A Study on the Heat Transfer Rate Performance of the Hot Water Circulating in the Tubes in the Hot Water Panels Laid in the Walls and Floor of a Small Leisure Cabin in Relation to Changes in the Temperature and Flow Rate of the Hot Water

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ABSTRACT

In this study, hot water panels were laid in the three walls as well as the floor of a small leisure cabin to implement radiant heating with the heat supplied by the hot water circulating inside the hot water tubes in the hot water panels. As a result of the study as such, compared to the forced convection heating at the current technology level in which air is forced to circulate by the air conditioner, the radiant heat transfer by the hot water panels laid in the floor and walls of the small leisure cabin in this study implemented more comfortable heating and wellbeing heating beneficial to health because it implemented heating without any movement or circulation of air. In addition, this study investigated heater accessories suitable for small leisure cabins not larger than 6 m^2 to significantly reduce thermal energy and manufacturing costs. The thermal energy lost by hot water per unit time and the thermal energy obtained by air inside the small leisure cabin per unit time coincided well at the accuracy of $\pm$5%. Therefore, the reliability of the result of the heat transfer rate accuracy experiment in this study was secured. As the mass flow rate of the hot water increased, the heat transfer rate performance of the small leisure cabin improved. In addition, as the mass flow rate of hot water increased, the heat transfer rate performance of the small leisure cabin improved linearly.

Keywords:

Small Leisure Cabin, Heat Transfer Rate Performance, Hot Water Panels Laid in the Walls and Floor, Hot Water, Heating Device Technology, Wellbeing Heating

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I. Introduction

Recently, studies on heating device technologies suitable for small leisure cabins are urgently required because the demand for construction of small leisure cabins is gradually increasing [1]. However, currently, relevant study reports are insufficient, and this study is desperately required because people are relying on air conditioner heating and electric heater heating even in cold midwinter [2-4]. In addition, since there are no appropriate heating device accessories (boiler, piping parts, etc.) required for small leisure cabins, accessories suitable for house buildings larger than 24 m^2 are used in small leisure cabins not larger than 6 m^2 leading to large thermal energy losses and great increases in installation costs [5,6]. In addition, although many studies on heating technologies using heating panels have been reported, they are for simplified heating panels and study reports on small leisure cabins are insufficient [7]. There are many reports of studies on heating devices that supply heat from hot water by laying a hot water panel in the floor of a small leisure cabin and configuring a system so that hot water circulates inside the hot water panel, and many study reports indicate that wellbeing heating beneficial to health is implemented by hot water panels laid in the floor of small leisure cabins because the heating is implemented by radiant heat transfer [8-10]. However, reports of studies on implementing radiant heat heating by laying hot water panels in the floor as well as the walls of a small leisure cabin are insufficient. Therefore, in this study, wellbeing heating beneficial to health was implemented by laying hot water panels in the floor as well as three walls of a small leisure cabin and installing hot water tubes inside the hot water panels to supply radiant heat energy from the hot water flowing inside the hot water tubes for the first time at home and abroad. This study was conducted to implement radiant heat transfer heating with the thermal energy supplied by the hot water circulating inside the hot water tubes by laying hot water panels in the three walls as well as the floor of the small leisure cabin. As a result of the study as such, compared to the forced convection heating at the current technology level in which air is forced to circulate by the air conditioner, the radiant heat transfer by the hot water panels laid in the floor and walls of the small leisure cabin in this study implemented more comfortable heating and wellbeing heating beneficial to health because it implemented heating without any movement or circulation of air. In addition, this study investigated heater accessories suitable for small leisure cabins not larger than 6 m^2 to significantly reduce thermal energy consumption and manufacturing costs.

