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The influence of wind pressure on the ventilation system in a high-rise building

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Introduction

A building rising vertically up to 20 or more stories poses some serious problems for heating and ventilation design. Wind effect, the stack effect, and mechanical ventilation as well as people's behaviour can affect the air infiltration of a building. For a high-rise building, the influence of these factors is much more complex and important.

Consider the pattern of wind-flow over a high-rise building, shown in Fig. 1. It is obvious that the positive pressure on the windward side can cause undesirable effects within the building if leakage through windows occurs or even worse, if the window is opened. The doors between the room and the corridor may be difficult to open due to the larger pressure difference. Infiltration on the windward side may account for a high rate of air-change, which causes a difficulty in regulating the indoor air temperature. Meanwhile, on the leeward side, air movement tends to be outward. There will be more second-hand air infiltration from the corridor, which could give rise to an indoor air quality problem. Furthermore, due to the changing of the indoor pressure, the operation of the mechanical ventilation system will also have a significant influence. It is known that the opening of windows in high-rise building is not advisable, but there is a lack of knowledge on how it influences the operation of the mechanical ventilation systems in high-rise buildings. (This is what has been analysed in the current paper.)

Example

A high-rise building is simulated, as shown in Fig. 2 and Fig. 3. There are fourteen floors with a stair well. A balanced ventilation system is designed, see Fig. 4. The floor and the ceiling are extremely tight, $k_t = 0.0$, where k_t is the leakage coefficient (1 m^3/s at 1 Pa), see Li et al (1990). The internal walls between each floor and the stair well have k_t values of 0.0005, where the doors are assumed to be closed. There will always be some leakage in the cracks between the door and the frame. The k_t value for the envelope is 0.0001.

The wind pressure coefficient, c_p, are assumed to be uniformly distributed along the height. The simplification is due to the unavailabilities of c_p values for high-rise buildings. The meteorogical wind speed data and other climate data, measured at 10 meters above the ground, were used. The measurements were taken in Norrköping, Sweden, February 2 1985, see Li (1990).

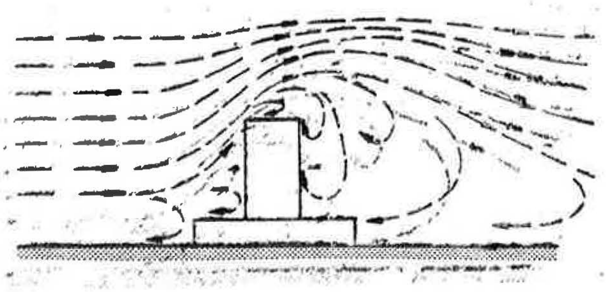

Fig. 1. Air flow pattern around a high-rise building.

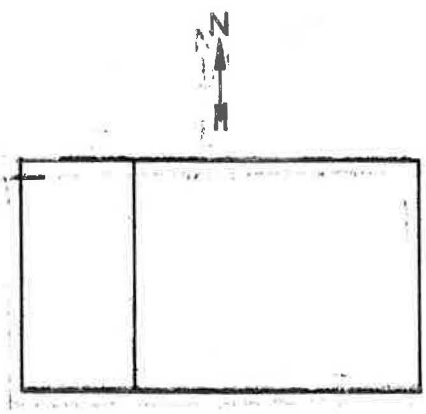

Fig. 2. Floor plan.

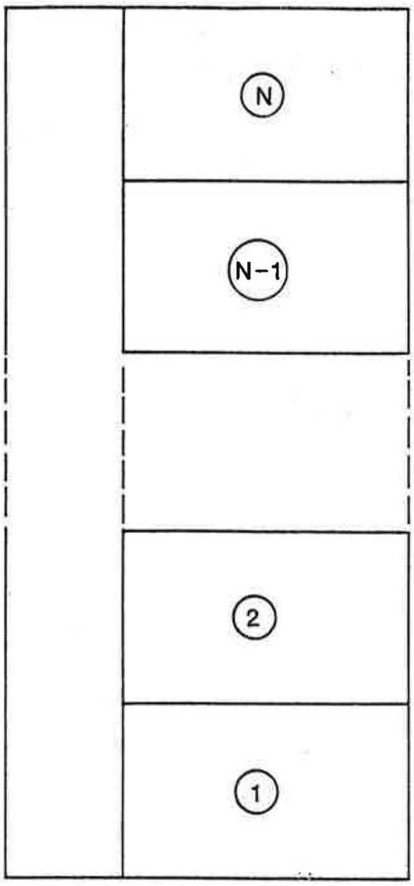

Fig. 3. Vertical section of building.

