

Natural Ventilation in Atria

a case study

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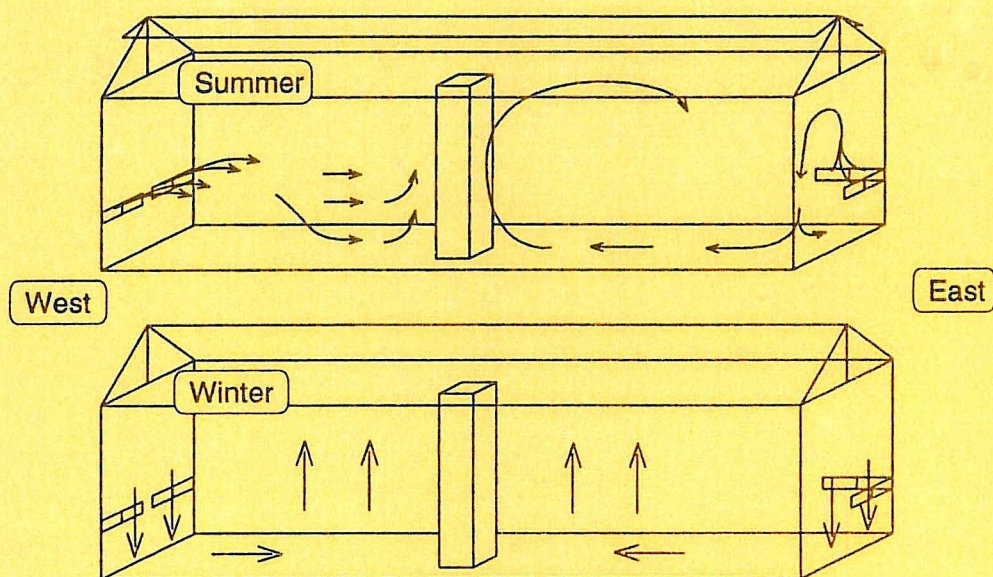
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PAPER NO. 55

Presented at ROOMVENT '96, Fifth International Conference on Air Distribution in Rooms, Yokohama, Japan, July 17-19, 1996

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ABSTRACT

This case study comprises a monitoring programme as well as a Computational Fluid Dynamics (CFD) analysis of a natural ventilated atrium. The purpose has been to analyse the performance of a typical natural ventilation system in Denmark under both summer and winter conditions. The monitoring programme consisted of measurements in two short-term periods under summer and winter conditions, respectively. Vertical temperature distribution, surface temperatures, air change rates and thermal comfort conditions were measured. CFD simulations were carried out in the same cases. The influence of the inlet opening position and the solar radiation on thermal comfort and ventilation capacity were also investigated. The results showed a well working natural ventilation system under both winter and summer conditions. The results also showed that CFD simulation was a useful tool to predict the performance of the system.

KEY WORDS

Natural Ventilation, Atria, CFD, Field Measurements.

INTRODUCTION

In recent years large glazed enclosures have found an increased use, both in connection with renovation of buildings and as a part of new buildings. One of the objectives of such enclosures is to add an architectural element, which combines indoor and outdoor climate. In order to obtain a satisfactory climate in these large semi-indoor spaces natural ventilation is an obvious choice, even if knowledge of performance and control strategies are limited. In the design stage it is crucial to be able to predict the performance of the natural ventilation system regarding thermal comfort and energy consumption to ensure an attractive environment at reasonable costs. In this connection a determination of the air movements in the space and especially in the occupied zone is an important issue.

The objective of this project is to analyse the performance of a typical natural ventilation system in a Danish atrium under both summer and winter conditions using different control strategies, and to evaluate the application of CFD as a practical design tool.

DESCRIPTION OF SUKKERTOPPEN

The atrium used as the case in this study is a part of Sukkertoppen, an old sugar refinery in Copenhagen, which was redeveloped into a multimedia house in 1992, see Figure 1. A new building was added south of the existing building, and the two buildings were coupled with an atrium. The purpose of the atrium is to reduce space heating load in adjacent buildings and to improve the daylight conditions. The atrium is used as circulation area and it has no permanent occupation.

