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THE PREDICTION OF THE BEHAVIOUR OF SMOKE IN A BUILDING USING COMPUTER TECHNIQUES.

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SUMMARY

A method is described for calculating the movement of smoke in a building caused by a fire in one or more rooms, using a digital computer. The density of the smoke, as well as the smoke spread, can be estimated.

KEY WORDS: Behaviour, Building, Computer, Movement, Smoke.

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

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1. Introduction

The theoretical study of the movement of air throughout a building involves a very complex set of calculations but by using a digital computer this becomes practicable.

For the purposes of the calculation the building is considered to be a network of air flow paths and, provided the law which governsthe relationship between air flow, air flow path (i.e. window or door crack) and air pressure is known and the absolute values of some of these quantities also known, then air flows and air pressures for the whole building can be calculated.

Having established the air movement pattern for normal conditions, it becomes possible to introduce new values to some of the quantities used in the calculations so that the effect that a fire in the building will have on the movement of air (and therefore smoke) in it, can be analysed.

2. The study of the movement of air through a naturally ventilated building.

2.1. The factors which influence natural ventilation

The process of natural ventilation is dependent on a number of factors which may be divided into three categories namely (1) the motive forces, (2) the external shape and dimensions of the building, and (3) the resistance to air flow through the building.

(1) The two motive forces primarily responsible for natural ventilation are caused by wind impingement and the difference of indoor and outdoor air temperature. The impingement of wind generates regions of substantially different pressures on the faces of a building, and although the pressures are neither uniform nor constant since both the speed and direction of wind undergo continual change, it is possible to specify typical mean wind speeds and assess the pressure distribution on a building for various wind directions by full scale or wind tunnel tests.

2.

2.1.

(1) cont'd

The second motivating force, known as stack effect, arises from temperature differences between air inside and outside the building. These differences result in differences in air density so that, over vertical distances, pressure gradients between inside and outside exist. For example, if the air temperature within a building is higher than that outside, an internal pressure lower than the external pressure is produced in the lower part of the building with an inward flow of air as a consequence. The direction of flow is reversed at the upper levels of the building.

(2) The degree to which the natural forces produce ventilation is governed to a certain extent by the external shape and dimensions of the building. For instance, one would expect the effect of wind to be different on a tall slender building than that on a wide building of the same height. Similarly, the height of a building affects both the influence of wind and air temperature differences.

(3) The rate at which ventilation takes place in a building is not only dependent on the external parameters but also on the resistance to the movement of air through the building. This in turn depends on the air-tightness of the building envelope as well as the internal layout and construction. Apart from openings specially designed for ventilation purposes, the primary air leakage paths are through windows that can be opened and through doors.

2.2. Equation of airflow

The equation governing the flow of air through the cracks and around the windows and doors is

$$V = C.\ell.\ (\Delta p)^{\frac{1}{n}} \qquad (1)$$

where V is the volume flow of air (m^3/h)

C is the air leakage coefficient, being the rate of air leakage per unit length of crack at unit pressure difference.

ℓ is the total length of the crack around the window or door (m)
(= total circumference of openable parts)

Δp is the pressure difference across the component (N/m^2)

$\frac{1}{n}$ is an exponent in which n has a value between 1 and 2

2.2. (cont'd)

The air leakage coefficient, C, is mainly a function of the tolerance to which the component has been constructed and is a measure for the greater or lesser air - tightness of the crack. The exponent $\frac{1}{n}$ is also related to the characteristics of the crack but is not subject to much appreciable variation. The actual values of C and n may be assessed by leakage tests, described in British Standard B.S. 4315, on the types of component under consideration.

2.3. Method of calculating air flow through a building

While it is relatively simple to calculate the flow through a single aperture given the appropriate values of pressure and leakage coefficient, the problem becomes extremely complex when a complete building, with its external and internal pressure gradients and multiple flow paths, is considered. The solution is rendered particularly difficult by the exponential characteristic of the equation of flow and if the value of n is not the same throughout the building, then manual calculation becomes practically impossible. A more suitable technique for the determination of ventilation rates throughout a building, making use of a digital computer, was developed.

To use the digital computer programme, the ventilation paths of the building in question are defined by a series of inter-connected nodes, as illustrated by the example in Figure 1. Each node in the network represents a particular zone of the building and is separately identified. The inter-connections represent the air flow paths between the zones and the equation of flow is used in the calculation of the flow along each path. In the example in Figure 1, node number 1 represents the external pressure zone on one side of the building at ground level, node 36 represents the office space within the building on that side and the interconnecting line (1-36) indicates the flow path, in this case, through the windows.

