Analysis of the Surface Temperature and Energy Performance for the Double Paned Glazing Filled with Carbon Dioxide as an Insulating Gas

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Abstract : Background/Objectives: The purpose of this study is to develop a double glass infused with CO2 as a part of the work to resource greenhouse gases in buildings.

Methods/Statistical analysis: In the case of analysis of the results, the analysis point was focused on January during the heating period with a large indoor/outdoor temperature difference. The amount of energy lost, and the amount of heating energy used in the room. In addition, details of the concept, characteristics, and heat transfer process of the CO2 double glass have been described in detail in the previous study and will be omitted in this paper.

Findings: This study aims to analyze the insulating and energy performances for the double paned glazing filled with carbon dioxide (CO2) gas as one of works to utilize greenhouse gases in buildings . For this, double paned glazing with CO2, Air, Argon, and Krypton gases respectively apply to the building designed by the computer simulation program, and then, hourly surface temperatures in the indoor pane, hourly energy losses, and total energy consumption in the building are compared. The simulation programs are Therm & Window and EnergyPlus. The results revealed that the indoor surface temperatures of the glazing with CO2 gas are located between the glazing with Air and Krypton gases, and are similar to the glazing with Argon gas. In analysis of energy performance, it was shown that the building with CO2 glazing consumes heating energy at a similar level to the case of Argon gas.

Improvements/Applications: The insulation and energy performance when CO2 gas was injected into the double glass was verified, and it was found that it exhibited similar performance to the existing Ar gas and thus has high potential as an insulating gas.

Keywords: Carbon dioxide, Double paned glazing, Energy performance, Greenhouse gas, EnergyPlus.

1. Introduction

The main greenhouse gases that cause global warming are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), fluorinated carbon (HRCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). Of these, CO2 is the most greenhouse gas emitted in the atmosphere by artificial production activities in each industry. Therefore, in order to effectively mitigate global warming, it is essential to develop technologies that capture and store CO2 already emitted while reducing CO2 emissions from production activities. In particular, in Korea, it has long focused on the development of technologies for capturing and storing CO2 in the atmosphere, and as a result, technologies that can capture and store CO2 and control it artificially have developed to a considerable level. Most of these captured and stored CO2 is permanently buried in the ground, but some CO2 gases are regenerated through chemical separation technology and mechanical process technology, and are reused as resources in each industry.[1]

While various efforts have been made to utilize stored CO2 as a resource in other industries, the building sector is focusing on reducing CO2 emissions, and research and technologies to utilize CO2 as a resource are still somewhat insufficient. to be. In particular, from the viewpoint of heat and energy, pure CO2 gas can exhibit higher thermal insulation performance than air and is relatively inexpensive. Therefore, if CO2 is used as a heat insulating material in a building, it will be able to exhibit effective heat insulation performance at a low cost. [2-4]

The only element that can use gaseous CO2 as an insulating material in a building will be the hollow layer of the double glazing of the building envelope and windows. Of these, since it is almost impossible to form the hollow layer of the building envelope into a completely enclosed space, there is a very high risk of being discharged back into the atmosphere even when CO2 gas is injected. In contrast, since the hollow layer of the double glass in the window can be kept in a completely sealed state by applying two or more sheets of glass and edge sealing technology, there is little risk of being discharged into the atmosphere even when CO2 is injected. [5] If CO2 is used as an insulating gas in double glass, the price of windows can be considerably lowered by replacing the existing expensive insulating gases Argon (Ar) and Krypton (Kr) with CO2. In particular, existing

