Proposal of the Methodology to Predict Convection Heat Transfer by Insulating Gases in Double-Glazed Panes

Sanghoon Baek, Sangchul Kim

Abstract*: Helium, Argon, krypton, and Xenon are the representative insulating gases which be used for window systems, and convective heat transfer by the gases is one of the important factors to decide the heat performance of the entire window system. Window ver. 7.4 provided by Lawrence Berkeley National Laboratory U.S. (LBNL), which is the window professional research organization, was used in order to calculate the insulating performance of the double-glazed pane with the inserted noble gas and heat transfer by convection. This program can calculate heat transfer by conduction, convection, and radiation occurring in an indoor and outdoor surface temperature of the double-glazed pane and gas layer. It is necessary to examine convection heat transfer by an insulating gas to improve the insulating performance of the entire window system. This study aims to propose a methodology to predict convection heat transfer by insulating gases in double-glazed panes through a heat transfer theory and a computer simulation program. As the results, the insulating gases that can be utilized for a double-glazed pane are the noble gases, Helium, Neon, Argon, Krypton, Xenon, and each gas has a different convection heat transfer. In summer and winter conditions, the convection heat transfer of xenon is lowest, followed by Krypton, Argon, air, Neon, and Helium.The research shows that it is necessary to use insulating gases which have low convection heat transfer to make high-insulating window systems.

***Index Terms*: Convection heat transfer,Double-glazed pane, Insulating gas, U-value, Window system**

I. INTRODUCTION

The Korean Intended Nationally Determined Contribution (INDC) aims to reduce greenhouse gases by 37 % below Business As Usual (BAU) by 2030 [1], and, based on the INDC, the greenhouse gas emissions in the building sector require the highest reductions among all domestic industry sectors [2]. Thus, it is of paramount importance to reduce greenhouse gas emissions from energy consumptions in the building sector in order to reach the national greenhouse gas reduction goal. In the building sector, the energy is used for cooling and heating accounts for approximately 45% of total energy consumption [3]. In order to lower this energy consumption level, it is necessary to improve the insulating performance of building envelopes. In particular, it is vital to improve the insulating performance of window systems, which have low insulating performance compared to other elements such as exterior walls, roofs, and floors in buildings. In addition, to date, several studies focusing on the development of high-insulating window systems have been conducted [4]. Double-glazed panes applied to modern buildings consist of two panes, an insulating gas, an insulating spacer, PVC or aluminum frame including thermal bridge, and low-emission coating [5]. Of these elements, an insulating gas performs the role of mitigating heat transfer in between two panes which are placed in indoor and outdoor spaces [6]. Thus, it is necessary to examine convection heat transfer by an insulating gas to improve the insulating performance of the entire window system. This study aims to propose a methodology to predict convection heat transfer by insulating gases in double-glazed panes. To this end, the insulating gases which can be used for a double-glazed pane are explained in section 2, and the theory and method for calculating their convection heat transfer presented. A computer simulation program was used to apply the methodology suggested in section 2 to an actual double-glazed pane. Subsequently, the method for modeling a double-glazed pane and setting the boundary conditions for calculating convection heat transfer is described in section 3. Next, the results from the computer simulation are analyzed and presented in section 4.

Revised Manuscript Received on May 22, 2019.

SanghoonBaek, Industry Academic Cooperation Foundation, HanKyong National University, 327, Jungang-ro, Anseong-si, Gyeonggi-do, 17579, South Korea.

Sangchul Kim, School of Architecture, HanKyong National University, 327, Jungang-ro, Anseong-si, Gyeonggi-do, 17579, South Korea

II. THEORY

A. Nobel gas

Insulating gas that can be inserted into the double-glazed pane is noble gas belonging to the Group 8A (VIIIA of Main Group) on the periodic table of the elements. These gases have very stable atomic structures, almost no reaction to temperature changes, and hardly make a chemical bond with other materials in the atmospheric environment [7]. Thus, if noble gas is used as an insulating gas in windows, it can retain its physical properties by not mixing with impurities such as water vapor or organic vapor penetrated in the manufacturing process of the window that can lower insulating performance of the gas. It can be utilized as the best gas in the window in order to demonstrate insulating performance [8,9]. Other than Radon, which is a radioactive material, Helium, Neon, Argon, Krypton, and Xenon have been used as insulting gas up to now. Their physical and chemical properties are as shown in the following Table 1.