The relevant leakage characteristics and exponents for each flow path are tabulated together with the values of pressure (due to wind and/or stack effects) which are known for some of the nodes. With these data, the computer programme approaches a solution by making successive corrections to the pressure value at each of the nodes at which the pressure value was not specified, until a flow balance at each of these nodes is achieved. The print-out of the results of this iterative calculation incorporates the rate and direction of the flow along all the interconnections and the pressure level at each node.

2.3. (cont'd)

This technique thus enables the rate of natural ventilation throughout a building to be calculated with speed and efficiency, and it is particularly advantageous for building of unique or complex design.

3. Study of the movement of air in a naturally ventilated building which also has some mechanical ventilation.

In the study of the air movement in a building under natural ventilation conditions the known quantities introduced into the calculations were the values of air pressure developed on the outside of the building by reason of the action of the wind, values for the conductances of the air flow paths, and when appropriate, the pressures developed in the building by the thermal gradient.

In order to introduce the effect of a mechanical ventilation system it is necessary to be able to specify an extra set of known pressures at selected points in the building - these points corresponding to the terminations of the air input or extract ducts. It will not be necessary to make any changes in the values specified for the conductances of the air flow paths since these represent the values of the cracks around the doors and windows and no change will have been made in these.

This is possible in the programme outlined in (2) and represents the easiest way of taking account of the effect of mechanical ventilation.

However, in a ventilating system, design information concerning the pressure developed in any particular room of the building is not normally available, but the volume of air being fed into the various parts of the building by the duct system in a given time is usually the figure which is available either from the initial specification or from performance measurements.

By suitably rearranging the presentation of the specified data, it is possible to use the programme in its present form for calculations in which air flow inputs (or extractions) are specified for some points inside the building in addition to the pressures developed on the outside by wind conditions.

3. (cont'd)

An added advantage of using the programme in this way is that the effect on the pressure developed by the air input caused by opening a door can immediately be found by changing the characteristic of the appropriate air flow path, whereas if pressure is specified and an open door simulated, then the only effect shown by the calculation is a large increase in air input in order to maintain the specified pressure.

Figure 2 shows in diagrammatic form, the result of calculations of air flow in a three-storey building when air is fed by a mechanical system to the three lobbies marked 'P', thus achieving a degree of pressurization in these areas. In this case the air flow into the lobbies was specified for the purpose of the calculations.

4. Extension of calculation to include the effect of fire and smoke in a building.

When a fire occurs in a building a large quantity of hot smoke is generated which is moved round by the action of the temperature differences which are established.

Thus the fire creates pressure differences between the fire room and the adjacent parts of the building and these pressure differences will mainly be a function of the temperature conditions in the fire room although they will also depend on the openings into and out of it, i.e. whether doors and windows are open.

Measurements have already been reported[2] of the pressure differentials (see Fig. 3) which exist in a well ventilated fire between the fire chamber and a corridor at the top of a normal door and the simplest way to simulate a fire for the purpose of the computer calculation is to impose a fixed positive pressure in the fire chamber since the largest effect of a fire will be to drive air out. This approximation is in question only if the openings in the upper and lower halves of the door are of very different sizes.

This can be done several times, each time with a slightly increased imposed pressure so that the effect of fire development can be simulated.

Variations in the characteristics of the air flow paths which represent the door and windows into the fire chamber can be made quite simply so that the condition of broken windows or open doors can be examined. Fig. 4 shows

4. (cont'd)

an example of such a calculation, a positive pressure of 1.25 mm wg (0.5 in wg) has been imposed in the room marked 'Fire' and the conductance of the air flow path representing the window has been increased to simulate it as being broken, and Fig. 5 shows a similar calculation for the same building and the same fire but with the lobbies between the corridor and stairs pressurized.

A more sophisticated representation of the movement of air and smoke into and out of the fire chamber can be made by considering the door between the fire chamber as being several air paths, with air entering the room through the lower ones and smoke going out into the corridor through the upper paths. In the same way the window, either broken or intact, would also be represented by several paths, the lower drawing air into the room and the upper taking smoke out of it.