The atrium dimensions are $L \times W \times H = 58 \text{ m} \times 10 \text{ m} \times 18.5 \text{ m}$. There are 8 low positioned openings, 4 in each end of the atrium, and openings in the ridge in the full length of the atrium, see Figure 2. All glazed surfaces facing outwards are equipped with low-energy glazing with a U-value of $1.6 \text{ W/m}^2\text{K}$. The atrium is heated to $16\text{--}18^\circ\text{C}$ in the winter season by a finned tube system located along outdoor glazed surfaces.

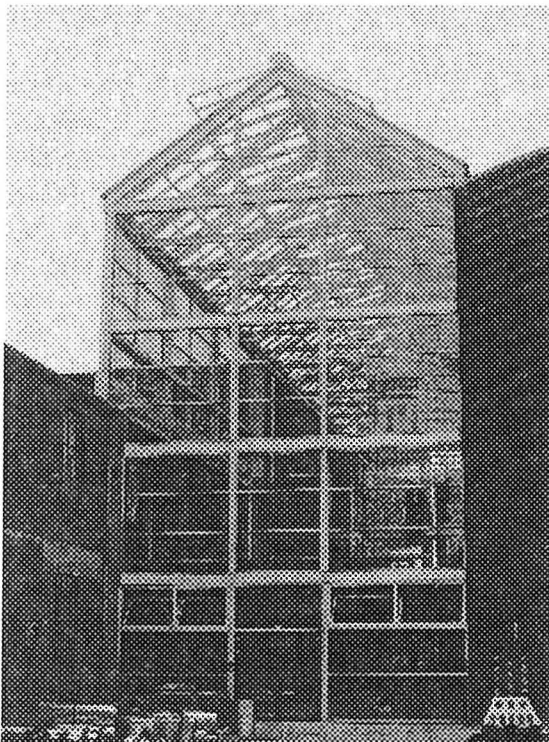


Figure 1. West end wall of the atrium in Sukkertoppen.

The natural ventilation system is controlled by the air temperature in the atrium. When the air temperature exceeds the set point, openings in the ridge will start to open in the full length of the atrium. First on minimum level in the leeward side and then on minimum level in the windward side. With increasing temperature the opening level increases until a maximum level is reached. The openings in the end walls will not open until the ridge openings have reached their maximum level, then one opening in each end of the atrium will start to open. When the first opening has reached its maximum it will be followed by the second opening and so on. With this control strategy the opening areas will always be much larger in the top of the atrium than in the bottom.

ANALYSIS METHOD

The project was carried out as a case study, and it comprised a monitoring programme as well as a CFD analysis. The

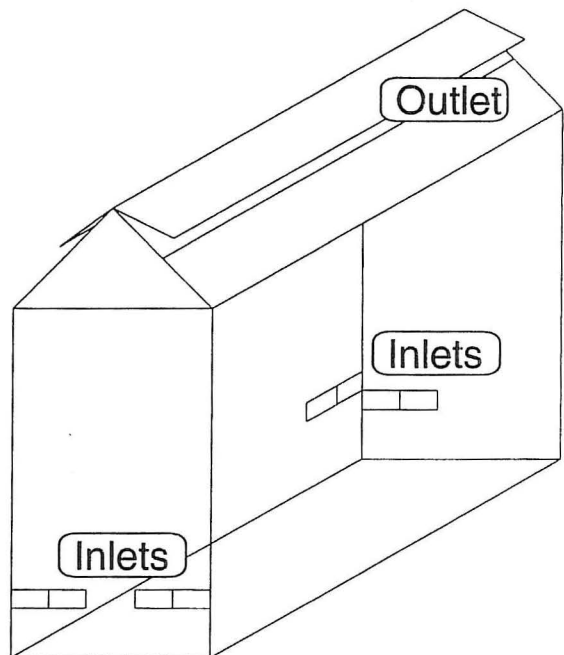


Figure 2. Outline of the atrium with openings.

monitoring programme consisted of detailed measurements in two short-term periods under summer and winter conditions. During a period of two days the following parameters were measured:

- 1) outdoor air temperature, wind velocity and wind direction
- 2) vertical air temperature distribution in the middle of the atrium,
- 3) surface temperatures on the floor, all walls and glazed surfaces,
- 4) air change rate,
- 5) air temperatures, radiant temperatures and air velocities 1.1 m above the floor in the symmetry plane of the atrium
- 6) air distribution visualized by smoke tests.

