Saving Heating and Cooling Energy by Sub-soil Conditioning of Supply Air at the German Museum of Technology

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ABSTRACT

In 2003 the new extension of the German Museum of Technology (Deutsches Technikmuseum, Berlin), which comprises around 12,000 m² of exhibition space was completed as a low-energy building. Planning and building this construction took almost 20 years (from 1987 to 2003). Validation measurements have been conducted since 2004. The building has been monitored by the Fraunhofer Institute for Building Physics IBP and IBUS (Institut fuer Bau und Umwelt, Berlin) during construction, in the commissioning phase, and during the period of validation measurements.

The inner leaf of the building's external walls and the interior walls were built from materials (KLB bricks) that easily absorb humidity from the indoor air to rerelease it back into the room when the level of indoor-air humidity has decreased. In this way it was not necessary to provide an expensive air-conditioning system which would also have caused high operational costs.

For structural reasons, a crawlspace had been designed beneath the thermally insulated floor slab. Part of the supply air is conducted through this crawl space before it is transferred into the museum building. In this manner, the air is preheated in winter and it is cooled in summer. As the validation measurements have proved, this procedure results in substantial energy savings.

KEYWORDS

German Museum of Technology, low-energy building, hollow floor, heat recovery, supply air heating, validation measurements, preheating, cooling energy

INTRODUCTION

The new extension of the German Museum of Technology (Deutsches Technik-museum, Berlin) was designed as a low-energy building ensuring optimized daylight supplies. The building was completed in 2001. Typically, large public buildings have considerable energy saving potentials, which can be utilized by applying intelligent concepts. The energy concept was designed by the Fraunhofer Institute for Building Physics (IBP) and the Berlin IBUS Institute (Institut fuer Bau-, Umwelt- und Solartechnik Forschungsgesellschaft). Both institutions also monitored the execution of the construction work and conducted the validation measurements after completion of the building. The results have been compiled in reference [1]. The project was funded by the German Federal Ministry for Economy and Technology (BMWi).

The major elements that contribute to saving energy are the thoroughly insulated building envelope, the optimized supply of daylighting and the use of solar energy, in conjunction with heat recovery and the sub-soil conditioning of supply air in a hollow floor located below the building. This paper deals with the latter.

BUILDING

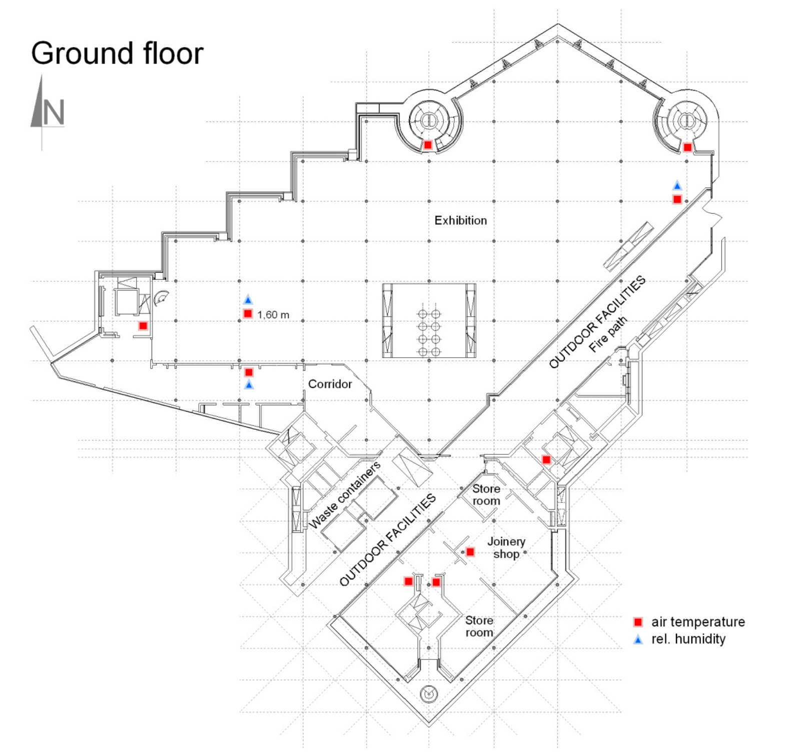

Fig. 1:
Ground floor plan

The annex comprises a utility block, which is situated on the south side and a north-oriented exhibition wing. The ground floor plan is represented in Fig. 1, the north and east views are shown in Fig. 2.

