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

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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 m² building in Remscheid has been used as the central office for the Waste Disposal Unit (1900 m² office area), and also houses the garages for the fleet of vehicles (2200 m²), with changing rooms and bathrooms (500 m²) 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].
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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).

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].

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 CO₂ concentration. The variation of the CO₂ concentration throughout the day was monitored, and air change measurements were carried out according to VDI 4300 [VDI] using CO₂ as the tracer gas. A single air exchange (80 m³/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/(m³/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 m³/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 CO₂ concentration during working hours in a two-person office (left), and an air change measurement with CO₂ as the tracer gas according to the concentration decay method of VDI 4300 (right).
Air quality measurements based on the CO₂ 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/(m³/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 m³/h, now 45 m³/h per office (n = 1.0 h⁻¹ and n = 0.6 h⁻¹), flows through the vents even for small pressure differences. In the case of night ventilation (n = 2.0 h⁻¹), 160 m³/h enters if a pressure difference exceeding 22 Pa is established (with completely opened vents).

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 m³/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

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