An existing low-rise building was to be extended to expand a printing house. That was an opportunity to improve the graphic design and office workstations already housed there at the same time. The company also wanted to demonstrate their commitment to environmental protection in this measure, as it is an advertising selling point beyond the printing process. The energy requirements were set high together with the objective to optimise workspace comfort for the employees. As in many open-plan offices built in the sixties and seventies, the climate in the low-rise building was never particularly pleasant, neither in summer nor in winter. The workspaces were difficult to ventilate and to provide with natural light. The heat from the artificial lighting increased the room temperature. The copious equipment required for “pre-press” work not only heated the air, but also polluted it. Opening windows was the only way to intervene. In order to make the working conditions reasonably bearable in summer, split unit air conditioners had been retrofitted in some areas.

The overall concept developed for refurbishment and extension solved these problems and provides a convincing solution from a design and functional point of view. Using waste heat from machines to heat the building and ventilate it, combined with surface cooling via borehole heat exchangers make working conditions far more comfortable with lower energy consumption. Ample glazing with external sun protection allows better use of daylight. The key criterion for all decisions was the aim of increasing occupant comfort. Both the initial investment and the operating costs were taken into account for financial evaluation. The refurbishment was planned in 2004 and implemented one year later by a general contractor. Since then, the energy balance of the building has been tracked precisely. As part of its “Energy-oriented refurbishment of building fabric” research area, the German Federal Ministry of Economics and Technology (BMWi) promotes the recording and evaluation of the measurements of the ambitious project.
Initial state

The printing house consists of a three-storey office building and a connected low-rise building, also used for offices, to which, in turn, the production halls are connected. The construction work focused on the low-rise building as a result of the idea of adding storeys to it for the required extension. The problems there were obvious: Although the equipment typical for a printing house, such as plotters and high-performance copiers were primarily located in the working area, there was no ventilation system. For this reason, the windows often had to be opened, both in summer and winter. Also, in the summer there were significant temperature fluctuations during the day, and high peak temperatures. The supply of daylight to the workspaces also left something to be desired. The artificial lighting which was on all the time as a result increased the temperature.

Work on the building

First, the low-rise building was gutted and the façade was demolished. Without the suspended ceiling, the ground floor provides higher and brighter workspaces after refurbishment. The concrete ceiling is used as thermal mass. In order to minimise the static loads, a lightweight steel construction was placed on the building shell. The measure allowed us to add an open foyer in front of the existing structure, thus not only improving the lighting and access situation, but also to facilitate open building ventilation. A glass façade there opens the building to the west over two storeys. External sun protection reduces undesirable solar heat influx. The two-part drape system improves the ability to use daylight without being blinded.

Energy concept

Heating

The building is heated in the ground floor via underfloor heating, and uses the waste heat from the printing hall. In order to minimise the installation work, the existing gas boiler supplies the installed radiators. Subsurface convectors at the large glass façade prevent cold air drafts.

Cooling

Managing high internal and solar loads such that cooling is only implemented via natural heat sinks is a challenge. Effective sun protection is essential for this. The concrete ceiling is available as a thermal mass in the ground floor. Capillary tube mats, which can be filled with water cooled via borehole heat exchangers, are embedded in the floor, and thus can actively dissipate the heat.

Ceiling cooling panels in the lightweight construction upper floor combine capillary tube mats with latent heat storage material (PCM). The PCM can absorb temperature increases via phase changes and decouples heat supply and dissipation temporarily. At night, the panels are thermally discharged via active cooling by the borehole heat exchangers.

The idea was to keep the borehole heat exchanger array small – and thus cost-effective via offset operation of capillary tube mats and ceiling cooling panels. The fact that the 12 borehole heat exchangers with a depth of 44 metres each are used without a separate heat exchanger increases the energy efficiency and reduces the complexity of the system.

Table: Selected building characteristics

<table>
<thead>
<tr>
<th>Construction</th>
<th>Built in 1978</th>
<th>Refurbished in 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground floor:</td>
<td>Reinforced</td>
<td>Reinforced</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>concrete</td>
<td>concrete</td>
</tr>
<tr>
<td>Upper floor:</td>
<td>Steel structure and lightweight construction</td>
<td></td>
</tr>
<tr>
<td>Gross floor area</td>
<td>580 m²</td>
<td>1,390 m²</td>
</tr>
<tr>
<td>Net floor area, heated</td>
<td>480 m²</td>
<td>1,110 m²</td>
</tr>
<tr>
<td>Gross volume</td>
<td>1,250 m³</td>
<td>4,910 m³</td>
</tr>
<tr>
<td>Façade U-value</td>
<td>2.6 W/m²K</td>
<td>0.3 W/m²K</td>
</tr>
<tr>
<td>Window U-value</td>
<td>2.7 W/m²K</td>
<td>1.4 W/m²K</td>
</tr>
<tr>
<td>Roof U-value</td>
<td>0.5 W/m²K</td>
<td>0.2 W/m²K</td>
</tr>
</tbody>
</table>

Fig. 2: Selected building characteristics

Fig. 3: Section of the extended building

Fig. 4: The steel frame is built on the gutted existing building.

Fig. 5: Ceiling cooling panels and two-part sun protection provide comfortable working conditions in the new upper floor.

Fig. 6: Building services equipment schematic
Natural night ventilation cools the building mass and the air in the room effectively in the summer. The louver windows at the bottom and top of the façade are used for this. The reconstruction allowed the building to be optimised for free circulation and to use the thermal lift in the room volume.

**Ventilation**

Mechanical basic ventilation significantly improves the quality of the air and can be supplemented individually by opening windows. This ventilation is primarily used in winter, during operating hours, depending on the room temperature and outdoor temperature. The supply air is blown into the individual zones and the exhaust air is discharged centrally at the highest point of the building. This reduces the ventilation paths and the installation work. Heat recovery reduces the energy required for heating.

