

ISO 11855 - The international standard on the design, dimensioning, installation and control of embedded radiant heating and cooling systems



JAE-HAN LIM
Ph.D., ASHRAE member,
Associate Professor,
Department of
Architectural Engineering,
Ewha Womans University
Limit0@ewha.ac.kr



KWANG-WOO KIM
Arch.D., Fellow ASHRAE and IBPSA,
Convener of ISO/TC205/WG8,
Professor, Department of Architecture and
Architectural Engineering,
Seoul National University
snukkw@snu.ac.kr

This article introduces the structure and contents of ISO 11855 Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems. This is the first international standards on radiant heating and cooling system, published in 2012. ISO 11855 includes the processes and conditions needed to determine the heating and cooling capacity of radiant heating and cooling systems in new construction and the retrofit of existing buildings. In addition, the standard stipulated the design conditions regarding components such as the heat supply, hydronic distribution systems, panels, and control systems of radiant heating and cooling systems.

Keywords: Radiant heating and cooling system for occupants’ comfort, Determination of the design heating and cooling capacity, Design and dimensioning, Thermo Active Building Systems (TABS), Installation, Control.

Structure of ISO 11855

In recent years, radiant heating and cooling systems have seen considerable use not only in residential buildings but also in commercial buildings because of their many advantages including higher comfort level, lower noise level and greater possibility of integration to the architectural design in comparison with other HVAC systems. In particular, these systems have gained attention as heating and cooling systems with a high possibility of utilizing renewable energy sources because they can provide heating at a low temperature of hot water and cooling at a high temperature of cold water. Nowadays many countries in Europe, USA and Asia have developed and applied separate components such as pipes, prefabricated panels, manifolds and controller to new and existing building construction. Generally a few product standards had been adopted for the international trade of related products at that time. For that

reason, CEN had been working on developing related standards for determining the heating and cooling capacity and finally developed EN 15377 (refer to **Figure 1**). However, there was no single and comprehensive international standard for the design of radiant heating and cooling system. Therefore it was impera-

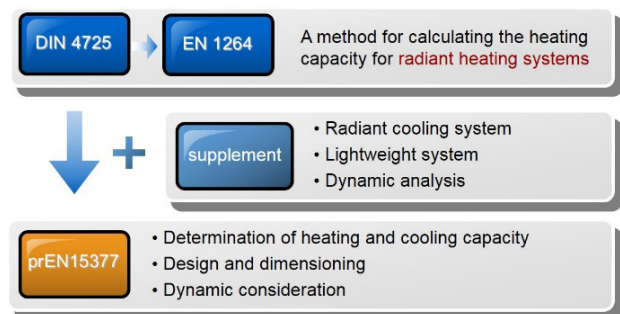


Figure 1. Structure of European standards about radiant heating and cooling system design.

tive that design standards that maximize the advantages of radiant heating and cooling systems should be developed. So the ISO Standards need to deal with the determination of the heating and cooling capacity, system construction, commissioning and operation all together. And this work could be done by supplementing above mentioned EN 15377. Furthermore, for the development of new ISO Standards, some regional characteristics needed to be considered. For example, some particular floor structures used in each country should be categorized to include the all types of radiant heating and cooling system in use. And different comfort criteria which has been preferred traditionally (e.g. maximum floor surface temperature) should be considered accordingly during design process.

The scope of ISO 11855 is the radiant heating and cooling systems that perform heating and cooling in new construction and the retrofit of existing buildings. Most of HVAC systems undergoes the life cycle as shown in **Figure 2**. To ensure the system performance, technical standards should be applied to each step of the life cycle.

To establish the basic design principles, the design process and conditions were firstly addressed. So it was imperative that the established systems should be able to perform in accordance with occupants' comfort. And the process regarding the determination of the heating and cooling capacity and system construction (heat supply, hydronic distribution systems, panels and control systems) must be provided to make it possible to secure the same performance even when the designers are different. As for the performance of radiant heating and cooling systems, energy consumption throughout the building's life cycle must be taken into consideration. ISO Standards for determining the energy performance of radiant heating and cooling systems should be developed by providing methods for conducting dynamic analysis during design process. It is also imperative that standards be developed to make possible energy reduction, prolongation of the life cycle of heating and cooling equipment, and operation of radiant heating and cooling systems according to their design.

