Thermal Comfort Measurements in a Hybrid Ventilated Office Room

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SUMMARY

Global climatic warming trends are becoming more and more obvious. They are characterized by longer and more intense heat wave periods as witnessed in extreme by the summers 2003 and 2006. This situation asks for mechanical cooling applications in office buildings. Is it possible to reach good indoor environmental conditions using hybrid ventilation strategies only? This question has been investigated by measurements in the *Forum Chriesbach*, a new low energy office building located in Dübendorf, Switzerland. The ventilation concept of this building is based on an earth-to-air heat exchanger system for hygienic air supply during day-time and a passive night cooling strategy by stack ventilation through window openings in the façade and towards a large atrium with roof outlets. Outdoor and indoor climatic conditions as well as internal heat loads have been measured in an office room over the summer heat wave period 2006. The measured data shows, that the hybrid ventilation system is able to hold the operative room temperatures during the heat wave period 2006 in the acceptable comfort range of ±0.5 PMV and to meet the requested indoor air quality limits (CO2 < 1000 ppm). It thus confirms the thermal simulation results made by the project design team.

INTRODUCTION

Hybrid ventilation, the combination of natural and mechanical ventilation, is an encouraging strategy to achieve energy-efficient office buildings with good indoor air quality and thermal comfort. International studies carried out within IEA Annex 35 “Hybrid Ventilation in New and Retrofitted Office Buildings”[1] have shown, that there exist hybrid ventilation solutions which together with other sustainable technologies such as daylighting, passive solar heating and passive cooling strategies may be able to provide good indoor environmental conditions and low energy use in office buildings in moderate climates like those in central Europe. For this kind of buildings an integral approach in the design of the energy, indoor climate, fire safety and security concept is required. Since low-energy buildings interact strongly with solar radiation and indoor load conditions an appropriate overall robust control strategy has to be applied which includes a particularly effective sun protection system. In addition a higher user satisfaction concerning the thermal comfort can be attained when an individual control of the windows is possible.

Air cooling in summer and preheating in winter with buried pipe systems acting as earth-to-air heat exchangers are becoming popular in Switzerland. Studies made at the University of Geneva [2] have shown good energy saving potentials for office buildings at competitive costs. Passive cooling by night ventilation is mainly used to improve the thermal comfort situation in summer and has been applied with success in high mass office buildings. Detailed thermal analysis and simplified design tools have been developed and validated by monitoring the new building of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg [3]. In a German demonstration and monitoring programme on the energy performance of 22 advanced office buildings without mechanical cooling systems it has been shown, that the yearly primary energy use can be kept within a limit of 100 kWh per m^2 net heated floor area [4] The

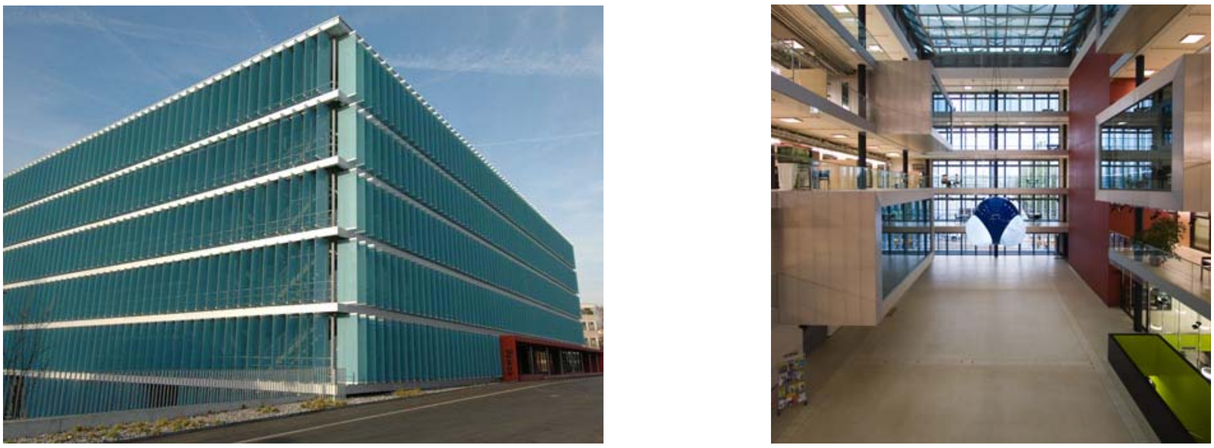
Forum Chriesbach is designed to get along with about 14 kWh/(m^2 a) end energy use respectively 36 kWh/(m^2 a) primary energy use for heat, cold and electricity.