II. EXPERIMENTAL APPARATUS AND METHOD

2.1 Experimental Apparatus –

Fig. 1 shows a heat transfer rate performance experimental apparatus for changes in the temperature and flow rate of hot water circulating in the tubes in the hot water panels laid inside the walls and floor of a small leisure cabin. Fig. 2 shows a 3D schematic diagram of the heat transfer rate performance experimental apparatus. As shown in Fig. 1 and Fig. 2, in this study, hot water panels were laid in the walls and floor of a small leisure cabin, and hot water tubes were installed inside the hot water panels to raise the temperature of the air existing in the space inside the small leisure cabin by supplying thermal energy with hot water. The size of the small leisure cabin is 2000 mm wide, 1500 mm long, and 1700 mm high. The heating area of the small leisure cabin experimental apparatus is 3 m^2, and the hot water panels were laid in the bed and wall. The experimental apparatus was configured so that hot water circulates inside the hot water panels to supply radiant heat energy, which is beneficial to health, to carry out an experimental study to implement wellbeing heating beneficial to health and carry out a 3D simulation. As a result of the study as such, compared to the forced convection heating at the current technology level in which air is forced to circulate by the air conditioner, the radiant heat transfer implemented more comfortable heating and wellbeing heating beneficial to health because it implemented heating without any movement or circulation of air [11]. The experimental apparatus was configured to include a hot water boiler and a hot water pump to supply hot water to the hot water panels in the small leisure cabin so that the thermal energy held by the hot water flowing in the hot water tubes laid in the walls of the small leisure cabin is supplied to the air existing inside the small leisure cabin. Existing small-sized heating devices are for heating of houses or offices not smaller than 26 m^2 and implement heating with forced convection. However, study reports on small leisure cabins not larger than 3 m^2 are insufficient. Therefore, this study was conducted as a study that can be used for a small leisure cabin not larger than 3 m^2.

Figure 1. Small leisure cabin's heat transfer rate performance experimental apparatus.

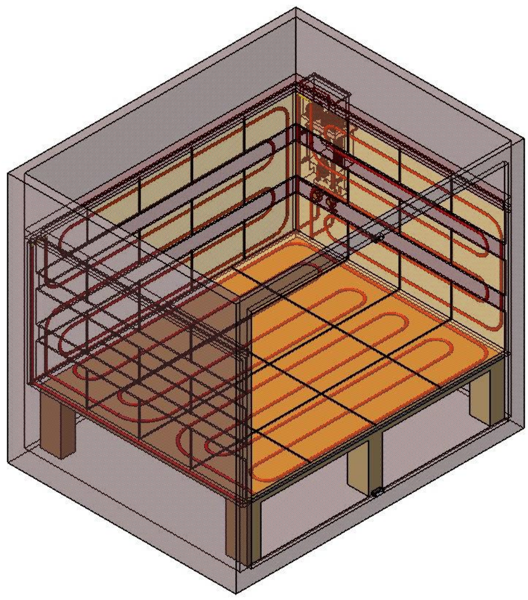

Figure 2. 3D design drawing of small leisure cabin's heat transfer rate performance experimental apparatus

Fig. 3 shows a hot water boiler that supplies thermal energy to the hot water circulating in the tubes in the hot water panels laid inside the walls and floor of a small leisure cabin. As shown in Fig. 3, an experimental study was conducted after installing a hot water boiler for hot water heat supply to the hot water panels laid inside the walls and floor of the small leisure cabin. The noise of the hot water boiler supplying thermal energy to hot water was studied not to exceed 40 dB, so that there would be no sleep disturbance caused by noise when sleeping in the small leisure cabin at night. As such, by developing the indoor wall-mounted hot water boiler technology, the study was conducted to reduced energy losses by at least 5% compared to existing technologies for hot water boilers installed outdoors when considering outdoor heat dissipation losses and pipeline losses.