After the review of current EN Standards and discussions on references and the world-wide experts' opinions, 8 parts of ISO Standard structure was firstly proposed as shown in **Figure 3**. At the development stage, these standards were assigned to ISO 11855 series, and the structure of standards was changed into 6 parts accordingly. Experts agreed that ISO 11855 would deal with the embedded surface heating and cooling system that

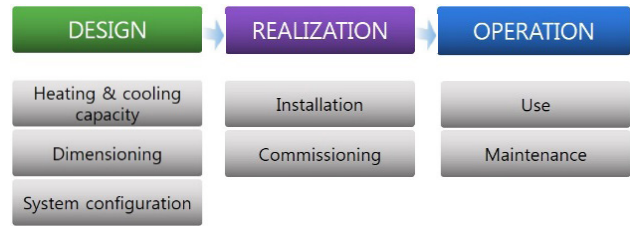


Figure 2. Life cycle of general HVAC system design.

directly controls heat exchange within the space, and does not include the system equipment itself, such as heat source, distribution system and controller. The ISO 11855 series addresses an embedded system that is integrated with the building structure. Therefore, the panel system with open air gap, which is not integrated with the building structure, is not covered by this series.

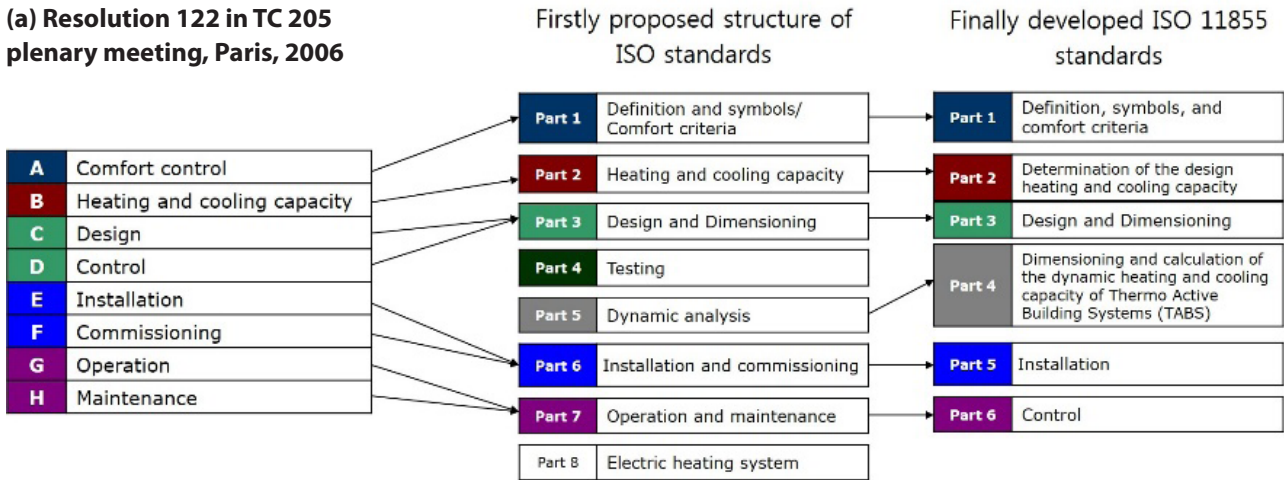
The objective of the ISO 11855 series is to provide criteria to effectively design embedded systems. To do this, it presents comfort criteria for the space served by embedded systems, heat output calculation, dimensioning, dynamic analysis, installation, operation, and control method of embedded systems.

Part 1 of these standards specifies the comfort criteria which should be considered in designing embedded radiant heating and cooling systems, since the main objective of the radiant heating and cooling system is to satisfy thermal comfort of the occupants. Part 2 provides steady-state calculation methods for determination of the heating and cooling capacity. Part 3 specifies design and dimensioning methods of radiant heating and cooling systems to ensure the heating and cooling capacity. Part 4 provides dimensioning and calculation method to design TABS (Thermo Active Building Systems) for energy-saving purposes, since radiant heating and cooling systems can reduce energy consumption and heat source size by using renewable energy. Part 5 addresses the installation process for the system to operate as intended. Part 6 shows proper control methods of the radiant heating and cooling systems to ensure the maximum performance when the system is being actually operated in a building.

