New European standards for design, dimensioning and testing embedded radiant heating and cooling systems.

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SUMMARY

Due to the increasing use of embedded, hydronic systems for heating and now also cooling of buildings there has been a need to revise the existing European standard EN1264-part2 for floor heating. At the same time a new set of standards EN15377 for these systems has been developed in relation to the many CEN-standards developed for implementing the Energy performance of Buildings directive.
The EN1264 standard series [1,2,3,4,5] have been revised as testing and prove standards for floor heating. A new part is now included for other surfaces (ceiling, walls) and also for cooling. The standard presents a test method either by calculation or by experimental testing. In this way the heating-cooling capacity can be tested under standardized conditions and used for certification.
The new standard EN15377 [6,7,8] includes calculation method for design and dimensioning of embedded radiant heating and cooling systems. For some systems the same calculation methods as in EN1264 is used for design and dimensioning. For other system types not covered by EN1264 new calculation methods are included. A separate part is dealing with systems (TABS) embedded directly in the building mass (slabs). This part shows how to take into account the dynamic behavior of the system.

INTRODUCTION

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The new standard for embedded, water based surface heating and cooling systems, EN15377 consists of the following parts:

— Part 1: Determination of heating and cooling capacity

— Part 2: Design, dimensioning and installation

— Part 3: Optimizing for use of renewable energy sources and dynamic considerations

In Part 1 the steady state heating and cooling capacity is determined calculation in accordance with design documents and a model. The calculation models are listed in prEN1264 part 2 and 5 and in EN15377-1. In the case of special constructions and if necessary, the determination of thermal performance by calculation is combined with a test method according to EN1264-2.
The heating-cooling capacity is given as a function of the temperature difference between room and mean water temperature.
The surface temperature and the temperature uniformity of the heated/cooled surface, nominal heat flow intensity between water and space, the associated nominal medium differential temperature and the field of characteristic curves for the relationship between heat flow intensity and the determining variables are given as the result.
The standard include several methods like general Finite Difference or Finite Element methods, simplified calculation methods depending on position of pipes and type of building structure. The simplified calculation methods are specific for the type of system. The standard is for

systems which are calculable in accordance with EN1264 part 2 and part 5. The simplified methods include certain boundary conditions, which must be met before the given method is applied.

CONCEPT OF THE METHOD TO DETERMINE THE HEATING AND COOLING CAPACITY

A given type of surface (floor, wall, and ceiling) delivers, at a given average surface temperature and room temperature (operative temperature θ_i), the same heat flow intensity in any space independent of the type of embedded system. It is therefore possible to establish a basic formula or characteristic curve for cooling and a basic formula or characteristic curve for heating, for each of the type of surfaces (floor, wall, and ceiling), independent of the type of embedded system, which is applicable to all heating and cooling surfaces.
Two methods are included in this standard:
Different simplified calculation methods are included in for calculation of the surface temperature (average, maximum and minimum temperature) depending on the system construction (type of pipe, pipe diameter, pipe distance, mounting of pipe, heat conducting devices, distribution layer) and construction of the floor/wall/ceiling (covering, insulation layer, trapped air layer, etc). The simplified calculation methods are specific for the given type of system, and the boundary conditions listed in the standard must be met. In case a simplified calculation method is not available for a given type of system, either a basic calculation using two or three dimensional finite element or finite difference method can be applied or a laboratory testing in combination with a calculation may be applied according to EN1264
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. If proved certificated values for the specific thermal output shall be used, generally EN 1264 part 2 and/or Part 5 apply.

HEAT EXCHANGE COEFFICIENT BETWEEN SURFACE AND SPACE

The relationship between heat flow intensity and the temperature difference between room and average surface temperature (θ_i - $\theta_{S,m}$) is given by equations (1) to (4)) depending on the type of surface (floor, wall, ceiling) and whether the temperature of the surface is lower (cooling) or higher (heating) than the space temperature.

Table 1 - Total heat exchange coefficient (combined convection + radiation) between surface and space, recommended max/min surface temperatures and heating capacity by 20 °C room temperature and cooling capacity by 26 °C room temperature for cooling (EN15377-1, Olesen et. al. 2000 [10]).