Figure 3. Hot water boiler that supplies thermal energy to the hot water circulating in the tubes in the hot water panels

2.2. Experimental mathod –

Fig. 4 shows the temperature sensors to measure the air temperature and wall temperature inside the small leisure cabin. The wall temperature of the small leisure cabin was measured by attaching three each Pt 100 Ω temperature sensors to the upper, middle, and lower areas of the right wall and the center wall of the small leisure cabin, respectively. In addition, three each Pt 100 Ω temperature sensors were attached to the floor at equal intervals on the left and right sides of the small leisure cabin, respectively to measure the floor surface temperature in the interior space of the small leisure cabin. In addition, three Pt 100 Ω temperature sensors were installed at equal intervals at the upper, middle, and lower positions of the interior space of the small leisure cabin to measure the air temperature of the interior space of the small leisure cabin. Furthermore, Pt 100Ω temperature sensors were installed at the inlet and outlet of the hot water panels laid inside the walls and floor of the small leisure cabin to measure the inlet and outlet temperatures of hot water. Fig. 5 shows the flow rate measuring device for the hot water flowing in the hot water panels inside the small leisure cabin. As shown in Fig. 5, flowmeters were installed at the tube inlets of the hot water panels laid inside the walls and floor of the small leisure cabin to measure the hot water flow rate.

Figure 4. Temperature sensor and thermometer temperature measurement of a small leisure cabin

Figure 5. Flow meter for hot water flow measurement

III. Result

3.1 Result of 3D simulation of small leisure cabin's heat transfer rate –

Fig. 6 shows the 3D simulation shape of the hot water panel for heating in a small leisure cabin and Fig. 7 shows the Hexahedral+ tetrahedral mixed unstructured mesh of the hot water panel. The size of the hot water panel is 1,700 mm wide, 850 mm long, and 23.5 mm thick. As shown in Fig 6 and Fig. 7, the simulation was carried out at a temperature of 70 ^{o}C of the hot water flowing into the inlet of the hot water panel laid inside the walls and floor of the small leisure cabin. In addition, the simulations were carried out under the conditions of a flow rate of hot water of 3 L/min and an outdoor air temperature of 15 ^{o}C. ANSYS FLUENT R19 was used as analysis software. The simulation of heat transfer from the walls of the small leisure cabin to the air in the indoor space was carried out under the natural heat convection conditions of gravity and incompressible ideal gas air. Fig. 8 shows a 3D simulation of the process of laying hot water panels inside the floor as well as the walls of a small leisure cabin, installing hot water tubes inside the hot water panels, and supplying radiant heat to the hot water flowing inside the hot water tubes. As shown in Fig. 8, the temperature of the hot water flowing into the inlet of the hot water panels is 70 ^{o}C and the simulation was carried out at a hot water flow rate of 3 L/min. The flow of the hot water is a turbulent steady flow, and the heat transfer from the hot water panel is conjugated heat transfer, that is, the thermal energy held by the hot water is transferred to the air existing in the small leisure cabin. Based on the results of the 3D simulation, the temperature of the hot water flowing inside the hot water tubes decreased linearly. From the simulation results as such, it can be seen that the thermal energy held by hot water was normally transferred to the air existing in the small leisure cabin. In addition, it was thought that the heat transfer rate performance improved as the flow rate of hot water increased. In this study, the heat transfer rate performance value measured in the experimental study and the heat transfer rate performance value shown in the simulation result matched well with each other.

