Experimental Results and Experience from the Retrofit of an Office Building with Passive Cooling – REB Remscheid

Peter Engelmann, Karsten Voss
Bergische Universität Wuppertal, Fachbereich D, Abteilung Architektur
Bauphysik und Technische Gebäudeausrüstung
Pauluskirchstraße 7, 42285 Wuppertal, Germany
Email: engelmann@uni-wuppertal.de, Tel: +49 (0)202 439 -4293 Fax: -4296
www.btga.uni-wuppertal.de

ABSTRACT:
The office building belonging to the Remscheider Entsorgungsbetriebe REB (Waste Disposal Unit in Remscheid), which was constructed in 1968, was thoroughly renovated in 2004. The utilisation quality was greatly improved with a combination of measures including efficient thermal insulation and solar control, fan-controlled ventilation, better use of daylight and active use of solar energy for domestic hot water – while the energy consumption values were reduced appreciably at the same time.
A key aspect of the renovation was to improve comfort during summer without applying active air-conditioning. The concept of passive cooling by night ventilation was implemented here. The rate of heating up in summer was decreased and overheating was prevented by reducing solar gains, buffering heat gains during working hours and cooling the building by increasing the air change rate with cooler outdoor air during the night.
Measurements demonstrate that the fan-controlled ventilation guarantees high air quality. Comfort in summer proved to be very good, even though (internal) air leakage hindered efficient operation of the night ventilation during the first two years of operation. Airtight construction of the ventilated zone is of elementary importance for the construction and operation of a night ventilation system. It became evident that not only the whole building envelope must be airtight but that internal connections between different ventilation zones also play a role.

KEYWORDS
Refurbishment, passive cooling, night ventilation, thermal comfort, renovation

THE BUILDING

Since the renovation, the 4-storey, 4600 m^2 building in Remscheid has been used as the central office for the Waste Disposal Unit (1900 m^2 office area), and also houses the garages for the fleet of vehicles (2200 m^2), with changing rooms and bathrooms (500 m^2) for the waste collectors and sewerage service staff.
This article presents analyses and experience concerning the office part of the building. The usage profile for the other sections of the building (changing rooms, bathrooms and garages) is very different, so that only the office area will be discussed here. Analyses of the entire building can be found on the Internet site for the accompanying research, www.enob.info/en and in [Engelmann2008].

Fig. 1: Exterior view of the building before and after renovation. (Sources: l: [amcs], r: [Riehle])

The energy concept and the architectural quality were recognised by the State of NRW with the “State Prize for Architecture, Residential Building and Urban Planning”. The Bergische Universität in Wuppertal is responsible for monitoring and evaluation of the building operation within a project funded by the German Federal Ministry for Economics BMWi in the EnSan section of the Energy-Optimised Building EnOB Programme [EnOB].

PASSIVE AIR-CONDITIONING CONCEPT

The basis for a pleasant indoor climate during summer is so-called “passive cooling”: Starting with effective solar control, which already appreciably reduces the solar gains from outdoors during summer, the heat which is stored during the day in the building mass is removed at night by automated ventilation. To this purpose, passive vents with a variable cross-section are integrated into the new wooden, lightweight façade (see Fig. 2).

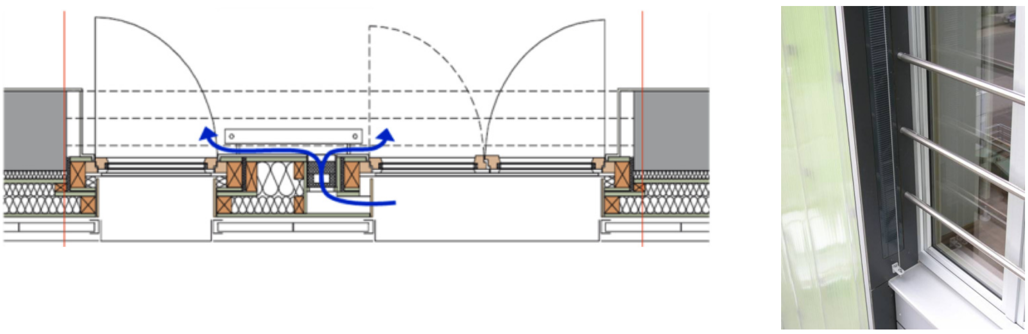

Fig. 2: Horizontal cross-section through the façade near a window and exterior view of a window recess. (Drawing: [acms], Photo: [btga])

An air extraction unit draws fresh air in through the vents and ensures adequate air exchange for the offices. The vents are half-open for operation during the day. Outside working hours, the air extraction unit is switched off and the vents are closed. In summer, specifically if the daily average temperature exceeds a certain limit, the vents are completely opened during the night and the offices are ventilated with a double air change rate ($n = 2\ h^{-1}$).