METHODS

Building description

Forum Chriesbach, the new main headquarters of the Swiss Federal Institute of Aquatic Science and Technology (Eawag), is an innovative low energy office building [5]. As winner of an architectural competition, the project team has chosen a holistic approach for the design of a sustainable house of the future, which meets the client requirements concerning healthy indoor environmental conditions and substituting primary energy by renewable energy sources and optimizing the careful use of land, materials, water and finances.

The key elements of the 6-story building with a total volume of 38'615 m^3, a ground surface area of 1'886 m^2 and a total floor surface area of 8'533 m^2 are the highly insulated building envelope, the large atrium buffer zone with a glazed double roof, massive concrete floor constructions and fire escape balconies on the façade with moveable blue glass panels for solar control as shown in Figure 1. The smart energy concept consist of 50 m^2 vacuum solar collectors with a heat storage water tank of 12 m^3, 459 m^2 photovoltaic panels on the roof and a mechanical ventilation system using an earth-to-air heat exchanger for preconditioning the air including a heat recovery system (see Figure 2) with a design ventilation rate of 8.3 l/s per person. In summer an additional passive cooling strategy by night stack ventilation through the windows via the large atrium in the centre of the building (see Figure 3) is used.



a) b)

Figure 1. View of the office building with a) glass lamellae for solar protection and b) atrium

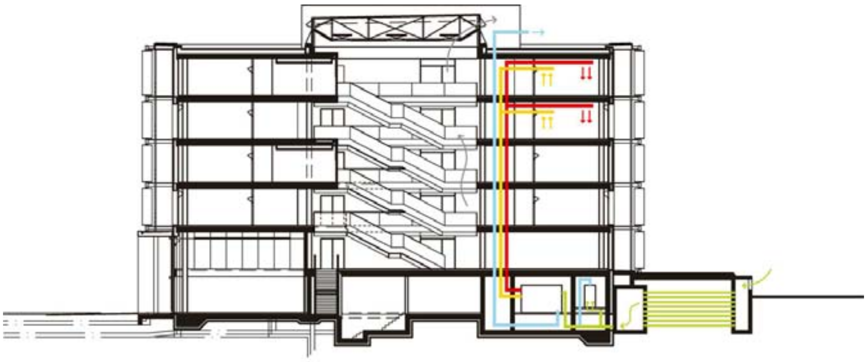


Figure 2. Day time mechanical ventilation via earth-to-air heat exchanger with buried pipes

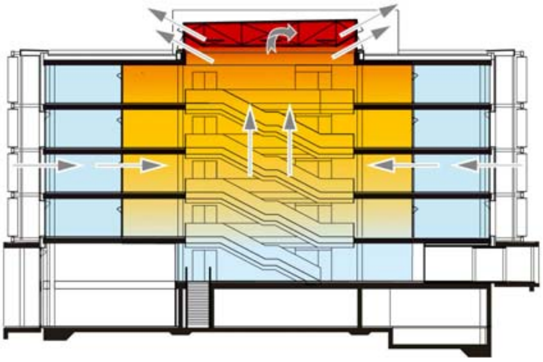


Figure 3. Night time passive cooling by stack ventilation via the atrium to the roof outlets

Measurement layout

The measurement of the indoor environmental conditions has been made in the office room FC-D41 with 30 m^2 floor area in the south-west corner of the 4th level (see Figure 4). The room has 4 working places and was occupied by 1-3 persons (1.2 met, 0.5 clo). The data acquisition system used consists of a comfort analyzer B&K 1213 complying with the requirements given in ISO 7726 [6] and two separate data loggers for the indoor air quality and the electric power measurements. The specifications of the sensors used are given in Table 1. The goal of the measurement was to check if the comfort and indoor air quality criteria given in ISO 7730 [7] and EN 15251 [8] are met during the heat wave period in summer 2006.