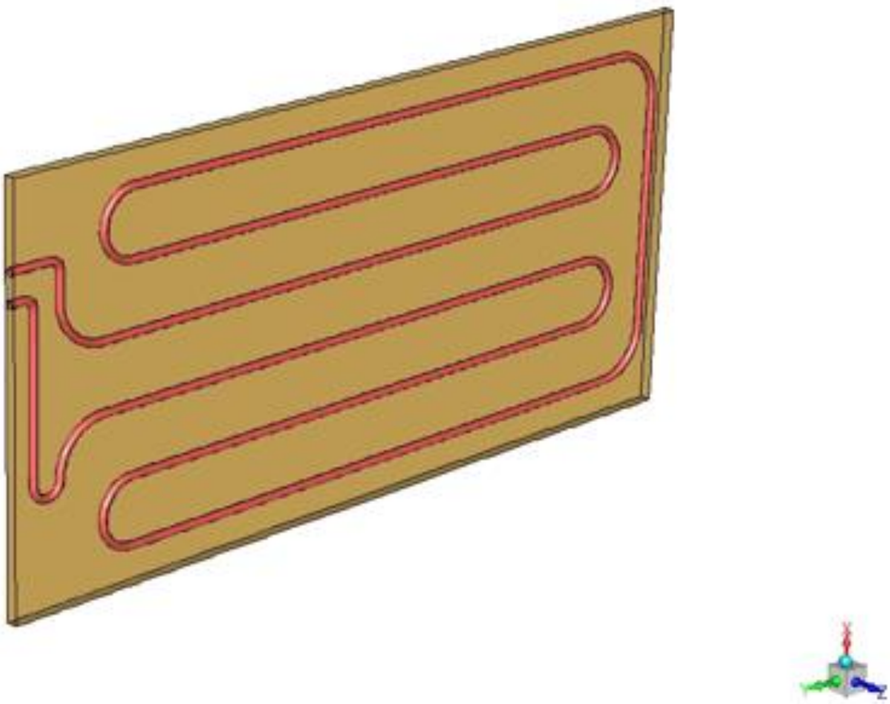

Figure 6. Shape of 3D simulation of the small leisure cabin

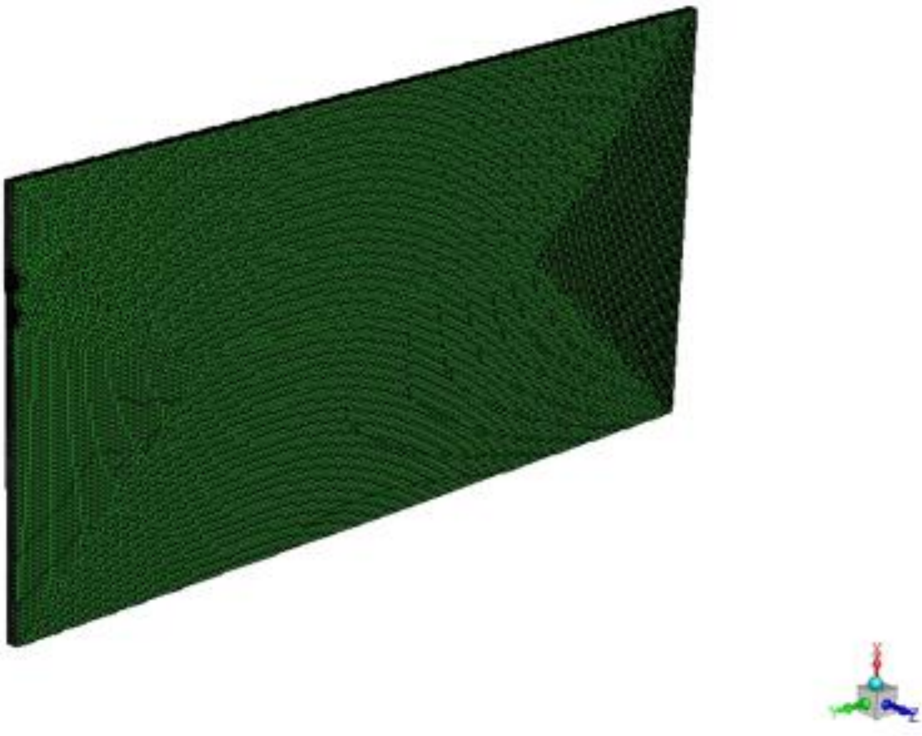

Figure 7. Hexahedral+tetrahehedral mixed unstructured mesh of the small leisure

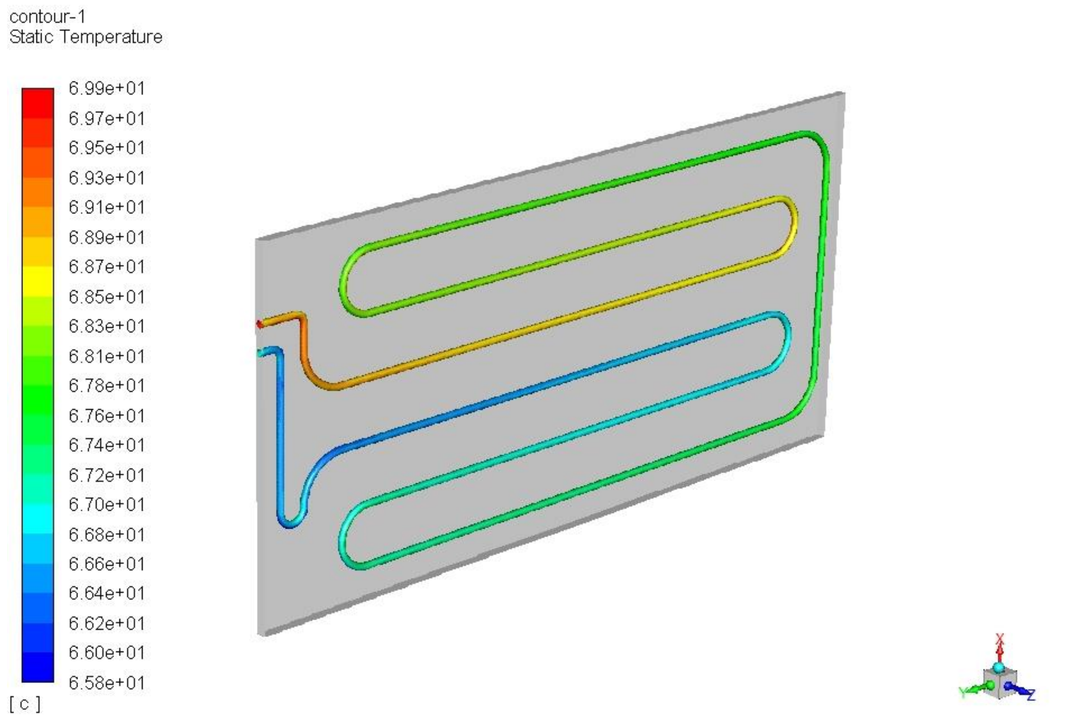

Figure 8. Temperature distribution of the hot water flowing inside the hot water tube

3.2 Verification of experimental heat transfer rate value of the small leisure cabin –

Fig. 9 shows the accuracy of the matching between the thermal energy lost by the hot water flowing inside the hot water tube and the thermal energy obtained by the air existing inside the small leisure cabin. The thermal energy lost by the hot water per unit time was obtained with Equation (1).

$$Q_{h,w} = m_w\, Cp_w(T_{w,2} - T_{w,1}) \qquad (1)$$

where, $Q_{h,w}$ represents the thermal energy lost by the hot water per unit time, m_w denotes the mass(kg) of the hot water, $T_{w,1}$ denotes the inlet temperature (K) of the hot water, and $T_{w,2}$ denotes the outlet temperature of the hot water. The thermal energy obtained by the air existing in the small leisure cabin per unit time was obtained with Equation (2).

$$Q_{h,a} = m_a\, Cp_a(T_{a,2} - T_{a,1}) \qquad (2)$$

where, $Q_{h,a}$ denotes the thermal energy (W) obtained by the air inside the small leisure cabin per unit time. m_a denotes the mass of air (kg), $T_{a,1}$ denotes the initial temperature (K) inside the small leisure cabin, and $T_{a,2}$ denotes the final temperature of the air inside the small leisure cabin. As shown in Fig. 9, the thermal energy lost by the hot water per unit time and the thermal energy obtained by the air inside the small leisure cabin per unit time matched well at the accuracy of $\pm 5\%$. Therefore, it is considered that the reliability of the heat transfer rate accuracy experimental results in this study was secured.