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

Table 1: Properties of noble gases

Name	Atomic Number	Atomic Mass (g/mol)	Melting Point (°C)	Boiling Point (°C)	Energy of first ionisation (kJ/mol)	Isotopes
Helium (He)	2	4.0026	-272.2(26 atm)	-268.9	2,372	2
Neon (Ne)	10	20.179	-489.0	-246.0	2,080	3
Argon (Ar)	18	39.948	-189.0	-185.7	1,520	6
Krypton (Kr)	36	83.800	-157.0	-153.0	1,351	15
Xenon (Xe)	54	131.290	-112.0	-107.0	1,170	21

B. Convection heat transfer by noble gas

Noble gases inserted into the double-glazed pane, as shown in Figure 1, transfer heat from one surface of the window to the other surface through a convective motion, in particular as a form of natural convection according to the temperature difference in an enclosed gas layer. Convective heat transfer can be calculated by the following equations (1)-(7), which uses the physical properties of the gas, Newton's law of cooling, and a dimensionless number defined as Nusselt (Nu), Grashof (Gr), Rayleigh (Ra), and Prandtl (Pr) Numbers [10].

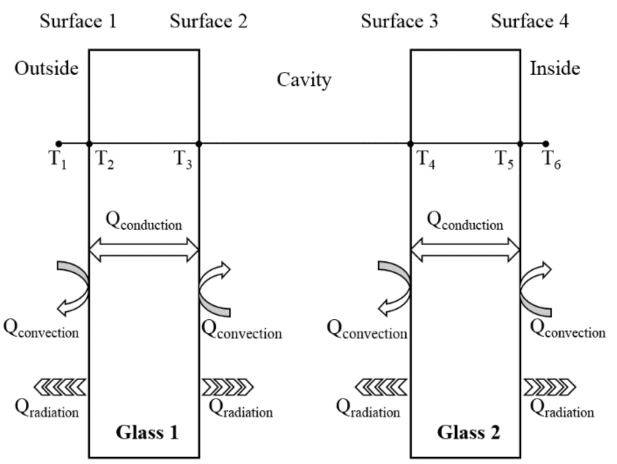

Figure 1. Heat transfer mechanism in the double-glazed pane

$$Q_{convection} = kNuA\frac{T_{high} - T_{low}}{\delta} \quad (1)$$

$$Nu = 0.197Ra^{1/4}\left(\frac{H}{\delta}\right)^{-1/9} \quad (2)$$
$$(2 \times 10^3 \leq Ra \leq 2 \times 10^5)$$

$$Nu = 0.073Ra^{1/3}\left(\frac{H}{\delta}\right)^{-1/9} \quad (3)$$
$$(2 \times 10^5 \leq Ra \leq 2 \times 10^7)$$

$$Nu = 1 \quad (4)$$
$$(Ra < 2 \times 10^3)$$

$$Ra = GrPr \quad (5)$$

$$Gr = \frac{g\beta(T_s - T_\infty)\delta^3}{\nu^2} \quad (6)$$

$$Pr = \frac{\mu\rho C_p}{k} \quad (7)$$

In this equation, $Q_{convection}$ refers to heat transfer by convection (W) and k, Nu, and A is the thermal conductivity of fluid (W/m·°C), Nusselt number, and surface areas of panes (m2). Also, T_{high} and T_{low} refer to high temperature (°C) and low temperature (°C) between the gas and the surface of the pane, and δ, $Ra,$ H, $Gr,$ $g,$ β and ν represent the characteristic length of the fluid (m), Rayleigh number, height of gas layer (m), Grashof number, gravity acceleration (m/s2), volume expansion coefficient, and kinematic viscosity (m2/s), respectively. Besides, T_s and T_∞ refer to the temperature of the pane surface facing gas (°C) and around fluid temperature (°C), respectively; $Pr,$ μ and C_p represent the Prandlt number, viscosity coefficient of gas (kg·s/m2), and the specific heat under constant pressure (W/kg·°C), respectively. Based on these theoretical contents, computer simulation for the insulating performance of the window was used in order to analyze the insulating performance of the double-glazed pane, where noble gas had been inserted and the heat transfer by convection and simulation methods and conditions are as follows.