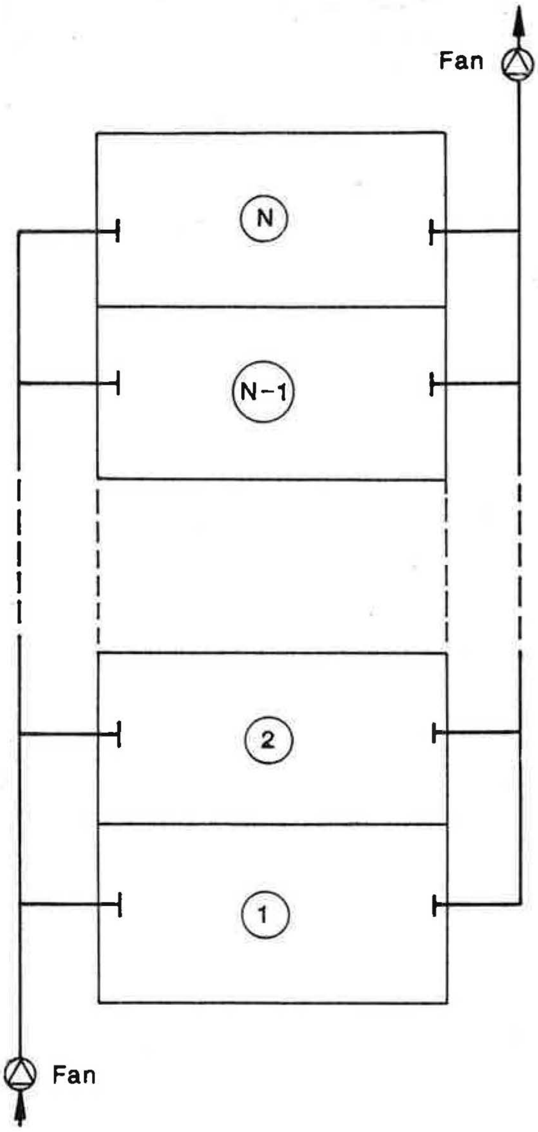

Fig. 4. Ventilation system.

Discussions

Calculations concerning the ventilation of high-rise building are normally made in order to design the ventilation systems. Such calculations are necessary to choose the right components for the system. However, they don't give any hints about the flow of air inside the building, neither the infiltration, nor the exfiltration. The calculations presented here give that information. Due to the wide variaty of buildings, one example has being chosen. However, some conclusion can be found even from these simple cases.

Fig. 5 shows the infiltration rate, exfiltration rate, exhaust ventilation rate, supply ventilation rate and total ventilation rate of the model building. Due to the changing of the weather, the changing of the infiltration is between 0,2 to 0,6 ach, which means that the air pollutants rising from cars or a nearby positioned chimney can be transfer into building, and can give rise to indoor air quality problems. The change of total ventilation flow rate in the model building, is of course not that big magnitude as the infiltration, but of the order ±20 %, which is quite enough to influence the indoor thermal enviroment. Fig. 6 shows the balanced

