Results of Monitoring a Naturally Ventilated and Passively Cooled Office Building in Frankfurt A.M., Germany

M. Kleber and A. Wagner

Division of Building Physics and Technical Services, University of Karlsruhe, Englerstr.7, 76131 Karlsruhe, Germany, E-Mail: mk@fbta.uni-karlsruhe.de

ABSTRACT

In this article the concept of a new energy-efficient office building and results of a 3-year monitoring are described. The monitoring was performed within the German funding programme ENOB.
In this building most of the offices are naturally ventilated and passively cooled. Another focus of the energy concept is on regenerative heating.
Monitoring results show that the integrated planning enabled a very low consumption of energy for heating, ventilation, cooling and lighting. The monitoring could help to reveal operating problems and to lower the usage of energy.
Though passively cooled, the rooms provided good thermal conditions. The given limits of room temperatures were exceeded only in an acceptable manner. Good air quality could be achieved just by natural ventilation.

KEYWORDS

energy efficiency, night ventilation, natural ventilation, passive cooling, thermal comfort, air quality

BUILDING AND ENERGY CONCEPT

The new office building of the KfW Banking Group (Figure 1) was built in 2002 and is now occupied by about 300 employees. Five of the seven floors are used as offices and the two top floors as apartments. The offices are arranged around an atrium which plays a central role in the passive cooling concept as it is used for night venting the building. Funded by the German programme "Energie optimiertes Bauen (ENOB)" [1], in this project energy consumption, operation of the technical equipment and the occupants' comfort conditions have been monitored since May 2003, using about 300 sensors. The programme's targeted primary energy consumption for heating, cooling, ventilation and lighting of less than 100 kWh $m^{-2}a^{-1}$ is an ambitious aim but can be achieved, as examination of 25 other demonstration buildings has shown [2].
This building has a high insulation standard and good daylight availability. The atrium increases the compactness of the building (area-volume ratio is 0.25 m^{-1}) thus minimizing the heat loss through the facade.
The energy for heating is provided by a pellet boiler and a condensation boiler handling peak loads. The pellets cover about 75% of heating energy over the year. The offices are heated by radiators mounted on the balustrade.

Figure 1: The south-elevation of the new KfW building

Moderately glazed areas with high selectivity and an efficient automatic external shading system help to reduce the ambient heat loads during warm weather conditions. Only rooms with high heat gains are conditioned by active cooling.
The majority of the offices is however cooled passively by night ventilation and activating the building's thermal mass. Thereby the natural ventilation concept utilizes the stack effect in the central atrium (Figure 2). For this purpose the skylights in the facade and towards the hallways are opened automatically – with different opening angles to achieve similar air changes at individual floors.

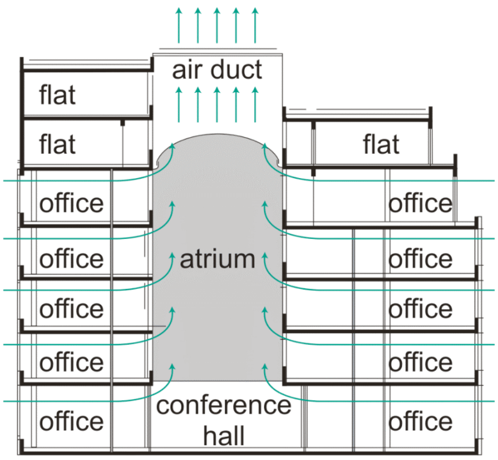

Figure 2: Cross section of the KfW building with the central atrium, showing air flow pathway during night ventilation

In each office night ventilation is only activated when the indoor air temperature is at least 1K higher than the ambient air temperature. However, night cooling will interrupt in cases when the inside air temperature falls below 18°C (20°C since 2005) to avoid too cold conditions for the employees in the morning. The skylights of an office open again once the air temperature in this office exceeds 20°C (22°C). At 6:45 a.m. all night ventilation is stopped.
In addition to the night venting option the rooms offer the opportunity for day-time (single-sided) natural ventilation by manually operable windows and skylights. Here the user can determine the opening times of the skylights himself or choose a short-term ventilation on the control panel which lasts for 3 minutes.

RESULTS

As a result of the three year's monitoring the surveyed building achieved high standards regarding both very low energy consumption and good comfort levels. Even during the record hot summer 2003 the offices provided thermally comfortable conditions for the occupants. However, the aimed primary energy consumption of 100 kWh $m^{-2}a^{-1}$ for heating, ventilation, cooling and lighting could not be fully achieved, though it is likely to fall below this value during the year 2006.

