J. Integr. Sci. Technol. 2021, 9(1), 30-36 Article

Integrated Science

Journal of Integrated
SCIENCE & TECHNOLOGY

A study on the characteristics of Cooling Load due to the heat absorption of cold water circulating inside the Ocher Walls of small Cabins of one person

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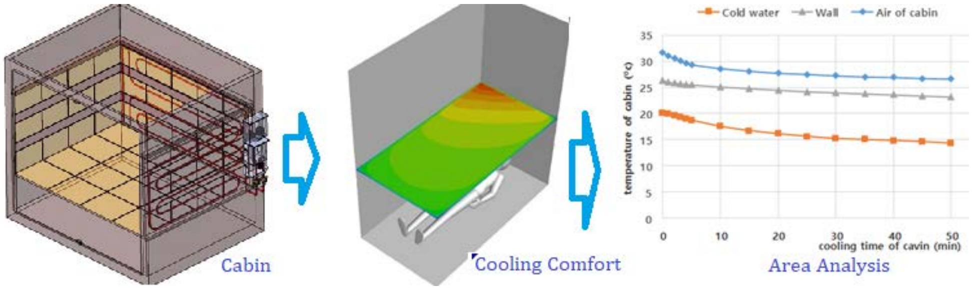
Received on: 01-Feb-2021 Accepted and Published on: 21-Aug-2021

ABSTRACT



This study was conducted to lay cold water X-L pipes inside the ocher walls of a cabin for one person and install cold water X-L pipes inside the cold water panels for radiant cooling with the absorption of thermal energy by the cold water for the first time. The air temperature distribution measured in an experimental study and the air temperature distribution shown in the results of simulations in this study were in good agreement. The air flow rate in the simulations was shown to be much lower than that of cooling by forced convective heat transfer, which is the existing cooling method. The results of simulations in this study verified that cooling is achieved by radiative heat transfer, which is beneficial to health. As the mass flow rate of the cold water circulating in the cold water X-L pipes increases, the air temperature inside the small cabin for one person decreased proportionally.

Keywords: Ocher Walls, Cold Water, Cooling Load, Natural Convective Heat Transfer, Thermal Energy, Cold Water Panel

1. INTRODUCTION

One-person households are increasing, and the current number of one-person households is 6.61 million (National Statistics Office, total census data), accounting for 28.6% of all households.[1,2] However, study reports on small cabins for one person are rare. In addition, since the demand for buildings not larger than two units such as pensions, ocher rooms, and small accommodations is gradually increasing and such buildings rely on fans or natural ventilation for cooling even in hot summer, study reports on suitable cooling technologies for such buildings are desperately required, but the current study reports are insufficient.[3,4] Cooling systems for summer are mainly supplied to buildings that use them for rooms not smaller than eight units, and there are many study reports on cooling technology for the forced convective heat transfer by air circulation method.[5] As the demand for houses of one-person households is gradually increasing, studies on technologies for cooling systems suitable for small cabins for one person are urgently required, but the current study result reports are insufficient.[6,7] Study reports on cooling technologies for elderly persons' small cabins for one person, which are beneficial to both sleeping and health, are desperately required but such study reports are still somewhat insufficient.[8–10] Therefore, it is considered that if a bed for small houses for one person that can be also used as an ocher cold pack room is studied and supplied based on the results of this study, elderly persons' health will be improved substantially due to comfortable sleep and ocher room radiant heat cold pack. In addition, since there are no suitable cooling system accessories (circulation pump, heater, etc.) required for residential spaces not larger than one unit, accessories suitable for buildings larger than eight unit are used in buildings not larger than one unit leading to

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Cite as: *J. Integr. Sci. Technol., 2021, 9(1), 30-36.*

