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SIMULATION AND EXPERIMENTAL STUDY ON THE HEATING PERFORMANCE OF A SMALL TWO-PERSON PENSION

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ABSTRACT: In this study, a heating device capable of radiant heating of a small two-person pension was studied. Radiant heating by hot water was implemented by circulating hot water through the circulation tubes on the three walls (side wall 2, rear wall 1) and floor of the building of a two-person small pension. A small wall-mounted hot water boiler was developed, and hot water was supplied from the hot water boiler for heating. As a result of this study as such, well-being heating, which is comfortable and beneficial to health, was implemented because radiant heating is implemented without movement or circulation of air unlike the forced convection heating at the current technical level, which is implemented with forced circulation of air by the air conditioner. In the results of this study, the theoretical natural convective heat transfer coefficient and the experimental natural convective heat transfer coefficient of the two-person small pension were in good agreement. Therefore, the reliability of the experimental results in this study was verified. The thermal energy supplied by the hot water circulating in the hot water panel and the thermal energy absorbed by the air inside two-person pension matched well at ±5%, and the temperature distribution of the hot water flowing inside the hot water panel was in good agreement with the experimental temperature distribution. In addition, as the amount of hot water flowing through the hot water panel increased, the temperature of the hot water at the wall surface increased. Therefore, the heating performance of the small two-person pension was improved in proportion to the increase in the hot water flow rate.

KEYWORDS: Small two-person, Heating performance, Radiant heating, Hot water, Natural convective heat transfer coefficient

I. INTRODUCTION

As the demand for buildings not larger than 6 m^2 such as pensions, loess rooms, and small accommodations is gradually increasing, studies on heating device technologies suitable for areas not larger than 6 m^2 are urgently required, but the current development of such technologies is insufficient and since the relevant buildings rely on air conditioner heating even in cold midwinter, this study is in desperate need(Kim, 2011; Nielsen, 2000). In addition, since there is no heating device accessories (circulation pump, heater, etc.) suitable for small pensions not larger than 6 m^2, accessories used in residential buildings not smaller than 24 m^2 are used in pensions not larger than 6 m^2 leading to great electric power energy loss and drastic increases in installation costs (Kim and Kim. 2020; Tien et al., 2007). Furthermore, although many studies on heating technologies for small heating mats have been reported, they are for portable heating mats, and reports of studies on heating mats for small pensions are insufficient(Faghri et al., 1989; Kim and Yeom, 2020; Yu and Shin, 2019). Therefore, in this study, a heating device (indoor wall-mounted hot water boiler) capable of radiant heating was studied for the first time in South Korea and abroad. The radiant heating using the heat of hot water was implemented by circulating hot water in circulation tubes on the three walls (side wall 2, rear wall 1) and floor of the pension building. A hot water boiler was developed to supply hot water for heating. As a result of this study as such, well-being heating, which is comfortable and beneficial to health, was implemented because radiant heating is implemented without movement or circulation of air unlike the forced convection heating at the current technical level, which is implemented with forced circulation of air by the air conditioner. In addition, this study has contributed greatly to the saving of electric power energy and the reduction of manufacturing costs by studying heating device accessories suitable for buildings such as pensions not larger than 6 m^2.

II. EXPERIMENTAL METHODS

Fig. 1 shows a small two-person pension with a heating system in which heating is implemented by hot water panels embedded in the walls of thew small two-person pension building. The size of the small pension is 2000 mm wide, 1100 mm long, and 1800 mm high. Fig. 2 shows a 3D schematic diagram of the heating device in which heating is implemented by hot water panels embedded in the walls of the small two-person pension. As shown in Fig.1, in this study, a heating device capable of heating by radiant heat transfer by supplying thermal energy from hot water by embedding hot water panels inside the walls of a small pension was studied for the first time at home and abroad. A hot water circulation tubes were embedded in the three walls of the building (side wall 2, rear wall 1), and the hot water was circulated to implement radiant heating by supplying thermal energy of hot water. In the previous studies, forced convection heating was studied in which high-temperature air was circulated by force by the air conditioner(Zhang at al., 2010). However, as a result of this study, well-being heating, which is comfortable and beneficial to health, was implemented because radiant heating is implemented without movement or circulation of air. In addition, there is no commercialized heating device for small pensions not larger than 6 m^2 examined in this study. Therefore, in this study, a heating device that can be used for a pension building not larger than 6 m^2 was studied.

