NatVent™

Work Package 2: Performance of naturally ventilated buildings

Detailed Monitoring Report
BRF-kredit Headquarters (DK2)

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Table of contents

1. Introduction

The work within the pan-European research project NatVent™ **"Overcoming technical barriers to low energy natural ventilation in office-type buildings in moderate and cold climates"** has been divided into three work packages. The second work package, WP2, is titled **"Performance of naturally ventilated buildings"** and it is centred on evaluating the performance of existing buildings designed and constructed specifically as energy-efficient naturally ventilated buildings. This detailed monitoring report forms part of the reporting of the work carried out within WP2.

The report documents results and findings of measurements performed in the BRF-kredit Headquarters being one out of three Danish buildings investigated within WP2 of the NatVent™ project. In addition to this detailed monitoring report a summary report is available and also a CD-ROM.

2. Ventilation of office buildings

Increased concern over the adverse environmental impact of energy use has encouraged the design and construction of energy efficient buildings. This has lead to a growing interest for natural ventilation strategies and much attention is being given to the development of such systems.

Whether mechanical or natural ventilation systems are applied two basically different performance situations must be considered. In the winter-time the major challenge for the ventilation system is to provide a good indoor air quality, whereas in the summer-time the challenge is to control the internal temperature in order to avoid overheating.

During winter the ventilation concept for achieving acceptable indoor air quality is essentially based on the dilution principle. Outdoor air is supplied to the space and the concentration of contaminants in the room air is reduced through dilution. The resulting indoor air quality is primarily linked to the source strength of the contaminants and the air flow rate even if also adsorption and desorption effects should be considered. Utilising natural ventilation the air flow rates varies as a function of time and depends on prevailing climatic conditions, i.e. wind and temperature. Therefore, optimisation is essential in order to be able to combine good indoor air quality and low energy demand.

During summer the aim is to have maximum exchange of heat between the building structure and the ventilation air. Utilising natural ventilation large openings in the building envelope should be applied in order to facilitate high air flow rates. In addition, as the outdoor air is relatively cold night-time ventilation should be applied. Controlling the air flow rates is normally not an issue. Important parameters influencing the internal temperature are heat gains, i.e. internal heat gains and solar gains, building characteristics including thermal mass and the use of the building.

The required air flow rates for achieving good indoor air quality in the winter-time are different from the air flow rates required for controlling the internal temperature in the summer-time. Hence, the sizes of the required ventilation openings are different for the two situations.

3. Procedure

In order to gain a better understanding of the applicability and limitations of natural ventilation, 2-3 office-type buildings have been selected and studied in each of the seven European countries participating in the NatVent™ project. Of the selected buildings, BRF-kredit Headquarters is one out of three office buildings that have been studied in Denmark.

Studies have been conducted during the summer-time – cooling season – as well as during the winter-time – heating season. During each of the seasons technical measurements have been performed, questionnaires have been filled in by the occupants and additional registrations and interviews have been conducted.

3.1 Technical measurements

Technical measurements have been carried out in selected offices. The table below summarises the measured parameters and the equipment used.

Measured parameter	**Unit**	**Equipment used**
Indoor air temperature (Measurements taken 0.1 m above floor as well as 1.1 m above floor)	[°C]	TinyTalk II, Orion Components
Mean air velocity (Probe placed on the desk)	[$m \cdot s^{-1}$]	Dantec Multichannel Flow Analyser, type 54N10
CO concentration CO_2 concentration H_2O concentration (Measurements taken in a representative point in the office)	[$mg \cdot m^{-3}$] [ppm] [$g \cdot kg^{-1}$]	Brüel & Kjaer Multi-gas Monitor, type 1302
Dosed tracer (SF_6) Indoor air tracer gas concentration (SF_6)	[$ml \cdot s^{-1}$] [ppm]	Brüel & Kjaer Multi-gas Monitor, type 1302 and Multipoint Sampler and Doser, type 1303

Based on the measured parameters a number of related parameters have been calculated including the turbulence intensity [%], relative humidity [%], ventilation air supply [$l \cdot s^{-1} \cdot m^{-2}$] and air change rate [$h^{-1}$]. In addition to the measurements performed in the building measurements have been taken outdoors. These comprise CO, CO_2 and H_2O-concentration.

Climatic data have been obtained from a nearby meteo station. The data exists as hourly values and they comprise:

- temperature [°C]
- relative humidity [%]
- wind velocity [$m \cdot s^{-1}$]
- wind direction [°]

As the purpose of the summer-time ventilation (indoor temperature control) is different from the winter-time ventilation (indoor air quality control) the arrangement and the set-up of the measurements has been adjusted according to season. Further information on the basic monitoring procedures and the general monitoring protocol including duration of continuous

measurements, sampling intervals, averaging timings etc. can be obtained from Annex A, Detailed Monitoring Protocol.

3.2 User questionnaire

A questionnaire has been distributed to the occupants. The questionnaire has been distributed twice – once in the summer-time and once in the winter-time. The questionnaire concerns the occupants views on various environmental conditions in their office, and it is intended to complement the technical measurements.

4. Description of the building

BRF-kredit is a financing institute for property mortgages. The BRF-kredit Headquarters is located in Lyngby about 10 kilometres north of Copenhagen City. The building, completed in 1986, is a four-storeyed office building consisting of a main building and three office blocks. Figure 1 is showing a typical floor plan.

