Thermo-active building systems

High-comfort, energy-efficient heating and cooling of non-residential buildings

A service from FIZ Karlsruhe
Straight to the point

Can buildings be cooled with environmental energy? Yes – with the aid of thermo-active building systems. Conventional chillers become unnecessary if buildings are planned and built in an architecturally and physically energy-optimised manner. And if using thermo-active building systems, the building’s own storage capacity can be utilised for temperature compensation, and activated via natural heat sinks such as the ground, ground water, or the cool night air. Since the 1990s, more and more buildings are being cooled with these systems – and heated as well.

But how much flexibility remains in the utilisation of buildings? How energy-efficient are the thermally inertial surface cooling and surface heating systems? What are the prerequisites for the concept to be economically viable? What level of comfort is actually achieved? These questions are discussed here, also on the basis of three new buildings from the monitoring programme “Energy-Optimised Construction” (EnOB), a research initiative of the German Federal Ministry of Economics and Technology (BMWi). Here, building and energy concepts, as well as new materials and technologies, are extensively tested under real operating conditions, and are assessed according to scientific criteria. With this Themeninfo brochure, we present a substantiated initial assessment of concrete core temperature control, which is a commonly implemented thermo-active building system.

The energy consumption for heating, cooling, ventilation and lighting, analysed in terms of primary energy, is below 115kWh/m² p.a. in all the buildings presented here, and is 2 to 3 times lower than the consumption values of today’s standard new office buildings. The thermo-active building systems perform so well in this regard because natural heat sources and heat sinks can be utilised.

One note of an internal nature: after what is now 10 years, the time has come for a fundamental revision of the concept and appearance of our Themeninfo brochures. We will continue to present current energy topics in the context of application-oriented research projects. With the new Themeninfo brochures, we hope to make it easier for you to obtain an overview by presenting the information in a more clear and concise manner, and with new perspectives. What do you think of the new look? We would welcome any criticisms or suggestions.

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Passive cooling with TABS

"Slim" building concepts employ energy-efficient and sustainable system solutions characterised by building services equipment of reduced dimensions, and low operating costs for heating, cooling, ventilation, lighting, and maintenance. Even under changed framework conditions, they can ensure thermal, hygienic, and visual room comfort. The cooling and, if certain prerequisites are met, also the heating of office buildings using environmental energy from the ground, ground water, and outdoor air, are of particular interest, both in terms of energy, and economically.

Today, energy-optimised buildings with a comparatively low heating and cooling requirement can be realised. In these buildings, it is also possible to establish a pleasant interior climate without costly building services equipment. This is made possible primarily by a combination of carefully coordinated measures with the following basic elements: very good thermal insulation and sun protection, sufficient thermal storage capacity in the building, and an air-tight building envelope in conjunction with basic ventilation and hygienically necessary air renewal as well as heat recovery. Abandonment of active cooling in summer in favour of passive cooling is only possible if buildings are planned carefully so that architecture, structural design, occupants’ requirements, and building services equipment are coordinated in an integral overall concept.

Cooling concepts with natural or mechanical overnight ventilation have been successfully implemented in office buildings and commercial buildings in recent years. Experience gained in low-energy office buildings cooled via overnight ventilation shows that pleasant room temperatures are achieved during summer even without air conditioning systems. However, when high temperatures persist for long periods, e.g. in the summers of 2003 and 2006, relatively high outdoor overnight temperatures prevent sufficient cooling of the thermal building mass. In such cases, structural measures and mechanically supported overnight ventilation are often insufficient to guarantee a comfortable interior climate during the day.

Thermo-active building systems, "TABS" for short, are considerably more effective. These systems cool the building structure using tube heat exchangers which are integrated into the building elements in order to condition the interior climate, either completely, or as a support system. If TABS are supplied with cold from the ground, or from the outdoor air via a cooling tower, energy is only needed for distribution, and not generation, of the cooling energy. Buildings with low heating requirements can also be heated using TABS.

Systematics of thermo-active building systems

Water-carrying tube systems, integrated into ceilings and floors for year-round temperature control of buildings, have been widespread for quite some time. However, no generally accepted term has as yet been adopted to refer to these systems. The most commonly used terms, depending on the application, are: concrete core activation, concrete core temperature control, thermo-active (concrete) slabs, building element heating / building element cooling, building element activation, concrete core cooling, and underfloor heating or cooling. The following terms are also used from time to time: active storage systems, active surface systems, building element conditioning, floor temperature control, partially active floors, and imbedded surface heating and cooling systems. In the interests of standardisation, the
The generic term "thermo-active building systems (TABS)" seems adequate, in order to encompass all systems which, due to a suitable construction method, actively incorporate the building structure into the energy management of the building. As most TABS which use water as the working fluid can be used for both heating and cooling, the term "temperature control" is appropriate for further classification. TABS are subdivided according to the position of the tubes in the building element: capillary tube systems, concrete core temperature control, underfloor temperature control, and double surface building element temperature control.

**Focus: water-carrying concrete core temperature control**

From the multitude of thermo-active building systems, this article is limited to the commonly implemented water-carrying concrete core temperature control (CCTC), which in turn encompasses the following system combinations:

1. CCTC solely for building element cooling; combined with conventional heating systems (radiators) and natural or mechanical ventilation. In this application, concrete core temperature control replaces a conventional cooling system.

2. CCTC as the room’s sole heating and cooling surface, combined with mechanical ventilation.

3. Supplementary systems: due to the thermal inertia and the resultant insufficient controllability of CCTC systems, supplementary heating and cooling systems are sometimes implemented. The CCTC system serves as the base load system for heating and cooling, supplemented by an additional system in the room, for individual, demand-oriented room control. Possibilities include subsurface convectors in the facade, but also system combinations which thermally activate the slab in a layer near the surface (edge strip element, capillary tube mats) as well as in the concrete core. The combination of a CCTC system with radiators or convectors must be considered critically in the planning phase.