Fig. 1 Experiment device for Small two-person pensions

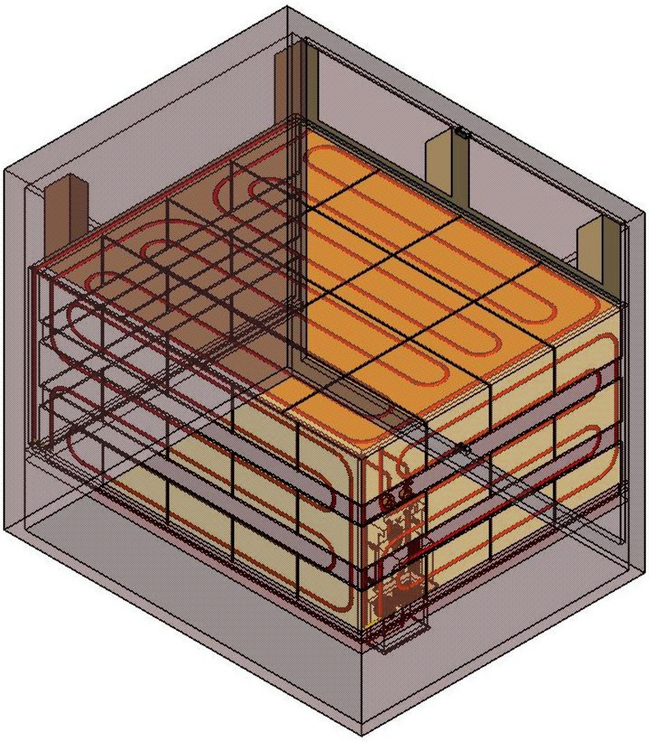

Fig. 2 3D schematic diagram of a small two-person pension building

Fig. 3 shows a hot water boiler to supply thermal energy to a small two-person pension. Fig. As shown in Fig. 3, an integrated boiler combining the hot water heating heater and the water tank was studied to minimize the size of the hot water boiler to develop the boiler that can be attached to the interior wall of the building. Currently, the heating performance is greatly lowered because the low level of the technology to separate and discharge the air bubbles coexisting in hot water flowing in domestic and international small ondol panels. Therefore, in this study, a non-bearing

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underwater key type hot water circulation pump was developed, and a push-type liquid pump and a circular heater were used so that the air rises upward as soon as generated and is discharged on the top. As a result of this study, the heating performance was greatly improved.

Fig. 3 A hot water boiler to supply thermal energy to a small two-person pension

Fig. 4 shows a diagram of installation of the temperature sensor for measuring the air temperature and the temperature on the surface of the wall inside the small two-person pension and a measuring thermometer. The temperatures on the surfaces of the walls and the floor and the air temperature were measured by installing nine temperature sensors on the wall, three on the floor, and three in the space. Pt 100Ω temperature sensors were used to measure the temperatures.

Fig. 4 A diagram of installation of temperature sensors for measurement of air temperature and wall surface temperatures inside a small two-person penaion

III. RESULTS AND DISCUSSION

3.1 Simulation of the heating performance of a small two-person pension

Fig. 5~Fig. 7 shows the results of simulation of the flow velocity distribution, pressure distribution, and temperature distribution of hot water flowing inside the hot water panel of a small two-person pension. The simulation was performed when the temperature of the hot water flowing into the inlet of the hot water panel was 70°C. The flow rate of the hot water was set to 3 L/min, and the outdoor temperature was set to 15°C. ANSYS FLUENT R19 was used as a software for analysis. The flow of hot water used for the simulation was turbulent flow. The meshes for analysis used for the simulation was hexahedral + tetrahedral mixed unstructured meshes, and the number of meshes was 658,770. From the simulation results shown in Fig. 5~Fig. 7, the temperature at the outlet of the hot water panel was found to be 67.3°C, the pressure loss of hot water was found to be 926.2 kPa, and the average temperature of the hot water panel was found to be 41.4°C. Based on the results of simulation as such, it could be seen that the heating of the two-person

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small pension was carried out normally, and that the heating performance of a small two-person pension was well achieved.