Each of these paths will be terminated in the fire chamber by a positive or negative imposed pressure and these can be estimated from the results of measurements already reported[1]. Fig. 6 shows the calculation for a building with this more complicated simulation of the fire condition, and Fig. 7 shows the pressure and air flow conditions for the Fire Room when this simulation is used. In this calculation, the air flow in the corridor outside the 'fire' room is shown as the total, i.e. as the net result taking account of the air flow into it and the air flow out of it. This, therefore, assumes a condition of 100 per cent mixing of the air and smoke outside the 'Fire' room and is undoubtedly an oversimplification. However, the programme would allow account to be taken of stratification in the corridor by breaking this volume down into several air flow paths, in much the same way as has been done for the fire chamber - provided suitable factors for the law governing the flow of air in this circumstance are introduced.

The results obtained from the methods described above allow the movement of air and smoke in a building to be studied. It is possible also to assess the smoke density present in any part of the building be deciding how the air flow at any part of the building is constituted, i.e. what proportion is fresh air and what proportion is dense smoke coming from the fire chamber.

5. Conclusion

Using the ideas and calculation techniques developed for the study of the air movement in a naturally ventilated building and making the modifications described to take account of the introduction of ventilation and of fire conditions, the potential movement of smoke and its density can be readily studied for any building.

This will eventually prove to be a very valuable tool for assessing the effectiveness of the means of escape proposals in a building at the early design stage.

6. References

(1) British Standard Specification No. 4315, 1968. "Window and Casket glazing systems".

(2) Fire Research Note No. 704. Pressurization as a means of controlling the movement of smoke and toxic gases on escape routes. E. G. Butcher, P. J. Fardell and J. J. Clarke, April, 1968.

