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The influence of air tightness on the operation of balanced supply/exhaust systems

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Introduction

Ventilation and air infiltration have a major influence on indoor air quality, moisture problems and energy consumption. In the past, most buildings have been ventilated by air leakage through the envelope due to the effect of indoor-outdoor temperature differences and the wind, i.e. the infiltration and natural ventilation. During recent decades, mechanical ventilation systems have been used in many countries, i.e. mechanical exhaust ventilation and balanced supply/exhaust ventilation.

To avoid making the ventilation rate too high causing excessive energy consumption, and to avoid inadequate ventilation causing poor indoor air quality, it is necessary to analyse the influence between infiltration and the operation of mechanical ventilation. This paper employs the multi-room model MIX described by Li et al (1990) to analyse the influence of air tightness on the operation of a balanced supply/exhaust system in multi-room buildings. The effect of infiltration on exhaust ventilation was discussed in the above mentioned paper.

Balanced supply/exhaust systems

Before analysing quantitatively, the effect of the room pressure on balanced ventilation will be examined qualitatively. It should be noted that "the balanced system" as used in the following does not mean that the system is completely balanced.

The operating point of a ventilation system is the interaction of the fan characteristic and the system characteristic, as illustrated in Fig. 1.

A change in the room pressure will change the total pressure of the supply fan and the exhaust fan, but in opposite directions, see Fig. 2.

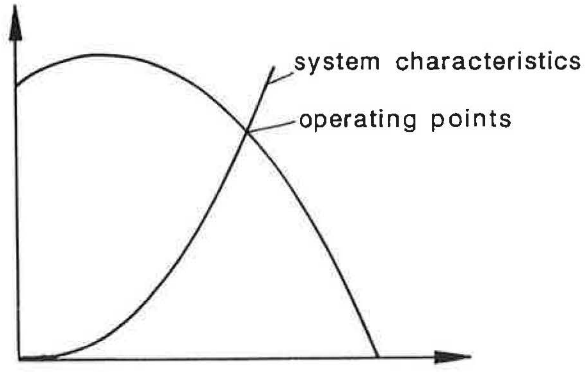

Fig. 1. Fan and system characteristics.

Suppose a simple room which has a completely balanced ventilation system, is at atmospheric pressure. This means

$$Q_s = Q_e \qquad (1)$$

Where

Q_s = the supply volume air flow rate
Q_e = the exhaust volume air flow rate.

When the room pressure increases above atmospheric pressure, the supply fan total pressure will increase, and the exhaust fan total pressure will decrease. In such circumstances, a slight imbalance in the supply/exhaust flow rate will occur.

$$Q_s < Q_e \qquad (2)$$

Under similar circumtances, when the room pressure decreases below atmospheric pressure, a slight imbalance will also exist, but in this case the supply rate exceeds the exhaust rate.

$$Q_s > Q_e \qquad (3)$$

Since a completely balanced system will not change the overall pressure balance within the building, it offers no resistance to the effects of wind and stack induced air infiltration and exfiltration. That is why it is necessary to design a slight imbalance in the supply/exhaust rates in favour of extraction, of around 10%. However this is only designed for a room of fixed pressure, for example, a

