DESIGN, MONITORING AND EVALUATION OF A LOW ENERGY OFFICE BUILDING WITH PASSIVE COOLING BY NIGHT VENTILATION

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ABSTRACT

In moderate climates, one promising feature to reduce the energy demand of office buildings for air conditioning without reducing comfort is passive cooling by night ventilation. An office building has been designed, realised and monitored for a long time period in the framework of the German research programme solar optimised buildings. The night cooling of the office building has been realised by natural ventilation. The unique possibility of stepwise realisation from design through the maintenance and the monitoring up to the optimisation is used to evaluate the contribution of simulation tools on the design of the buildings.

KEYWORDS

Night Ventilation, Monitoring, Passive Cooling, Simulation

BACKGROUND

Former research indicates clearly, that the primary energy demand of new office buildings is dominated by the electricity demand for lighting, ventilation and air conditioning. [Weber 1999]. From a study made by Nilson on Swedish office buildings some recent trends can be derived [Nilson 1997]: Office buildings have experienced a continuous decrease in heating demand following the development of stricter building codes. This increased efficiency of the thermal envelop has been accompanied by higher electricity demands. These data can be transfered to the Central Europe building stock. To reduce the electricity demand without reducing comfort passive cooling by night ventilation is used in the office building of DB Netz AG in Hamm, Germany.

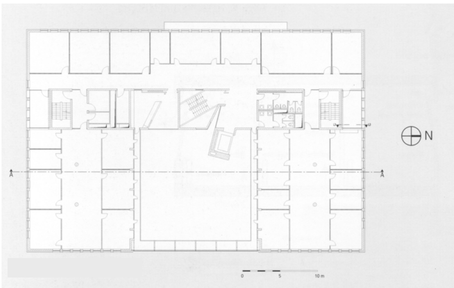

Figure 1: View and Floor Plan. The building has an U-shaped floor plan with offices oriented to the ambient and to an atrium, which is defined as an pre-conditioned outer space.

This building has been designed, realised and monitored for a long time period in the framework of the German research programme solar optimised buildings *SolarBau*, for more information about the building and the programme see www.solarbau.de. The absence of investment subsidies ensured that all design solutions (total primary energy use below 100 kWh/(m_a) with excellent visual and thermal comfort) were realised under representative economical conditions. Concerning the temperature performance in summer, the focus usually lies on the avoidance of not wanted solar gains in the moderate German climate. The remaining internal loads can often be counterbalanced by controlled ventilation, additional night ventilation or by earth-to-air-heat exchangers [Voss 2000].

BUILDING DESCRIPTION AND MONITORING OF NIGHT VENTILATION

Within the design process thermal and daylight simulation were used to optimise the energy performance of the building [Wambsganß 1998]. Artificial lights are dimmed and the building is sun-protected by external venetian blinds. The ventilation strategy during the operation hours uses both natural (from ambient and atrium) and mechanical ventilation in the offices, the multifunctional floor areas are mechanically ventilated with air intakes and exhausts. Night ventilation is used to activate the thermal capacity of the bare concrete ceiling. Cooling capacity of an earth-to-air-heat exchanger adds on night ventilation. Fresh air flows through opened flaps due to the stack effect caused by the atrium. In summer, it is automatically activated by the BMS from 2am – 8am. Fig.2 gives an overview on the building, its ventilation and the location of the monitored offices. The ventilation strategy depends on ambient temperature (night ventilation), operation time (mechanical ventilation), and user behaviour (natural ventilation).

