ENERGY MANAGEMENT AND VENTILATION

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The energy used in the heating of air for ventilation forms a large part of a building´s energy requirements. In homes ventilation accounts for 30-40% of the total heating demand and for an even larger share in offices, hospitals, etc.. From the point of view of energy conservation it is of interest to study the oppurtunities that are available for reducing the energy requirement for ventilation. In principle there are two methods of reducing the energy requirement for ventilation, namely a reduction in the number of indoor air changes as well as the exchange of heat between incoming and outgoing air. Before discussing both of these oppurtunities an analysis is given of different ventilation systems.

VENTILATION SYSTEMS

Fig.1 illustrates three, in principle dissimilar, ventilation systems and the different flows that occur in them. The total ventilation in all systems is described as $\dot{V}_{tot}$, which is the measure of the number of m^3 of fresh air that enter the premises.

Natural ventilation

Natural ventilation results in the entry of fresh air through cracks and vents as well as through the opening of doors and windows. The evacuation of ventilation air takes place by means of ventilation ducts, through cracks and vents as well as by the opening of windows and doors. The total ventilation can be expressed as:

$$\dot{V}^s_{tot} = V^s_{t1} + V^s_{t2} = V^s_{f1} + V^s_{f2} + V^s_{f3}$$

V^s_{tot} is determined by the following factors:

the degree of insulation of the building
the ventilation system
the outdoor climate
the occupants (the opening of doors and windows)

It can be assumed that a too large V^s_{tot} is unlikely to be corrected by the occupants themselves. Too great ventilation does not result in any direct disadvantages under normal circumstances except for increased heating costs. Should ventilation be less than that desired by the occupants, this can be corrected by them by opening windows, at least when they are up and about.

Nothing is known about how large V^s_{tot} is. A number of measurements have been made in occupied dwellings, but in these cases measurements have always been carried out when doors and windows have been shut. While these can provide an answer to the way in which the first three above-mentioned factors affect the change of air indoors, they provide no information about the fourth.

Agneta Olsson at the Department of Building Science at the Lund Institute of Technology, has carried out measurements of the change of air with the aid of trace gas and found the values which are listed in table 1. These refer to multi-family dwellings of various ages. The number of air changes varies between 0.25 to 1.0 changes per hour with an average of 0.55.

On different occasions the National Swedish Institute for Building Research has tested ventilation with the aid of trace gas. For detached and terrace houses measurements were carried out in the spring of 1975 in over thirty houses with natural ventilation. The highest value in this series of measurements was 0.37 and the lowest 0.09 air changes per hour. The average value was 0.2.

Bergetzi et al (.977) have presented measurements carried out in houses in Switzerland. In new low-rise dwellings they found air changes of 0.1 - 0.3 per hour, and values between 0.5 and 1.0 in older houses.

As mentioned earlier, the effects of opening and closing doors and windows has not been investigated in connection with other forms of ventilation. Bergetzi et al have studied the effects that the opening of windows has on the change of air. The following values were obtained:

closed windows	0.15 air changes per hour
window, open 100 mm	2.5 " " " "
window, open 45°	6.0 " " " "
window, completely open	7.5 " " " "

Brundrett (1976) has carried out observations on the opening of windows in British homes. He discovered that the opening of windows could be correlated to the outdoor temperature, low temperatures resulting in the low frequency of the opening of windows and higher temperatures with an increased frequency in the opening of windows. The observations refer to winter conditions. In order to obtain a true appreciation of V^S_{tot} and its required dimension, more extensive investigations, of a type not yet carried out, must be investigated. In the USA, long-term surveys using trace gas has been carried out but these can hardly by regarded as the basis of a series of extensive investigations. The way in which this sort of study couls be carried out is discussed later.