Fig. 2:
View of the east façade with closed sun shading devices

The north façade of the building is fully glazed. Looking at the eastern façade in Fig. 2, one can see the lowered sun shading elements. The exhibition wing comprises 4 storeys, its conditioned net floor area is 17,950 square meters. The south-oriented five-storey utility wing, which houses a library, seminar rooms, meeting rooms and workshops has a conditioned net floor area of 6,107 m². The surface to volume ratio of the entire annex is equal to 0.13 m^{-1}.

The load-bearing structure of the building is openly demonstrated, from the inside just like from the outside. This kind of architectural concept has benefits and disadvantages. The storage masses are considered to be beneficial, because they can be used (without lining or suspended ceilings) to enhance the building's thermal performance. On the other hand, any apertures or penetrations of the thermal envelope seem to be a disadvantage. The external walls consist of a two-leaf construction. The outer leaf is made from clinker bricks, the inner leaf is made from lightweight insulating blocks (KLB bricks). Mineral wool was inserted between the two leaves. The U-value is equal to 0.52 W/(m²K). KLB bricks were selected for the inner leaf construction because these bricks are characterized by a high hygric absorption capacity. It was decided to build the extension without a conventional air conditioning system, as the energy optimization of the new annex was governed by the principal objective of minimizing the required building services installations, building costs and, most of all, maintenance costs should be reduced to a minimum without neglecting requirements concerning comfort and utilization.

BUILDING SERVICES SYSTEMS

The major part of the building is mechanically ventilated. The heating system includes supply air heating, underfloor heating and radiator heating. The building is connected to the VATTENFALL GmbH district heating network.

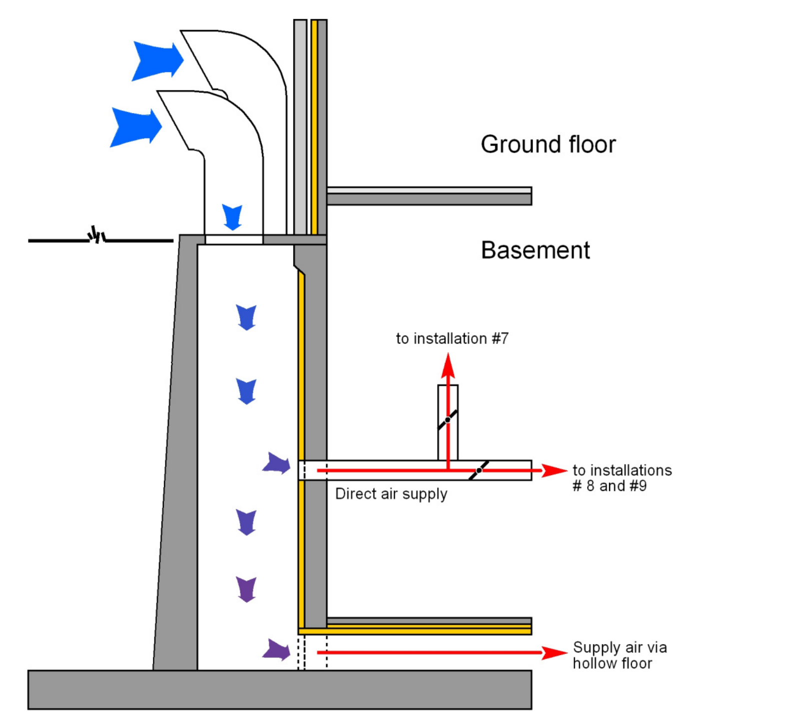

Fig. 3:
Supply-air intake

The installations that ensure the ventilation of the exhibition wing are located in the basement. There are two options: either, outdoor air can be conducted through the hollow floor or it can be conveyed directly to the ventilation installations through the air pipes in the basement. Figure 3 shows the outdoor air intake, Fig. 4 represents the surface area of the hollow floor. As the basement was placed in the groundwater, a hollow floor was established below the actual basement floor, in order to protect the store rooms in the basement from moisture.