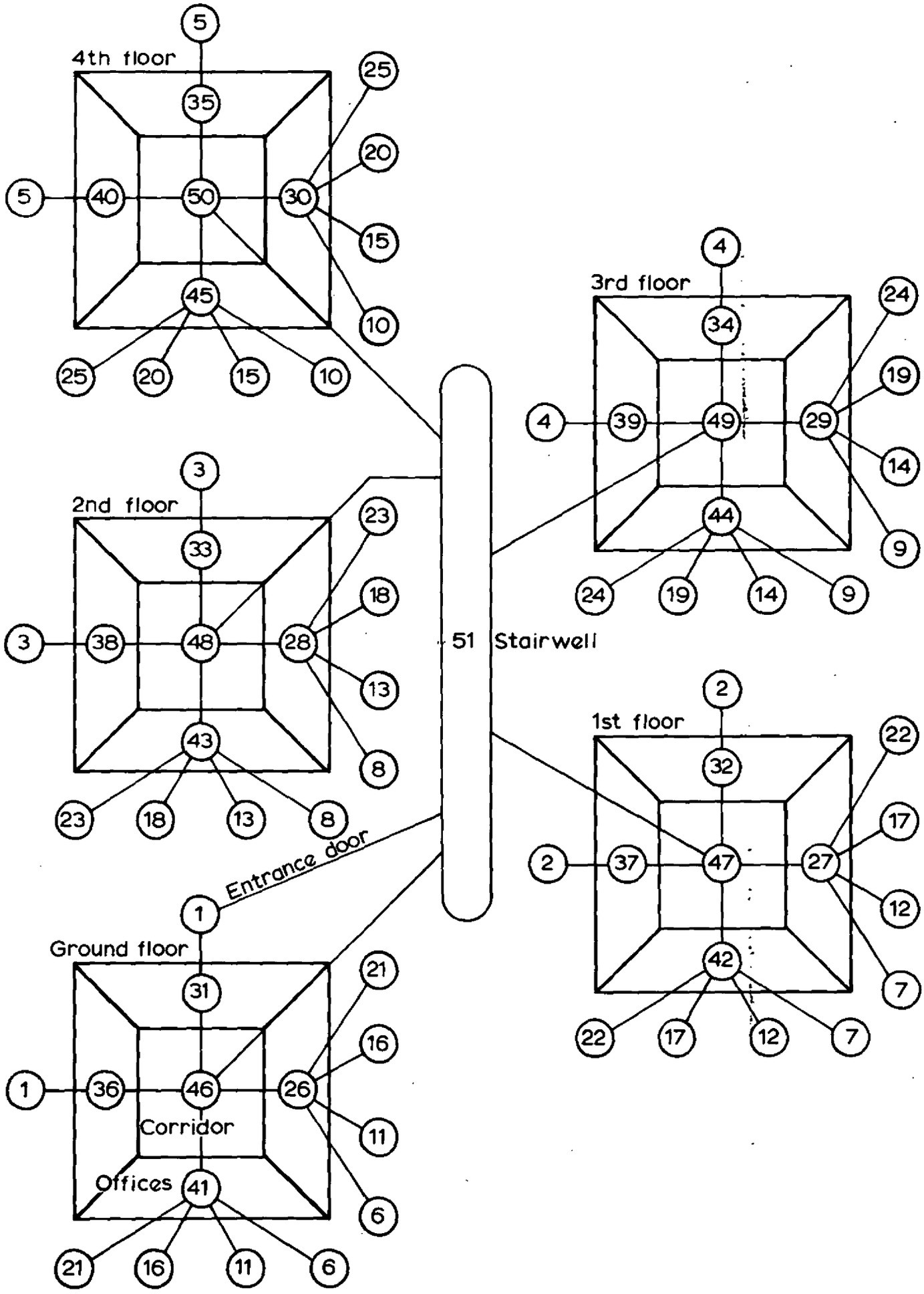

FIG. 1. EXAMPLE OF IDENTIFICATION OF AIR FLOW PATHS FOR USE IN DIGITAL COMPUTER PROGRAMME

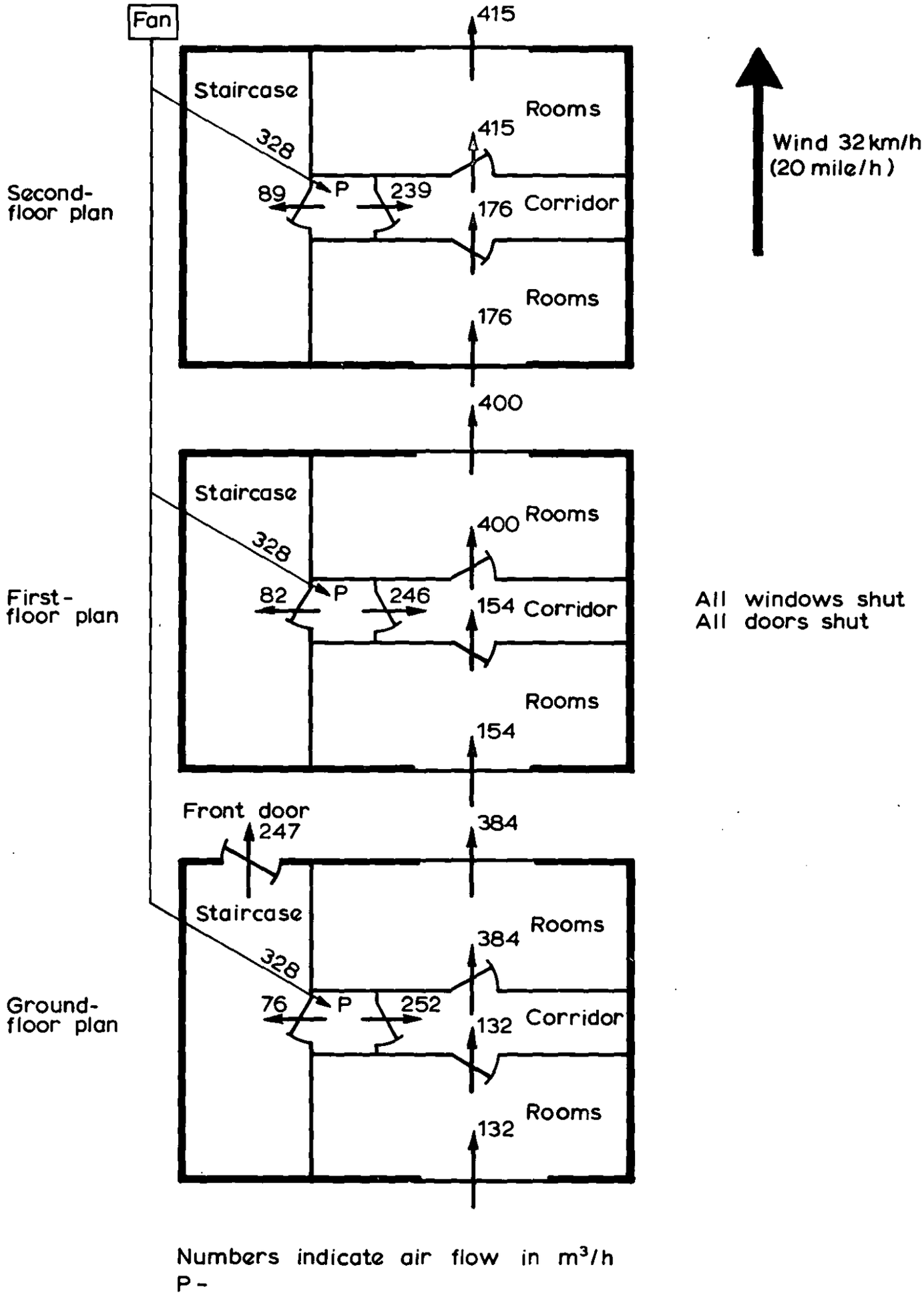