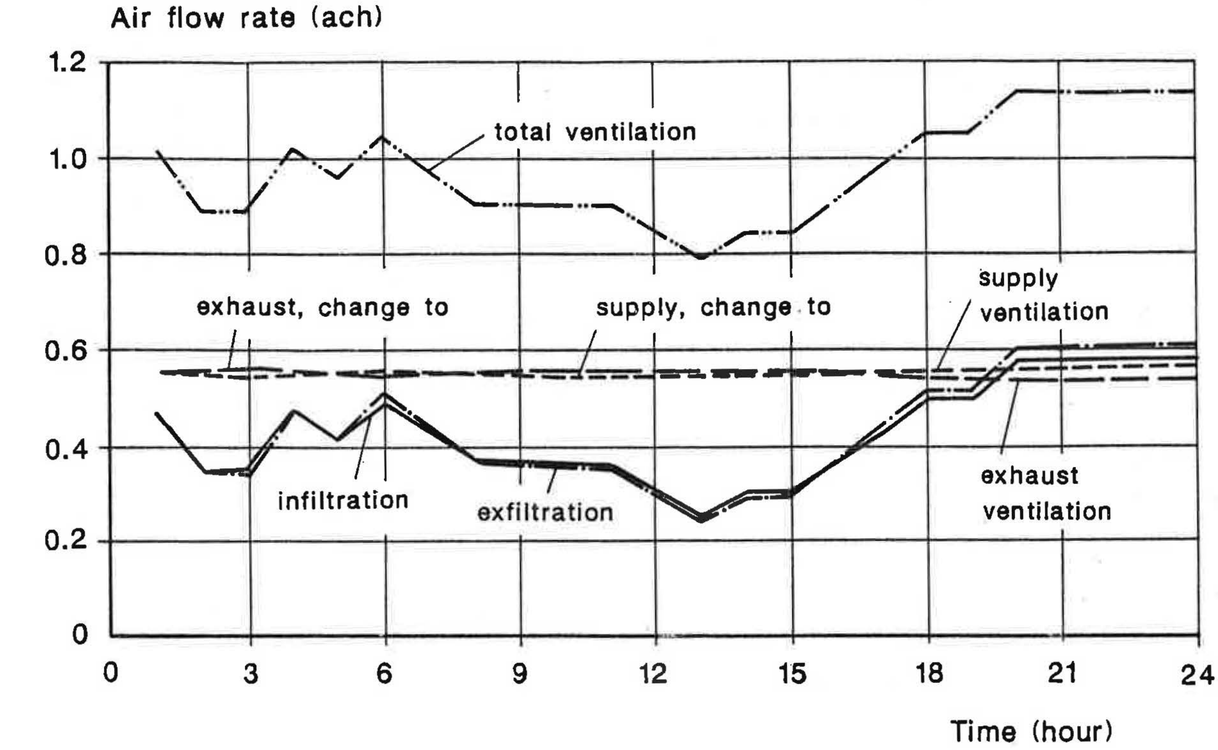

Fig. 5. Ventilation rate of the model tall building.

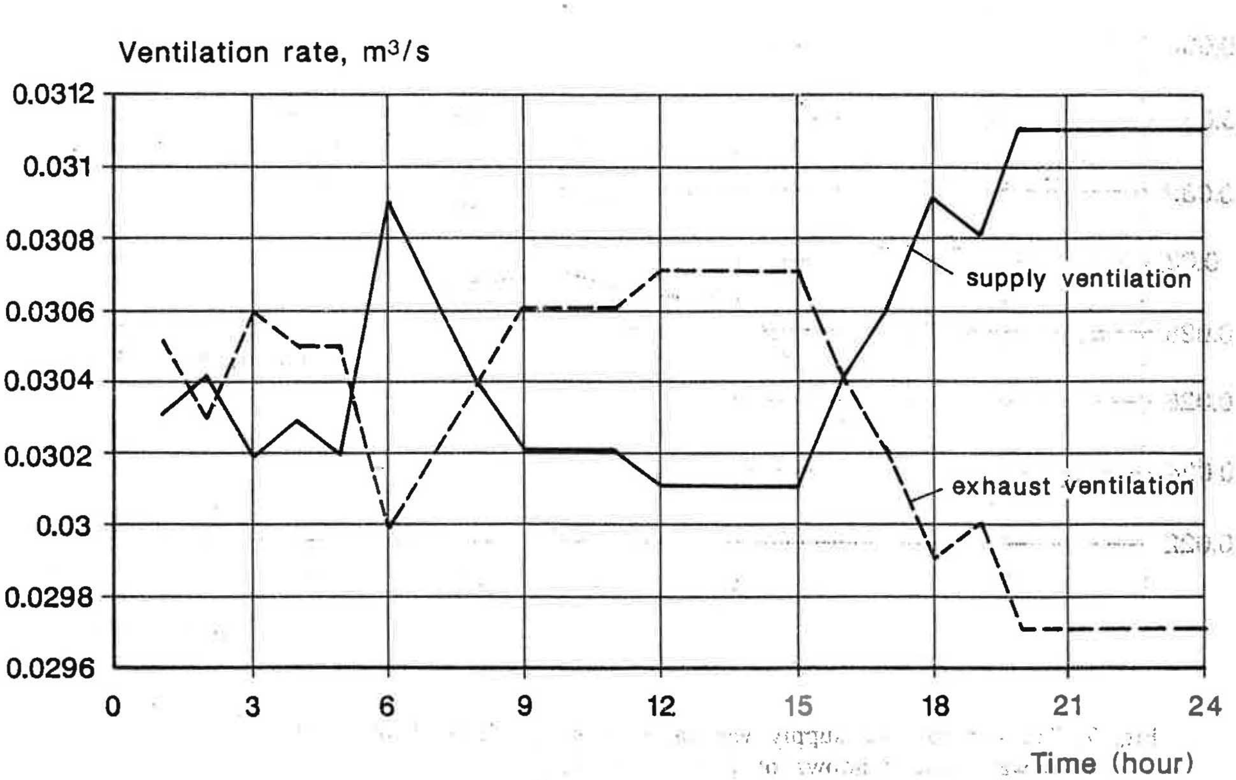

Fig. 6. Balanced ventilation rates of the model tall building for each floor (floor 7, or floor 2, or floor 13).

ventilation for individual floors which in this case has no window openings. It should be noted that this system is designed in favour of extraction by 10%.

