ISO 18566, the international standard on the design, test methods and control of hydronic radiant heating and cooling panel systems

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This article introduces the structure and contents of under developing 'ISO 18566 Building Environment Design — Design, test methods and control of hydronic radiant heating and cooling panel systems.' This is the second international standard on radiant heating and cooling system. ISO 18566 includes: technical specifications and requirements of radiant heating and cooling panel system, the test facility and test method for heating and cooling capacity of ceiling mounted radiant panels and the design considerations and process of ceiling mounted radiant panels, and the control of ceiling mounted radiant heating and cooling panels.

Application field of the ISO 18566

Typical applications are low temperature radiant heating and high temperature radiant cooling and are classified as embedded radiant heating and cooling system and prefabricated radiant heating and cooling panel system. ISO 11855 standards are for embedded radiant heating and cooling system without open air gap. The developing ISO 18566 standards are for radiant heating and cooling panel system with open air gap. This standard specifies the design, test conditions and methods for the determination of the heating and cooling capacity and control of radiant heating and cooling panels with an open air gap. This standard applies to all types of prefabricated radiant panels that are part of the room periphery such as ceiling, walls and floor. This standard does not cover panels embedded into ceiling, wall or floor structures and hybrid (combined thermal radiation and forced-convection) ceiling panels.

And the experts agreed that this work item would be based on existing standards such as EN 14240, EN 14037 and ANSI/ASHRAE Standard 138 and experts in ISO/TC205/WG8 decided to develop a new ISO 18566 series. In the beginning, this standard was suggested to have 6 parts:

- Part 1: Definition, symbols, technical specifications and requirements
- Part 2: Design of ceiling mounted radiant panels
- Part 3: Test facility for thermal output of ceiling mounted radiant heating and cooling panels
- Part 4: Test method for cooling capacity of ceiling mounted radiant panels
- Part 5: Test method for heating capacity of ceiling mounted radiant panels
- Part 6: Control and operation of ceiling mounted radiant heating and cooling panels

This new proposal was approved in January 2013. The proposed new standard will affect the manufacturers of radiant heating and cooling panels and also mechanical engineering companies. They can use the proposed ISO standards for determining the thermal output of radiant heating and cooling panels and for designing the HVAC system.

Ceiling mounted radiant heating and cooling panel systems have become more popular for new building construction as well as renovation projects in Europe, USA and Asia because they can provide a comfortable environment by controlling surface temperatures and minimizing excessive air motion within the space. As shown in **Table 1**, there are several existing standards regarding ceiling mounted radiant panels in Europe and USA. However, there is no single and comprehensive international standard for the design of ceiling mounted radiant heating and cooling panel systems. This ISO 18566 standard covers this lack of standardization by addressing the technical specifications and requirements, the determination of test method for thermal output, design considerations and control methods all together in one standard.

As shown in **Table 1**, CEN had been working on developing related standards to describe the test method for thermal output and rating method of ceiling mounted radiant panels during heating and cooling operation and finally developed EN 14240:2004 and EN 14037 in May 2003 (see **Table 1**). Part 1 of EN 14037 defines the technical specifications and requirements of ceiling mounted radiant panels, heating and cooling surfaces fed with water at temperatures below 120°C connected with a centralized heating and/or cooling supply source. And this also defines the additional common data that the manufacturer shall provide to the trade in order to ensure the correct application of the products. But this does not apply to independent heating and/or cooling devices. Part 2 of EN 14037 describes the test method and the test facility for determining the thermal output of ceiling mounted radiant panels according to the specifications of EN 14037-1. And part 3 of EN 14037 describes the procedure to determine the rated thermal output (Φ_D) and the mean surface temperature (t_{rp}). This test method for determining the thermal output of ceiling mounted radiant panels give reliable results for comparing different products. Meanwhile this EN 14037 series has been revised in September 2015.

Table 1. Relevant standards regarding ceiling mounted radiant panels.