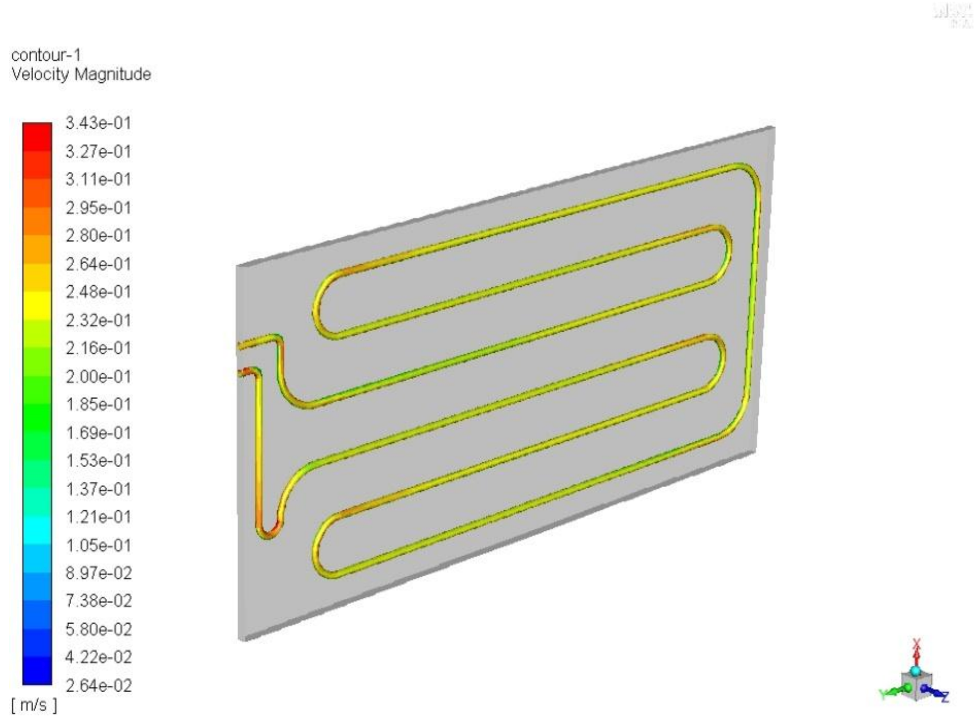

Fig. 5 Distribution of the flow velocities of hot water flowing inside the hot water panel of a small two-person pension

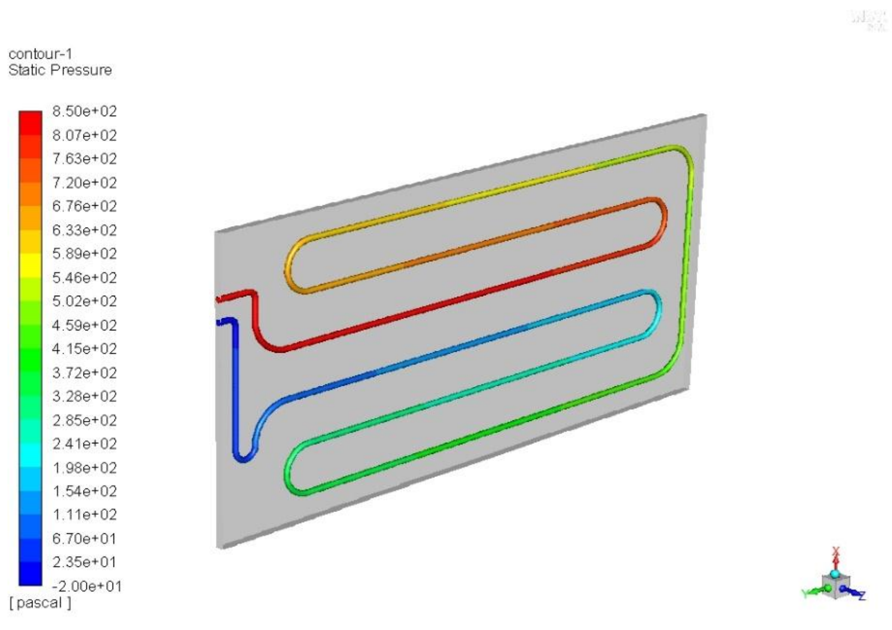

Fig. 6 Distribution of the pressures of hot water flowing inside the hot water panel of a small two-person pension