From the point of view of the operation of mechanical ventilation system, it can be seen that even a k_t value of 0.0001 is not tight enough. The influence of the natural ventilation is quite significant. It is therefore necessary to keep or make the envelope very tight. For the buildings with balanced systems, especially high rise buildings, more attention should be paid to the design and operation of ventilation systems.

Fig. 7 shows the exhaust ventilation and supply ventilation for floor 7, when the windward side windows of this floor are open. For comparison, the leeward side windows of floor 7 are open in another case and this result is shown in Fig. 8. A large imbalanced ventilation rate occurs due to the changing of indoor pressure. Two opposing effects occur, depending on whether a window is open on the leeward side or the windward side. In this particular high-rise building situation in Sweden, airing is normally not allowed. Figs. 7 to 10 give a good background to that.

Two different influence also exist depending on whether a window is opened near the top or near the ground level. These are shown in Figs. 9 and 10. The effect will be more significant if the windows are opened on the floor nearest to where the fan is situated. In Fig. 9, the windows on the second floor are open.

The supply inlet of floor 2 is located near the fan while the exhaust outlet is far away from the fan. The supply ventilation rate is more varied than the exhaust ventilation rate which remains relatively constant. This is a serious problem, as it could cause the

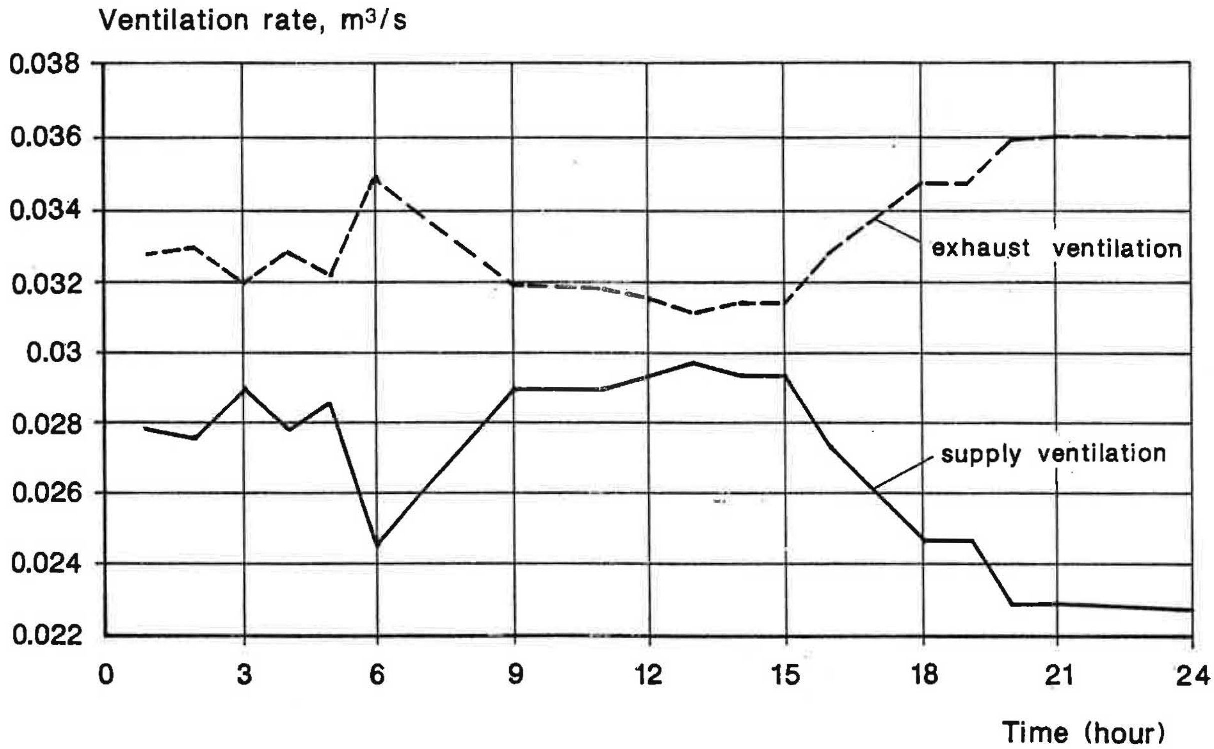

Fig. 7. The exhaust and supply ventilation rates for floor 7 when the windward side windows of floor 7 are open.