Measured outdoor conditions and surface temperatures served as boundary conditions for a CFD analysis, while other parameters were used for verification of the simulation results. Temperatures were measured with thermocouples and an automatic datalogging system, velocities with hot-sphere anemometers and air change rates by tracer gas technique.

Three-dimensional CFD calculations

were performed for one situation in each short-term measurement period. The situation with the most stationary conditions was chosen. It was assumed that the flow was symmetric around the centre planes of the atrium, i.e. 1/4 of the total volume was simulated.

Furthermore, the performance of the natural ventilation system configuration in the atrium was studied by two-dimensional calculations of different combinations of outdoor conditions, location and size of inlet and outlet openings and solar radiation on different surfaces in order to evaluate the control strategy for the system. A commercial CFD code was used for the analysis. In the present study a fixed viscosity turbulence model was used in combination with a built-in model for the calculation of wall heat flux. This model is less sensitive to the near-wall grid distance than traditional wall-functions combined with the standard $k-\epsilon$ model. For the 2D performance study, solar radiation on surfaces was introduced as a constant heat flux as described in the IEA Solar Heating and Cooling Programme, Task 12 (1995).

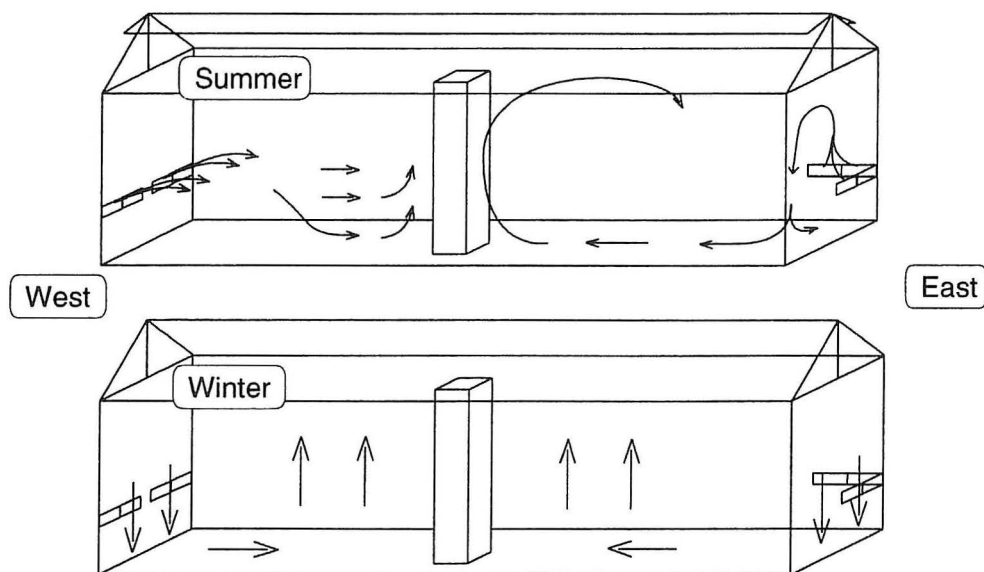


Figure 3. Air flow patterns in the atrium observed by smoke visualizations. In the summer time the air is well mixed due to the large inlet jets. In the winter time the air is well mixed due to buoyant flow at the cold glazed surfaces and the warm walls of the adjacent buildings.