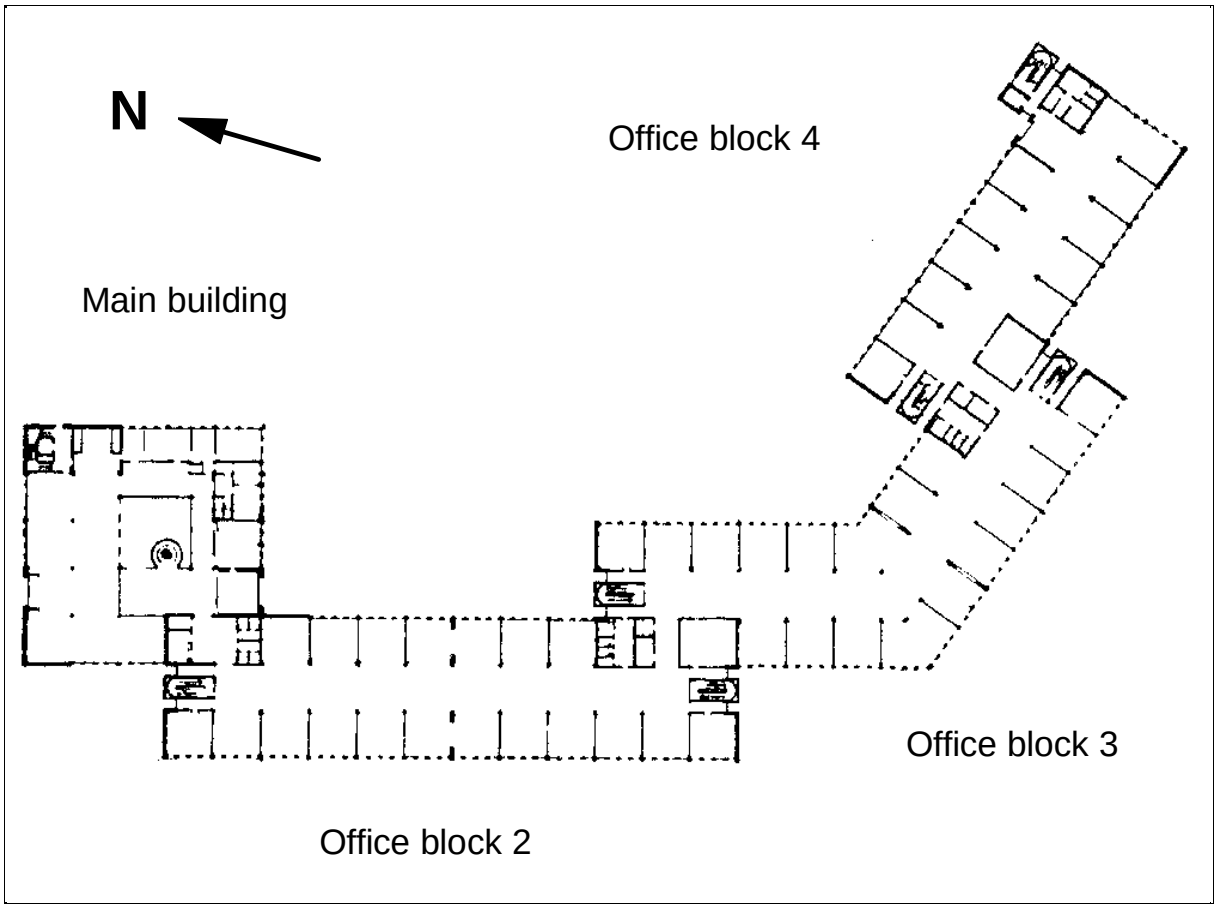

Figure 1: Typical floor plan. The depth of the offices is about 5 metres.

Figure 2: Outside view of the BRF-kredit Headquarters with the main building in the foreground and one of the office blocks (office block 2) to the right. The facades of the building have a finish of brickwork.

The facade of the main building faces a moderately busy road whereas the three office blocks, which in effect holds the offices, faces quiet surroundings.

The four sections of the building are linked together and at the connection points between the buildings there are staircases, lifts and toilets. Each of the building sections has a glass covered central room. In the main building there is a quadratic shaped atrium and in the office blocks there are arcade rooms, stretching lengthwise between the two ends of the block

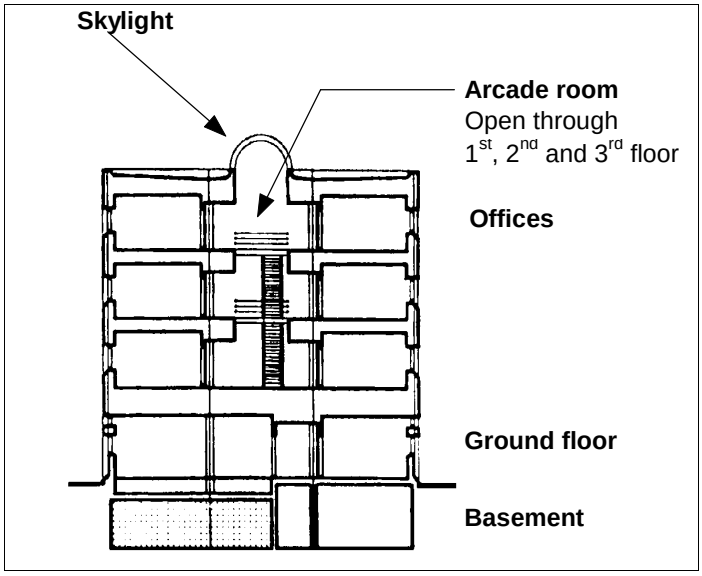

Figure 3: Sectional view of an office block

The quadratic shaped atrium in the main building is open from ground floor through third floor whereas the arcade rooms in the office blocks are open through first, second and third floors. There is no access of daylight to the circulation area of the ground floor.

This investigation has been focusing on the offices in the office blocks and figure 3 is showing a sectional view of an office block.

Figure 4: View from the second floor of the arcade room in one of the office blocks.

The main structure of the building includes a vertical supporting system of reinforced concrete columns and, at the internal balconies, reinforced concrete girders. Facades and horizontal divisions are prefabricated elements. Facades have a finish of brickwork, as can be seen from figure 2. The thermal mass of the building can be characterised as heavy. Windows are aluminium frames with three layers of normal float glass; skylights are two layers. In the skylights in the arcade rooms there are 4 m^2 of window per m in the longitudinal direction of the building and the transparent part amounts to 85 percent.

Figure 4 is showing a view of the arcade room of one of the office blocks

Being a financing institute for property mortgages the activity in the building is mainly paperwork. There are both open plan offices holding up to 10-15 persons and cellular offices. About 600 persons are working in the building.

The floor area of the building is about 20.000 m^2; about 10.000 m^2 (50 percent) is offices and meeting rooms, 6.000 m^2 (30 percent) is circulation area and the remaining 20 percent is toilets, cloakrooms and service area.

5. Ventilation philosophy and aims

Mechanical ventilation is provided only in the meeting rooms, toilets, canteen and the central computer room. Mechanical cooling is provided only in the central computer room. Space heating is covered by a conventional radiator system with thermostats on each radiator. Space heating and hot water is supplied from a joint heating plant, the fuel being natural gas.

Both in the summer situation (temperature control) and in the winter situation (indoor air quality control) the ventilation in the offices in the office blocks is based on the occupants use of multi-position windows in connection with automatically controlled opening of windows in the skylights in the arcade rooms. Night time cooling is part of the ventilation strategy. In addition, automatically controlled exterior solar shading will contribute to reducing the risk of overheating due to excess solar radiation.

6. Technology

Considering the open architecture of the arcade rooms in the office blocks the ventilation in the offices is based on natural ventilation. Effectively, the ventilation is based on manually operated openable windows in the offices and automatically controlled openable windows in

the skylights in the arcade rooms. Hence, ventilation is based on a combination of cross ventilation and stack driven air flows. Figure 5 and figure 6 are showing interior views from the offices.

Figure 5: In the offices there are manually operated multi-position windows, the so-called tilt and turn windows.

Figure 6: Solar shading in the offices is exterior Venetian blinds.

The windows in the offices are equipped with exterior Venetian blinds. The blinds are operated automatically and controlled through the use of light sensors. The blinds can also be operated manually on an individual basis. However, even if it is possible to override the automatic control, the manually chosen position cannot be permanently fixed, i.e. after some time it will be changed according to the automatic control system.

Figure 7: Skylights in the arcade rooms. Solar protection is external fabric shading, which can be seen to the left in the picture.