Reference Standard	Title	Publication Date
EN 14037-1	Ceiling mounted radiant panels supplied with water at temperature below 120°C – Part 1: Technical specifications and requirements	01 May 2003
EN 14037-2	Ceiling mounted radiant panels supplied with water at temperature below 120°C – Part 2: Test method for thermal output	01 May 2003
EN 14037-3	Ceiling mounted radiant panels supplied with water at temperature below 120°C – Part 3: Rating method and evaluation of radiant thermal output	01 May 2003
EN 14240	Ventilation for buildings. Chilled ceilings. Testing and rating	29 Jan. 2004
ANSI/ASHRAE Standard 138	Method of Testing for Rating Ceiling Panels for Sensible Heating and Cooling	28 Jan. 2009

Design, test methods, control and operation of radiant heating and cooling panel systems.

- Part 1: Definition, symbols, technical specifications and requirements
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ISO 18566 Building Environment Design — Design, test methods and control of hydronic radiant heating and cooling panel systems

- Part 1: Definition, symbols, technical specifications and requirements
- Part 2: Determination of heating and cooling capacity of ceiling mounted radiant panels
- Part 3: Design of ceiling mounted radiant panels
- Part 4: Control of ceiling mounted radiant heating and cooling panels

Figure 1. Development of ISO 18566 series structure.

EN 14240 specifies test conditions and methods for the determination of the cooling capacity of chilled ceilings and other extended chilled surfaces. This test method applies to all types of surface cooling systems using any medium as energy transport medium. This standard refers to water as the cooling medium throughout. In addition, this standard refers to chilled surfaces which include ceiling, wall or floor as appropriate.

At the development stage, these standards were assigned to ISO/TC205/WG8. Finally, the ISO 18566 series consists of 4 parts and deals with, free hanging hydronic radiant heating and cooling panel systems. This standard specifies the design, test conditions and methods for the determination of the cooling and heating capacity and control of radiant heating and cooling panels with an open air gap. This standard applies to all types of prefabricated radiant panels that are part of the room periphery such as ceiling, walls and floor.

ISO 18566-1specifies the comfort criteria, technical specifications and requirements which should be considered in manufacturing and installation of radiant heating and cooling systems. Part 2 provides the test facility and test method for heating and cooling capacity from ceiling mounted radiant panels. Part 3 specifies the design considerations and design processes of ceiling mounted radiant panels. And part 4 addresses the control of ceiling mounted radiant heating and cooling panels to ensure the maximum performance which was intended in the design stage when the system is actually being operated in a building.

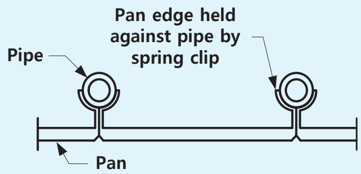
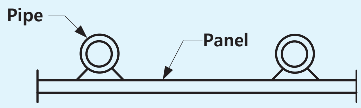
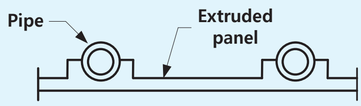
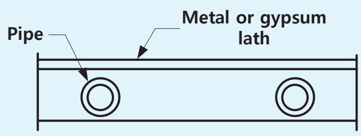
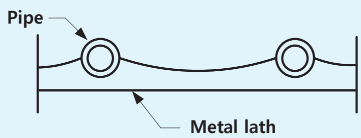
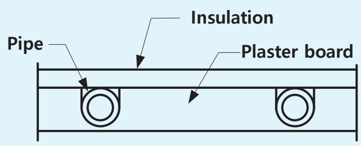
Technical specifications and requirements in part 1

Technical specifications include the system types, specifications which are to be considered in manufacturing and installation stage. The technical requirements include the thermal and hydronic performances, safety and maintenance.

Major types of radiant panels

The radiant panel system is characterized by open air gap. The major components of radiant panel system are a radiant panel and pipes. The types of radiant panels were generally determined by the arrangement of major components. For each type, the heat transfer characteristics are different. Insulation is necessary for preventing heat losses to unoccupied part of the space. In addition, a heat transfer layer, fixing equipment (hangers, wire net, and etc.) and finishing material (plaster and etc.) may be necessary. The major types of a radiant panel are illustrated in **Table 2**.