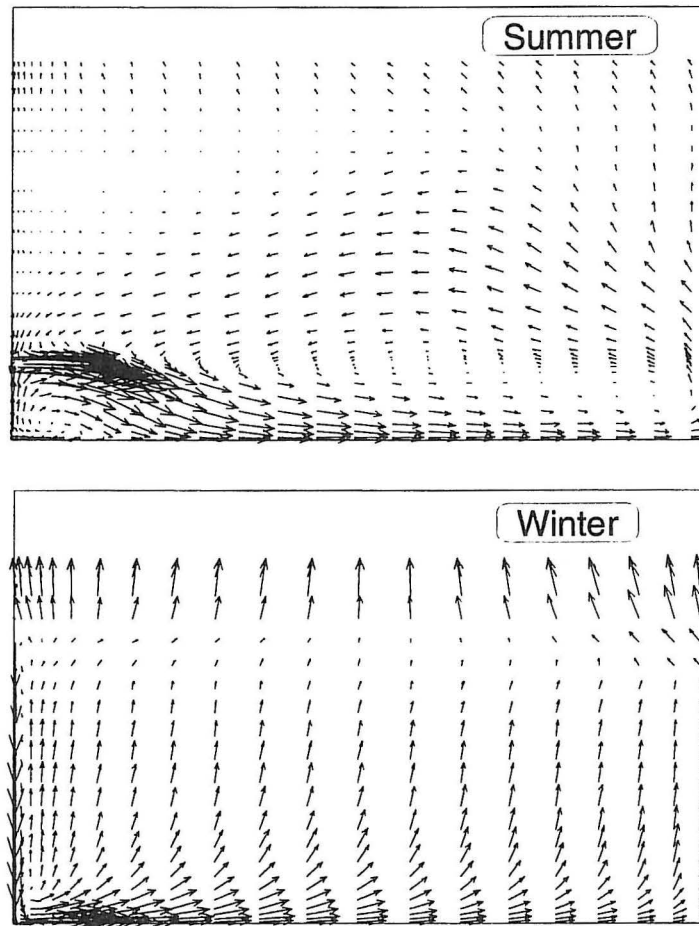


Figure 4. The air flow under summer and winter conditions was simulated by a 3D-model. The upper picture shows the flow field in the summer situation in a plane at the centre of the inlet. For the winter situation the calculated flow is showed in a plane close to the warm wall of the adjacent building.

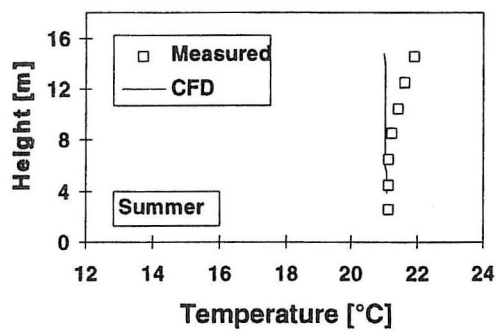


Figure 5. Measured and calculated temperature profile near the centre of the atrium under summer conditions.

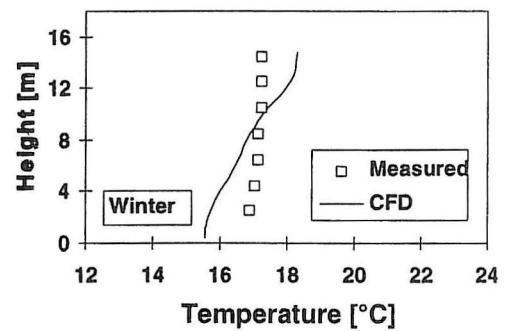


Figure 6. Measured and calculated temperature profile near the centre of the atrium under winter conditions.

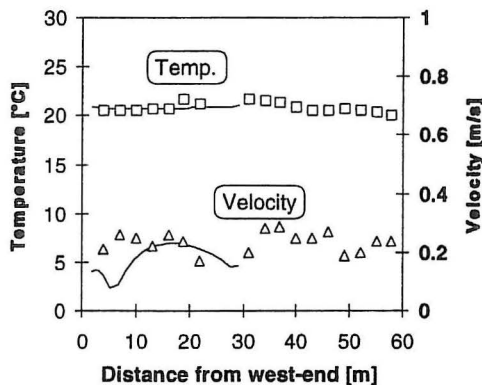


Figure 7. Air velocity and temperature in the occupied zone in the summer situation. Lines are simulations, marks are measurements.