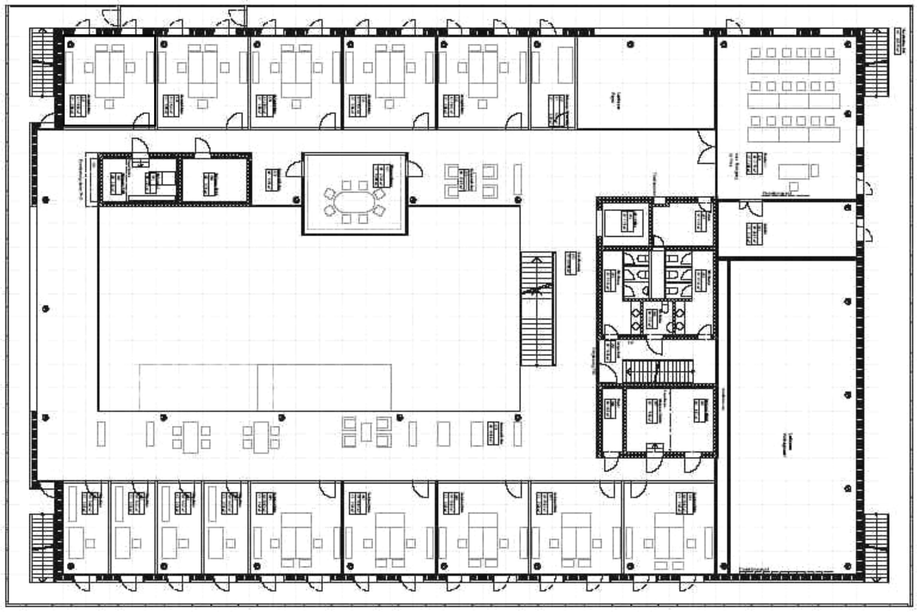


Figure 4. Floor level D with the measured office room D41 in the south-west corner (yellow)

Table 1: Measurement sensors with specifications

Quantity	Sensor	Transducer	Unit	Accuracy
Air temperature	Pt100	MM0034	°C	± 0.3 K
Operative temperature	Pt100	MM0060	°C	± 0.3 K
Air velocity – anemometer	Hot wire	MM0038	m/s	± 0.05 m/s
Supply air temperature	Pt100	Hygroclip	°C	± 0.1 K
Relative humidity	Capacitive	Hygroclip	%	± 3 %
CO2 concentration	Vaisala NDIR	GMW 22D	ppm	± 5 %
Global solar radiation	Kipp & Zonen	CM21	W/m^2	± 2 %

RESULTS

The measurements in room FC-D41 have been started on July 15th and included a heat wave period of 17 sunny days with maximum outside air temperatures up to 35°C, followed by a colder period characterized by a temperature drop of 15 K (see Figure 5 and 6). During this heat wave period, the cooling effect of the earth-to-air heat exchanger is demonstrated in Figure 7: During daytime the supply air temperatures lay 7-10 K lower than the outdoor air temperatures and hardly exceeded the upper comfort limit temperature of 26°C. The operative temperatures are in the requested comfort range and reach at the end of the heat wave period the upper limit of 26 °C (see Figure 8). The relative humidity lies during daytime between 40-60% and during night between 60-80% due to the temperature drops caused by the night cross ventilation (see Figure 9). The same picture can be observed with the air velocity in the office

