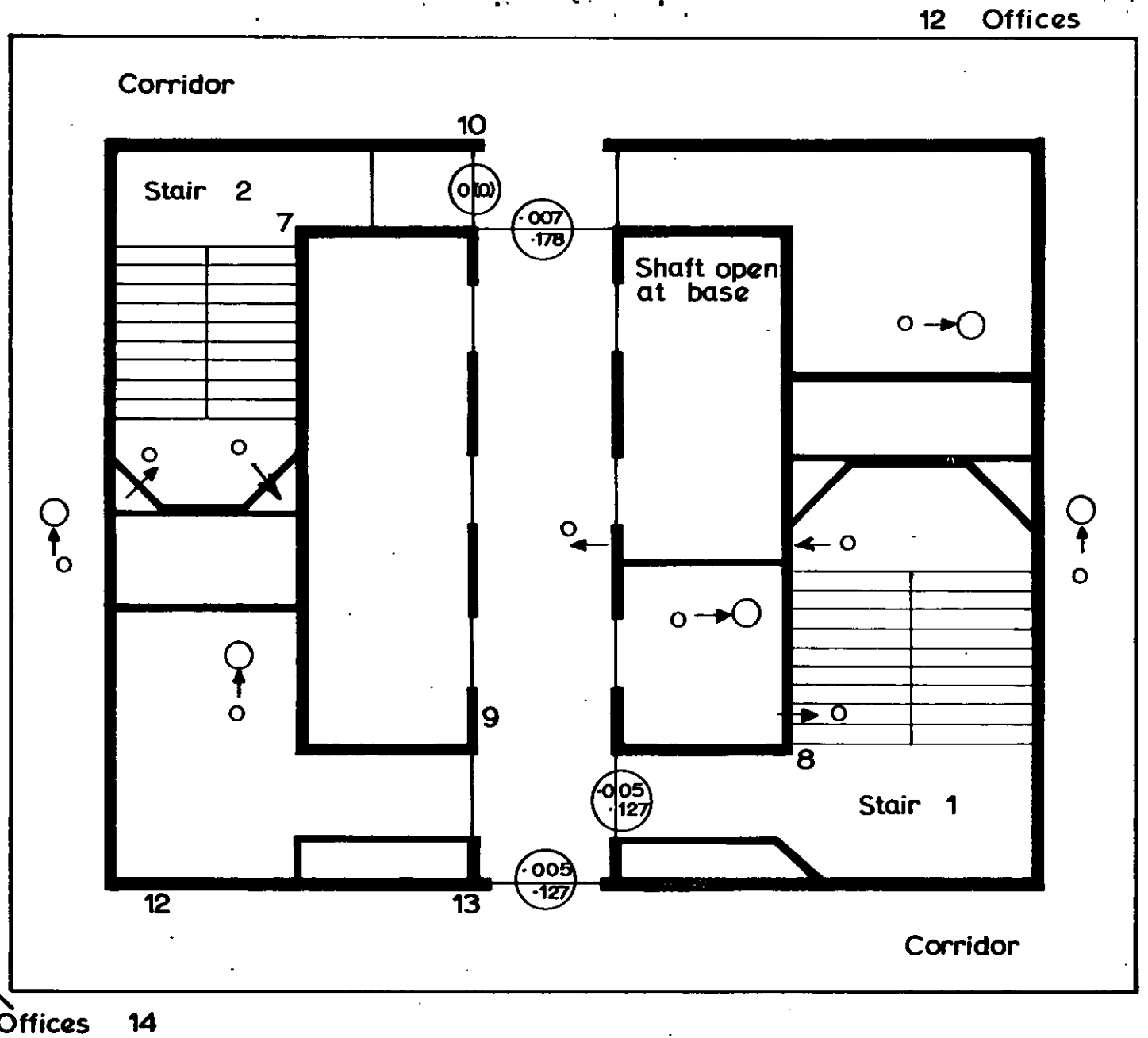
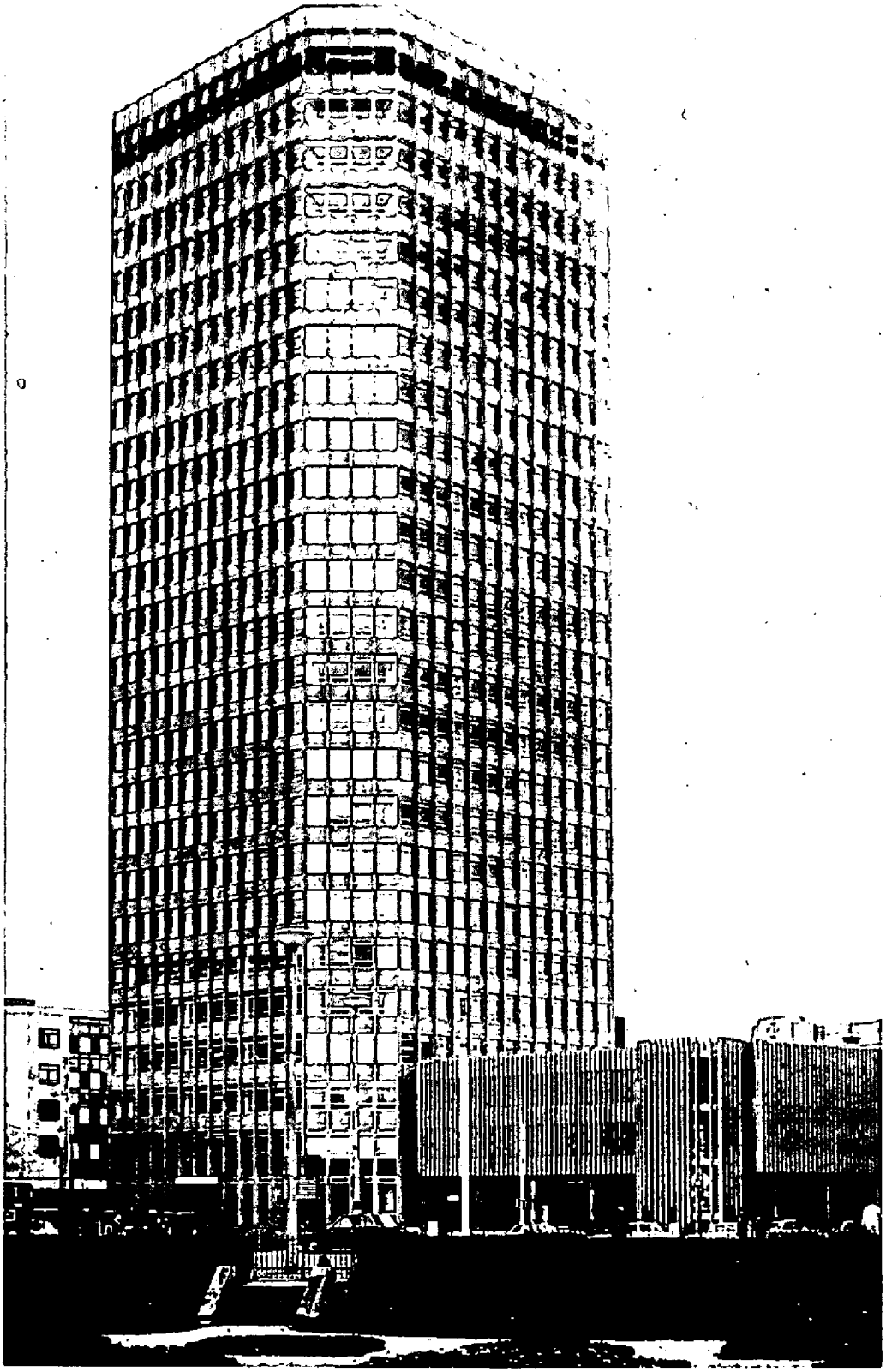


FIG. 6. MEASUREMENTS AND AIR FLOW CONDITIONS WITH NO FANS OPERATING



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BUILDING USED WITH CARDIFF FIRE BRIGADE
IN PRESSURIZATION TESTS TO LIMIT SMOKE MOVEMENT

PLATE 1