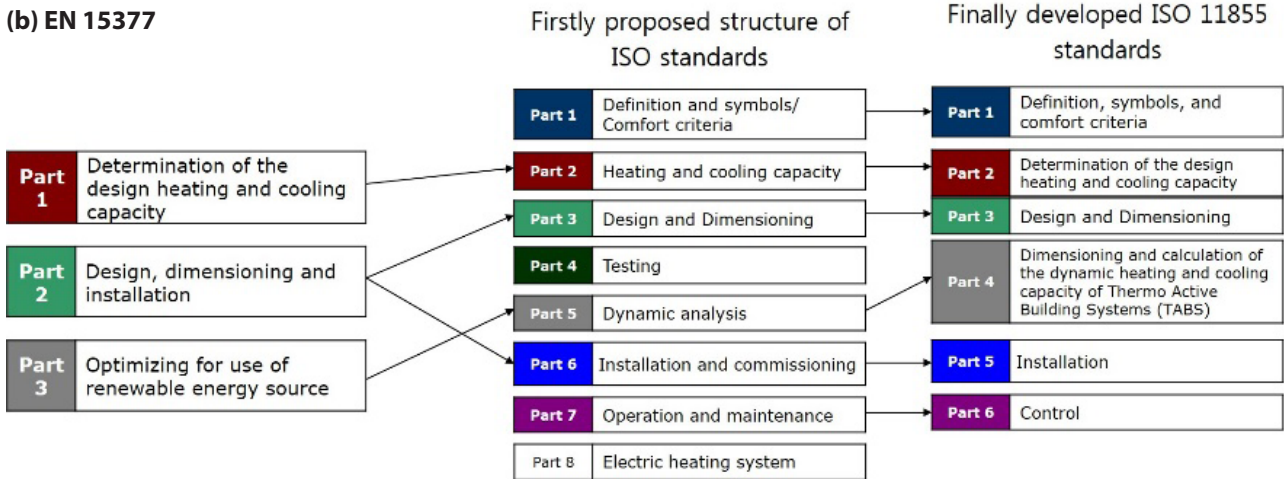
Radiant heating and cooling system for occupants' comfort

Occupant's thermal comfort would be the primary objective that any HVAC system pursues. Radiant heating and cooling systems can be used as primary or hybrid systems which are combined with an air system and provide unique and cost-effective approaches dealing with numerous conditions affecting human

