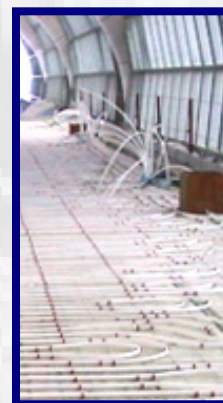


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# Radiant Floor Cooling Systems



By **Bjarne Olesen, Ph.D.**, Member ASHRAE

In many countries, hydronic radiant floor systems are widely used for heating all types of buildings such as residential, churches, gymnasiums, hospitals, hangars, storage buildings, industrial buildings, and smaller offices. However, few systems are used for cooling.

People choose floor heating because it uses space wisely, temperature distribution is uniform and it is a low-temperature heating system. One advantage compared with air systems is that floor heating is a more efficient means of transporting energy. The demand for comfort, better building insulation, and greater internal loads from people and equipment have increased interest in installing a cooling system to keep indoor temperatures within the comfort range. This resulted

in the introduction of floor systems for cooling.<sup>1-3</sup>

Because these systems operate at a water temperature close to room temperature, they increase the efficiency of heat pumps, ground heat exchangers and other systems using renewable energy sources.

More than half the thermal energy emitted from a floor heating system is in the form of radiant heat. The radiant heat exchange directly influences the heat

exchange with occupants and surrounding surfaces such as walls and ceilings. In this way, a uniform thermal environment is established. Because of the high radiant heat output and the fact that occupants are close to the floor surface, it's an obvious choice to use the same floor system for cooling. However, the convective heat exchange coefficient for floor cooling is much lower than it is for floor heating. Several comfort factors such as acceptable floor temperature, vertical air temperature difference, radiant asymmetry and dew-point temperature may reduce the cooling capacity of a floor system. The floor construction (slab thickness,

## About the Author

**Bjarne Olesen, Ph.D.**, is director of the International Centre for Indoor Environment and Energy, and a professor at the Technical University of Denmark.

floor covering) and system (type of pipes, distance between pipes, water flow rate) may limit the cooling capacity. Therefore, the design of a floor system for highest cooling capacity may be different than for heating.

This article describes a floor cooling system that includes such considerations as thermal comfort of the occupants, which design parameters will influence the cooling capacity and how the system should be controlled. Examples of applications are presented.

### Thermal Comfort and Floor Cooling

The thermal environment may be described by the following parameters: thermal insulation of the occupants clothing, activity level of the occupants, air temperature, mean radiant temperature, air velocity, and humidity.<sup>4,5</sup> The combined influence can be described by the PMV-PPD index.<sup>4,5</sup> To provide thermal comfort, it is also necessary to account for local thermal discomfort, which may be caused by radiant temperature asymmetry, draft, vertical air temperature differences, and too warm or too cool floor temperatures.

#### Operative Temperature

The two main parameters for providing acceptable thermal conditions in a space, which may be significantly influenced by the heating/cooling system, are the air temperature and the mean radiant temperature. The combined influence of these two temperatures is expressed as the operative temperature. For low air velocities (<0.2 m/s [0.66 fps]), the operative temperature can be approximated with the simple average of air and mean radiant temperature. This means that the air temperature and the mean radiant temperature are equally important for the level of thermal comfort in a space.

For a radiant cooling system, an important factor is the angle factor between the occupants and the radiant heat source or sinks.<sup>6</sup> This factor depends on the distance between a person and the surface and the area of the surface. This means a floor normally has the highest angle factor of all surfaces (walls, ceiling, windows, etc.) in a space to the occupants. For a person positioned at the center of a 6 m by 6 m (20 ft by 20 ft) floor the angle factor is 0.40 for sedentary. For a 12 m by 12 m (39 ft by 39 ft) floor, the corresponding angle factors are 0.46. This should be placed in relation to the angle factor for a half room, 0.5. If the floor surface temperature is decreased by 5°C (9°F) and all other surface temperatures are assumed to be unchanged, then the mean radiant temperature will decrease by 2°C (4°F). The impact on an occupant is expressed by the operative temperature, which will decrease by 1°C (2°F). Put another way, a 5°C (9°F) lower floor surface temperature