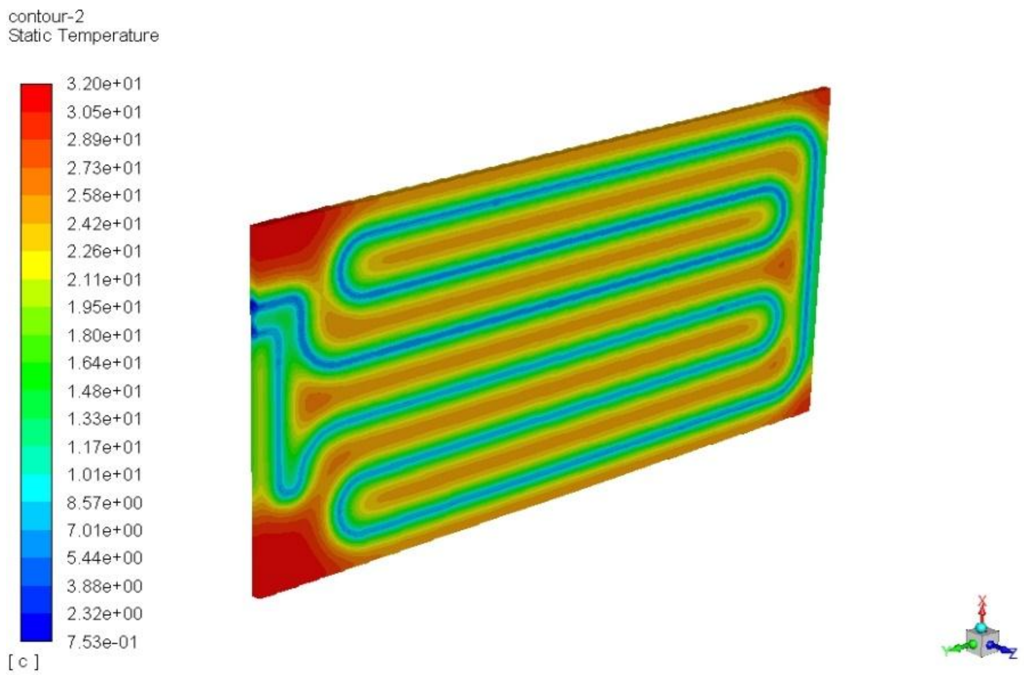

Fig. 7 Distribution of the temperatures of hot water flowing inside the hot water panel of a small two-person pension

3.2 Equilibrium of heating thermal energy in a small two-person pension

Fig. 8 shows the thermal equilibrium between the thermal energy supplied by hot water from the hot water panel and the thermal energy absorbed by the air inside the small two-person pension. The thermal energy (W) supplied by hot water was obtained using Equation (1).

$$QH = mhCp(Th2 - Th1) \tag{1}$$

where, QH represents the thermal energy (W) supplied by hot water. The thermal energy (W) absorbed by the air inside the small two-person pension was obtained using Equation (2).

$$QA = maCp(Ta2 - Ta1) \tag{2}$$

where, QA represents the thermal energy absorbed by the air inside the small two-person pension, ma denotes the air mass (kg) inside the small pension, Ta1 denotes the initial air temperature (K), and Ta2 denotes the final air temperature (K). As shown in Fig. 8, the thermal equilibrium between the thermal energy supplied from thermal energy held by the hot water in the hot water panel and the thermal energy obtained by the air inside the small pension was achieved well at ±5%. Therefore, the experimental results of this study are considered to have secured reliability.

