Applied Thermal Engineering 117 (2017) 76–84

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

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

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HIGHLIGHTS

- Experimental research on heated/cooled radiant ceiling in the climatic chamber.
- New values of radiant, convective and total heat transfer coefficients.
- Coefficients required in dimensioning or scientific analyzes of radiant ceiling.
- Comparison of heat transfer coefficients for radiant ceiling and for radiant floor.

ARTICLE INFO

Article history:
Received 12 August 2016
Revised 25 December 2016
Accepted 5 February 2017
Available online 7 February 2017

Keywords:
Heat transfer coefficients
Radiant ceiling
Radiant heating
Radiant cooling
Designing

ABSTRACT

The heat transfer coefficients are very important parameters which are used to design and analyze the radiant heating/cooling systems in detail. However, in order to do this properly, the values of heat transfer coefficients should be estimated on the basis of heat/cold emitted to the room, rather than heat/cold supplied to the radiator.

This article presents the experimental results of heat transfer coefficients for a heated/cooled radiant ceiling, which were estimated on the basis of heat/cold emitted to the room.

The heat transfer coefficients were compared with the ones commonly used in the literature and the recommendations for improvements were provided.

It was noticed that the values of heat transfer coefficients are overestimated, especially for the heated radiant ceiling.

Attention was paid to the assumption of proper reference temperature depending on the mechanism of heat transfer. The comparison of heat transfer coefficients for the heated/cooled radiant ceiling and heated/cooled radiant floor was presented as well.

1. Introduction

At present, the radiant low temperature heating and high temperature cooling systems are increasingly often used for heating/-cooling of buildings, which is connected with a decrease in energy demand of buildings and the tendency of using low temperature heat sources. This fact caused the return to scientific research focused on radiant heating/cooling systems in different aspects [1,2], aiming to deliver the most accurate parameters for designers and users of such systems.

Fontana [3] analysed the influence of furniture presence on the energy performance of a radiant floor heating system, because it should be taken into account while performing analyses of such systems. The influence of solar radiation on heat transfer in the case of radiant floor cooling system was also taken into account [4,5], and a new method of designing a radiant floor cooling system was proposed [6].

The comparison and evaluation of energy performance of radiant system with other systems commonly used in practice were provided as well [7–11].

The research also focuses on heat transfer coefficients which are used by designers dimensioning radiant floor [12–22], ceiling [23–25] and wall heating/cooling systems [26–28].

For example, there are several dependencies used to estimate the convective heat transfer coefficient for radiant heating/cooling systems, which were presented by Khalifa [15,16] and Karadag et al. [21,22]. The convective heat transfer coefficient may be estimated taking into account the difference between the total heat flux and radiant heat flux or by using Nusselt number and Rayleigh number in the form of criterial dependencies.

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http://dx.doi.org/10.1016/j.applthermaleng.2017.02.019
1359-4311/

Nomenclature

A	area of surface (m^2)
$F_{\varepsilon_{s-j}}$	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

However, most of these heat transfer coefficients were not estimated according to heat/cold emitted to the room, measured in a direct and experimental way, but according to the heat/cold supplied to the radiator, which is inaccurate in the case of radiant floor, ceiling or wall. Nevertheless, accurate heat transfer coefficients are very important not only for the system designers but also for the researchers who made thermal analyses of such systems and would like to obtain high correlation rate between the calculated and numerical results.

We have already made such estimation for heated/cooled radiant floor [29], but for radiant ceiling such analyses have not been available until now. Therefore, in this study we have developed the values of heat transfer coefficient for heated/cooled radiant ceiling, according to the amount of heat emitted from the radiant surface.

2. Materials and methods

2.1. Description of the laboratory stand and experimental program

A test chamber which was used to carry out the experiment was located in the laboratory room in which the indoor air temperature was controlled and identical for all measurements. Internal dimensions of the test chamber were equal to 1.56 m × 1.56 m × 2.21 m (Fig. 1). In order to obtain stable conditions during experiments, the floor and walls of the chamber were painted black and were insulated with 10 cm thick styrofoam. The emissivity of the chamber surfaces and radiant ceiling surface were estimated experimentally with the use of an infrared thermal imaging camera and calibrated PT500 sensors, and are equal to 0.95 and 0.9, respectively. In order to evaluate the ceiling radiator, the ceiling was the only heated or cooled surface in the test chamber.