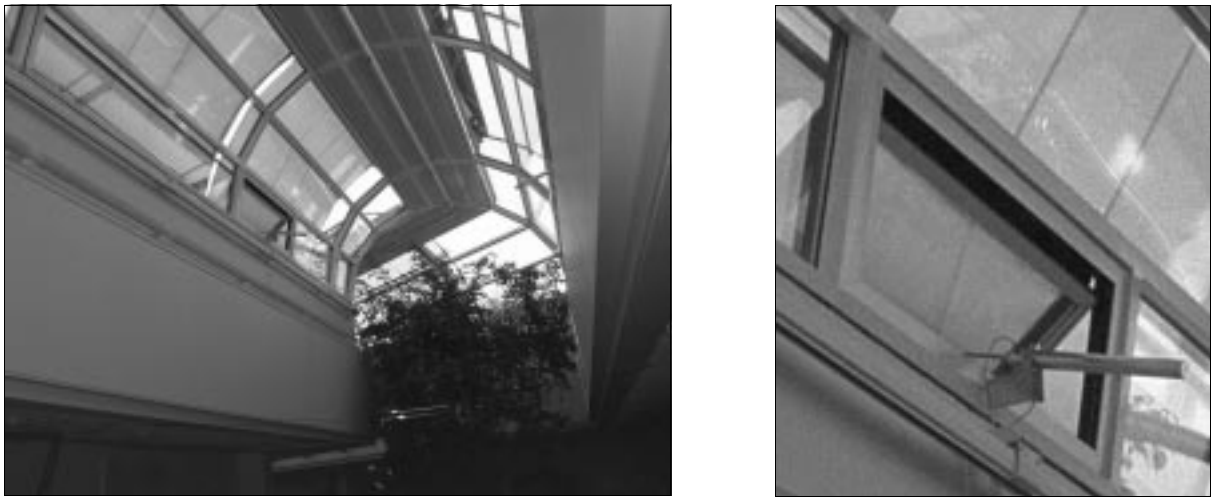

Figure 8: The ventilation openings in the skylights in the arcade rooms are automatically controlled through a number of temperature sensors positioned in the upper part of the arcade room.

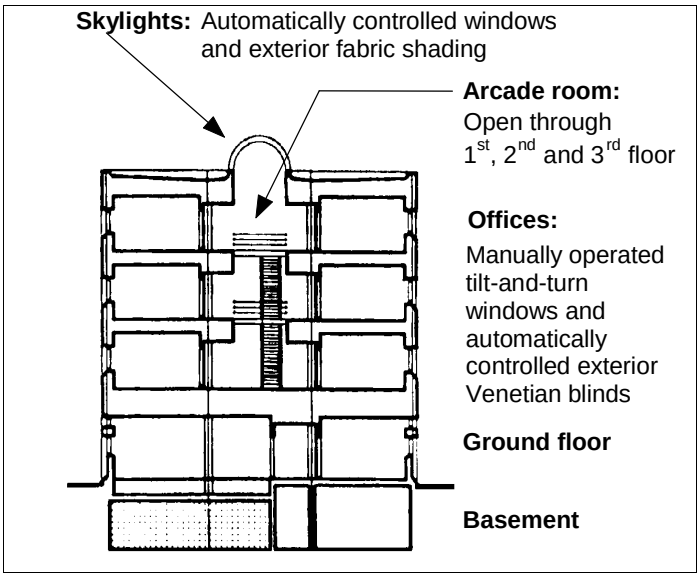

Figure 9: Summary of ventilation provisions in the office blocks. The ventilation in the offices is based on cross ventilation and stack driven air flows in the arcade rooms.

7. Investigated offices

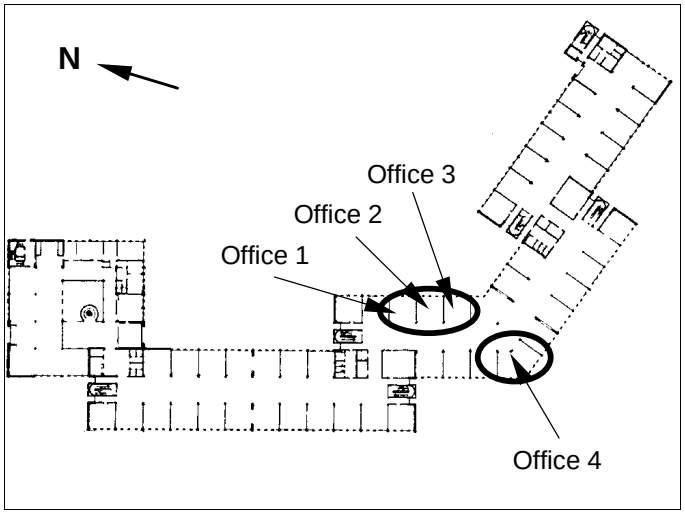

Figure 10: Location of the investigated offices on the third floor of office building 3. The offices 1, 2 and 3 are cellular offices and office 4 is an open plan office holding 8 persons.

Four offices located on the third floor of office block 3 were chosen for the investigation, see figure 10.

Office 1 is a relatively large cellular office of 25 m^2, office 2 and 3 are smaller cellular offices of equal size, 12 m^2 each, and office 4 is a large open plan office of 50 m^2 holding 8 persons. Office 1, 2 and 3 are facing essentially east, whereas office 4 is a corner office facing south west.

8. Monitoring results, summer season

8.1 Measurements

The main objective of the summer season monitoring has been to provide data for evaluation of the performance of the ventilation system concerning the thermal conditions in the building during the "cooling" season. Figure 11 is showing indoor and outdoor temperatures and figure 12 and 13 are showing examples of results of measurements in office 2 and 4, respectively.

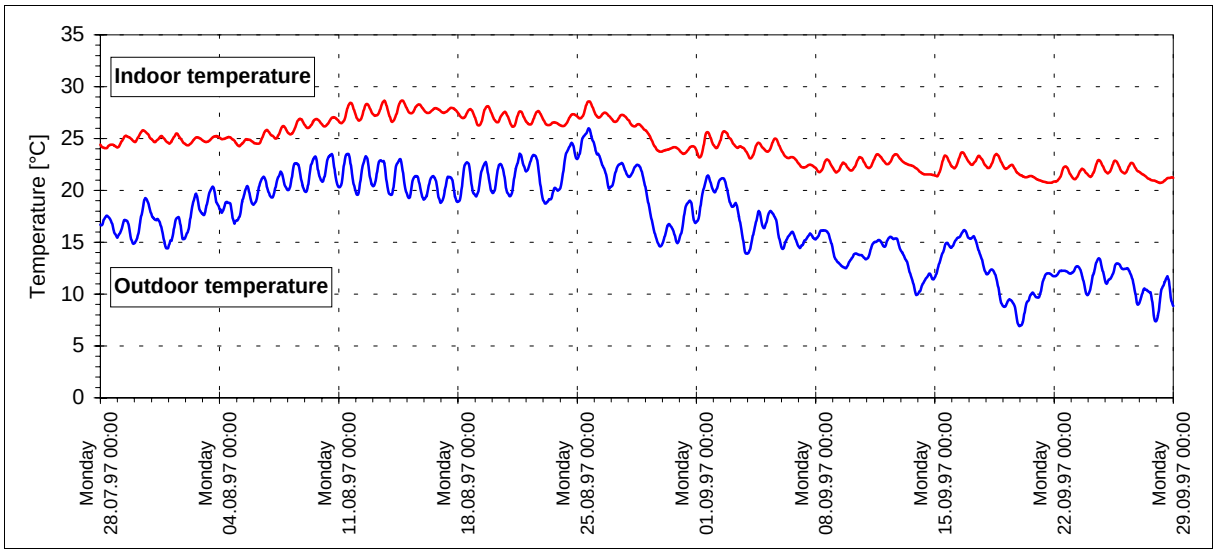

Figure 11: Indoor and outdoor temperatures during a two months period. The indoor temperature, [°C] is averaged from recordings taken simultaneously in office 1, 2, 3 and 4 every 30 minutes. The outdoor temperature, [°C] is hourly values from a nearby meteo station. The curves have been "smoothed" in order to emphasise the overall trends.

