HYBRID VENTILATION AND USER BEHAVIOUR IN SUMMER

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ABSTRACT

Hybrid ventilation is one promising approach to reduce energy consumption in office buildings. On the one hand, a minimum air change rate is supplied to the rooms, even if the windows are closed. On the other hand, the energy demand for ventilation can be reduced if natural forces (wind and buoyancy driven air flow) are used to ventilate the building. The user behaviour has an important but often unknown influence on the thermal building performance and the indoor climate. Thus, an accurate user model should be used in designing hybrid ventilation. This paper focuses on the data evaluation of measurements at the institute building of Fraunhofer ISE [SolarBau:Monitor (2004 a)] concerning user attendance and user behaviour with regard to the use of blinds, equipment and windows in 16 offices. The stochastic user behaviour is derived from a data analysis, is taken into account by a Monte Carlo-simulation and is compared with the assumptions from the design phase.

KEYWORDS

Hybrid Ventilation, User Behaviour, Building Simulation, Thermal Comfort, Summer

INTRODUCTION, BUILDING DESCRIPTION AND MEASUREMENTS

There is a wide knowledge regarding user behaviour in residential buildings for the winter period. Thus, the impact on user behaviour on the heating demand in residential buildings is well known. However, there are only a few investigations regarding the user behaviour in office buildings for the summer period and its impact on the thermal comfort. Furthermore, the user behaviour determines the solar (use of blinds) and internal (attendance and use of office equipment) heat gains. Using monitored data (window and door contacts, occupancy sensors, electricity consumption and status of blinds) from the Fraunhofer ISE building in Freiburg, Germany, the influence of user behaviour and weather on the room temperature can be calculated by building simulation.

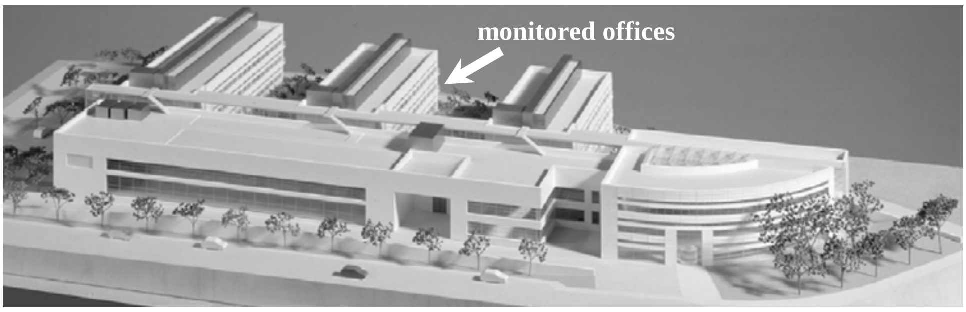

Figure 1: View of the Fraunhofer ISE building from West. The monitored offices are located in the second building wind on the 2nd and 3rd floor (South orientation).

The user behaviour is analysed in 16 office rooms with an floor area of 12 m² or 18 m², respectively. The offices are occupied by 1 – 3 persons. For more information about the building and its use, the reader is referred to Pfafferott (2003).

Availability of controls and their appropriate use is key to better building performance and for improving occupant satisfaction. Raja et al (2001) shows that the use of various controls (e.g. “open windows” and “blinds down”) plays a significant role in modifying indoor thermal conditions. Raja derived strong relationships between these user actions and the outdoor temperature from an extensive survey. The proportion of windows open and blinds closed increases with an increase in indoor or outdoor temperatures. (In most cases the correlation with indoor temperature is similar to that with outdoor temperature. The reason for using the outdoor temperature in analysis is that the outdoor temperature is a part of the input of any simulation, whereas the indoor temperature is an output.)

All data are recorded every minute, whereas the data evaluation deals with hourly mean values. Figure 2 shows the user behaviour regarding the window opening in comparison to a field study in naturally ventilated buildings and measurements in another low-energy office building. Corresponding to the ventilation concept, the mean user behaviour differs from one building to the next. The hourly data at Fraunhofer ISE represent the mean window status of 16 offices for one year and show the high deviation at outdoor temperatures above 10 °C.