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**Fig. 3 Thermo-active building systems (TABS): capillary tube systems, concrete core temperature control, underfloor temperature control, and double surface building element temperature control. From the multitude of various TABS, this Themeninfo brochure will focus on water-carrying concrete core temperature control (CCTC).**
Office buildings with prospects

If the total energy consumption of today’s office buildings is considered in terms of primary energy, the electrical energy consumption for ventilation (15%), lighting (27%), and usage (33%), and the energy used for active cooling (11%), make up a high proportion of the total energy consumption. Increasing insulation measures entailed by the German Energy Saving Ordinance (EnEV) heighten the significance of electricity consumption in the overall equation. Due to the fact that the greatest potentials for energy savings reside in the areas of ventilation, air conditioning, and lighting technology in particular, cooling concepts which use environmental energy can significantly reduce electrical energy consumption, and thus also significantly reduce the primary energy requirement.

Ground water on the 40th floor

The contractor Deutsche Post World Net wanted its new company headquarters in Bonn, Germany, to be a presentable building with optimal working conditions for 2,000 employees. And a “pioneering high-rise building for the 21st century” was the desired result. Thus, the “Post Tower”, with its 162.5 metres, now projects well above the neighbouring “Langer Eugen” (112 m) and even the Cologne Cathedral (157 m). The building concept is based on a double-skin facade with a great deal of glass and high transparency, which simultaneously enables a natural supply of fresh air and moderate supply air temperatures. The energy concept is based on ground water; up to 130 litres per second are flushed through the entire building. Temperature control of the building occurs in this manner during summer, and in winter the thermal energy of the ground water is used for heating in conjunction with a heat pump. In all normal offices, the cooling in summer is supplemented by floor convectors, which are also operated with ground water when in cooling mode. Conventional air conditioning systems were abandoned, with the exception of the management storey.

Yet the concept of concrete core temperature control appears to work well here too: on a particularly hot August day in the record-breaking summer of 2003, the air temperatures in the south-facing offices remained below the 26°C mark, which was a noticeable advantage for the staff, with outdoor temperatures at over 39°C. In the year 2003, the energy used for circulating the ground water was around 10 kWh/m².

Further information regarding the Post Tower is available at www.energie-projekte.de

Slim buildings

The term “slim buildings” refers to buildings which already, on the basis of well thought-out design and physical construction qualities, offer good conditions for achieving high thermal comfort with slimmed-down building services equipment. Here, the architecture, construction system, structural design, and building services equipment are coordinated so as to achieve the lowest possible energy requirement for heating, cooling and lighting. Thus, slim office buildings fulfil the prerequisites for the implementation of thermo-active building systems for room conditioning.
Concrete – with quality temperature control

Regardless as to whether it is too warm, or too cold – with conventional room conditioning technology, active counteraction, i.e. cooling or heating, is always necessary. This is not the case with concrete core temperature control: here, the building structure is utilised for storage of thermal energy, in order to release it when required.

To better understand concrete core temperature control (CCTC), a distinction is made between the phases "charging", "storage", and "discharging":

**Charging:** The floor slabs are charged with heating or cooling energy by means of hot or cold water circulating through the tube heat exchangers integrated in the building element. As the water flows through the tube system, it transfers heating capacity or cooling capacity to the slab, thus heating or cooling it, depending on the water temperature. This process can be actively controlled by varying the supply temperature, mass flow rate, and charging time. Due to the inertia of the system, the key challenge is in storing sufficient heating or cooling energy in the building element to cover the expected thermal loads of the following day. However, as it is not possible to know a room’s exact heating or cooling requirements in advance, the nature of this system causes charge reserves to arise, which entail higher energy consumption. Ideally, CCTC is operated in conjunction with a suitable storage management, in order to avoid additional thermal outlay, and overheating or overcooling of the rooms.

**Storage:** Like all thermal storage systems, the thermally activated slab bridges the time gap between energy supply and energy demand, and partially shifts the thermal loads to the night. Excess heat, caused by solar irradiation and by waste heat from persons and devices (internal loads), is transferred to intermediate storage in the slab, and causes the building element’s core temperature to increase. Parallel to this temperature increase, the operative room temperature also rises, although this is significantly curbed by the thermal masses. For example: if a 14 cm-thick layer of concrete is heated or cooled by 2 K, this corresponds to storage of approximately 190 Wh/m² of heat or cold, i.e. capacity of 23 W/m², which is available for 8 hours.

**Discharging:** In CCTC, room conditioning occurs by means of two effects which run in parallel: 60% of the heat or cold stored in the concrete core is transferred to the room via radiation, and 40% via convection. Due to the considerable system inertia, room-specific rapid temperature control is not possible. Thus, discharging occurs in a completely passive manner, without the room’s occupant being able to influence it directly.

In the event of temperatures which are slightly too high or low, the large heat transfer surface of the slab makes it possible to transfer considerable amounts of capacity to the room. Thus, CCTC systems can make effective use of even the relatively low differences between room temperature and the temperatures of natural heat sinks (summer) or heat sources (winter): ground, ground water, and outdoor air. In a steady state, cooling capacities of 30 to 40 W/m² are achieved. The upper limit for the cooling capacity is determined by the indoor air temperature dew point, as otherwise condensation forms on the ceiling. For a indoor air temperature of 26°C with 50% relative air humidity, the dew point is around 15°C. Thus, primarily the influx of solar loads must be reduced by means of effective sun protection. Due to the relatively "high" supply temperatures of natural heat sinks, the dew point is almost never fallen short of. If heating is required, power densities of 25 to 30 W/m² can be achieved.
Fig. 8 Energy balance for a room heated / cooled by means of concrete core temperature control

Fig. 9 Comparison of simulated room and slab surface temperatures (validity of building and system model based on measured data) for a Fraunhofer SOBIC room in the low-energy office building Solar Info Center (SIC), Freiburg, Germany, for 4 days in August 2004: without room conditioning, as well as cooling via overnight ventilation (quadruple air renewal), and CCTC. Due to the storage capacity of the concrete slab, and the heat dissipation via water by means of CCTC and a wet cooling tower, the room temperature is lower, and fluctuates during the day considerably less than in the case of night ventilation or the unconditioned room.
Structure of the concrete core