3.3 Comparison of theoretical and experimental natural convection heat transfer coefficients of a small two-person pension

Fig. 9 shows the comparative values of the theoretical natural convective heat transfer coefficient and experimental natural convective heat transfer coefficient of air inside a small pension. Equation (3) represents the experimental natural convection heat transfer coefficient.

$$\mathrm{hex} = \frac{\mathrm{QA}}{\mathrm{A(Ta-Tw)}} \tag{3}$$

where, QA represents the natural convective heat transfer rate (W) of the air inside the small pension. A represents the heat transfer surface area (m^2) of the surface of the small pension, Ta represents the indoor air temperature (K), and Tw represents the wall temperature (K) of the small pension.

Equation (4) represents the Rayleigh number.

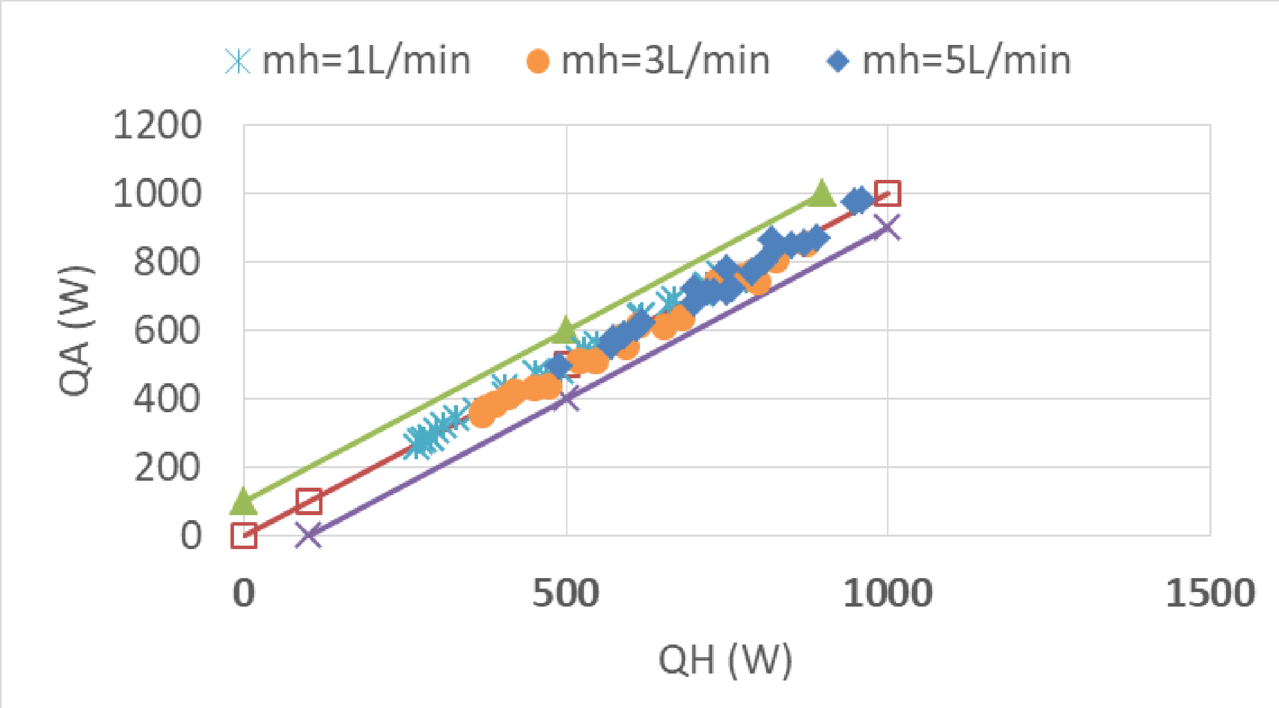

Fig. 8 Thermal equilibrium between the thermal energy supplied by hot water from the hot water panel and the thermal energy absorbed by the air inside the small pension

$$Ra = \frac{g\beta(Tw - Ta)L^3}{\nu\alpha} \quad (4)$$

where, g represents the gravitational acceleration (m/s^2), β represents is the volumetric thermal expansion coefficient (1/K), ν represents is the kinematic coefficient of viscosity (m/s^2), α represents the thermal diffusibility (m/s^2), and L represents the height (m) of the wall of the small pension. Equation (5) represents the Nusselt number of natural convective heat transfer.