Table 2. Major types of a radiant panel.

Description	Shape
Pipes fixed to pan edge	
Pipes secured to panel	
Pipes fixed to extruded panel	
Pipe fixed under metal/gypsum lath	
Pipe fixed on metal lath	
Plaster board	

Specification

The thermal output of a radiant panel is mainly transferred to the space by radiation. The thermal output on the reverse side of the panel to the unoccupied part of the space shall be minimized by insulation. So the non-heated or non-cooled side of the radiant panels shall be provided with insulation. The thermal resistance of the insulation has a substantial influence on the thermal output to unoccupied space. The surface of the radiant panels require protection against corrosion. For example, the paint used for protection shall not contain any chemical substances which is not allowed in building products. And the compliance with the relevant domestic regulations shall be stated by the manufacturer of the radiant panel. The radiating heating/cooling surface shall have an emissivity not lower than 0,8. The dimensions of plastic pipes must comply with the requirements of the following ISO 15875-1 for PE-X, ISO 15876-1 for PB, and ISO 15874-1 for PP. Copper piping must comply with the requirements of EN 1057 (for pipes) and EN 1254 (for fittings). Minimal pipe thickness should comply with the requirements for service conditions, operation pressure (higher than 4 bar) and durability (more than 50 years). The use of pipes with an oxygen-barrier layer is recommended to reduce corrosion problems. The oxygen permeability should be less than or equal to (0,1 g/m^3·d) at a water temperature of 40°C, where d is the average outer diameter of the pipe.

During the installation of the panel system, it is necessary to ensure that the fixing point can bear the load of panels and ensure that the coupling should be installed to prevent leakage. The fixing points on the radiant panel shall be designed to withstand a load of 5 times the allocated mass of the panel, including water, without failure. A loading up to 3 times of the allocated filled mass shall be achieved without any occurrence of permanent deformation. The manufacturer shall submit a statement for the suitability and stability of the fixing points in accordance with national regulations if exist, rather than recommended values. When coupling a panel to other panels, the bending radius shall not be less than the minimum bending radius defined in the relevant product standards. This operation should be carried out in accordance with the manufacturer's instructions.

Technical performance

The rated thermal output and the thermal output under different operating conditions (characteristic curve) are to be determined in a test laboratory according to the part 2 of this standard. Thermal performance is influenced by insulation which prevents thermal output to unoccupied space. The manufacturers shall declare the rated thermal output of the radiant panels. And the manufacturer shall provide the means to calculate water flow resistance for the different types of unit with connections and internal pipe layout.

The water flow distribution for the panels should be balanced. When no manifold is applied, the distribution method by piping like reverse return should be used. When manifold is applied, headers, flow control valves, actuators and air discharge valves should be used. The installation specification should be carried out in accordance with the manufacturer's instructions. The water flow within a pipe is necessary to be turbulent (Re>4000) to enhance the thermal performance. However, laminar flow may be acceptable in some cases (e.g. at low load situation). Laminar flow is also considered in part 2 and 3 of this standard. The lower end of velocity range is based on the ability of flowing water to move air bubbles along a vertical pipe. The average flow velocity of 0,6 m/s or higher can entrain air bubbles that are in a downward water flow. The upper end of velocity range is 1,2 m/s which is based on minimizing noise generated by the flow.

Safety

The headers and their connections to the pipes of the active length (wet surface) of all products leaving the factory shall be tested for leaks with a test pressure equal to at least 1,3 times the maximum operating pressure stated by the manufacturer. The materials from which the appliances are made (steel, aluminium, plaster board, etc.) should be considered to meet required fire class. In EU countries, the appliances made from steel or aluminium are considered to be reaction to fire class A1 without the need for testing (provided that any organic part of the paint or coating is less than 1% by mass or volume). If the organic part of the paint or coating exceeds 1% by mass or volume, the material shall be tested and classified according to EN 13501-1 and the resulting class stated.