FIG. 2. RESULTS OF CALCULATION OF AIR FLOW IN BUILDING IN WHICH AIR IS DUCTED TO A LOBBY ON EACH FLOOR

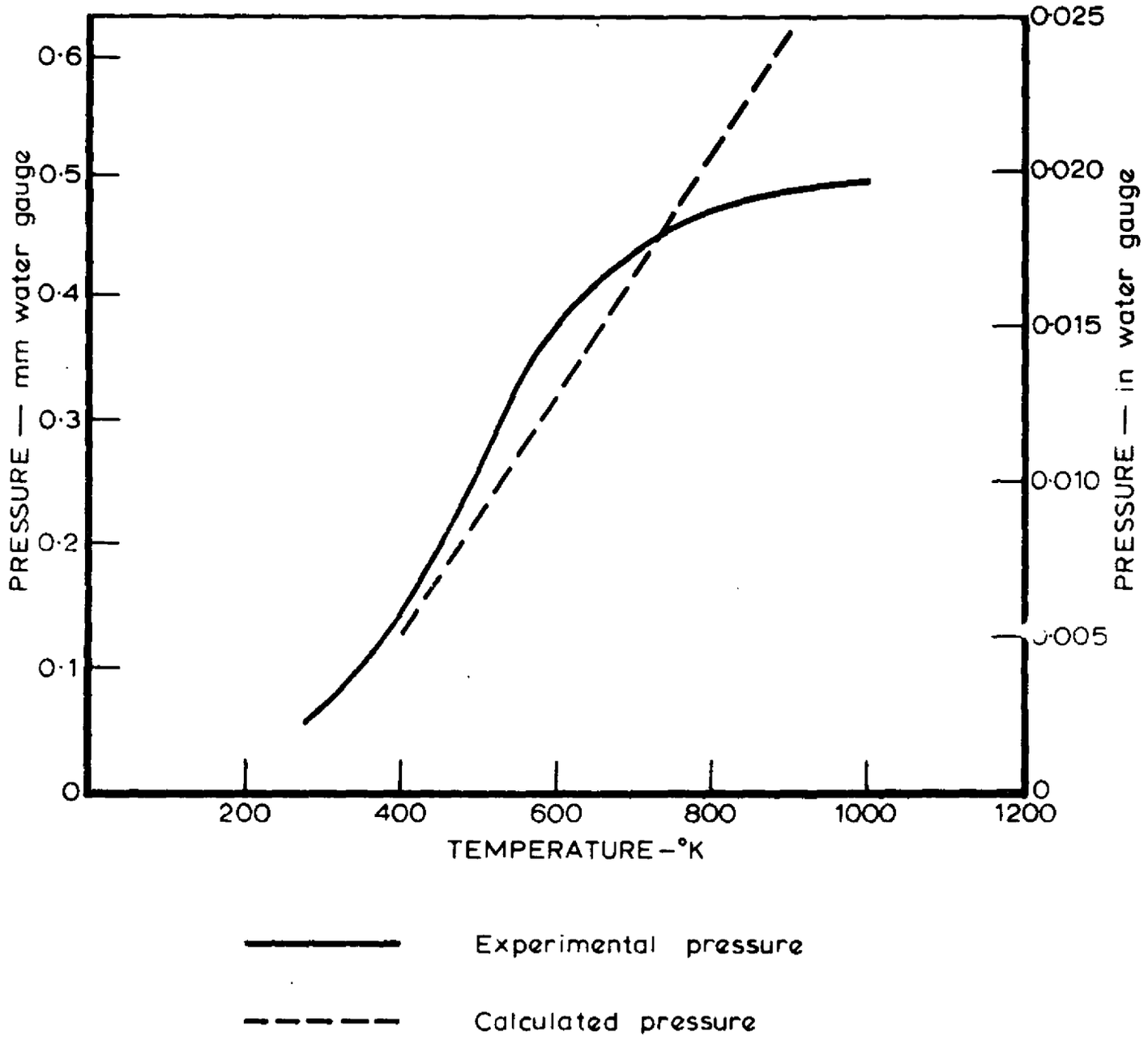

