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Analysis of the Use of Radiant Floor Heating as a Cooling System †

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† Presented at the Innovations-Sustainability-Modernity-Openness Conference (ISMO'19), Bialystok, Poland, 22–23 May 2019.

Published: 20 June 2019

Abstract: The aim of this paper was to analyze the operational parameters of a radiant floor heating system working as a cooling system, in order to determine the value of possible heat flux and the floor surface temperature that can be obtain on the floor surface. The influence of variable air and water temperatures, pipe spacing, and thermal resistance of floor covering on surface heat flux and temperature was analyzed. The admissible values of water temperature that assure thermal comfort according to standard ISO 11855 were determined for the analyzed variables.

Keywords: floor cooling; radiant floor; heat flux; surface temperature; numerical simulation

1. Introduction

Radiant floor heating is widely use in Poland, especially in single family houses. When a heat pump is used as the heat source, there is the opportunity to use floor heating as a cooling system by reversing the operating mode of the heat pump. In reversible cycle, the heat pump in winter transports heat from the bottom heat source (ground) and transfers it to the building, while during the summer, the heat is taken from the building and transferred to the ground. Examples of the use of a heating/cooling radiant floor with a reversible ground-coupled heat pump are present in the literature [1,2].

The use of a heating system as a cooling system results in lower investment costs for the cooling system, because there is no cost for additional air-conditioning devices [3]. It was also found that the usage of a radiant cooling system results in a decrement of energy consumption in comparison to the use of convectional air-conditioning systems, due to the high temperature of the cooling medium that increases the efficiency of the chiller [4]. Thermal comfort in a room with radiant cooling is assured as a result of the small vertical air temperature gradient and low air velocity, as has been proved by computational fluid dynamics (CFD)simulations, experiments [5], and questionnaires filled out by houses' occupants [6].

As the construction of a radiant floor in heating or cooling mode is the same, the efficiency of the cooling system will strongly depend on the construction of a heating system. The aim of this paper was to analyze the operational parameters of a radiant floor heating system working as a cooling system, in order to determine the value of the possible temperature and the heat flux that can be obtained on the floor surface. The influence of variable air and water temperatures, pipe spacing, and heat resistance of floor covering on surface heat flux and temperature was analyzed. The values resulted from our calculations were compared with those required according to standard ISO 11855 [7] for minimum surface temperature assuring thermal comfort in the cooling space. The admissible values of water temperature in the cooling system which assure thermal comfort were determined for the analyzed variables.

2. Materials and Methods

In the analysis, the floor heating system most widely used in Poland was considered, i.e., type A, with pipes (16 × 2 mm) attached to the thermal insulation and located in the cement screed of thickness 6.5 cm. The value of heat resistance of thermal insulation of this system meets the requirements of standard ISO 11855 [7] and equals 0.75 m^2K/W. On the upper and bottom surface of the cooling floor, the III type boundary condition was set, which is described by the value of air temperature and the heat transfer coefficient. Many researchers have investigated the values of the heat transfer coefficient for floor cooling, taking into account the radiative and convective coefficient separately, and variable conditions, like air velocity, temperature, distance from the cooled surface [4,8,9]. Since variable values have been presented by researchers, in this analysis, the values of the heat transfer coefficient were set as constant and were derived from the standard ISO 11855: 6.5 W/m^2K for the upper surface, and 11 W/m^2K for the bottom surface. Inside the pipe, the III type of boundary condition was set for constant water velocity of 0.25 m/s (turbulent flow). The heat transfer coefficient h_w for the surface between water and pipe was calculated from the formula [10]:

$$h_w = 0.116(Re^{2/3} - 125)Pr^{1/3}(1 + (d_i/L)^{2/3})\lambda_p/d_i \, [W/m^2K] \quad (1)$$

where L is the characteristic length [m] of the pipe, λ_p is the thermal conductivity of the pipe [W/mK], d_i is the inner diameter of the pipe [m], Re is the Reynolds number [-], Pr is the Prandtl number [-].