Exhaust air ventilation

As fig.1 illustrates, the ventilation flows are the same in principle, for exhaust air ventilation as for natural ventilation. An exhaust extractor, with a capacity of V^F_F results in a larger underpressure indoors than is the case with natural ventilation, which results in higher values of V^F_{t1} than for the corresponding flows with natural ventilation. As a rule the total flows are therefore larger than in the case of natural ventilation. The total air change will be:

$$V^F_{tot} = V^F_{t1} + V^F_{t2} = V^F_{f1} + V^F_{f2} + V^F_{f3}$$

The exhaust fan is only responsible for a part of the evacuated air, thus:

$$V_F^F = V_{f3}^F$$

There are no investigations of the air change in occupied, exhaust air ventilated houses where consideration has also been given to the opening and closing of windows for airing. There are, however, a number of cases where measurements have been made of the exhaust air volume V_F^F, simultaneously with the measurement of air change with the aid of trace gas.

The National Swedish Institute for Building Research has studied a number of exhaust air ventilated houses, both of single and multi-family type. On these occasions exhaust air volumes have been measured at the fan, as well as the total ventilation with the help of trace gas when windows have been shut. In the multi-family dwellings measurements have also been carried out after adjustment to the ventilation system. The involuntary ventilation, defined as the difference between the ventilation measured with the help of trace gas and the exhaust air volume at the extractor fan, was found in the case of the flats to be an average of 0.10 air changes per hour and 0.12 before, respectively after, the adjustment. A total of 27 flats, distributed in different buildings, were investigated. No adjustment was made in the case of the one-family houses. The involuntary ventilation, as defined above, was in a group of 8 houses 0.13 and in another group of 9 houses 0.14.

It can be stated that the involuntary ventilation, measured as the difference between the measurements using trace gas and measurements in the extractor fan, vary on average between 0.10 and 0.15 air changes per hour.

Fresh air and exhaust air systems

With fresh air and exhaust air systems, the so-called FT-system, there is controlled ventilation of both incoming and outgoing air flows. The fan flows are V_F^{FT} and V_T^{FT} respectively. It is not necessary that the capacity of both fans are similar. If the exhaust air fan has greater capacity than the fresh air fan, underpressure will develop indoors. It is also possible that the fresh air is greater than the exhaust air flow, so that overpressure develops indoors. However this is not to be recommended from a construction point of view.

The total air volume entering the premises, and which is to
is

$$V^{FT}_{tot} = V^{FT}_{t1} + V^{FT}_{t2} + V^{FT}_{t3} = V^{FT}_{f1} + V^{FT}_{f2} + V^{FT}_{f3}$$

Heat exchange can only take place between V^{FT}_{f3} and V^{FT}_{t3}. If the exhaust air flow is greater than the incoming flow of fresh air, there is somewhat improved efficiency in the heat exchange and the incoming fresh air obtains greater heat than in the case of the incoming and outgoing flows being equal.

As far as is known, no organized series of measurements have been carried out on FT-ventilated houses. It is true that there are measurements of the fan flows in practically every type of house, but the corresponding measurements of the air change are not available.

REQUIRED VENTILATION

There are several reasons why premises need to be ventilated. The primary reason is that a good standard of air quality is required. In the Swedish Building Code (Svensk Byggnorm), Supplement 1, standards of air quality are referred to in chapter 36. The minimum reqiurement given there is 0.35 liter of fresh air per second per m^2 net floor area. With a floor to ceiling height of 2.4 m this entails an air change of 0.5. Work, meeting and teaching premises usually require a greater supply of fresh air. With a floor to ceiling height of 3 m, and with one person per 10 m^2 net floor area, the air change reqiurement per hour will be:

for premises where smoking is likely to occur	1.4
for premises where smoking is <u>unlikely</u> to occur	0.9