COMPARISON BETWEEN MEASUREMENTS AND CALCULATIONS

Results

Measured and calculated air flow patterns and temperature profiles are shown for summer and winter conditions in Figures 3 to 6. Figures 7 and 8 show measured and calculated air velocities and temperatures in the occupied zone of the atrium.

Discussion of the summer situation

Under measured summer conditions with an outdoor temperature of 20°C and low windspeed all openings were opened at their maximum level. Air was supplied to the space through openings in the end walls, and outflow went through openings in the ridge. From time to time, depending on windspeed, air was also supplied through the windward openings in the ridge causing a local high air change rate in the upper part of the atrium.

The air change rate in the atrium as a whole was measured to be 4.9 h⁻¹, while calculations based on only thermal effects, i.e. pressure differences due to differences between indoor and outdoor temperature, gave a value of 3.5 h⁻¹. Consequently, wind velocities varying between 2.1 m/s and 2.8 m/s during the

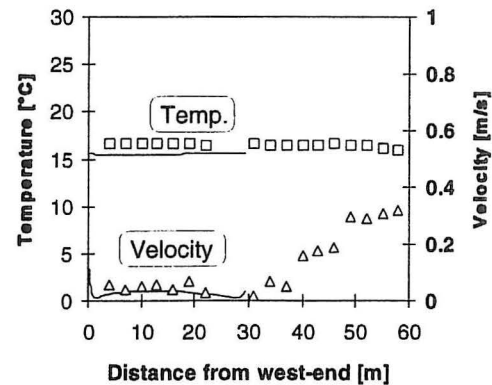


Figure 8. Air velocity and temperature in the occupied zone in the winter situation. Lines are simulations and marks are measured.

measurement period contributed significantly to the air change.

The air was supplied to the space with a relatively high velocity through the end wall openings forming large air jets from both ends of the atrium, because the openings in the end walls were much smaller than the openings in the ridge, Andersen (1995). Therefore, the air in the space was well mixed with moderate thermal stratification as a result.

The overall air flow pattern simulated in the west end of the atrium (Figure 4) shows a reasonable agreement with the observed air flow shown in Figure 3. The temperature profile in Figure 5 also show a good agreement between measurements and calculations of the summer situation.

Thermal comfort has been evaluated by air velocity and temperature measured 1.1 m above the floor. Figure 7 shows that calculated and measured temperatures are close to 20 °C in the full length of the atrium. Measured and calculated air velocities are in the range from 0.2 to 0.3 m/s.

Discussion of the winter situation

Under measured winter conditions with an outdoor temperature of approximately 0°C and moderate windspeeds all openings were closed, and the only ventilation in the atrium was caused by infiltration through outdoor surfaces. The infiltration air change rate was measured to be 0.35 h^{-1} . Both smoke tests, tracer gas and temperature measurements showed a mixed air flow pattern in the space with downward air flows along glazed outdoor surfaces and upward air flows along interior walls.

Figures 3 and 4 show that the simulated overall air flow patterns agree with the observed air flow. Figure 6, however, shows that the simulations predict a thermal stratification which is not in agreement with the measurements showing a fully mixed air space. Different possibilities were tried out in the modelling of boundary conditions, e.g. heat balance at walls and infiltration. Both the energy balance and the temperatures in the atrium proved to be very sensitive to the treatment of the boundary conditions.

Comfort conditions were evaluated by air temperature and velocity 1.1 m above the floor in the full length of the atrium. Figure 8 shows a homogeneous temperature level in the entire occupied zone, while air velocities are significantly higher in the east end than in the west end of the atrium. There may be two effects explaining the higher velocities. Firstly, the glazed surface in the east end consists of two parts joining in the corner of the building as indicated by the inlet positions in Figure 2. This geometry may increase the cold downdraught along the surfaces. Secondly there was a wind pressure of a few metres per second on the east end of the building during the measurements. This may increase the infiltration in the full height of the building resulting in an increased downdraught.

Therefore, the assumption of symmetrical conditions may not be suitable in the winter situation.