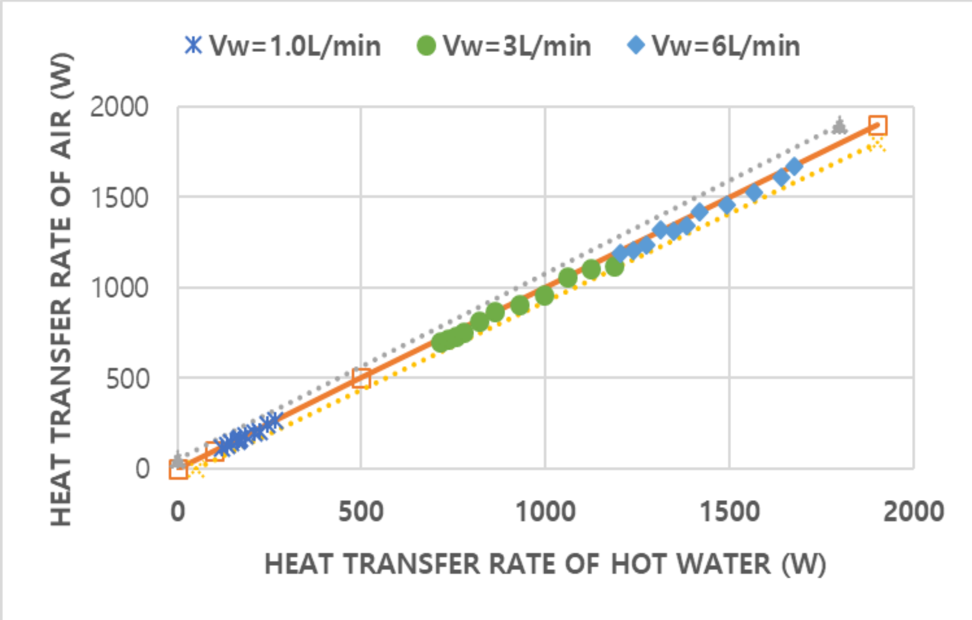

Figure 9. Accuracy of heat energy lost by hot water and heat energy obtained by air in small leisure cabin

3.3 Heat transfer rate performance of small leisure cabin –

Fig. 10 shows the changes in the heat transfer rate in relation to the changes in the hot water flow rate of the hot water flowing through the hot water panels laid in the walls and floor of the small leisure cabin. The mass flow rate of the hot water was experimented under three conditions: 1.0 kg/min, 3.0 kg/min, and 5 kg/min. As shown in Fig. 10, the heat transfer rate of hot water increased in proportion to the increase in the mass flow rate of hot water and the amount of thermal energy supplied per unit time increased in proportion to the heating time. Therefore, it is believed that the thermal energy held by the hot water is normally transferred to the air existing inside the small leisure cabin. In addition, it is thought that as the mass flow rate of the hot water increases, the heat transfer rate performance of the small leisure cabin is improved. Furthermore, the heat transfer rate balance in the experimental results of small leisure cabin was well achieved. Therefore, the reliability of the experimental results in this study was verified.

Fig. 11 shows the temperature of the air existing in the space inside the small leisure cabin in relation to the changes in the temperature of the hot water circulating in the hot water panel laid in the walls of the small leisure cabin. The mass flow rate of the hot water was experimented under three conditions: 1. kg/min, 3.0 kg/min, and 5.0 kg/min. As shown in Fig. 11, as the temperature of the hot water increased, the temperature of the air in the space inside the small leisure cabin increased. Therefore, it is considered that the heat transfer is normal in the small leisure cabin. In addition, as the temperature of the hot water increased, the air temperature inside the small leisure cabin increased. Therefore, it is considered that as the mass flow rate of the hot water increases, the heat transfer rate performance of the small leisure cabin improves linearly.