Published by: ScienceIN
JIST ISSN: 2321-4635 http://pubs.iscience.in/jist

great electric power energy losses and large installation charges.[11] Therefore, this study was conducted to implement a small cabin for one person which can also be used as an ocher cold pack room with an area of 2m^2 with cold water **X-L pipes** laid in its walls, in which cold water is circulated to absorb radiant heat for a room cooling beneficial to health.[12] Ocher beds and ocher walls, which were verified as being beneficial to health in the results of many previous studies, were constructed so that residential life on bed and ocher cold park room can be implemented simultaneously. A well cooling technology beneficial to health was developed by implementing ocher radiant heat cooling by constructing the bed and walls to have ocher cold water panels. Since there is a risk of facial nerve palsy when the bed floor is cold, room cooling in summer was implemented with radiant cooling through the cold water circulating only in the ocher cold water panels laid in the walls to develop a cooling technology beneficial to health. In addition, this study was conducted to develop a technology for ocher cold pack rooms for summer implemented through the reduction and control of the temperature of the cold water circulating in the wall cold water panels so that cold pack can be taken in the bed space depending on the residents.

Furthermore, this study ensured that in spring and autumn, the ceiling of the small cabin for one person, which is also used as an ocher cold pack room, can be placed at the height of the ceiling of the room, the walls of the bed are placed in close contact with the walls of the room, and the front door of the cabin can be widely opened or easily detached so that the cabin can provide the same feeling and sense as general beds. In addition, this study ensured that the relevant cabin can be used to take radiant heat cold pack at any time even in spring or autumn depending on the taste of the resident by closing the door and operating the radiant heat cold pack room. Whereas the existing cooling of one-person houses heated the entire room (10 to 13 m^2), in this study, a technology that can cool only the bed space (2 m^2) was developed to significantly reduce the cooling energy consumption rate.

EXPERIMENTAL APPARATUS AND METHOD

EXPERIMENTAL APPARATUS

Figure 1 shows the experimental apparatus for cabins for one person, in which cooling is implemented as the cold water circulating in the X-L pipes of the cold water panels in the ocher walls of the cabins for one person absorb the thermal energy held in the hot air inside the space of the small cabin for one person. Figure 2 shows a 3D plan of a small cabin for one person in which cooling is implemented as the cold water circulating in the X-L pipes of the cold water panels laid in the ocher walls of the small cabin for one person absorb the heat energy held in the hot air inside the space of the cabin for one person. As shown in Figure 1 and Figure 2, cold water X-L pipes were laid in the ocher walls of the cabin for one person, and cold water X-L pipes were installed inside the cold water panels to carry out radiant cooling with the absorption of heat energy by the cold water to fabricate and study the relevant experimental apparatus for the first time at home and abroad. The size of the small cabin for one person is 2,100 mm wide, 1,100 mm long, and 2,200 mm high. The width and length of the cabin for one person were made to be the same as those of a single bed so that the cabin for one person can be used as a bed at normal times and can be used to take cold pack at home by those who like cold pack in summer. In addition, the cooling area of the experimental apparatus for small cabins for one person is 2m^2, and cold water X-L pipes were laid inside the walls to configure the experimental apparatus so that cold water is circulated inside the cold water X-L pipes thereby implanting the natural convective radiative heat transfer to carry out an experimental study and 3D simulations to implement a cooling beneficial to health. The experimental study and 3D simulations were carried out so that the residential life on bed and ocher cold pack room can be simultaneously implemented by constructing an ocher bed and ocher walls. Ocher cold water panels were constructed in the bed and the walls to implement a natural convective radiative heat transfer cooling thereby implementing a cooling technology beneficial to health. Since there is a risk of facial nerve palsy when the bed floor is cold, room cooling in summer was implemented with radiant cooling through the cold water circulating only in the ocher cold water panels laid in the walls to develop well-being cooling technology beneficial to health. In addition, the study was conducted to develop a technology for ocher cold pack rooms in summer implemented through the reduction and control of the temperature of the cold water circulating in the wall with cold water panels so that cold pack can be taken in the bed space depending on the residents.

