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Experimental investigation of heat transfer coefficients between hydronic radiant heated wall and room

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ABSTRACT

The reason radiant heating systems are highly preferred in recently designed or a modernized construction is due to their energy efficiency and low exergy destruction. Radiant heating systems are different from typical HVAC systems because they heat surfaces rather than air and can save large amounts of energy while providing higher levels of comfort.

The fundamental design parameters for a radiant heating system are heat transfer coefficients such as radiation, convection and total heat transfer coefficients. In this study, the values of radiant, convective and total heat transfer coefficients were calculated based on the experimental results that were taken from the climatic test chamber.

This article presents the results based on an experimental research on heated radiant hydronic wall panels mounted in the climatic test chamber. The aim was to estimate the values of heat transfer coefficients for different location configurations of radiant wall heating panels experimentally. This experimental study was conducted under the location configurations of 3 different wall panel arrangements for 7 water flow temperatures ranging from 30 °C to 42 °C.

It was noticed that the amount of radiation heat transfer increased when the crosswise area of the window surface was heated and simultaneously the heat transfer capability of radiation rose by 70% of the total heat transfer.

1. Introduction

Since number of environmental problems, one of which is global warming, has increased and its magnitude has started to threaten peoples' lives, the efficient usage of energy has become of the most important issues. In many fields, people are trying to lower the energy consumption and use energy in more efficient ways. The energy usage in buildings is one of the biggest portions of the total energy demand in the world, and that is considered to be 40%. The main reason for this high energy consumption rate is HVAC systems, which are mounted on buildings for cooling and heating applications. Implementing positive change and that is to reduce the energy consumption rate in this field requires a great amount of research. Moreover, technology has been improving quite fast recently and many papers have been released [1–11].

In terms of the aforementioned facts, radiant heating-cooling systems, which are quite convenient alternatives for the traditional HVAC systems, meet the efficiency requirements by producing more comfortable environments. They reduce energy consumption [12–21] because of low-temperature heating and cooling operations. The radiant heating and cooling system consists of large radiant surfaces installed on room walls, floors or ceilings. A conditioned surface is called as a radiant panel if 50% or more of the designed heat transfer on the temperature-controlled surface takes place by thermal radiation [22]. Thus, it is feasible to use lower supply temperatures for heating and higher supply temperatures for cooling. This factor improves energy efficiency and at the same time reduces energy consumption. In addition, they could easily be combined with alternative low exergy sources such as geothermal energy, groundwater, heat pumps and recovered waste heat [23–26].

The indispensable parameters used in radiant heating and cooling systems are heat transfer coefficients. The determination of heat transfer coefficients for the radiant panels is fundamental to the design procedure of radiant heating-cooling systems, CFD analysis, thermal comfort studies, building information and modeling

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Nomenclature

A	area (m^2)
T_a	air temperature (°C)
T_{op}	operative temperature (°C)
T_s	surface temperature (°C)
T_w	Water temperature (°C)
T_{ref}	reference temperature (°C)
AUST	Area weighted average temperature (°C)
h_{tot}	Total heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_r	radiation heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_r	convective heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
q_{tot}	total heat flux ($W\,m^{-2}$)
q_c	convective heat flux ($W\,m^{-2}$)
q_r	radiation heat flux ($W\,m^{-2}$)
U	coefficient of thermal transmittance of surfaces ($W\,m^{-2}\,K^{-1}$)
F	view factor

(BIM). The calculation for radiant wall systems as in (Eq. [1]), which is given in EN 1264-5 [27] and EN 15377 [28], is often used in engineering processes for radiant heating and cooling.

$$q_{total} = 8.(T_{op} - T_s) \quad (1)$$

To design the radiant system, the radiant heat transfer coefficient (h_r) and convective heat transfer coefficient (h_c) values are necessary to estimate the heating and cooling capacity of a radiant system. In the literature, several values and calculations for heat transfer coefficients are given by Khalifa [29–31], Awbi et al. [32–34], Karadag et al. [35–37], Min et al. [38]. The average convective heat transfer coefficient in the literature for a heated floor or a cooled ceiling configuration, are between 2.8 and 4.8 $W\,m^{-2}\,K^{-1}$. And the radiant heat transfer coefficient is between 5.4 and 6.2 $W\,m^{-2}\,K^{-1}$ [28,39,40]. Furthermore, total heat transfer coefficients range from 7.8 to 9.3 resulting in an average value of 8.5 $W\,m^{-2}\,K^{-1}$ [29–39].