FIG. 3. PRESSURE DEVELOPED BY A FIRE

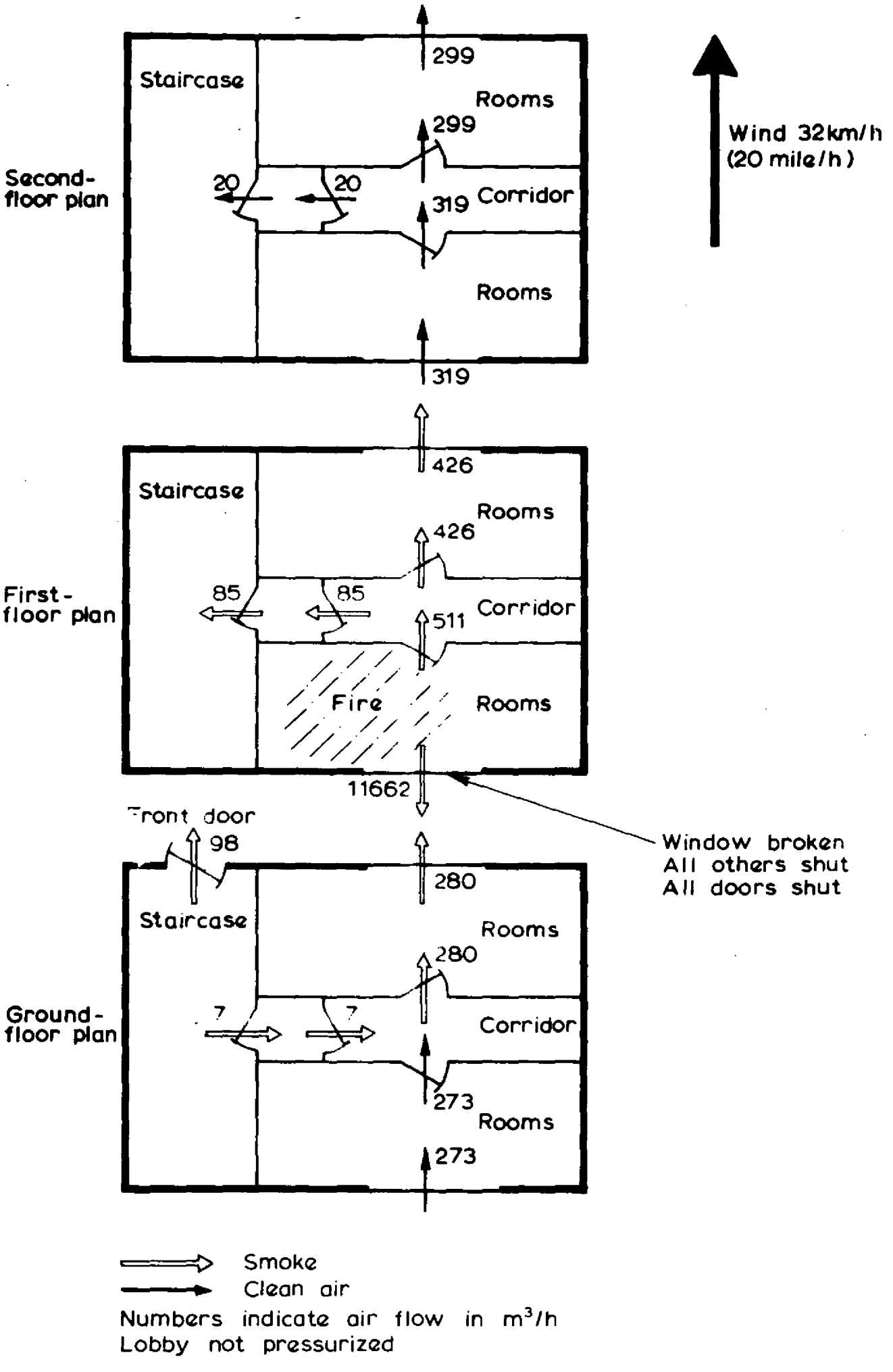

FIG. 4. RESULTS OF CALCULATION OF SPREAD OF SMOKE THROUGH BUILDING WITHOUT PRESSURIZATION

