DTU Library

# Thermo Active Building Systems Using Building Mass To Heat and Cool

**Olesen, Bjarne W.**

*Published in:*
ASHRAE Journal

*Publication date:*
2012

*Document Version*
Publisher's PDF, also known as Version of record

*Thermo Active Building Systems*

# Using Building Mass To Heat and Cool

**By Bjarne W. Olesen, Ph.D.,** Fellow ASHRAE

Using the thermal storage capacity of the concrete slabs between each floor in multistory buildings to heat or cool is a trend that began in the early 1990s in Switzerland.[1,2] Pipes carrying water for heating and cooling are embedded in the center of the concrete slab. In central Europe (Germany, Austria, Netherlands, etc.), this type of system has been installed in a significant number of new office buildings since the late 1990s. The trend is spreading to other parts of the world (the rest of Europe, North America and Asia).

Thermo active building systems (TABS) are primarily used for cooling multistory buildings. By activating the building mass, there is a direct heating-cooling effect. Also, because of the thermal mass, the peak load will be reduced and some of the cooling load will be transferred beyond the time of occupancy. Because these systems for cooling operate at water temperatures close to room temperature, they increase the efficiency of heat pumps, ground heat exchangers and other systems using renewable energy sources.

## TABS Concept

TABS are an embedded water-based surface heating and cooling system, where the pipe is embedded in the central concrete core of a building's construction (*Figure 1*).

The great feature of this type of radiant surface system is the thermal coupling of the emitting element (e.g., pipe coil) with the main building structure (concrete ceiling or wall).

Thermo active building systems exploit the high thermal inertia of the slab to perform peak shaving, which consists of reducing the peak-required cooling power (*Figure 2*) so that it is possible to cool the structures of the building during a period in which the occupants are absent (during nighttime as in offices. This way, the energy costs can be reduced using the lower nighttime electricity rate. At the same time, a reduction in the size of heating/cooling system components (including the

**About the Author**

**Bjarne W. Olesen, Ph.D.,** is director, professor, International Centre for Indoor Environment and Energy, Technical University of Denmark in Lyngby, Denmark.

chiller) is possible. As the water temperature used is near room temperature, the COP of chillers and heat pumps will increase and the energy consumption reduced.

During daytime, heat is extracted from the occupied space by the ventilation system when the supply air temperature is lower than the exhaust air temperature. Much of it is stored in the concrete slabs (*Figure 3*). Then, during the night, the level of ventilation is reduced, and the circulation of cool water in the slabs removes the stored heat.

TABS may be used with natural and mechanical day and night ventilation, with or without dehumidification, depending on external climate and indoor humidity production. In the example in *Figure 2*, the peak cooling power needed to dehumidify the ventilation air during daytime is sufficient for cooling the slab during nighttime.

This approach to radiant heating/cooling of the building system that consists of pipes embedded in concrete slabs between stories began in the 1930s. In Switzerland in 1937, a radiant system was installed (called “Crittall”) that was constructed with embedded steel-welded pipes in a concrete slab.

Most of the early systems failed because of the condensation that often occurred during operation in cooling mode. This problem was further studied and results showed that condensation could be avoided if the radiant system was used in combination with a control of the water supply temperature or a ventilation system for keeping a low absolute humidity of the indoor air. Another problem was the use of steel pipes and risk of leakages. In the early 1990s, the popularity of TABS began to increase. In Switzerland in 1993, R. Meierhans constructed a system using embedded plastic PEX pipes.

TABS can be used for both heating and cooling. However, the main reason to use TABS is the need for cooling as most of the heat exchange is over the ceiling where the internal heat exchange coefficient is highest compared to other surfaces (ISO 11855-2).[3]

TABS often are used in multistory buildings and partly substitute for a full air-conditioning system. The air system can be downsized (only ventilation), and suspended ceilings avoided. This may reduce the height of each floor by ~0.6 m (2 ft) and save on building materials, etc. As the piping is embedded in the building structure, there is basically no maintenance.

