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ABSTRACT

During the last years thermal insulation of commercial buildings has been improved resulting in a decreasing demand for heat energy. However, due to lower heat transmission through the facade in office and administration buildings, adverse effects can arise in summer. Through the better insulated facade, the nocturnal heat loss is strongly reduced. Together with the internal heat loads and the increased comfort requirements of the users a cooling demand in winter and during the transitional period is required. Therefore, more energy efficient buildings that have relatively low energy requirements for heating and cooling are in demand today. The heating and cooling of office and administrative buildings with environmental energies from soil, groundwater and outside air are energetically and economically very interesting. Conventional air conditioning systems generally require low system temperatures and are suitable only for limited use of environmental energy. To counteract this effect the thermal concrete core activation is particularly efficient. Water-carrying pipe systems for year-round temperature control of buildings are installed in the solid components with high heat storage capacity. If these pipes are directly supplied with cold from the ground or from a cooling tower in the surrounding air, only the energy to transport the cold water to the user is needed. The heat requirements in winter can also be covered in part with environmental energy by heat pumps. With the use of cooling towers the supply (low outside air temperatures during the night) and the demand of the building (cooling during the day) has a temporal shift. Therefore, the thermal storage capacity of the solid components is important for the temporal displacement of energy peaks. The large heat transfer surfaces allow for a significant heat and cooling capacity already at temperatures with small under- and overheat. Heat supply and heat discharge are under constant change throughout the year. This paper provides a guideline for planning and execution of concrete core activation systems.

1. INTRODUCTION

The thermal concrete core activation was first used by the ancient Romans in the form of hypocaust heating systems (Latin *hypocaustum*, Greek *hypocauston*). Heated air and flue gases streamed from a fireplace trough the cavity under the stone floor of the building and heated or thermally activated the whole stone mass. With this system heat energy was stored over a longer period, thereby increasing the refueling intervals of the decentralized fireplace and significantly increasing the comfort of the residents.

In the early 20th century the company Crittall already placed on the market a ceiling heating system in the form of concrete elements with steel pipe integrated registers. Known as the"Crittall-ceiling" this system was used in Europe in the 1920s and 1930s with great success. A serious drawback of the Crittall-ceiling were its huge 5/4 inch pipes, which were necessary due to insufficient thermal insulation of buildings. In these days the main problem with thermal activated building parts was the formation of condensation water due to insufficient control systems. The "Down Building" in Zurich (Switzerland, 1991, 7500 m) brought the concrete core activation for passive cooling back into focus. With precise temperature control and humidity control of indoor air condensation water formation could be excluded. It was followed just three years after the construction of the "Down Building" by the "Sarinaport Office Building" (Switzerland, 1994, 9500 m). This was one of the first buildings that used thermal concrete core activation for both heating and cooling. In the early 21st century concrete core activation enjoys more and more popularity. Already in 2003, approximately 30 % of all new commercial buildings were designed for concrete core activation and implemented with such systems.

Figure 1: Flexible mounting of the pipe network at the Mercedes Benz Museum - Stuttgart/Germany

Today's commercial and industrial buildings have an increasing demand for energy efficiency, flexibility and not least for thermal comfort. Architects, planners and building technology companies need to adapt to this situation flexibly in order to survive in the market. "Lean" building concepts focus on energy-efficient and sustainable system solutions, which are characterized by a low level of building and operating costs for heating, cooling, ventilation, lighting and maintenance. In these buildings a high level of thermal comfort can be achieved even with low investment and low operation costs. Carefully matched construction innovations such as very good heat and sun protection, an adequate building thermal storage capacity and an air-tight building envelope paired with a basic ventilation system for the necessary hygienic air change make the use of economic and environmentally friendly systems possible. The architecture design is not affected by the concrete core activation (Figure 1).

2. SYSTEM DESCRIPTION

2.1 Function

The cooling and heating of office and management buildings with environmental energy from soil, groundwater and air are energetically and economically particularly interesting. Especially in today's office buildings, thermal comfort plays an increasingly larger role. Due to various HVAC standards and court rulings, employers need to offer a thermally comfortable environment for their employees in the summer and during the transition months. Conventional ventilation and air conditioning cooling systems require very low temperatures (forward / reverse = 8 °C / 12 °C) and are therefore not particularly interesting for the use of environmental energy. They need a conventional compression refrigeration system to supply these low temperatures. The thermal concrete core activation provides a much more favorable approach here: Water-carrying pipe systems for year-round temperature control of buildings over a large area integrated within solid components (concrete floors and concrete ceilings) with high heat storage capacity. With the circulation of water into solid components, these components are loaded with cold or heat energy depending on the flow temperature. Unlike the familiar 60 mm screed with a conventional under floor heating system the concrete core activation has a significantly higher heat loading potential.