Numerical simulations were performed for 2D model with the use of Workbench 19.2 ANSYS Steady-State Thermal Analysis System, which uses the mechanical APDL solver. The calculations were performed for four pipe spacings (0.1, 0.125, 0.15, 0.2 m) and for variable air temperature in a cooled room (24, 26, 28, 30 °C), water temperature (10, 12, 14, 16, 18, 20, 22 °C), and thermal resistance of floor covering (0.02, 0.05, 0.1, 0.15 m^2K/W).

3. Results

The numerical simulations provided the values of heat flux and temperature that can be achieved on the surface of a floor, when using a floor heating system as a cooling system. The maximum heat flux on the floor surface and the minimum average surface temperature were measured for the lowest pipe spacing (0.1 m), the lowest thermal resistance of floor covering (0.02 m^2K/W), and the lowest temperature of cooling water (10 °C). For these parameters and a design air temperature of 26 °C, the maximum heat flux equaled 62.5 W/m^2, and the average surface temperature was 16.4 °C (Figure 1). The minimum heat flux and the maximum average surface temperature were obtained for pipe spacing of 0.2 m, floor covering resistance of 0.15 m^2K/W, and water temperature of 22 °C and equaled, respectively, 8.6 W/m^2 and 24.7 °C, assuming that room temperature was 26 °C.

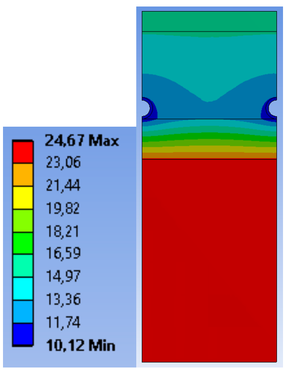
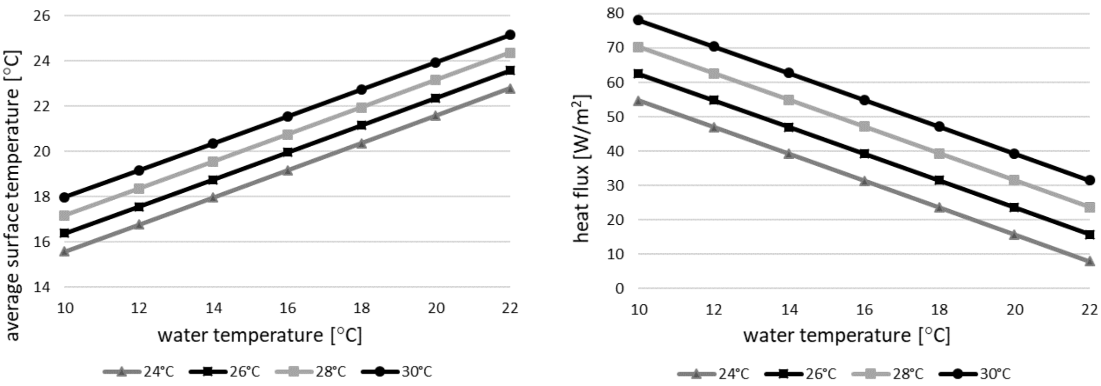


Figure 1. Temperature distribution in a floor cooling system (air temperature 26 °C, water temperature 10 °C, resistance of floor covering 0.02 m^2K/W, pipe spacing 0.1 m).