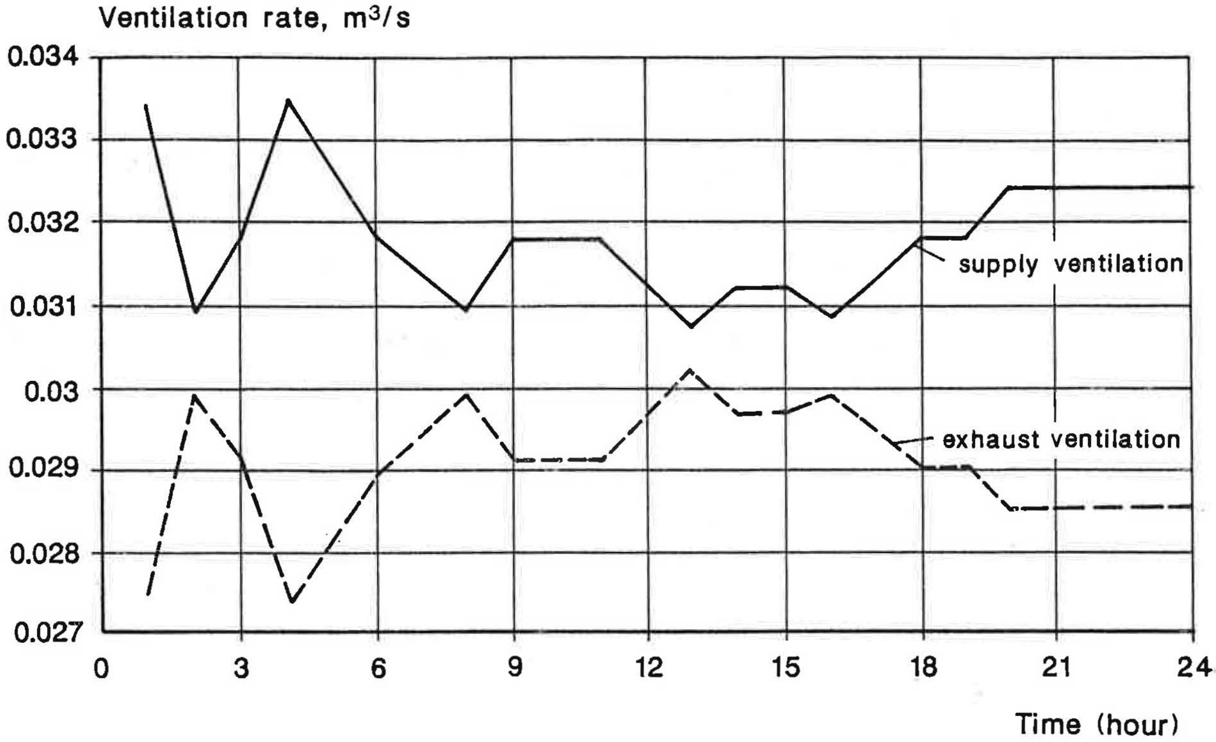

Fig. 8. The exhaust and supply ventilation rates for floor 7 when the leeward side windows of floor 7 are open.