Due to activated building material the thermal heat load is shifted. Today this effect can be seen in old buildings like churches or castles that were built with very thick outer walls without interior lining. These buildings always maintain a pleasant cool indoor room temperature even at high outside temperatures. As a result of the large heat transfer area, the system allows for slight over or under temperatures in comparison to the indoor air temperature, significant heating or cooling capacities. The pipe network for the concrete core activation is usually made out of polyethylene or aluminum multi-layer composite pipes with diameters of 16 – 20 mm (Figure 2). For installation cable ties are used. Besides the exact mounting of the pipes a precise hydraulic balance is an important point. For the only way to ensure that water is uniformly distributed in all circuits a precise and high quality water distributor is required. Another important point is the energetic structure of the object. In recent decades, architects and designers have attached high importance to the primary energy consumption of buildings. Therefore thermally very tight building envelopes with the resulting low U-values have been created. Because of the flow temperatures being nearly equal to the room temperatures (as opposed to a conventional refrigeration system) it is not possible to counteract extreme peak loads. Due to this problem planners and architects need to take great care especially of the building's sun protection.

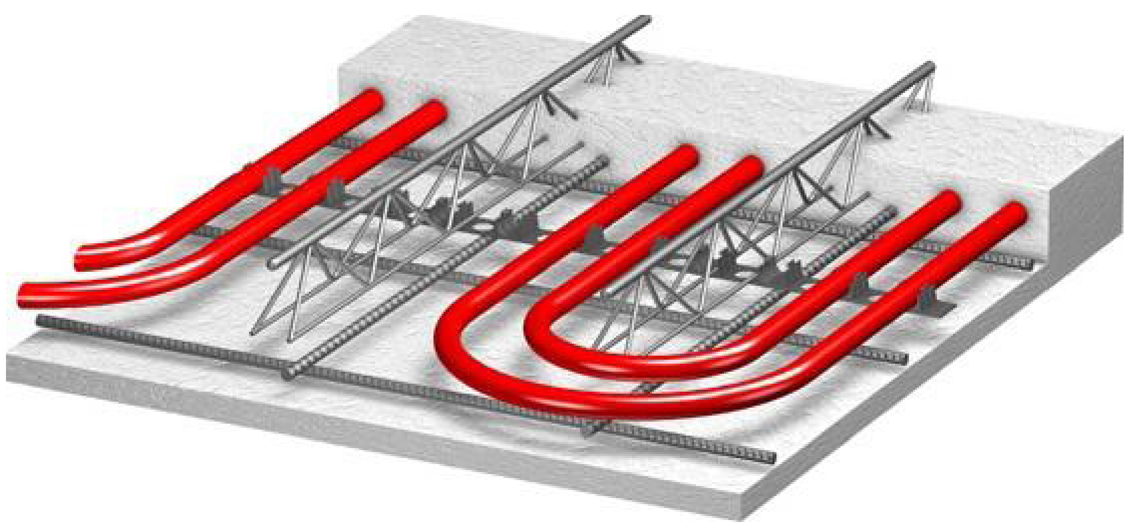

Figure 2: Pipe network in the structural floor

2.2 Structural requirements

If the building is heated or cooled only with concrete core activation architecture specific requirements and building technology requirements have to be taken into account. Due to the large thermal mass and the associated inertia of the system only small temperature differences between the heating or cooling medium and the room temperature can be achieved .The thermal activated surfaces usually have surface area temperatures between 21 °C and 25 °C. The resulting overall performance usually reaches up to 60 W/m^2 in the cooling case and up to 40 W/m^2 in the heating case. Using appropriate structural and user-side measurements the heating and cooling loads of the building can be equalized with the performance of the concrete core activation.

2.3 Limitation of heat loads

Thermal insulation of the building envelope needs to pay the highest attention to improved thermal protection, especially with glass facades. A further reduction of heat energy can be achieved i.e. with a heat recovery system in the exhaust air. High attention is also required for the planning of the concrete core system in rooms with high thermal loads. There it is maybe required to place a second heat transmitting system.

2.4 Limitation of cooling loads

The direct solar radiation and the diffuse radiation have the greatest potential in cooling loads. The most important requirements to protect against summer overheating are small window areas and good shading (Table 1). However, there is a conflict with the desired passive solar energy use in winter and with the maximum use of daylight. This problem can be solved only through an effective external sun protection system. Also internal cooling loads - caused by people, lighting and computer and office equipment - have to be reduced. Cooling loads produced by persons can hardly be limited but i.e. trough a tailored lightning concept cooling loads produced by the lightning can be lowered significantly.