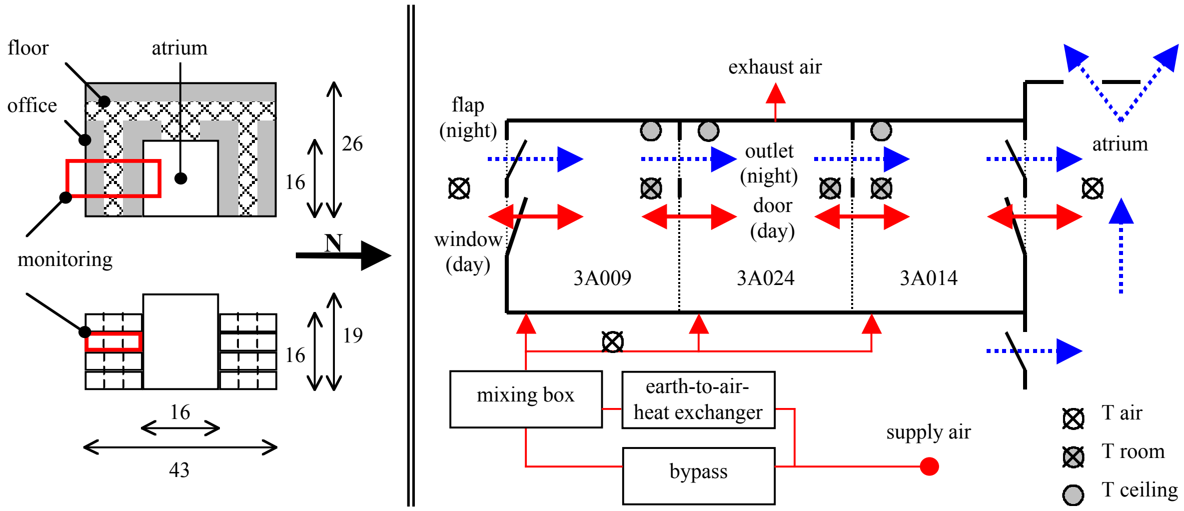

Figure 2: Floor Plan, Cross Section and Detail of the monitored office building. Typical ventilation scheme (dotted line: natural night ventilation; drawn line: hybrid day ventilation) and position of the monitored sensors.

The buildings energy performance was monitored over 2 years with a high time resolution. Within the monitoring campaign energy demand for heating and ventilation, the internal loads caused by equipment, operative and intra-fabric temperatures, flow volumes by mechanical ventilation as well as climatic site conditions were measured. Occupancy correlates strongly to the working hours. These measurements were completed by short term measurements of air leakage rates using tracer gas technique with the concentration decay method in order to get a more detailed information on the flow paths in different operation status. Tab.1 gives the key information on the building. Information concerning energy consumption, climate and internal loads results from measurements.

TABLE 1
Building key information on geometry and energy performance (01/01/2001 – 31/12/2001).

gross volume [m_]	net. floor area [m_]	operation hours	elect.demand f. service tec. [kWh/m_a]	heat demand (design) [kWh/m_a]	mean daily internal load [W/m_]	T – ambient (mean) [°C]	I - glob,hor (mean) [kWh/m_d]
25,705	5,974	8am – 6pm	22.3	65	6.4	11.2	2.56

OPERATIVE TEMPERATURE

The results from a one year monitoring on an hourly base have been analysed regarding the operative temperature. A detail study (short-term measurement) showed that the monitored

temperature (Pt 100 mounted at the wall) is not the air temperature but almost identical to the operative temperature. The criterion used is the annual temperature distribution within the office hours (Monday to Friday from 8am to 6pm), the percentage with operative temperatures above 25°C should be lower than 10%. Fig.3 shows the cumulative annual air temperature distribution for three office rooms which represent an outside room (3A009), the multifunctional zone (3A024) and an inside room (3A014). The results shows acceptable indoor climate conditions, though they do not match strictly the comfort criteria.
The dots represents the operative temperature in 3A009, but sorted by the ambient dry bulb temperature. It shows, that only with ambient temperatures above 26°C there is a strong relationship between the indoor operative temperature and the ambient, while below that temperature other effects like internal and external loads dominate.