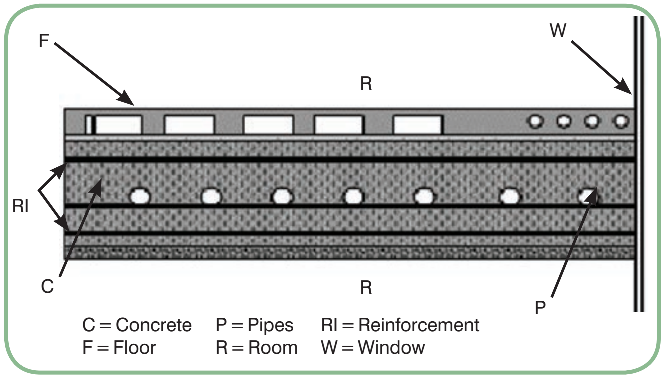


**Figure 1:** Example of position of pipes in thermo active building systems (TABS).

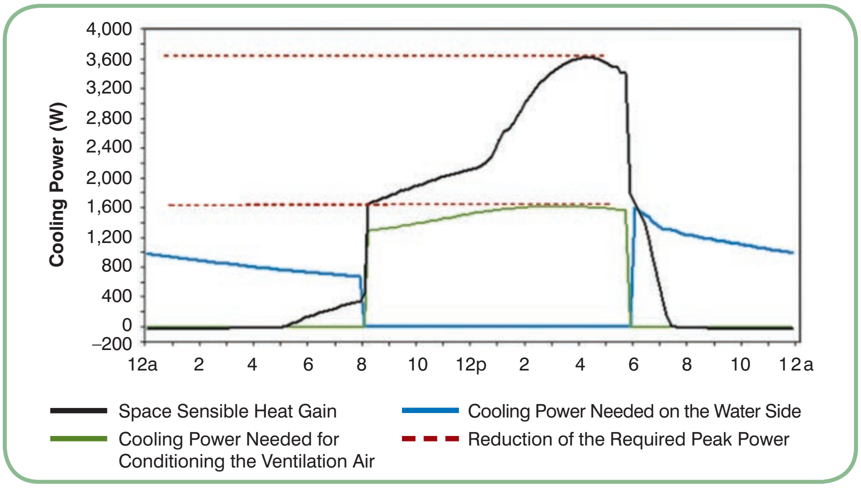


**Figure 2:** Theoretical example of peak-shaving (reducing the peak load) effect (time versus cooling power [W]).

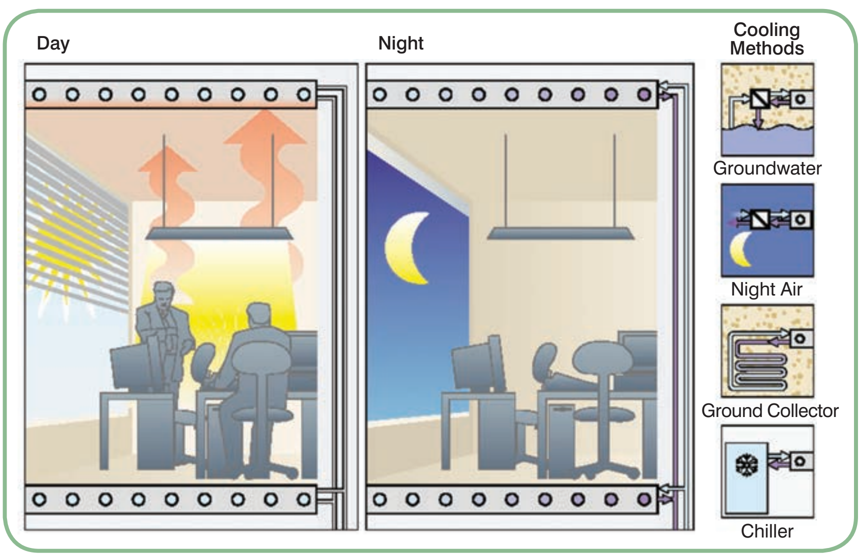


**Figure 3:** Concept of operation of thermo active building systems.

## Design of TABS

Regarding the design of TABS, the planner needs to know if the capacity at a given water temperature is sufficient to keep the room temperature within a given comfort range. Moreover, the planner needs to know the heat flow on the water side to be able to dimension the heat distribution system and the chiller/boiler. There is an international need for a design manual for TABS. ISO11855-4[4] and Olesen, et al.,[5] will give some help and guidance regarding the design of TABS.