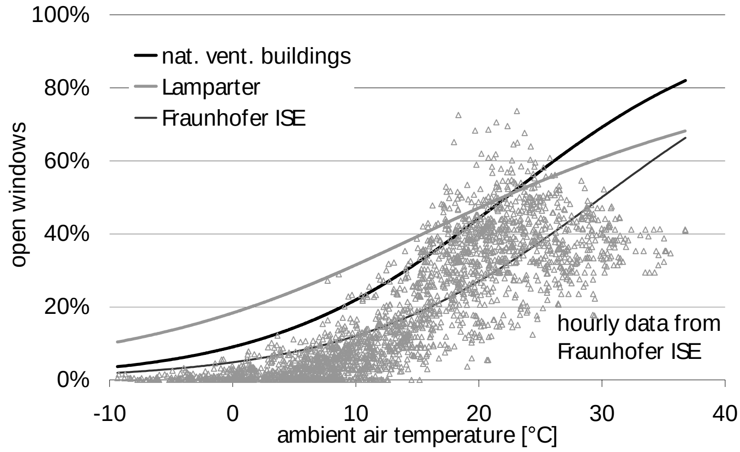

Figure 2: User Behaviour with regard to window-opening during working hours. The model for European naturally ventilated buildings is from Nicol (2001). The Lamparter building [SolarBau:Monitor (2004 b)] (data from 1 office room for 2 years) has a supply / exhaust air ventilation and the Fraunhofer ISE building (data from 16 office rooms for 1 year) an exhaust air ventilation. Both data series are analysed using Nicol’s approach. The correlation coefficient r is 0.6 – 0.8 corresponding to the time period used for data analysis.

In hybrid ventilated buildings, window opening probability mainly depends on the ambient air temperature and the time of day, whereas the time profile differs from season to season. While windows are opened almost as often in winter as in summer, windows are opened longer in summer than in winter. Hence, the user behaviour is analysed from June 12 to July 23, 2003. This period is short enough to carry out many simulation runs in a row and long enough to cover different summer weather conditions. (There are no data gaps within the period considered for data analysis.)

Figure 3 shows that the windows are opened (tilted or turned) in the morning and are closed during the working time. 50 % of all windows are opened during the night. Doors are opened in the morning and the afternoon according to the attendance. The skylight and the ventilation flaps over the door are used unfrequently and most of them are open during the whole day.

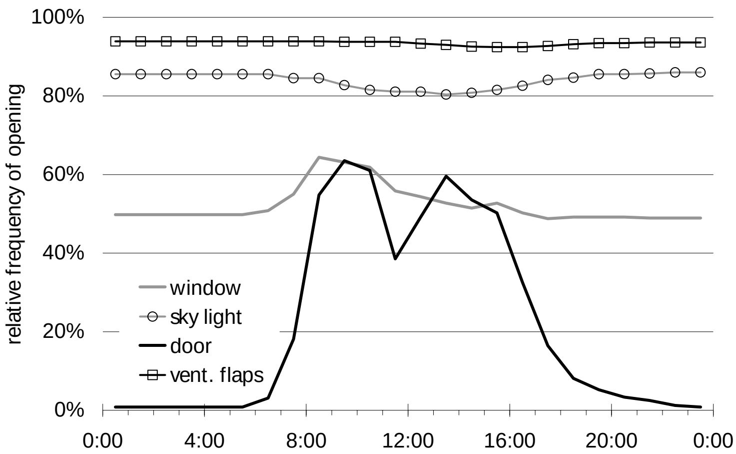

Figure 3: Time dependent user behaviour during 30 working days in summer 2003.

The heat gains are calculated from the occupancy data, the electricity consumption and the status of blinds. Figure 4 shows that heat gains vary from one room to the next and can vary strongly from one day to the next: The daily mean heat gains vary from 219 to 515 Wh/(m² d) and the standard deviation reaches 43 % for solar heat gains, 70 % for equipment and even 93 % for internal heat gains from persons in particular offices. (For simulation studies, the heat gain in the 18 m²-offices are converted into the specific heat gain of a 12 m²-office.)