III. TEST METHOD

Window ver. 7.4 provided by LBNL (Lawrence Berkeley National Laboratory U.S.), which is the window professional research organization, was used in order to calculate the insulating performance of the double-glazed pane with the inserted noble gas and heat transfer by convection. This program can calculate heat transfer by conduction, convection, and radiation occurring in an indoor and outdoor surface temperature of the double-glazed pane and gas layer. In particular, an algorithm of the equation (1)-(7) above can calculate heat transfer by convection. A simulation procedure is made in the order of the configuration of a single pane: the selection of the insulating gas (air and noble gas), the configuration of the double-glazed pane, the input of the boundary condition, and the input of the indoor and outdoor environmental conditions; calculation and creation of the results and the contents are as follows [10].

A. Single pane

A clear pane having a thickness of 5mm was selected as a single pane among panes that are actually produced in order to achieve realistic results. Physical properties of the pane are as shown in Table 2 [11].

Table 2: Thermal and physical properties of a single pane

Thickness (mm)	Tsol	Rsol 1	Rsol 2	Tvis	Rvis 1	Rvis 2	Tir	Emis 1	Emis 2	Cond. (W/m·°C)
5.0	0.894	0.079	0.079	0.910	0.082	0.082	0	0.837	0.837	1.000

In this equation, Tsol refers

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

to the transmittance of the total solar radiation (total waves), and Rsol 1 and Rsol 2 represent the reflexibility of the total solar radiation on the indoor and outdoor pane surface. Also, Tvis refers to the transmittance of the visible light, and Rvis 1 and Rvis 2 represent the reflexibility of visible light on the indoor and outdoor pane surface. And Tri, Emis 1, Emis 2, and Cond. represent infrared transmittance, Emissivity on the indoor and outdoor pane surface, and thermal conductivity.

B. Noble gas

Except for Radon that is a radioactive substance, more than five types of Helium, Neon, Argon, Krypton, Xenon among six noble gases on the Periodic Table of Elements are insulating gases used for the application of the simulation. Traditionally used air was added in order to compare the insulating performance between the existing gas that has been generally used and noble gas. The physical properties of each gas are shown in the following Table 3 [11].

Table 3: Physical properties of air and noble gases

No.	Name	Atomic number	Cond. (W/m·℃)	μ (kg/m·s)	ν (m2/s)	C_p (W/kg·℃)	P (kg/m3)	Pr
1	Helium	2	0.146163	0.000019	0.00010647	530.1410823	0.178460	0.6645
2	Neon	10	0.045399	0.000029	0.00003221	105.1202509	0.900331	0.6666
3	Air	-	0.024070	0.000017	0.00001315	102.6415235	1.292498	0.7197
4	Argon	18	0.016348	0.000021	0.00001178	53.2466109	1.782282	0.6705
5	Krypton	36	0.008663	0.000023	0.00000615	25.3099680	1.782282	0.6705
6	Xenon	54	0.005160	0.000021	0.00000358	16.1536682	5.857955	0.6543

C. Double-glazed pane

A total of six kinds of the double-glazed pane applied to the simulation consisted of two panes with a thickness of 5mm and gas layer with a thickness of 10mm by using two single panes and gases configured in advance. Their structure and properties are shown in the following Table 4.

Table 4: The structure and properties of the DPU consisting of a single glass and insulating gas

No.	Total thickness (mm)	Width × Height (mm)	Structure: Outside glass (mm)	Structure: Gas layer (mm)	Structure: Inside glass (mm)	Gas type	Purity
1	20	1000 × 1000	5	10	5	Air	Pure
2	20	1000 × 1000	5	10	5	Helium	Pure
3	20	1000 × 1000	5	10	5	Neon	Pure
4	20	1000 × 1000	5	10	5	Argon	Pure
5	20	1000 × 1000	5	10	5	Krypton	Pure
6	20	1000 × 1000	5	10	5	Xenon	Pure

D. Boundary condition

Since Korea has conflicting climatic conditions in winter and summer, the boundary conditions of the pane should be input by classifying it into conditioners and heaters when setting indoor and outdoor environment conditions. Also, the conditions defined as "the Building Energy-saving Design Standards" was used for temperature conditions of a building design in the summer and winter; velocity at the surface of the indoor and outdoor walls and windows, and heat transfer resistance and heat transfer coefficient and contents are shown in the following Table 5 [12].