$$Nu = 0.825 + \frac{0387 Ra^{1/6}}{[1 + (0.492/Pr)^{0.56}]} \quad (5)$$

where, Pr represents the Prandtl number. The theoretical natural convective heat transfer coefficient of the air inside a small pension was obtained using equation (6).

$$\mathrm{hth} = \frac{kf Nu}{L} \quad (6)$$

where, kf represents the thermal conductivity coefficient (W/mK) of the air. As shown in Fig. 4, the experimental natural convective heat transfer coefficient value obtained from Equation (5) and the theoretical natural convective heat transfer coefficient value obtained from Equation (8) agreed relatively well throughout the entire range of experiments. Therefore, the reliability of the experimental results of this study is considered to have been verified.

3.4 Heating performance of small two-person pension

Fig. 10 shows the temperatures of the hot water at the inlet and outlet according to changes in the flow rate of the hot water circulating in the hot water panel embedded in the wall of the two-person pension. The experiment was conducted at a hot water flow rate of 1.5 L/min. As shown in Fig. 10, the inlet and outlet temperatures of the hot water flowing inside the hot water panel increased in proportion to the heat supply time. Therefore, it is considered that the inlet and outlet temperatures of the hot water supplied to the small two-person pension rise normally. In addition, as the mass flow rate of hot water in the small pension for two persons increased, the range of changes in the inlet and outlet temperatures of hot water increased. Therefore, it is considered that the heating performance of the small two-person pension is improved as the hot water flow rate increases. In addition, the results of simulation of a small two-person pension and the experimental results in this study were in good agreement. Therefore, the reliability of the experimental results in this study was verified.

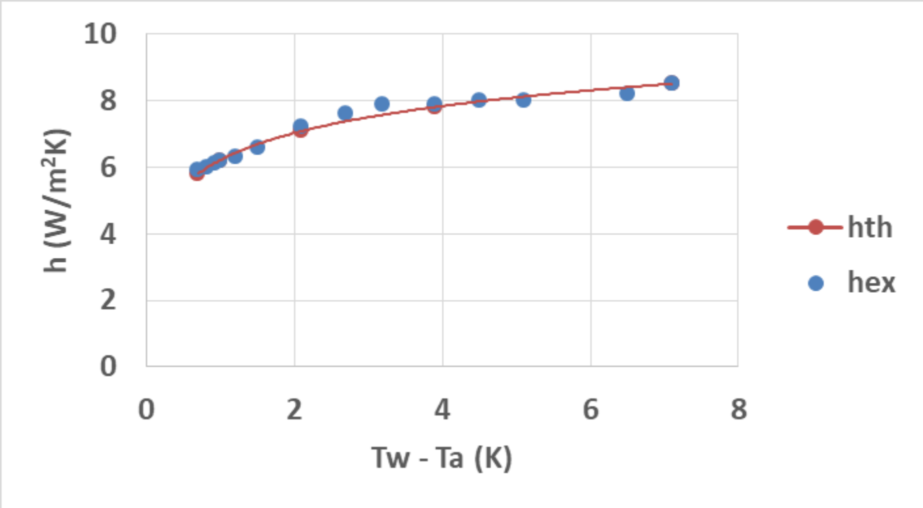

Fig. 9 Comparison of the theoretical natural convection heat transfer coefficient and the experimental natural heat transfer coefficient of small pension