		Total heat exchange coefficient W/m².K		Acceptable surface temperature °C		Maximum capacity W/m²	
		Heating	Cooling	Max. Heating	Min. Cooling	Heating	Cooling
Floor	Perimeter	11	7	35	19	165	42
	Occupied Zone	11	7	29	19	99	42
Wall		8	8	~40	17	160	72
Ceiling		6	11	~27	17	42	99

Floor Heating and Ceiling Cooling $q = 8,92\ (\theta_i - \theta_{S,m})^{1,1}$ (1)

For other types of situations the following relations shall be used:

Wall heating and Wall cooling:	$q = 8\ (\mid \theta_i - \theta_{S,m} \mid)$	(2)
Ceiling Heating:	$q = 6\ (\mid \theta_i - \theta_{S,m} \mid)$	(3)
Floor cooling:	$q = 7\ (\mid \theta_i - \theta_{S,m} \mid)$	(4)

SIMPLIFIED CALCULATION METHODS FOR DETERMINING HEATING AND COOLING CAPACITY OR SURFACE TEMPERATURE

Two types of calculation methods can be applied according to the type of system:
One method is based on a single power function product of all relevant parameters developed from the finite element method (FEM). Another method is based on calculation of equivalent thermal resistance between the temperature of the heating or cooling medium 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 (position of pipes, concrete or wooden construction) and the boundary conditions listed in the standards.

Universal single power function according to EN1264-2.

The heat flux between embedded pipes (temperature of heating or cooling medium) and the space is calculated by the general equation:

$$q = B \cdot \prod_i (a_i^{m_i}) \cdot \Delta\theta_H \qquad \text{(W/m}^2\text{)} \qquad (5)$$

where:

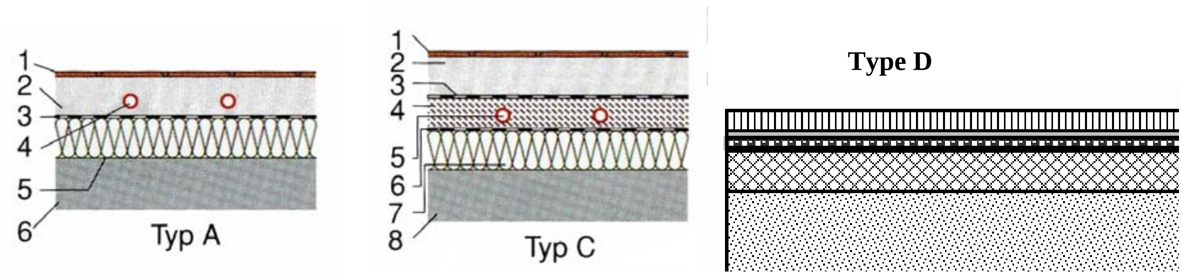
B a system-dependent coefficient in W/(m2·K). This depends on the type of system and on the heat exchange coefficient

$\prod_i (a_i^{m_i})$ the power product, which links the parameters of the structure (surface covering, pipe spacing, pipe diameter and pipe covering).

The heat flow density is proportional to $\Delta\theta_H$ where the heating /cooling medium differential temperature is:

$$\Delta\theta_H = \left| \frac{\theta_V - \theta_R}{\ln \dfrac{\theta_V - \theta_i}{\theta_R - \theta_i}} \right| \qquad °\text{C} \qquad (6)$$

Where: θ_i = Room operative temperature, °C
Θ_V = Supply water temperature, °C
θ_R = Return water temperature, °C



1-Floor covering; 2-Screed; 3-PE foil; 4-pipes; 5-Insulation; 6-Structure slab; -

1-Floor covering; 2-Screed; 3-PE foil; 4-Scred; 5-pipes; 6-vapour barrier; 7-insulation; 8-structure slab.

Floor covering, load distribution Plane floor section, insulation, Structure slab

Figure 1: System type A, C and D covered by the calculation method in EN1264-2 and 5.