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windows and doors have been recognized as a building element that releases CO2 gas by promoting the consumption of cooling and heating energy in buildings, but if one of the greenhouse gases, CO2, is injected into the glass, the building with such glass is CO2 like forest. It can have the advantage that can be converted into architectural elements that absorb. Therefore, this study aims to develop a double glass infused with CO2 as part of the work to make greenhouse gases into resources in buildings. To do this, a wide range of research and verification must be conducted, including verification of thermal insulation performance for CO2 gas, determination of the optimal thickness of gas, fusion of frame and edge sealing technology, and possibility of fusion with other technologies for super insulation such as vacuum and suspended film. The current study focuses on verifying the adiabatic performance of CO2 gas as an initial step. In this regard, this author compared the insulation performance of CO2 gas with Air, Ar, and Kr gases, which have been widely used as insulating gases for glass, by using the Thermal & Window program, a glass and window analysis program in the previous study. As a result, the adiabatic performance of CO2 gas was higher than Air and lower than Kr gas. In particular, it was analyzed that the double glass injected with CO2 in terms of the heat transfer rate U-value showed a very similar U-value value to the double glass injected with Ar gas. When applied, as in the existing U-value analysis results, the computer simulation program is to verify whether the double glass with CO2 in the actual building exhibits similar energy performance to the double glass with Ar gas.
As a research method, first, a modeling method of windows and buildings for performing computer simulation, as well as indoor and outdoor environmental conditions and heating and cooling equipment conditions applied to the simulation will be described. In addition, in the case of analysis of results, the time of analysis focused on January during the heating period with a large indoor/outdoor temperature difference. The amount of energy lost, and the amount of heating energy used in the room. In addition, the details of the concept, characteristics, and heat transfer process of CO2 double glass are omitted in this paper because they have been described in detail in the previous study. [6] Window and Energy Analysis program, EnergyPlus version 8.7. In addition, for the overall theory and analysis methodology for calculating the surface temperature, heat transfer process inside the glass, and deriving energy consumption during the simulation process, refer to the EnergyPlus Engineering Reference. [7,14,15]

2. Research Methods

2.1. *Composition of carbon dioxide double glass*

Fig. 1 shows the structure and characteristics of the CO2 double glass proposed in this study. The system consists of two sheets of glass, CO2 gas, edge sealing, and a frame, just like a normal double glass. In particular, Edge sealing that seals the gas layer is composed of Primary sealing (Spacer bar) and Secondary sealing including desiccant. Also, in order to apply such glass in EnergyPlus, thermal and physical values for glass, CO2 gas, and frame must be entered. First, in the case of glass, the Therm & Window program provided by Lawrence Berkeley National Laboratory (LBNL) includes various types of glass produced in each country, and is constantly updated every year.[8] Therefore, the glass applied to this simulation is It is a low-emission glass produced by 'Saint-Gobain Glass', one of the glasses provided by LBNL, and the thickness of the glass was selected as 5 mm, which is generally widely used. Table 1 shows the thermal conductivity of the glass and the optical properties of the front and back surfaces.

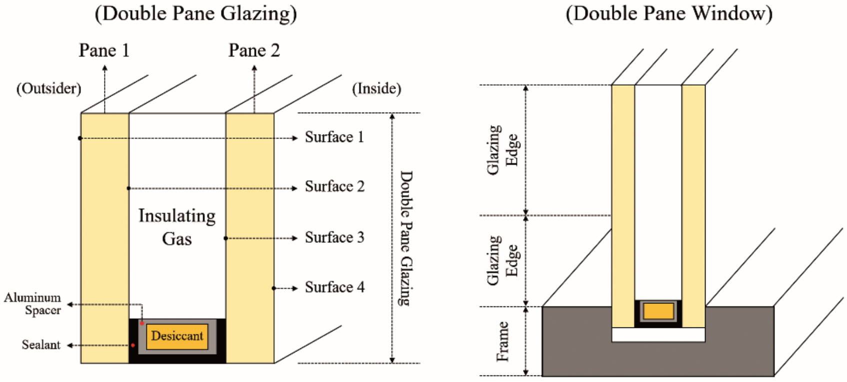

Fig. 1 The structure of the double paned glazing with CO2 gas

In addition, Table 2 shows the thermal and physical values of each gas at standard atmospheric pressure as an insulating gas applied to EnergyPlus.[9] The thickness of the gas is 10 mm, which is generally applied in actual double glass. In particular, in order to verify the level of insulation and energy performance of double glass by CO2 gas, the insulating gases of the existing double glass, Air, Ar, and Kr gases were applied as comparison objects. In addition, Table 3 shows the material and thickness of the frame combined with the double glass, the thermal conductivity, and the length protruding from the double glass. The total thickness of the double glass combined with these materials is 20 mm, and the total width of the windows applied to the building by combining the double glass and the frame is 220 mm.