The tube heat exchangers are cast directly in the concrete core of the slabs or floors in a meandering or spiral-shaped coil channel. Plastic tubes or multi-layered composite tubes made of PE and aluminium are implemented as coils. These tubes have a diameter of 15 to 20 mm. The tubes lie at intervals of 10 to 30 cm at a central height, mostly within the concrete slab’s statically neutral zone. As most heat transfer occurs via the ceiling (around 2/3) and not via the floor (1/3), the tubes can also be fixed nearer to the thermally effective ceiling surfaces, if the building’s static load characteristics allow it. By means of the arrangement of the coils, and the position at which they are installed in the structure of the concrete slabs, different heat capacities can be selected for different times. Due to the fact that in CCTC, heat generally flows from the water-carrying tubes in the direction of the slab surface (when heating is required) or in the opposite direction (when cooling is required), all layers with high heat transmission resistance (e.g. plaster or suspended ceilings) reduce efficiency.

Construction physics requires...

If the building is to be heated or cooled solely by means of concrete core temperature control, the architecture and building services equipment must meet certain requirements. Because the performance of CCTC is limited due to the minimal temperature difference between the heating or cooling medium and the room temperature, despite the large heat transfer surfaces. The individual requirements are:

1. To limit the cooling load in summer: thermal loads active in the room must be kept to a minimum. In energy-optimised office buildings, the effective total energy transmission coefficient of the facade is reduced in order to reduce the influx of solar heat into the rooms. This is achieved by means of a moderate window surface area, windows with a reduced g-value, and exterior sun protection. Solar absorption on the opaque facade surfaces is not to be disregarded. Thus, a low U-value for the entire facade is also advantageous in summer. Corner rooms are often critical, as they have higher solar loads, even with good sun protection. The internal loads can be further reduced by means of consistent use of daylight, demand-oriented control of artificial lighting, and energy-saving office devices.

2. To limit the heating load in winter: The heating requirement can be reduced by means of very good thermal insulation of the facade, with heat recovery from exhaust air, and with passive utilisation of solar energy. A lack of edge strip elements in the window area increases the demand on the facade, as cold air draft should be prevented. Particularly careful planning is necessary for rooms with higher heat transmission losses on the top floor and on the ground floor, as well as corner rooms, especially if the facade has large glass surfaces.

"History" of thermally activated building systems

Heating and cooling slab systems have a long-standing tradition. Dating back as far as 1938, there are records of slabs with a heating function, also used for cooling purposes. However, the market launch was swiftly followed by disillusionment. This was due to the insufficient thermal insulation of buildings, as well as inadequate control technology and system design. One of the first buildings with water-carrying CCTC was the “Dow building” (Switzerland, 1991, 7,400 m² thermally activated cooling surface). One of the first buildings with CCTC as integrated heating and cooling system is the “Sarinaport office building” (Switzerland, 1994, 9,500 m² thermally activated heating and cooling surface). In the year 2001 in Germany, there were more than 60 non-residential buildings with CCTC either under construction, or already in operation. Already by the year 2003, the proportion of new commercial buildings in which concrete core temperature control systems were planned or realised, was estimated to be as much as one third.
3. Solid floor slab construction: The floor slabs must be able to store a great deal of heat and cold. Accordingly, concrete core temperature control can only be implemented in thermally “heavy” buildings. This calls for building materials with high thermal conductivity and a good thermal storage capacity (concrete).

4. Free slab surfaces: Suspended ceilings or ceiling claddings significantly reduce heat transfer via convection, as well as direct radiation exchange, and are therefore not to be combined with CCTC. For CCTC, slab surfaces are to be kept as free as possible (exposed concrete). As uncovered concrete slabs are acoustically “hard”, attention must be paid to the reverberation time; sound-absorbent constructions are usually necessary. However, these usually have a thermally insulating and radiation-inhibiting effect, and if possible should not be installed in front of the thermally activated surfaces. Investigations have shown that placing sound-absorbent surfaces on dividing walls or office furniture can be advantageous.

Well planned

For CCTC, the building can be subdivided into zones in order to control the temperatures of the different areas according to demand. The zones are established according to orientation, storey, use, or facade concept, and catered for with different supply temperatures (3-conductor system) and different charging times, according to requirements. Each respective zone is allocated a heat exchanger size, in a similar manner to how the radiator size for a room is determined. However, there is little leeway, as the available slab surface is limited, and because the tube spacing in the heat exchangers cannot be less than 10 cm for production-related reasons. If, in summer, the heat in individual rooms cannot be dissipated, supplementary measures such as quick-reacting ceiling radiant cooling panels which can be controlled in a decentralised manner, for example, are necessary.

For the concept phase, there are indeed planning handbooks and simple dimensioning aids, but thermal simulation of the building and systems is the most important planning instrument. On the basis of the load characteristics for heating and cooling the building, the necessary supply and return temperatures and the overall mass flow rates at the main CCTC distributors are obtained.

Parallel to this, on the generating side, the heat sink / heat source, the system hydraulics, and a simple control concept are calculated. Finally, the simulation allows assessment and optimisation of the building’s energy balance and energy consumption, and how this interacts with the heat sink / heat source with regard to different variations or specific planning decisions.

Of particular importance during planning:

1. The planners require special planning tools: the familiar calculation methods, hydraulic circuits, and control concepts for the layout of cooling ceilings and underfloor heating systems are inadequate for the dimensioning and operation of CCTC due to its inertia.

2. The implementation of CCTC can only meet the current standard expectations of an air conditioning system to a limited extent. The contractor, or occupant, and planners must clearly define the thermal comfort requirements. To this end, the current standards (prEN 15251 or ASHRAE 55) provide appropriate criteria.