OPERATING EXPERIENCE

The operation and functionality of the applied measures have been monitored with fine resolution. In the following sections, we will focus on the effect of the (night) ventilation concept on summer comfort and the air quality in the offices.

Indoor climate in summer

To check the functionality of the concept, both user surveys [Schakib2008] and temperature measurements were made. Despite initial difficulties with the night ventilation (see next section), the implemented concept resulted in a very comfortable indoor climate. This was confirmed by the answers of users to questionnaires [Schakib2008] and by measurements and assessment of the comfort according to DIN EN 15251 [EN15251], [Voss2008], [Voss2007].

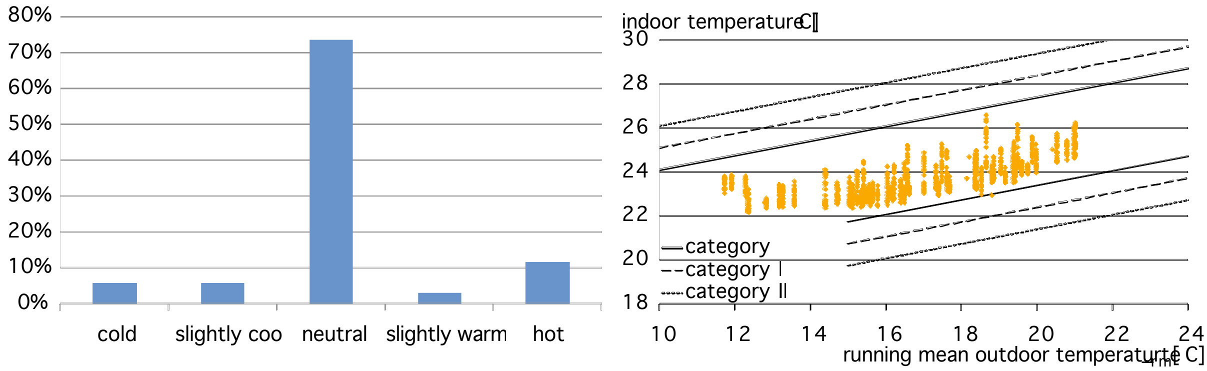

Fig. 3: Results of a user survey in summer 2007 (left) and the measurement results as averages for various south-oriented offices in the first storey graphed in accordance with the comfort criteria specified in DIN EN 15251 for buildings without active air-conditioning. The measured temperature values refer to the working hours (Mon – Fri, 6 a.m. to 6 p.m.). Comfort Class I refers to a predicted user acceptance of 94 %.

DIN EN 15251 specifies the limits for summer comfort in buildings without active air-conditioning with the aid of an adaptive comfort model. With this model, a day with high outdoor temperatures is evaluated as being less “hot” if high temperatures had already prevailed during the previous day. This assumes that the users can influence ventilation actively (primarily by opening windows) and are able to adapt their choice of clothing according to the weather. Figure 3 shows a graph of the hourly averages for the measured operative indoor temperature plotted against a sliding average of the outdoor temperature. All values during working hours fall completely within the limits for Comfort Class I (94 % user acceptance).

By contrast, the limits for Comfort Class I are occasionally exceeded on the northern side. Unlike the southern side, there are no exterior sun-shading devices here (but solar-control glazing is installed). As the building is oriented slightly toward the north-east, radiation from the low sun enters the ground-floor offices during the early hours of the morning (which also have large transparent façade areas) and causes a rapid increase in temperature (see building plan in Fig. 4).