So far, a great deal of research on thermal properties and the heat transfer coefficients for radiant heating and cooling systems have been conducted. Andres-Chicote et al. [41] had done an experimental study on the cooling capacity of a radiant cooled ceiling system. A series of experimental tests about hydronic heating and cooling radiant ceiling panels were performed by Fonseca Diaz [42] Tian et al. conducted research on the actual cooling performance of ceiling panels [43]. Dongliang et al. focused on the operating characteristics of lightweight radiant floor heating systems by analyzing experimentally and numerically [44]. Okamoto et al. developed a calculation method for estimating heat fluxes from ceiling radiant panels for different insulation materials and supply water temperatures in heating and cooling cases [25].

Causone et al. evaluated the heat transfer coefficients between a radiant ceiling and a room in typical conditions of occupancy in an office or residential building [45]. He indicated that, for the heated and cooled ceiling the radiant heat transfer coefficient can be considered constant at 5.6 $W\,m^{-2}\,K^{-1}$. The data is very close to the ones calculated by Olesen et al. [39] Furthermore the total heat transfer coefficient for cooled ceiling has an average value of about 13.2 $W\,m^{-2}\,K^{-1}$. These values are significantly higher than the ones typically shown in the literature (~11 $W\,m^{-2}\,K^{-1}$) [40].

Cholewa [46] proposed the total heat transfer coefficient for heated floor in the range of (8.5–11.1 $W\,m^{-2}\,K^{-1}$). Furthermore he proposed using the value of radiant heat transfer coefficient (h_r) of 5.6 $W\,m^{-2}$ for heated radiant floor, as recommended by Causone et al. [45].

Myhren et al. [24] did research to find out how different heating systems and their locations affect the indoor climate. Tye-Gingras et al. carried out a numerical study on radiant heating panels which were modeled at different locations in the room and the effects of these applications on thermal comfort were discussed by taking the results numerically from the CFD analysis [47].

In the present study, heat transfer coefficients were calculated for different wall panel location configurations by using a real size test chamber. Most of the submitted studies have been encouraging for ceiling and floor heating-cooling systems. However, in this study the heat transfer coefficients of wall mounted radiant heating systems were investigated.

The reason a real size test chamber was used in this study was to obtain the most realistic results and to compare them with the heat transfer coefficients which were calculated before by using some prior standards. One of the goals of this study is to discuss to what extent the results obtained by these standards coincide with real life conditions.

The main aim of this research is to provide further experimental information for a better understanding of heat transfer phenomena from radiant wall heating surfaces and to clarify the vague conceptions in heating operations. For this reason, the heat transfer coefficients, which were investigated under different thermal conditions and heating operations in the test chamber, were fulfilled by advanced test chamber measuring devices. The outside conditions of the test chamber were adjusted to a certain temperature.

Heating tests were done for three different location configurations which are the west wall (case-1), the north (case-2) wall and the both combined (case-3).

The experimental facility for measuring the system's heating output was provided. Natural convection conditions and a wide range of tolerable temperatures were also considered during the investigation. The heat transfer correlations were studied and the amount of radiation and convection heat transfer was calculated for all different configurations. Then, the findings were analyzed and compared with those found in the literature.

2. The experimental setup

2.1. The arrangement of the test chamber

The climatic test chamber was constructed to get realistic test results for different heating applications under different climatic conditions. The climatic chamber used during the tests was built in such a way as to reproduce the possible structure and characteristics of a real size room which is presented in Fig. 1 as accurately as possible. This chamber, which is composed of 5 volumes: ceiling (volume-1), floor (volume-4), exterior (volume-2), inner volume (volume-3) and studied volume (volume-5), encloses the test chamber, which is characterized by a floor area of 24 m^2 (6.00 m × 4.00 m) and an internal height of 3.00 m. The wall types are chosen as the sandwich type with polyurethane insulation between two layers made out of sheet steel which has engagement and locking mechanism to increase the strength. The insulation thicknesses and the coefficient of thermal transmittance of walls for different zones were determined according to Turkish Standard (TS) item 825 (thermal insulation requirements for buildings), presented in Table 1 [48]. The window, (115 cm × 160 cm) which overlooks the zone-2, is double-glazed and the door (82 cm × 204 cm) is single glazed with U-value of 2.20 $W\,m^{-2}\,K^{-1}$ and 2.60 $W\,m^{-2}\,K^{-1}$, respectively.

Temperature, humidity and air velocity range of the composed 4 volumes are presented in Table 2.