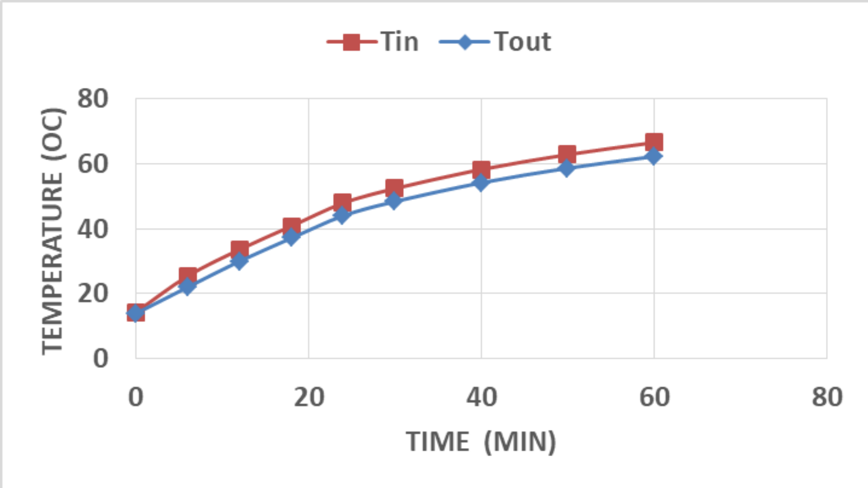

Fig. 10 Temperatures at the inlet and outlet of the hot water panel according to changes in the flow rate of hot water circulating on the wall of the two-person pension

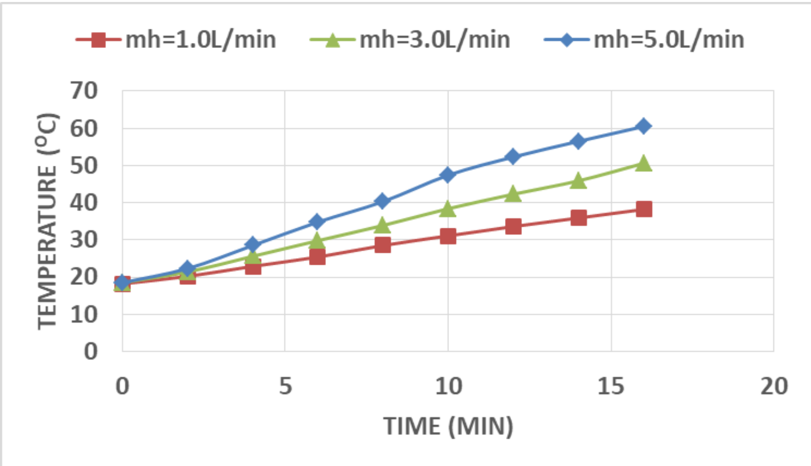

Fig. 11 Temperature distribution of hot water circulating on the wall of a small two-person pension according to changes in the flow rate

Fig. 11 shows the temperature distribution of hot water according to changes in the flow rate of hot water circulating in the hot water panel embedded in the wall of the loess jjimjilbang. The experiments were conducted under three conditions of hot water flow rates: 1.5 L/min, 3.5 L/min, and 6.5 L/min. As shown in Fig. 11, the temperature of hot water increased proportionally with the passage of the hot water boiler operation time. Therefore, it is considered that

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the heating of the loess jjimjilbang operates normally. As the mass flow rate of hot water increased, the temperature of hot water increased. Therefore, it is considered that heating performance improves as the hot water flow rate increases.

IV. CONCLUSION

In this study, simulations and experimental studies on the temperature changes of hot water circulating in the hot water panel embedded in the wall of a small two-person pension, the temperature distribution on the wall of a small two-person pension, and the heating performance of a small two-person pension were conducted and the following results were derived.

The theoretical natural convective heat transfer coefficient and the experimental natural convective heat transfer coefficient of the small two-person pension agree well with each other. Therefore, the reliability of the experimental results in this study was verified.

The thermal energy supplied by the hot water circulating in the hot water panel and the thermal energy absorbed by the air inside the small two-person pension matched well at ±5%, and the temperature distribution of hot water flowing inside the hot water panel was in good agreement with the experimental temperature distribution. Therefore, the reliability of the experimental results in this study was verified.

As the flow rate of hot water flowing through the hot water panel increased, the wall temperature of the hot water increased. Therefore, the heating performance of the small two-person pension was improved in proportion to the increase in hot water flow rate.

As the flow rate of hot water flowing inside the hot water panel embedded in the wall of the small two-person pension increased, the amount of thermal energy transferred to the air inside the small pension increased. Therefore, as the flow rate of hot water in the hot water panel increased, the thermal conductivity of the heat supplied to the small pension improved.

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