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On the heat transfer coefficients between heated/cooled radiant floor and room

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ABSTRACT

The radiant floor heating/cooling systems are more often used in new designed and modernized buildings, what renewed the interest in the study of the characteristic parameters, which are taking in to account by dimensioning or detailed scientific analyzes of such a systems.

Very important and fundamental characteristic parameters for radiant floor are heat transfer coefficients.

This article presents the results of experimental research on heated/cooled radiant floor conducted in the laboratory room in the climatic chamber, which aim was to estimate experimentally the values of heat transfer coefficients for the surface of cooled/heated radiant floor.

The values of radiant, convective and total heat transfer coefficients were developed on the basis of the amount of heat emitted from the radiant surface and by the use of proper and clearly defined reference temperature depending on the kind of heat transfer coefficient.

It was noticed, that the values of heat transfer coefficients for heated/cooled radiant floor, which are commonly used in practice, are overestimated, even in the range of 10–30%.

1. Introduction

Nowadays, radiant floor heating/cooling systems are commonly used in new residential and commercial buildings, that is why proper dimensioning is very important for later problem-free exploitation of this kind of systems. However, problems still exist in the estimation of cooling/heating capacity in the design stage [1] and may lead to increased energy consumption.

The main parameters, which are used for dimensioning, thermal comfort analysis or dynamic thermal simulations (CFD) of radiant systems, are heat transfer coefficients.

It may be the total heat transfer coefficient (h_{total}), which is most often used in engineering practice. Values of h_{total} may be assumed on the basis of EN 1264-5 [2] and then they remain constant, equal to 10.8 W m^{-2} K^{-1} and 6.5 W m^{-2} K^{-1} or from the guidebook [3] where are equal to 11.0 W m^{-2} K^{-1} and 7 W m^{-2} K^{-1} for radiant floor heating and cooling, respectively. Another way of h_{total} calculation for the radiant floor heating system, given in EN 1264-2 [4] and EN 15377-1 [5], is the use of Eq. [1].

$$h_{total} = 8.92 \cdot (T_s - T_{op})^{0.1} \quad (1)$$

However, for more detailed and exact thermal analyses convective heat transfer coefficient (h_c) and radiant heat transfer coefficient (h_r) values are necessary.

In case of the radiant heat transfer coefficient value from the surface of the radiator, it is recommended to assume it as the constant value equal to h_r = 5.5 W m^{-2} K^{-1} [6,7].

Then, for h_c calculation, many authors formulated dependencies, what was shown by Khalifa [8–10], Awbi et al. [11–13], Karadag et al. [14–17] and De Carli and Tomasi [18].

However, using these dependences, it can be ascertained that received results of h_c are divergent, which can cause the uncertainty during their use [19].

Some of these above values of h_{total}, h_c or h_r are used in more recent research in the construction of heat transfer model [20] or capacity calculation of radiant system [21,22], what may overestimate the heating/cooling capacity and may increase energy consumption and thermal discomfort during exploitation stage.

It is connected with the fact that the values of well-known heat transfer coefficients are estimated for amount of heat supplied to

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Nomenclature

$F_{\varepsilon_{s-j}}$	radiation interchange factor
F_{s-j}	view factor between radiant surface and j-surface
h_c	convective heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_r	radiant heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_{total}	total heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
q_c	convective heat flux density ($W\,m^{-2}$)
q_r	radiant heat flux density ($W\,m^{-2}$)
q_{total}	total heat flux density ($W\,m^{-2}$)
T_a	air temperature (°C)
T_{AUST}	average unheated surface temperature (°C)
T_j	j-surface temperature (°C)
T_{mr}	mean radiant temperature (°C)
T_{op}	operative temperature (°C)
T_{return}	return water temperature (°C)
T_{supply}	supply water temperature (°C)
T_s	radiant surface temperature (°C)
ε	emissivity
λ	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
σ	Stefan–Boltzmann constant ($W\,m^{-2}\,K^{-4}$)

Subscripts

a	air
0.1	at 0.10 m
0.6	at 0.60 m
1.1	at 1.10 m
1.7	at 1.70 m
c	convective
j	j-surface
r	radiant
s	radiant surface

the radiator, which is calculated in such a way by, e.g. Hajabdollahi et al. [23].

But the values of heat transfer coefficients should be calculated according to heat emitted from the radiant surface (obtained in experimental way), which is naturally not equal to the heat supplied to radiator, especially in case of commonly used radiant floor [24].

Therefore, the aim of this paper is to estimate experimentally the values of heat transfer coefficients for the surface of cooled/heated radiant floor, which will be calculated according to the real amount of heat emitted from the radiant surface.