PERFORMANCE STUDY OF NATURAL VENTILATION CONFIGURATION

Results

The chosen control strategy for the natural ventilation system in the atrium is evaluated by a CFD analysis comparing alternative strategies under different possible working conditions.

The performance under summer conditions is examined for three different opening strategies as shown in figure 9:

- air inlet in end walls and air outlet in ridge openings
- air inlet and outlet in ridge openings
- air inlet in end walls and ridge openings and air outlet in ridge openings

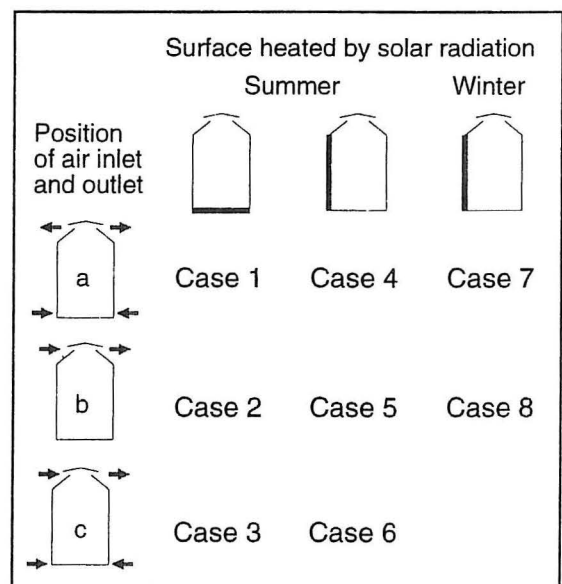


Figure 9. Analysed opening strategies and solar radiation locations.

Situation a) occurs when openings both in the walls and in the ridge are open, and the opening areas are approximately of the same size. Situation b) occurs when only the ridge openings are opened and situation c) occurs when the ridge opening area is much larger than the wall opening area. In cases b) and c) a wind pressure is simulated to force the air to flow in and out of the left and right top opening, respectively. Each situation is analysed with respect to solar radiation on the floor and on the south facing wall.

The performance under winter

conditions is examined for two different opening strategies, a) and b), with solar radiation on the south facing wall. Figure 9 shows all the combinations analysed. Results of the calculations are shown as temperature profiles in Figures 10 and 11.

Discussion

The summer situation in Figure 10 shows that the location of both the openings and the solar radiation determines the temperature conditions and the air change rates in the atrium.

Solar radiation on the floor results in

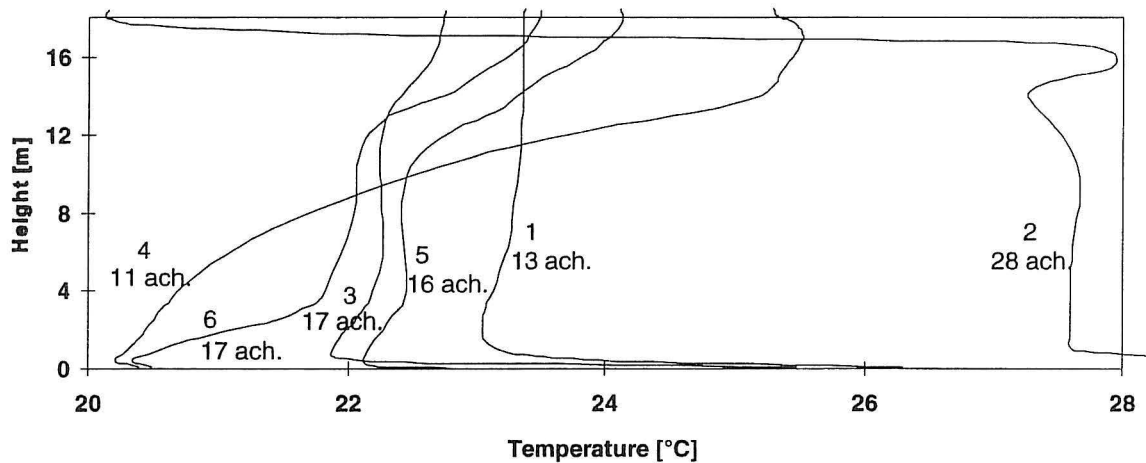


Figure 10. Calculated temperature profiles and air change rates of the cases 1 - 6.