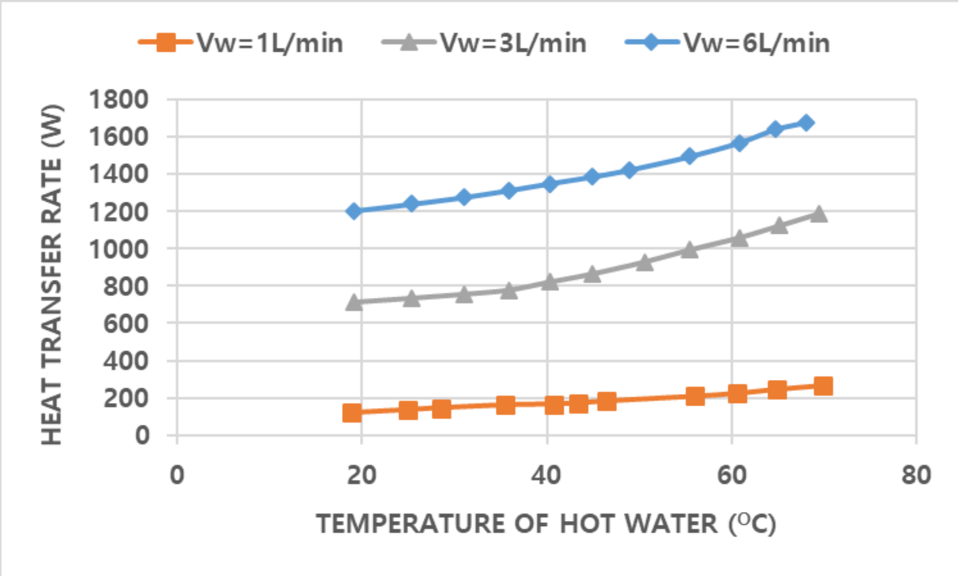

Figure 10. Changes in heat transfer rate for changes in hot water temperature and flow rate

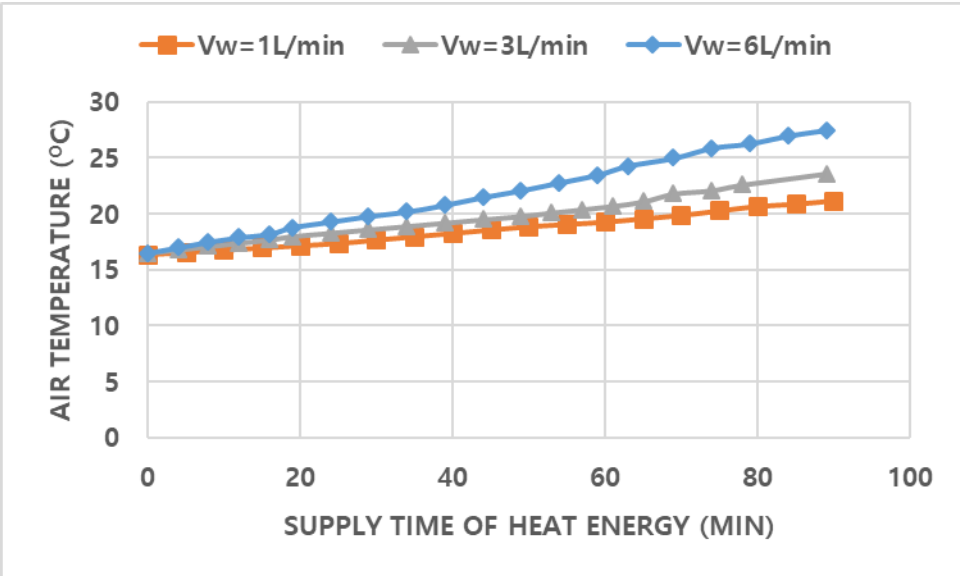

Figure 11. Temperature changes of air existing in the interior space of small leisure cabin over time of heat energy supply

IV.CONCLUSION

In this study, experiments were carried out on the heat transfer rate performance in relation to the changes in the temperature and flow rate of the hot water circulating in the tubes in the hot water panels laid inside the walls and floor of a small leisure cabin and the following results were derived.

Based on the results of 3D simulations for the heat transfer rate performance in relation to the changes in the temperature and flow rate of the hot water circulating in the tubes in the hot water panels laid inside the walls and floor of the small leisure cabin, the temperature of the hot water flowing inside the hot water tubes decreased linearly. From the results of the simulation, it can be seen that the thermal energy held by the hot water was normally transferred to the air existing in the small leisure cabin.

The thermal energy lost by the hot water per unit time and the thermal energy obtained by the air inside the small leisure cabin per unit time match well at the accuracy of ±5%. Therefore, the reliability of the heat transfer rate accuracy experimental results in this study was secured.

As the mass flow rate of the hot water increased, the heat transfer rate performance of the small leisure cabin improved. In addition, as the mass flow rate of the hot water increased, the heat transfer rate performance of the small leisure cabin improved linearly.

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