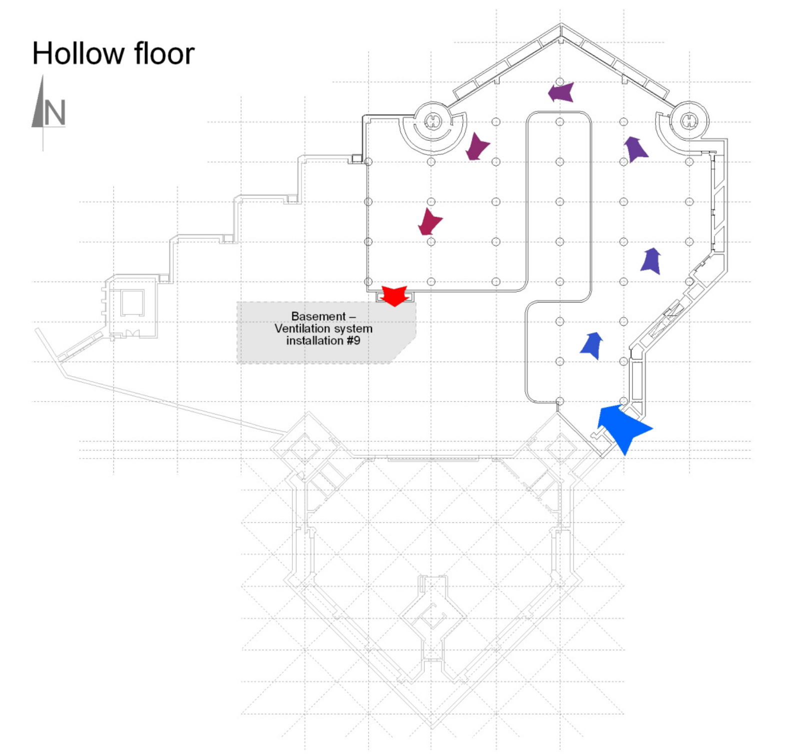

Fig. 4:
Air ducts in the hollow space

Figure 5 presents a scheme of the ventilating installations no. #8 and #9 in the exhibition wing and the air ductwork inside the hollow floor. The maximum flow of fresh outside air passing through the hollow floor is equal to 7,750 m³/h. The share of the outdoor air in the total supply air flow is 12 %.
By closing the ventilation flap KS 9b and by opening the ventilation flap KS 8a the system can be switched to direct outdoor-air supply.