Energy Consumption

Regarding effective energy the energy for heating was identified as representing the major part of the building's total energy consumption. To this point constantly high supply temperatures for the heating circuits of up to 90°C were measured even during summer. The reason was that two supplemented hot water boilers needed permanently high temperatures. The high supply temperatures and active heating circuits lead to heat losses even in summer.

High exhaust temperatures of the pellet boiler revealed a further problem. An expert report indicated that the efficiency of the boiler was too small which lead to a higher consumption of the pellets.

Regarding primary energy heat has less influence, as wooden biomass is regarded with a primary energy ratio of only 0.2 whereas electric power is multiplied by 3.0.

The mechanical cooling for the IT and technical service rooms used a big amount of primary energy. The cooling machine runs with electrical power, its COP (coefficient of performance) is only 2.6. In the beginning in a lot of IT rooms set temperatures of 20°C made the cooling run even 24 hours a day. Changing the operation rules and rising the set temperature to 26°C helped significantly to save both electrical power for ventilators and energy for cooling (Figure 3).

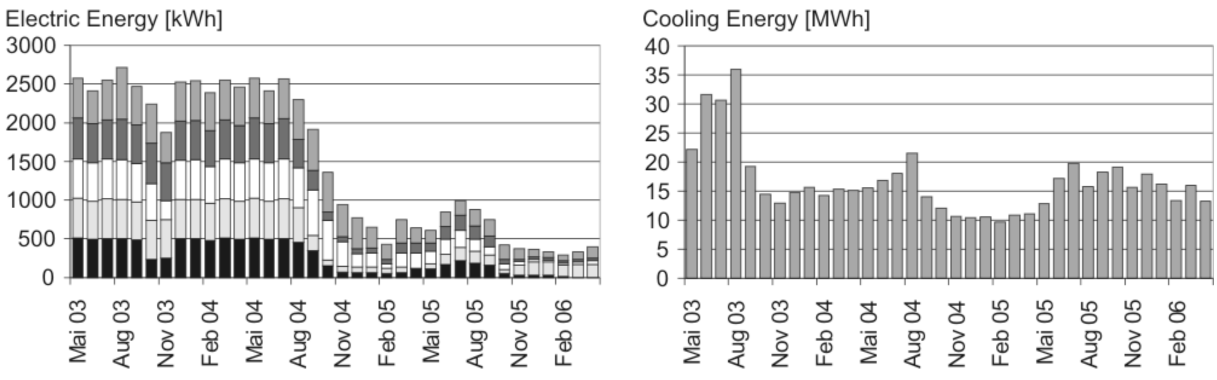

Figure 3: Monthly electrical energy usage of 5 measured ventilators for air-conditioning the IT-rooms (left) and total cooling energy for conditioning all technical rooms (right) could be lowered by monitoring, analysing and adopting parameters

The above is just an example of how monitoring can help to reveal problems and reduce and optimise the energy consumption of a building. Thereby the main problem weren't necessarily conceptional flaws but an improper operation of the technical equipment. Figure 4 shows the total primary energy consumption of the building for 3 measured years and expected values for the 4th year.

During the three years of monitoring not only problems could be found but it also was shown that the building had a very low energy consumption compared to usual office buildings. The performance of ventilation and lighting turned out to be very good and user comfort could be achieved without active cooling.

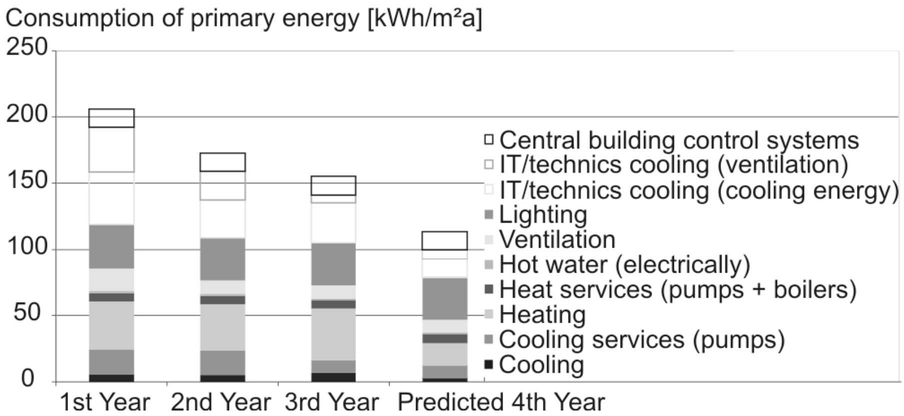

Figure 4: Primary consumption of energy during the 3 years of monitoring including a prediction for the fourth year, all according to criteria of the funding programme. Energy for building control and IT-cooling is marked differently as it is not included in each of the compared buildings from the programme.