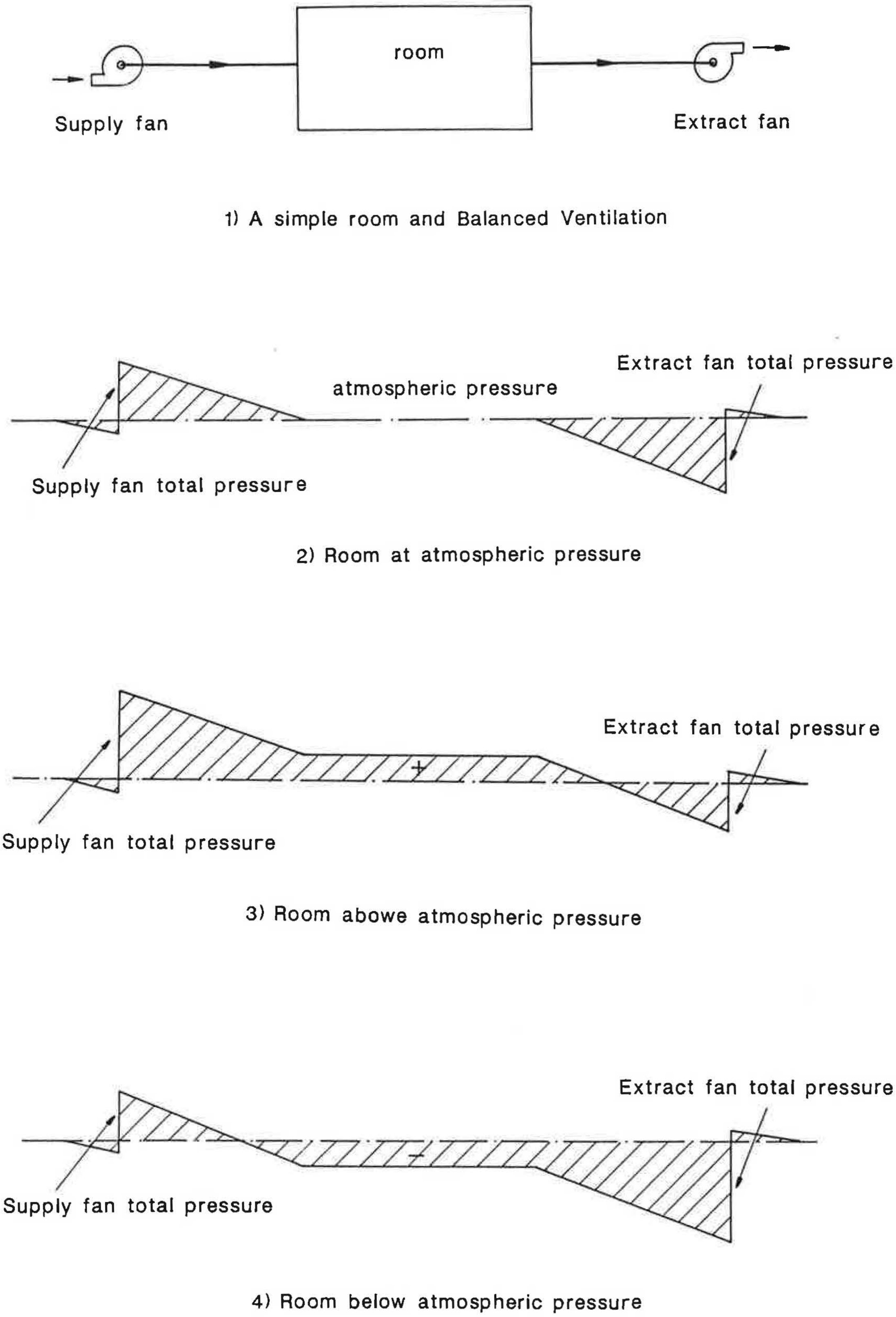

Fig. 2. Effect of room pressure on balanced ventilation.

room at atmospheric pressure. However, the room pressure will change due to change in wind speed, direction, indoor and outdoor temperature differences, different occupant behaviour and even the mechanical ventilation itself. The supply and exhaust flow rates are not fixed and will be changed when the conditions of the room alter. If the room pressure is reduced below atmospheric pressure, as discussed above, the supply rate will increase and the exhaust rate will decrease. A situation could therefore arise where the supply rate is larger than the exhaust rate, even though the system was originally designed in favour of extraction. This problem will be discussed quantitatively below. It will be shown that 10% favour of the exhaust is still not enough.

Example

A study of the influence of infiltration on the operation of supply/exhaust ventilation was performed using a model building, the same one used by Li et al (1990). The floor plans are shown in Figs. 3, 4, and 5. Fig. 6 is a section of the building. There is a total area of 450 m^2 on three floors and a volume of 1125 m^3.

A sample exhaust ventilation system was designed from rooms 6, 9, 13, which were considered as kitchens or bathrooms, whereas a sample supply ventilation system was designed from rooms 3, 7, 11, which were considered as living rooms or bedrooms, see Fig. 7. The supply/exhaust system was designed in favour of extraction by 10%. The model building was considered as an interconnected system of the flow

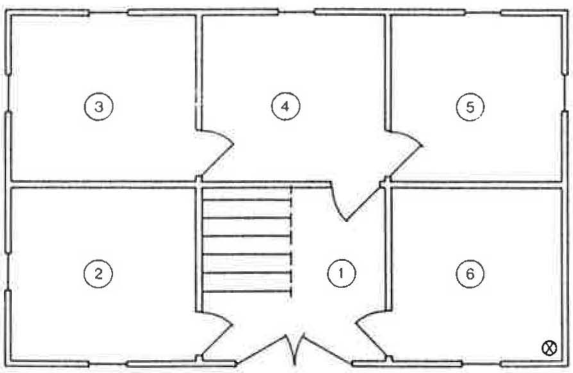

Fig. 3. First floor plan of the example building.

