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The passively cooled KfW building in Germany - Monitoring results

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ABSTRACT

Air-conditioning and cooling contribute significantly to the energy consumption of a lot of existing office buildings, especially when primary energy factors are taken into account. "Lean" building concepts however can diminish the cooling energy demand by passive cooling strategies. Compared to mechanically cooled or air-conditioned buildings the resulting indoor temperatures are floating in a broader band during summer and might exceed the given boundaries of codes and regulations on thermal comfort for short periods. This paper presents the results of a passively cooled bank building in Germany and shows that even during the very hot summer of 2003, the indoor climate could be held in an acceptable range by only passive means if the rooms were operated properly.

1. ENERGY CONSUMPTION IN OFFICE BUILDINGS

Numerous office buildings of the eighties and nineties show a very high energy consumption due to the fact that they have been designed without respect to the interdependence between outdoor and indoor climate. As a result the thermal comfort at work places can only be guaranteed with extensive technical building services for heating, ventilation, cooling or air-conditioning. High investment costs and a space demand of about 20 to 30 % of the building volume for HVAC equipment characterise many of these buildings. The electricity consumption is dominated by HVAC and lighting facilities and not by office equipment. Therefore the resulting primary energy consumption often exceeds 500 kWh $m^{-2}a^{-1}$.

A higher consciousness of resources, an increasing awareness of operation costs of buildings and the preference of users towards individual control of the indoor climate have led to so-called "lean" building concepts with reduced HVAC equipment, moderately glazed facades, a high amount of daylight at the work places and the option of natural ventilation through windows that can be opened. However, a combination of integrated measures for passive cooling is a pre-requisite to ensure summer comfort without actively cooling or dehumidifying the inlet air.

In order to promote these concepts which also coincide very well with the European directive on energy performance, the funding programme SolarBau has been initiated by the German Ministry of Economy and Labour in 1995. It supports the realisation and evaluation of energy-efficient commercial buildings. The absence of investment subsidies ensures that all design solutions have to be realised under real economic market conditions. Funding is restricted to buildings with a primary energy consumption for heating, cooling, ventilation and lighting of less than 100 kWh $m^{-2}a^{-1}$.

So far 23 demonstration buildings have been realised (SolarBau, 2005). The results show that a primary energy consumption of less than 100 kWh $m^{-2}a^{-1}$ is an ambitious target but can be reached with investment costs that are in the same range as costs of conventional projects (Voss, 2005). This paper will focus on passive cooling and comfort aspects of one of the funded buildings - the KfW bank building in Frankfurt.

2. THE KFW BANK BUILDING

The "East Arcade", a new extension building of the KfW bank group, is situated in the middle of Frankfurt, Germany (Fig. 1). The 7 storey high building has a net floor area of 8585 m² of office space. Five floors with office rooms and two upper floors with apartments are grouped around an atrium in the centre of the building, which is used for night ventilation for all passively cooled offices.

The energy-related features of the building include a high insulation standard (mean U-value of the building envelope of 0.54 W/m²K with a form factor of 0,25 m^{-1}), high daylight availability at the work places as well as natural ventilation for the offices on the eastern and western facades with manually operable windows and manually/remote-controlled skylights.

Moderately glazed areas with low energy transmittance but high selectivity and an efficient external shading system with optional daylight transmittance in the upper part were chosen to minimise external heat loads during summer. In the offices only TFT screens with a low heat emission are used for the computers. The passive cooling is further realised by discharging the internal building mass - concrete ceilings in the office rooms without any suspension - with night ventilation due to the stack effect in the centralised atrium (Fig. 2).

In offices where air-conditioning is necessary (about 20% of all rooms) the cooling loads are mainly covered by tab water cooling, backed by a conventional compressor water chiller. Heating energy is provided by a boiler fired with wood pellets and a condensation boiler for peak loads. A thermal solar system contributes to the hot water demand of the canteen.

In the first year of the monitoring period the

Figure 1: View of the KfW building from south-east.