This calculation method is given in EN1264 part 2 for the system types A, B, C, and D (see figures 1 and 2)

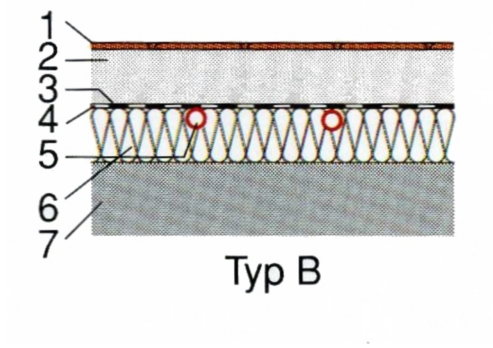
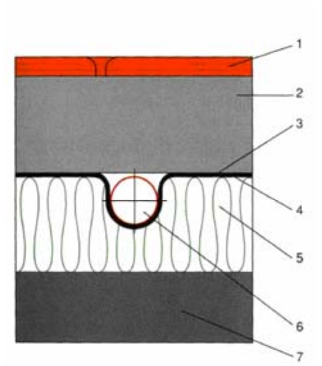
	
1-Floor covering; 2-Screed; 3-PE foil 4-Heat conducting plate (device); 5-Pipes 6-Insulation; 7-Structure slab	1-Floor covering; 2-Screed; 3-PE foil 4-Heat conducting plate (device); 5-Pipes 6-Insulation; 7-Structure slab

Figure 2: System type B covered by the calculation method in EN1264-2 and 5.

Thermal resistance methods

The heat flux between embedded pipes (temperature of heating or cooling medium) and the space or surface is calculated using thermal resistances. The concept is shown in Figure 3.
An equivalent resistance, R_{HC}, between the heating or cooling medium to a fictive core (or heat conduction layer) at the position of the pipes is determined. This resistance includes the influence of type of pipe, pipe distance and method of pipe installation (in concrete, wooden construction, etc). In this way a fictive core temperature is calculated. The heat transfer between this fictive layer and the surfaces, R_i and R_e (or space and neighbor space) is calculated using linear resistances (adding of resistance of the layers above and below the heat conductive layer).
The equivalent resistance of the heat conductive layer is calculated in different ways depending on the type of system. This calculation method, using the general resistance concept, is given in for the following two types of systems shown in figure4 (Type E and F) and figure 5(Type G).
The equivalent resistance of the conductive layer may also be determined either by calculation using Finite Element Analysis (FEA) or Finite Difference Methods (FDM) or by laboratory testing according to prEN1264-2.
The heating and cooling capacity are in some of the described calculation methods determined directly (see EN1264 part 5).
In other calculation methods, the average surface temperature is determined and the heating and cooling capacity is calculated according to:

$$q_{des} = h_t (| \theta_{s,m} - \theta_i |)$$

For evaluation of the performance of the system – and when calculating the total heating and cooling power needed from the energy generation system (boiler, heat exchanger, chiller, etc.) – the heat transfer at the outward (back) side shall also be considered. This heat transfer shall be regarded as a loss if the outward side is facing the outside, an un-conditioned space or another building entity, and it depends on the temperature difference between the pipe-layer as well as the heat transfer resistance to and the temperature in the neighbor space or outside.

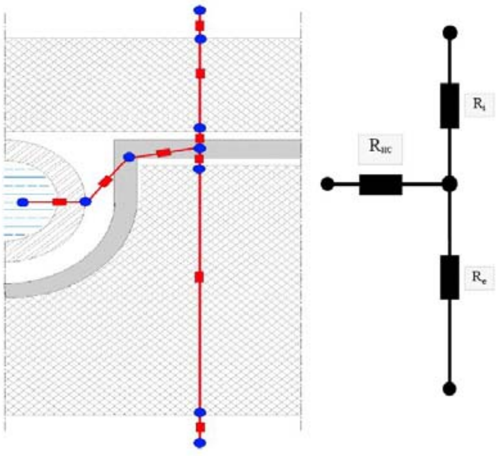


Figure 3 Basic networks of thermal resistances

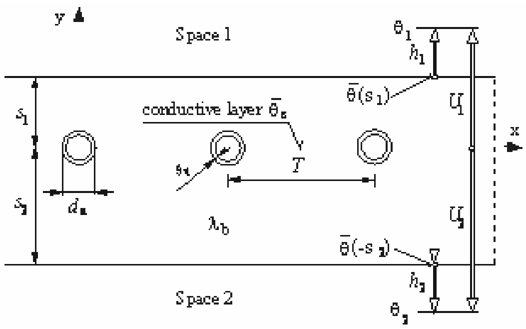


Figure 4a Pipes embedded in a massive concrete layer, Type E (EN15377-1)