With a doubling of the density of the number of persons, the need for air change will be more than double. It is to be noted that in premises where smoking occurs, the need for ventilation is considerable. Another reason for the need for ventilation can be a desire to keep indoor humidity low. As is well-known, condensation on the inside of external walls and windows was previously a serious hygienic problem. For economic reasons, and to avoid draughts, windows were always taped over during the winter. This, together with poor heat insulation, resulted in surface condensation. With the more modern window design, which do not require taping over in the winter, ventilation during the winter is increased. Together with improved heat insulation and higher indoor temperatures, problems of surface condensation are rare. More recently, however, surface condensation has again become a problem, particularly in connection with double-glazing in houses with electric radiators. For reasons of economy ventilation is limited in such houses and indoor temperatures are kept relatively low, and this has sometimes resulted in the problem of surface condensation on the inside of double-glazed windows. There are even cases of surface condensation occurring on the inside of triple-glazed windows. Another very likely reason for increased surface condensation occurring indoors is the general improvement in the prevention of draughts indoors which has led to reduced ventilation and increased indoor humidity.

As mentioned, Brundrett (1976) has stated that the opening of windows is proportional to the outdoor temperature, a low outdoor temperature resulting in a low frequency of the opening of windows. Brundrett has put forward the hypothesis to me that the opening of windows depends on the indoor humidity, and that opening windows to air the home occurs more frequently with high outdoor temperatures in order to reduce the relative humidity indoors. This is to be investigated further.

Another reason for opening windows is that the indoor temperature is too high. Airing thus becomes a method of adjusting the indoor temperature. In the Tensta survey in Sweden, Adamson et al (1975) found out that a reduction of the average indoor temperature in blocks of flats from 23^{o}C to 21^{o}C, together with the simultaneous adjustment of the heating system so that the same temperatures were obtained throughout the building, resulted in the reduction of the annual heating requirement by about 20%. This considerable saving of energy depended very greatly on the reduction in frequency of the opening of windows. It would therefore not be incorrect to suppose that too high temperatures are corrected in this way and that this is generally widepsread in blocks of flats in Sweden.

It can be stated that it is rather meaningless to talk about ventilation without taking into consideration the airing of homes by the opening of windows. From the point of view of saving energy, it is the total volume of incoming air that is of interest. There is a lack of studies that can provide the answer to the dependence of the total ventilation on the following factors:

indoor temperature
relative humidity indoors
indoor activities, cooking, smoking, etc.
outdoor temperatures

On the basis of investigations of this sort it should be possible to determine what people in general regard as being the required amount of ventilation. Of course this must presuppose that the least amount of ventilation is some form of measure of the minimum amount of ventilation, since occupiers cannot reduce ventilation but can, instead, increase this by opening windows.

INVESTIGATION OF THE MINIMUM REQUIRED TOTAL VENTILATION

The measurement of total ventilation

Two methods are available, in principle, for the measurement of total ventilation i.e. inclusive of the airing of homes by the opening of doors and windows, during a long period of time, namely:

1. the measurement of air change with the aid of some form of trace gas, and
2. the measurement of the utilization of energy for the heating of air for ventilation.

The method mentioned first has been used, to a great extent, to determine the air change in unoccupied houses where the windows are shut. In these cases helium, carbon dioxide or nitrogen dioxide (laughing gas) have been used. These types of investigation of the way which a concentration of gas is reduced as a result of air change do not normally take longer than a few hours. Inspite of this the cost for gas can be quite high should many tests be carried out. For longer periods the above-mentioned gases have not been used. In the USA a gas analyzer, developed at the National Bureau of Standards, which utilizes nitrogen hexafloride as a trace gas has been employed. The gas is introduced at particular intervals of time and its concentration is noted. Since it is possible to record small quantities of the gas, this method can be used during longer periods of time, e.g. weeks. Even in this case it is however, impossible to carry out measurements in an occupied house. A trace gas that could be utilized in principle, is radon which appears in certain building materials e.g. shale-based aerated cement. It would be possible to place a block of this material in each room, or better still, to utilize a house constructed from this material, for the investigation. Measurement methods would probably have to be further developed, so that very small amounts of radon could be recorded. This method could be utilized in homes during long periods of time assuming that the recording apparatus did not take up too much room.