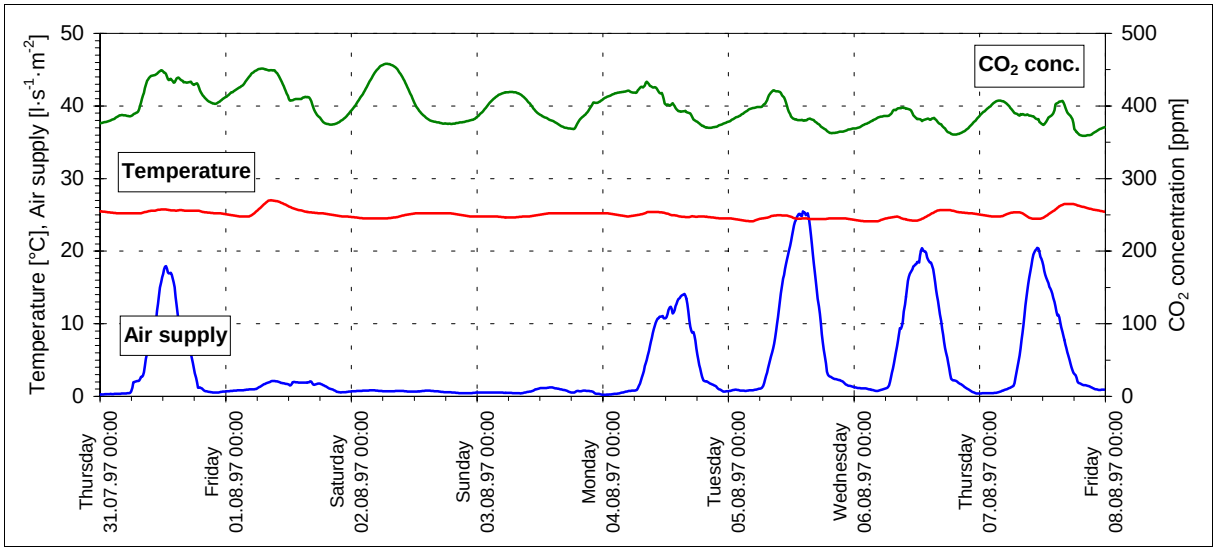

Figure 12: Results of measurements in office 2 (cellular office) during about one week. The temperature, [°C] taken 1.1 m above floor, has been recorded every 30 minutes. The CO_2-concentration, [ppm] and the air supply, [$l \cdot s^{-1} \cdot m^{-2}$] have been recorded approximately every 10 minutes. The curves have been "smoothed" in order to emphasise the overall trends.

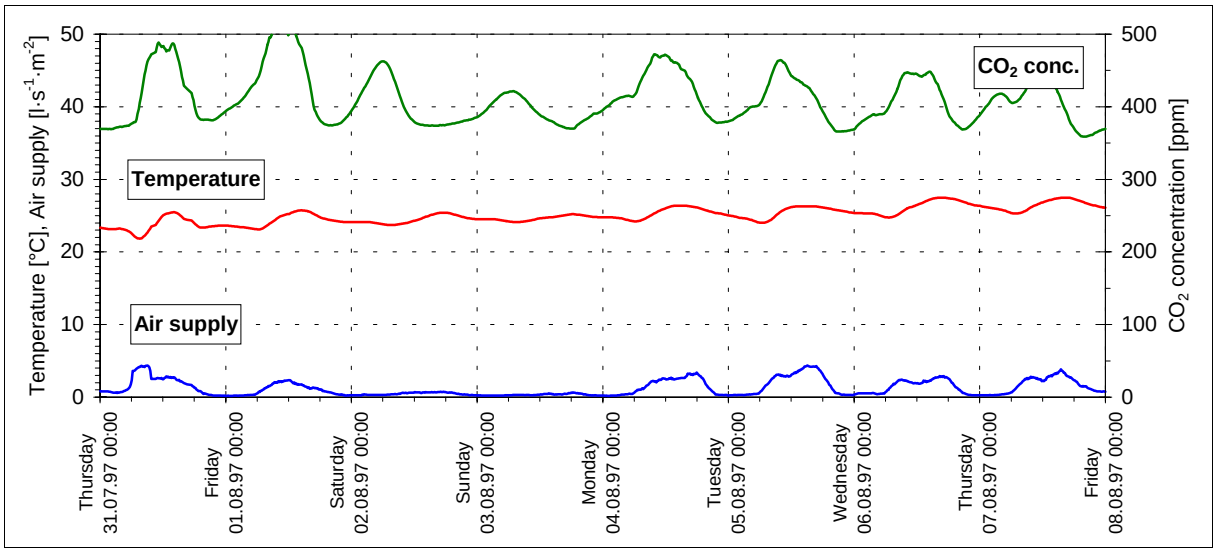

Figure 13: Results of measurements in office 4 (open plan office) during about one week. The temperature, [°C] taken 1.1 m above floor, has been recorded every 30 minutes. The CO_2-concentration, [ppm] and the air supply, [$l \cdot s^{-1} \cdot m^{-2}$] have been recorded approximately every 10 minutes. The curves have been "smoothed" in order to emphasise the overall trends.

Figure 14 and figure 15 are showing examples of results of measurements of the air velocity in office 2 and in the corridor adjacent to office 2, respectively.