Determination of heating and cooling capacity of ceiling mounted radiant panels

ISO 18566-2 deals with the determination of heating and cooling capacity of ceiling mounted radiant panels. Ceiling mounted radiant panels covered by this standard are limited to a width from 0.3 m up to 1,5 m. This standard also defines the additional common data that the manufacturer shall provide in order to ensure the correct application of the products.

Test booth

The booth for testing ceiling mounted radiant panels shall be constructed in a way that all six surrounding surfaces can be chilled. Walls, ceiling and floor shall have smooth inside surfaces covered with a coat of mat paint having a degree of emissivity of minimum 0,9. The test booth construction shall be sufficiently tight to prevent air infiltration.

During the heating capacity test, the cooling system will be operated to maintain the temperature difference between the 6 surrounding inside surfaces of the test booth is not higher than 0,5 K. That condition shall be maintained at the tests for the determination of the characteristic equation.

During the cooling capacity test, the test booth will be heated with a number of electrically heated cooling load simulators which are positioned on the floor of the test booth for covering the cooling capacity. The output of each simulator must not exceed 180 W and shall be continuously adjustable. Each simulator shall have an identical heat output. The housing of the simulator is made of painted steel sheet. The emissivity of the inside and outside surface shall be at least 0,9. The active power of the simulators shall be measured with a measuring instrument of the accuracy of 1,0% or better. The surfaces, floor and ceiling of the test booth shall be insulated in the way that the average heat flow in those surfaces is lower than 0,40 W/m² during the test. This heat flow shall be determined by preliminary calibration tests of the booth or by calculations. The reference temperature during the measurement shall be 32°C ± 0,5 K in the steady condition for minimum 30 minutes. The temperature(s) of inner surfaces of walls, floor and ceiling of the test booth (under the insulation) shall be controlled and be kept at the value, which is necessary to guarantee a maximum temperature difference between these surfaces and the reference temperature be less than 1,0 K.

Test method

The aim of the thermal output test is to establish the standard characteristic equation of a ceiling mounted radiant panel by determining the related values of thermal output and cooling capacity and temperature difference. Neither of these quantities can be measured directly, but shall be calculated using the values of other measurable quantities, either directly or with additional information (calibration test, material properties table), by using mathematical relationships.

The thermal output Φ_{me} is calculated based on the water flow rate q_m and the measured temperatures q_1 and q_2. These temperatures are used to calculate the specific enthalpies (h_1 and h_2) as determined by the international steam tables at a reference water pressure of 120 kPa:

$$\Phi_{me} = q_m(h_1 - h_2) \qquad (1)$$

The water flow rate is measured directly by a calibrated flow-meter in a closed water circuit or calculated using the mass of the water m collected in a measuring vessel and the relevant time interval τ. The standard provides detailed requirements for the position of the panels in the test booth, the water flow rate, temperatures, installed insulation at the panel and the connectors.

Test Report

The following data shall be stated in the test report:

- Name and address of the test institute
- Location of test (if different from the test institute)
- Name and address of the customer
- Identification of the test method used
- Description of the test booth
- Identification of the test samples including trade mark, model number and dimensions
- Dates of testing
- Documents of the manufacturer (drawing No, report of the pressure test, report of the factory test) confirmation of the producer or declaration of product identity
- Test results:
  - Results of the resistance to pressure test
  - Control of the general construction specifications
  - Control of the dimensional tolerances, all dimensions of the test sample shall be documented with the nominal dimension, the measured dimension, nominal tolerance and the measured differences in a table.
  - Test data including e.g. water temperatures, air temperatures, globe temperature, water flow rate, corresponding Reynolds number at 50°C (heating case)
  - Standard total output and the characteristic equation of the tested panel
  - Standard output and the characteristic equation of the active length of the tested panel
  - Standard output and the characteristic equation of connection components of the tested panel
  - Standard modular output and exponents of the tested panel and the interpolated/calculated panels
  - Rated thermal output of the tested panel and the interpolated/calculated panels
  - For characteristic equation with deviations from the standard characteristic equation
    - Exact description of the boundary condition: parameters, thermal output values of standard temperature difference, equation for the characteristic.