### Using low exergy

The printing house’s energy concept, based on underfloor heating, which uses waste heat, and cooling via borehole heat exchangers and night ventilation, relies on low exergy systems. Thermal exergy is the part of energy which can perform work. Natural resources are used efficiently if the exergy supply is coordinated with the exergy demand. High-quality, exergy-rich energy is to be reserved for high-quality energy services such as power generation, while low-exergy energy forms can be activated for heating and cooling at room temperature level. With corresponding (surface) systems, such as underfloor heating, minor temperature differences between the room and the heating or cooling medium are sufficient for heating or cooling. Waste heat or natural cooling from the soil can be used as energy sources. Reduction of the loads, in particular by optimising the building shell, and using exergy-efficient energy conversion systems are the key to exergy-optimised design. Low exergy systems (LowEx) are a focus of the research on energy by the German Federal Government.

www.enob.info/de/forschungsfelder/lowex

### Planning and implementation

The building and energy concept was developed in the Fraunhofer ISE, in close coordination with the builder. The companies for the borehole heat exchangers and cooling ceilings were also involved at an early stage. A general contractor was commissioned for the construction work. As a result of this interface, much of the planned energy quality was lost – the implementation in numerous sub-areas no longer meets the characteristics assumed in the planning phase. For this reason, the energy figures actually reached are excellent for a refurbished old building, but do not meet the original targets. As the building was to be heated almost exclusively via waste heat from the printing house, and was to be cooled using environmental energy (cooling from the soil and natural night ventilation), energy was only to be required to distribute the energy. However, both low exergy systems do not work as planned. Intensive monitoring played a significant role in discovering problems and possible improvements.

### Heating

The degree of heat recovery of the ventilation system, 60%, is substantially lower than assumed during planning (85%). In order to guarantee a sufficient supply air temperature, a backup heat exchanger had to be retrofitted. As the specifications of the underfloor heating system were too small, the waste heat from production could not be used to the extent planned: It only achieves 7 instead of 18 kWh/m² p. a.

In the next expansion stage, the borehole heat exchangers are to be used as a heat source for a heat pump in winter, thus replacing the existing boiler. That also improves the conditions for the use of the ground for cooling in the summer, as the temperatures of the soil decrease.

### Cooling

High pressure losses in the main distributor – which lead to partially insufficient circulation of the ceiling radiant cooling panels - decrease the effectiveness of regenerative cooling. The cause of this is an incorrect implementation of the hydraulic system in the cooling distribution circuit. Added to this is the fact that the temperature in the ground is higher than assumed in planning. As the cooling capacity is lower than the planning objectives, and a too large circulation pump is used, the annual coefficient of performance of the system in 2007 was only 2.7 kWh_kWh_el and not, as planned, 8 kWh_kWh_el. The cooling output flows primarily into the ceiling cooling panels; the capillary tube mats in the ground floor are hardly used. For summer 2008, the hydraulic system of the cooling system was modified, improving the annual coefficient of performance to 3.3 kWh_kWh_el.

The occupants are satisfied with the semi-automatic operation of the sun protection. The solar thermal loads correspond to the planned values. In 2006, there was no natural night ventilation, as the opened glass louver windows collided with the sun protection. This problem has now been solved via an additional positioning sensor for the sun protection.

### Ventilation

The energy targets for ventilation were not reached, as the ventilation was planned for a minimum exchange of air and now is not operated accordingly. The fans installed also have a lower efficiency class than planned.

### Comfort

The key objective of creating workspaces with contemporary comfort was achieved: The interior temperatures measured met the requirements for new buildings and refurbishment projects. Comfort class B is fulfilled and only exceeded for less than 5% of the working hours. The daylight situation also improved significantly.
Costs and economic viability

According to the established costs, the construction costs (cost group 300) were EUR 860/m² and the costs for technical equipment (cost group 400) were EUR 370/m². Building services equipment was selected based on an overall cost-effective solution. The evaluation of economic viability took operating, maintenance and servicing costs into account, in addition to the investment costs. Interrelations between the technologies were also considered: For example, the use of waste heat requires a low temperature heating system – radiators cannot be used. However, the key decision criterion for the energy concept was always the improvement of workspace quality – and productivity. No incentives and grants were used for planning and construction. Only the subsequent monitoring is subsidised with research funds.

Conclusion

The building was improved in aesthetic and functional terms as a result of the refurbishment and extension. The generous natural lighting with glare protection, and the cooling concept provide occupants with a high-quality workspace. As a result of the particular commitment of the builder and their interest in the area of energy efficiency, the project combines many innovative ideas. For example, the ceiling cooling panels were used for the first time in this building. The energy consumption is relatively low but does not reach the planning targets. Low exergy concepts can only work if all framework conditions are right. Errors or deviations in the planning or implementation are doubly significant with such low energy values and can make the entire concept questionable. In this example, the underfloor heating system is too small, and the heat recovery of the ventilation system calculated to decrease the energy required for heating does not reach the planned efficiency. Therefore, the building cannot be primarily heated via the waste heat of the printing presses. Fortunately, the existing boiler can provide additional thermal heat, otherwise an expensive retrofitting job would have been necessary. Cooling via night ventilation and borehole heat exchangers creates a pleasant indoor climate in summer. However, both implementation and design errors reduce its efficiency.

The project demonstrates that close cooperation of all parties involved is an important requirement for the success of energy-efficient buildings. Builders, planners and companies performing the work must pursue the objective of energy efficiency together from the beginning. Short information routes and the option of discussing errors which occur directly facilitate achieving ambitious planning targets in real operation. Monitoring in the first years of operation provides key support in increasing efficiency and discovering problems.