

Office comfort with regenerative cooling

Fig. 1



- ▶ **Primary energy requirement for heating, ventilation, cooling and lighting just 81 kWh/m² p.a.**
- ▶ **Only once full occupancy is reached, can the energy consumption confirm the planned values.**
- ▶ **Borehole heat exchangers as economical source of heat and cold for concrete core temperature control. An optimising control concept ensures low electricity consumption for pumps.**

The size of the office building's window surfaces provides an optimal level of daylight with the lowest solar loads possible. The ventilation system's suction towers are seen the foreground.

The EU directive on the energy performance of buildings requires a broad perspective when conducting energy assessments of non-residential buildings. Now for the first time, the total energy required for operating the building is included in the calculations, unlike earlier, when only the heating requirements were considered. The German Federal Ministry of Economics and Technology (BMWi) has already been taking this approach for several years in its support initiative Energy-Optimised Construction (EnOB). The demonstration projects (new non-residential buildings) as part of EnBau, a branch of this initiative, were designed to achieve a primary energy requirement for heating, cooling, ventilation and lighting of less than 100 kWh/m² p.a.

One implementation possibility is to take the passive house concept (now proven in residential buildings) and apply it to other building types, interpreted according to requirements. The premise of very good thermal insulation, air tightness, and ventilation with heat recovery is also a very good basis for ensuring overheating protection in summer, which is often critical for office buildings.

This possibility was also chosen by the Software AG Foundation as investor in the construction of a new office building in Ulm, Germany. As this foundation promotes, among other things, measures which

"help nature", ecological objectives were also foremost while making a valuable real estate investment. Thus, from the onset, the passive house standard was called for in a limited-invitation competition for planning teams. High comfort and an up-market atmosphere with economical construction methods were additional requirements.

With 8,000 m² gross floor area, this passive house office building is as yet unique in its size. As a very compact building form was chosen, the planners had more scope for optimisation. It was possible to dimension the windows regardless of orientation. Furthermore, it was not necessary for all of the utilised building elements to satisfy the highest thermal standard in order to meet the requirements overall. A comfortable interior climate is achieved with the implemented design by means of high quality thermal insulation, concrete core temperature control, mechanical ventilation, and flexible sun protection. The use of renewable energy sources lowers the primary energy requirement.

The integral planning of architecture, construction physics, and building services equipment in a project team of experienced partners, the implementation of proven components and construction materials, as well as diligent quality assurance, were decisive factors in the success of this ambitious project. The building was finished in October 2002. The analysis of the subsequent measurement phase is now available.

► Building concept

Fig. 2: Building summary

Contractor / Investor	Software AG Foundation
Architecture	oehler faigle archkom solar architektur, Bretten, Germany
Location	Science-Park II, Ulm, Germany
Planning and construction timeframe	Competition result 04/2000, Construction period 04/2001 – 10/2002
Structural design	Reinforced concrete skeleton construction with wooden curtain wall facade elements
Net floor area (NFA), heated	6,911 m ²
Gross volume per DIN 277	32,223 m ³
A/V ratio	0.22 m ¹

The shape of the compact five-storey building structure is reminiscent of the piston of a Wankel engine. Due to the positioning on a south-facing slope, the entrance on the north-east side is at ground level, as is the south-facing terrace of the cafeteria, one storey below. The kitchen and seminar rooms are also housed on the garden storey. The office areas occupy the upper storeys. The air supply centre and an underground car park are situated outside the insulated building envelope, beneath the plaza in front of the entrance. A spacious glass-covered atrium ($U_g = 1.2 \text{ W/m}^2\text{K}$) forms the centre of the building. Walkways and stairs, as well as open areas oriented towards the atrium on the individual storeys make the atrium a hub of communication. It also serves for ventilation, and for use of daylight. Due to strategic co-

ordination of the fire protection and climate concept, it was not necessary to seal off the offices from the atrium.

