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A numerical investigation of fluid flow and heat transfer inside a room for floor heating and wall heating systems

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ABSTRACT

In this study, a comparative study between floor heating system and wall heating system is carried out. Air flow and heat transfer inside a room which is heated by floor heating and wall heating systems are investigated numerically for a residential building located in Kocaeli province, Turkey. Computations are performed for three different water temperatures, namely 30 °C, 40 °C and 50 °C. Computations show that a strong circulation occurs in the room for the floor heating system which covers the whole occupied zone and may exceed the thermal comfort conditions while a weak circulation forms in the room for the wall heating system which is gentle enough to be unnoticed for human body. It is also observed that a homogenous temperature distribution occurs in the room for the floor heating system. Although a thermal stratification occurs in the room for the wall heating system, the temperature gradient is less than 1 °C/m, which does not cause discomfort. It is concluded that engineers should consider wall heating system rather than floor heating system since better thermal performance and thermal comfort conditions can be achieved with lower water temperature, thus the fuel consumption and consequently emissions of greenhouse gases can be reduced considerably.

1. Introduction

Hydronic radiant floor heating is a system of pipes embedded into floor that carries hot water into rooms, dispersing the heat through the floor surface. Although it has being used since ancient times, it was almost forgotten in the last century with the spread of panel heating system. Once again there has been a growing interest in radiant heating system in the last decades due to its advantages in comparison with other heating systems. For instance, more than 50% of the new generation of residential buildings in Europe is constructed with radiant floor heating system [1]. It is reported that the radiant floor heating system market has steadily grown in North America [1]. Also, it is widely used in most of eastern countries where people traditionally tend to directly sit or sleep on the floor [2,3]. Floor heating systems have become popular in Japanese houses as well particularly for elderly people since it allows the elderly to live comfortably and safely [4]. The application of floor heating system is seen not only in the residential buildings but also in public buildings such as mosques where people sit and pray on the floor in countries such as Turkey. The main advantage of the floor heating system is significant improvement in both thermal comfort and energy efficiency due to utilization of lower temperatures of heating medium, which results in direct energy savings due to better boiler efficiency. Increasing the boiler efficiency will decrease building energy consumption. Consequently, global fossil fuels consumption and environmental issue will be reduced significantly since about 40% of total energy is used in buildings in the most of developed countries. In addition, due to lower temperature of water, radiant heating system can be operated by solar energy or waste heat which eliminates the requirement of fossil fuels [5,6]. Furthermore, it is quiet due to absence of blower fans and flexible due to absence of the terminal heaters in the room and safe.

Efficiency and thermal comfort of floor heating system have been investigated extensively by a number of research groups in recent years ([1–5,7–29] to cite a few). The heat output of radiant heating system is determined by pipe spacing, water temperature, flow rate and floor covering. The effect of several design parameters such as pipe diameter, type, number, thickness and cover of system on the radiant floor heating system performance is studied numerically in [7]. It was shown that pipe type and diameter have the minimum effects while type and thickness of the cover have the maximum effect on the thermal performance of the floor heating system. Jin et al. [8] studied the effect of thermal resistance of pipe and water velocity on the performance of floor cooling system. They showed that the performance of the system is affected only when the thermal conductivity of the pipe is low and the effect of water velocity on the performance of the cooling system is not significant. Song [3] investigated experimentally the performance of the

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ONDOL floor heating system for 10 types of covering materials and showed that temperature fluctuations in the floor surface decrease with lower contact coefficient of the covering material. Thermal performance of radiant heating floors in furnished enclosed spaces is investigated experimentally in [9]. It is shown that the furniture presence affects the thermal performance of floor heating system. The efficiency of radiant wall mounted panels is investigated experimentally in [10]. It is reported that the introduction of heating–cooling wall panels resulted in considerable energy reduction also in better indoor comfort because of large vertical heating and cooling areas with optimal surface temperatures.

Fluid flow and heat transfer in the room heated by radiant heating system is investigated numerically in [11–15]. Gingras and Gosselin [12] presented a hybrid numerical optimization study of a heating ceiling and wall hydronic radiant panel system in a residential building located in Quebec city, Canada. It was reported that controlling of water temperature is the most important parameter for maximizing comfort and minimizing energy consumption of radiant heating system. The effects of ceiling and floor surface temperatures and room dimensions on the Nusselt number for a floor heating system were investigated numerically in [13]. The effect of the insulated ceiling conditions was also considered in [14].

Even there are numerous advantages of floor heating system, performance of the system depends strongly on the thermal resistance of covering material of the floor [3,7] which is the weakest link of the floor heating system since users can alter the thermal resistance of the floor by covering the floor with carpets without being aware of design conditions. This causes some problems in using of the floor heating systems particularly in the eastern countries where the carpet is essential since people tend to directly sit or sleep on the floor. Embedding pipes into the wall instead of the floor, which is called wall heating system, may eliminate such problems. The wall heating systems operate on the same principle as floor heating systems. Besides, the floor area can be freely used without limitations on architectural design or occupant use. Therefore, in this study the performance of the wall heating system is investigated for different water temperatures and compared with that the floor heating system. So, a numerical study is performed to model the flow and heat transfer in a residential building located in Kocaeli province, Turkey for both heating systems.