Table 5: Indoor and outdoor boundary conditions in the summer and winter

Season	Space	Temperature (℃)	Fluid velocity (m/s)	Surface heat transfer resistance (m2·℃/W)	Surface heat transfer coefficient (W/m2·℃)
Summer	Outside	31.2	4.81	0.043	23.24
	Inside	26.0	1.27	0.110	9.08
Window	Outside	-11.3	4.81	0.043	23.24
	Inside	20.0	1.27	0.110	9.08

E. Indoor and outdoor environmental condition

The Korea Standard Weather Data provided by The Korean Solar Energy Society was used for conditions of direct solar radiation, diffused solar radiation, and sky temperature that affect the insulating performance of the window. In particular, hourly data analyzing weather data for 30 years within the Seoul district was used because the area for simulation is Seoul, South Korea. The contents of the applied weather data are shown in the following Table 6 [13].

Table 6: Air and solar radiation conditions in the summer and winter

Location	Season	Horizontal direct solar radiation (W/m2)	Sky temperature (℃)	Sky emissivity
Seoul in South Korea	Summer	986.11	-11.3	1.00
	Window	483.33	31.2	1.00

IV. ANALYSIS OF RESULTS

A. Surface temperatures of Double-glazed panes

1) Summer

Figure. 2 and Table 7 show the changes in the surface temperature of each pane by heat transfer from the outdoor to indoor when the outdoor and indoor temperature was set at 31.2 ℃ and 26.0 ℃, respectively in the summer.

Table 7: Each surface temperature of the double-glazed panes in the summer

Type of Gas	Pane surface: T1	T2	T3	T4	T5	T6
Helium	31.2	30.4	30.3	29.2	29.2	29.1
Neon	31.2	30.6	30.5	28.6	28.6	28.5

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Air	31.2	30.6	30.6	28.4	28.4	28.3
Argon	31.2	30.7	30.6	28.2	28.2	28.2
Krypton	31.2	30.7	30.6	28.1	28.1	28.0
Xenon	31.2	30.7	30.7	28.0	28.0	28.0

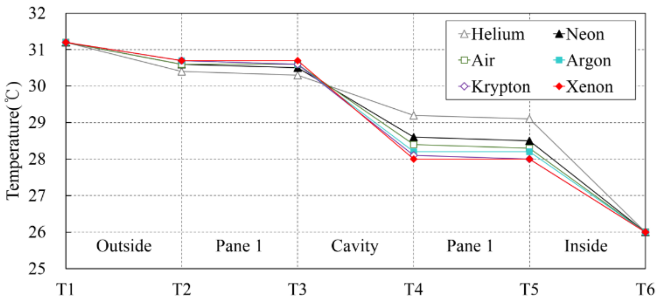

Figure 2. A pattern of temperature change in the double-glazed pane in the summer

Although the gas type of the dual glazing units is different, all double-glazed panes showed similar temperature change pattern from T1 that represents outdoor air temperature to T3 that is the temperature corresponding to Surface 2. However, it can be verified that the temperatures of the panes vary greatly by the difference in the heat transfer by convection of the gases with different properties in the glazing layer where the gas had been inserted. In particular, Helium can heavily move the indoor heat to the indoor which is air-conditioned due to the vigorous heat transfer by convection. In contrast, Krypton and Xenon effectively blocked the heat from the outside due to a relatively small heat transfer by convection, compared to Helium. As a result, it was analyzed that the temperature difference between the pane surface (Surface 3) and indoor was the lowest.

2) Winter

Figure 3 and Table 8 show that the changes in the surface temperature of each pane by heat transfer from indoor to outdoor when the outdoor and indoor temperatures were set at -11.3 ℃ and 20.0 ℃, respectively.