When using TABS, the indoor temperature changes moderately during the day, and the aim of a good design of TABS is to maintain daytime occupied space comfort conditions within the ranges (i.e., –0.5 < PMV < 0.5) specified by ISO EN 7730[6] or ASHRAE Standard 55-2010.

The systems allow separation of ventilation and thermal conditioning. Ventilation systems are designed to provide the required amount of fresh outdoor air, remove latent heat loads and supplement the space sensible cooling in peak hours. In many cases, moisture should be controlled because of biological concerns (bacteria, viruses and molds), which will reduce the dew point and risk of condensation on cooled surfaces in a TABS.

TABS are often designed with a pipe spacing of 150 to 200 mm (0.5 to 0.7 ft). A water flow rate in a TABS system is often based on a temperature increase in the water temperature (difference supply-return of 3 to 5 K [5.4°F to 9°F]). This is to increase the cooling capacity, avoid too low supply temperatures (condensation risk) and keep a relatively small temperature difference between the water and the room.

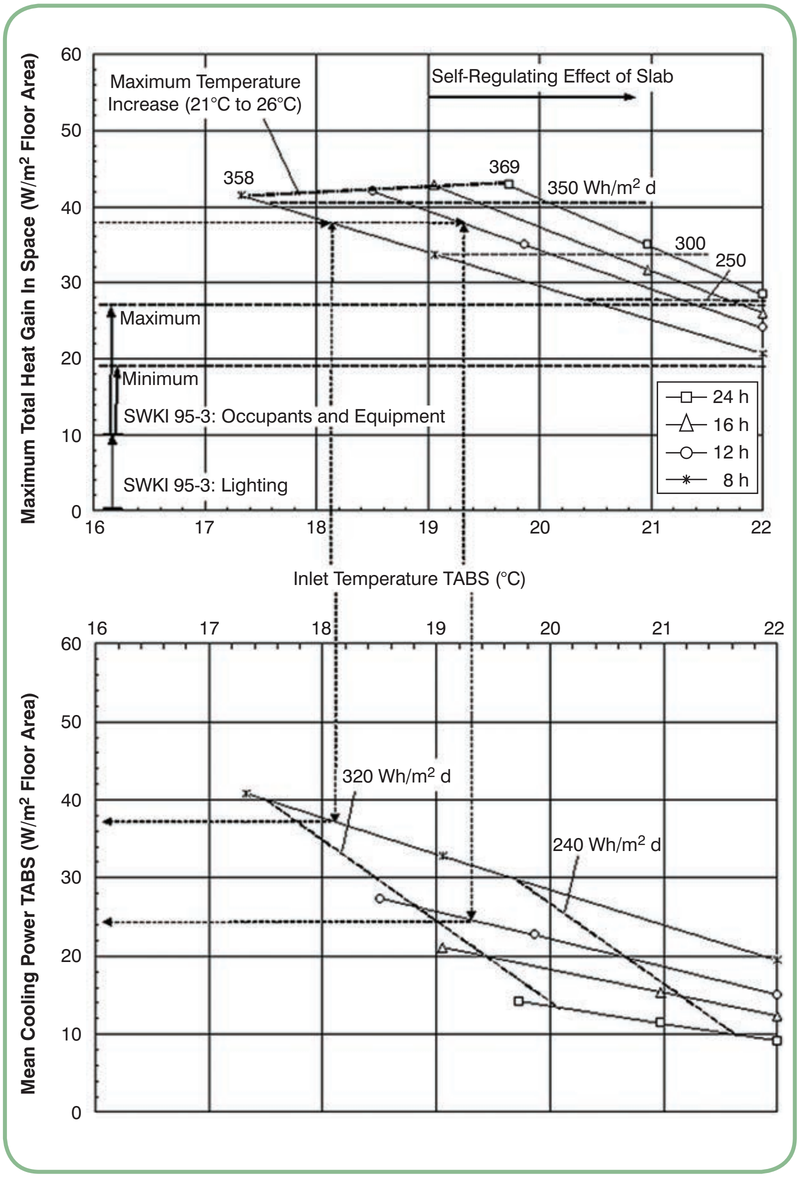

**Figure 4:** Working principles of thermo active building systems.

## Indoor Environment and TABS

Due to the high thermal mass of the system, the indoor temperatures will drift within a thermal comfort zone. This means that the heating or room-conditioning system does not keep a constant temperature, but a comfort range. Kolarik, et al.,[7] and Toftum, et al.,[8] have shown that people find temperature drifts within the comfort zone acceptable up to a rate of 4 K/h (7.2°F/h). In typical TABS' buildings, the rate of change is 0.5 to 1.0 K/h (0.9 to 1.8°F/h). It is important to notice that it is not acceptable for the occupants to drift outside the comfort range, which means a total drift of 3 K to 4 K (5.4°F to 7.2°F) during time of occupancy.

TABS do not have a direct effect on the indoor air quality. However, an advantage is that in buildings with TABS, the ventilation system is designed to meet the criteria for indoor air quality and/or the requirement for dehumidification. As the required water temperatures in most cases are higher than 19°C (66.2°F), it will also be possible in many applications to have operable windows and rely on natural ventilation.