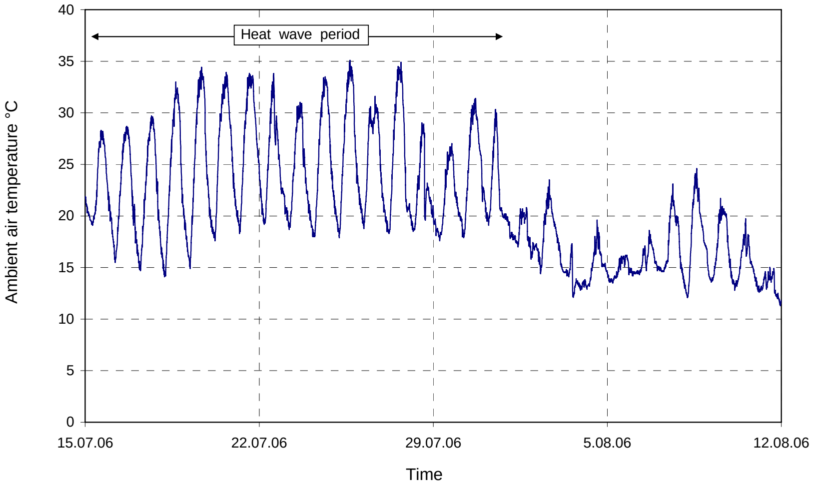


Figure 5: Air temperature in Dübendorf, period 15. July – 12. August 2006 [§]

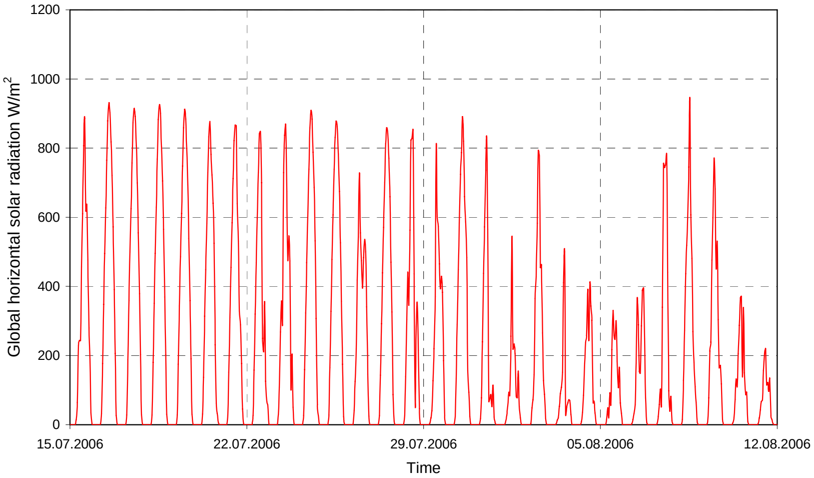


Figure 6: Solar radiation in Dübendorf, period 15. July – 12. August 2006

[§] Measured by the NABEL monitoring network station in Dübendorf (BAFU / Empa) room (Figure 10), which shows some peaks due to controlled window openings during night and some openings in the morning by the occupants.