Table 8: Each surface temperature of the double-glazed pane in the winter

Type of Gas	Pane surface					
	T1	T2	T3	T4	T5	T6
Helium	-11.3	-6.4	-5.8	1.6	2.2	20.0
Neon	-11.3	-7.6	-7.1	5.7	6.2	20.0
Air	-11.3	-8.0	-7.6	7.5	7.9	20.0
Argon	-11.3	-8.3	-7.9	8.3	8.7	20.0
Krypton	-11.3	-8.4	-8.1	9.0	9.4	20.0
Xenon	-11.3	-8.5	-8.1	9.1	9.5	20.0

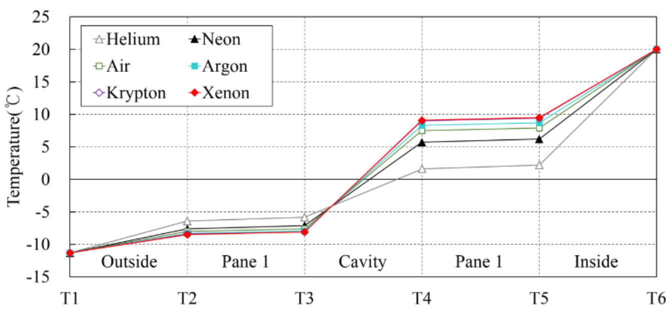

Figure 3. A pattern of temperature change in the double-glazed pane in the winter

Even though there was a big difference between indoor and outdoor temperatures, compared to the summer, the changes in the temperature of the panes in winter were also found to be similar to the summer, relatively. First, the surface temperature was shown to be the lowest and changes in the indoor temperatures were found to be the largest because heat loss from the pane surface was significantly shown due to its active convection movement in the dual glazing units where Helium had been inserted. However, heat loss by convection was relatively small in the dual glazing units where Krypton and Xenon had been inserted. Thus, it was analyzed that the difference in the indoor temperature was shown to be the lowest.

B. Convection heat transfer by noble gas

The quantitative values of heat transfer by convection caused by each gas was calculated and evaluated by checking how much each gas inserted into the double-glazed pane would cause heat transfer by convection based on the theoretical analysis and simulation results and using Eq. (1)-(7) in the preset indoor and outdoor conditions.

1) Summer

Table 9 shows the calculated results of the cubical expansion coefficient of the fluid, coefficient of kinematic viscosity, and Grashof number that determines the momentum of the gas to analyze heat transfer by convection caused by noble gas in summer. Also, Table 10 shows the convection heat transfer ($Q_{convection}$) convection that was calculated by using the calculated Grashof, Rayleigh, Prandtl, and Nusselt numbers.

Table 9: A calculation of the Grashof number by each gas in the summer

Gas Type	β	g (m/s2)	T3 - T4 (℃)	δ^3 (m)3	ν^2 (m2/s)2	Gr
Helium	0.00330306	9.8	1.1	0.000001	0.00010647	3.1
Neon	0.00330524	9.8	1.9	0.000001	0.00003221	59.3
Air	0.00330579	9.8	2.2	0.000001	0.00001315	412.0
Argon	0.00330688	9.8	2.4	0.000001	0.00001178	560.2
Krypton	0.00330743	9.8	2.5	0.000001	0.00000615	2141.2
Xenon	0.00330743	9.8	2.7	0.000001	0.00000358	6809.8

Table 10: A calculation of the Rayleigh, Nusselt number, and $\boldsymbol{Q_{convection}}$ by each gas in the summer

Gas Type	Gr	Pr	Ra	Nu	k (W/m·℃)	A (m2)	$Q_{convection}$ (W)
Helium	3.1	0.6645	2.1	1.000	0.146163	1.0	16.08
Neon	59.3	0.6666	39.5	1.000	0.045399	1.0	8.63
Air	412.0	0.7197	296.5	1.000	0.024070	1.0	5.30
Argon	560.2	0.6705	375.6	1.000	0.016348	1.0	3.92
Krypton	2141.2	0.6718	1,438.4	1.000	0.008663	1.0	2.17
Xenon	6809.8	0.6543	4,455.6	0.965	0.005160	1.0	1.34

As a result, the convective heat transfer of Helium was the highest at 16.08 W and

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

that of Neon, Air, Argon, and Krypton was calculated as 8.63 W, 5.30 W, 3.92 W, and 2.17 W, respectively, but that of Xenon was the lowest at 1.34 W. Thus, as shown in Figure. 4, Helium and Neon have a higher heat transfer by convection than air, which has been traditionally used, so their insulating performance falls dramatically. Thus, it was verified that they are not appropriate to use as gases for the high insulating window. Also, in the case of using Argon, Krypton, Xenon instead of air that has been traditionally used, it was analyzed that heat transfer by convection was reduced by 26 %, 59 %, and 75 %, respectively.