The optimal capacity of TABS is obtained when there is free heat exchange between the space and the concrete slabs. This may require solving acoustical issues without using suspended ceiling panels. Other surfaces may be used for sound absorption; or partly covered ceilings or vertical positioned absorption devices can be installed without impairing the heat transfer.

## Cooling Capacity of TABS

Some detailed building system calculation models have been developed for the determination of heat exchanges under unsteady state conditions in a single room, determination of thermal and hygrometric balance of the room air, prediction of comfort conditions, a check of condensation on surfaces, availability of control strategies and calculation of the incoming solar radiation.[9] The use of such detailed calculation models is limited due to the high amount of time needed for the simulations. The development of a more user-friendly tool is provided in ISO 11855-3.[10]

The diagrams in *Figure 4* (ISO 11855-3) show an example of the relation between internal heat gains, water supply temperature, heat transfer on the room side, hours of water circulation operation and heat transfer on the water side. The diagrams refer to a concrete slab with raised floor (R = 0.45 [$m^2$·K]/W, [2.55 h·$ft^2$·°F/Btu]) and an allowed room temperature range of 21°C to 26°C (69.8°F to 78.8°F). In this example the acceptable room temperature range is wider than normally used, because it has been accepted to start in the morning with a lower room temperature due to a somewhat higher activity level when people arrive to work.

The upper diagram shows the maximum permissible total heat gain in space (internal plus solar gains) (W/$m^2$) on the y-axis, and the required water supply temperature on the x-axis. The lines in the diagram correspond to an occupancy of 8 hours and different operational periods (8 h, 12 h, 16 h, and 24 h) of the TABS and different maximum amounts of energy supplied per day (Wh/[$m^2$·day]).