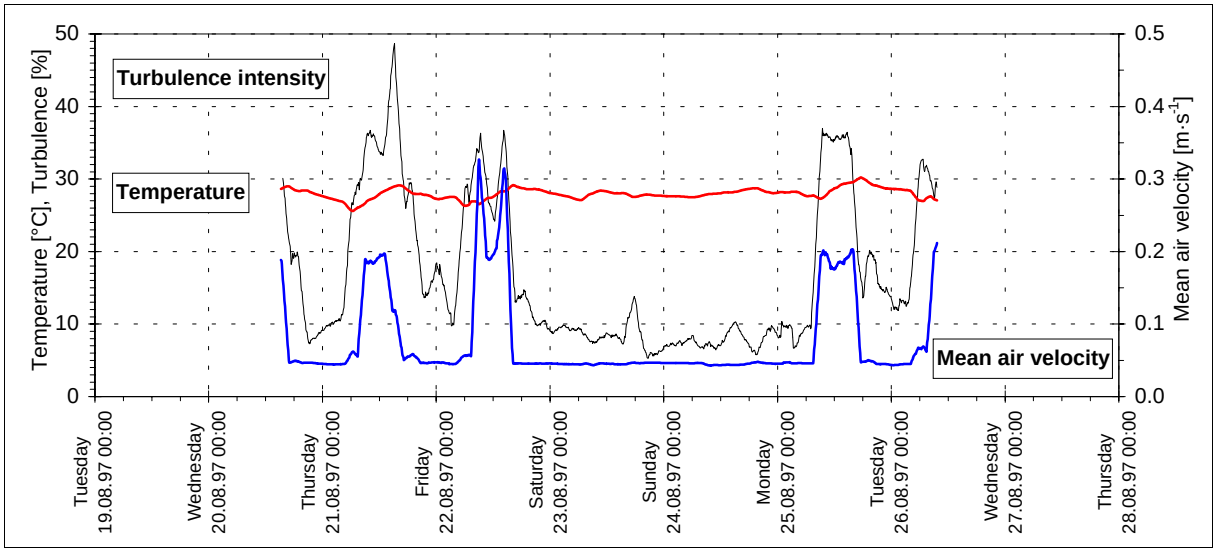

Figure 14: Results of measurements in office 2. The turbulence intensity has been calculated from measurements of the mean air velocity and the room temperature recorded every 5 minutes as an average value over the previous 3 minutes. The curves have been "smoothed" in order to emphasise the overall trends.

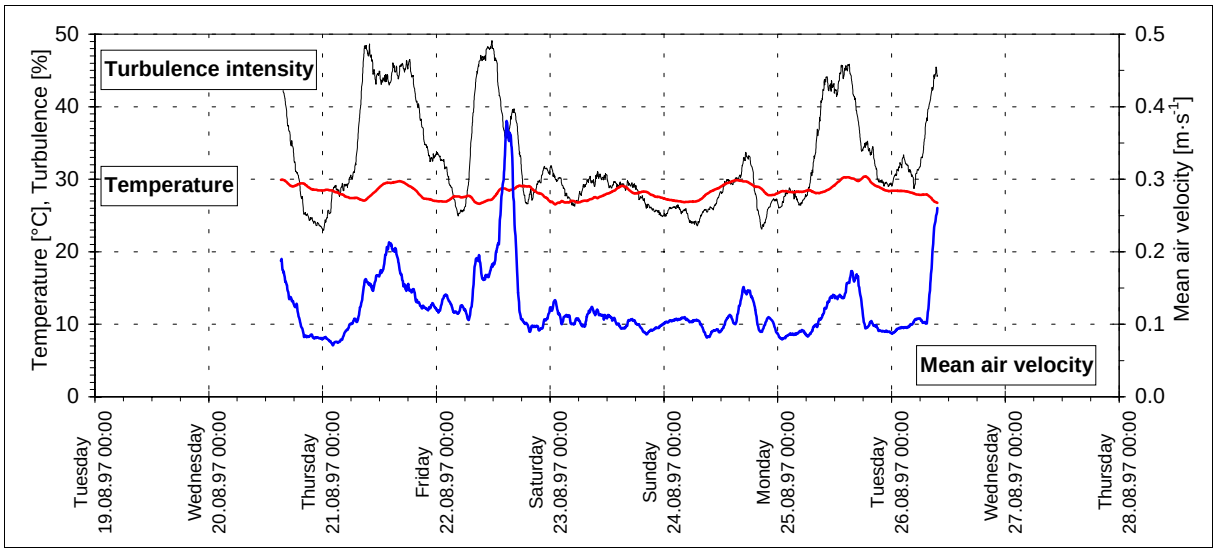

Figure 15: Results of measurements in the corridor adjacent to office 2. The turbulence intensity has been calculated from measurements of the mean air velocity and the room temperature recorded every 5 minutes as an average value over the previous 3 minutes. The curves have been "smoothed" in order to emphasise the overall trends.

8.2 Questionnaire

Through the questionnaire the occupants were encouraged to express their views on various environmental conditions in their office. The questionnaire included two identical parts. One part was to be filled in with respect to the summer season in general and the other was to be filled in with respect to one particular period, namely the one in which the technical measurements were performed. The occupants expressed their views by placing marks on dimensionless horizontal lines of equal length each ranging from *most positive* to *most negative*. Figure 16 summarises the ratings reported.

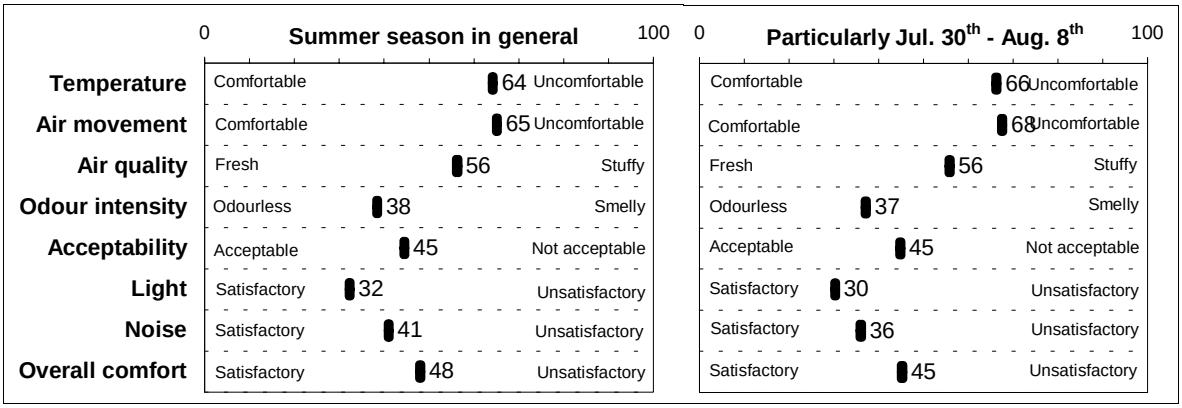

Figure 16: Averages of about 100 occupants ratings of various conditions in their office. Each occupant indicated his/her rating of each of the conditions (temperature, air movement etc.) through placing vertical marks on dimensionless, horizontal lines of equal length ranging from *most positive* (comfortable, fresh etc.) to *most negative* (uncomfortable, stuffy etc.). The rating is quantified by measuring (in millimetres) the distance along each line from *most positive* to the occupant's mark. For practical purposes, the ratings have been converted into the range 0–100. To the left is shown average ratings concerning the summer season in general, and to the right is shown ratings concerning the period in which the measurements were performed.

Also, the occupants were ask to indicate to what extent they felt they could control the temperature, the ventilation and the lighting in their office. Figure 17 summarises the results.

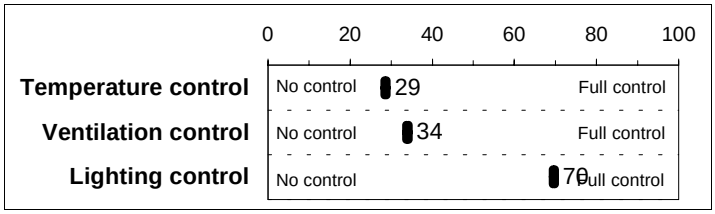

Figure 17: Averages of about 100 occupants views on to what extent they feel they can control the temperature, the ventilation and the lighting in their office. Each occupant placed vertical marks, according to his/her rating, on dimensionless, horizontal lines of equal length ranging from *No control* to *Full control*. The rating is quantified by measuring (in millimetres) the distance along each line from *No control* to the occupant's mark. For practical purposes, the ratings have been converted into the range 0–100.