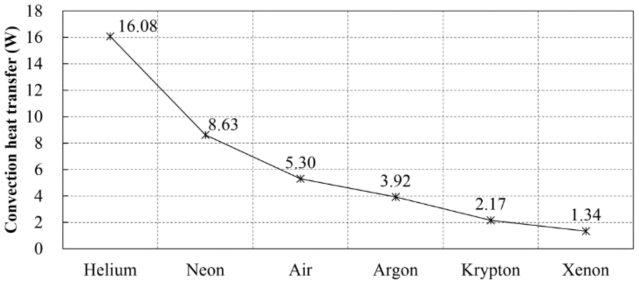

Figure 4. Convective heat transfer by gas type in the summer

2) Winter

Table 11 shows Grashof number calculated to analyze heat transfer by convection caused by noble gas in the winter, and Table 12 shows convection heat transfer ($Q_{convection}$) calculated by using Grashof, Rayleigh, Prandtl, and Nusselt numbers

Table 11: A calculation of the Grashof number by each gas in the winter

Gas Type	β	g (m/s2)	T3 - T4 (°C)	δ^3 (m)3	ν^2 (m2/s)2	Gr
Helium	0.00369140	9.8	7.4	0.000001	0.00010647	23.6
Neon	0.00367242	9.8	12.8	0.000001	0.00003221	444.0
Air	0.00366367	9.8	15.1	0.000001	0.00001315	3133.9
Argon	0.00366032	9.8	16.2	0.000001	0.00001178	4185.8
Krypton	0.00365698	9.8	17.1	0.000001	0.00000615	16,193.4
Xenon	0.00365631	9.8	17.2	0.000001	0.00000358	47,956.9

Table 12: A calculation of the Rayleigh, Nusselt number, and $\boldsymbol{Q_{convection}}$ by each gas in the winter

Gas Type	Gr	Pr	Ra	Nu	k (W/m·°C)	A (m2)	$Q_{convection}$ (W)
Helium	23.6	0.6645	15.7	1.000	0.146163	1.0	108.16
Neon	444.0	0.6666	296.0	1.000	0.045399	1.0	58.11
Air	3313.9	0.7197	2,255.5	0.814	0.024070	1.0	29.58
Argon	4185.8	0.6705	2,806.6	0.860	0.016348	1.0	22.76
Krypton	16,193.4	0.6718	10,878.8	1.206	0.008663	1.0	17.87
Xenon	47,956.9	0.6543	31,378.2	1.572	0.005160	1.0	13.95

Since there was a larger temperature difference in the indoor and outdoor than that in summer, the size of the heat transfer by convection was significantly greater than in summer. But heat transfer by convection in winter showed a similar pattern like in summer. Frist, the convective heat transfer of Helium was calculated as the highest of 108.16 W and that of Neon, Air, Argon, and Krypton was calculated as 58.11 W, 29.58 W, 22.76 W, and 17.87 W, respectively, and that of Xenon was shown to be the lowest convective heat transfer at 13.95 W. Thus, as shown in Figure. 8, in the case of using Argon, Krypton, Xenon, instead of traditionally used air, it was analyzed that heat transfer by convection was reduced by 26 %, 59 %, and 75 %, respectively.