Table 2 The thermal characteristics of Air, A, Kr, and CO2 gases

Type of insulating gas		Air	Ar	Kr	CO2
Thickness	(mm)	10	10	10	10
Molecular Weight	(mol/g)	28.970	39.948	83.800	44.010
Pressure	(Pa)	101325	101325	101325	101325
Prandtl Number		0.7197	0.6704	0.6717	0.7808
Conductivity coefficients	(W/m・K)	0.002873	0.002285	0.0009443	0.00037
Viscosity coefficients	(kg/m・s)	0.00000372	0.00000338	0.00000221	0.00000116
Specific heat coefficients	(J/kg・K)	1002.7	521.9	248.1	558.8

Table 3 The type and thermal characteristics of the frame system

Type of frame	Material	Thickness (m)	Projected length (m)	Conductivity (W/m・K)
Side sliding	PVC	0.08	0.1	0.16

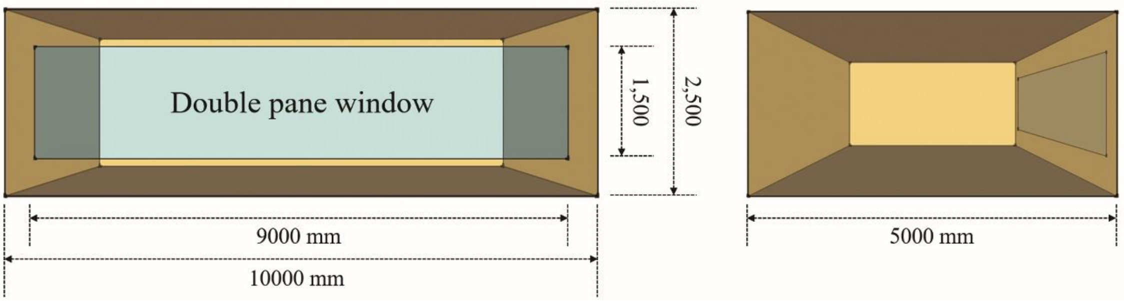

Fig. 2 The residential building molded by EnergyPlus program

2.2. *Building modeling and window application*

Fig. 2 and Table 4 show the building and basic information modeled in EnergyPlus to apply the previously modeled windows. The location of the building is assumed to be Seoul, and its purpose is residential. The building is also 10 m wide, 5 m deep, and 2.5 m high. The incense of the building is south, and a window of 9 m wide and 1.5 m high is installed on the south wall. In addition, the weather data applied for simulation was used for the standard weather data of Seoul, which is provided by a domestic accredited institution.[10] Table 5 also shows the structure and heat flow rate of each shell constituting the building. The building was modeled as a concrete structure, and the heat permeation rate of each envelope was constructed to meet the heat permeability standard of the central region suggested in the 'Energy-Saving Design Standard of Buildings'.[11]

Table 4 Overview of the standard building

Site location	: Seoul	Length of building	: 10 m
Latitude	: 37.34	Width of building	: 5 m
Longitude	: 126.57	Height of building	: 2.5 m
Direction of building	: Corrected south	Window size	: 9 m × 1.5 m

Type of weather data	: Standard weather data of seoul region: EPW (EnergyPlus weather) file

Table 5 The structures of each building envelope

Structure	Type of material	Thickness (m)	Conductivity (W/m・K)	Thermal transmittance (W/m2・K)
Floor	Concrete slab	0.21	1.4	0.178 (Domestic standard: 0.180)
	Insulating material	0.17	0.034	
	Auto-cleaved Lightweight Concrete (ALC)	0.04	0.15	
	Mortar	0.04	0.72	
	Finishing material	0.005	0.16	
Wall	Concrete wall	0.18	1.4	0.258 (Domestic standard: 0.260)
	Insulating material	0.12	0.034	
	Gypsum board	0.01	0.17	
Roof	Mortar	0.08	0.72	0.142 (Domestic standard: 0.150)
	Concrete slab	0.21	1.4	
	Insulating material	0.09	0.035	
	Air cavity	0.1	0.025	
	Gypsum board	0.01	0.17	