The building is a reinforced concrete skeleton construction with facades made of prefabricated wooden elements of largely equal dimensions. 20 cm-thick insulation material under the foundation slab, 35 cm in the facade, up to 50 cm in the roof, and thermally insulating triple glazing in thermally insulated frames ($U_w = 0.84 \text{ W/m}^2\text{K}$) contribute to a very high degree of insulation. Here, care was taken in the design to ensure an almost complete absence of thermal bridges. For areas where the support structure is penetrated, and which are subjected to heavy loads (e.g. pillars in the cellar, and foundations of emergency staircases), economically feasible details which offer protection from mould and condensation were determined by means of heat flow analyses. In other locations, it was possible to compensate for the somewhat higher thermal bridge losses in a significantly more cost-effective manner. As glass accounts for 44% of the building envelope, solar loads are kept low, and nevertheless, the best possible use of daylight is guaranteed. A blower door test with the result 0.2 h^{-1} confirmed the high quality of the construction. Laminated amorphous solar cells are applied to the flat roof surfaces to form a PV system which covers 328 m².

Fig. 3: Entrance storey floor plan

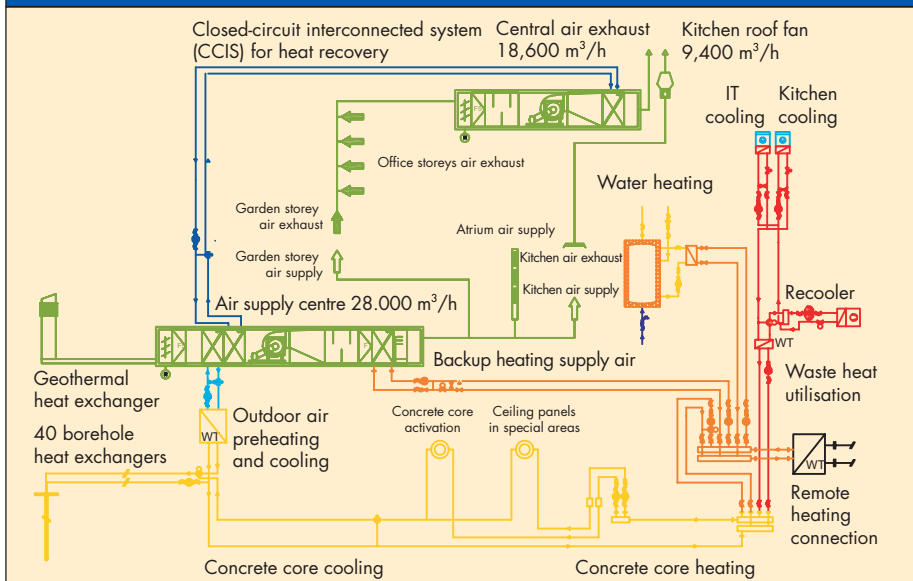


Fig. 4: Walkways, stairs and open areas enliven the atrium



► Heating, cooling and ventilation

Fig. 5: Technical building equipment diagram



For heating and cooling, the building primarily uses concrete core temperature control (CCTC). Due to the fact that with a thermally activated slab, the laws of physics dictate that the cooling capacity exceeds the heating capacity, the system is highly suitable for covering the established loads of this passive-house-standard office building.

For the purposes of CCTC, plastic tube heat exchangers with a surface area of around 5,000 m² are laid with 10 cm clearance from the undersides of the slabs. For temperature control, 40 borehole heat exchangers protrude 100 m deep into the ground. Water flows in a closed circuit from the borehole heat exchangers, through the

tube heat exchangers, and back. Thus, the ground functions as heat storage or cold storage, and the bivalent utilisation supports thermal regeneration. In the planning phase, various temperature control options (remote cooling and remote heating alone or in combination with earth-to-air heat exchanger) were compared. The implementation of borehole heat exchangers with water flowing through them proved to be the most cost-efficient and environmentally friendly solution.

Due to large-scale activation, even very slight overtemperatures or undertemperatures are sufficient to heat or to cool the energy-optimised building. One advantage of CCTC is that it also balances out temperature differences between the individual sections of the building. In winter, the building's internal yields are often enough to ensure thermal comfort. If the water for CCTC needs to be reheated, this occurs primarily via waste heat from the compression refrigeration machines for the server rooms and cold storage rooms for food. The remaining heat energy requirement is covered by remote heating.

The thermal inertia of the concrete core calls for a sophisticated control concept. To charge the concrete core optimally, the required pump

running time is determined upon consideration of the room temperature, slab temperature, and water temperature. The situations in which heating is required, and in which cooling is required, are separated by a neutral tem-

perature range. Individual room control is not possible.