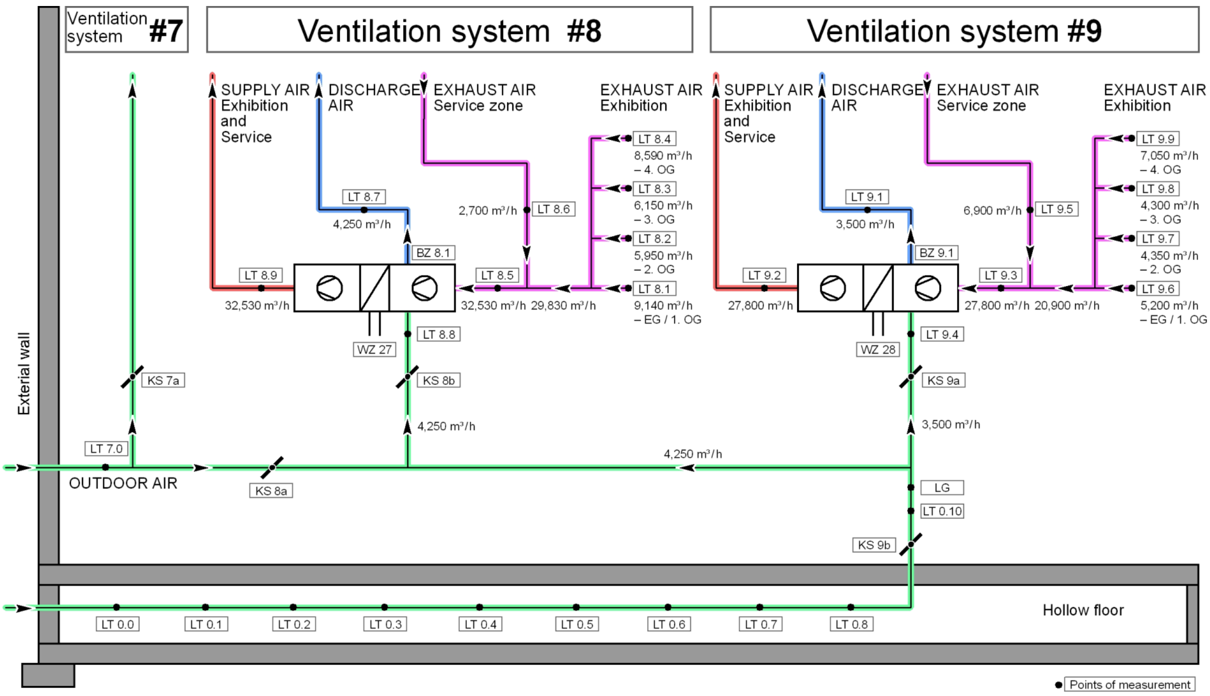

Fig. 5: Scheme of the air ducts in ventilation systems #8 and #9

MEASUREMENTS

Subsequent to the completion of the extension buildings and the opening of the exhibition, validation measurements were conducted and analysed in the period from 2005 to 2008. Even after this period it was continued to record large amounts of this data, which is displayed under www.maneg.de .
The measurements are serving two purposes: they are intended to optimize and adapt the building services to the building, to validate the applied building concept, and to record the user behaviour. In part, this performance data is captured by the building services control system. To record further required data, Fraunhofer IBP use their own specialized measurement system.

MEASURED RESULTS

Apart from the energy consumption and the associated energy costs, which burden the annual budget, the indoor-air temperatures and the levels of indoor-air humidity are of particular importance in a museum building. The indoor-air temperatures were recorded at 51 measurement positions inside the museum, the indoor-air humidity was measured at 21 positions. This data was collected every minute and then stored as hourly mean values. Figure 6 presents all hourly means of the indoor-air temperature recorded at the measuring point in the north-west part of the ground level (at a height of 1.6 m) in 2007. These values are plotted against the hourly mean of the outdoor-air temperature.

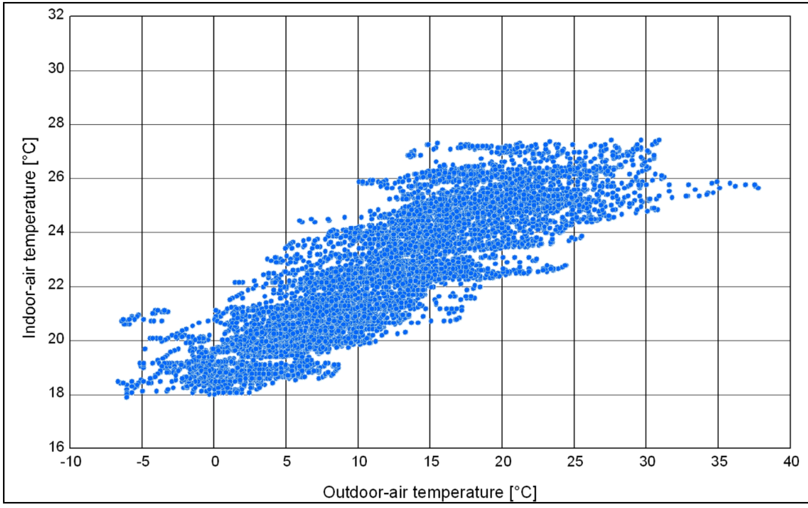

Fig. 6:
Hourly means of the indoor-air temperatures measured in the ground-floor exhibition wing in 2007

The represented values are fluctuating in a margin between 18 °C and 27 °C. For instance, indoor-air temperatures of 20 °C and of 24 °C were recorded when the outdoor-air temperature was 10 °C.
The indoor-air humidity values, which are plotted above the hourly means of the relative outdoor-air humidity (measured at the same spot as the indoor-air temperatures given above) are compiled in Fig. 7.