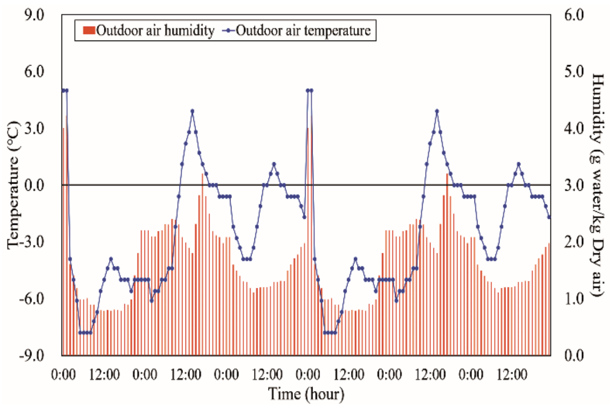

Fig. 3 Hourly outdoor temperature and humidity

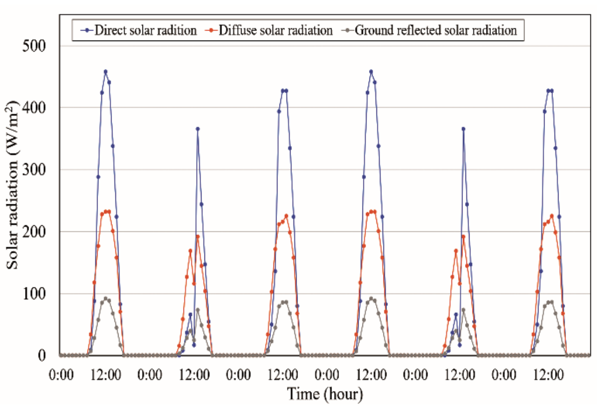

Fig. 4 Hourly direct, diffuse, and ground reflected solar radiations

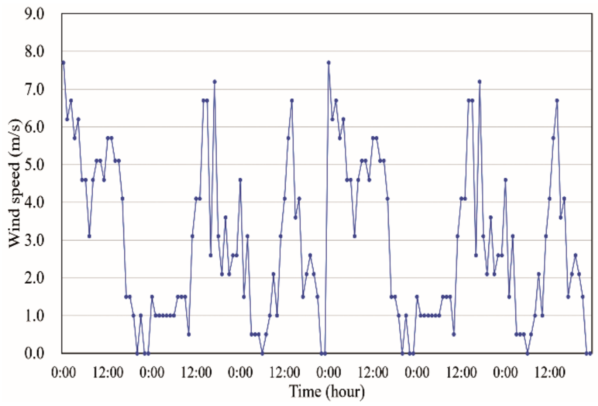

Fig. 5 Hourly wind speed

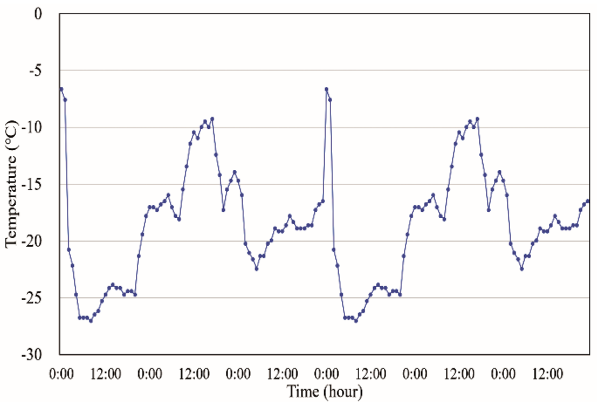

Fig. 6 Hourly sky temperature

2.3. *Indoor and outdoor environmental conditions*

2.3.1. Outdoor conditions

Among the standard weather data applied to EnergyPlus, the analysis period was applied for about 1 week from 0:00 on January 1 to 0:00 on January 7. Each data of weather data was input by time, so the result of energy performance of double glass was also analyzed based on hourly data. Fig. 3, 4, 5, and 6 are representative data among hourly weather data for one week, and show outdoor temperature, solar radiation, wind speed, and puncture temperature.

2.3.2. Applying Air conditioning equipment

For indoor air conditioning and heating equipment, an electric air system including an electric heat exchanger was applied, and Table 6 shows the characteristics of the system. The indoor heating and cooling set temperatures are 22°C and 25°C, respectively, and the heat source supply capacity is set to be automatically calculated as infinity. The sensible and latent heat exchange efficiency by the total heat exchanger was applied to the maximum value of 0.9 in the simulation, and the external air condition was set to be calculated through the standard weather data described above.

2.3.3. Indoor heating element and temperature control

Indoor heat loss and heat acquisition factors were applied to occupants, lighting, bedding, and ventilation, and the hourly schedule of each element is shown in Fig. 7, 8, 9. First of all, it was assumed that a total of 4 residents live. There are no occupants from 8:00 to 18:00, and other time is set to 4 persons. In addition, the lighting use is the same as the occupant schedule, and the size of the lighting was applied as a ratio from minimum 0 to maximum 1.