2. Problem description and numerical method

In this study, air flow and heat transfer inside a room which is heated by floor heating system and wall heating system are investigated numerically. A schematic representation of the room conditions is shown in Fig. 1. As seen in the figure, the width (W) and height (H) of the room are taken as 2.8 m. The floor construction for floor heating system and the inner wall construction for wall heating system are illustrated in Fig. 1a and b, respectively. As seen in the figure, pipes of diameter 16 mm are installed into the floor for floor heating system and into the inner wall for wall heating system. The finishing layer is assumed to be wood for floor heating system while it is assumed to be gypsum plaster for wall heating system which of both are the most common materials used in such applications in Turkey. Thus, conductive resistance of the wall heating system is lower than that of floor heating system. Since a comparison study is carried out in this study the carpet on the floor is not considered in the computations which increase the conductive resistance further and reduce the thermal performance of the floor heating system. The exterior wall is in contact with environment of −3 °C temperature which is design temperature for Kocaeli province, Turkey. The heat transfer coefficient between the exterior wall surface and the environment for winter conditions is 34 W/m^{2}K [30]. Conductive

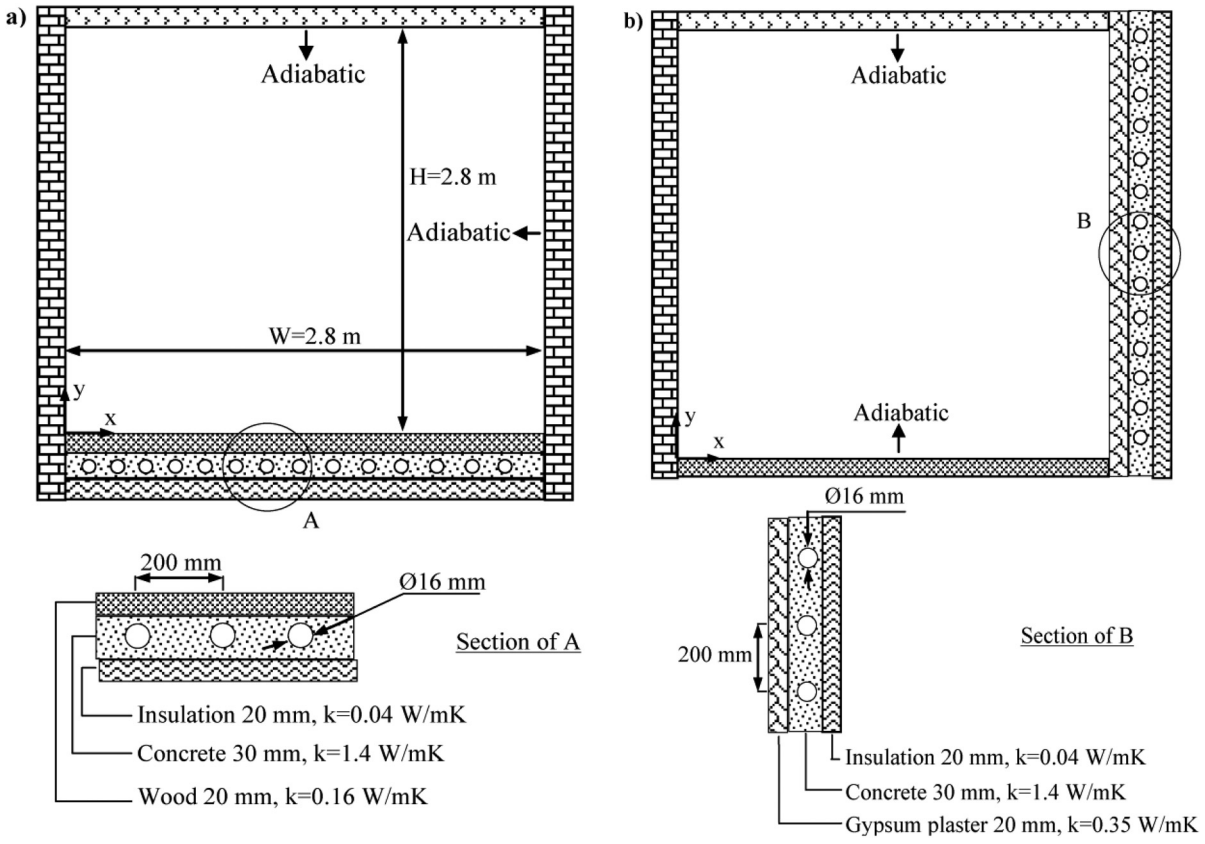

Fig. 1. The schematic representation of the geometries (a) floor heating system (b) wall heating system.