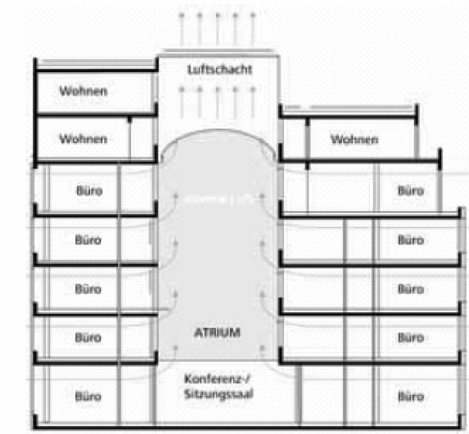

Figure 2: Section of the KfW building and air flow paths during night ventilation.

building showed an end energy consumption for heating of 64 kWh $m^{-2}a^{-1}$ and a primary energy consumption of 172 kWh $m^{-2}a^{-1}$ (Wagner, 2005). The reason for exceeding the target values was mainly a non-optimal operation of the HVAC systems which already has been modified to a large extent.

3. INDOOR CLIMATE AND COMFORT

Within the monitoring programme which is carried out by the University of Karlsruhe, 14 office rooms have been evaluated with regard to their room (air) temperature. Figure 3 shows the mean temperatures of four rooms which are exclusively cooled by passive means together with the ambient temperatures during the summer of 2003 and 2004.

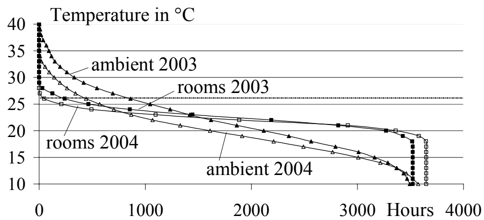

Figure 3: Cumulative frequency distributions for hourly averaged room (air) and ambient temperatures from May 1st to September 30th in 2003 and 2004. Due to the type and position of the temperature sensors, indoor air temperatures approximately represent an operative temperature. The room temperature is an average out of 4 office rooms which are exclusively cooled by passive means.

Having gone into operation in the winter of 2002, the building had to face a first real challenge during the very hot summer of 2003. As Figure 3 shows, the frequency of ambient temperatures above 30°C is more than twice as high in 2003 compared to 2004, with maximum values exceeding 40°C. Therefore also the room temperatures are on a higher level in the first summer but do not exceed 30°C if all hours of the time period are taken into account. In 2004 the room temperatures remain below 28°C.

According to the German regulations for work places, the room temperatures in non-air-condi-tioned commercial buildings should not exceed 26°C under normal ambient conditions (ASR, 2001). For the KfW building it was agreed upon during the design phase that this limit of 26°C is valid for ambient temperatures up to 32°C and above that a difference of 6 Kelvin between room and ambient temperature should be kept as a minimum.

In Figure 4 the frequencies for exceeding this limit are shown for the four passively cooled and manually ventilated rooms and for one air-conditioned room with a cooled ceiling. Besides summing up all hours of the whole period, a better assessment of the users' thermal comfort conditions is to only take into account either a fixed time interval which corresponds to the daily working time (8 to 18 hours during week days) or the real (measured) attendance time of the users. It can be seen that there is a large difference in exceeding frequencies between "all hours" and the two other integrals. The reason is that room temperatures normally increase continuously during the day depending on the internal and external loads and will at least stay constant as long as the night ventilation is not activated (ambient temperature above room temperature). Also weekend hours are counted in the first case which do not count for comfort evaluation because of users' absence.

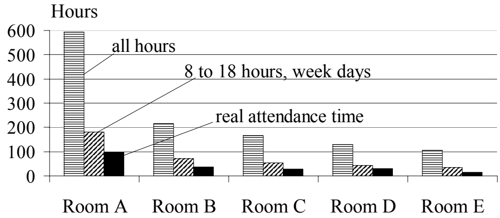

Figure 4: Frequencies for exceeding the maximum allowed room temperature of four passively cooled rooms (B to E) and one air-conditioned room (A) during the summer of 2003 (May 1st to September 30th). The maximum allowed room temperature is 26°C for ambient temperatures up to 32°C, and above that 6 Kelvin below ambient temperature.