3. Requirements must be clearly defined regarding control and operational management. This includes many
Integral planning and interdisciplinary construction

Cooling concepts using environmental energy have extensive effects on architecture, construction physics, and building services equipment: limitation of heating and cooling loads, utilisation of the building’s heat storage capacity, incorporation of the building’s structure in the energy management of the building, selection and dimensioning of suitable natural heat sources and sinks, layout of concrete core temperature control and hydraulics, as well as sophisticated control due to the large system-related thermal inertia. Consequently, these building concepts require a complex holistic approach regarding the interaction of the different tasks involved in the planning and construction. High quality utilisation can only be achieved by means of high quality planning and execution, because after incorrect planning, flawed execution of construction work, or changes in utilisation, the comfort cannot be actively readjusted by means of an air conditioning system.

Fig. 11 Integral planning and execution process for thermo-active building systems (according to Zent-Frenger)

Temperature control and ventilation

As a heating and cooling system, concrete core temperature control serves to ensure thermal comfort in the building. The system does not contribute to improvement of indoor air quality, nor to control of indoor air humidity. Generally, office buildings with CCTC are mechanically ventilated while the occupants are present, in order to ensure the minimum level of air renewal necessary for reasons of hygiene, while the supply air can be preheated or precooled via a ground-air heat exchanger, or a borehole heat exchanger. The air intake and exhaust systems are equipped with heat recovery in order to reduce the ventilation heat losses or additional backup heating of the supply air in winter. In parallel to the ventilation system, openable windows for individual window ventilation are usually present. Depending on the climate conditions and how humidity develops in the respective rooms, "active" dehumidification of the supplied outdoor air is usually not required at any time of the year.
Vocational training school in Biberach, Germany

This three-storey school building comprises one wing as a solid reinforced concrete construction, and one cubic classroom building as a reinforced concrete skeleton construction. Due to the high density of occupancy, relatively high air renewal rates are necessary. Here, unlike in a conventional school building with window ventilation, controlled ventilation with heat recovery ensures good air quality and lower ventilation heat losses. The air intake is controlled on a room-by-room basis by means of mixed gas sensors, according to air quality. One window can be opened per room module. As soon as this occurs, the ventilation system deactivates in the respective room.

For heating and cooling, the building primarily uses thermo-active building systems (TABS): in the classrooms and corridors, conditioning occurs by means of concrete core temperature control, and in the toilets and atrium via underfloor heating. There are no additional radiators in the classrooms. Due to the ground water streams present at the site, the conditions are excellent for use of ground water, which serves as a source of heat and cold. The base load of the building’s heat supply is covered by two heat pumps, which can be adjusted in steps, and which are connected to the ground water via a 16 m-deep supply well and two injection wells. For optimal operation of the heat pumps in conjunction with the concrete core temperature control, a maximum temperature level of up to 28°C is targeted for the heating water. In addition, to cover peak loads, a wood pellet boiler is also provided, although as yet this has seldom been used. In summer, the building is also cooled by means of concrete core temperature control with ground water, via a heat exchanger. Active cooling is not necessary. The temperature level of the entire building is controlled centrally, and cannot be altered for individual rooms.

In the year 2005, the building’s heating consumption was 36 kWh/m² p.a. Around 2/3 of the heat comes from the ground water, and 1/3 from the electrical energy for the heat pumps. Generally, the monitoring results document high thermal comfort with good air quality, both in winter and summer. The biomass boiler was practically unnecessary in 2005, as the output of the heat pumps was completely sufficient.

Overall, the set target of a primary energy characteristic value for heating, ventilation, cooling and lighting of less than 100 kWh/m² p.a. was not quite reached in 2005, with 116 kWh/m² p.a. However, it can be expected that this target will be reached in the future, due to the optimisation measures which have already been taken, especially regarding the control technology.

In practice

Energy concept

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<th>Ventilation</th>
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<td>- Air intake and exhaust system with heat recovery (70%)&lt;br&gt;- Window ventilation</td>
<td>- CCTC system (rooms and corridors)&lt;br&gt;- Underfloor heating (atrium, toilets)&lt;br&gt;- Ground water&lt;br&gt;- Heat pump, wood pellet boiler (peak load)</td>
<td>- CCTC system&lt;br&gt;- Ground water</td>
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Fig. 12 View and floor plan of the Gebhard Müller School in Biberach, Germany. This vocational training school with a net floor area of 10,650 m² was designed as a low-energy building. Architecture: Elwert & Stottele Project Group (Ravensburg, Germany), energy concept: Ebert-Engineers (Munich, Germany), monitoring: Biberach University of Applied Sciences. Photograph: Biberach University of Applied Sciences

Fig. 13 Outdoor temperature (OT), supply and return temperature of the CCTC, and the supply and return temperature of the ground water ahead of the cold water heat exchanger [°C] for one week in July 2005. The CCTC is charged with cooling energy overnight. By means of a heat exchanger, the CCTC water circuit is cooled to a supply temperature of 18 to 19°C. Data: Biberach University of Applied Sciences

More information about this building is available at www.enob.info
Where shall heat and cold come from?

The advantages of concrete core temperature control are used optimally if, whenever heating and cooling, small temperature differences are worked with. Thus, energy sources which have a low temperature level, and which are advantageous both ecologically and in terms of primary energy, can be used for heating and cooling. Here, suitable options are the ground and ground water, and in certain situations also outdoor air as a heat sink.

In principle, energy for concrete core temperature control can be provided in a conventional manner. But the advantage of CCTC is that due to the large heat transfer and cold transfer surfaces, it is possible to heat or cool effectively, even with very slight temperature differences between slab temperature and room temperature. The cooling water temperatures are often 18 to 22°C and the heating water temperatures no more than 27 to 29°C. So it is quite possible to heat or cool with regenerative supplies of heat and cold. In winter, the naturally present temperature level of the environmental energy is increased slightly and economically by a heat pump. Waste heat, if present, can also be used for heating, due to the low temperature level. In summer, the environmental energy is used directly. Optionally, a chiller can be provided as a backup system.