This study ensured that in spring and autumn, the ceiling of the small cabin for one-person household, which is also used as an ocher cold pack room, can be placed at the height of the ceiling of the room, the walls of the bed are placed in close contact with the walls of the room, and the front door of the cabin can be widely opened or easily detached so that the cabin can provide the same feeling and sense as general beds thereby being used as a bed. This study ensured that the relevant cabin can be used to take radiant heat cold pack at any time even in spring or autumn by closing the door and operating the radiant heat cold pack room. In addition, whereas the existing cooling of one-person houses heated the entire room (10 to 13 m^2), in this study, a technology that can only cool the bed space (2 m^2) was developed to significantly reduce the cooling energy consumption rate. This study fabricated an experimental apparatus for ocher cold pack room that went beyond the jjimjilbang culture to enable people to take cold pack at the houses they reside and investigated the temperature distribution characteristics of the cold pack room. As a result, comfortable cooling beneficial to health were implemented because unlike forced convection cooling in which air is forcibly circulated by the air conditioner, natural convective radiative heat transfer[13] cooling implements cooling without moving or circulating air. An experimental apparatus was constructed to implement cooling by circulating cold water through cold water X-L pipes laid in the walls of the small cabin for one person by configuring a chiller and a cold water pump to supply cold water to the cold water panel. Existing small cooling devices are for cooling of houses or offices not smaller than 26 m^2 and achieve cooling by forced convection methods. However, study reports are insufficient for cooling devices for cabins for one person not larger than 2 m^2 . Therefore,

Figure 1. Experimental apparatus for natural convective radiative heat transfer cooling load for small cabins for one person

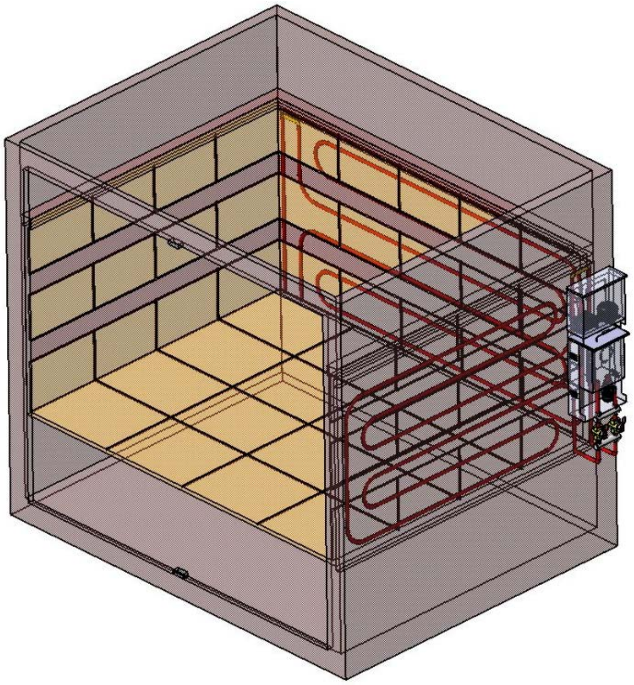

Figure 2. 3D plan of the experimental apparatus for natural convective radiative heat transfer cooling load for small cabins for one person

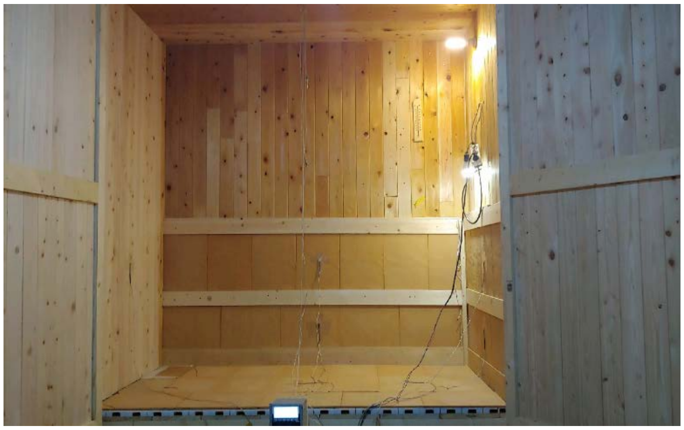

Figure 3. 3D plan of the experimental apparatus for natural convective radiative heat transfer cooling load for small cabins for one person

this study investigated a cooling system that can be used in small buildings such as pensions not larger than 2 m^2.