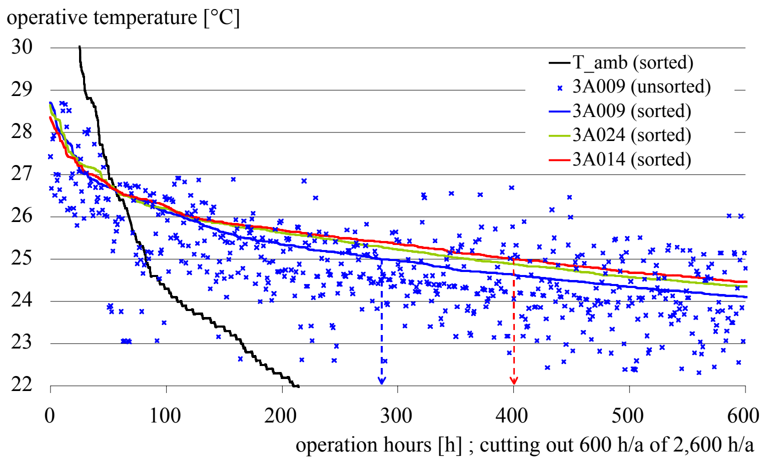

Figure 3:
Results of monitoring of the DB Hamm building: cumulative operative temperature distribution for typical office rooms within the working hours 8am-6pm (Apr 2000 – Mar 2001). The temperature exceeds 25°C in 3A009 in 280h and in 3A014 in 400h of 2600h office hours.

The effect of night ventilation (efficiency evaluated by the operative temperature) in the office located at the facade (3A009) is higher then in the office located at the atrium (3A014).

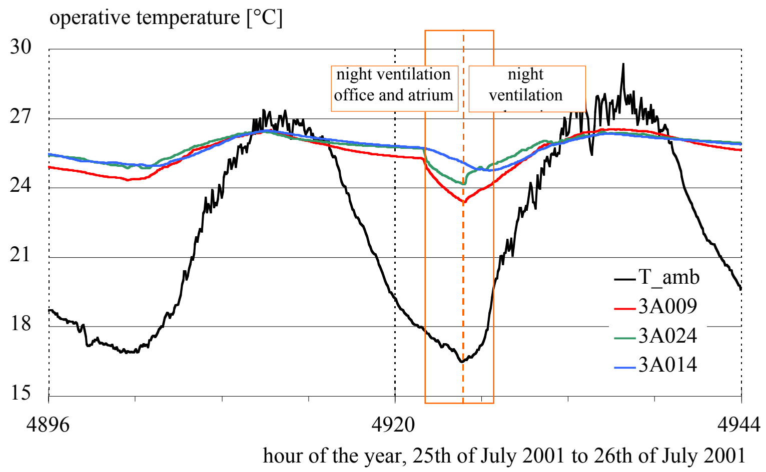

Figure 4:
Operative temperatures from outside to inside: 3A009, 3A024 and 3A014. The outside room benefits from the cool ambient air. If the outside flaps are closed, room 3A014 will benefit from the natural ventilated atrium and night ventilation will stop in room 3A009 (almost no air change).

The first experiment is during day: The hybrid ventilation is evaluated by measurement with / without mechanical ventilation and with / without natural ventilation (flaps). Mechanical and natural ventilation intensify each other (in room 3A009). The second experiment is for night ventilation: The flaps both in all rooms and at the bottom and the top of the atrium are opened. The doors between office and multifunctional zone are partly open, partly closed. The measured air change rates in rooms in the second (2B023), third (3A014 and 3A009) and forth floor (4B012) are given in Tab.2. Due to the reduction of the hydraulic resistance, the air change in rooms with open door is conspicuously higher than in rooms with closed doors. Due to the stack effect the air change rate decreases with the position of the room.

TABLE 2
Air change rates measured by SF6 tracer gas concentration decay method on August 2000 and July 2001, wind velocities remain below 20 km/h during experiment.