From the ground

The almost constant temperatures deep underground (up to 100 m) can be utilised particularly economically (in terms of energy and in terms of the operating processes involved) for (direct) geothermal cooling/heating, by means of borehole heat exchangers or energy piles, for example. Borehole heat exchangers generally consist of 2 to 3 double pipes made of plastic, with a diameter of 32 mm, which are lowered into a 50 to 100 m-deep borehole. Water is pumped through this buried system which, depending on the time of year, either releases heat into the ground, or absorbs heat from it. Energy piles are foundation piles of a building, which protrude 20 to 30 m into the ground, and are used as borehole heat exchangers.

Both borehole heat exchangers and energy piles utilise the seasonal heat storage capacity of the ground, or ground water’s heat flows. At depths of 30 to 100 m, the ground’s temperature is just 1 kelvin above the annual
average air temperature of the location. The seasonal fluctuations in temperature can be measured to depths of 5 m, but deeper underground, temperatures remain almost constant. If designed appropriately, borehole heat exchangers and energy piles can be used not only in summer for cooling, but also in winter as a heat source, always in combination with a heat pump. Alternating utilisation of the ground as a storage medium for heating and cooling supports rapid regeneration of the ground storage, because in summer, heat is stored in the ground, and this heat is then extracted from the ground again in winter. Thus, the efficiency of the system as a whole is higher than that of one-sided utilisation (either heating or cooling), and a long-term temperature shift in the ground is avoided.

Analyses of the Energon office building in Ulm, Germany (see p. 14) show that the undisturbed temperature of the ground is stable throughout the day, and remains almost constant at 10°C throughout the year at greater depths. The supply temperatures arising from the borehole heat exchanger vary between 6 and 23°C.

From cool night air

The cool night air can be used as a further natural heat sink via a cooling tower. Here, a distinction is drawn between dry and wet cooling towers. With dry coolers, recooling of the water is only possible if the outdoor temperature is below the required water temperature. Thus, during the warm seasons, the recooling period is restricted to the night, and the early hours of the morning. With wet coolers, on the other hand, the heat exchanger on the air side is also sprayed by means of a secondary water circuit. The evaporation of the water allows the heat exchanger surface to be reduced on the one hand, and on the other hand, the wet-bulb temperature can be taken into account instead of the outdoor air temperature. The wet-bulb temperature is significantly lower than the outdoor air temperature, especially if the outdoor air is dry, because the evaporation cooling effect is included. Thus, the recooling duration can be extended. The lower temperature also has a positive effect on the energy efficiency and the maximum cooling capacity. The efficiency of recooling with a cooling tower increases with decreasing overnight outdoor temperatures. Unlike the ground, or ground water, outdoor air can scarcely be considered a viable option as a heat source for operation in winter.

From ground water

Ground water also offers good conditions for use as a heat source or sink, with its year-round temperature of 8 to 12°C. Utilisation requires boring down to the water-carrying layers. Ground water is extracted from a supply well by means of a submersible pump. This water transfers heat or cold to the water of the “internal” CCTC circuit via a heat exchanger, and is then returned via an injection well. The distance between the supply well and the injection well should be at least 10 m, in order to prevent thermal short-circuits. Ground water can be used as a heat source / sink at any time, all year round. The performance is primarily dependent on the volume of the available ground water.

Fig. 16 Implementation of borehole heat exchangers (BOB building, Aachen, Germany). Photographs: University of Applied Sciences Cologne and VIKI Ingenieur GmbH

Fig. 17 Wet cooling tower in Fraunhofer SOBIC (in the Solar Info Center Freiburg, left) and wellhead of the suction well (in the base of a riser shaft in the GMS Biberach building, right). Photographs: solares bauen GmbH and Biberach University of Applied Sciences

Fig. 18 The efficiency (coefficient of performance, COP) of a small wet cooling tower at Fraunhofer SOBIC in the Solar Info Center (SIC) in Freiburg, Germany, increases as outdoor air temperature decreases. The cooling tower is operated from 10 pm to 6 am. The COP is defined as the ratio of the cooling capacity to the electricity which it requires.

![Graph showing COP vs. Average outdoor temperature]
In practice

Office building compliant with the passive house concept

In summer, cooling occurs by means of concrete core temperature control. The cold comes from the ground – with forty 100 m-long borehole heat exchangers, a cooling capacity of up to 120 kW is achieved. Water flows in a closed circuit from the borehole heat exchangers through the tube heat exchangers in the slabs and back. A total of 350 plastic tube heat exchangers are laid over a slab area of 5,000 m². The heat exchangers lie 10 cm from the underside of the 28 cm-thick slabs. The borehole heat exchangers’ water circuit is also used for cooling and heating the supply air by means of an additional heat exchanger with antifreeze protection.

The offices are heated solely via CCTC with the building’s internal waste heat (server rooms) and remote heating. The borehole heat exchangers provide heat to the cold supply air via the preheating heat exchanger in the air intake device. Only a few areas on the garden floor which are used for special purposes (cafeteria, seminar rooms) are equipped with additional underfloor heating, or acoustic thermal panels.

The CCTC is generally operated overnight, i.e. outside the hours of office usage. Once the circulation pump has been activated, the charge state of the concrete core is determined by means of the temperature difference between supply and return. Based on the required supply temperature, a pump running time is calculated, which is corrected at regular intervals as required. Here, due to the intermittent method of operation, larger temperature fluctuations arise in the borehole heat exchanger circuit.

During the day, when cooling, it is primarily the supply air which is cooled; the CCTC is operated overnight as much as possible, i.e. outside the hours of office usage. When heating, the slabs are charged overnight with the building’s internal waste heat (from cooling of groceries and servers) and remote heating. The supply temperature is always below 24°C, and the concrete core temperatures reach no more than 23.5°C. The temperatures of the concrete core and the indoor air fluctuate only slightly (1 kelvin). Due to the passive house standard, even when heating, the supply temperatures are always so low that rooms with high internal loads are automatically cooled. In the Energon building, this allows realisation of a unified control zone for all rooms. The CCTC is activated at around 7 pm. Before this time, all building element temperatures exhibit the gradual decrease which is to be expected during discharging. During cooling, the dynamics are more pronounced: overnight, heat is extracted from the slabs by means of cold water (21 to 22°C). The slab surface temperature and the room temperature are lowest in the morning, and increase when work begins, due to internal and solar loads. The supply temperature never drops below 20°C.