The lower diagram shows the cooling power (W/$m^2$) required on the water side (to dimension the chiller) for thermo active slabs as a function of supply water temperature and operation time. Further, the amount of energy rejected per day is indicated (Wh/[$m^2$·d]). The example shows that, for a maximum internal heat gain of 38 W/$m^2$ (12.0 Btu/h·$ft^2$) and 8 hours of slab cooling operation, a supply water temperature of 18.2°C (64.4°F) is required. Instead, if the slab cooling system is in operation for 12 hours, a supply water temperature of 19.3°C (66.2°F) is required. In total, the amount of energy rejected from the room is approximately 335 Wh/$m^2$ (106 Btu/$ft^2$) per day. Under the same conditions, the required cooling power on the water side is 37 W/$m^2$ (11.7 Btu/ h·$ft^2$) (for 8-hour operation) and 25 W/$m^2$ (7.9 Btu/h·$ft^2$) for 12-hour operation, respectively. Therefore, by 12-hour operation, the chiller can be sized smaller.

**Photo 1:** Prefabrication of slabs with integrated piping.

The important factors for the heating and cooling capacity of surface systems are the heat exchange coefficient between the surface and the room, the acceptable minimum and maximum surface temperatures based on comfort, and consideration of the dew point in the space and heat transfer between the pipes and the surface. The heat exchange coefficient depends on the position of the surface and the surface temperature in relation to the room temperature (heating or cooling). While the radiant heat exchange coefficient is, for all cases, approximately 5.5 W/$m^2$·K (0.97 Btu/h·$ft^2$·°F), the convective heat exchange coefficient will change.

## Installations

TABS are installed in situ during the building construction or installed in prefabricated building elements (*Photo 1*). In situ installation means the pipes are normally mounted between the upper and lower reinforcement in the slabs. To speed up the installation, it is often common to use a prefabricated module. It is important to perform a pressure test of the pipes before and after pouring the concrete.

## Control

Even if surface heating and cooling systems often have a higher thermal mass than other heating/cooling systems, they have a high control performance. This is partly due to the small temperature difference between the room and the system (water, surface) and the resulting high degree of self-control. To avoid condensation on a cooled surface, there is a need to include a limitation on water temperature, based on the space dew-point temperature.

In this case, individual room control is not reasonable, but a zone control (south–north) is recommended where the supply water temperature, average water temperature or the flow rate may be controlled from zone to zone. The zoning should consider the external and/or internal heat loads. Relatively small temperature differences between the heated or cooled surface and the space are typical for TABS. This matter results in a significant degree of self control. In specific cases regarding well-designed systems with low heating/cooling load, a concrete slab can be controlled to a constant core temperature year-round.

For example, if the core is kept at 22°C (71.6°F), it will provide heat when the room temperature is below 22°C (71.6°F), and cool when the room temperature is above 22°C (71.6°F). To avoid condensation (on the surface or inside the structure), the surface temperature and the absolute humidity must be controlled. One possibility is to set the lower limit for the supply water temperature to equal the dew-point temperature, i.e., absolute humidity in the space. The capacity of the radiant cooling system also can be increased when the dehumidification is performed by a ventilation system.

Intelligent operation of TABS may lead to reducing peak power demand each night by storing energy and releasing it in the daytime, or by having only intermittent daytime operation of the pump. The heat gains during occupancy are accumulated in the active structure (slabs, walls) component and during the night are extracted by circulating cool water or by free night cooling. Therefore, significant peak shaving can be accomplished by shifting partial loads to nighttime and the heat source/sink (chiller, heat pump) can be scaled down to ~60% to 70% (depending on application).

In an earlier study, Olesen, et al.,[9,11] used dynamic computer simulation to study summer performance under several different operational parameters (time of system operation, intermittent operation of circulation pump and supply water