Design of ceiling mounted radiant panels

The ceiling mounted radiant panels work by circulating warm or cold water through pipe circuits. Radiant heating and cooling panels can be installed in a single room or throughout an entire building, and it is used for areas with normal and high ceilings. Ceiling mounted radiant panels function as heat exchangers between the room air and the chilled/hot water. The ceiling panels absorbs or emits heat from heat sources in a room and exchanges it with the circulating chilled/hot water. After the heat emission from panel surface, the chilled or hot water is transferred to a chiller or boiler. With radiant panel systems, room thermal conditions are maintained primarily by direct transfer of radiant energy rather than by convection heating and cooling. Radiation heat exchange takes place between objects with different surface temperatures. In order to provide acceptable thermal conditions, air temperature and mean radiant temperature should be taken into account. Compared with conventional convective heating and cooling systems, a radiant heating system can achieve the same level of operative temperature at a lower air temperature and a radiant cooling system at a higher air temperature. However, in all practical thermal environments, a radiation field has an asymmetric feature to some degree. If the asymmetry is sufficiently large, it can cause discomfort. Also the thermal stratification of air may cause thermal discomfort. Therefore, these comfort criteria should be considered at the design stage of ceiling mounted radiant panels. Furthermore, ceiling mounted radiant panels are generally built as an architectural finishing product. And generally the copper pipes are thermally bonded and panel piping arrangements are in a serpentine pattern or in a parallel pattern. So ISO 18566-3 specifies the design considerations such as thermal resistance in the panel, panel heat loss or gain, water velocity in pipes and surface condensation problems during cooling operation. Also this addresses the basic design process, including key points to consider while designing a ceiling mounted radiant panel system.

General design consideration

Thermal resistance in the panel to transfer heat from or to its surface will reduce the thermal performance of the panel itself. Thermal resistance to the heat flow may vary considerably among different panels, depending on the type of bond between the piping and the panel material. Influential factors such as corrosion or adhesion defects between lightly touching surfaces and the method of maintaining contact may change the bond with time. The actual thermal resistance of any proposed system should be verified by testing. And specific resistance and performance data, when available, should be obtained from the manufacturer.

Heat transferred from the upper surface of ceiling panels is considered as a panel heat loss. Panel heat losses are part of the building heat loss if the available heat is transferred outside of the building. If the heat is transferred to another heated space, the panel loss will be a source of heat for that space instead. In either case, the magnitude of panel loss should be determined during the design process and panel heat loss to spaces in outside of the room should be kept to a reasonable amount by insulation.

At the design stage, attention should be given to proper water velocity. Water velocity that is too low causes laminar flow, which reduces internal heat exchange. Generally, the heat exchange coefficient within the range of turbulent flows including the transition area is different from that of laminar flows. Approximately we can assume that the average heat exchange coefficient of turbulent flow is about 2200 W/m²K and that of laminar flow is about 200 W/m²K. Flow characteristics can be determined by the internal diameter of the pipe, the average velocity of the flow and the kinematic viscosity of the water. The maximum water velocity per loop depends on the selection of pumps. When the design temperature differences between supply and return water are decreased, the design water velocity should be increased. The higher the water velocity the higher the friction loss, and more pump energy is required during operation. Most pipe circuits are designed according to energy criteria with a pressure drop between 10 to 25 kPa.