The least humidity values are equal to 30 %, the highest ones amount to 60 %. For example, at a given relative outdoor-air humidity of 30 %, indoor-air humidities of 30 % will result, just like humidities of 60 %. This is also true for an outdoor-air humidity 95 %.

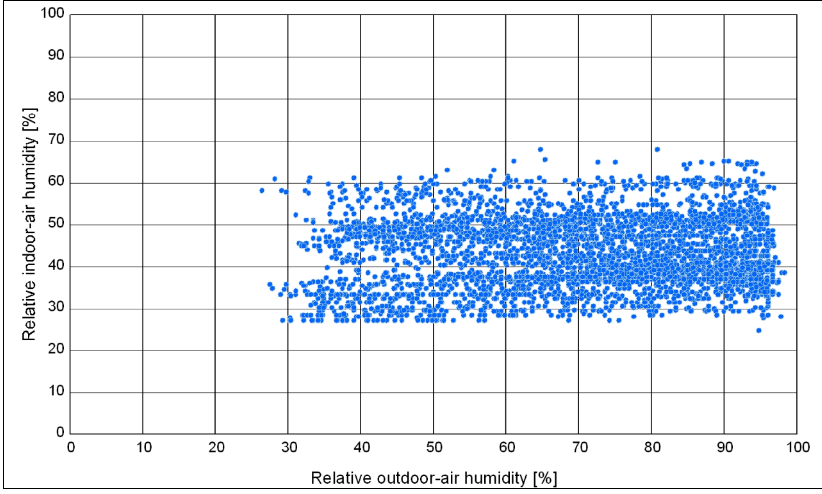

Fig. 7:
Hourly means of the relative indoor-air humidity measured in the ground-floor exhibition wing in 2007

The climatically adjusted consumption of final energy for heating the extension building amounts to 55.7 kWh/(m²a) in 2005, to 49.7 kWh/(m²a) in 2007, and to 44.6 kWh/(m²a) in 2008 (see Fig. 8). This reduction could be achieved by taking measures to optimize the performance of the heating and ventilation systems.

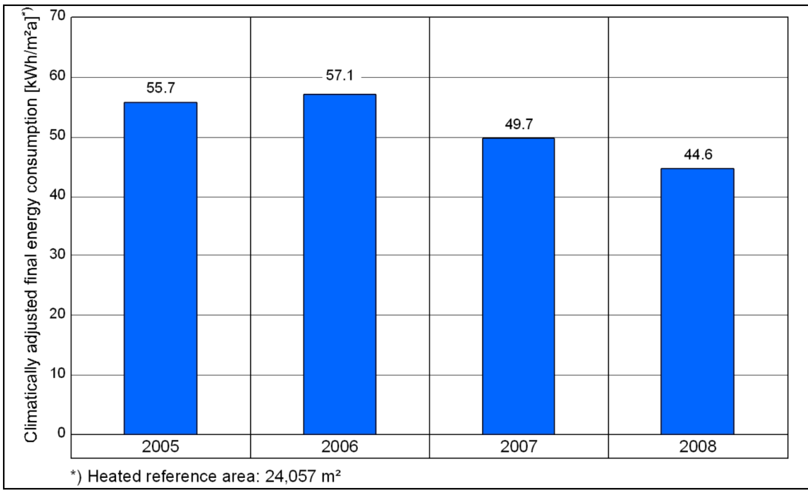

Fig. 8:
Final energy consumption for heating the museum (figures adjusted to take account of climatic conditions)

The efficiency of preheating the outdoor air inside the hollow floor is demonstrated in Fig. 9. The three diagrams present the temperature profile of the outside air that is flowing through the hollow floor, measured on three different days in winter. The external air temperature continuously rises up to 19 °C approximately.