In particular, 8:00 ~ 18:00 without occupants was set to 0 without lighting, and 6:00-8:00 and 18:00-22:00 were applied to the maximum lighting usage rate of 1. In addition, from 22:00 to 6:00 the next day, it was assumed to be bedtime, and the minimum lighting was set to 0.1. In addition, indoor infiltration was assumed to be an energy-saving building and applied once per hour [12], and indoor ventilation was set at 0.5 times per hour, citing domestic standards.[13]

Table 6 Indoor heating and cooling system

Type	All-air method with a heat recovery unit	
Indoor set-point	Heating set-point	22 ℃
	Heating limit	No limit
	Cooling set-point	25 ℃
	Cooling limit	No limit
Supply air	Maximum heating temperature	50 ℃
	Maximum heating humidity	0.0156 (kg/kg Dry Air)
	Maximum cooling temperature	10 ℃
	Maximum cooling humidity	0.0077 (kg/kg Dry Air)
	Temperature control	Heating & cooling set-point
	Air flow rate control	Autosize
Return air	Heat recovery type	Enthalpy
	Sensible heat recovery rate	0.9
	Latent heat recovery rate	0.9
Outdoor air	Outdoor air condition	Weather data
	Flow rate control	Autosize

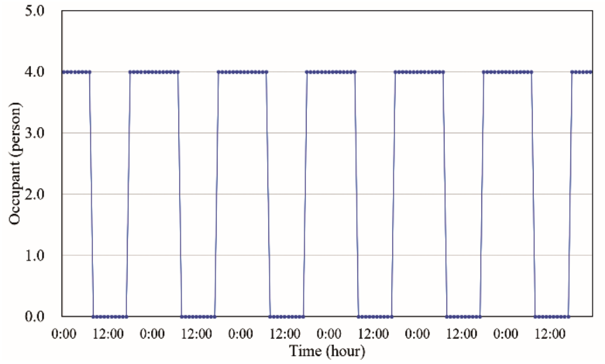

Fig. 7 Occupant schedule

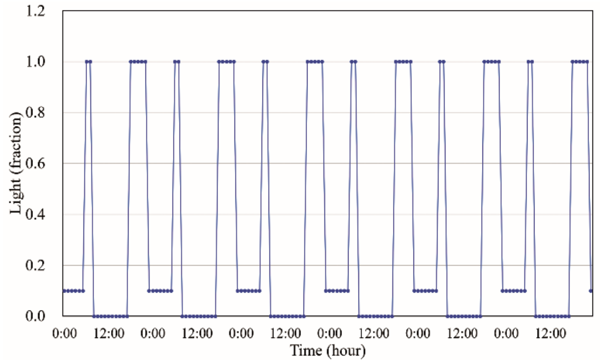

Fig. 8 Indoor light schedule

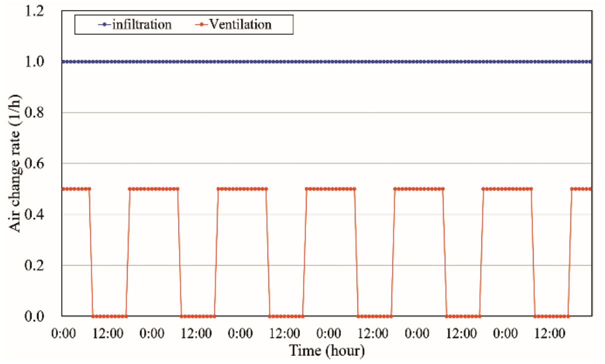

Fig. 9 Infiltration and ventilation schedules

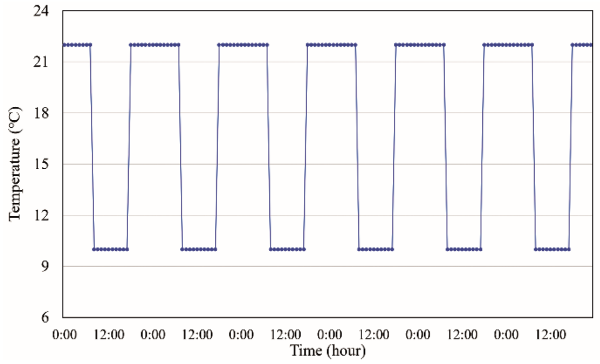

Fig. 10 Indoor temperature schedule

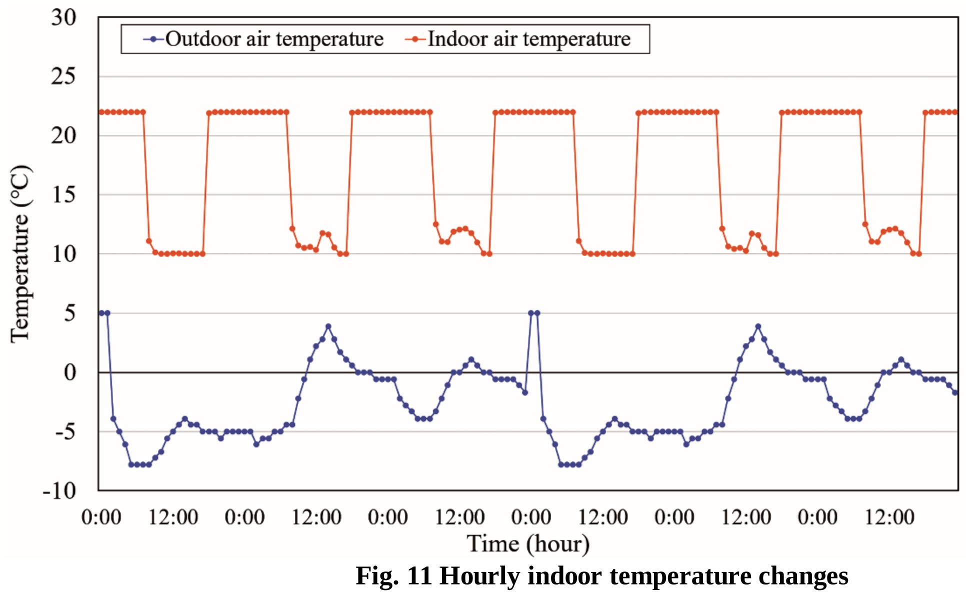

Fig. 11 Hourly indoor temperature changes

3. Results and Discussion

3.1. *Indoor temperature*

Fig. 11 shows the change in indoor temperature by hour from 00:00 on January 1 to 00:00 on January 7. As described above, the room temperature was set to maintain 22° C. during the heating time and 10° C. or higher in the non-heating time. Simulation results show that the indoor temperature maintains the set temperature from 18:00, the heating time, to 08:00, the next day, for all periods of one week, and 10℃ or higher from 8:00 to 18:00, the non-heating time zone. It can be seen that it is controlled to maintain.

3.2. *Room surface temperature of double glass*