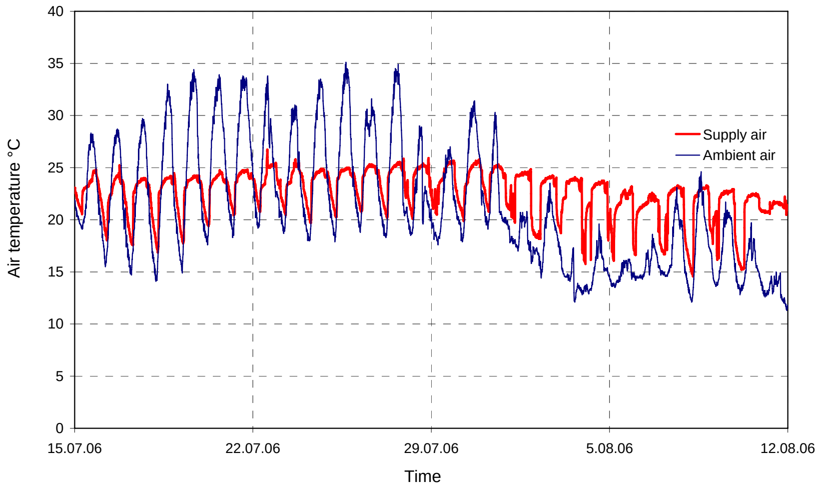


Figure 7: Supply air temperature versus ambient air temperature

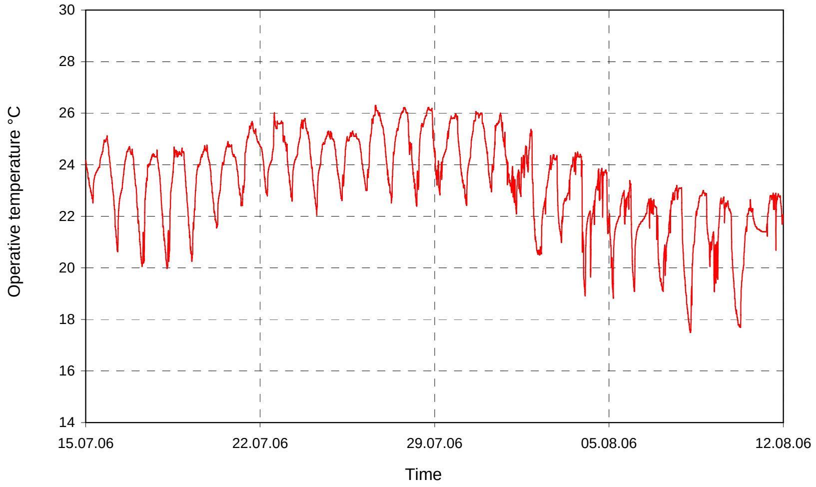


Figure 8: Operative temperature in the office room FC-D41

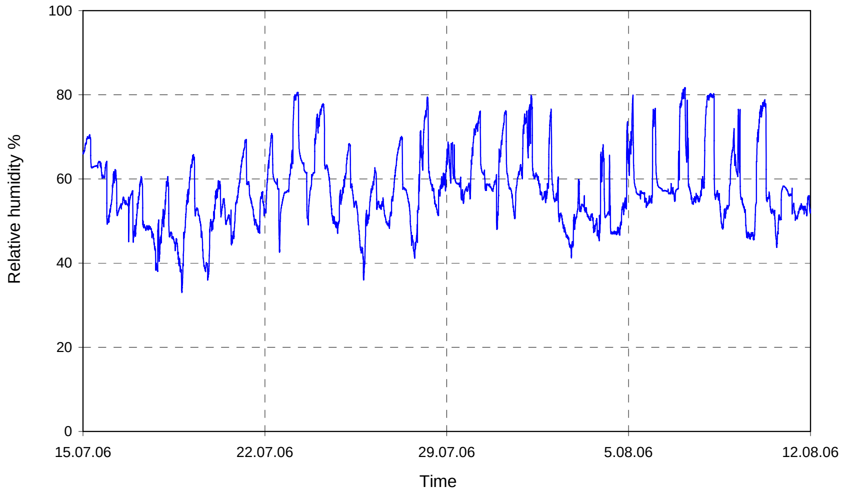


Figure 9: Relative humidity of the supply air in the office room FC-D41

The CO2 concentrations shown in Figure 11 are in an acceptable range, the chosen design supply air flow rate of 17 l/s for the room is obviously sufficient. The total internal heat loads from people, equipment and lightning are given in Figure 12.