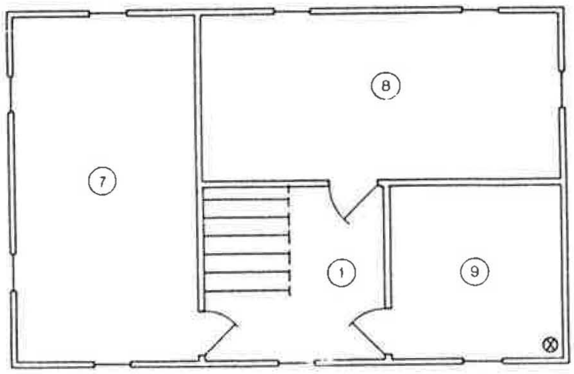

Fig. 4. Second floor plan of the example building.

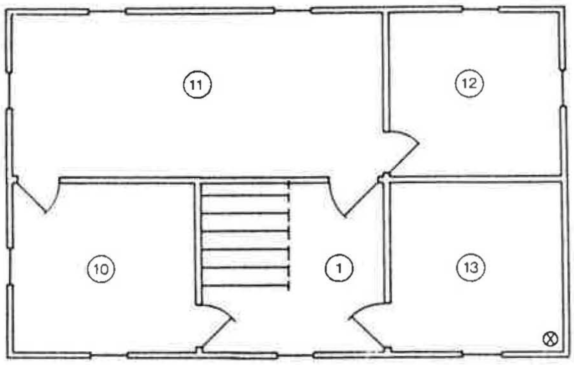

Fig. 5. Third floor plan of the example building.

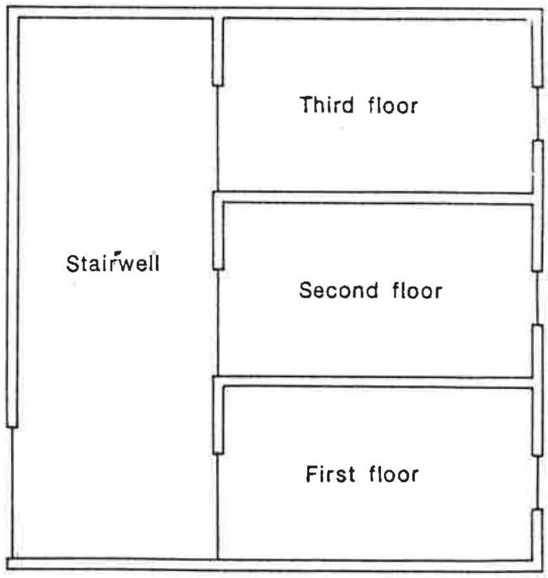

Fig. 6. A section of the model building.

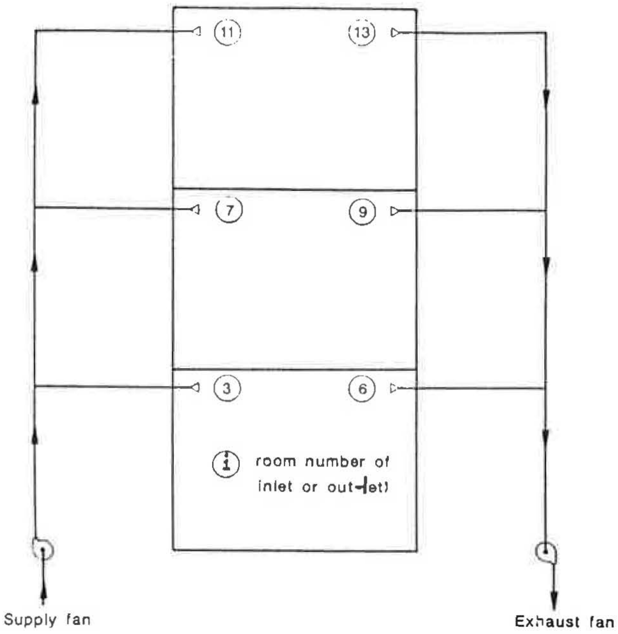

Fig. 7. Balanced ventilation system in the model building.

paths in the multi-room model. The multi-room model MIX was used to calculate the air flow, infiltration and ventilation flow rates by balancing infiltration, exfiltration and mechanical ventilation under the combined pressure conditions resulting from the different ventilation driving forces.