As shown in Figure 3, a chiller for supplying cold water was installed on the cold water panels of small cabins for one person to carry out an experimental study. The chiller for cold water supply was studied to have a noise level of 40 dB so that there was no sleep disturbance caused by noises when sleeping in the cabin for one person at night. By studying indoor low-noise chiller technology, this study was conducted to prevent energy losses exceeding 3% when compared to the case where the existing technology was installed outdoors considering outdoor cooling losses and X-L pipes losses.

EXPERIMENTAL METHOD

Figure 4 shows the temperature sensors to measure the low air temperature and wall temperature inside the cabin for one person. Three Pt 100 Ω temperature sensors were attached each to the right wall and the center wall of the cabin for one person, on the upper, middle, and lower areas, to measure the low air temperature and wall temperatures inside the small cabin for one person. In addition, three Pt 100 Ω temperature sensors were attached each at equal intervals to the left and right areas of the floor of the small cabins for one person to measure the floor surface temperatures. Furthermore, three Pt 100 Ω temperature sensors were installed at equal intervals in the upper, middle, and lower areas of the inside space of the cabin for one person to measure the low air temperatures. Figure 5 shows the flow rate measuring device for the cold water flowing in the cold water panels inside the small cabin for one person. As shown in Figure 5, a flow meter was installed in the cold water Also, Pt 100 Ω temperature sensors were installed at the inlets and outlets of the cold water X-L pipes laid inside the walls and floor of the cabin for one person to measure the inlet and outlet temperatures of cold water. Instrument meter was set at the entrance of the small cabin for one person to measure the cold water flow rate.

Figure 4. The areas of the natural convective radiative heat transfer cooling load experimental apparatus for the small cabins for one person where temperature sensors were installed

Figure 5. Flow measurement device for the cold water circulating inside the tube of cold water panels of the small cabin for one person

RESULTS

3D SIMULATION OF COOLING LOAD IN RELATION TO CHANGES IN THE AIR TEMPERATURE INSIDE THE SMALL CABIN FOR ONE PERSON

Figures 6 and 7 show the analysis shape and analysis mesh of the cooling load simulation for changes in the air temperature inside the small cabin[14,15] for one person. The size of the small cabin for one person is 2,100 mm wide, 1,100 mm long, and 2,200 mm high. As shown in Figure 6, the simulation was carried out when the temperature of the cold water flowing into the inlet of the cold water.[16] Also, Pt 100 Ω temperature sensors were installed at the inlets and outlets of the cold water X-L pipes laid inside the walls and floor of the cabin for one person to measure the inlet and outlet temperatures of cold water. Temperature of pipes laid inside the walls and floor inside the cabins for one person was 0.3 ℃. The simulation was carried out under the conditions of a flow rate of cold water of 3 L/min and an outdoor temperature of 32 ℃. ANSYS FLUENT R19 was used as analysis software. Figures 8 to 10 show the results of simulations of the surface temperatures[17] of the ocher walls and ocher floor inside the cabins for one person and the air temperature distribution and air flow distribution in the space[18] inside the cabin for one person. The size of the cabins for one person is 2,100 mm wide, 1,100 mm long, and 2,200 mm high. As shown in Figure 8, the simulation was carried out when the temperature of the cold water flowing into the inlet of the cold water Also, Pt 100 Ω temperature sensors were installed at the inlets and outlets of the cold water X-L pipes laid inside the walls and floor of the cabin for one person to measure the inlet and outlet temperatures of cold water. The temperature of pipes laid inside the ocher walls inside the cabin for one person was 0.3 ℃. In addition, the simulation was carried out under conditions of a flow rate of cold water of 2.8 L/min and an outdoor temperature of 32 ℃. ANSYS FLUENT R19 was used as analysis software. The natural convective heat transfer inside the cabin for one person was simulated with gravity and incompressible ideal gas air.[19] The results of simulation of the temperature distribution of air inside cabins for one person in Figure 9 and Figure10 showed that the average temperature of the air inside the cabin for one person was 26.17 ℃, the air temperature at a height of 300 mm from the base side of the small cabin for one person was 26.57 ℃, and, the air temperature at a height of 1,000 mm from the base side of the small cabin for one person was 26.17 ℃. The results of simulation of the air temperature distribution indicated that the temperature distribution of the cold air due to the natural convective radiative heat transfer inside the cabin for one person was uniform, which is considered as a well-being temperature distribution beneficial to health.