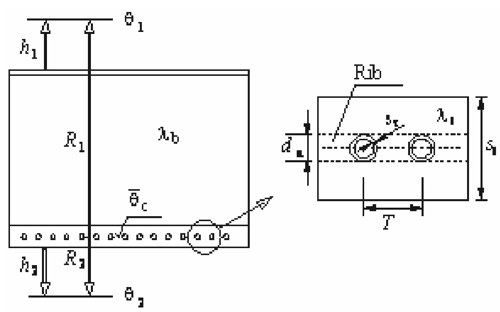


Figure 4b Capillary pipes embedded in a layer at the inner surface, Type F (EN15377-1)

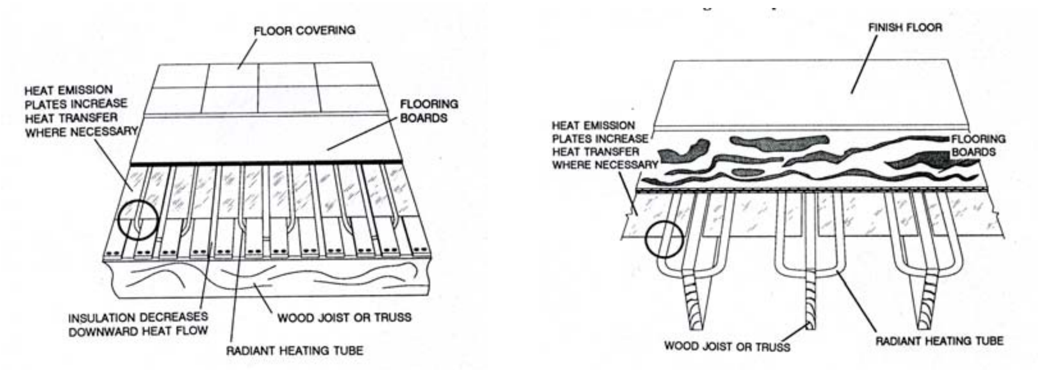


Figure 5 Pipes embedded in a wooden floor construction, Type G (15377-1, [11]

EN15377- PART 3: OPTIMIZING FOR USE OF RENEWABLE ENERGY SOURCES

The aim of this standard is to give a guide for the design of water based embedded heating and cooling systems to promote the use of renewable energy sources and to provide a method for actively integrating the building mass to reduce peak loads, transfer heating/cooling loads to off-peak times and to decrease systems size. A section in the standard describes how the design and dimensioning can be improved to facilitate renewable energy sources. Peak loads can be reduced by activating the building mass using pipes embedded in the main concrete structure of the building (**T**hermo-**A**ctive-**B**uilding-**S**ystems, TABS). For this type of systems, the steady state calculation of heating and cooling capacity (part 1 of this standard) is not sufficient. Thus, several sections of this standard describe methods for taken into account the dynamic behavior. The proposed methods are used to calculate and verify that the cooling capacity of the system is sufficient and to calculate the cooling requirements on the water side for sizing the cooling system.

Thermo Active Building Systems (TABS)

A Thermo-Active-Building-System (TABS) is a water based heating and cooling system, where the pipes are embedded in the central concrete core of a building construction. The heat transfer takes place between the water (pipes) and the concrete, between the concrete core and the surfaces to the room (ceiling, floor) and between the surfaces and the room.
The peak-shaving is the possibility to heat and cool the structures of the building during a period in which the occupants may be absent (during night time), reducing also the peak in the required power (Figure 6). In this way energy consumption may be reduced and lower night time electricity rate can be used. At the same time a reduction of the size of cooling system including chillier is possible