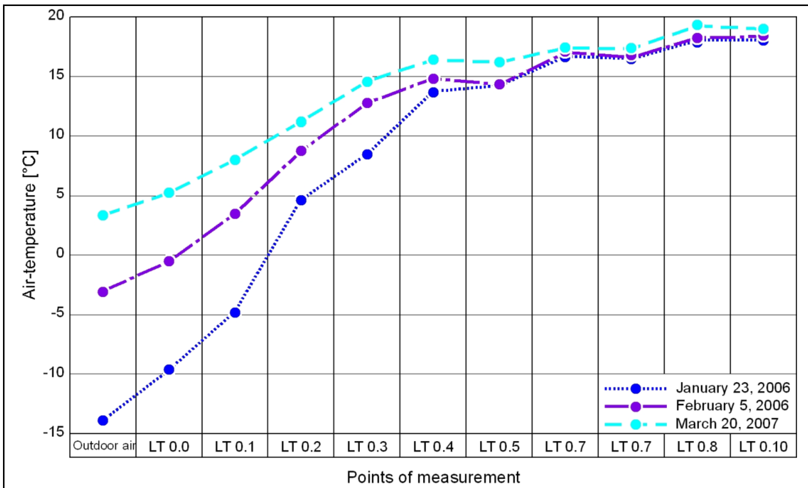

Fig. 9:
Temperature profile of the air flow from the hollow floor inlet to the outlet, recorded on three different winter days at 5 p.m.

In summer the hollow floor is also suited for cooling the supplied outdoor air (see Fig. 10). The temperature of the air flowing through the hollow floor decreases until reaching measurement position LT 0.5. Having passed this point, the temperature rises again slightly.

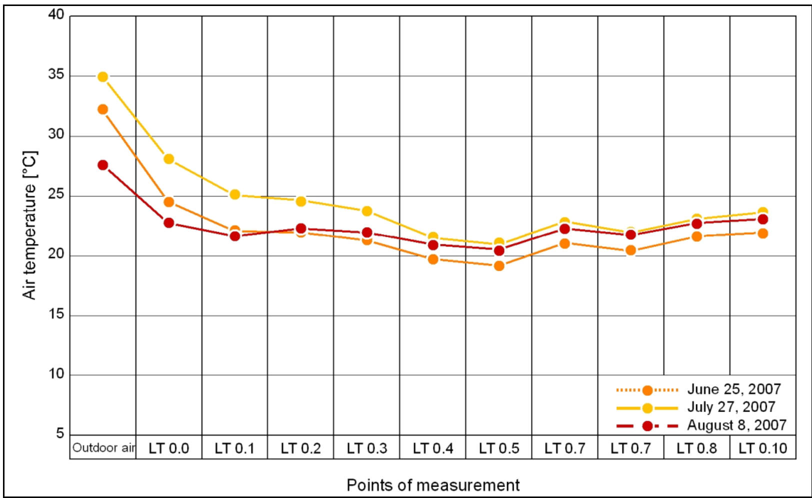

Fig. 10:
Temperature profile of the air flow from the hollow floor inlet to the outlet, recorded on three different summer days at 12 noon.

In Fig. 11 there is a compilation of the amounts of heating and cooling energy that are supplied to the exhibition wing each month. When related to the thermally conditioned net floor area of the exhibition wing, this quantity is equal to 3.11 kWh/(m²mth) for the month of January 2006. The maximum quantity of the cooling energy introduced in the summer months is 0.36 kWh/(m²mth).