Results and Discussions

Infiltration and room pressure

Calcultions have been made for two sets of conditions. Firstly with all the doors between rooms open and secondly with them all closed. As discussed in Li et al (1990), when the internal openings were much larger than the envelope, the internal pressure could be considered as uniform. Fig. 8 shows the effect of wind speed on the change in room pressure. For the case with all the doors are open two observations can be made. For buildings with and without supply/exhaust ventilation systems.

o A supply/exhaust ventilation with a slight bias towards extraction (10%) has a very small influence on the room pressure, when internal openings are much larger.

o When the wind speed is less than a critical speed U_c the supply/exhaust ventilation creates a slight internal underpressure. When the wind speed is larger than U_c, the supply/exhaust ventilation creates a slight internal overpressure.

As the indoor pressure changed, the operation points of both the supply and exhaust ventilation systems also changed. This caused a change in the supply and exhaust flow rate in the supply/exhaust system. Fig. 9 shows these trends, and again two observations can be made.

o There is a critical point for the supply and exhaust flow rate. Originally, the system was designed so that the exhaust flow rate was slightly greater than the supply flow rate. However, the room pressure changes when the driving force alters. When wind speed is larger than the critical value, the supply flow rate will be slightly larger than the exhasut flow rate. The position of the critical point will be dependent on the supply/exhaust system. If the fans are made much stronger, the critical value will not appear within the actual wind speed range in certain terrain and shielding conditions.

o This critical value is also the turning point of the changing trend of infiltration and exfiltration, but the difference between the infiltration and exfiltration is very small. This means that the supply/exhaust ventilation system offers very small resistance to the efforts of wind and stack induced infiltration. If we compare Fig. 9 with Fig. 10, where the leakage coefficient k_t is double that of Fig. 9 it can be seen that the infiltration value almost doubles. For this reason, the background leakage and other non-intentional openings must be reduced to an absolute minimum.

The ratio of the exhaust and supply flow

Fig. 11 shows the trend of the Q_e/Q_s on different indoor-outdoor temperature differences. When the outside temperatue increases, i.e. the indoor-outdoor temperature difference becomes smaller, the critical wind speed increases slightly. However, the influence of the temperature is not so large. A tightening of the envelope will tend to increase the critical wind speed by a small amount, see Fig. 12.