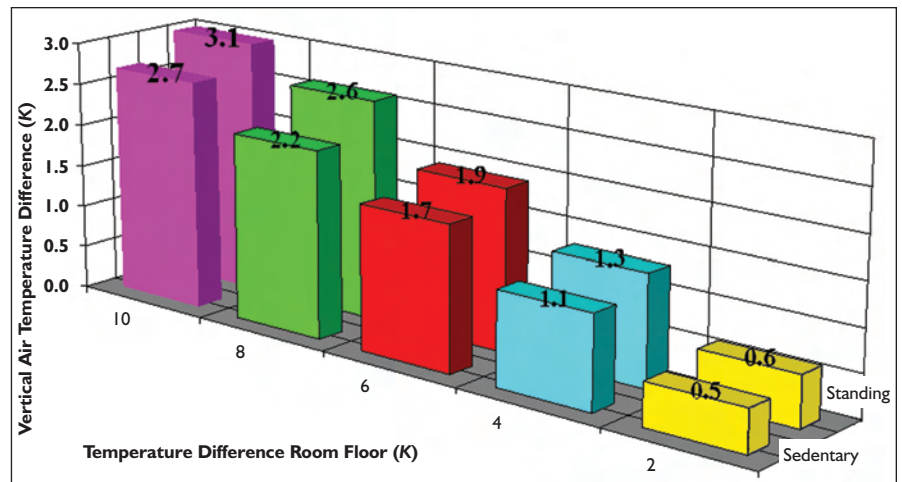


Figure 1: Vertical air temperature difference (K) between ankle and head (0.1 m and 1.1 m for sedentary, 0.1 m and 1.7 m for standing), depending on the temperature difference (K) between the room operative temperature and the surface temperature of a cooled floor.

has the same cooling effect as lowering the air temperature by 2°C (4°F).

In most standards,<sup>1,6</sup> the upper limit for the operative temperature in summer is 26°C (79°F) for spaces with mainly sedentary occupants (1.2 met) and summer clothing (0.5 clo).

#### Floor Surface Temperature

As mentioned earlier, discomfort may occur at too-low or too-high floor temperatures. In most national and international standards,<sup>4,5</sup> a floor temperature interval of 18°C/19°C to 29°C (64°F/66°F to 84°F) is recommended for rooms occupied with sedentary and/or standing people wearing normal shoes.

For sedentary persons, a lower limit of 20°C (68°F) for floor cooling is normally used.

#### Vertical Air Temperature Difference

It is usually recommended to limit the air temperature difference between ankles (0.1 m [4 in.] level) and head (1.1 m [4 ft] level) to 3 K for sedentary persons.<sup>4,5</sup> Because most of the heat exchange between a cooled floor and the space is by radiation, the air at the ankle level will not be cooled too much due to the low convective heat exchange. The vertical air temperature differences with floor cooling will not cause any discomfort. This has been confirmed in an experimental study.<sup>6</sup> In this study the vertical temperature differences are less than 0.5 K, which is similar to the vertical temperature difference 0.4 K without floor cooling. Another experimental study,<sup>7</sup> shows somewhat higher values (Figure 1) but still within acceptable comfort limits.

#### Humidity

A limiting factor for the floor temperature and the cooling capacity is the dew-point temperature in the space. Some standards<sup>5</sup> recommend a limit for the relative humidity in a space to 60% or 70% rh, which at an air temperature of 26°C (79°F) corresponds to a dew point between 17°C and 20°C (63°F and 68°F). Others<sup>4</sup> recommend an absolute humidity

level of approximately 11.5 g/kg (80 gr/lb), which corresponds to a dew point of 16°C (61°F).

This means the floor surface temperature must be higher than 16°C to 20°C (63°F and 68°F). The use of dehumidification in a room by an air-conditioning system or a simple dehumidifier will decrease the dew-point temperature and then increase the cooling capacity of a floor system.

### Hydronic Floor Cooling Capacity

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 (Table 1<sup>2,8</sup>).