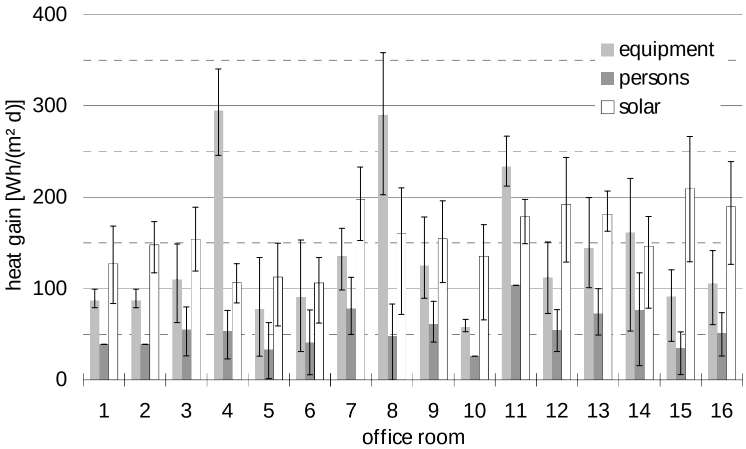

Figure 4: Daily heat gains and 1-σ deviation during 30 working days in summer 2003.

The simulation model has been validated against two data sets from April und July 2002 and is used for Monte Carlo-simulation with the weather data from summer 2003 and the test reference year, which was used for the building design simulation. Pfafferott et al (2004) used Monte Carlo-simulation for model validation with regard to uncertain building physical parameters and material properties. The ESP-r system, version 9 series is used for building simulation, Clarke (2001).

STATISTICAL SIMULATION OF USER BEHAVIOUR

The user behaviour is drawn from the following procedure: (1) Preparation of hourly data for window status, blind status, electricity consumption and attendance. (2) The time series (columns) differentiates working days and weekends. (3) The data are sorted by the time of the day (lines). (4) From this information, relative frequencies of status (i.e. 4 windows in each office) and heat gain (i.e. solar heat gains, internal heat gains from equipment and persons) are calculated for each hour of the day.

The aim is to model the heat gains as close to reality as possible and to investigate the user behaviour with special regard to ventilation. Hence, the information is used for the Monte Carlo-simulation according to the following procedure: (1) The hourly time series of heat gains is taken for one room. At the next time step, the next room is chosen. After 16 simulations, the procedure starts with the first room again. (2) Random determination of mechanical air change according to the statistical distribution of hydraulic resistances. (3) Calculation of window opening. For each hour of the working day / weekend, the status of window, sky light, door and ventilation flap is calculated with the Gauß function. Mean value and standard deviation are known from the data analysis. The opening status increases or decreases over the time but does not oscillate from one hour to the next, i.e. mathematically conservative time series. (4) For each simulation run the hourly room temperatures are saved.

Figure 5 compares the results from 1,000 simulation runs, which cover 10^{18} possible combinations of heat gains and ventilation states, with the monitored room temperature in the 16 offices. For this comparison, the daily mean room temperature and the 16 / 84 % quantile are identified from the monitoring in 16 offices and the 1,000 simulation runs for each day. In this 6-weeks period, the mean monitored and simulated room temperature differ from each other by only 0.2 K, and every day the simulated room temperature meet the monitored temperatures within the standard deviation. Thus, the energy balance and the dynamic building performance are calculated accurately. As expected, the deviation is higher in the simulation than in the monitoring, since the balancing heat transfer between adjacent rooms (in the real building) is disconnected by adiabatic boundary conditions (in the numerical simulation).