The flow of a certain amount of sensible and latent heat energy supplied to the indoor space through the heating system to the outside through the double glass is in the order of the indoor space, the indoor surface of the glass, the insulating gas, and the outdoor surface of the glass. Among them, minimizing the flow of heat energy between the interior space (Inside of Fig. 1), which is the initial flow, and the indoor side surface of the glass (Surface 4 of Fig. 1) reduces the total heat energy loss through the double glass. It is necessary to reduce the temperature difference between the two sides to the maximum by lowering the indoor temperature and increasing the surface temperature of the glass. However, in general, since the indoor heating set temperature is fixed at a constant time during the heating time, as a result, it can be said that maintaining the high indoor surface temperature of the glass can minimize heat energy loss. In addition, the indoor surface temperature of the glass changes according to the influence of the cold outdoor glass surface. At this time, the better the insulating performance of the injected gas, the higher the indoor surface temperature can be maintained. Therefore, prior to analyzing the energy performance of the double glass, when only the insulating gas was changed in the same glass, the first analysis was made on how the temperature distribution of the indoor surface of the glass varies with each gas. Fig. 12 shows the hourly data for the indoor surface temperature of the double glass injecting CO2 and Air, Ar, and Kr gases. After about 2 hours, after about 2 hours from 18:00 when heating started, the indoor surface temperature of the double glass was maintained at a stable state of about 10 to 14°C. In the case of the distribution of the surface temperature according to the gas, the surface temperature of the indoor side of the double glass injected with air was the lowest, and the surface temperature of the Kr gas was the highest. On the other hand, it was confirmed that the surface temperature of the indoor side of the double glass in which CO2 and Ar gas was injected is located between the air and the Kr gas. Although the Ar gas was slightly higher than the CO2 gas, the surface temperature distribution of the two gases was analyzed to be almost similar. Therefore, it is expected to show this pattern in energy loss and heating energy consumption by double glass.