Figure 4 indicates that even under the extreme conditions of the summer of 2003 a high work place quality was reached with passive cooling. Room B showed a maximum of only 72 hours above the agreed temperature limit between 8 to 18 hours during week days for from June to September. In 2004 the exceeding frequencies of these rooms were reduced by about 50%. Only room D had the same number of hours in both summers which shows the influence of the user behaviour. Room A represents approximately a mean value for the five rooms with the highest exceeding frequencies (121 to 270 hours) in 2003; they are all air-conditioned.

Regarding all the 14 rooms which have been evaluated, the room temperatures of 10 offices did not exceed the agreed limit by more than 2% of the overall attendance time in the summer of 2003. The higher exceeding frequencies of four rooms are mostly due to a non-optimised operation of the HVAC systems - the building had gone into operation only nine months before - and to the specific usage of the rooms. During a hot period of 12 days with a maximum ambient temperature of 41°C the room temperature of a properly operated room did not exceed 28°C.

In summer 2004 the five highest exceeding frequencies reached from 34 to 224 hours, the lowest one representing the passively cooled room D and the other ones air-conditioned offices in a different order compared to 2003. This again shows the influence of user behaviour or attendance patterns.

Figures 5 and 6 give some hints of the user behaviour in two rooms during the summer of 2003. The difference between the total hours when windows are opened manually are either due to different attendance times of the users in the two rooms or to different behaviour. The users do react on ambient conditions with their ventilation activities which is shown by the decrease of ventilation hours with ambient temperatures above 26°C.

In Figure 6 only hours were considered when the users where in the room and the agreed tem-

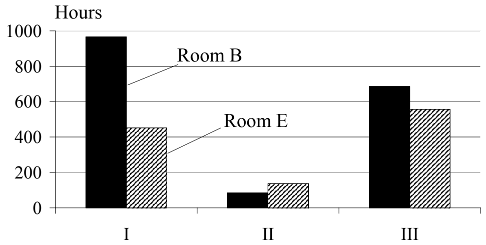

Figure 5: Frequencies of different sensations in room B (east) and E (west) during summer 2003 (May 1st to September 30th, 3672 hours): (I) windows opened manually; (II) windows opened manually with ambient temperatures above 26°C; (III) shading system closed at least 70% (of the whole window area).

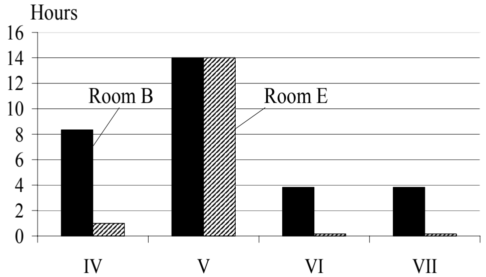

Figure 6: Frequencies of different sensations in room B (east) and E (west) during summer 2003 (May 1st to September 30th) with only considering the hours when the temperature limit was exceeded during the attendance time: (IV) windows opened manually; (V) shading system opened; (VI) window and shading system opened; (VII) shading system closed at least 70% and window opened.

perature limit was exceeded. The difference in hours with open windows coincides with the exceeding frequencies of the two rooms (room B: 38 hours above the temperature limit during attendance time; room E: 15 hours above the temperature limit).

4. CONCLUSIONS

In the KfW bank building, a low energy office building with a passive cooling strategy for most of the work places, 14 office rooms have been monitored and evaluated with regard to their room (air) temperature. Even during the very hot summer of 2003, the four passively cooled offices showed remarkably good comfort conditions. Considering all investigated offices, the room temperatures of 10 rooms did not exceed the agreed limit by more than 2% of the overall attendance time in the summer of 2003. Although only a rather small number of offices was monitored in the whole building, the results indicate that the lean building concept meets the requirements of the specific usage of the building. This could also be shown for other buildings of the funding programme SolarBau (Voss2, 2005).

The exceeding frequencies of the room temperatures depend strongly on the attendance patterns and the user behaviour. In order to improve the thermal comfort assessment during the design phase, appropriate statistical models for simulating:

- the user behaviour in terms of operating windows and solar shading, and
- the predicted votes for thermal comfort under dynamic boundary conditions,

are necessary.

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