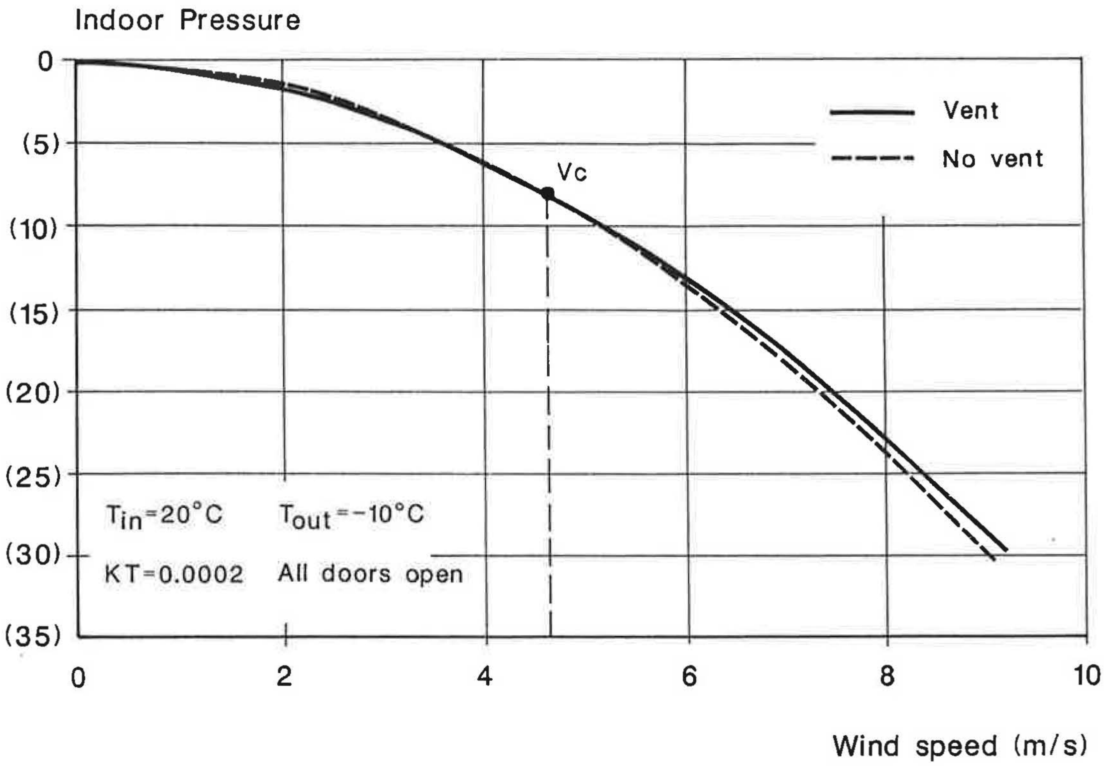

Fig. 8. Indoor pressure in the model building with balanced ventilation and without ventilation as a function of wind speed.

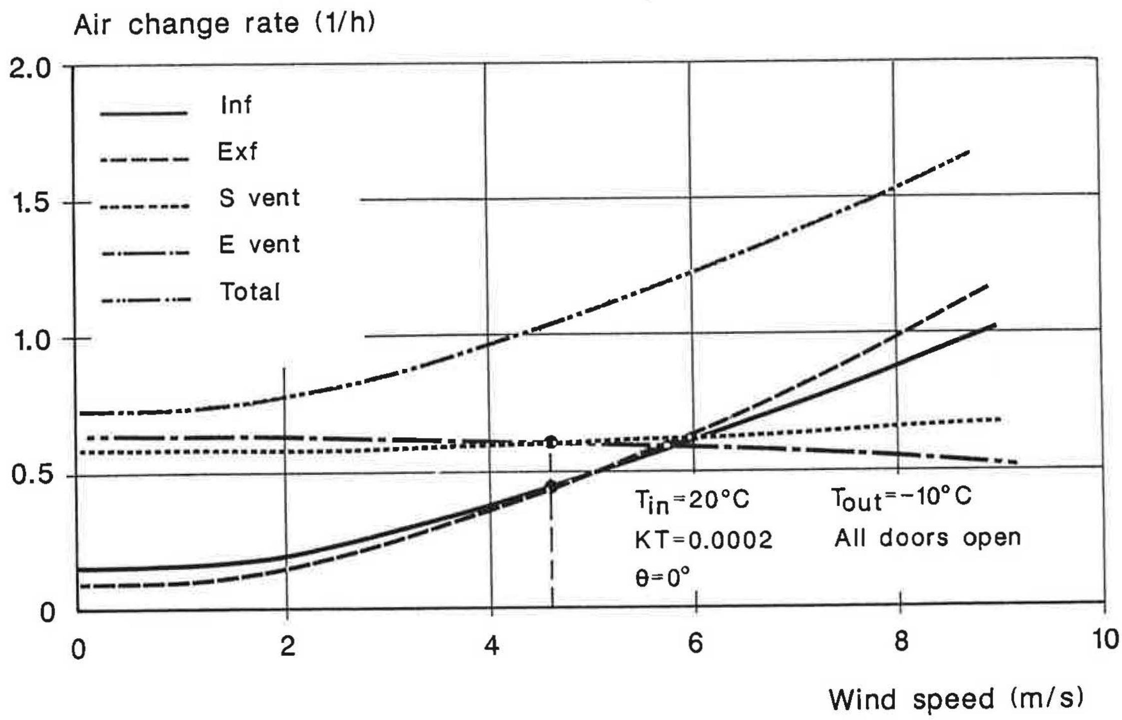

Fig. 9. Air change rate due to supply and exhaust ventilation, exfiltration and infiltration as a fuction of wind speed.