In 2005, the building’s final energy consumption for heating, ventilation, cooling and lighting was 46.8 kWh/m² p.a., including building cooling and cafeteria (final energy consumption: electricity 23.4 kWh/m² p.a. and heat 23.4 kWh/m² p.a.). The building’s primary energy consumption for 2005 was 81.0 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 had to be controlled manually, the tenants experienced no utilisation restrictions.

### Energy concept

<table>
<thead>
<tr>
<th>Ventilation</th>
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<tr>
<td>• Air intake and exhaust system with heat recovery (65%)</td>
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</tr>
<tr>
<td>• Window ventilation</td>
<td>• Building’s internal waste heat</td>
<td>• Borehole heat exchangers</td>
</tr>
<tr>
<td>• supply air via geothermal heat exchangers, borehole heat exchangers, heat recovery, and remote heating</td>
<td>• Remote heating</td>
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More information about this building is available at [www.enob.info](http://www.enob.info)

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Fig. 19: Energon office building in Ulm, Germany – with about 7,000 m² net floor area, the world’s largest office building compliant with the passive house concept (2006). Comfortable working conditions are provided by concrete core temperature control in conjunction with comprehensive thermal insulation, mechanical ventilation, and flexible sun protection. Architecture: oehler faigle archkom (Bretten, Germany), energy concept: ebök ingenieurbüro (Tübingen, Germany), monitoring: Steinbeis Transfer Centre for Energy Technology, University of Applied Sciences Ulm. Photograph and floor plan: Software AG Foundation, Darmstadt, Germany.

Fig. 21: Above: Heating and cooling performance of the borehole heat exchangers in the years 2004 and 2005 (readings, relating to the heated net floor area of 6,911 m²) and average monthly outdoor air and indoor air temperatures. Note: no complete measurement data is available for 9/2004. Below: Annual heating and cooling performance of the borehole heat exchangers. Data: Steinbeis Transfer Centre for Energy Technology, Ulm, Germany.
In the space of one decade, thermo-active building systems have established themselves in Germany as another system for surface heating and cooling. And rightly so. Many successful and well-functioning examples back up this success story, one which more and more contractors and planners are becoming part of. However, once built, thermo-active building systems are quite literally planning and execution set in concrete, systems with typically narrow boundaries regarding capacity and controllability. In standard applications, this does not represent a problem. In challenging individual cases, however, the requirements for optimal planning, system technology, and operational management can be very strict, and for cases such as these, it can by no means be said that answers have been found for all of the questions arising in the practice of planning and construction. So in this regard, there is still a need for high quality application-based research, instruction, and training.

Concrete core temperature control is already almost standard in today’s construction practice. Yet, as the limits of what is possible are approached in many buildings, with regard to architecture, interior climate, costs, and energy efficiency, thermo-active building systems can prove their versatility. A thermally activated floor, in the broader sense, has been realised, for example, in the Academy of the Arts in Berlin, and also in the new international airport in Bangkok. In these cases, the temperature-controlled floor surface serves not so much as an active cooling element, but more as a heat sink for all short-wave and long-wave radiation gains which can be extracted from the room before they noticeably warm the floor surface, and therefore the room. In Germany, there are already many successful projects with thermo-active building systems. Now is the time to multiply this planning and construction competence on an international scale, especially as we are also implementing systems adapted for other climate conditions, e.g. in Winnipeg, Baltimore and Beijing.

Prof. Roland Koenigsdorff
Teaches the subjects of simulation technology, construction physics, and energy concepts at the Biberach University of Applied Sciences. Research and projects for system integration of thermo-active building elements. Evaluation of the Gebhard Müller School in Biberach (EnBau model project).

Matthias Schuler
Founder and managing director of the company Transsolar. Guest professor at the Graduate School of Design (Harvard University). Energy concept for the Post Tower, among other projects.

"Concrete core temperature control is already almost standard in today’s construction practice. Yet, as the limits of what is possible are approached in many buildings, with regard to architecture, interior climate, costs, and energy efficiency, thermo-active building systems can prove their versatility. A thermally activated floor, in the broader sense, has been realised, for example, in the Academy of the Arts in Berlin, and also in the new international airport in Bangkok. In these cases, the temperature-controlled floor surface serves not so much as an active cooling element, but more as a heat sink for all short-wave and long-wave radiation gains which can be extracted from the room before they noticeably warm the floor surface, and therefore the room. In Germany, there are already many successful projects with thermo-active building systems. Now is the time to multiply this planning and construction competence on an international scale, especially as we are also implementing systems adapted for other climate conditions, e.g. in Winnipeg, Baltimore and Beijing."
Dynamics of heating and cooling

In buildings with concrete core temperature control as the sole heating and cooling system, room temperatures cannot be individually or quickly adjusted. As room temperatures are also influenced by usage, for instance by internal and solar loads, as well as by ventilation, anticipatory charging management for heating or cooling is necessary.

Due to the minimal temperature difference between building element surface temperature and room temperature, a functional self-controlling effect occurs: usually the surface temperatures of the thermally activated slabs fluctuate within a narrow range between around 21°C and 25°C. If the room temperature is higher than the slab surface temperature, the building element functions as a cooling surface. In the opposite scenario, it functions as a heating surface. For example, if the slab surface temperature is around 20°C, and an as-yet unoccupied room has a room temperature of 18°C in the morning, this room will inevitably be heated. If, due to internal and external loads, the room temperature rises to over 21°C during the course of the day, the room will be cooled. To a certain extent, the heat transfer between the thermally activated slab and the room controls itself.