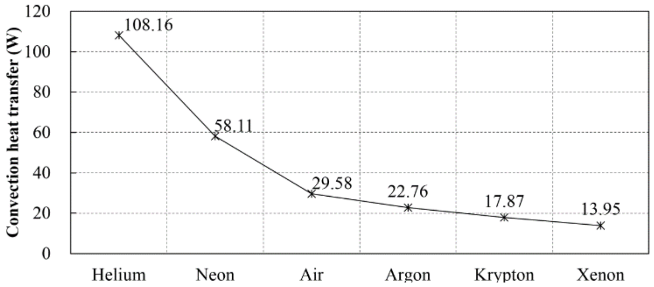

Figure 5. Convective heat transfer by gas type in the winter

C. U-value of double-glazed pane by gas type

Figure 6 shows the U-value, which means the thermal transmission coefficient of the double-glazed pane by the gas type [14]. U-value of the double-glazed pane where Helium had been inserted was shown to be the highest at 4.243 W/m2·°C in summer, but that of Xenon was shown to be the lowest at 2.580 W/m2·°C. There was a difference in U-value in the winter, but the same pattern was shown in the summer. The reason why U-value was not smooth but showed a rapid difference (more than about 2.0 W/m2·°C) was because of the a significant impact of heat transfer by convection of the gas had a significant impact. It is not because of heat transfer by the conduction and radiation of the glass. Thus, as there is a difference in U-value according to the type of gas, it is necessary to select and apply appropriate gas to meet the performance criteria of the region and building in designing the double-glazed pane. In addition, it will be more effective to use Argon, Krypton, and Xenon with a high insulating performance than air that has been traditionally used for double-glazed panes.

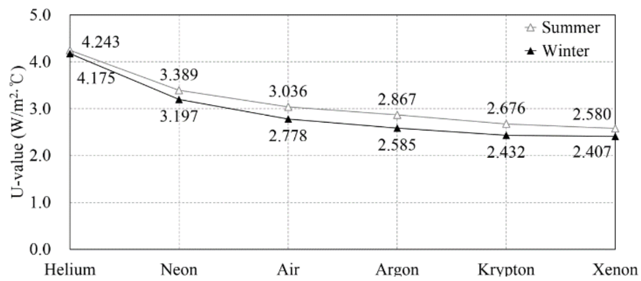

Figure 6. The U-value of the double-glazed pane by gas type in the summer and winter

V. CONCLUSION

This study has been conducted to propose a methodology for predicting convection heat transfer by insulating gases in a double-glazed pane, and the results are as follows:

1) The insulating gases that can be utilized for a double-glazed pane are the noble gases, Helium,

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Neon, Argon, Krypton, Xenon, and air, and each gas has a different convection heat transfer according to their physical and thermal characteristics.

2) This study proposed a theoretical methodology to predict convection heat transfer by the insulating gases in a double-glazed pane. It is possible to calculate this by using Eqs. 1-7 as suggested in section 2.
3) In order to apply the methodology suggested to an actual double-glazed pane, a computer simulation program was used, and as the result, it was revealed that the convection heat transfer by types of insulating gases has great differences.
4) The insulating gases used in this study are Helium, Neon, Argon, Krypton, Xenon, and air. In summer and winter conditions, the convection heat transfer of xenon is lowest, followed by Krypton, Argon, air, Neon, and Helium (in order of lowest to highest). Therefore, it is necessary to use insulating gases which have low convection heat transfer to make high-insulating window systems.
5) This study analyzed the convection heat transfer for a representative case of a double-glazed pane. It is possible to examine the convection heat transfer for the double-glazed panes under various conditions by using the theory and analysis process suggested in this study.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (2018R1D1A1B07048848).