To prevent the surface condensation problems, the surface temperature of the radiant ceiling can be controlled to be above the dew point temperature. For this purpose, it is necessary to monitor the air temperature and air humidity levels. In a simple manner, the supply water temperature to the panels must be controlled to avoid the possibility of surface condensation. To prevent condensation on the room side of cooling panels, the panel water supply temperature should be maintained at least 1 K above the room design dew-point temperature. This minimum difference is recommended to allow for the normal drift of temperature controls for the water and air systems, and also to provide a factor of safety for temporary increase in space humidity. The most frequently applied dehumidification method is cooling coils. Several chemical dehumidification methods are available to control latent and sensible loads separately. When chemical dehumidification is used, hygroscopic chemical-type dew-point controllers are required at the central apparatus and at various zones to monitor the room dew-point temperatures. When cooled ceiling panels are used with a variable air volume (VAV) system, the air supply rate should be near maximum volume to assure adequate dehumidification before the cooling ceiling panels are activated.

Design processes of hydronic panel systems

Ceiling mounted radiant panels can be integrated into a HVAC system. In such a system, a source of dehumidified ventilation air is required in summer, so this integrated system is classified as an air-and-water system. Also, various amounts of forced air are supplied year round for fresh air supply. When radiant panels are applied for heating only, a ventilation system may be required depending on local codes. Radiant ceiling systems are usually designed in spaces where the suspended acoustical ceiling can be combined with panel heating and cooling. The panels can be designed as small units to fit the space module, which provides extensive flexibility for zoning and control system, or the panels can be arranged as large continuous areas for maximum economy. Some ceiling installations require active panels to cover only a portion of the room and compatible matching acoustical panels for the remaining ceiling area. Panel design requires determining panel area, panel type, supply water temperature, water flow rate, and panel arrangement. Panel performance is directly related to room conditions. Ventilation and dehumidification system also should be designed. Heating and cooling loads may be calculated by procedures in accordance with standards for heating and cooling load calculation, e.g. ISO/FDIS 52016-1", Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures" based on an index such as operative temperature. **Figures 2 and 3** show the design process of cooling and heating operation respectively.

Control of ceiling mounted radiant heating and cooling panels.

ISO 18566-4 includes guidelines on the control of ceiling mounted radiant heating and cooling panels. The requirements specified are applicable only to the components of the heating/cooling systems and the installed elements which are parts of the radiant panels. This standard describes the control of hydronic systems to enable all radiant panel systems to perform as simulated. The design of the control system shall take

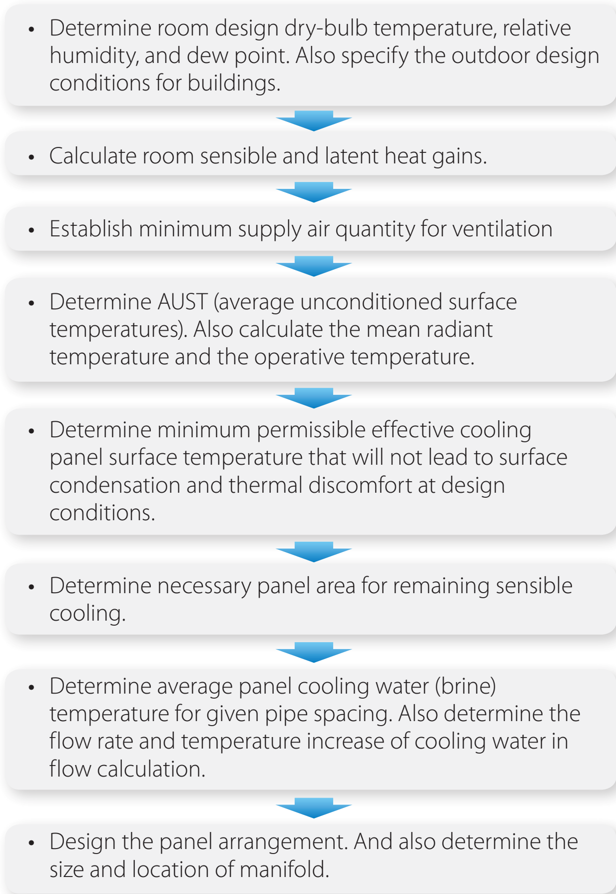


Figure 2. Design process of cooling operation.