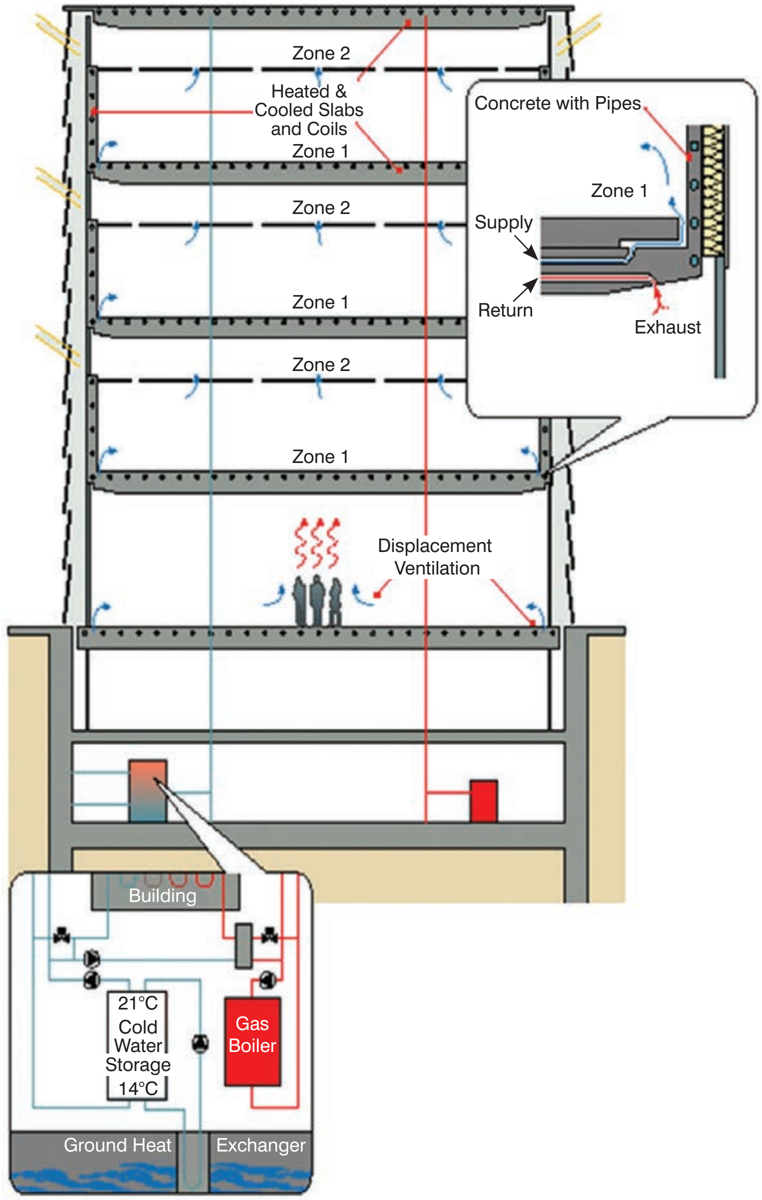


**Figure 5:** Art museum Bregenz. HVAC systems with thermo active building systems in walls and concrete slabs for heating and cooling. Details show the displacement ventilation and the heat source/sink for cooling and heating.

temperature control). It was found that operation of the system during the night was sufficient, intermittent operation of the pump was possible and that the water temperature should be controlled over the season based on outside temperature.

## Cooling Source

A thermo active building system is a high-temperature cooling system and a low-temperature heating system. This will result in a high efficiency of a heat pump system. This can be an air/water, water/water, ground/water type or an absorption heat pump. As the ground temperature often is around 10°C to 14°C (50°F to 57°F), it also will be possible to directly supply a water temperature of 18°C to 20°C (64°F to 68°F) from a ground heat exchanger and cool a building without using a heat pump.

TABS often are used together with a mechanical ventilation system. TABS may take care of most of the sensible load, while the air system will take care of the latent load. At the same time the dew point in the space will be lowered and any condensation avoided. Another advantage is the high return water temperature from a TABS, 22°C to 24°C (71.6°F to 75.2°F), which will increase the efficiency of a chiller designed with a higher evaporator temperature.

## Applications

TABS are primarily used in multistory buildings such as offices, museums, hospitals, etc. One example is shown in *Figure 5*. The four-story art museum has a double skin external envelope with an outer open glass wall. In the original design, an air-conditioning system with 25 000 m³/h (14,700 cfm/min) air was planned. Due to difficulties in getting space for the ducts, and the visibility of the ducts between the glass ceiling and the concrete slab, another solution was needed.