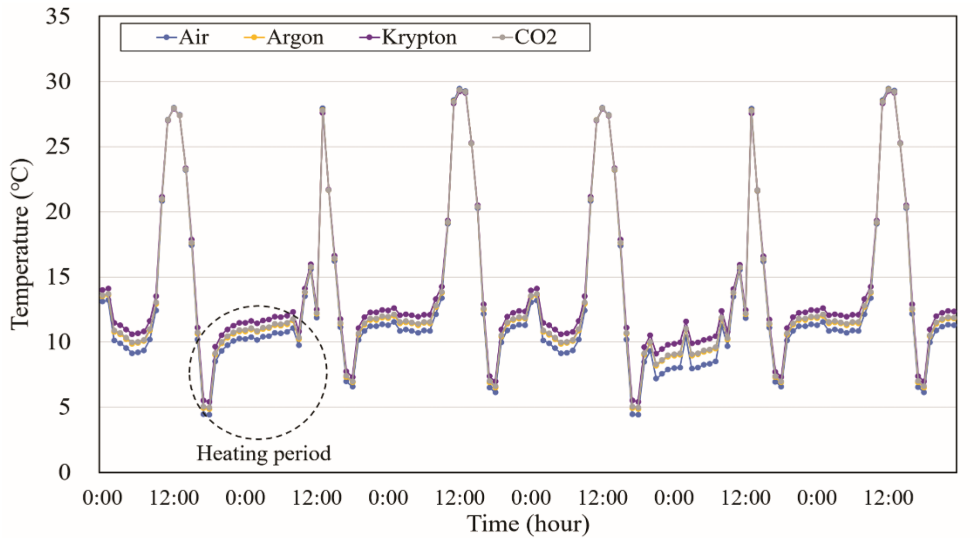

Fig. 12 Hourly temperature changes in indoor surface of the glazing

3.3. *Heating energy consumption*

Fig. 13 shows the amount of energy lost over time by the double glass injected with CO2 and Air, Ar, and Kr gas, and the amount of loss for all double glass was distributed in the range of about 0.3 to 0.9 kWh. In addition, the double glass injected with air showed the most thermal energy loss, while the double glass injected with Kr gas showed the least thermal energy loss. In particular, the double glass injecting CO2 and Ar gas appeared to have a medium level of Air and Kr gas, as shown in the pattern of the surface temperature described above, and it was analyzed that the heat energy loss by time of the two gases showed a similar pattern.

In addition, Fig. Fig. 14 shows the total heating energy consumption of a building with double gas injected with four gases during the entire simulation period. The double glass injected with air was 449.5 kWh, which was the highest in heating energy consumption, and the Kr gas injection was 441.2 kWh, which was the lowest consumption of heating energy. In comparison, the heating energy consumption of Ar gas and CO2 gas was 445.5 kWh and 444.8 kWh, respectively, and Ar gas was slightly higher than CO2, but it was analyzed that it showed almost similar consumption.

When synthesizing the above analysis results, it was confirmed that the insulation and energy performance of the double glass injected with CO2 gas was almost the same as the U-value pattern suggested in the previous study. In particular, the CO2 double glass showed lower thermal insulation and energy performance than the Kr gas, but could exhibit higher performance than the traditional thermal insulation gas, Air, and showed almost similar performance to Arn gas. Therefore, it is judged that CO2 gas can be used as an insulating gas for double glass in buildings. Nevertheless, CO2 gas is one of the greenhouse gases. In consideration of this, when using this gas for double glass, it is considered that the gas injection and recovery technology should be secured together so that it is not exposed to the atmosphere during production and disposal.