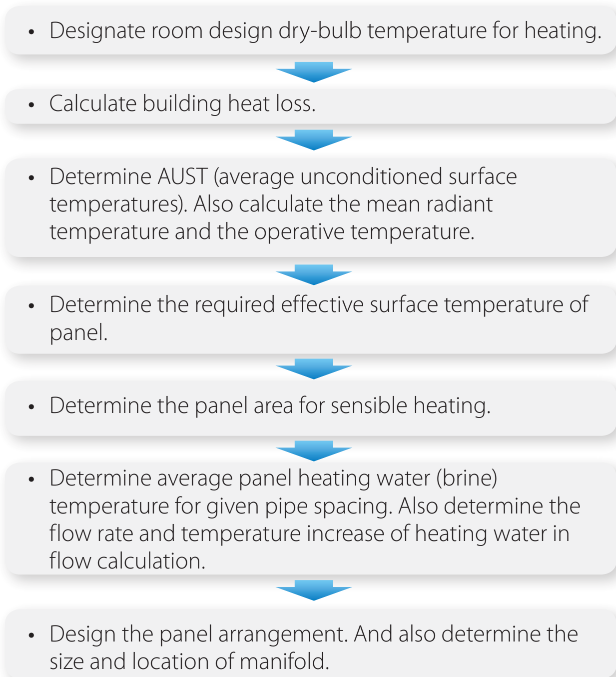
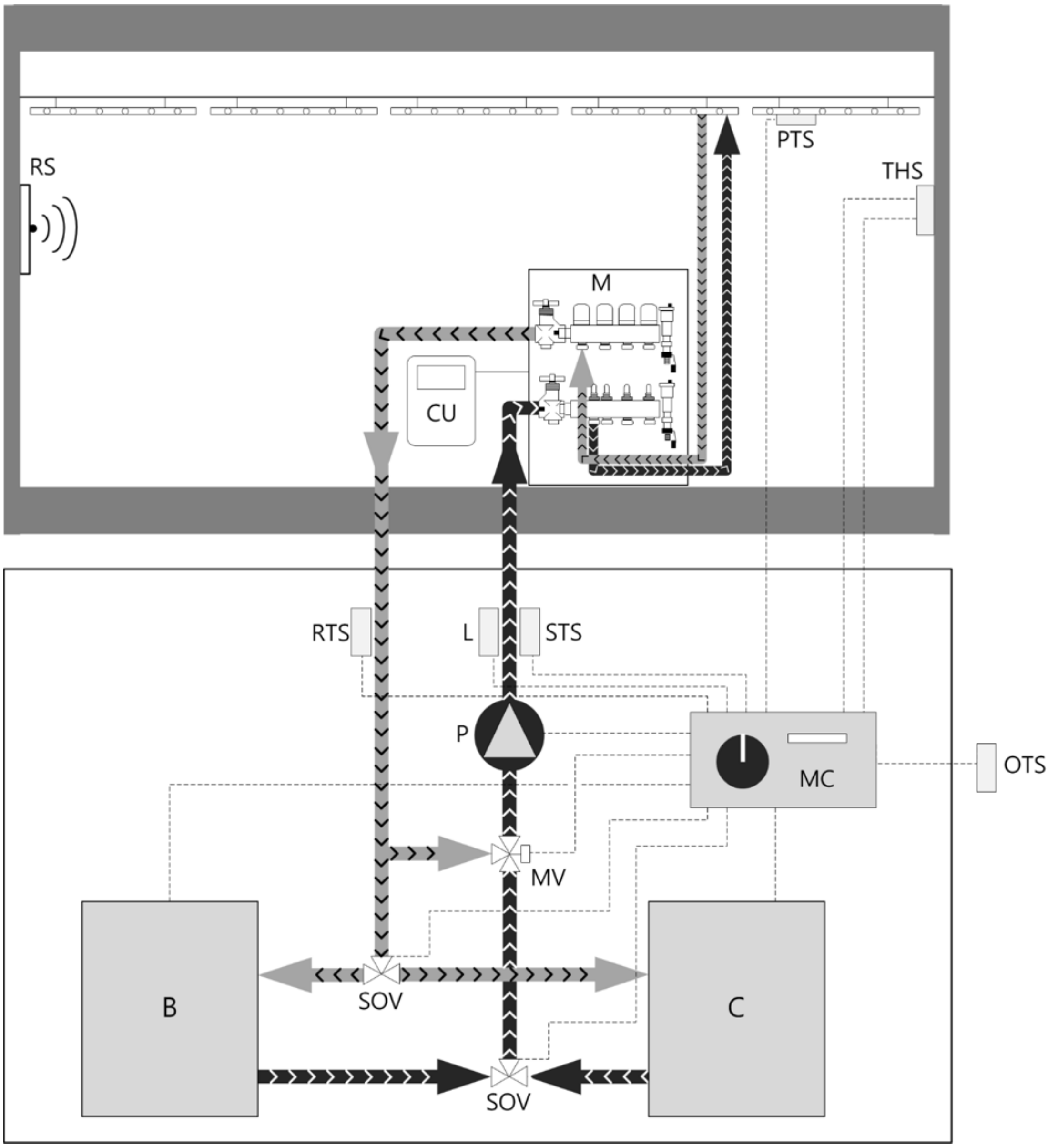