THERMAL ENERGY BALANCE BETWEEN COLD WATER AND COLD AIR IN THE SMALL CABIN FOR ONE PERSON

Figure 11 shows the heat energy absorbed by the cold water circulating inside the Also, Pt 100Ω temperature sensors were installed at the inlets and outlets of the cold water X-L pipes laid inside the walls and floor of the cabin for one person to measure the inlet and outlet temperatures of cold water.

The heat energy absorbed by the cold water circulating inside the X-L pipes in the cold water panels laid in the walls of the cabin for one person was obtained with equation (1).

$$Qc,w \;= mc,w\; Cp_w\; (T_{w,2} \;-\; T_{w,1}) \qquad (1)$$

where, Qc,w represents the heat energy per unit time absorbed by the cold water circulating inside the X-L pipes in the cold water panels laid in the walls of the small cabin for one person, $m_{c,w}$ represents the mass flow rate (kg/s) of cold water, $T_{w,1}$ represents the inlet temperature (K) of cold water, and $T_{w,2}$ represents the outlet temperature of cold water. The heat energy per unit time lost by the cold air existing in the cabin for one person was obtained with equation (2).

$$Qc,a \;= mc,a\; Cpa\; (T_{a,2} \;-\; T_{a,1}) \qquad (2)$$

where, Qc,a represents the thermal energy (W)\ per unit time lost by the cold air existing in the space inside small cabin for one person, mc,a represents the mass flow rate (kg/s) of the cold air, $T_{a,1}$ represents the initial temperature (K) inside cabin for one person, and $T_{a,2}$ represents the final temperature of the cold air inside the cabin for one person. As shown in Figure 11, the heat energy absorbed by the cold water circulating inside the X-L pipes in the cold water panels laid in the walls of the small cabin for one person and the thermal energy lost by the cold air existing in the cabins for one person were well matched at ±5%. Therefore, the reliability of the results of the experimental of the heat energy balance between the cold water and the cold air in the cabin for one person in this study is considered to have been secured.

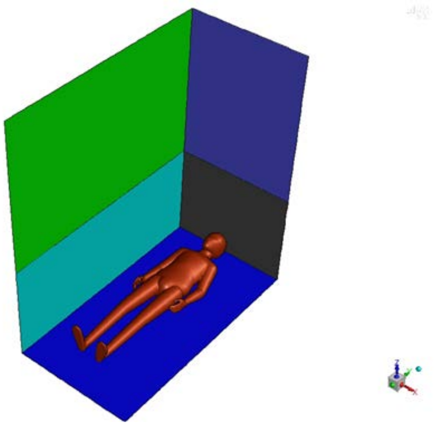

Figure 6. Analysis shape of simulation of cooling load in relation to changes in the temperature of air inside the cabin for one person

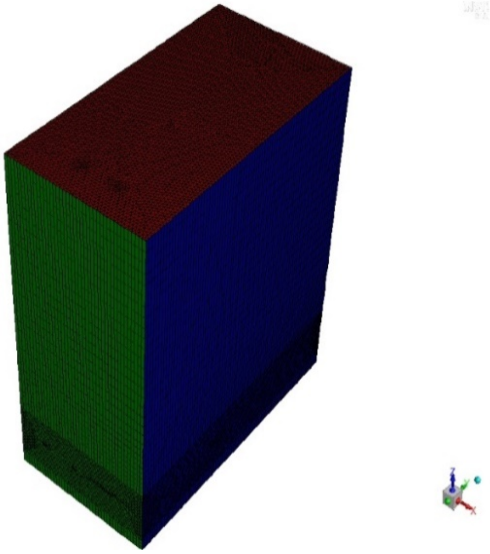

Figure 7. Analysis mesh for simulation of cooling load in relation to changes in the temperature of air inside the cabin for one person