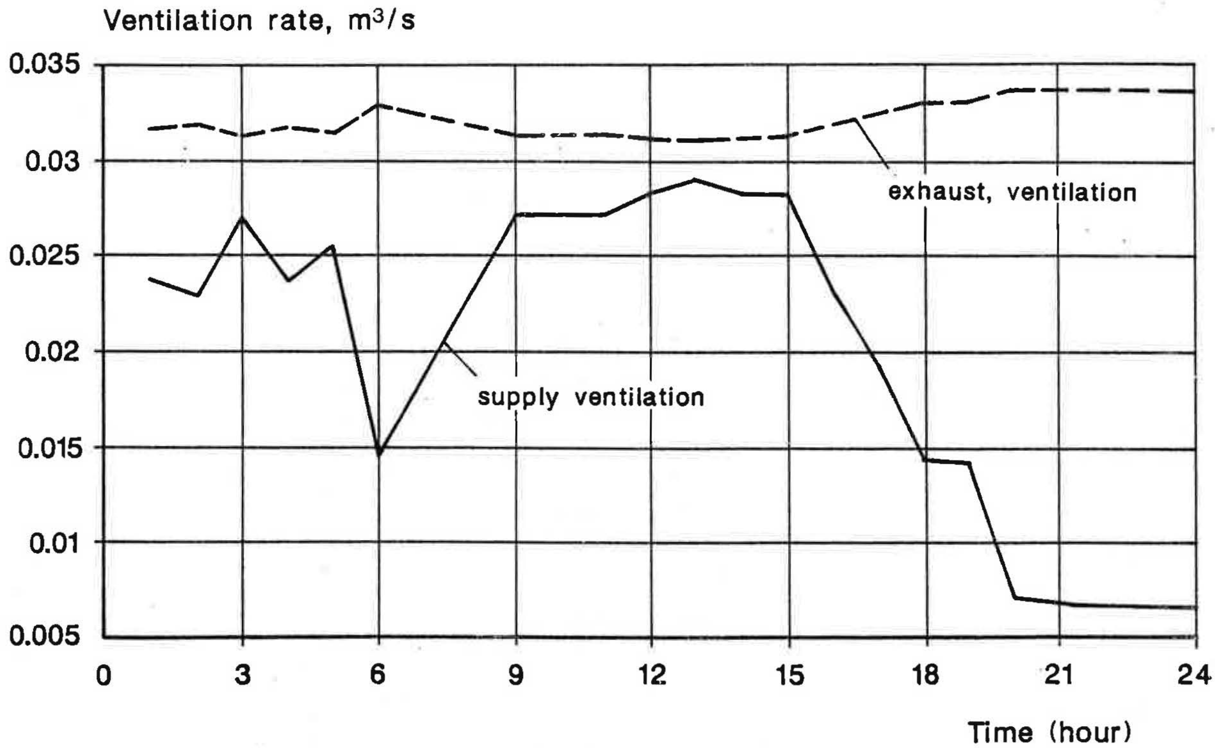

Fig. 9. The exhaust and supply ventilation rates for floor 2 when the windward side windows of floor 2 are open.

unstable operation of the mechanical ventilation. A similar situation is shown in Fig. 10. It is obvious that in a practical situation, the wind speed at the top of the building will be much higher than that at ground level and so the influence of the wind on the indoor air pressure on the top floor will be much larger. It is, therefore not desirable to open the top windows for the normal operation of the mechanical ventilation system.

As the whole ventilation system is driven by the same fan the opening of a window on one floor will to some extent affect the mechanical ventilation rate on adjoining floors, see Figs 11 to 14. The floor near the fan will be much more sensitive to the opening of the windows on the neighbouring floors.

It shoud be noted that one inherent weakness in this study is the simplification of the uniform wind pressure distribute over the building spatially. But, in fact, the wind pressure is mostly higher on the top part of the building, say, around 0,75 of the height. So the imbalanced ventilation rate is higher for the top part of the building. Actually, the leakage coefficient k_t on the top part is quite often higher, due to the damage by the long-time action of the higher wind force or in some cases due to damage by the concentric force of rain, see Peterson (1989), and so on. This higher leakage, together with higher wind pressure probably will have a undesirable effect on the operation of the ventilation system.

Another weakness inherent in this study is the large variation about the mean wind pressure, both in magnitute and in direction were not considered. Both of the mean wind pressure and the fluctuating wind pressure on the surface give rise to pressure differences across the building envelope. This will give a different prediction, especially for the lower wind speed, or the bottom of the building, where the fluctuating pressure is much bigger.