The CCTC is supplemented by a sophisticated ventilation concept. Outdoor air is channelled through a 28 m-long underground duct to the

air supply centre, where it is further cooled (or heated, depending on the requirement) by the borehole heat exchangers. If heating is required, the heat recovered from exhaust air is used. In the event of very cold outdoor temperatures, the air can be further heated using remote heating. Spray humidification keeps the relative humidity of the supply air above 30% even in cold periods.

The conditioned supply air is then channelled into the atrium. From there, it flows through noise-insulated overflow openings in the atrium facades, and through air ducts in the concrete slabs, to the exterior offices. Air quality and temperature in the atrium are monitored with measuring instruments. If required, the atrium can be ventilated naturally via smoke and heat vents; all offices and lounges have openable windows.

Exhaust air is actively extracted by suction in the offices, and channelled to the central air exhaust on the roof. The concept of minimal, space-saving and cost-saving air supply and exhaust ducts entails heat recovery in the closed-circuit interconnected system.

Ventilation of all office areas is controlled centrally, according to a time program. The rooms on the garden storey which are used for special purposes, such as the kitchen, cafeteria, and IT training, are directly connected to the central air ducts. In these areas, in order to take into account the significantly fluctuating load conditions, individual room control is possible by means of additional heating and cooling surfaces, as well as volume flow controllers.

► Energy concept: system components

System	Components	Details
Heating / Cooling	Concrete core temperature control	5,000 m ² plastic tube heat exchangers Designed for supply temperatures of max. 24.4 °C (heating) / min. 18.8 °C (cooling)
	Source of heat or cold	40 borehole heat exchangers, each 100 m deep, supply temperature 7 °C (outdoor air preheating) / 16 °C (cooling 80% CCTC and 20% supply air)
	Backup heating	Building's internal waste heat (see below); remote heating
	Underfloor heating	830 m ² on garden storey for the higher heating and cooling loads which occur there
	Compression refrigeration units	IT centre and cold food storage rooms (waste heat to the concrete core temperature control or to the environment via recooling system)
Ventilation	Ventilation system	Volume flow up to 28,000 m ³ /h
	Temperature control	Earth-to-air channel l=28 m d=1.8 m; borehole heat exchangers heat recovery (HR) via closed-circuit interconnected system (heat recovery level approx. 65%), remote heating
	Distribution	Directly to special areas on garden storey, other rooms via atrium Overflow into inner offices Air ducts into outer offices Exhaust air directly from offices into central air exhaust
Lighting	Natural lighting	By means of optimised glass surfaces (position and size) on the outer facades and via atrium
	Sun protection and glare protection	Two-section, light-diverting exterior blinds for atrium: translucent sun-protection film roller blinds between double glazing
	Artificial lighting	Electronically controlled T5 fluorescent lamps daylight-dependent control; motion detectors
Control	DDC building control technology	Controls the ventilation system, concrete core temperature control, shading; data acquisition
Water heating	Hot water storage tank	Garden storey (kitchen): central water storage tank (750 l) with stratified charging from remote heating
	Decentralised electric continuous-flow heaters	Office storeys
Heat supply	Remote heating	From CHP (40% from biomass) connected load: 185 kW
Electricity generation	PV systems (grid feeding)	PV modules integrated into flat roof 15 kW _p system on multi-storey car park 137 kW

► Energy balance

In 2005, the final energy consumption for heating, ventilation, cooling and lighting, including building cooling and the cafeteria (without refrigeration devices) was very low at 47.2 kWh/m² p.a., and well beneath the support initiative's required level. However, the heating consumption of 34.6 kWh/m² p.a. is still above the calculated requirement of 12 kWh/m² p.a. This is primarily due to the fact that only about half of the building was occupied, i.e. half of the internal heat gain is missing. Room temperature which is almost 3 K higher than planned for also plays a role. Simultaneously, solar yields are missing due to the fact that the unused rooms are permanently shaded – a rule which does not correspond to the planning. Meanwhile, the cafeteria, which is also used to a great extent by persons from outside, has a heightened ventilation requirement, due to its full capacity utilisation.

In 2005, the primary energy requirement was 81 kWh/m² p.a. If the energy fed from the PV system on the building's roof is taken into ac-

count, this is reduced by another 5 kWh/m² p.a. Both the contractor and the occupants are highly satisfied with the building and the workplace comfort. Even during the inaugural phase, when the ventilation was not yet fully functional, and the heating was controlled manually, the tenants experienced hardly any utilisation restrictions.