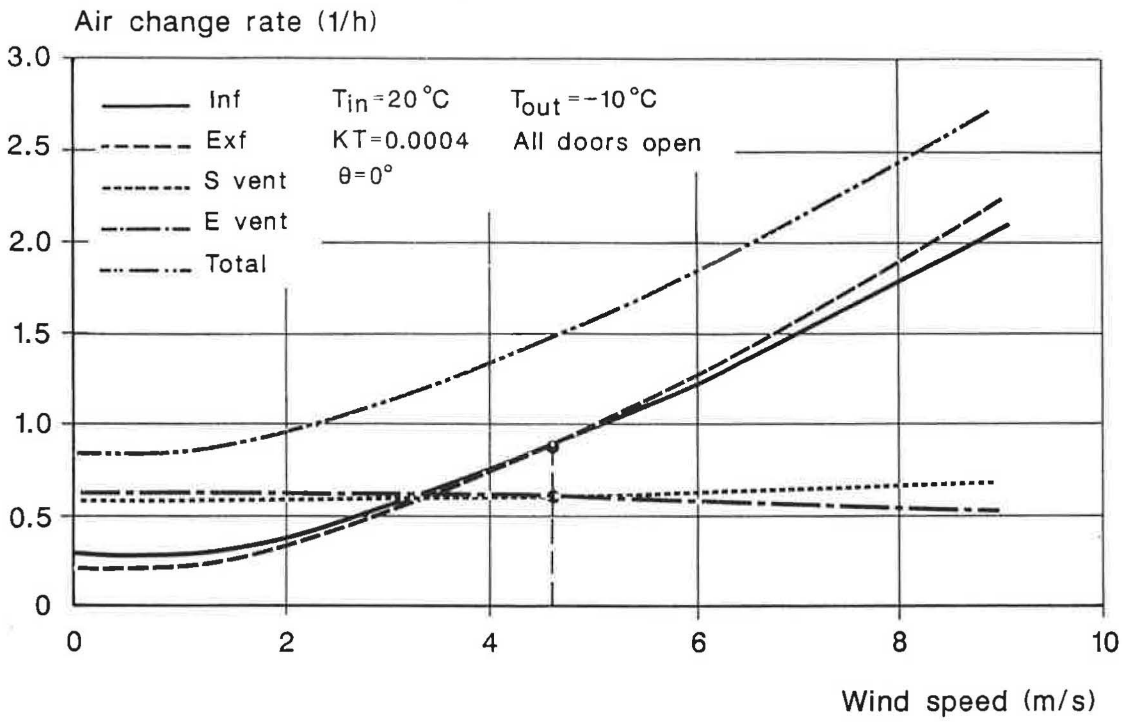

Fig. 10. Air change rate due to supply and exhaust ventilation, exfiltration and infiltration as a fuction of wind speed.

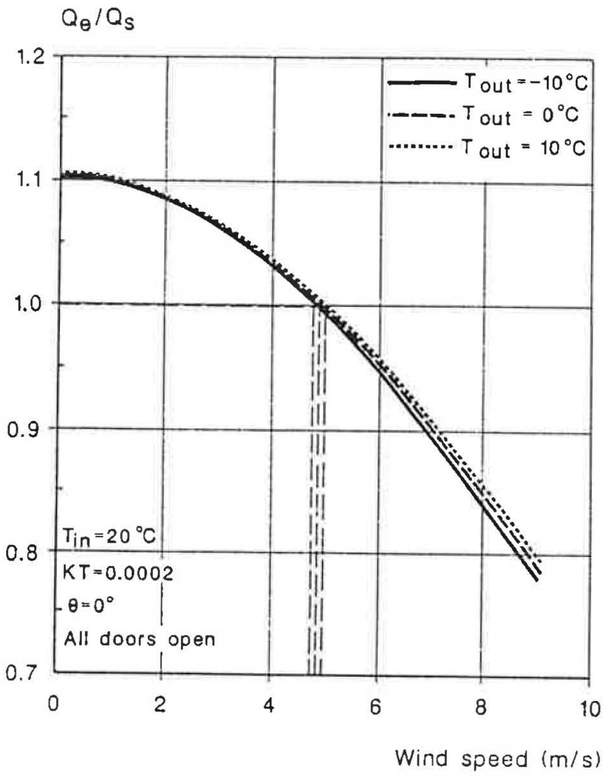

Fig. 11. The ratio Q_e/Q_s for different outside temperature as function of wind speed.