Thermal Comfort

In order to evaluate the thermal comfort conditions in the offices, air temperatures and the attendance were recorded in 10 rooms (out of 200) since 2003 and in 20 further rooms from autumn 2004 on.

The room temperature limit for acceptable conditions had been defined to 26°C for ambient temperatures up to 32°C and with a minimum temperature difference of 6 Kelvin between the indoor and ambient air temperature when the ambient temperature exceeded 32°C (referred to as 32/6-limit) [3]. Even during the hot summer of 2003 the room temperatures of frequently used and passively cooled rooms in average surpassed this limit by only 2.1% (32 hours) of the overall attendance time [4]. The maximum temperature in these offices reached 29.6°C with the outdoor air temperatures reaching 40°C (Figure 5).

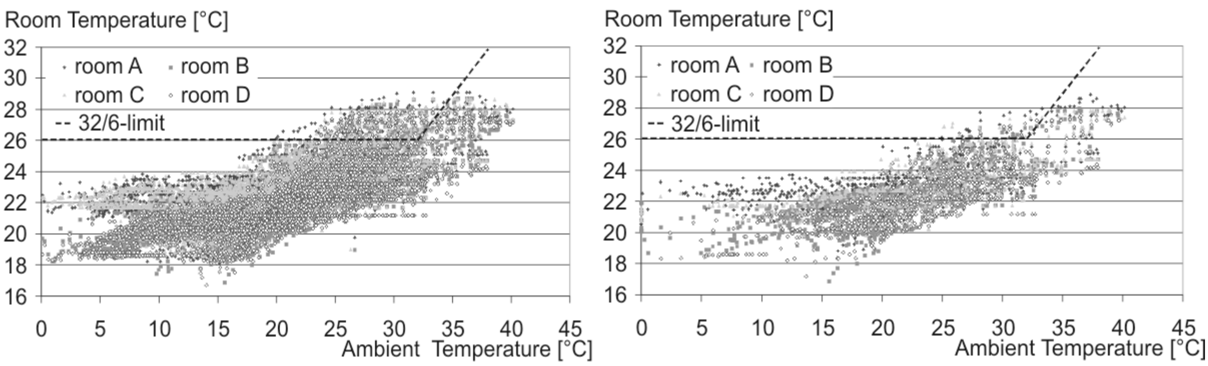

Figure 5: Average hourly air temperature of four passively cooled offices from May 2003 to October 2003 plotted over the actual ambient air temperature. Data including all recorded hours (left) indicate a number of hours when the comfort limit was exceeded. With considering the attendance times (right) there were rarely any temperatures above the limit. The left picture also shows the lower limit of 18°C for the night cooling.

In 2004 the average time above the limit conditions was 0.4%, in 2005 2.1% of the total attendance time. The maximum temperature recorder in these offices was 27.2°C during the second summer and 28.2°C in the summer of 2005, respectively.
This shows that comfortable temperatures in these rooms can be achieved, but this depends on how the rooms are operated.
In ten rooms also the temperatures of the ceiling (on the surface and in a depth of 4 cm) were recorded to obtain information on the effect of room air temperatures on the thermal behaviour of the concrete ceilings during night ventilation.
In rooms featuring exposed concrete ceilings there was a pronounced effect of the room air temperature on the ceiling temperatures. Figure 6 shows how the cooler air temperature decreased the ceiling temperatures. On the other hand, some offices had suspended ceilings in which case there was no correlation between the room air and the ceiling temperatures.