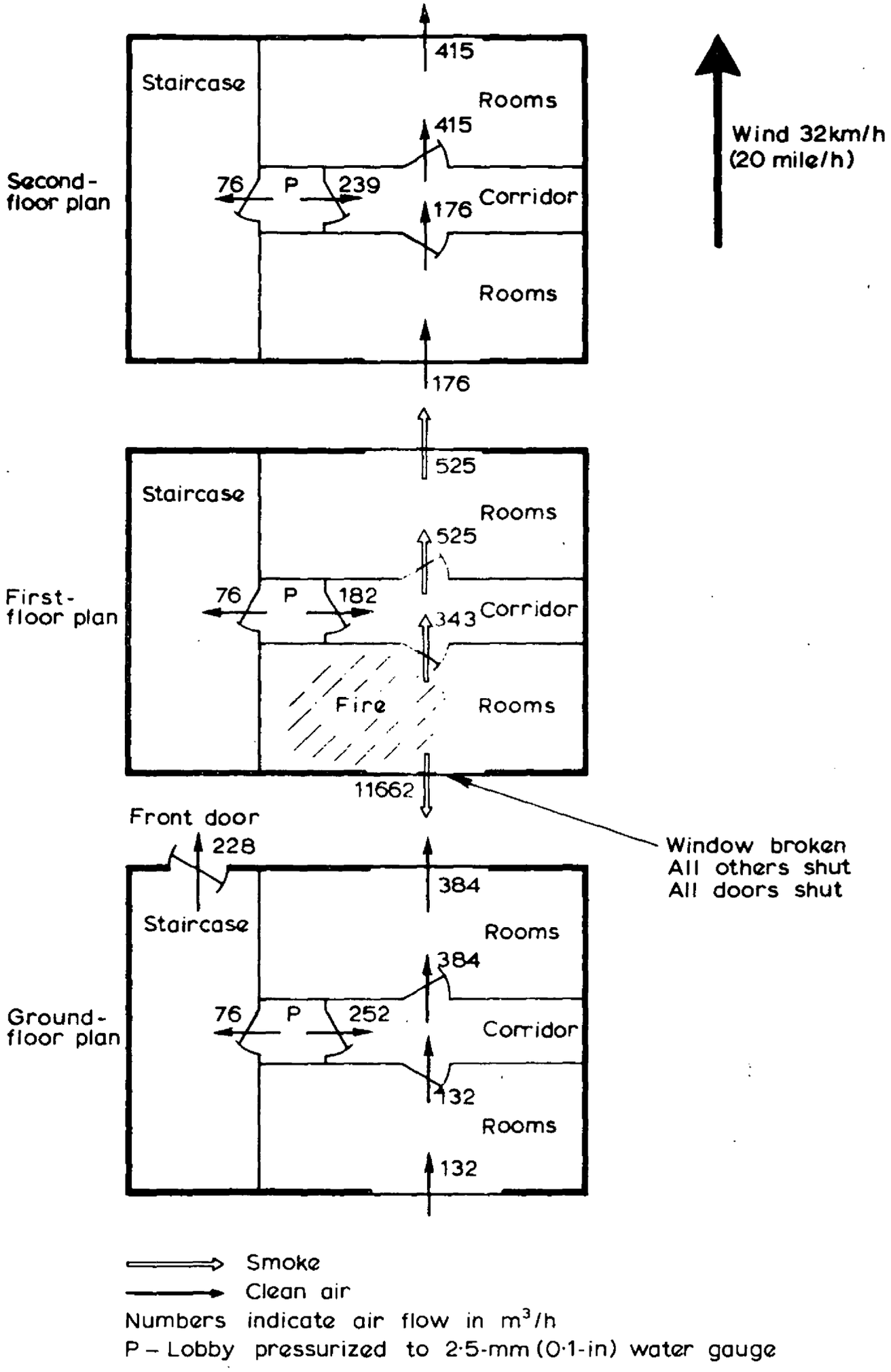

FIG. 5. RESULTS OF CALCULATION OF SPREAD OF SMOKE THROUGH A BUILDING WITH PRESSURIZATION