(a) Resolution 122 in TC 205 plenary meeting, Paris, 2006



(b) EN 15377



(c) EN 1264

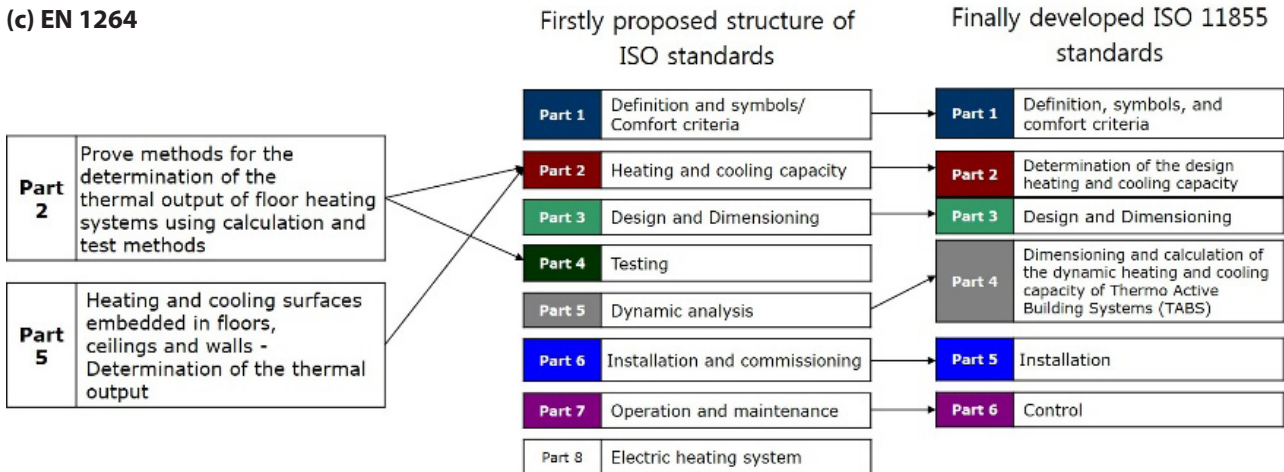
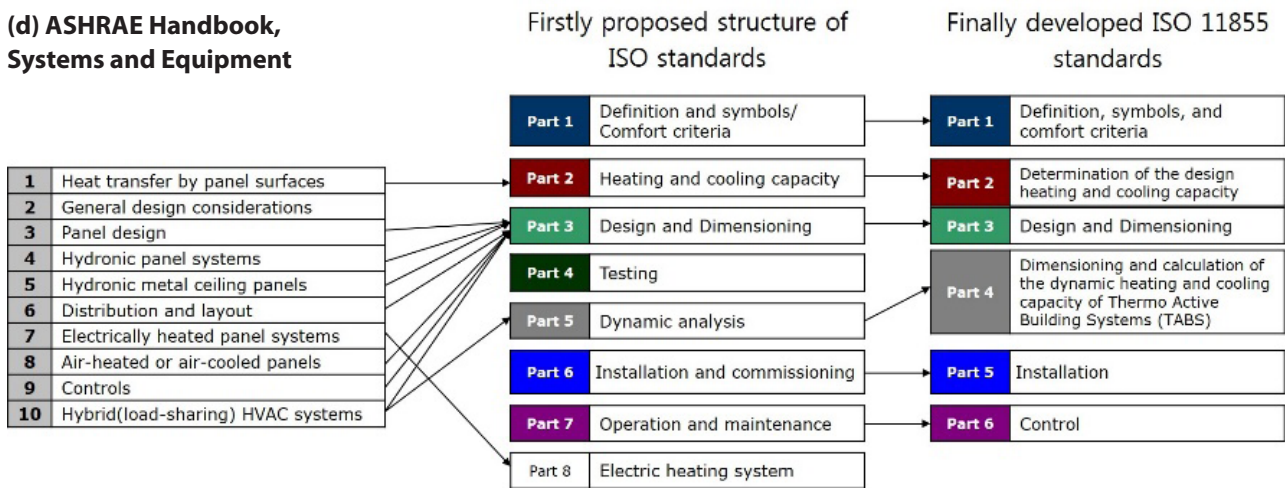


Figure 3. Basic structure of ISO 11855 considering the current EN Standards and other references.

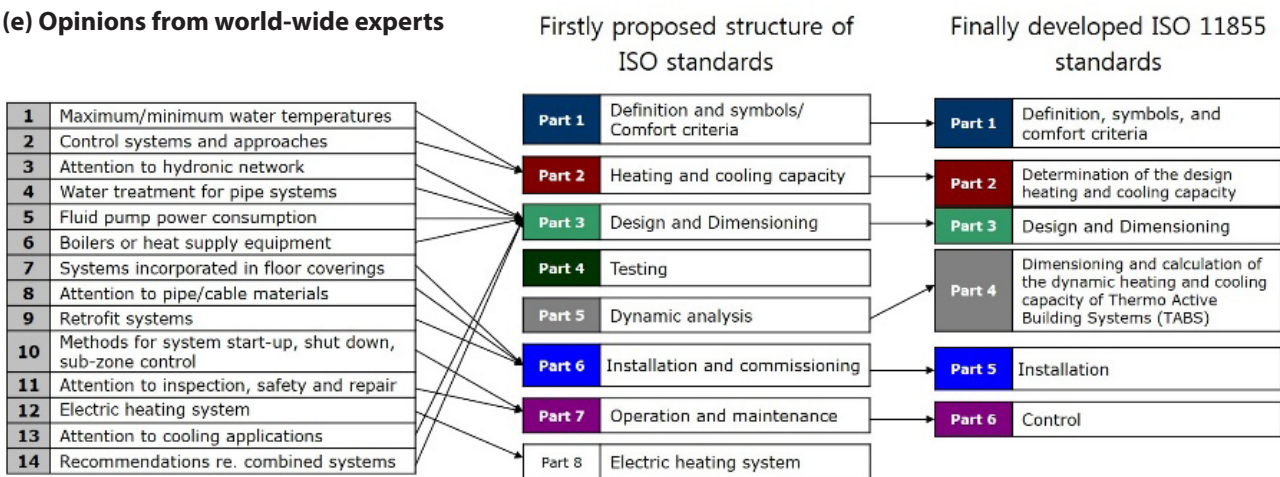
thermal comfort. Radiant heating and cooling systems can be used to directly provide heat to humans as well as to spaces. As long as the occupants are radiantly heated in a radiant heating system, the same comfort level can be maintained with a lower air temperature in comparison to a convective heating system. For radiant