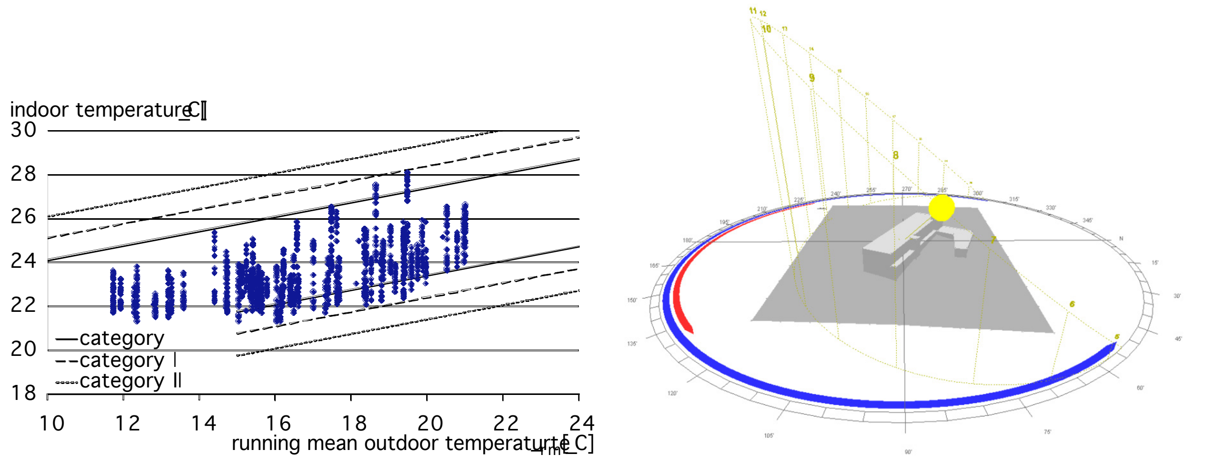

Fig. 4: Temperature measurements for north-oriented offices on the ground floor. The limits for Comfort Class I are exceeded here occasionally in summer. Not only is the proportion of transparent areas significantly higher than in the upper storeys, but there are also no external sun-shading devices on the northern side. As the building is oriented slightly toward the north-east, noticeable solar gains occur during the early hours of the morning. The plan on the right shows a low-resolution model of the building and the sun's position during 1st July (graph: Ecotect 5.5).

Ventilation and air quality

The air quality in the offices was investigated by measuring the CO_2 concentration. The variation of the CO_2 concentration throughout the day was monitored, and air change measurements were carried out according to VDI 4300 [VDI] using CO_2 as the tracer gas. A single air exchange (80 m^3/h) for the offices was foreseen during planning. However, measurements showed that the system operated with a high specific electric power consumption of 0.33 $W/(m^3/h)$. For various reasons (dry indoor air in winter, complaints about draughts during the transitional seasons, high electricity consumption), the system operation was reduced to app. 45 m^3/h per office and the fan-assisted ventilation of the corridors was switched off. The corridors thus became part of the ventilation route from the offices to additional air extraction zones such as the toilets.

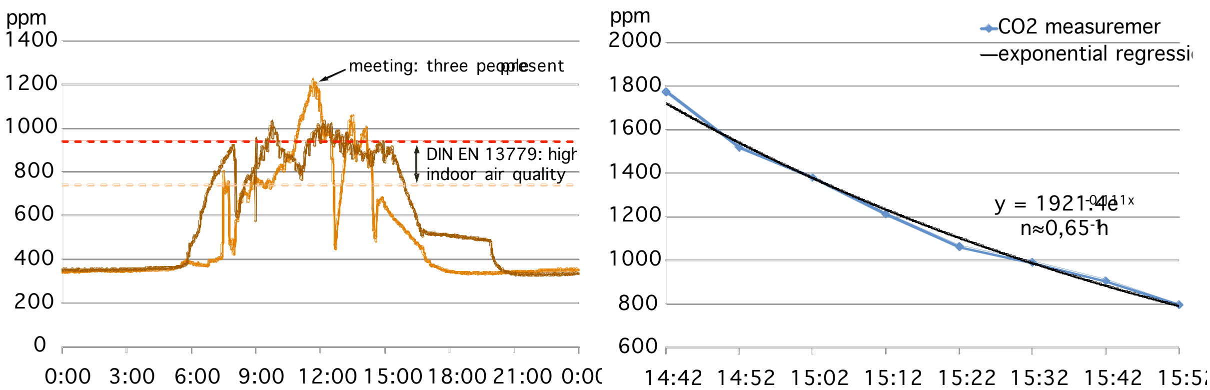

Fig. 5: Measurement of the CO_2 concentration during working hours in a two-person office (left), and an air change measurement with CO_2 as the tracer gas according to the concentration decay method of VDI 4300 (right).

Air quality measurements based on the CO_2 concentration (Fig. 5) show that good air quality is maintained during normal occupancy (two persons in the office, window closed). The resulting air change rate is 0.65 h^{-1} as determined by the concentration decay measurement. The specific system power consumption was considerably reduced by the modifications to the ventilation system to 0.12 $W/(m^3/h)$.

Airtightness and zoning

To achieve an adequate air change rate, it must be ensured not only that corresponding volumes of air are removed by the air extraction unit but also that sufficient underpressure is maintained in the offices for outdoor air to enter through the vents. Figure 6 shows the characteristic curve measured on site for an outdoor air vent in two positions, completely open (night ventilation operation) and 50 % open (operation during the day). The volume of air extracted during daytime operation, originally 80 m^3/h, now 45 m^3/h per office ($n = 1.0\ h^{-1}$ and $n = 0.6\ h^{-1}$), flows in through the vents even for small pressure differences. In the case of night ventilation ($n = 2.0\ h^{-1}$), 160 m^3/h enters if a pressure difference exceeding 22 Pa is established (with completely opened vents).