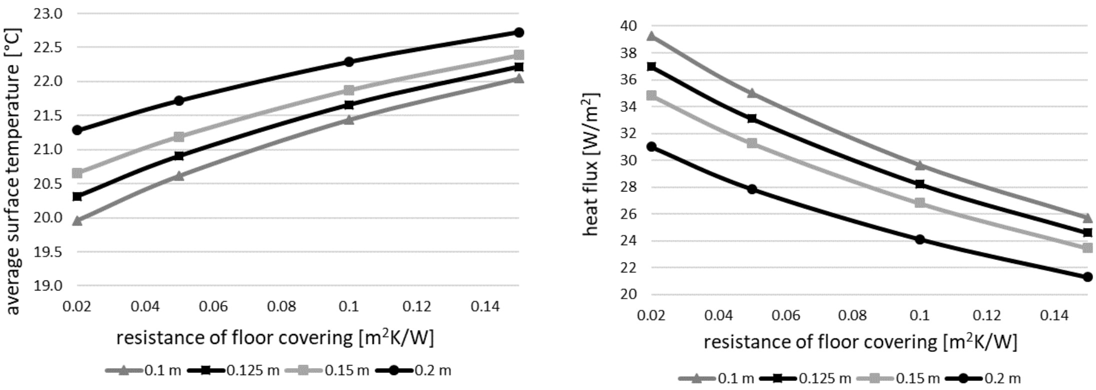
The operational parameters of floor cooling strongly depended on the water temperature and the air temperature in a cooled room. The lower the water temperature in the cooling system loop, the lower the value of surface temperature and the higher the heat flux (Figure 2). With the increase of air temperature in the cooled space, the surface temperature and the heat flux increased (Figure 2).



(**a**) (**b**)

Figure 2. Relation between (**a**) average surface temperature on the cooling floor; (**b**) heat flux on the surface of the cooling floor, and temperature of the cooling medium for variable room temperature (pipe spacing 0.1 m, thermal resistance of floor covering 0.02 m²K/W).

The surface temperature and heat flux of floor cooling depended on the thermal resistance of floor covering. The higher the resistance, the higher the surface temperature and the lower the heat flux (Figure 3).



(**a**) (**b**)

Figure 3. Relation between (**a**) average surface temperature of the cooling floor; (**b**) heat flux at the surface of the cooling floor, thermal resistance of floor covering for variable pipe spacing (water temperature 16 °C, room temperature 26 °C).

Taking into account the requirements of the standard 11855 for the minimum surface floor temperature (19 °C), the admissible water temperature for which thermal comfort is assured depended on the pipe spacing and the thermal resistance of floor covering (Figure 4). For all analyzed constructions, the water temperature should not be lower than 10 °C. The lower the thermal resistance of floor covering, the higher the admissible value of water temperature.

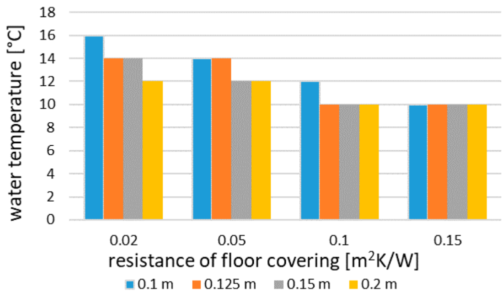


Figure 4. Admissible value of water temperature for variable thermal resistance of floor covering and pipe spacing (air temperature 26 °C).

4. Conclusions

It was proved that the operational parameters of floor cooling depend on pipe spacing, thermal resistance of floor covering, water temperature, and air temperature in the cooled space. When using a floor heating system as cooling system, the only parameter that can be changed by the user of the system in order to obtain the required system efficiency is water temperature. The minimum temperature of the cooling water should be set individually, taking into consideration the construction parameters of the radiant system, such as the pipe spacing and the resistance of floor covering, and the admissible minimum surface temperature for floor cooling. Although the theoretical cooling efficiency of a radiant floor can be very high, in practice, it is limited by the minimum surface temperature of a cooling floor, which strongly depends on air humidity (in order to avoid the risk of condensation) and on the requirements of thermal comfort in rooms with floor cooling established by standard 11855.

Author Contributions: A.J. Werner-Juszczuk conceived and performed the simulations, analyzed the data, and wrote the paper.

Acknowledgments: The research was carried out at Bialystok University of Technology and financed by a subsidy provided by the Ministry of Science and Higher Education of Poland, from the resources of the WZ/WBiIŚ/4/2019 work. The research was carried out with the use of the program ANSYS 19.2, which was provided to Bialystok University of Technology on the basis of an agreement between Bialystok University of Technology and ANSYS Inc. (Canonsburg, PA, USA) and MESco Sp. z o.o. (Tarnowskie Góry, Poland).

Conflicts of Interest: The authors declare no conflict of interest.

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