3A009: daytime	No ventilation, flaps closed	Ventilation, flaps closed	No ventilation, flaps open	Ventilation, flaps open
air change per hour	0.3	1.2	2.0	4.1
different rooms: night ventilation	2B023 door open	4B012 door closed	3A014 door open	3A009 door closed
air change per hour	6.5	2.5	3.7	2.7

DATA EVALUATION BY SIMULATION

In order to quantify the cooling capacity by night ventilation and to better understand the thermodynamic phenomena an adapted simulation is performed. Reasons are to derive hints on the uncertain input parameter of simulations in the design phase, on the optimisation potential of passive cooling and on the necessary complexity of simulation tools. The methodology to use simulation for data analysis can shortly be described in three steps. Set-up of the model, parameter identification based on short term measurements, and analysis of the accuracy of the simulation with long term measurements. We do not aim primarily at an accurate result for every time step but at the excellent modelling of user behaviour and long term building characteristic based on monitoring of a building in service.
For a deeper analysis a 4 week summer period from 16th of July 2001 to 12th of August 2001 is chosen which represents different climatic conditions concerning ambient temperatures, wind and irradiation. A detailed simulation of a cross section of the building is performed using ESP-r [Clarke 2001]. The measured internal loads and the climatic conditions are used as boundaries. Air flow is modelled by an flow network. (Discharge factors of the flaps are adapted by an parameter variation.) Due to the absence of status information of doors and windows, the user behaviour concerning free ventilation is derived from a Fourier analysis on measured temperatures to identify dates of temperature gradients (opening or closing of flaps etc.). A sufficient correlation between measurements and model is shown in Fig.5.

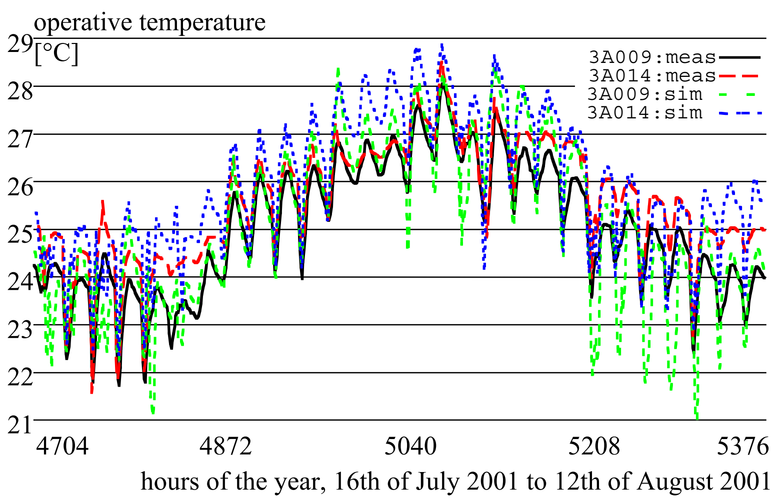

Figure 5:
Measured and simulated operative temperatures in office rooms 3A009 and 3A014. Despite of some uncertainties in simulation and measurement the operative temperatures during operation hours are a good match. The period with increasing ambient temperature and solar radiation fit very well in both long term and short term characteristics.

The measured operative and surface temperatures of the ceiling are used to quantify the differences between measurements and simulation. The simulation model is checked in two ways. First a Monte Carlo variation on the three main characteristics according to [Keller 1997] was performed (deviation within 2 σ-boundaries): Building capacity *C* (25%), heat loss coefficient K (20%), and heat gain coefficient Ψ (20%). From the results given in Tab.3, two lessons can be learned: The mean value of the outer office (3A009) fits better while the deviation in the room attached to the atrium is lower. Room A3009 is less sensitive on uncertain model parameters than on ambient conditions and user behaviour.

TABLE 3
Results of a Monte-Carlo simulation of the four main characteristics of the simulation model.
Deviation δ of the difference $T_{simulation}$ - $T_{measurement}$ within 2 σ-boundaries.

	3A009		3A014	
	T - operative	T – ceiling	T - operative	T - ceiling
mean bias [K]	0,06	0,06	0,16	0,16
deviation [K_ / 672]	0,050	0,016	0,012	0,024

Secondly a Fourier analysis is performed on both measured and simulated temperatures in order to quantify the buildings dynamic. The operative temperature is characterised by two elements of the Fourier row (4 weeks and 1 day), to characterise the ceiling temperatures an additional period of a week is needed. The results given in Tab.4 show a good correlation of measurements and simulation of both the operative and ceiling temperatures for the long term period. The short time dynamic agrees less for the operative temperature (2h phase shift), since the night ventilation leads to a supplementary, not uniformly distributed harmonic oscillation.