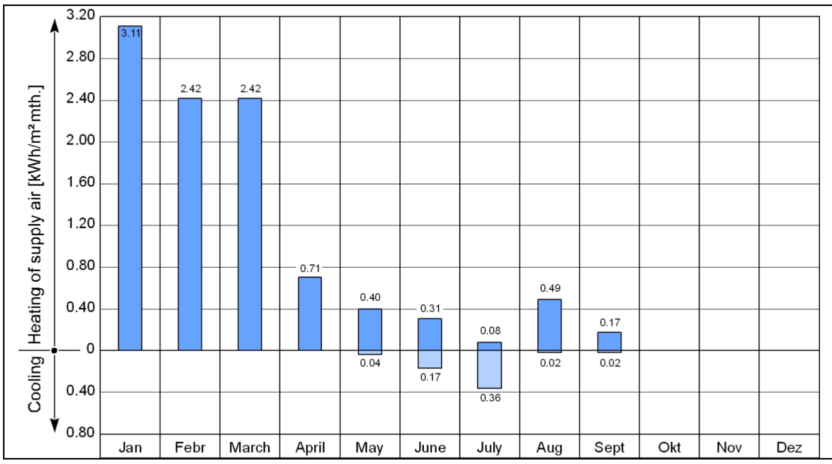

Fig. 11:
Monthly specific energy gains due to warming and cooling of the supply air (in 2006)

It also becomes evident from Fig. 11 that in the summer months heat was introduced into the museum building by preheating the outdoor air. This was done unintentionally, as the museum indoor-air temperatures are rather too high in summer. The supplied external air will always be heated if the outdoor-air temperature is lower than the hollow-floor temperature. In summer, this situation is given particularly at night and in the early morning hours. During these periods, the outdoor air should not pass through the hollow floor. Instead, the air should be conveyed directly into the building. To ensure direct supply, the outdoor-air temperature-controlled supply of fresh air is required. However, this type of control system is lacking. Whether the external air will be passed through the hollow floor or directly supplied to the building is currently managed by manual control. Further, this figure implies that from October to December the outside air was no longer passed through the hollow floor but directly conveyed to the museum. As a consequence, free environmental energy for heating the building was wasted, particularly in the winter months of November und December.

CONCLUSION

The annex to the German Museum of Technology in Berlin was completed in 2001. Subsequent to arranging the exhibition, it was opened for the public. About 80 % of the usable floor areas are mechanically ventilated. The hollow floor, which is located below the basement, allows winter preheating and summer cooling of the external air supplied to the exhibition wing. An air-conditioning system was not installed. To stabilize the relative humidity, the walls were constructed from unplastered light-weight insulating blocks (KLB bricks). These blocks will absorb moisture from the indoor air when the relative humidity is high, to release it again once the indoor air humidity is getting low. The architectural style of the annex, which openly displays the structure, contributes to activating the mass of the building and to establishing a thermally well-balanced indoor environment.

The validation measurements that were conducted from 2005 to 2008 provided the following information regarding the thermal indoor environment and the preheating (resp. cooling) of outdoor air inside the hollow floor:

- Both the indoor-air humidities and the indoor-air temperatures were found to have a larger fluctuation range than expected. In winter, indoor humidity was about 25 %. This fact caused the museum management to retrofit a humidifier system at the end of 2007. In summer, indoor-air temperatures frequently exceed 26 °C, particularly in the third floor of the building. This is due to the high power supply for lighting. Initially, it had been planned to include daylighting to a much greater extent so as to save lighting energy.
- In winter, the outdoor air can be heated to approx. 18 °C after flowing through the hollow floor, even if outdoor temperatures are well below zero. This allows to gain an energy amount of about 3 kWh/(m² mth.) in the winter months (related to the net floor area of the exhibition wing). In summer, the supply air can be cooled to about 23 °C after passing the hollow floor, even at outdoor-air temperatures of 35 °C. It is considered to be a shortcoming of the system that it does not automatically switch to direct air supply when the outside air temperature is below the hollow floor temperature. Presently, the mode of operation still needs to be switched manually using the building services control system.

A major part of the measured data can be read on-line on the web (see www.maneg.de). Also, all the data recorded since January 2005 has been stored here. Both daily and yearly profiles of this data can be displayed.

REFERENCES

[1] Hillmann, G.; Jakobiak, R., Reiss, J., Erhorn, H., Erhorn-Kluttig, H., Beckert, M.: Museum als Niedrigenergiegebäude mit optimierter Tageslichtversorgung – Messprogramm und Evaluierung. Schlussbericht Phase III.