Figure 3. Design process of heating operation.

into account the dynamics of building, its intended use and the effective functioning of the panel system, efficient use of energy and avoiding conditioning the building to full design conditions when not required. The controls shall keep the distribution heat losses as low as possible, e.g. by reducing flow rates and temperatures, when normal comfort temperature level is not required. Control of the system will enable control of the conditioning systems to obtain possible savings of operational costs meeting the required indoor environmental conditions. The control shall ensure that heating and cooling is not occurring at the same time. In order to maintain a stable thermal environment, the control system needs to maintain the balance between supplied energy from the system and the losses/gains of building environment under transient conditions.

Figure 4 shows a diagram of the control principles. The supply water temperature can be controlled by a mixing valve, actuated to maintain the desired condition. In



B	boiler	M	manifold	RS	room sensor
C	chiller	MC	main controller	RTS	return medium temperature sensor
CU	control unit	MV	mixing valve	SOV	shut off valve
PTS	panel temperature sensor	OTS	outside temperature sensor	STS	supply medium temperature sensor
L	limiter	P	Pump	THS	temperature-humidity sensor

Figure 4. Principal diagram of a radiant ceiling panel system for heating and cooling.

the occupied space, there is a sensor for temperature and humidity, which can be used for zone control and/or give input to the control of the mixing valve and provide information to the Building Management System (BMS) to determine space dew point temperature which is necessary to prevent condensation in the building (surface, construction). Outside temperature sensors, supply-return water temperature sensors and in some cases surface temperature sensors are to be installed to influence the control.

The thermal mass and time constant of radiant panel systems are in most cases negligible compared to the thermal mass and time constant of a space. The time response and the thermal storage capacity of systems will depend on the design and materials used for the panels with integrated pipes. Panels with a higher thermal mass or panels with PCM (phase change materials) will have a significant effect if a change in room temperature level is needed. On the other hand, regarding controlling for variations in external climate and internal loads (people, sun, etc.), all the systems are quite fast in response on the room side because of the self-regulating effect.

Conclusions

In principle, ceiling mounted radiant panel systems are able to accommodate varying space sensible loads by controlling panel surface temperature. Heat is transferred from the radiant panel by the heat transfer mechanisms of convection and radiation. ISO 18566 series applies to all types of prefabricated radiant panels with an open air gap that are part of the room periphery such as ceiling, walls and floor. This standard specifies the design, test conditions and methods for the determination of the cooling and heating capacity and control of radiant heating and cooling panels with an open air gap. The ISO 18566 parts are integrated design standards including the design of the entire panel system by providing technical specifications and requirements, test facility and test method for heating and cooling capacity of ceiling mounted radiant panels, the design considerations and design processes, and control of ceiling mounted radiant panels system.

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