8.3 Major findings

8.3.1 Thermal comfort

From figure 11 it appears that during a hot summer season and with night time cooling in operation indoor temperatures of around 25 °C is not unusual. In fact, during almost a three week period in the month of August, the indoor temperature, taken as the average of simultaneous recordings in four offices, was constantly exceeding 25 °C. In the period some days were exceptionally hot and even the night time temperature was extraordinary high, around 20 °C, and on those days the indoor temperature peaked close to 30 °C.

From around mid September the outdoor temperature dropped, and the curve for the indoor temperature is clearly showing five peaks for the week days and a decaying temperature during the week end.

8.3.2 Indoor air quality

From figure 12, showing results from a cellular office, it is evident that the occupant of office 2 kept both the window and the door to the adjacent corridor open during office hours. Apparently the office was not in use Friday August 1st. Due to security reasons the door to the office must be closed out of office hours and during nights and week ends. The CO_2-concentration is well below critical levels.

In office 4, being an open plan office holding 8 persons, the air supply is noticeable lower than in office 2, see figure 13. This leads to a slightly higher CO_2-concentration, but still well below critical limits.

8.3.3 Occupants views

The occupants reported dissatisfaction regarding the thermal conditions and the internal air movements. Also, the occupants feel they have limited possibilities of controlling the temperature and the ventilation in their office, see figures 16 and 17.

9. Monitoring results, winter season

9.1 Measurements

The main objective of the monitoring during the winter season has been to provide data for evaluation of the performance of the ventilation system with respect to providing acceptable indoor air quality. Figure 18 is showing indoor and outdoor temperatures and figure 19 is showing indoor and outdoor CO_2-concentrations.

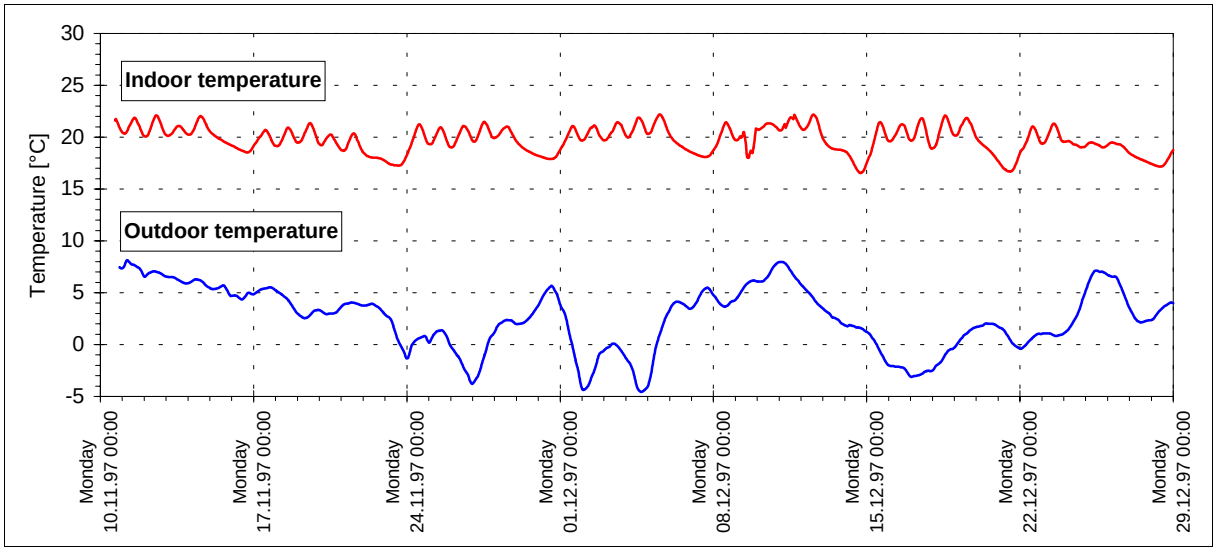

Figure 18: Indoor and outdoor temperatures during a two months period. The indoor temperature, [°C] is averaged from recordings taken simultaneously in office 1, 2, 3 and 4 every 30 minutes. The outdoor temperature, [°C] is hourly values from a nearby meteo station. The curves have been "smoothed" in order to emphasise the overall trends.

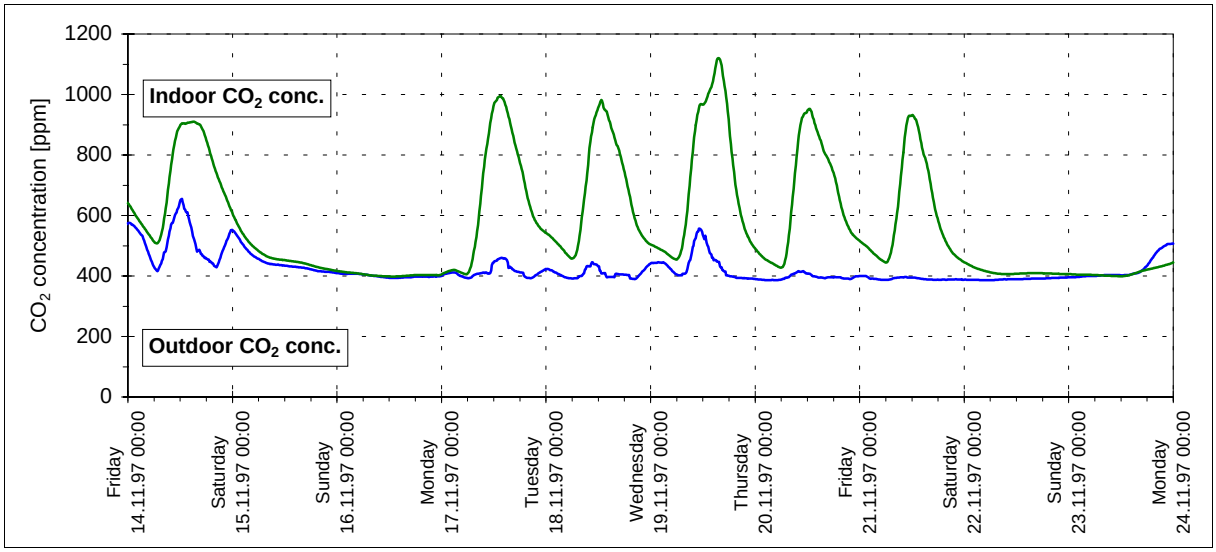

Figure 19: Indoor and outdoor CO_2-concentration during about one week. The indoor CO_2-concentration, [ppm] is averaged from recordings taken simultaneously in office 1, 2 3 and 4. Both indoor and outdoor concentration has been recorded approximately every 30 minutes. The curves have been "smoothed" in order to emphasise the overall trends.

Figures 20 and 21 below are showing examples of measurement results obtained in office 2 (cellular office) and 4 (open plan office), respectively.