The heat exchange coefficient depends on the position of the surface and

	Total Heat Exchange Coefficient W/m <sup>2</sup> · K		Surface Temperature °C		Capacity W/m <sup>2</sup>	
	Heating	Cooling	Maximum	Minimum	Heating	Cooling
Floor	11	7	29	20	99	42
Wall	8	8	~40	17	160	72
Ceiling	6	11	~27	17	42	99

Table 1: Heat exchange coefficient, minimum and maximum recommended surface temperature and cooling and heating capacity.<sup>2,8</sup>

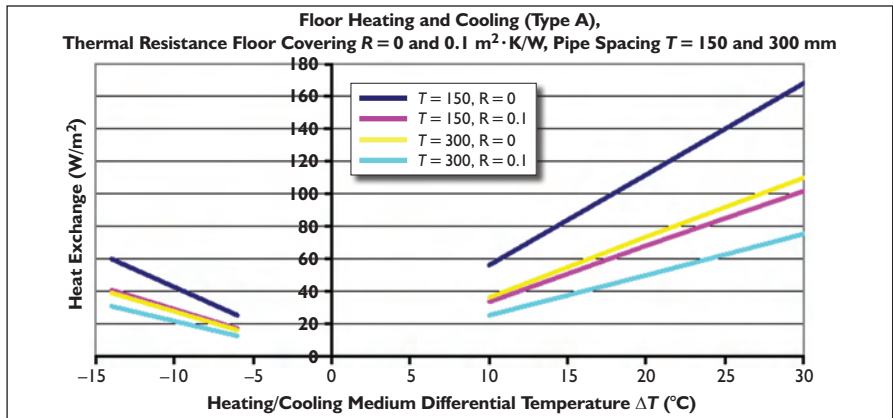


Figure 2: Heat exchange expressed as the function of  $\Delta T$  between water and room, type of floor covering (R), and pipe spacing (T). Carpet:  $R=0.1 \text{ m}^2 \cdot \text{K/W}$  and no covering  $R=0$ .

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the surface temperature in relation to the room temperature (heating or cooling). While the radiant heat exchange coefficient is for all cases approximately  $5.5 \text{ W/m}^2 \cdot \text{K}$  ( $0.97 \text{ Btu/h} \cdot \text{ft}^2 \cdot ^\circ\text{F}$ ), the convective heat exchange coefficient will change. The listed maximum temperature for the wall is based on the pain limit for skin temperature, approximately  $42^\circ\text{C}$  ( $108^\circ\text{F}$ ), and the risk of being in contact with the wall over a longer period of time. The maximum temperature of the ceiling is based on the requirement to avoid temperature asymmetry. The minimum surface temperatures for wall and ceiling are based on consideration of the dew point and risk of condensation.

A special case for floor cooling is when there is direct sun radiation on the floor. Then the cooling capacity of the floor may exceed  $100 \text{ W/m}^2$  ( $32 \text{ Btu/h} \cdot \text{ft}^2$ ).<sup>1</sup> This is also why floor cooling is increasingly used in spaces with large glass surfaces such as airports,<sup>3</sup> atriums, and entrance halls.

The heat transfer between the embedded pipes and the surface of the wall, ceiling, or floor follow the same physics as long as there is no airspace in the construction. This has been included in a new European standard<sup>9</sup> for calculation of the heating and cooling capacity of floor, wall, and ceiling systems. The heat exchange for floor cooling is based on an experimental study.<sup>8</sup> *Figure 2*<sup>10</sup> shows a diagram based on this standard where the cooling capacity and heating capacity for a typical floor system is shown.

#### Design

A floor heating system is often designed with a tube spacing of 150 mm (6 in.) or more. However, to increase the cooling capacity, it may be necessary to design a floor cooling system with smaller spacing. A water flow rate in a floor heating system often is based on a water temperature difference of  $10^\circ\text{C}$  ( $18^\circ\text{F}$ ) between supply and return. Again, to increase the cooling capacity and avoid excessively low supply temperatures (condensation risk), a floor cooling system should be designed with a  $3^\circ\text{C}$  to  $5^\circ\text{C}$  ( $5^\circ\text{F}$  to  $9^\circ\text{F}$ ) temperature

difference between supply and return water. This means a higher water flow rate and a higher pressure drop in the tubes. It may be necessary with a larger circulation pump or to use a shorter tube circuit, but will still obtain enough flow rate to establish a turbulent flow. For maximum cooling capacity (and for

highest system/plant efficiency), it is important to avoid floor coverings with a high thermal resistance such as heavy wall-to-wall carpets.