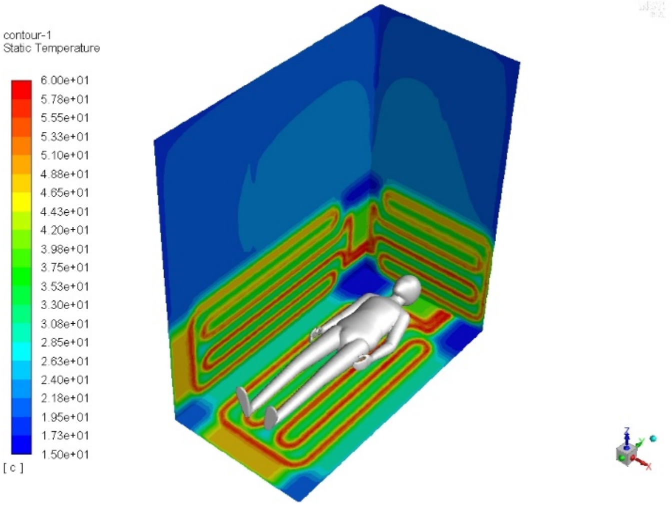

Figure 8. Distribution of temperatures of the walls inside the cabin for one person

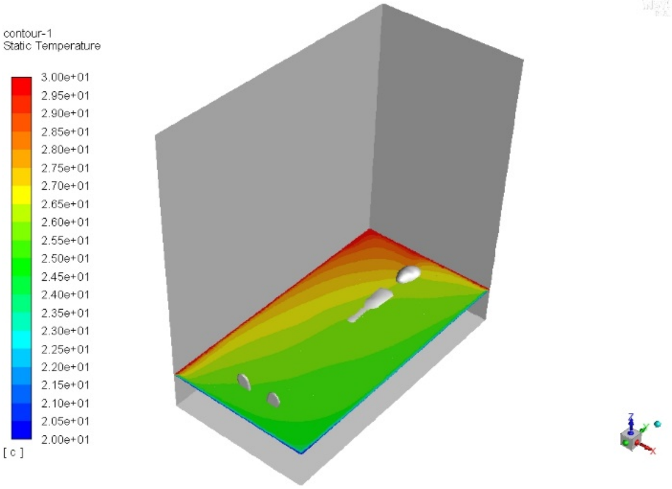

Figure 9. Distribution of temperatures of the air at a height of 0.3m from the floor of the cabin for one person

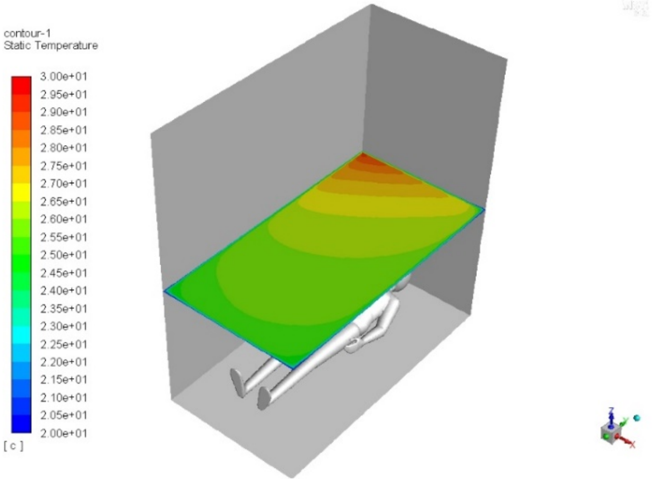

Figure 10. Distribution of temperatures of the air at a height of 1.0m from the floor of the cabin for one person

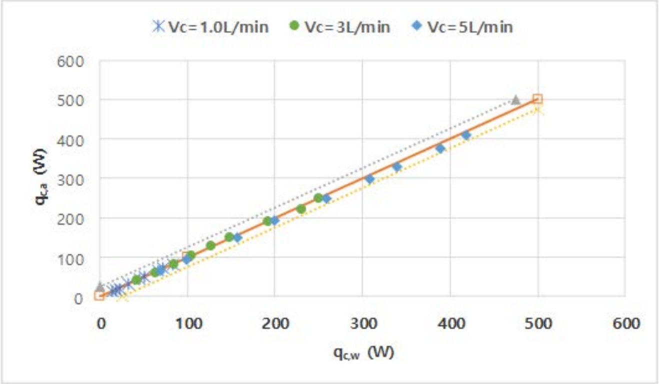

Figure 11. Balance between the rate of transfer of the thermal energy absorbed by the cold water in the small cabin for one person and the thermal energy lost by the low-temperature air existing inside the small cabin for one person