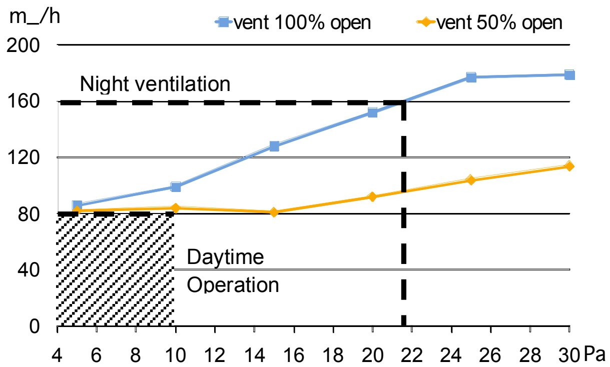

Fig. 6: Characteristic curve for an external air vent, measured on site. The flow rate of the entering outdoor air depends on the pressure difference between indoors and outdoors. To ensure that the entry rate for outdoor air is sufficient for the night ventilation, an underpressure of 20 Pa must be established in the building.

Measurements of the pressure difference have shown that contrary to planning, the required underpressure is not established in the offices. When an extracted air flow rate of 160 m^3/h is measured in the case of night ventilation, some of the air enters through leaks and not exclusively through the outdoor air vents. In several blower-door measurements, it was determined that the leaks were primarily internal leaks between zones which should be cooled by night ventilation (the offices) and zones without planned night ventilation – such as stairwells and service rooms. These interfaces must be investigated critically when a night ventilation concept is to be implemented, as internal leaks reduce the effectiveness of night ventilation in the zones where it was originally intended.

For example, conduits for cables and piping have proved to cause difficulties. Most of these met fire safety specifications (impenetrable for smoke) but were not airtight. Improvements were needed in several cases. In particular, the fire zone barriers to the stairwells had faults.

Outlook

Despite difficulties in achieving the necessary airtight construction in the building envelope and interior – which were also related to the original need for renovation – it is evident that a pleasant indoor climate in summer can be achieved without application of active cooling. The concept is transferable to many buildings, particularly public buildings of similar age and construction type.
The effects of optimising operation as a result of the accompanying research underline the importance of targeted analysis during the first years of operation, during which planning data are compared with real operating data and the intended operation of systems and components is tested.

References

[acms] Architektur Contor Müller Schlüter, Kolkmann- Haus Hofaue 55, 42103 Wuppertal, Germany

[btga] Bergische Universität Wuppertal, Fachbereich D, Abteilung Architektur, Lehrgebiet Bauphysik und Technische Gebäudeausrüstung, Prof. Dr.-Ing. Karsten Voss, Pauluskirchstraße 7, 42285 Wuppertal, Germany

[EN15251] DIN EN 15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, Beuth Verlag GmbH, Berlin, 2007

[EN13779] DIN EN 13779, Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems, Beuth Verlag GmbH, Berlin, 2007

[Engelmann2008] Engelmann, P., Voss, K.: Bürosanierung zum Niedrigenergiehaus – REB Remscheid, Erfahrungen und erste Analysen, 3. Internationales Anwenderforum Energieeffizienz + Bestand, Bad Staffelstein, Februar 2008

[EnOB] EnOB: Research for Energy-Optimised Building, http://www.enob.info/en

[Riehle] Tomas Riehle, architectural photographer, Eifelstraße 68, 50677 Cologne, Germany

[Schakib2008] Schakib-Ekbatan, K., Nutzerzufriedenheit in Bürogebäuden, Auswertung Remscheider Entsorgungsbetriebe, Sommerbefragung, Zwischenbericht, Universität Karlsruhe, fbta, November 2008

[VDI] VDI 4300, Sheet 7, Indoor-air pollution measurement - Measurement of indoor air change rate, Beuth Verlag GmbH, Berlin 2001

[Voss2007] Voss, K., Pfafferott, J.: Energieeinsparung contra Behaglichkeit?, Schriftenreihe des Bundesamts für Bauwesen und Raumordnung, Nr. 121, Bonn, 2007

[Voss 2008] Voss, K., Engelmann, P., Kugel, D., Sanierung eines Bürogebäudes zum Niedrigenergiehaus mit Passiver Kühlung – REB, Remscheid, 2. Internationales Anwenderforum Energieeffizienz + Bestand, Bad Staffelstein, Februar 2008