It is not possible to make direct measurements of the energy consumed in the heating of air for ventilation. It is possible to measure the amount of energy required for heating, but from this must be subtracted the transmission losses through walls, roofs, windows, etc. as well as adding on the free heat obtained from people, electrical domestic appliances, daylight radiation through windows, etc. Transmission losses can be calculated and should be possible to determine experimentally for periods of time when the amount of free heat is small. This could be done by determining, when the windows are shut at night, the heat consumption for the building as a whole and simultaneously the air change for certain flats. The transmission losses will then be the difference between the total consumption of energy for heating minus the ventilation losses plus the free heat from individuals and certain electrical domestic appliances. This free heat is easy to calculate. However, to determine the amount of free heat during the day, to a reasonable degree of accuracy would be virtually impossible. The finite determination of energy consumption for ventilation air during a longer period of time is probably practically impossible. However, the method could be used for the comparison of two similarly oriented buildings in which a number of the factors could be varied systematically in order to study their influence on ventilation. If the buildings are provided with exhaust air systems it would be possible to e.g. reduce the amount of exhaust air ventilation in the one building while simultaneously observing the utilization of energy for heating. It can be assumed that the amount of free heat is identical in both buildings which, in addition, are assumed to have a large number of flats. With the aid of measurements with trace gas and the simultaneous observation of the amount by the opening of windows, a good assessment can be obtained of the effects of a change. Should the residents regard the ventilation as being too little it is probable that windows will be opened for siring. Experiments of this sort must, of course, be supplemented with interview surveys.

The influence of particular factors

In order to study the way in which particular factors influence e.g. the total ventilation, the airing of rooms by opening windows, the air change when windows are shut, ideas about the quality of the air, etc., a building should be selected with an axhaust air system or with both an incoming fresh air and exhaust air system. With these systems the degree of ventilation can be considerably affected by altering the flows of the fans. It is also possible, of course, to alter influence indoor temperatures by varying the ingoing temperatures. Preferably, heating costs should be separately metered so that there would be an incentive to economize. Houses of this sort are infrequent.

The factors which can ve varied are:

- the ventilation, by adjusting the revolutions of the fan
- the indoor temperature, by adjustment of the temperature

The buildings to be used for this investigation are to have a sufficient number of flats so that the habits of the residents will not affect the total consumption of energy. In addition the building must have some form of meter for the measurement of the amount of heat required for heating, or be provided with this type of meter if lacking. Records should also have been kept of the consumption of energy for heating purposes during some period of time, so that any differences in the consumption of energy can be analyzed, and that their effect on the investigation can be evaluated. The buildings should be identical and be similarly oriented so that free heat from daylight radiation will be the same in both cases. It is assumed that the average shading effect of curtains will be equal.

Before any particular factor is changed, an interview survey should be carried out in order to acquire the opinions of residents concerning the indoor climate, which will form the basis for further interviews about changes which will then follow. In addition, measurements of the air change should be made in a few flats with the aid of trace gas. This should be carried out when windows are shut as well as they are open at varying amounts. Under normal conditions the ventilation as measured when windows are shut should not differ that much from the ventilation measured in the extractor fan with velocity flowmeter.

For the initial, and all subsequent periods when changes are introduced, the following factors should be observed:

- the energy consumption for heating purposes during the period cencerned
- the air exchange and the exhaust air flows in particular flats
- the total exhaust air flow through the extractor fan system
- the opening of windows, the average amount and duration
- the temperature of the exhaust air
- the relative humidity of the exhaust air
- interviews about the quality of air

Interview surveys must, of course, be formulated in such a way that they do not interfere with the investigation as a whole.