NATURAL CONVECTIVE HEAT TRANSFER COEFFICIENT FOR COOLING LOAD OF SMALL CABIN FOR ONE PERSON

Figure 12 shows the comparative values of the theoretical natural convective heat transfer coefficient of the cold air existing in the cabin for one person and the experimental natural convective heat transfer coefficient to analyze the cooling load characteristics of small cabins for one person and the accuracy of the experimental results. Equation (3) represents the experimental natural convective heat transfer coefficient for cold air.

$$Hex = \frac{Qc,a}{As(Tc,a-Tc,w)} \qquad (3)$$

.

where, As represents the heat transfer surface area (m^2) of the small cabin for one person, Tc,a repreesernts the indoor cold air temperature (K), and Tc,w represents the wall temperature (K) of the small cabin for one person

The theoretical natural convective heat transfer coefficient for cold air for cooling inside the small cabin for one person was obtained with Equation (4).

$$Hth = \frac{kf}{L} Nu \tag{4}$$

where kf represents the thermal conductivity coefficient (W/mK) of cold air. As shown in Figure 12, the experimental natural convective heat transfer coefficient value in the cooling of the small cabin for one person obtained with Equation (3) and the theoretical natural convective heat transfer coefficient value of the cold air for cooling obtained with Equation (4) are relatively in good agreement throughout the experiment. Therefore, the reliability of the experimental resultant values for the cooling load of the small cabin for one person in this study is considered to have been verified.

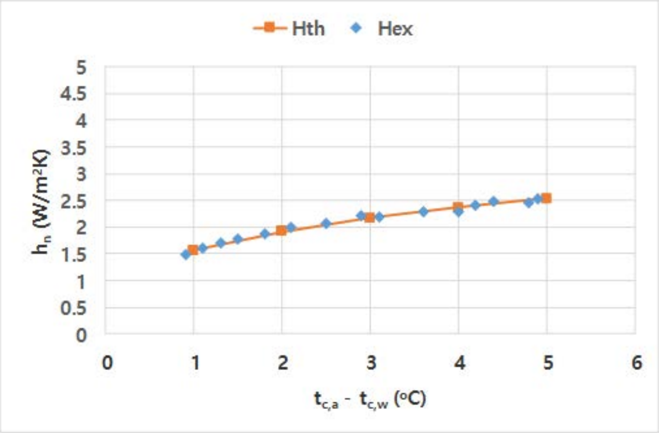

Figure 12 Comparison of theoretical natural convective heat transfer coefficient and experimental natural heat transfer coefficient of small cabins for one person

THERMAL ENERGY BALANCE BETWEEN COLD WATER AND COLD AIR IN THE CABIN

Figure 13 shows changes in the temperature of the cold air inside the cabin for one person following changes in the flow rate of the cold water circulating inside the X-L pipes in the cold water panel laid on the walls.

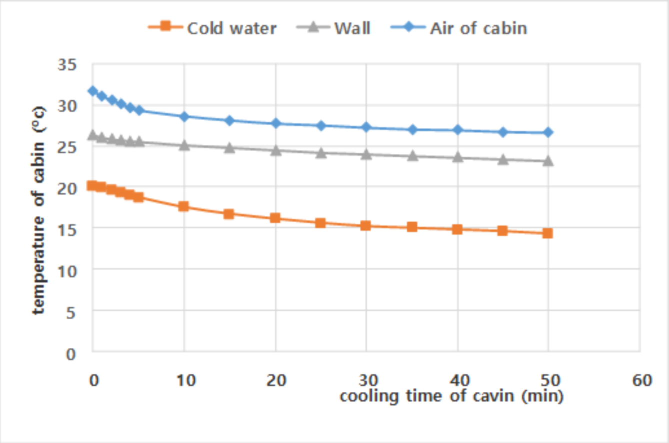

Figure 13. The rate of changes in the temperature of the cold air inside the cabin for one person in relation to changes in the flow rate of the cold water circulating in the cold water X-L pipes inside the walls of the cabin for one person.