Operating method and control strategies

Short-term control of performance during the course of a day occurs for the most part by means of the self-controlling effect described above. As befitting the respective required system function (heating or cooling), the following operating methods and control strategies are possible:

Day-night operation: If the concrete slab is charged with heating or cooling energy outside the usage period (overnight), there must be sufficient storage capacity to heat or cool the slab enough to ensure that sufficient capacity is available during the day. As this is barely possible in practice, it is necessary to either store more energy than is required, or to tolerate a broader range of fluctuation in room temperature. Strictly speaking, control on the basis of room temperature does not occur with this operating method. Rather, a more or less effective storage management is operated. This can be further optimised if alongside the current charge state of the storage, a prognosis of the next day’s expected weather behaviour and an estimate of the expected heat release from internal sources are incorporated in the control strategy. The least favourable room in each control circuit determines the charge level.

Continuous operation: The charging of the floor slabs with cooling energy can also be operated continuously, if the heat sink, such as the ground or ground water, for example, is available without any restrictions with regard to time.

Control: The slabs are charged with heating or cooling energy, discharged, or deactivated, depending on the average outdoor temperature, the room temperature, or the difference between the supply and return temperatures. Predicative control on the basis of weather forecasts is also possible. The supply temperature, the mass flow rate, and the pump running time serve as control parameters in order to make limited adjustments to the room temperature. If the borehole heat exchangers or the cooling tower are used in direct operation, no control of the supply temperature occurs.
Concrete core temperature control and comfort

The radiation conditions in the room influence comfort. The term “radiation asymmetry” refers to the maximum temperature difference which arises between two opposite surfaces in a room. The resulting one-sided heating or cooling of persons due to the unequal temperatures of the surrounding surfaces can lead to thermal discomfort. Therefore, if heating occurs solely via the slab, the surface temperature must not exceed approximately 27°C. When cooling is required, the temperature difference between the cold slab surface and the other surfaces in the room should not exceed 14 K (ISO 7730). These criteria are adhered to in low energy buildings with concrete core temperature control. In combination with natural heat sinks, the supply temperatures are between a minimum of 18°C and a maximum of 29°C, so that the slab surface temperatures are near to the room temperature. In the Energon building, for example, the slab surface temperatures in 2005 fluctuated within a temperature range of 20.5 to 25.0°C. Due to the low radiation asymmetry, the interior climate is fully within the comfort zone.

Detailed analyses of the Energon building (see p. 14) and the BOB (see p. 18) show that with cooling by means of concrete core temperature control, the required room temperatures, with regard to the occupant’s behaviour, can (almost) always be maintained, provided that there is a consistent reduction of solar and internal thermal loads. Also in winter, concrete core temperature control can ensure thermal comfort in these buildings, without additional static heating surfaces.

As ventilation in conjunction with CTC performs only a hygienic function, and not a conditioning function, the air volume can be limited to the hygienically required minimum air renewal (40m³/h*person for offices). The low air velocities and reduced noise which result from the reduced air volume flow also increase the comfort.

Key research area "Energy-Optimised Construction" (EnOB)

EnOB is a key research area for the German Federal Ministry of Economics and Technology (BMWi) as part of the 5th Energy Research Programme “Innovation and New Energy Technologies”. In the EnOB research projects, the building of the future is being worked towards. For new buildings, this means that the primary energy requirement is to be further reduced to at most 50% below that of today’s technology (German Energy Saving Ordinance EnEV 2006 / German industry standard DIN V 18599). This includes the energy expenditure for domestic water heating, ventilation, air conditioning and lighting, as well as auxiliary energy for pumps and fans. At the same time, concepts and technologies for zero-emission houses are being worked on.

With regards to building fabric, the focus is on further development of concepts for consistent and sustainable energy-oriented refurbishment. For non-residential buildings, the intention is to be at least 30% below the requirements to which new buildings are subjected to by EnEV 2006 / DIN V 18599. For residential buildings, the goal is to be at least 50% below the requirements to which new buildings are subjected to by EnEV 2006. Here, in research-intensive projects, ambitious refurbishment concepts are being tested in conjunction with innovative technologies. One important EnOB research area is EnBau, which refers to “energy-optimised new buildings”:

In the past, more than twenty office and administration buildings, as well as public and commercial buildings, all with minimal energy requirements, have been planned and built as part of the research area EnBau (earlier known as Solar-Bau). In the future, these buildings are to be scientifically evaluated over an extended occupation period, and optimised while in operation. Thus, the possibilities and advantages of optimal planning with regard to primary energy are being assessed in real model projects.

Prerequisite for participation in "EnBau": the buildings’ heating requirement may not exceed 20 kWh/m² p.a., and the total primary energy requirement for heating, light, ventilation and air conditioning must be under 75 kWh/m² p.a., i.e. must be less than 50% of the reference building requirements according to German Energy Saving Ordinance EnEV 07. Residential buildings with zero emissions in the annual balance represent a new focal area of EnBau.

Further information on this subject is available at www.enob.info
Office building in Aachen, Germany

This four-storey office building has a solid, compact building structure, and very good thermal insulation. The annual heating consumption was 25.0 kWh/m² p.a. in 2005. Due to the glazing’s low g-value of approximately 50%, and a window surface area of 30%, exterior shading was not installed. There is indoor glare protection. The office building is mechanically ventilated. The air intake and exhaust system operates with heat recovery (heat recovery level 75%) on a storey-by-storey basis. Temperature control of the supply air occurs only by means of heat recovery, and the fact that the channels are laid in the concrete core.

With 28 borehole heat exchangers (each 45 m), the required heat is extracted from the ground in winter, and brought to usage temperature (26°C) by means of an electric compression heat pump. The heat is carried to the rooms via the concrete core temperature control (2,070 m² in total). For each storey, there are two control circuits (north and south). The tubes are laid at a distance of 12 cm from the underside of the slabs. The CCTC system is operated all year round with a supply temperature between 22 and 26°C. No additional heating surfaces are operated. In summer, the building is cooled directly by means of the borehole heat exchangers. Only electricity, as final energy source, is used for heating and cooling the building.