Fig. 6: Costs based on NFA

Gross construction costs calculated per DIN 276	
Building construction (cost group 300)	1,234 €/m ²
Technical systems (cost group 400)	454 €/m ²
Gross operating costs in the year 2004 (incl. cafeteria) per DIN 18960	
Per month	2.02 €/m ²
Of which heating, cooling, ventilation and lighting:	0.39 €/m ²

Fig. 7: Selected 2005 measurement data (m² based on heated NFA)

Borehole heat exchangers	Heat delivery (to supply air)	7.5 kWh/m ²
	Cold delivery (to supply air, concrete core)	13.0 kWh/m ²
	Borehole heat exchangers electricity consumption	2.5 kWh/m ²
	Borehole heat exchangers annual coefficient of performance	8.0 kWh _{therm} /kWh _{el}
	Winter months (only air preheating)	4.3 bis 6.3 kWh _{therm} /kWh _{el}
	Summer months (air and concrete core cooling)	13.0 bis 24.0 kWh _{therm} /kWh _{el}
	Primary energy annual coefficient of performance	2.8 kWh _{therm} /kWh _{prim}
CCTC	Pumps electricity consumption	1.5 kWh/m ²
	Waste heat fed in	8.9 kWh/m ²
	Remote heating fed in	13.7 kWh/m ²
Ventilation (V _{max} = 28,000 m ³ /h)	Ventilation electricity consumption (fans)	8.6 kWh/m ²
	Heat recovery electricity consumption (pumps)	1.3 kWh/m ²
	Heat recovery	29.1 kWh/m ²
	Heat recovery annual coefficient of performance	22.4 kWh/m ²

► Results

This construction project is ground-breaking, as no other office building of this size has as yet been built in accordance with the passive house concept. Integral planning was a prerequisite for the cost-effective and energy-efficient construction, which according to the building cost index is in the mid-range of the costs usual for conventional office buildings, despite a layout which is also sophisticated in the interior. Precise planning, prefabrication, and intensive quality control enabled a building envelope which is almost devoid of thermal bridges, and which is very air-tight – prerequisites for a well-functioning passive house.

The quality of the furnishing and the thermal comfort aid the investor in the attempt to attract tenants. Also, in the tenancy agreement, an upper limit of € 0.75/m² is guaranteed for the monthly ancillary costs incurred by heating, cooling and ventilation. However, at € 12/m² per month, the rent is relatively high from a local perspective. Upon completion of the building at the end of 2002, there was a great deal of unoccupied office space in Ulm, so renting out was correspondingly difficult. In 2004, the proportion of rented floor area increased from an initial 31% to 60% at the end of the year. In 2006, it is 80%. The Foundation is considering utilisation of the passive house standard again in a new construction project.

The concrete core temperature control, with the borehole heat exchangers as heat sink and heat source, has proven a success for cooling and heating the building. The passive house standard offers very good prerequisites for this, as due to the low heat losses, the building element temperatures must only deviate very slightly from the target room temperature. Even overnight, the building does not cool down significantly, which makes a morning heating phase unnecessary.

When cooling is required, the concrete core temperature control allows a load interruption of several hours each day, during which the cooling capacity of the borehole heat exchangers is used for cooling the supply air. The excess room heat which is temporarily stored in the building elements is then dissipated overnight. This saves having to use compression refrigeration machines or cold storage technology to cover the peak load.

For heating, cooling and auxiliary electricity with the current level of utilisation, the building requires only about 25% of the final energy required in a conventional office building. Nevertheless, with heating energy consumption of 34.6 kWh/m² p.a. in 2005, this is significantly higher than the calculated requirement and the passive house specifications. Missing here, most importantly, are the internal yields, which full occupancy of the building would entail. In order to pass final judgement on the success of the project, it is necessary to wait for data from years of full occupancy. Long-term monitoring over 5 further years will provide the data basis.

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Literature

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Internet

- www.enbau-monitor.de
- www.energon-ulm.de

Images

- Figs. 1, 2, 3: Software AG Foundation, Darmstadt, Germany
- Fig. 5: Ing.-Büro ebök, Tübingen, Germany

Service

- Additional information such as literature and internet links are available online from BINE at www.bine.info (Service/InfoPlus) in German.

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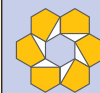
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