The cold water flow rates were experimented under three conditions: 1.5 L/min, 3.0 L/min, and 6 L/min. As shown in Figure13, the temperature of the cold air inside the cabin for one person decreased in proportion to the increase in the flow rate of cold water, and in proportion to the cooling time.[20] The temperature of the cold water produced by the chiller was normally increased as the cold water absorbed the thermal energy held by the air existing in the cabin for one person.[21] In addition, it is considered that the cooling load of the cabin for one person increases as the cold water flow rate increases. Furthermore, based on the results of the experiments conducted with the small cabin for one person, the balance of heat energy for cooling was achieved well. Therefore, the reliability of the experimental results in this study was verified.

Figure 14 shows the distribution of the temperatures of the walls of the cabin for one person in relation to changes in the flow rate of cold water circulating inside the X-L pipes in the walls. The cold water flow rates were experimented under three conditions: 1.0 L/min, 3.0 L/min, and 5.0 L/min. As shown in Figure 15, the temperature of the walls of the cabins for one person decreased proportionally as the chiller's operating time elapsed. Therefore, it is considered that the cooling load of single-person households operates normally.[22] As the mass flow rate of cold water increased, the wall temperature inside the small cabin for one person decreased proportionally. Therefore, it is thought that the cooling load of the small cabin for one person increases as the cold water flow rate increases.

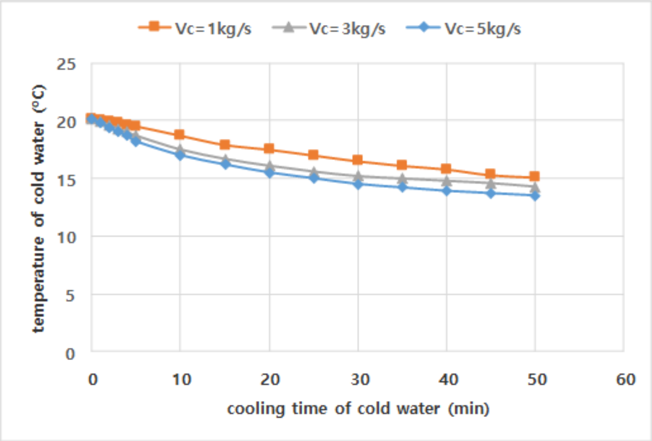

Figure 14. Rates of change in the temperature of the wall inside the cabin for one person in relation to changes in the flow rate of the cold water circulating in the cold water X-L pipes inside the walls of the cabin for one person

CONCLUSION

In this study, 3D simulations and experimental studies were carried out on the cooling load due to the heat absorption by water circulating inside the ocher walls of the cabin for one person, and the following results were derived.

The results of the simulation of the temperature distribution inside the cabins for one person indicated that the temperature distribution of the cold air in relation to the natural convective radiative heat transfer inside the cabin for one person was uniform, and well-being temperature distributions beneficial to health were implemented. In addition, in this study, the temperature distribution of the cold air measured in the experimental study which showed good agreement with the results of the simulation.

The heat energy absorbed by the cold water circulating inside the X-L pipes in the cold water panels laid in the walls of the small cabin for one person and the heat energy lost by the cold air existing in the cabin for one person were well matched at ± 5%. Therefore, the reliability of the results of the experiment of the heat energy balance between the cold water and the cold air in the cabin for one person in this study was secured.

In the cooling of the cabin for one person, the values of the experimental natural convective heat transfer coefficient and the theoretical natural convective heat transfer coefficient of cold air for cooling were relatively well matched throughout the experiment. The reliability of the experimental results for the cooling load of cabins for one person in this study was verified.

As the flow rate of cold water increases, the air temperature in the space in the cabin for one person decreased proportionally. Therefore, as the cooling water flow increases, the cooling load of the cabin for one person increases.

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