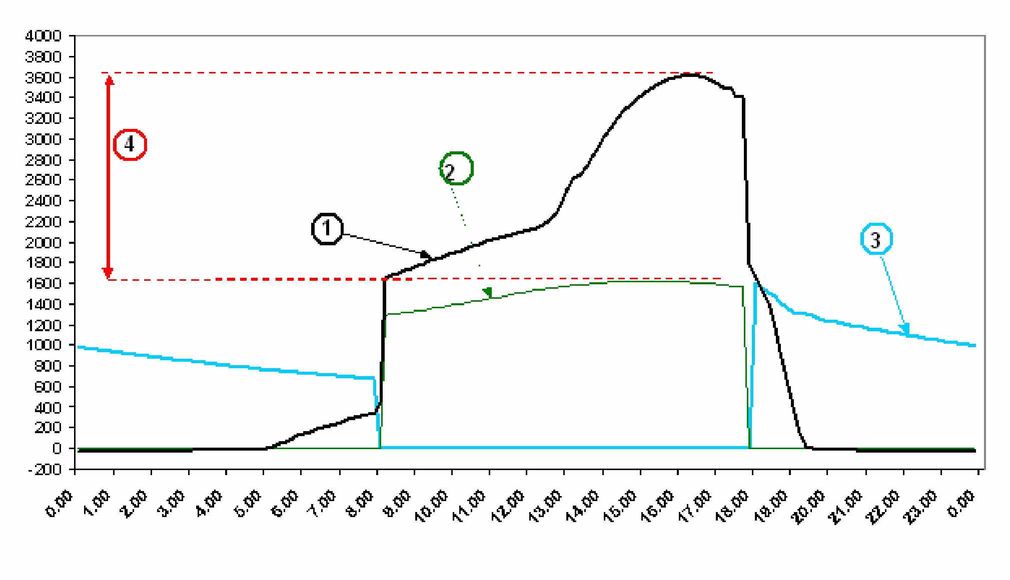


Figure 3 – Example of peak-shaving effect (X-axes: time; y-axes: cooling power W)
1) heat gain, 2) power needed for conditioning the ventilation air, 3) power needed on the water side, 4) peak of the required power reduction

The performance and dimensioning of TABS can be done by full dynamic building simulations with commercial programs including calculation models for embedded pipes. (Olesen and Dossi, [9]). The standard includes a more simplified calculation method. Besides the standard includes diagrams like the one shown in Figure 7 [12]. This simplified diagram give the relation between internal heat gains, water supply temperature, heat transfer on the room side, hours of operation and heat transfer on the water side. The diagrams correspond to a concrete slab with