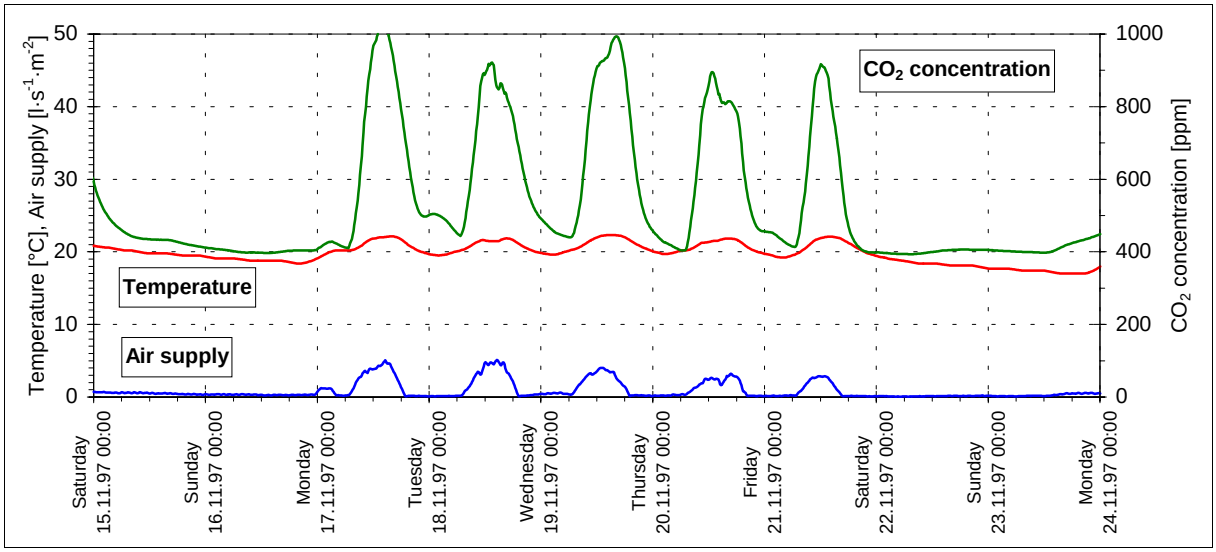

Figure 20: Results of measurements in office 2 (cellular office) during about one week. The temperature, [°C] taken 1.1 m above floor, has been recorded every 30 minutes. The CO_2-concentration, [ppm] and the air supply, [$l \cdot s^{-1} \cdot m^{-2}$] have been recorded approximately every 10 minutes. The curves have been "smoothed" in order to emphasise the overall trends.

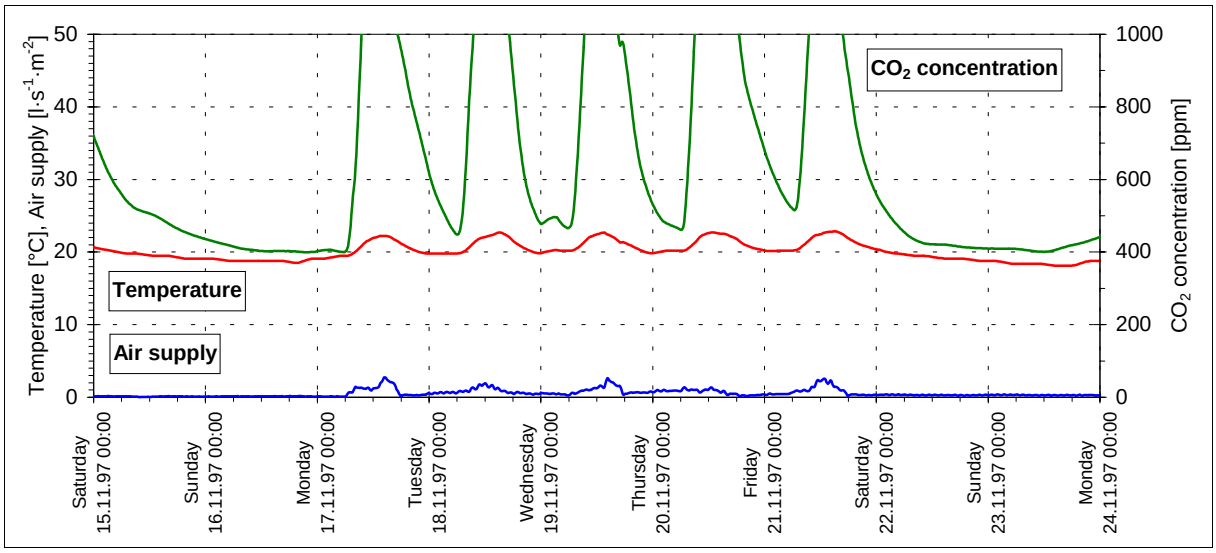

Figure 21: Results of measurements in office 4 (open plan office) during about one week. The temperature, [°C] taken 1.1 m above floor, has been recorded every 30 minutes. The CO_2-concentration, [ppm] and the air supply, [$l \cdot s^{-1} \cdot m^{-2}$] have been recorded approximately every 10 minutes. The curves have been "smoothed" in order to emphasise the overall trends.

Figure 22 is showing an example of results of measurements of the air velocity in office 2.

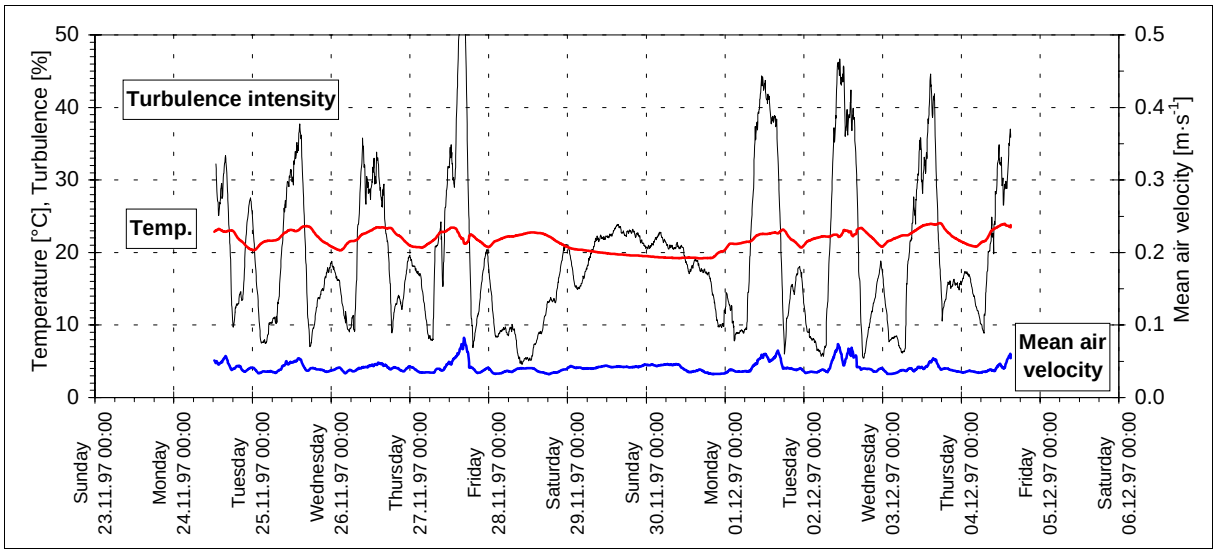

Figure 22: Results of measurements in office 2. The turbulence intensity has been calculated from measurements of the mean air velocity and the room temperature recorded every 5 minutes as an average value over the previous 3 minutes. The curves have been "smoothed" in order to emphasise the overall trends.