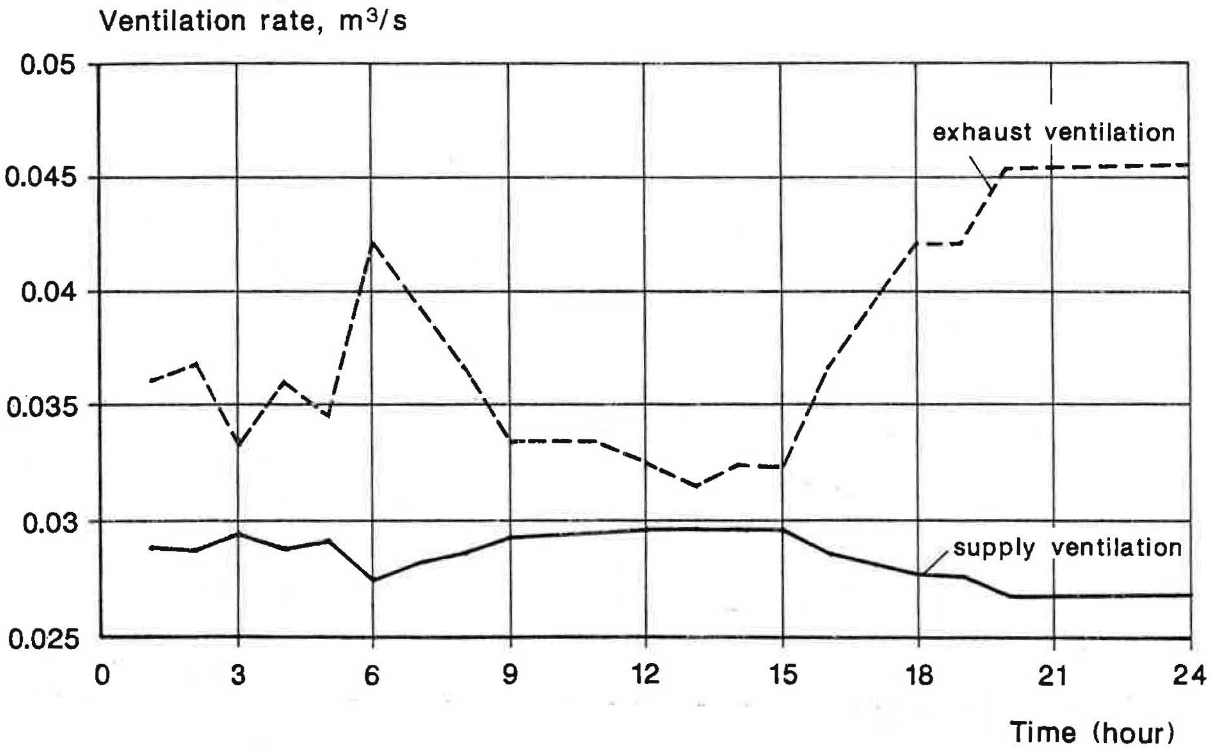

Fig. 10. The exhaust and supply ventilation rates for floor 13 when the windward side windows of floor 13 are open.

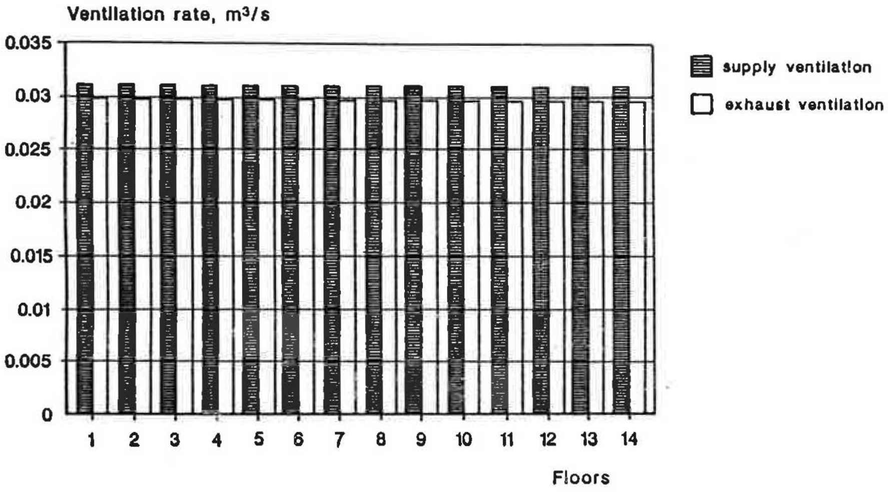

Fig. 11. The exhaust and supply ventilation rates for each floor when no windows is open.