2. Materials and methods

2.1. Description of the laboratory stand and experimental program

The special test chamber located in the laboratory room (with controlling indoor air temperature) was used to carry out measurements. The net internal dimensions of the test chamber are equal to 1.56 m × 1.56 m × 2.21 m (Fig. 1).

The test chamber has black walls, which are insulated from laboratory room with styrofoam (10 cm thick), what allows to get stable conditions during every experiments.

Also there is no other heated or cooled surface in the test chamber, which allows to evaluate only the analyzed floor radiator.

The floor radiator (1.56 m × 1.56 m) was made inside the chamber, in the wet technology. It consists of the following layers (counting from indoor air): terracotta (1.0 cm thick, λ = 1.050 $W\,m^{-1}\,K^{-1}$), layer of granolith (6.5 cm thick, λ = 1.200 $W\,m^{-1}\,K^{-1}$), pipes 16 × 2.0 PE-RT/Al/PE-RT with the distance of 15 cm and styrofoam (6.0 cm thick, λ = 0.045 $W\,m^{-1}\,K^{-1}$).

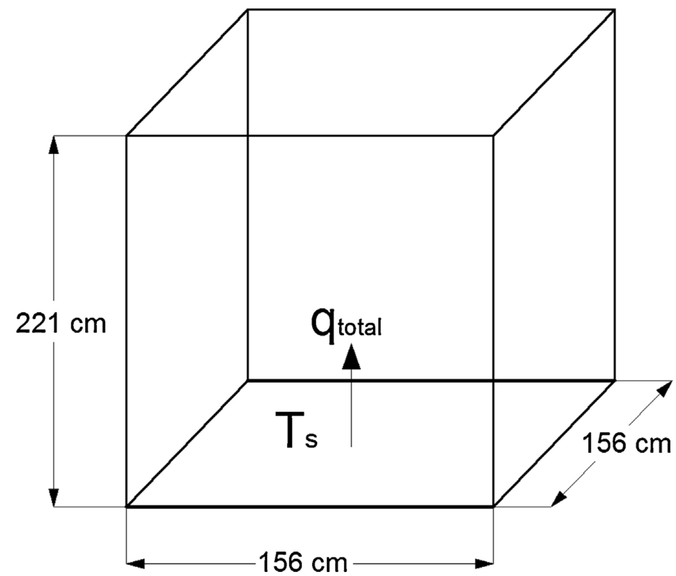

Fig. 1. Schema of environmental chamber.

The emissivity of the chamber surfaces and radiant floor surface, which are used for radiant heat transfer calculations, were estimated with the use of an infrared thermal imaging camera and calibrated PT500 sensors. The surface temperature was measured using the temperature sensors. Then the surface emissivity was changed in the setup of infrared camera in order to get the same temperature of the analyzed surface as obtained before by the use of temperature sensor.

The heat source for the analyzed system was ultrathermostat, which allows to keep constant temperature on supply.

The archive system and PT500 sensors were used for the measurement of the temperature of indoor air on different heights in the center of test chamber (0.1 m, 0.3 m, 0.6 m, 0.9 m, 1.1 m, 1.3 m, 1.7 m), black globe temperature (at heights 0.6 m, 1.1 m, 1.7 m), temperature of heating medium on supply (T_{supply}) and on return from floor radiator (T_{return}), temperature of radiant floor surface (9 sensors) and walls of the climatic chamber (10 sensors). The diameter of black globe is equal to 15 cm.

All above temperature sensors (PT500) were calibrated and their accuracy was equal to 0.1 K.

Two calibrated sensors for heat flux density (12 cm × 12 cm) were used for the measurement of heat flux density emitted from the radiant surface (q_{total}). The accuracy of heat flow meter in analyzed range was equal to 2%.

It was very important to obtain very good contact between sensors and surface, that is why temperature sensors and heat flux density sensors were stuck very precisely to the surfaces with the special glue (1 mm thick), which is characterized by the large value of heat conduction coefficient (the value is close to copper and equal to λ = 400 $W\,m^{-1}\,K^{-1}$).

The temperature sensors and heat flux density sensors were placed on the radiant floor surface in the representative area (Fig. 2), in order to get the mean values of temperature of radiant surface and heat flux density emitted from the radiant surface, respectively.

The turbine-flow meter with the impulse output (600 impulse per liter) was used for the measurement of volume flow rate of heating medium.

The experimental program consist in supplying the radiant floor with heating medium, which temperature values were set at: 30 °C, 35 °C, 40 °C, 45 °C, 50 °C and 55 °C.