Energy concept

<table>
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<tr>
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<tr>
<td>• Air intake and exhaust system with heat recovery (75%)&lt;br&gt; • Window ventilation possible&lt;br&gt; • Temperature control of supply air via heat recovery</td>
<td>• CCTC system&lt;br&gt; • Borehole heat exchangers + heat pump</td>
<td>• CCTC system&lt;br&gt; • Borehole heat exchangers</td>
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More information about this building is available at www.enob.info
Overview

Concrete core temperature control check list

Requirements
- New buildings: Concrete core temperature control cannot be implemented in building refurbishments, and is restricted to new buildings. Old buildings can be activated with capillary tube systems, for example.
- Building envelope: An integrally planned building concept (optimal coordination of architecture, construction physics, and building services equipment) with consistent limitation of the heating and cooling loads is a prerequisite for the implementation of concrete core temperature control. This lowers the energy required for cooling, reduces the requirements for CCTC control, and improves the interior climate.
- Building mass: As the storage capacity is “actively” incorporated into the building’s load management, a good thermal storage capacity (solid construction) is required. To guarantee heat exchange with the room, the concrete slabs should not be covered by cladding or hangings.
- Indoor acoustics: Installation of uninterrupted suspended ceilings with insulating elements to influence the indoor acoustics (reverberation time, sound distribution) in rooms with concrete core temperature control is not possible, or very limited in terms of surface and layout. Rooms with strict acoustic requirements call for an appropriate indoor acoustics concept.
- Capacity: Usually, the surface temperatures of the thermally activated building elements fluctuate within a narrow range between approximately 21 and 25°C. Despite the slabs’ large heat transfer surfaces, the achievable heating and cooling capacities are thus limited to 30 to 40 W/m².
- Controllability: Due to the large thermal mass and inertia of CCTC, precise control to achieve a target room temperature is not possible. If specific room temperatures are to be guaranteed, an additional, controllable, and quick-reacting heating or cooling system is required.
- Zoning: In projects carried out to date, tube heat exchangers of a controllable water circuit have been installed in the slab surface mostly without consideration of the subsequent room layout. For this reason, there has been no individual, room-specific control. Today, CCTC heat exchangers are often divided into zones on a room-by-room basis, which allows the temperatures of individual rooms to be controlled independently of one another.

Benefits
- Utilisation of environmental energy: For cooling or heating, e.g. by means of free cooling (cooling towers), borehole heat exchangers, ground collectors, solar collectors, or ground water. The environmental energy can be utilised economically, either directly, or with slight temperature adjustment via chillers or heat pumps.
- Low primary energy consumption: Storage losses, limited controllability, and heat flows from the building element to the room (or vice versa) which cannot be manipulated, cause higher consumption of heat and cold than in ideal room conditioning. The nature of this type of system results in effective energy consumption which is higher in comparison to that of easily controllable systems which achieve room temperatures which deviate only slightly from the target temperatures. However, due to the use of environmental energy for heating and cooling, the primary energy consumption of CCTC systems is significantly reduced. The auxiliary energy used for distribution of heat and cold is less in water-carrying systems than in air-carrying systems.
- Reduction of peak loads: A sufficiently dimensioned CCTC leads to a reduction of peak loads, and a partial shift of this load to outside the period when occupants are present. Overnight operation allows energy consumption to be reduced due to greater efficiency (coefficient of performance, COP) and may also allow lower overnight electricity tariffs to be profited from.
- Self-controlling effect: Due to the relatively slight deviations of the slab temperature above and below that of the room, the self-controlling effect is very good. If the room temperature is higher than the building element’s surface temperature, the building element functions as a cooling surface. In the opposite scenario, it functions as a heating surface. This is particularly effective in the transitional seasons.
- Reduction of the ventilation system: CCTC uncouples thermal room conditioning (heating and cooling) from ventilation requirements. Reduction of the air volume flow to the hygienically required level results in downsizing of the channel network by up to 70%, and reduction of operating costs and energy consumption.
- Comfort: The system temperatures and surface temperatures which are close to the indoor air temperature, as well as the high proportion of radiation in the heat transfer, the absence of high air renewal rates and (depending on the system) high air velocities, all bring thermal comfort.
- Architecture: As the tube heat exchangers are integrated in the building element, the interior design is barely influenced – although suspended ceilings are to be avoided.
Outlook

With thermo-active building systems, the building structure and storage capacity of building elements can be utilised for active energy management of buildings. The systems offer versatile implementation possibilities. Concrete core temperature control is currently the most widespread thermo-active building system, and is of particular interest for the combination of heating and cooling, although not economically viable if used solely as a heating system. Thus, the use of concrete core temperature control is limited to new non-residential buildings. For residential buildings, other thermo-active building systems are more worthy of consideration, e.g. capillary tube systems, or underfloor temperature control.

The energy efficiency of the entire system, i.e. the ratio of effective energy (flow of energy to the room) to final energy expenditure (electricity for ventilation and chillers, or devices used for heating), is described as the COP factor (coefficient of performance). In the buildings presented, the energy efficiency of the thermo-active building systems achieves COP values between 2 and 4. This can still be significantly increased. COP values of around 10 should be strived for. This calls for consistent optimisation of the hydraulic system, and of the control strategy, in order to significantly reduce the auxiliary energy consumption of pumps, for example. If concrete core temperature control is to be combined with additional heating and cooling systems, the tasks of planning and system design are particularly demanding, because dynamic storage processes in the building, as well as remote heat gain, must be taken into account. These interrelations are to be examined more closely in further projects.

Various low-exergy systems represent an extension of the TABS concept. As part of the key research area “Energy-Optimised Construction” (EnOB), the German Federal Ministry of Economics and Technology is sponsoring the joint project “Low-Exergy Technologies” (LowEx – low exergy). Here, among other things, new construction systems are being developed, which are characterised by a significantly higher heat storage capacity due to integrated materials which store latent heat. These new building materials are actively charged and discharged by means of water-carrying systems such as capillary tube mats, for example. In this manner, systems’ control strategies and operating methods are being optimised with regard to energy balance and comfort. With construction systems such as these, heat management in buildings could react more effectively and flexibly to heating and cooling loads which arise dynamically.

Project funding

German Federal Ministry of Economics and Technology (BMWi)
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Project number
0335007 C, G, N, P

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Links

- www.enob.info
- www.enbau.info
- www.lowex.info

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