9.2 Questionnaire

Through the questionnaire the occupants were encouraged to express their views on various environmental conditions in their office. The questionnaire included two identical parts. One part was to be filled in with respect to the winter season in general and the other was to be filled in with respect to one particular period, namely the one in which the technical measurements were performed. The occupants expressed their views by placing vertical marks on dimensionless horizontal lines of equal length each ranging from *most positive* to *most negative*. Figure 23 summarises the ratings reported.

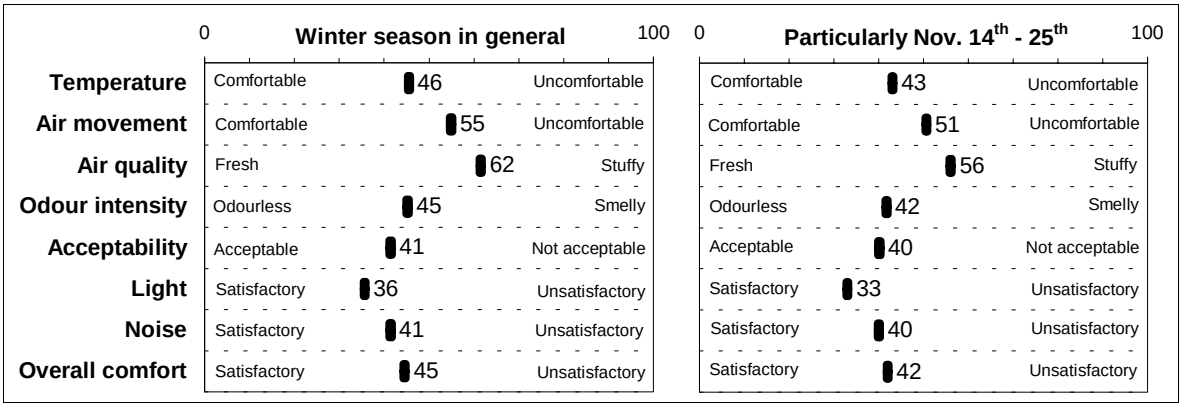

Figure 23: Averages of about 100 occupants ratings of various conditions in their office. Each occupant indicated his/her rating of each of the conditions (temperature, air movement etc.) through placing vertical marks on dimensionless, horizontal lines of equal length ranging from *most positive* (comfortable, fresh etc.) to *most negative* (uncomfortable, stuffy etc.). The rating is quantified by measuring (in millimetres) the distance along each line from *most positive* to the occupant's mark. For practical purposes, the ratings have been converted into the range 0–100. To the left is shown average ratings concerning the winter season in general, and to the right is shown ratings concerning the period in which the measurements were performed.

In addition to the occupants ratings of various environmental conditions, the occupants were ask to indicate to what extent they felt they could control the temperature, the ventilation and the lighting in their office. Figure 24 below summarises the results.

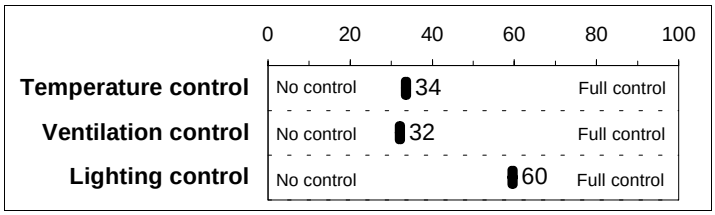

Figure 24: Averages of about 100 occupants views on to what extent they feel they can control the temperature, the ventilation and the lighting in their office. Each occupant placed vertical marks, according to his/her rating, on dimensionless, horizontal lines of equal length ranging from *No control* to *Full control*. The rating is quantified by measuring (in millimetres) the distance along each line from *No control* to the occupant's mark. For practical purposes, the ratings have been converted into the range 0–100.

9.3 Major findings

9.3.1 Thermal comfort

Figure 18 is indicating good heating control. As appears from the figures 18, 20, 21 and 22 the room air temperature reaches about 22 °C during occupancy indicating acceptable thermal conditions. In the open plan office there may be a tendency that the room air temperature is slightly higher. During week ends the indoor temperature drops to about 18 °C.

9.3.2 Indoor air quality

On average (four offices) the indoor CO_2-concentration during occupancy peaks at about 1.000 ppm, see figure 19. Focusing on a cellular office (office 2, figure 20) the maximum CO_2-concentration is about 1.000 ppm, which generally is considered just about acceptable. In the open plan office however, the CO_2-concentration peaks at 1.500-2.000 ppm, which must be considered critical, see figure 21. Comparing the two offices regarding the air supply significant differences can be seen as well. The results indicate some support of the general assumption, that in offices where many persons with individual comfort criteria have to come to an agreement regarding window opening (draught risk and indoor temperature considered), the ventilation may end up being too low.

9.3.3 Occupants views

The overall picture obtained from the questionnaire shows that the occupants are rating the indoor environment to be more on the comfortable side during the winter time than during summer time. Still, some discontent is detected regarding the occupants views on the freshness/stuffiness of the indoor air.

10. Lessons learnt and suggested improvements

- In certain periods the summer of 1997 was uncommonly hot. Nevertheless, indoor temperatures between 25 °C and 30 °C for longer periods must be considered unacceptable.
- From an engineering point of view, the automatic control system managing the openable skylights and the external fabric shading in the arcade rooms as well as the external Venetian blinds in the offices performed reliable and as intended.
- On the upper floors, second floor and third floor, the occupants are permitted to leave their window in the office ajar during night time. However, due to security reasons this is not allowed on the lower floors.
- In order to facilitate out door air supply out of office hours trickle ventilators should be installed.
- Due to security reasons, the occupants must keep the doors to the offices closed out of office hours. Closed doors will influence the performance of the cross/stack ventilation in the offices and prevent effective use of night cooling out of office hours.
- The tilt-and-turn windows, which can be left ajar out of office hours on the upper floors, are normally used in the bottom hung tilt position. This setting is unsuitable for providing effective single-sided ventilation.
- In order to provide air flow through the offices out of office hours grilles should be installed in the doors or in the parting walls to the corridor – in addition to the above mentioned trickle ventilators.
- An indicator of the occupants dissatisfaction concerning the thermal environment and internal air movements were seen from the wide use of desk ventilators which were found in a majority of the offices.
- Generally, in open plan offices holding many persons it may be problematic to establish a common understanding on the supply rate of outdoor air necessary for maintaining an acceptable indoor air quality.
- The overall picture obtained from the questionnaire shows that the occupants are rating the indoor environment to be more on the comfortable side during the winter time than during summer time. Still, some discontent is detected regarding the occupants views on the freshness/stuffiness of the indoor air.
- Despite the fact that not very favourable thermal conditions prevailed during the summer season and equally unfavourable indoor air quality conditions prevailed in the open plan office during the winter season the occupants expressed a positive attitude in general. This attitude may possibly be related to the choice of colours and materials and the internal architecture of the building in general, which appears very open, bright and friendly.