cooling systems, maintaining the same comfort level with a higher air temperature in comparison to convective cooling is possible. Therefore, compared with conventional heating and cooling systems, it is possible to reduce the energy loss due to ventilation, and infiltration while maintaining the same comfort level.

(d) ASHRAE Handbook, Systems and Equipment



(e) Opinions from world-wide experts



Thermal comfort can be defined as the psychological condition that expresses satisfaction with the thermal environment. Therefore, thermal comfort would be evaluated by asking all the occupants if they are satisfied with their thermal environment. However, in order to design and control radiant heating and cooling systems, it is necessary to predict the thermal comfort in a room without resorting to a polling result. To provide an acceptable thermal environment to the occupants, the requirements for general thermal comfort, e.g. predicted mean vote (PMV), operative temperature (OT), and local thermal comfort (surface temperature, vertical air temperature differences, radiant temperature asymmetry, draft, etc.) shall be taken into account. In radiant systems, floor, walls and ceilings can be used as the heat transfer surface for heating and cooling. For this reason, special care shall be paid to the surface temperature limit of the floor and wall with which the occupants can have direct contact.

The floor temperature has a direct impact on the comfort of the feet or buttocks. In ISO 7730, the floor temperature range of 19°C to 29°C is recommended in the space with sedentary and/or standing occupants wearing normal shoes. This is a limiting factor when deciding the capacity of floor heating and cooling systems. For heating, the maximum temperature is 29°C and for cooling, the minimum temperature is 19°C. However, this temperature range of 19°C to 29°C might be changed by the factor of whether the occupants wear shoes or not, or whether they usually sit on the floor or stand up in the occupied zone. Thus, the range of the surface temperature can be different depending on lifestyle habits. For this reason, it is recommended to follow the widely accepted standards of each country when deciding on the optimum range of floor surface temperature. For an electric heating system, an electrically-heated floor may cause discomfort and even skin burn if occupants have prolonged contact with the floor. This is due to the constant supply of heat from

an electrical heating source, whereas, for a water based heating system, the increase in surface temperature is limited by the water temperature. Therefore it is important to control the electrical heating source in order to keep the floor surface temperature under the lower limit of discomfort and skin burn. For wall heating, the maximum recommended surface temperature is in the range of 35°C to 50°C. The maximum temperature depends on factors such as whether occupants may easily have contact with the surface or whether buildings are used for more sensitive persons such as children or the elderly. When a skin temperature is 42°C to 45°C, there is a risk of burns and pain. The losses to the rear walls and its influence on neighboring spaces should be taken into account.

Determination of the design heating and cooling capacity

ISO 11855-2 specifies procedures and conditions to enable the heat flow in water based surface heating and cooling systems to be determined relative to the medium differential temperature for systems. The determination of thermal performance of water based surface heating and cooling systems and their conformity to this part of ISO 11855 are carried out by calculation in accordance with design documents and the model. This should enable a uniform assessment and calculation of water based surface heating and cooling systems. The surface temperature and the temperature uniformity of the heated/cooled surface, nominal heat flow density between water and space, the associated nominal medium differential temperature, and the field of characteristic curves for the relationship between heat flow density and the determining variables are given as the result. Based on the calculated average surface temperature at given combinations of medium (water) temperature and space temperature, it is possible to determine the steady state heating and cooling capacity.