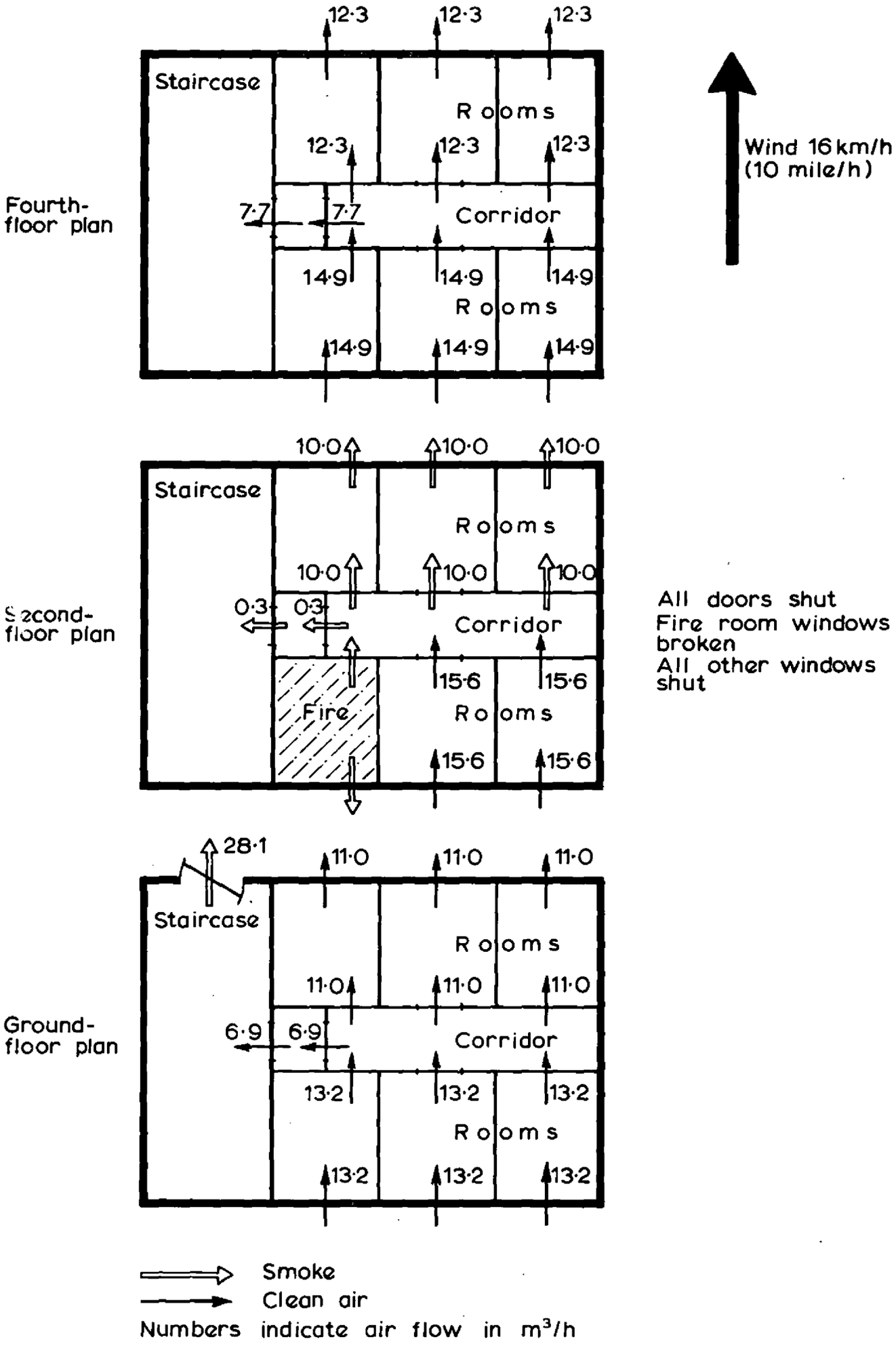

FIG. 6. DIAGRAM PLAN OF BUILDING SHOWING CALCULATED AIR FLOW USING A PRESSURE GRADIENT REPRESENTATION OF FIRE (SEE FIG. 7.)