Simulation Study to Derive a Determination Strategy of Window Spacer to Mitigate Heat Loss and Condensation Risk

Kyu-Nam Rhee[1], Mi-Su Shin[2], Ji-Yong Yu[3], Gun-Joo Jung[1]

[1]Department of Architectural Engineering, Pukyong National University, Busan, Republic of Korea

[2]Department of Architecture, Seoul National University, Seoul, Republic of Korea

[3]Division of Construction, Samsung C&T Corporation, Gyeonggi-do, Republic of Korea

Abstract

Window spacers are weak points in terms of heat loss and condensation, due to relatively high thermal conductivity. For this reason, thermally improved spacers (TIS) are considered as alternatives to mitigate condensation risk and heat loss of the window. However, it is difficult to expect the effect of the TIS on the condensation risk and heat loss, because it is usually composed of very thin foil and adhesive. In this context, simplified simulations using the two-box model were performed to investigate the impact of window spacers on condensation risk and heat loss of the window. For commercially available TISs, temperature factors and total U-value were analyzed with THERM and WINDOW simulation. Based on the results, design charts were suggested to help designers to select a proper window spacer which can mitigate condensation risk and heat loss through the window.

Introduction

Windows are one of the weakest points in building envelopes with regard to thermal insulation. Thus, it is of much importance to improve thermal performances of windows in order to reduce heat loss through windows, which can contribute to the reduction of not only surface condensation but also heating load of a building. In window elements, heat loss is particularly large at the edge region where thermal bridge can be generated due to adjoining frame and glazing. For this reason, it is required to minimize heat loss at the edge by improving insulation performance of window spacers as well as improving thermal performances of the glazing (Song et al. 2007).

In this context, thermally improved spacers (TIS hereinafter) have been applied to insulated glass units (IGU) for the purpose of reducing condensation risk and heat loss (van den Bergh et al. 2013). In particular, residential buildings are prone to condensation risks due to much moisture generated by occupants' respiration or activities (Lu 2003). Moreover, energy regulations on low-energy residential buildings are demanding high insulation performance of building envelope, which can be achieved by improving window thermal performances. It should also be noted that the effect of edge loss becomes more influential as windows are improved with low-e coatings and gas fills (Mitchell et al. 2011). As a result, the TIS has been increasingly applied to IGU in residential buildings.

To consider the impact of the TIS on condensation prevention and energy saving in window design, it is necessary to expect indoor surface temperatures and total U-value with TIS in the early design stage. This can be analyzed by conducting heat transfer simulation; however, it is somewhat complicated and time-consuming to make an explicit model of the TIS because it is composed of very thin foil, desiccant, sealant, adhesive, and so on. For this reason, this study evaluated thermal performances of the window by representing TIS with equivalent thermal conductivity, which is called as two-box model. Based on the simulation results, design charts were developed to determine a feasible TIS to reduce condensation risk and heat loss in residential windows.

Simulation method

Thermally improved spacer

Window spacers play a role of providing a cavity between multiple glasses for the purpose of improving the insulation performance. For this, they are usually made of rigid elements such as aluminum, steel, non-metalic materials, and so on, in order to provide the required structural strength. As the metalic element has high thermal conductivity, its thickness or thermal conductivity needs to be reduced to increase the thermal resistance of the spacer.

In ISO 10077, a window spacer is classified into the TIS if its properties satisfy equation (1), which can be calculated in accordance with Figure 1.

$$\sum(d \cdot \lambda) \leq 0.007 \quad (W/K) \qquad (1)$$

where d is the thickness of element perpendicular to the heat transfer direction, λ is thermal conductivity.