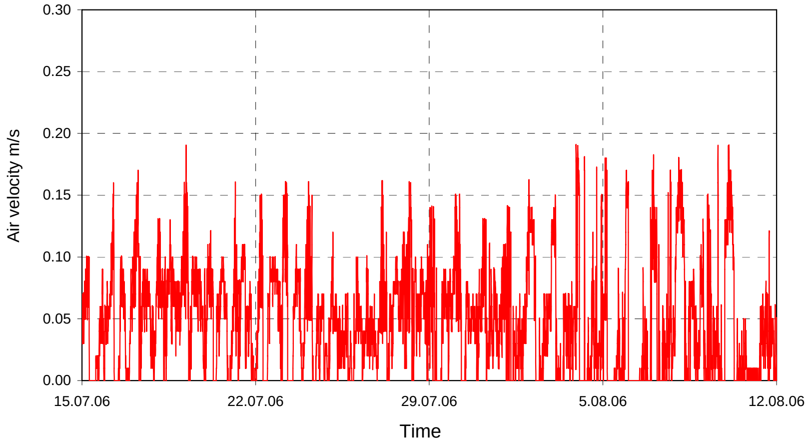


Figure 10: Air velocity in the office room FC-D41

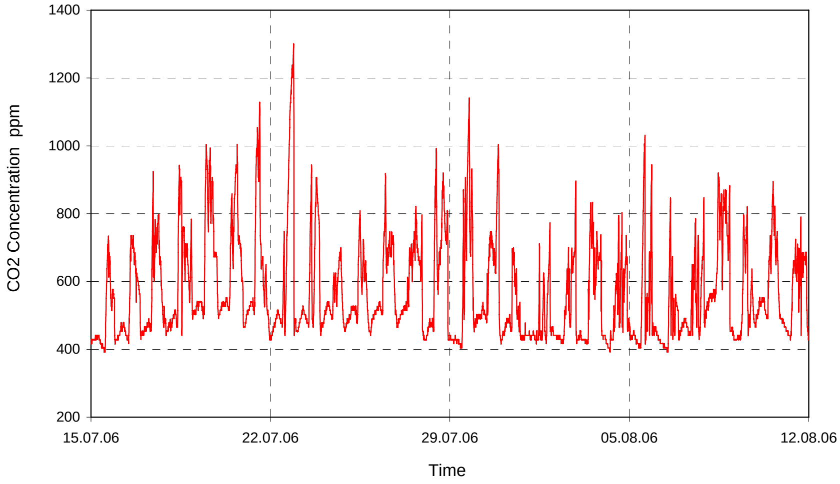


Figure 11: CO2 concentration in the office room FC-D41

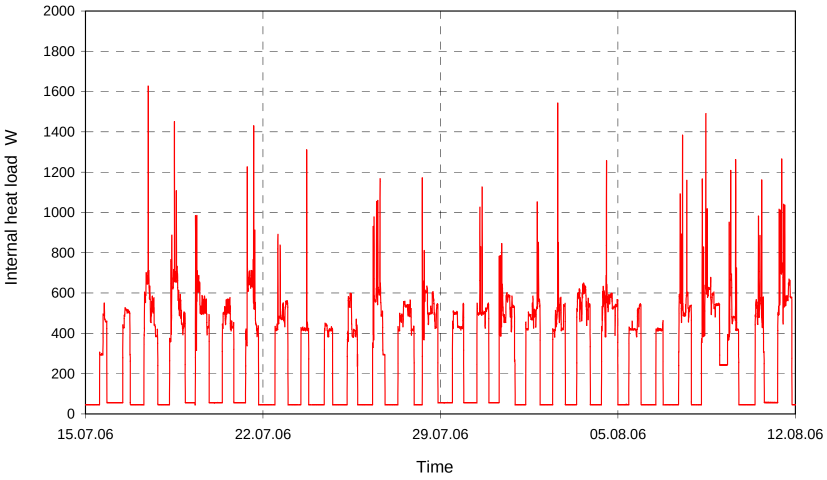


Figure 12: Total internal heat loads in the office room FC-D41

All measurement results are summarized in Table 2. In Figure 13 and 14, the indoor environmental conditions are classified according to EN 15251 for the 17 heat wave days, occupied from 8 am to 9 pm. The operative temperatures lie during 86% of the hours in the category I band (predicted mean vote PMV ± 0.2) and the indoor air quality criteria is met during 91% of the hours in the best category I ($CO2 \leq 750$ ppm).