ISO 11855-2 includes a general method based on Finite Difference or Finite Element Methods and simplified calculation methods depending on position of pipes and type of building structure. Two types of simplified calculation methods can be applied according to ISO 11855-2. One method is based on a single power function product of all relevant parameters developed from the finite element method (FEM), and another method is based on calculation of equivalent thermal resistance between the heating or cooling medium temperature and the surface temperature (or room temperature). A given system construction can only be calculated with one of the simplified methods. The

correct method to apply depends on the type of system, A to G (depending on position of pipes, concrete or wooden construction) and the boundary conditions.

The ISO 11855 series is applicable to water based embedded surface heating and cooling systems in residential, commercial and industrial buildings. The methods apply to systems integrated into the wall, floor or ceiling construction without any open air gaps. It does not apply to panel systems with open air gaps which are not integrated into the building structure. The ISO 11855 series also applies, as appropriate, to the use of fluids other than water as a heating or cooling medium. The ISO 11855 series is not applicable for testing of systems. The methods do not apply to heated or chilled ceiling panels or beams.

Design and dimensioning

ISO 11855-3 introduces the design and dimensioning of floor heating, ceiling heating, wall heating, floor cooling, ceiling cooling and wall cooling respectively. Basically the design and dimensioning methods for radiant floor heating and cooling were described. And wall and ceiling radiant heating and cooling can also be applied to the same procedure except for determination of limit curves because of physiological limitations concerning the surface temperatures of ceiling heating systems.

Floor heating system design requires determining heating surface area, type, pipe size, pipe spacing, supply temperature of the heating medium, and design heating medium flow rate. The design steps for floor heating system are as follows:

- Step 1: Calculate the design heating load Q_N . The design heating load Q_N shall not include the adjacent heat losses. This step should be conducted in accordance with standards for heating load calculation, e.g. EN 12831, based on an index such as operative temperature (OT) (see ISO 11855-1).
- Step 2: Determine the area of the heating surface A_p , excluding any area covered by immovable objects or objects fixed to the building structure.
- Step 3: Establish a maximum permissible surface temperature in accordance with ISO 11855-1.
- Step 4: Determine the design heat flux q_{des} . For floor heating systems including a peripheral area, the design heat flux of peripheral area $q_{des,R}$ and the design heat flux of occupied area $q_{des,A}$ shall be calculated respectively on the area of the peripheral heating surface A_R and on the area of the occupied heating surface A_A .

- Step 5: For the design of the floor heating systems, determine the room used for design with the maximum design heat flux $q_{\max} = q_{\text{des}}$.
- Step 6: Determine the floor heating system such as the pipe spacing and the covering type, and design heating medium differential temperature $\Delta\theta_{\text{H,des}}$ based on the maximum design heat flux q_{\max} and the maximum surface temperature $\theta_{\text{F,max}}$ from the field of characteristic curves.
- Step 7: If the design heat flux q_{des} cannot be obtained by any pipe spacing for the room used for the design, it is recommended to include a peripheral area and/or to provide supplementary heating equipment. In this case, the maximum design heat flux q_{\max} for the embedded system may now occur in another room. The amount of heat output of supplementary heating equipment Q_{out} is determined by the following equation:
- Step 8: Determine the backside thermal resistance of insulating layer $R_{\lambda,\text{ins}}$ and the design heating medium flow rate.
- Step 9: Estimate the total length of heating circuit.

If intermittent operation is common, the characteristics of the increase of the heat flow and the surface temperature and the time to reach the allowable conditions in rooms just after switching on the system shall be considered.

Floor cooling system design requires determining cooling surface area, type, pipe size, pipe spacing, supply temperature of the cooling medium, and design cooling medium flow rate. The design steps are as follows.