The main goals were the continuity of the relative humidity, as well as the avoidance of noise and dust. The solution takes advantage of the cooling ability of the concrete core (TABS) (*Figure 5*). The main objective of this project was not the phase shift of the cooling into the night hours. On the contrary, as the freely available cooling potential of the groundwater is always accessible and the phase shifting would cause temperature swings with too large amplitudes, the cooling is applied over the entire day.

The cooling medium is a water circuit embedded in 24 posts 18 m (59 ft) deep in the ground with large layers of groundwater. All the exterior walls of the building are equipped with plastic pipes and exterior insulation to completely cut the connection with the exterior climate. The only connection is through the outdoor air supply. For this, a volume flow rate of 750 m$^3$/h (443 cfm/min) is used. The incoming air will be supplied to the building with a constant temperature and humidity through displacement ventilation slits.

More examples of North American buildings are in ASHRAE's High Performing Buildings magazine and in Reference 12.

## Conclusions

Main advantages to thermo active building systems include:

• The cooling demand is distributed over a longer period during the day and shifted from daytime to nighttime. This leads to lower peak loads, allowing the use of conditioning plants of reduced sizes.

• By avoiding suspended ceilings, the building height can be reduced, which results in significant savings of building materials;

• It is possible to use heating/cooling systems with temperatures close to room temperature, which increases the energy efficiency of heat pumps, condensation boilers, solar collectors, ground heat exchangers;

• For cooling purposes, night ventilation can be used; and

• Low installation costs, low operation costs and maintenance costs are possible.

The requirements of thermally active systems include:

• Active thermal slabs are mainly used in multistory buildings;

• Absence of suspended ceilings requires alternative acoustical solutions due to the relative low cooling capacity;

• The building design is critical: adequate solar radiation screens are needed, as well as good envelope thermal insulation to keep external heat gains below 1 W/(m$^2$·K);

• If TABS is used in walls and floors (no insulation toward the room), the absorption of diffuse and direct sunshine will increase the cooling capacity significantly.

## References

1. Meierhans, R.A. 1993. "Slab cooling and earth coupling." *ASHRAE Transactions* 99(2).

2. Meierhans, R.A. 1996. "Room air conditioning by means of overnight cooling of the concrete ceiling." *ASHRAE Transactions* 102(2).

3. ISO 11855-2 (2012): Building Environment Design—Design, Construction and Operation of Radiant Heating and Cooling Systems – Part 2: Determination of the design heating and cooling capacity.

4. Olesen, B.W., et al. 2006. "Dynamic evaluation of the cooling capacity of thermo active building systems." *ASHRAE Transactions* 112(1).

5. ISO 11855-4 (2012): Building Environment Design—Design, Dimensioning, Installation and Control of Embedded Radiant Heating and Cooling Systems – Part 4: Dimensioning and calculation of the dynamic heating and cooling capacity of thermo active building systems (TABS).

6. ENISO 7730 (2005): Moderate thermal environments—determination of the PMV and PPD indices and specification of the conditions for thermal comfort.

7. Kolarik, J. 2011. "Simulation of energy use, human thermal comfort and office work performance in buildings with moderately drifting operative temperatures." *Energy and Buildings* 43(11):2988–2997.

8. Toftum, J. 2008. "Occupant Responses and energy use in buildings with moderately drifting temperatures," p. 145. Atlanta: ASHRAE.

9. Olesen, B.W., K. Sommer, B. Düchting. 2000. "Control of slab heating and cooling systems studied by dynamic computer simulations." *ASHRAE Transactions* 108(2).

10. ISO 11855-3 (2012): Building Environment Design—Standards for the Design, Construction and Operation of Radiant Heating and Cooling Systems – Part 3: Design and dimensioning.

11. Olesen, B.W., F.C. CurroDossi. 2004. "Operation and control of activated slab heating and cooling systems." CIB World Building Congress 2004.

12. Kiel, M. 2010. *Thermally Active Surfaces in Architecture.* Princeton Architectural Press. ■