The ceiling radiator was built by placing pipes on the ceiling of the chamber. The space between pipes has been filled with granolith (2 cm layer) and plasterboard was attached as the final layer. Dimensions of the ceiling radiator were equal to 1.56 m × 1.56 m. The specified parameters of the ceiling radiator layers (counting from indoor) were as follows: plasterboard (1.2 cm thick, $\lambda = 0.25\,W\,m^{-1}\,K^{-1}$), layer of granolith (2.0 cm thick, $\lambda = 1.2\,W\,m^{-1}\,K^{-1}$), pipes 16 × 2.0 PE-RT/A1/PE-RT. The distance between pipes was equal to 15 cm.

In order to determine the heat transfer coefficient from the radiant ceiling, the total heat flux density (q_{total}) and the temperature value were measured every 5 min for 24 h. The temperature was measured by means of PT500 sensors with the accuracy of 0.1 K. These sensors were calibrated and placed indoors at different heights in the centre of the chamber (0.1 m, 0.3 m, 0.6 m, 0.9 m, 1.1 m, 1.3 m, 1.7 m). Black globe (diameter equal to 15 cm) temperature was measured at heights of 0.6 m, 1.1 m and 1.7 m. The temperature of the radiant ceiling surface and the walls of the climatic chamber were measured by means of 9 PT500 surface sensors and 10 PT500 sensors, respectively. The temperature of heating medium on supply (T_{supply}), and return temperature (T_{return}) was measured as well. In order to keep constant conditions on supply, the ultrathermostat was used as a heat/cold source.

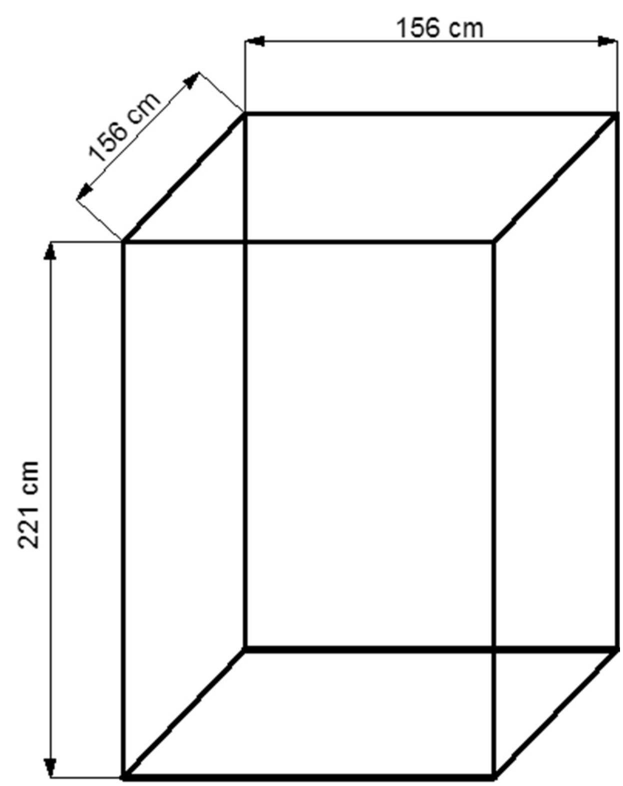

Fig. 1. Schema of the environmental chamber.

Heat flux density emitted from radiant surface (q_{total}) was measured with two calibrated sensors (12 cm × 12 cm) characterized by the uncertainty of measurement in the range of 2%.

The temperature and heat flux sensors were placed on the ceiling surface in the representative area, which is shown in Fig. 2. The arranged sensors allow to measure the mean values of the temperature of radiant surface (T_s) and heat flux (q_{total}).