#### Control

Even if surface heating and cooling systems often have a higher thermal mass

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than other heating/cooling systems, they do 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. Studies on controllability of floor heating/cooling show that floor heating controls the room temperature as well as radiators. 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.

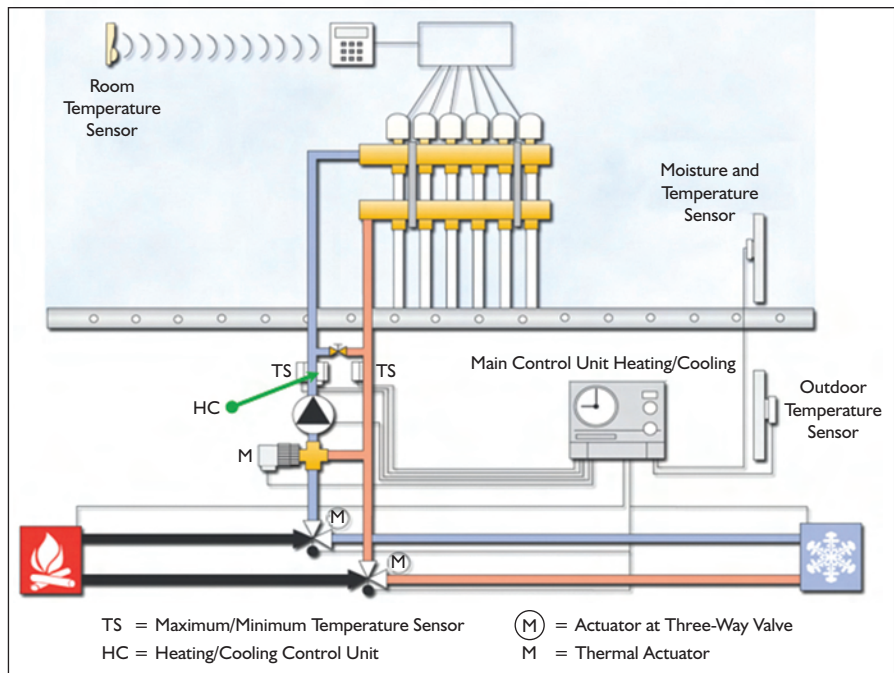
A control concept for a combined floor heating-cooling system is shown in *Figure 3*. For heating supply water temperature, the average value of the supply and return water temperature is controlled according to the outside temperature (flux control according to a preset heating curve). In addition, an individual room thermostat may control the water flow rate to each room. This will typically be an on-off control. For floor cooling the supply water temperature or the average value of the supply and return water temperature is also controlled according to the outside temperature (flux control according to a preset cooling curve) with a limiter based on the dew-point temperature in a reference room. In addition, an individual room control may be set to shut-off or open for the water flow to each room.

The heating and cooling curve give the relation between floor system water temperature and outside temperature. This curve will depend on internal loads, type of building, and external climate. In the control concept shown in *Figure 3*, the three-way valves ensure that the return water is going back to the chiller, when in cooling mode, and back to the heater, when in heating mode.