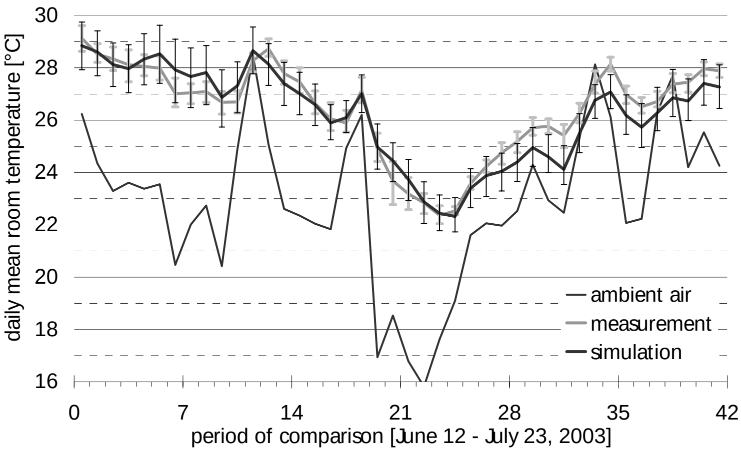

Figure 5: Daily mean room temperatures: The measured mean room temperature is 26.4 °C and the simulated 26.2 °C. The mean ambient air temperature is 22.9 °C.

STATISTICAL SIMULATION WITH DESIGN PARAMETERS

During the design process, the user behaviour regarding ventilation and control of blinds and the internal heat gains had to be estimated or were taken from the available models, respectively. With the statistical simulation, these design assumptions can be checked against the real building operation. Thereby, the different weather conditions has to be taken into account. Figure 6 compares the cumulative frequency of the daily mean ambient air temperature in the typical summer 2002 and the warm summer 2003 with the design weather.

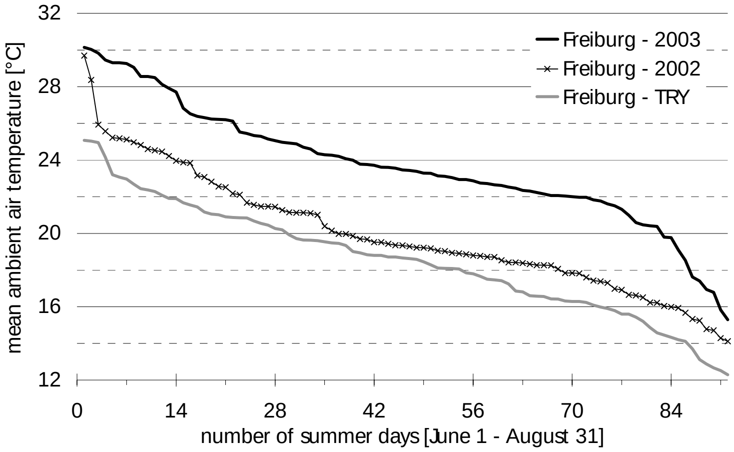

Figure 6: Comparison of ambient air temperature for the summer 2003 and the test reference year TRY 7. The summer 2002 was a typical summer. Obviously, the TRY 7 does not consider high ambient air temperatures. The summer 2003 was 5.2 K warmer than the design weather TRY 7 with long periods of warm weather.

Taking the weather data from test reference year TRY 7 and assuming that users behave in the average summer according to TRY 7 similar to the summer 2003, the predictions from the design simulation can be reviewed by the statistical simulation. Figure 7 shows that the simulated room temperatures follow a similar variation in time to the room temperatures predicted by the design simulation. However, the simulated room temperature is clearly higher: Even the coolest mean room temperature (considering the standard deviation) is 0.2 K higher than the predicted mean temperature, cf. Table 1.

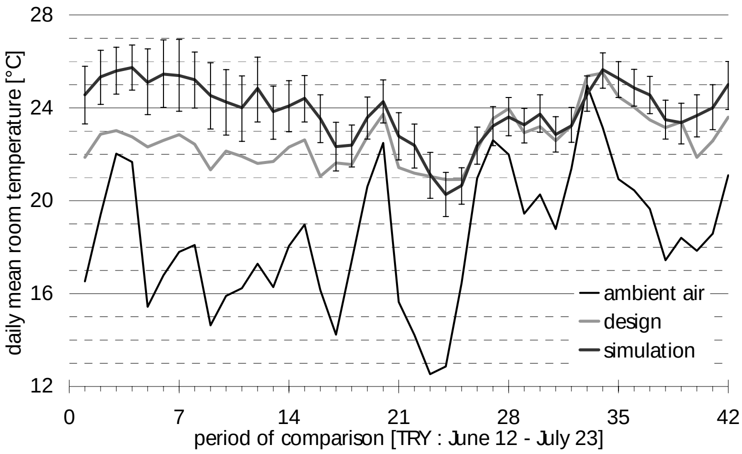

Figure 7: Daily mean room temperature from design and statistical simulation.