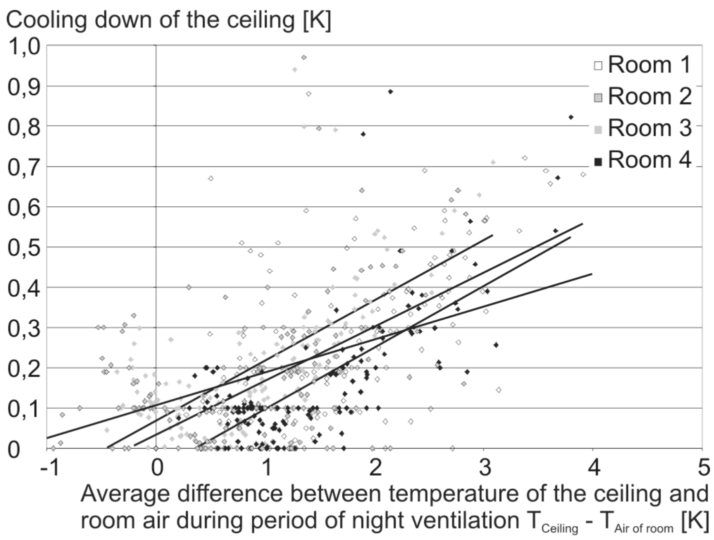

Figure 6: Cooling of the ceiling during the night ventilation from 21 p.m til 6 a.m. depending on the average difference between ceiling and the air temperature.

Air Quality

In 5 rooms the CO_2-concentrations were measured additionally. Two of these offices were ventilated by air conditioning, the other three by natural ventilation. The results of more than two years monitoring showed that the limit of 2000 ppm was never reached, the limit of 1500 ppm was exceeded just for a few hours - independent of the type of ventilation.
On average, the CO_2-concentration was below 1500 ppm for 99.8% and less than 1000 ppm for 98.6% of attendance time. Figure 7 confirms that in every room the concentration was below 800 ppm at least in 90% of the attendance time. There was no significant difference between naturally and mechanically ventilated spaces.

The analysis showed that the employee’s manual use of the skylights did not depend on the ambient temperature. As an example, on average the skylights were open as often in January 2005 as in June 2005. In contrast, the manual opening of windows was dependent on the outside climate. In June 2005 occupants used the windows more than three times as often for ventilation as in January 2005. With a decreasing frequency of opening the windows in winter, the chance to measure higher CO_2-concentrations rose (Figure 8).

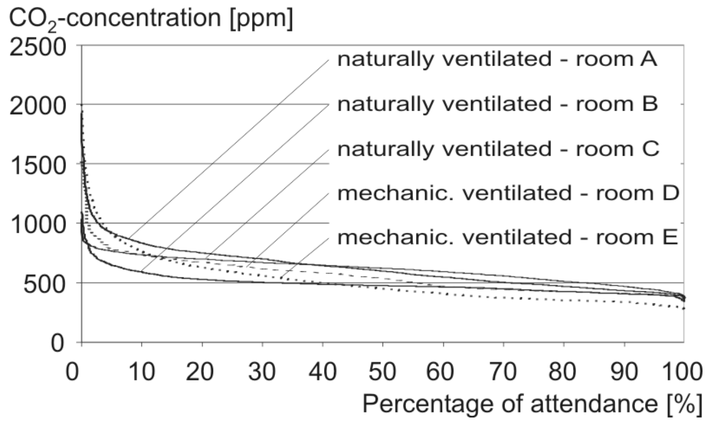

Figure 7: Cumulative frequency distributions for hourly averaged CO_2-concentration of air in 3 naturally and 2 mechanically ventilated offices. Data for one year, only hours with attendance of the occupant

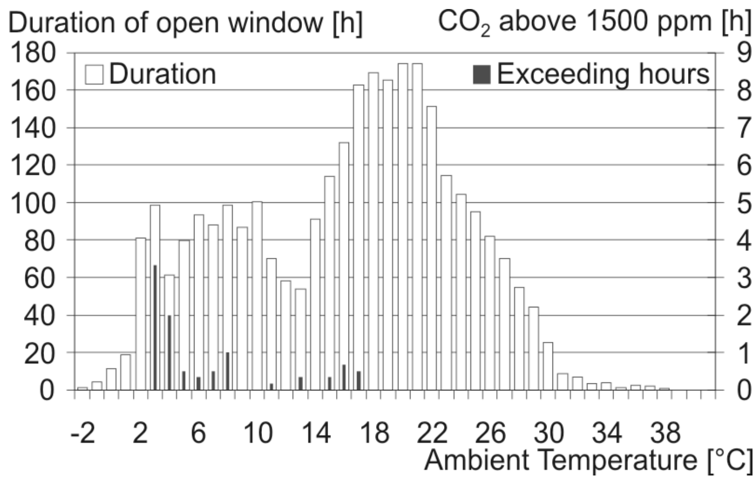

Figure 8: Total time of window opened with CO_2-concentration exceeding 1500 ppm for an office over one year, classified in steps of ambient temperature

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