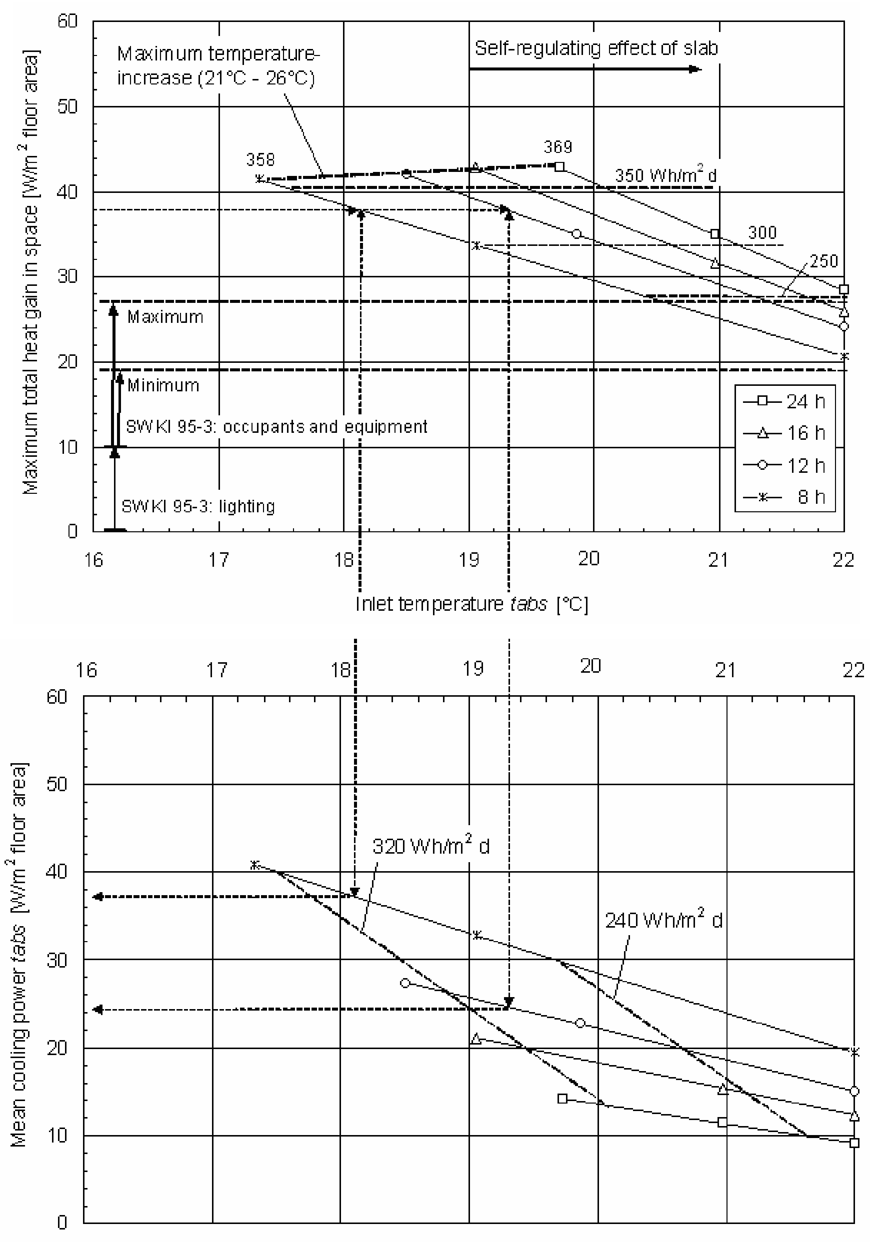


Figure 5 – Working principle of TABS (Koschenz and Lehmann [12]

raised floor (R=0.45 m^2K/W) and a permissible room temperature range of 21 °C to 26 °C. The upper diagram shows on the y-axis the maximum permissible total heat gain in space (internal gains plus solar gains) W/m^2 , and on the x-axis the required water supply temperature. The lines in the diagram correspond to different hours of operation (8h, 12h, 16h, and 24h) and different maximum amount of energy supplied per day Wh/m^2 d . The lower diagram shows the cooling power W/m^2 required on the water side (for dimensioning of chiller) for thermally activated 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 by a maximum internal heat gain of 38 W/m^2 and 8 hour operation, a supply water temperature of 18,2 °C is required. If, instead, the system is in operation for 12 hours, a supply water temperature of 19,3 °C is required. In total, the amount of energy rejected from the room is app. 335 Wh/m^2 per day. The required cooling power on the water side is by 8 hours operation 37 W/m^2 and by 12 hours operation only 25 W/m^2. Thus, by 12 hours operation, the chiller can be much smaller. The total heat rejection on the water side is app. 300 Wh/m^2 per day.

SUMMARY AND DISCUSSION

This paper presents a new and a revised European standard for the calculation of heating and cooling capacity for hydraulic, radiant surface heating and cooling systems. Different “simplified” calculation methods, depending on the type of construction, have been presented. In contrast to radiant heating and cooling panels, where the heating/cooling capacity must be determined by testing in a standardized test room, the determination for embedded systems is based on calculations. Besides the included “simplified calculation methods,” the standard also allows the use of finite difference and finite element methods. The manufacturers of radiant heating and cooling systems can use the standardized calculation methods to develop diagrams relating water temperature and space temperature to the cooling-heating capacity. This will avoid unnecessary testing of systems.

Besides the new standard includes a part describing methods to take into account the dynamic effects of thermally activated building systems (TABS), where the pipes are embedded in the main building structure (concrete slabs or walls), to activate the building mass.

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