Table 2: Measured data over the summer heat wave period 15. July – 1. August 2006

Parameter	Mean value	Maximum value
Outdoor environemt		
- Ambient air temperature (10 minutes data)	24,3 °C	35,1 °C
- Relative humidity of the air (10 minutes data)	57,7 %	96,1 %
- Global horizontal solar radiation (hourly data)	271 W/m^2	931 W/m2
Indoor environment		
- Daily internal heat loads (people, equipment, lighting)[**]	18,4 W/m^2	20,5 W/m^2
- Daily hours of occupancy and operation	11,5 h	15,5 h
- Daily internal heat gains (people, equipment, lighting)	211 Wh/m^2	292 Wh/m^2
- Room air temperature (6-minutes data)	24,1 °C	27,0 °C
- Operative room temperature (6-minutes data)	24,2 °C	26,3 °C
- Rel. humidity of the room air (6-minutes data)	57,1 %	80,6 %
- Air velocity (6-minutes data)	0,053 m/s	0,190 m/s
- CO2 concentration (6-minutes data)	585 ppm	1301 ppm

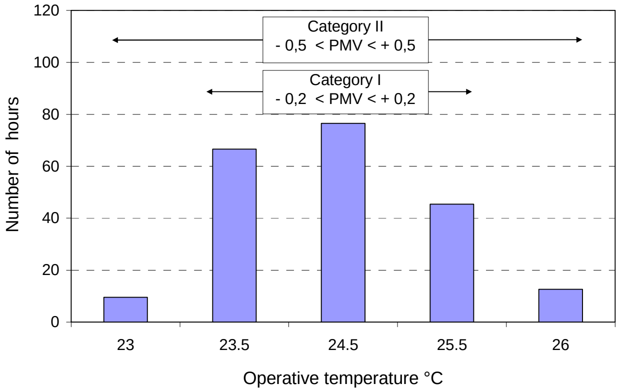


Figure 13: Operative temperature distribution over the period 15. July – 1. August 2006 [**]

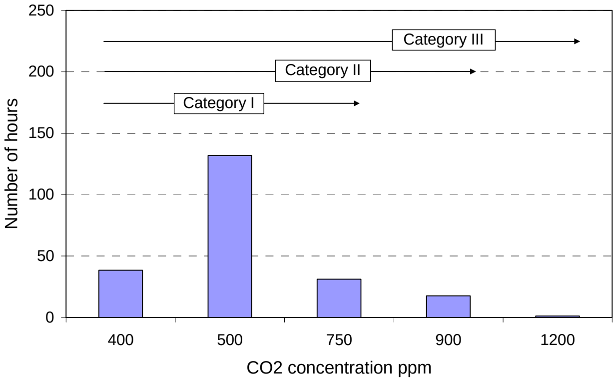


Figure 14: CO2 distribution over the heat wave period 15. July – 1. August 2006 [**]

[**] during hours of occupancy from 8 am to 9 pm all days

DISCUSSION

Low energy office buildings like the *Forum Chriesbach* tend to be strongly dominated by internal heat gains from people and electrical equipment. They are very welcome in winter to cover the heating demand, but can be a problem in summer leading to an unwanted cooling demand. The use of a hybrid ventilation concept is one possibility to overcome this summer problem. In the case of the *Forum Chriesbach* building, an earth-to-air heat exchanger system is used to satisfy the hygienic ventilation during occupancy time together with a passive night ventilation to use the high heat storage capacity of the massive concrete building structure. The extensive heat wave period in summer 2006 has been used to check if the *Forum Chriesbach* building is able to achieve the requested indoor climatic conditions. The measurement of the thermal comfort and the indoor air quality parameters has shown that the best comfort category I defined in the new European standard EN 15251 has been met during 86% of the occupied time and that the category II, which complies with the Swiss standard is fulfilled all the time. This result is remarkable since normally one would expect that with passive cooling principles some cut backs in the thermal comfort level have to be accepted. The measurement also demonstrated that the internal heat gain situation was higher than expected due to higher numbers of working hours and that the large ambient temperature drop after the heat wave period was not taken into account by the night ventilation scheme. Demand controlled ventilation becomes therefore a more important topic in order to react to this kind of unforeseen situations.

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