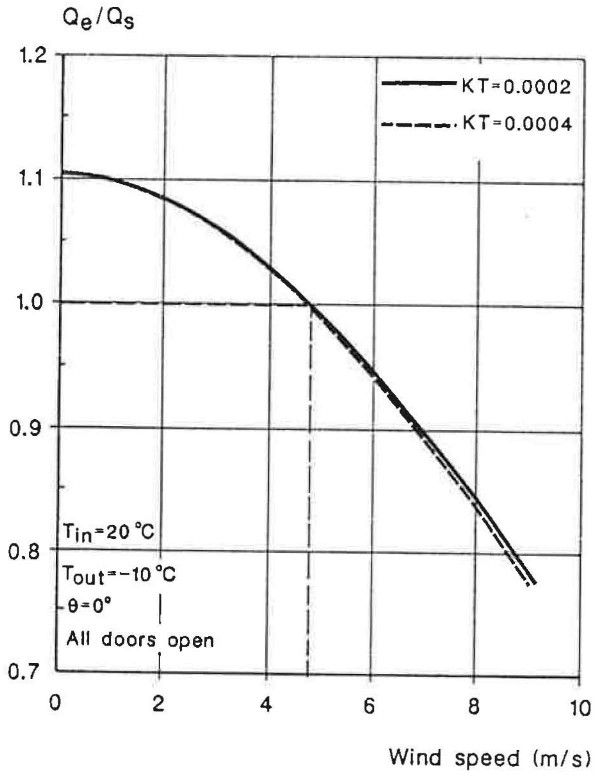

Fig. 12. The ratio Q_e/Q_s for different k_t values as a function of wind speed.

When all the internal doors are closed, there will be an overpressure in the room which is supply air by the supply system while the room which has air exhausted by the exhaust fan, will be at a reduced pressure. Refer to Fig. 2, at a certain wind speed, the supply fan total pressure will increase, and the exhaust fan total pressure also will increase. From this information only it is impossible to predict the trend of ratio Q_e/Q_S, but from Fig. 13 it can be seen that closing door causes a decrease in the critical wind speed.

It has been shown by Li et al (1990) that if all doors inside are open and assuming that every face of the building is exposed to the same degree of local shielding, for symmetrical leakage conditions, the influence of the symmetrical wind direction on the indoor air pressure and infiltration is small. This is also true for the ratio Q_e/Q_S, see Fig. 14. However, if the internal resistance is much larger, then the influence of the symmetrical wind direction will be more pronounced, see Fig. 15. It is impossible to predict this result by the single-cell model.

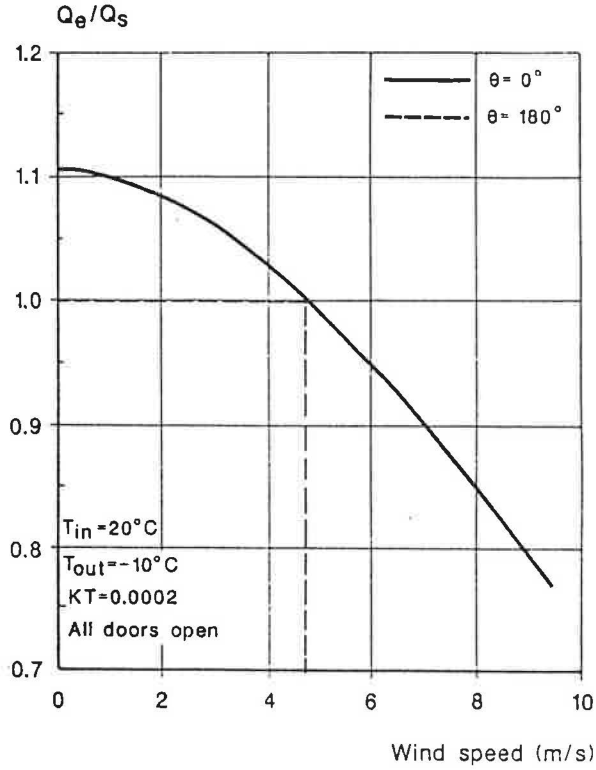

Fig. 14. The ratio Q_e/Q_s for two wind directions as a function of wind speed, when doors are open.