Table 1: Reduction factors of cooling loads

Sun protection system	**Reduction factor of cooling loads**
None	1.00
Inner sun protection	0.60…0.90
Outer sun protection	0.15…0.25

2.5 Thermal shift

Through the use of concrete core activation in the form of a thermal buffer in ceilings and walls, the system can counteract the daily temporary shift of the thermal load in the building. In summer the building is cooled during the night to an indoor air temperature of 20 °C. During the day the building heats up, but this process is slowed down due to the large thermal buffer and pleasant room temperature is still available till the early evening. Then the building is cooled down to 20 °C again during the night by a cooling tower or a heat pump during. During the night very efficient environmental energy can be used (i.e. heat pump or cooling tower). The annual coefficient of performance of the heat pump increases significantly compared to the use during daytime only.

2.6 Transport energy consumption

The costs of transporting thermal energy is significantly lower when using water as a transportation medium instead of air, since the specific heat capacity and density of water is substantially larger compared to air. As an example there is a cooling load of 1 kW each with an air cooling system and a water cooling system to supply. The difference between the air outlet and air inlet is 10 K. In the water system the temperature spread is 3 K.

<u>Volume flow of the air cooling system:</u>

$$\dot{V} = \frac{Q_{\mathrm{K}}}{\rho \cdot c \cdot \Delta t} = \frac{1000}{1.2 \cdot 1010 \cdot 10} = 0.0825\,\frac{\mathrm{m}^3}{\mathrm{s}} \approx 300\,\frac{\mathrm{m}^3}{\mathrm{h}} \qquad (1)$$

Electrical drive power for the fan with an efficiency ratio of $\dot{\eta}_{\text{total}} = 0.6$:

$$P = \frac{\dot{V} \cdot \Delta p}{\dot{\eta}_{\text{total}}} = \frac{0.0825 \cdot 1000}{0.6} \text{ W} = 138 \text{ W} \quad (2)$$

The calculation shows that with the air cooling system, almost 14 % of the cooling capacity need to be provided as additional drive power for the fan. It has been assumed that the air has a density of 1.2 kg/m³, a specific heat capacity of 1010 J/(kgK) and a pressure drop of 1.000 Pa.

Volume flow of the water cooling system:

$$\dot{V} = \frac{Q_{\text{K}}}{\rho \cdot c \cdot \Delta t} = \frac{1000}{1000 \cdot 4200 \cdot 3} = 0.000079 \frac{\text{m}^3}{\text{s}} \approx 0.29 \frac{\text{m}^3}{\text{h}} \quad (3)$$

Electrical drive power for the water pump with an efficiency ratio of $\dot{\eta}_{\text{total}} = 0.72$:

$$P = \frac{\dot{V} \cdot \Delta p}{\dot{\eta}_{\text{total}}} = \frac{0.000079 \cdot 30000}{0.72} \text{ W} \approx 3 \text{ W} \quad (4)$$

To transport this water flow only 3 W of electrical energy are needed. These are only 0.3 % of the original cooling capacity, which is to be classed as highly energy efficient. It has been assumed that the water has a density of 1.000 kg/m³, a specific heat capacity of 4.200 J/(kgK) and a pressure loss in the pipe system of 30.000 Pa.

The concrete core cannot always counteract the arising thermal loads at each time during the day and year. Thus, the temperature glide in the course of the day is a function of the available mass and the arising cooling loads. This means that calculations are necessary to estimate the inertia of the system during the early planning phase to calculate the loading and load removing phases within the concrete core. Many factors play an important role when planning such concrete core systems. The most important are:

- the weather with its solar radiation and the outer temperature gradient
- the structural aspects such as building mass, heat transfer coefficient, the facade and shading devices
- the internal loads such as people, lighting and electrical equipment
- user behavior and possibly other factors that play an important role

To avoid possible over or under temperature overruns out of the comfort zone or to predict their frequency the planner needs to review the whole building and facility concept with the above mentioned points and consider all parameters with their estimated time of occurrence.

3. CONCLUSION

Today's building standards (such as the EnEV in Germany) are designed for the use of regenerative cooling and heating systems in form of heat pump systems with temperatures close to the ambient temperature. The concrete core activation as a thermal distribution and storage medium is declared as the arising standard system in today's commercial construction among architects and planners. Air conditioning systems will in some cases still be required to counteract thermal load but will no longer have the primary use to control the temperature of the building. Particularly with the rising requirements for thermal comfort modern office buildings require the use of cooling systems. Unlike conventional cooling systems, the use of concrete core activation is possible with regenerative energy sources in combination with a soil or air heat pump. In addition, the concrete core impresses with its flexibility in relation to conventional heating and cooling devices.

The main problem of the concrete core activation system can be seen in mixed buildings (production area and office space). Since the concrete core activation supplies the temperature most efficiently in the whole building uniformly, a temperature spread between the production and office area can hardly be achieved (i.e. 18 °C for the production area and 22 °C in the office are). To achieve this temperature spread conventional A/C or heat radiators are required.

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