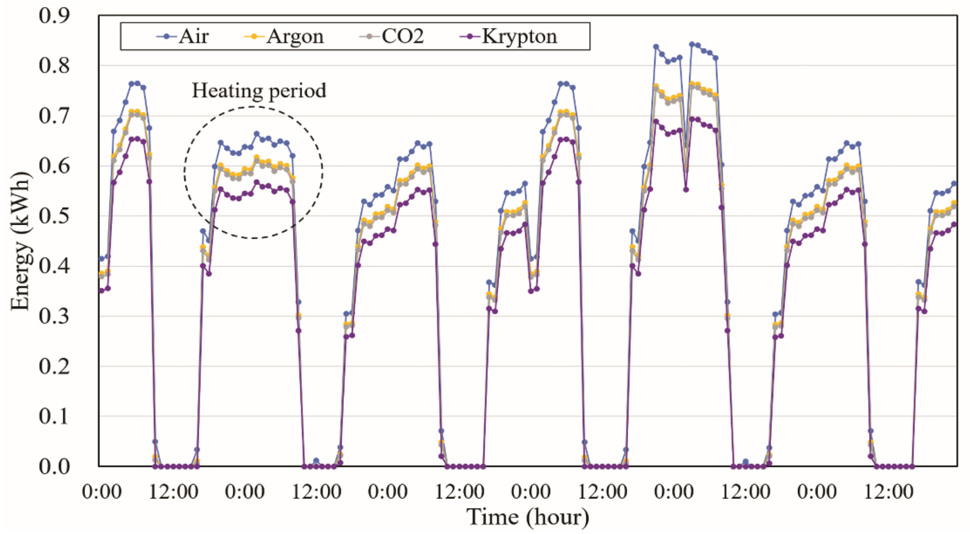

Fig. 13 Hourly heating energy lost by the glazing

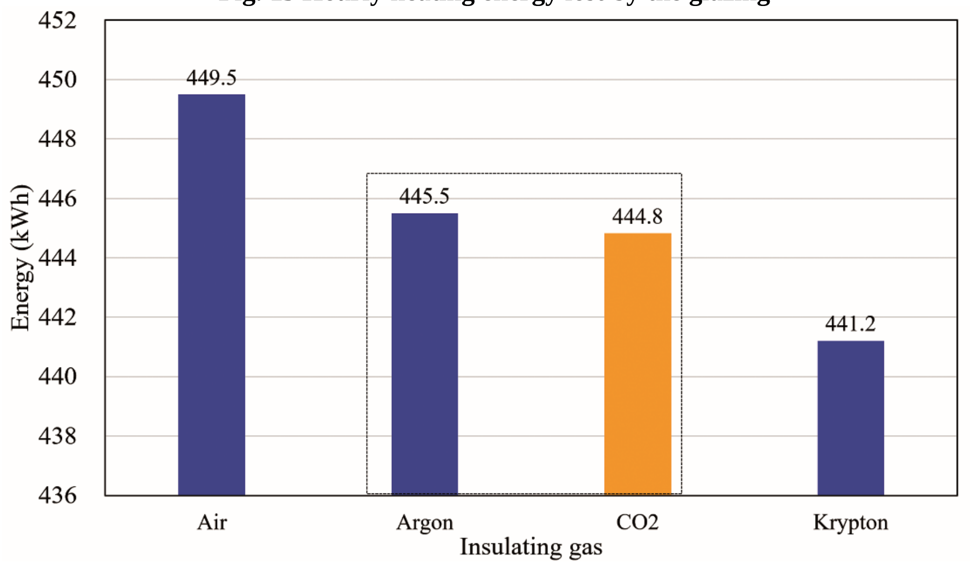

Fig. 14 Total heating energy consumptions

4. Conclusion

The study aims to analyze the thermal insulation and energy performance of the double glass infused with carbon dioxide (CO_2), and the results obtained through this study can be summarized as follows.

(1) As a result of comparing the surface temperature of the indoor glass against the double glass of air, ar, and kr gas, which is the existing insulating gas, and the CO2 double glass proposed in this study during the heating period, the double glass with air injected was the lowest. It appeared, and the double glass in which Kr was injected was kept the highest. The double glass of Ar and CO2 gas maintained the surface temperature between the Air and Kr gases, and the surface temperature of Ar and CO2 appeared almost similar at the same time.

(2) As a result of comparing the amount of energy loss by hour by the double glass in which these gases were injected, as the result of the surface temperature, Air showed the most energy loss, whereas Kr gas showed the lowest energy loss. Looked. Also, the energy loss of Ar and CO2 gas was found to be between Air and Kr gas, and the energy loss was also analyzed to be almost the same.

(3) As a result of comparing the total heating energy consumption used in the building for about a week during the simulation period, Kr gas showed the lowest heating energy consumption, about 441.2 kWh, while Air showed the highest energy, 449.5 kWh. It was analyzed that it consumed. In comparison, for Ar and CO2 gas, it was found that the heating energy consumption was almost the same while maintaining the intermediate levels of Air and Kr gas, respectively, 445.5 kWh and 444.8 kWh.

In the previous study and this study, the insulation and energy performance when CO2 gas, one of the greenhouse gases, was injected into the double glass was verified, and it was found that it exhibited similar performance to the existing Ar gas and thus was highly applicable as an insulating gas. Nevertheless, recent research trends focus on developing ultra-insulated glass with a zero-heat-permeability (U-value) of glass using a variety of materials and technologies. Therefore, future research will present the results of research on technology and performance verification to realize ultra adiabatic glazing using CO2 gas.

5. Acknowledgment
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