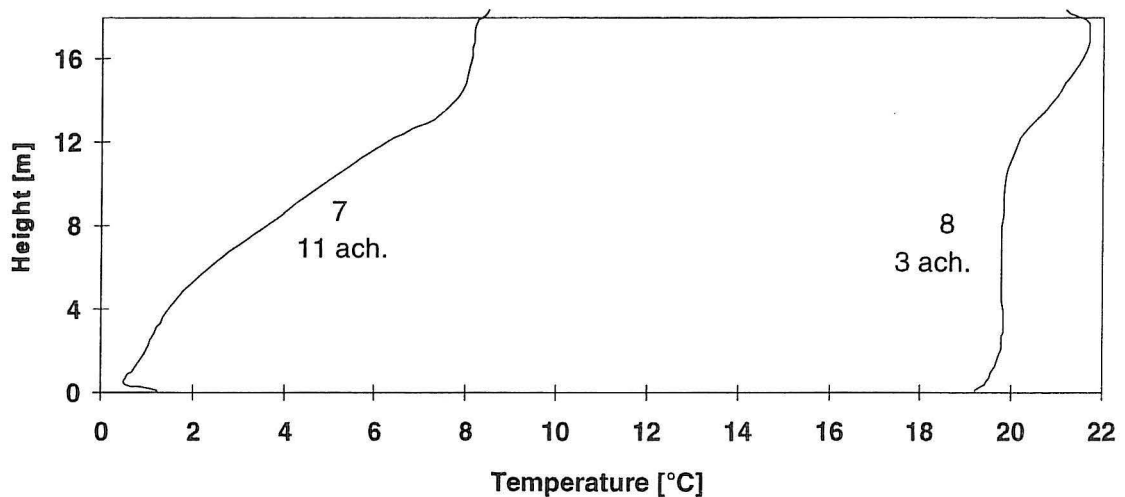


Figure 11. Calculated temperature profiles and air change rates in the winter, (case 7 and 8).

high temperatures close to the floor and an even temperature distribution in the rest of the space. The location of the openings determines the air change rate and thus the temperature level. As it could be expected only openings high up in the atrium cannot provide satisfactory conditions.

Solar radiation on a wall will create a temperature gradient in the space. The size of the gradient and the air change rate are determined by the location of the openings. The thermally driven case (case 4) results in a large temperature gradient in the atrium with temperatures close to outdoor conditions at the bottom of the atrium and high temperatures at the top. The partly wind driven case (case 5) with openings only at the top will in this situation be able to create acceptable conditions and to decrease the high temperatures at the top. In case 6 the best features of the two previous cases are successfully combined.

The winter situation in Figure 11 shows large differences between the two calculated configurations. Case 7, which is very similar to case 4, creates also in the winter situation a large temperature gradient and, due to the low outdoor temperatures, temperatures in the occupied zone become too low. Because of the large temperature difference between indoors and outdoors a very small opening area will result in a high air change rate, and with the configuration of the atrium with a large ridge opening, in an unstable system. The configuration in case 8 results in an even temperature distribution in the atrium and acceptable temperature levels in the occupied zone.

CONCLUSION

Project results showed a well-working natural ventilation system under both winter and summer conditions. With solar radiation falling on the floor only very early in the morning and late in the afternoon and on the south facing wall during the day, the existing control strategy in the atrium proved to be a good choice. Both measurements and calculations confirmed that it will be able to ensure acceptable temperature conditions in the occupied zone in both winter and summer situations with moderate temperature gradients and required air change rates. The location of the temperature sensor for system control 3-4 m above the floor gives a stable system with acceptable conditions in the whole atrium.

CFD simulations proved to be a useful tool to predict or to evaluate performance of the ventilation system and the indoor climate in the atrium. However, boundary conditions have to be treated very carefully in order to obtain reliable results.

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