TABLE 4
Results of a Fourier Analysis of the measured and simulated operative and ceiling temperatures in room 3A009.

	Operative temperature		Ceiling temperature	
	Measurement	Simulation	Measurement	Simulation
Mean value	25.0 °C	25.1 °C	25.5 °C	25.1 °C
Amplitude (672 h)	1.7 K	1.9 K	1.3 K	1.6 K
Phase shift	132 h	139 h	90 h	110 h
Amplitude (168 h)	-	-	0.1 K	0.1 K
Phase shift	-	-	40 h	4 h
Amplitude (24 h)	0.6 K	0.6 K	0.06 K	0.08 K
Phase shift	2.3 h	0.3 h	0.2 h	0.9 h

The simulation does not match the measurements at every time step (see Fig.5) but describes the building characteristics incl. user behaviour well (Tab.4), with small deviation (Tab.3).

OPTIMISATION OF NIGHT VENTILATION

Two strategies will lower the level of operative temperature. *Night ventilation (optimised)* is to control the flaps at the top of the atrium by the operative temperature in the multifunctional zone 3A024 (set point: 20°C, 10pm – 7am) and the flaps at the bottom of the atrium by the air temperature in the atrium (set point: 18°C, 4am – 8 am). Additionally, the windows are closed automatically when ambient temperature exceeds 26°C. No change in the shading control, and no mechanical ventilation occurs. This will halve hours with T > 25°C even without mechanical ventilation because the heat gains are reduced and the building is cooled down stepwise and effectively. *Mechanical ventilation (additional)* is to control the night ventilation time based (base case) without manual engagement (i.e. no illogical user behaviour) and to use mechanical ventilation (earth-to-air-heat exchanger) at operative temperature in the multifunctional zone 3A024 above 24 °C. The rooms related to the atrium (3A014) can significantly reduce the maximum temperature (direct cooling effect), while the mean temperature in all rooms remain higher (less effect by night ventilation). Additional, natural ventilation effect is partly disturbed (cp. Tab.2) by the mechanical ventilation during day time.

TABLE 5
Classification of temperatures: hours (operation and not-operation time) > 25 °C
for different night ventilation strategies (16/07/2001 – 12/08/2001; 672 h).

	hrs. > 24 °C			hrs. > 25 °C			hrs. > 26 °C		
Room	3A009	3A024	3A014	3A009	3A024	3A014	3A009	3A024	3A014
night ventilation (base case)	471	630	654	324	447	495	231	301	313
night ventilation (optimised)	259	382	475	156	224	296	54	101	175
mechanical ventilation (additional)	345	575	571	231	275	332	78	44	144
T ambient	122			111			85		

CONCLUSIONS AND FURTHER WORK

The building is designed to achieve moderate summer indoor climate conditions. The percentage with operative temperatures above 25°C is around 10%. Passive cooling by free night ventilation improves the thermal comfort without increasing the electricity demand. The presented methodology on data evaluation using simulation allows a deeper insight in the efficiency of night ventilation (air flow paths, user behaviour, building characteristics, heat transfer) and give the possibility to improve ventilation strategies. Hybrid ventilation strategies have to be implemented carefully in order to avoid disturbance of the natural ventilation by additional mechanical driven air flows. We will apply this methodology on other buildings and different ventilation strategies in order to model night ventilation efficiency more precisely. We prepared further experiments to ascertain the coefficient of performance *COP* for different passive cooling strategies - based on simulation and measurements of air flow and air, operative and surface temperatures: Mechanical (easy to control) and natural (no electricity demand) night ventilation in comparison with concrete slab cooling (not air driven). Further work is to be done to evaluate the influence of user behaviour and changes in the design phase on the efficiency of night ventilation.

Acknowledgements

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