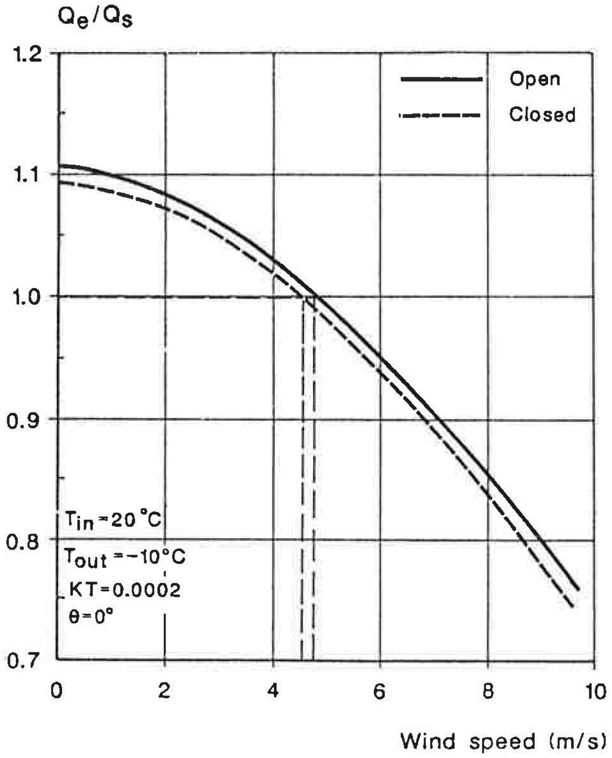

Fig. 13. The ratio Q_e/Q_s for two conditions, all doors open and closed, as a function of wind speed.

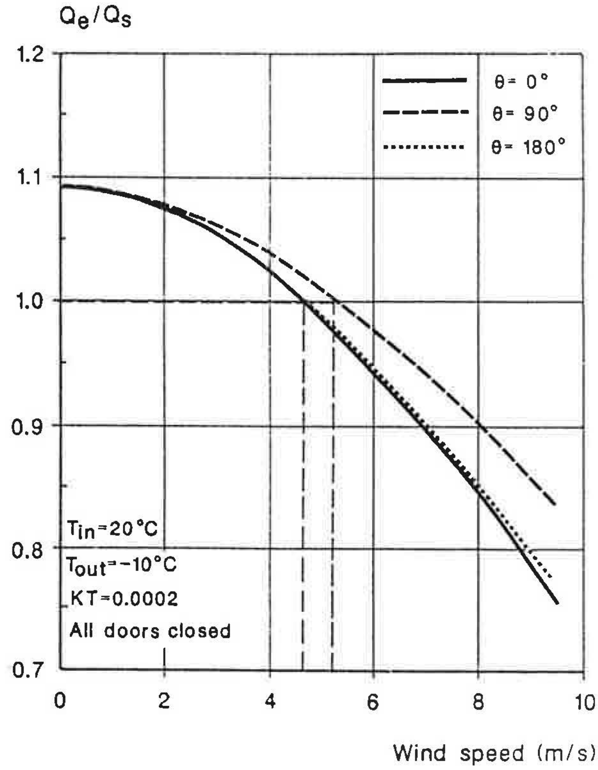

Fig. 15. The ratio Q_e/Q_s for three wind directions as a function of wind speed, when doors are closed.

Conclusions

An example application of the multi-room model has been given and it has been shown that it is impossible to obtain a completely balanced supply/exhaust ventilation system. It is also impossible to obtain a imbalanced supply/exhaust ventilation system with a fixed Q_e/Q_s ratio (1.1). A supply/exhaust ventilation in favour of extraction can be designed and run correctly under certain fixed conditions, but if the conditions change, the operation point will change. In the worst case, and if the fan is weak, the supply rate may become larger than the exhaust rate. So it is suggested here that it could be better to design "balanced ventilation" system with a favour of extraction 20-25%. In such a case, there will be higher infiltration if the envelope is not tight, then exfiltration with moisture condensation and freezing problem will be avoided.

The situation described above is a problem to which some attention should be given in order to provide adequate ventilation to maintain indoor air quality and a comfortable environment.

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The first International Symposium on Ventilation for Contaminant Control was held in Toronto in October 1985; the second was held in London in September 1988. The American Conference of Governmental Industrial Hygienists now announces the Third International Symposium to be held in Cincinnati, Ohio, in September 1991.

Ventilation '85 and Ventilation '88 brought together 400 participants from all over the world; they highlighted major areas of common interest and the need for improved communication in the field of ventilation for contaminant control. Ventilation '91 will build on this experience and will provide a forum for discussing activities and ideas on a wide range of topics, from the fluid mechanics of air flows to practical applications of contaminant control technology.

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