It is conceivable that an experiment could be carried out and evaluated in the following way:

1. Period 1: Normal ventilation

Observations	Building 1		Building 2
Consumption of energy for heating	W'_1		W''_1
Exhaust air flow[1)] from flat m	V'_{Fm1}		V''_{Fm1}
Air change in flat m, windows closed	n'_{m1}		n''_{m1}
Ventilation in flat m, windows closed	$n'_{m1} \cdot v_m$		$n''_{m1} \cdot v_m$
Total exhaust air flow[1)] from building	V'_{F1}		V''_{F1}
Average exhaust air temperature	t'_{F1}		t''_{F1}
Average relative humidity of exhaust air	φ'_{F1}		φ''_{F1}
Average opening of windows	G'_1		G''_1
Average opinion about the quality of the air, from interview survey	I'_1		I''_1
Average outdoor temperature		t_{u1}	
Average wind speed		s_{u1}	
Average relative humidity outdoors		φ_{u1}	

1) = Flow through extractor fan

2. Period 2: Half ventilation

Observations	Building 1		Building 2
Consumption of energy for heating	W'_2		W''_2
Exhaust air flow[1)] from flat m	V'_{Fm2}		V''_{Fm2}
Air change in flat m, windows closed	n'_{m2}		n''_{m2}
Ventilation in flat m, windows closed	$n'_{m2} \cdot v_m$		$n''_{m2} \cdot v_m$
Total exhaust air flow[1)] from building	V'_{F2}		V''_{F2}
Average exhaust air temperature	t'_{F2}		t''_{F2}
Average relative humidity of exhaust air	φ'_{F2}		φ''_{F2}
Average opening of windows	G'_2		G''_2
Average opinion about the quality of the air, from interview survey	I'_2		I''_2
Average outdoor temperature		t_{u2}	
Average wind speed		s_{u2}	
Average relative humidity outdoors		φ_{u2}	

1) = Flow through extractor fan

During period 1 the following units should be approximately equal:

$$W'_1 = W''_1$$
$$V'_{F1} = V''_{F1}$$

$$t'_{F1} = t''_{F1}$$
$$G'_1 = G''_1$$
$$I'_1 = I''_1$$

Between period 1 and period 2 the flow of the exhaust air through the extractor fans has varied by

$$\Delta V'_F = V'_{F1} - V''_{F2}$$

The effect of this change on total ventilation can then be recorded. Changes to the latter can be calculated from the reduced consumption of energy:

$$\Delta V = \frac{W'_1 - \frac{W''_1}{W''_2} W'_2}{c_p \cdot \frac{t'_{F1} + t'_{F2}}{2}}$$

in which c_p is the specific heat of the air. In addition, it is possible to study the effect of changes on:

- air change when windows are closed $n = \frac{\Sigma n_m \cdot v_m}{\Sigma v_m}$
- opening windows for airing G
- opinions about the quality of air I
- the relative humidity of the exhaust air

The above is only an outline of the way in which an investigation could be carried out. A pilot study should be carried out first in order to ascertain that the changes can be studied in the proposed manner and with reasonable accuracy. However, difficulties should be reckoned with concerning the precision of any relationship. This should not, however, preclude further studies because even results with certain deficiences in terms of precision are of importance.

THE REQUIRED TOTAL VENTILATION

On the basis of investigations of the type described in the foregoing section it should be possible to assess the volume of the minimum required total ventilation. It is conceivable that it will be necessary to differentiate between buildings with exhaust air ventilation and those with both exhaust and fresh air systems. Perhaps even a certain amount of geographical variation could be introduced.

By relating, in this way, the required minimum ventilation to people's opinions about the quality of the air, to the exhaust air flow or alternatively the incoming fresh air flow, an improved basis could be constructed for:

1. standards concerning minimum ventilation
2. decisions about the possible reduction of flows in fan-ventilated buildings
3. studies of how much energy can be saved by the draught prevention of windows and other building components.

Table 1 Recordes air change per hour in flats when the windows are shut. Measurements carried out during the winter with the aid of trace gas, by Olsson (1977).