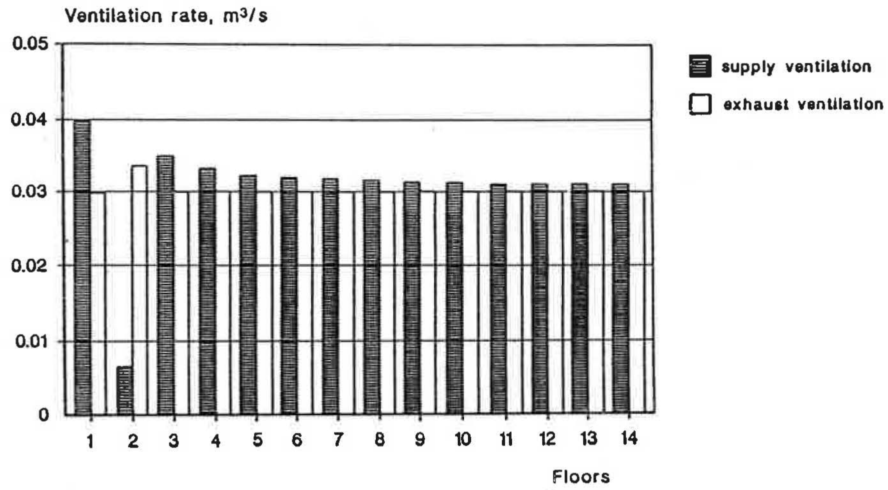

Fig. 13. The exhaust and supply ventilation rates for each floor when the windward side windows of floor 2 are open.

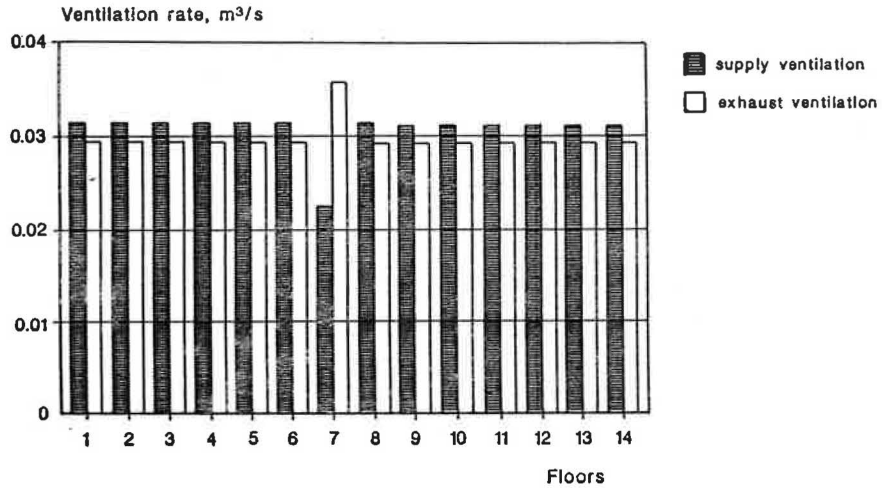

Fig. 12. The exhaust and supply ventilation rates for each floor when the windward side windows of floor 7 are open.

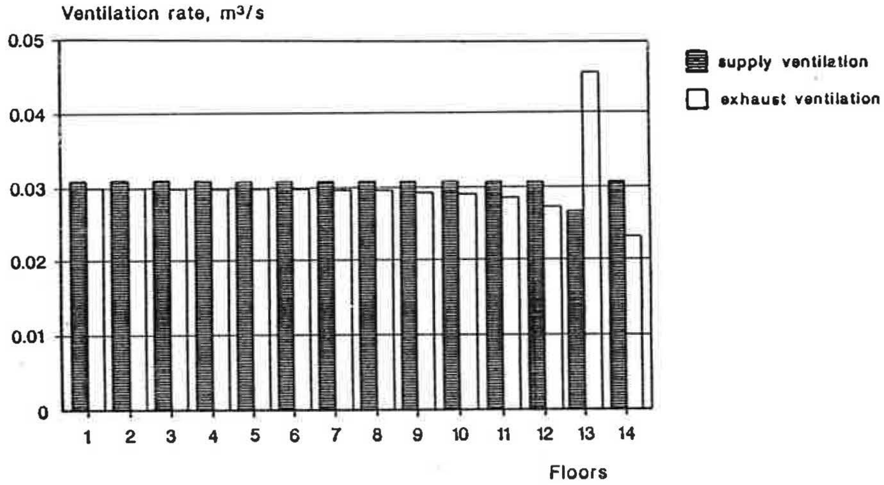

Fig. 14. The exhaust and supply ventilation rates for each floor when the windward side windows of floor 13 are open.

Conclusions

The analysis here has confirmed that a large imbalanced ventilation rates occur, due to the changing of indoor pressure. This can be attributed to an unstable operation of performance on the balanced ventilation system, such as when some windows are opened. The opposite effect occurs, when the window is opened on the windward side or the leeward side. The ventilation rate on the floor which is near the fan, will be much more sensitive to the opening of its own windows.

The example shows that the influence of wind pressure on the operation of the mechanical ventilation system is higher, and should be taken into account when designing the systems.

References

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