REFERENCES

1. unfccc.int. Submission by the Republic of Korea-Intended Nationally Determined Contribution [Internet]. [place unknown]: United Nations Framework Convention on Climate Change; 2015 [cited 2019 Mar 3]. Available from: https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/Republic%20of%20Korea/1/INDC%20Submission%20by%20the%20Republic%20of%20Korea%20on%20June%2030.pdf.
2. Me.go.kr. The load-map for reaching the national greenhouse gas reduction goal [Internet]. [place unknown]: Ministry of Environment; 2014 [cited 2019 Mar 3]. Available from: http://www.me.go.kr/home/web/board/read.do?menuId=290&boardMasterId=39&boardCategoryId=55&boardId=341045..
3. S. Lee,"Study on energy consumptions and retroaction estimation by usage types in a residential sector [Internet]," Ulsan (South Korea): Korea Energy Economics Institute; 2010 Oct 5 [updated 2010 Oct 5; cited 2019 Mar 3]. Available from: http://www.keei.re.kr/main.nsf/index_mobile.html?open&p=%2Fweb_keei%2Fd_results.nsf%2Fmain_all%2F0B6BF220B0D8EBF4492579C30039A7C8&s=%3FOpenDocument%26menucode%3DS0%26category%3D%25EA%25B8%25B0%25EB%25B3%25B8%25EC%2597%25B0%25EA%25B5%25AC.
4. S. Yoon, S. Song, Y. Kim, S. Yum."Energy saving effects according to the window performance for an apartment house and the estimation of the window economical efficiency,"*Journal of the Architectural Institute of Korea Planning & Design*. 2008 Aug; 24(8): 321-30. DOI: G704-A00167.2008.24.8.001.
5. Y. Lee, S. Lee, S. Lee. "Effect of components assembly and sizing on the thermal performance of windows,"*Journal of the Architectural Institute of Korea Planning & Design.* 2006 Jul; 22(7): 215-22. DOI: G704-A00167.2006.22.7.023.
6. S. Baek, J. Park. "Analysis on thermal performance of double-pane unit filled carbon dioxide,"*Proceedings of the SAREK 2015 summer annual conference*. 2015 Jun; 2015(6): 220-3.
7. W. Hee, M. Alghoul, B. Bakhtyar, O. Elayeb, M. Shameri, M. Alrubaih, K. Sopian. "The role of window glazing on daylighting and energy saving in buildings,"*Renew. Sust. Energ. Rev*. 2015 Feb; 42: 323-42. DOI: https://doi.org/10.1016/j.rser.2014.09.020.
8. S. Bergh, R. Hart, B. Jelle, A. Gustavsen."Window spacers and edge seals in insulating glass units [Internet]. Orlando (FL): Lawrence Berkeley National Laboratory; 2013 [cited 2019 Mar 3]," Available from: https://buildings.lbl.gov/sites/all/files/6122e.pdf.
9. G. Torok, A. Major, L. Miguel."Predicting time to fogging of insulated glass units [Internet]. Ottawa (Canada): Canada Mortgage and Housing Corporation; 2005 [cited 2019 Mar 3]," Available from: http://publications.gc.ca/collections/collection_2011/schl-cmhc/nh18-1-2/NH18-1-2-126-2005-eng.pdf.
10. Window.lbl.gov. Conrad 5 & Viewer 5 Technical and Programming Documentation [Internet]. [place unknown]: Carli, lnc. 2006 [cited 2019 Mar 3]. Available from: https://windows.lbl.gov/sites/all/files/Downloads/conrad-and-viewer-06-20-06.pdf.
11. Window.lbl.gov. Therm 6.3 / window 6.3 NFRC simulation manual [Internet]. [place unknown]: Lawrence Berkeley National Laboratory. 2013 [cited 2019 Mar 3]. Available from: https://windows.lbl.gov/sites/default/files/Downloads/nfrcsim6-3-2013-07-manual_0.pdf.
12. Law.go.kr. Design standard for saving of building energy [Internet]. [place unknown]: National low information center 2018 [cited 2019 Mar 3]. Available from: http://www.law.go.kr/%ED%96%89%EC%A0%95%EA%B7%9C%EC%B9%99/%EA%B1%B4%EC%B6%95%EB%AC%BC%EC%9D%98%EC%97%90%EB%84%88%EC%A7%80%EC%A0%88%EC%95%BD%EC%84%A4%EA%B3%84%EA%B8%B0%EC%A4%80
13. Kses.re.kr. Standard weather data of Republic of Korea [Internet]. [place unknown]: The Korean Solar Energy Society. 2015 [cited 2019 Mar 3]. Available from: http://www.kses.re.kr/data_06/list_hi.php.
14. B. Anderson."Conventions for U-value calculations [Internet]. Glasgow (Scotland): Building a better world together," 2006 [cited 2019 Mar 3]. Available from: https://www.bre.co.uk/filelibrary/pdf/rpts/BR_443_(2006_Edition).pdf.

AUTHORS PROFILE

SanghoonBaekis a research fellow in Hankyong National University in South Korea. His main concern is architectural environment and energy saving. He has focused on analyzing energy consumption and greenhouse gas emission emitted from commercial and residential buildings by using fossil fuels for heating, cooling, domestic hot water, and ventilation etc.

Sangchul Kimis a Professor in Hankyong National University in South Korea. His main concern is in construction management application to construction site. He has focused how to build construction management system and how to fit its system to construction employee. Nowadays, he has added a new field of building environmental system in a residential building.