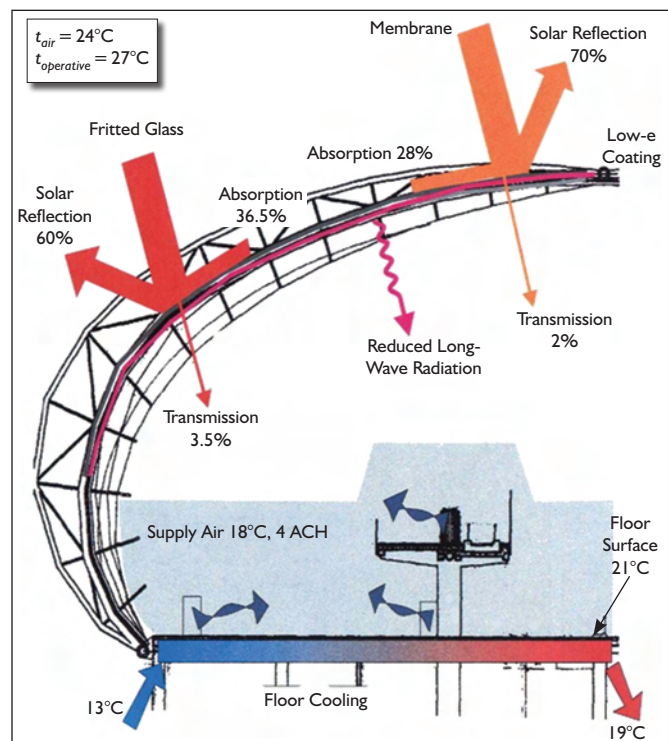
#### Cooling Source

As a floor system is a high-temperature cooling system, and a low-temperature heating system it provides the high efficiency of a heat pump. 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, it is possible to cool a floor directly from a ground heat exchanger without the use of a heat pump.

A floor cooling system may often be used together with a convective cooling system. Then, the floor system may take 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 a higher cooling capacity of the floor system may be obtained. Another advantage is the high return water temperature from a floor system, 18°C to 20°C (64°F to 68°F), which will increase the efficiency of a chiller designed with a higher evaporator temperature.



*Figure 3: Concept for the control of a combined floor heating and cooling system.*



*Figure 4: Design concept for concourses at the new Bangkok Airport.*

#### Applications

Floor cooling can be applied almost everywhere floor heating is applied (single-family homes, multifamily homes, offices, industrial buildings (hangars, storage spaces, large halls, etc.), museums, sports facilities, churches, etc). The system types are the same. Floor cooling is particularly efficient in large spaces

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with large windows where you can expect a significant influence of sun radiation either directly or due to a warm ceiling or wall surface (atria, airports, shopping malls, etc.). Floor cooling absorbs the sun radiation before it heats the space.

The world's largest construction with floor cooling is the new airport in Bangkok, Thailand.<sup>3</sup> Some 150,000 m<sup>2</sup> (1.6 million ft<sup>2</sup>) of floor cooling is installed in the concourses and main terminal buildings. The roof over the concourses (Figures 4 and 5) consists of glass and a plastic membrane construction. Due to the high outside temperatures and sun radiation, this results in a high cooling load. A combination of displacement ventilation and floor cooling has been installed (Figure 4). The floor cooling was dimensioned to remove 70 W/m<sup>2</sup> to 80 W/m<sup>2</sup> (22 Btu/h·ft<sup>2</sup> to 25 Btu/h·ft<sup>2</sup>) with a supply water temperature of 13°C (55°F), return water 19°C (66°F) and a floor surface temperature of 21°C (70°F). The manifolds for the floor system were installed inside the displacement air diffusers (Figure 5). As the dew point in the supply air is 10°C (50°F) and lower than the supply water temperature, there is no risk for condensation on the pipes. The design dew point in the space was 16°C (61°F) due to evaporation from the occupants. This is still 5°C (9°F) lower than the surface temperature of the chilled floor. Compared to a full air system a 30% reduction of energy consumption was predicted during the design.<sup>3</sup>

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**Figure 5:** Installation of floor cooling with manifolds in the displacement diffusers at the new Bangkok airport.

### Conclusions

- A hydronic floor cooling system provides sensible cooling without noise, draft, obstacles, or the need for cleaning.
- The maximum cooling capacity for most spaces is less than 50 W/m<sup>2</sup> (16 Btu/h·ft<sup>2</sup>). In spaces where the sun shines directly on the floor (atrium, entrance hall, showroom), the cooling capacity is significantly higher—up to 100 W/m<sup>2</sup> (32 Btu/h·ft<sup>2</sup>).
- A floor cooling system must be controlled to avoid condensation. This may be done by a supply water temperature that is controlled by the dew-point temperature.

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