- Step 1: Calculate the design sensible cooling load $Q_{\text{N,s}}$. The design sensible cooling load $Q_{\text{N,s}}$ does not include the adjacent heat gains. This step shall be conducted in accordance with standards for cooling load calculation, e.g. EN 15243, based on an index such as operative temperature (OT).
- Step 2: Determine the minimum supply air quantity needed for dehumidifying.
- Step 3: Calculate latent cooling available from supply air and also calculate sensible cooling available from supply air.
- Step 4: Determine remaining sensible cooling load to be satisfied by radiant system. Also designate or calculate the relative humidity and dew point, because cooling system shall operate within a temperature range above the dew point, which shall be specified depending on the respective climate conditions of the country.
- Step 5: Determine the area of the cooling surface A_{F} , excluding any area covered by immovable objects or objects fixed to the building structure.

- Step 6: Establish a minimum permissible surface temperature in accordance with ISO 11855-1 in consideration of the dew point.
- Step 7: Determine the design heat flux q_{des} . For floor cooling systems including a peripheral area, the design heat flux of peripheral area $q_{\text{des,R}}$ and the design heat flux of occupied area $q_{\text{des,A}}$ shall be calculated respectively on the area of the peripheral cooling surface A_{R} and on the area of the occupied cooling surface A_{A} .
- Step 8: For the design of the floor cooling systems, determine the room used for design with the maximum design heat flux $q_{\max} = q_{\text{des}}$.
- Step 9: Determine the floor cooling system such as the pipe spacing and the covering type, and design cooling medium differential temperature $\Delta\theta_{\text{H,des}}$ based on the maximum design heat flux q_{\max} and the minimum surface temperature $\theta_{\text{F,min}}$ from the field of characteristic curves.
- Step 10: If the design heat flux q_{des} cannot be obtained by any pipe spacing for the room used for the design, it is recommended to provide supplementary cooling equipment. In this case, the maximum design heat flux q_{\max} for the embedded system may now occur in another room.
- Step 11: Determine the backside thermal resistance of insulating layer $R_{\lambda,\text{ins}}$ and the design cooling medium flow rate.
- Step 12: Estimate the total length of cooling circuit.

Thermo Active Building Systems (TABS)

ISO 11855-4 allows the calculation of peak cooling capacity of Thermo Active Building Systems (TABS), based on heat gains such as solar gains, internal heat gains and ventilation, and the calculation of the cooling power demand on the water side to size the cooling system as regards the chiller size, fluid flow rate, etc. ISO 11855-4 defines a detailed method aimed at the calculation of heating and cooling capacity in non-steady state conditions. A Thermally Active Surface (TAS) is an embedded water based surface heating and cooling system, where the pipe is embedded in the central concrete core of a building construction. The building constructions embedding the pipe are usually the horizontal ones. As a consequence, floors and ceilings are usually referred to as active surfaces. Looking at a typical structure of the TAS, heat is removed by a cooling system (for instance, a chiller), connected to pipes embedded in the slab. Thermally active surfaces exploit the high thermal inertia of the slab in order to perform the

peak-shaving. The peak-shaving is to reduce the peak in the required cooling power, as it is possible to cool the structures of the building during a period while the occupants are absent (during night time, in office premises). This way the energy consumption can be reduced and the lower night time electricity rate can be used. At the same time a reduction in the size of heating/cooling system components (including the chiller) is possible.

TABS may be used both with natural and mechanical ventilation (depending on weather conditions). Mechanical ventilation with dehumidifying may be required depending on external climate and indoor humidity production. The required peak cooling power needed for dehumidifying the air during day time is sufficient to cool the slab during night time. As regards 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 also to know the heat flow on the water side to be able to dimension the heat distribution system and the chiller/boiler.

When using TABS, the indoor temperature changes moderately during the day and the aim of a good TABS design is to maintain internal conditions within the comfort range, i.e. $-0,5 < PMV < 0,5$, during the day, according to ISO 7730. Some detailed building system calculation models have been developed to determine the heat exchanges under unsteady state conditions in a single room, the thermal and hygro-metric balance of the room air, prediction of comfort conditions, check of condensation on surfaces, availability of control strategies and calculation of the incoming solar radiation. The use of such detailed calculation models is, however, limited due to the high amount of time needed for the simulations. The development of a more user friendly tool is required. Such a tool is provided in this part of ISO 11855, and allows the simulation of TAS.