Date of building´s construction	Air change per hour
1850	1.0
1884	0.3
1898	1.0
1898	0.35
1905	0.35
1919	0.6
1922	0.25
1930	0.4
1941	0.9
1946	0.25
1946	0.7
1950	0.65
1955	0.25
1955	0.65
Mean value	0.55

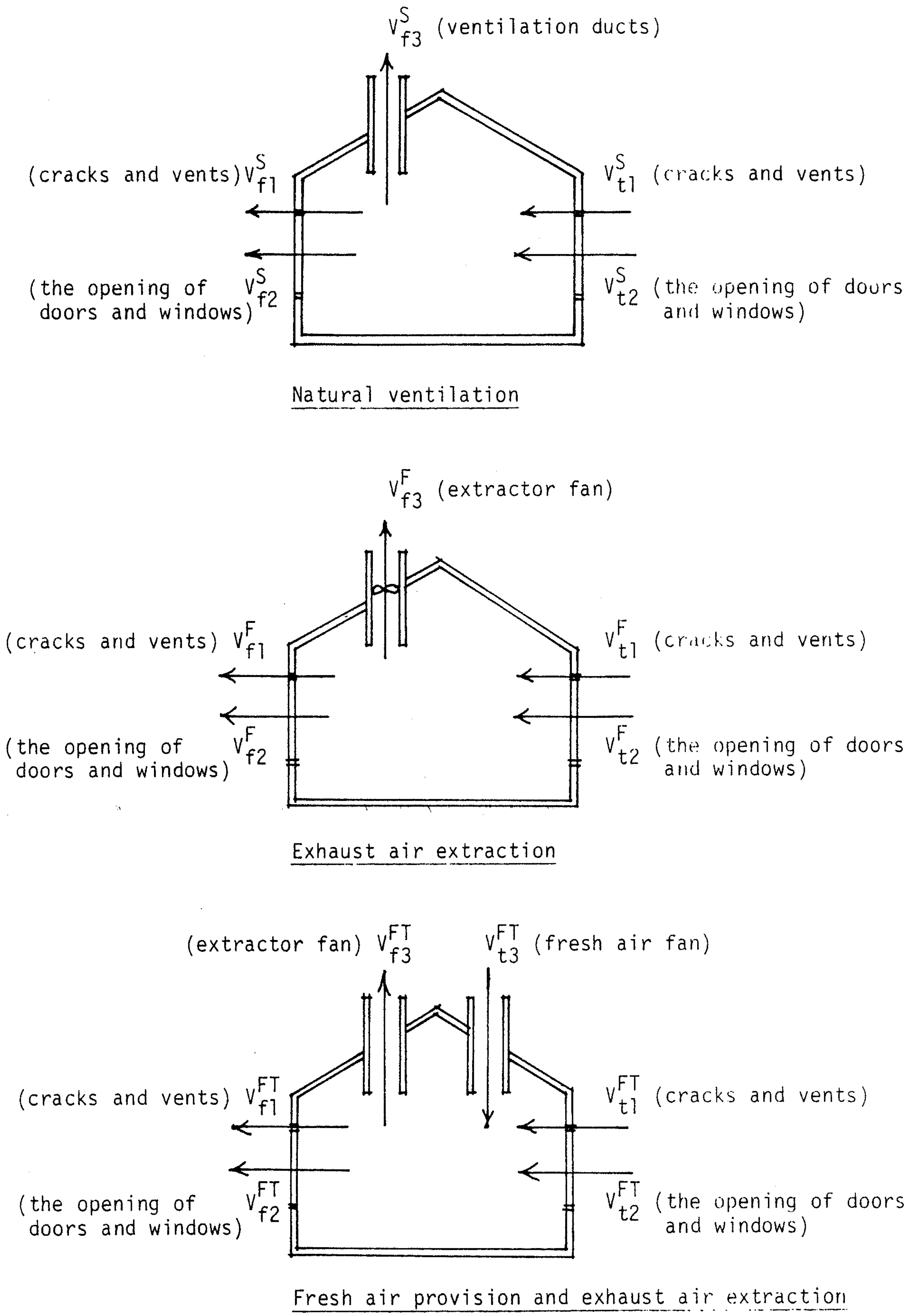

FIG.1 The air flows in different types of ventilation systems.