Though the statistical simulation is based on a much more complex air-flow network, the mean air change rates are similar in the design and the statistical simulation. Table 1 outlines that the monitored solar and internal heat gains are higher than their estimates according to Zimmermann (1999): (1) The work stations are located in the offices and not in separate IT rooms. (2) As the venetian blinds are mainly used to prevent glare, they are more rarely closed in summer than estimated. Noteworthy, the monitored solar heat gains during the weekends are lower than predicted, as the actually realised g-value of the façade is lower than expected.

Herkel and Pfafferott (2004) show how the energy balance of a room (i.e. heat gain, loss and storage) influence the room temperature using monitored data from 2 years in 3 office buildings. Though an appropriate use of windows can contribute to a lower room temperature, the heat loss due to natural ventilation cannot compensate the heat gains completely.

TABLE 1
Mean room temperature and heat gains from design and statistical simulation.

	mean temperature (with standard deviation)	heat gains (working days)	heat gains (weekend)
ambient air temperature	*18.47 °C*	–	–
room temperature: design simulation	22.61 °C	214 Wh/(m² d)	75 Wh/(m² d)
room temperature: statistical simulation	23.87 °C (+/- 1.01 K)	380 Wh/(m² d)	121 Wh/(m² d)

CONCLUSION

The comparison between the monitoring, the statistical simulation of user behaviour and the design simulation indicates clearly that a statistical user model for window-opening and blind-closing can contribute to a more realistic design of passive cooling concepts.

Though the solar heat gain coefficient through the façade is lower than predicted, the solar heat gains are clearly higher than estimated due to the user behaviour. Only a sophisticated model for the use of blinds can predict the solar heat gains accurately. The internal heat gains are in the same range of or even higher than the solar heat gains. Due to changes in the building use and the user behaviour, the actual mean heat gain is 80 % higher than predicted.

Both the user behaviour and the use of the building influence the thermal comfort in passively cooled buildings strongly. Furthermore, the room temperature in real buildings at given boundary conditions is a distribution rather than a single value. The data analysis suggests that computer simulations of naturally or hybrid ventilated buildings should assume not only an expected room temperature but also a probabilistic variation about it.

References

Raja, I.A., Nicol, J.F., McCartney, K.J., Humphreys, M.A. (2001). Thermal comfort: use of controls in naturally ventilated buildings. *Energy and Buildings* **33**, 235-244.

Herkel, S., Pfafferott, J. (2004). Summer 2003: impacts on the design of active and passive cooling. Proceedings of *EuroSun2004*, Freiburg, Germany, 600-608.

Nicol, J.F. (2001). Characterising occupant behaviour in buildings: towards a stochastic model of occupant use of windows, lights, blinds, heaters and fans. Proceedings of *Seventh International IBPSA Conference*, Rio de Janeiro, Brazil, 1073-1078.

Pfafferott, J., Herkel, S., Jäschke, M. (2003). Design of passive cooling by night ventilation: evaluation of a parametric model and building simulation with measurements. *Energy and Buildings* **35**, 1129-1143.

Pfafferott, J., Herkel, S., Wambsganß, M. (2004). Design, monitoring and evaluation of a low energy office building with passive cooling by night ventilation. *Energy and Buildings* **36**, 455-465.

SolarBau:Monitor (2004 a). Internet platform and project documentation Fraunhofer ISE.
http://www.solarbau.de/monitor/doku/proj04/mainproj.htm [2004-July-15]

SolarBau:Monitor (2004 b). Internet platform and project documentation Lamparter.
http://www.solarbau.de/monitor/doku/proj07/mainproj.htm [2004-July-15]

Zimmermann, M. (1999). *Handbuch der passiven Kühlung*. EMPA, Dübendorf, Switzerland. (In German.)

Clarke, J.A. (2001). *Energy Simulation in Building Design*. Butterworth-Heinemann.