Installation

ISO 11855-5 establishes guidelines on the installation of embedded radiant heating and cooling systems. It specifies uniform requirements for the design and construction of heating and cooling floors, ceiling and wall structures to ensure that the heating/cooling systems are suited to the particular application. The requirements specified by this part of ISO 11855 are applicable only to the components of the heating/cooling systems and the elements

which are part of the heating/cooling surface and are installed for the heating/cooling systems.

Control

ISO 11855-6 describes the control of hydronic systems to enable all embedded systems to perform as simulated. The design documents shall include specifications for the control system. The control system shall be capable of varying heating or cooling outputs as well as maintaining predetermined room or surface temperatures. The control system shall, if specified, protect buildings and equipment against frost and moisture damage where necessary (when normal comfort temperature level is not required) and prevent condensation from occurring. The design of the control system shall take into account the building, its intended use and the effective functioning of the embedded system, efficient use of energy and avoid conditioning the building at full design conditions when not required.

Due to the high impact that fast varying heat gains (e.g. sunshine through windows) may have on the room temperature, it is necessary that the radiant system control to compensate this by reducing or increasing the temperature difference between room and heated/cooled surface and partly on the difference between room and the average temperature output. For the low temperature heating and high temperature cooling systems, the “self-regulating effect” is significant. The “self-regulating” depends on the average water temperature in the panels. It means that fast change of operative temperature will equally change heat exchange and result in influence of total heat exchange. This impact is bigger for systems with surface temperatures close to room temperature because the change of one degree represents a higher percentage based on a small temperature difference than on a high temperature difference. The self-regulating effect of low temperature heating and high temperature cooling systems supports the control equipment (e.g. individual room temperature control) in maintaining a stable thermal environment providing comfort to persons in the room.

Water based radiant heating and cooling systems need hydronic balancing. The components shall be adjusted in order to ensure the required flow rates. Under dynamic conditions, e.g. during the heating up/cooling down period, it must be ensured that the hydraulic interaction between the different circuits is small (the flow rates in different circuits shall not

be greater than the design flow rates). Depending on the situation of the heating/cooling system, the panel distribution system shall be equipped with facilities for degassing and sludge separation.

The control modes of embedded systems are based on three system levels:

- 1) Local (room) control, where the energy supplied to a room is controlled
- 2) Zone control normally consisting of several spaces (rooms)
- 3) Central control where energy supplied to the whole building is controlled by a central system

The control system classification is based on performance level:

- 1) Manual: The energy supply to the conditioned space is only controlled by a manually operated device
- 2) Automatic: A suitable system or device automatically controls energy to the conditioned spaces
- 3) Timing: Function of energy supplied to a conditioned space is shut off or reduced during scheduled periods, e.g. night setback (not necessarily applicable for cooling)
- 4) Advanced timing: Function of energy supply to the conditioned space is shut-off or reduced during scheduled periods, e.g. daytime with more expensive electricity tariff. Re-starting of the energy supply is optimized based on various considerations, including reduction of energy use (not applicable in commercial buildings).

Conclusion

In general, HVAC systems have been designed as all-air HVAC systems in European countries. Radiant heating and cooling systems can be integrated with general HVAC system by separating the tasks of ventilation and thermal space conditioning. By using the primary air distribution to fulfill the ventilation requirements and the secondary water distribution system to thermally condition the space, the amount of air circulation through buildings can be reduced significantly, because the ventilation air can be supplied by outside fresh air without affecting the recirculation of air. To secure the performance of radiant heating and cooling system, there must be standards for processes and conditions that determine the heating and cooling capacity of radiant heating and cooling systems. The purpose of ISO 11855 lies above all in enabling the radiant heating and cooling

systems to perform in accordance with occupants' comfort by providing standards for determining the heating and cooling capacity of radiant heating and cooling systems. These standards may be seen as integrated design standards that make possible the effective design of the entire system by providing standards regarding heat emission calculation, panel design, and system construction. ■

References

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- ISO 11855-2 Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems — Part 2: Determination of the design and heating and cooling capacity.
- ISO 11855-3 Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems —Part 3: Design and dimensioning.
- ISO 11855-4 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).
- ISO 11855-5 Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems —Part 5: Installation.
- ISO 11855-6 Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems —Part 6: Control.

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