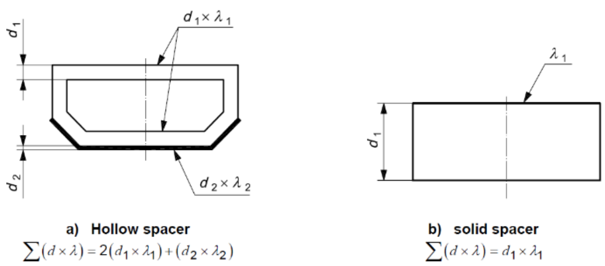


Figure 1: Examples of determination criteria for thermally improved spacers (ISO 10077(2006))

Table 1: Examples of the TIS

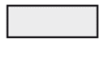
Shape				
Material	STS	STS /plastic	STS	Polyiso-butylene
Thickness	0.15 mm	0.10 mm	0.18 mm	6.0 mm
$\sum(d \cdot \lambda)$	0.00450	0.00177	0.00540	0.00150
Shape				
Material	STS	STS	Plastic /STS	Foil /Silicone
Thickness	0.20 mm	0.15 mm	0.1 /0.9 mm	0.10 /7.2 mm
$\sum(d \cdot \lambda)$	0.00600	0.00450	0.00168	0.00126

Table 1 shows some examples of the TIS currently available in the building industries. In this study, the TIS was represented using a two-box model (Gustavsen et al. 2011), by which a complicated spacer is replaced by simple two boxes composed of upper and lower box, as shown in Figure 2. While the lower box represents a sealant part, the upper box represents the thermal conductivity of the original spacer, which is defined as equivalent thermal conductivity (λ_{eq}). It is known that the λ_{eq} of the TIS ranges from 0.1 to 0.9 (Bundesverband Flachglas 2013). As for conventional window spacers, the λ_{eq} is known as approximately 1 to 8 W/mK (Baker 2005).

Thermal performances of the TIS were evaluated with the two dimensional steady-state heat transfer simulation –WINDOW7.4 and THERM7.4. A typical window (1m x 0.9m) which is widely installed in residential buildings was modelled as described in Figure 2. The Frame material was assumed as PVC (poly vinyl chloride) that is effective for reducing heat transfer through the frame section.

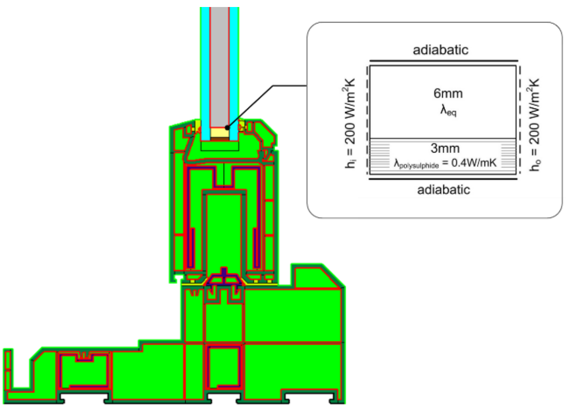


Figure 2: Vertical section of investigated window

Simulation case

The impact of the TIS can be varied depending on glazing type, low-e coating, infill gas and so on. Thus, this study investigated thermal performances of the TIS with different glazing type (double, triple), coatings (no coating, low-e soft coating, low-e hard coating) and infill gases (air, argon), as listed up in Table 2. In eah case, λ_{eq} of window spacers was varied from 0.1 to 8.0 W/mK.

Table 2: Simulation cases for investigating thermal performances of TIS*

Low- e coating	**Infill gas**	**Glazing**	
		Double	**Triple****
No	Air	[1] D-Leno-Air	[7] T-Leno-Air
No	Argon	[2] D-Leno-Ar	[8] T-Leno-Ar
Soft	Air	[3] D-Les-Air	[9] T-Les-Air
Soft	Argon	[4] D-Les-Ar	[10] T-Les-Ar
Hard	Air	[5] D-Leh-Air	[11] T-Leh-Air
Hard	Argon	[6] D-Leh-Ar	[12] T-Leh-Ar

* In all cases, window spacers were represented with the λ_{eq} of 0.1~8W/mK.
** For triple glazing, the frame structure was same with that of double glazing, except the width of glazing.

The performance of condensation prevention was evaluated with the temperature factor f_T, as formulated by equation (2), where the surface temperature at 13mm from the sightline was used to calculate the temperature factor in accordance with AAMA 1503(AAMA 2009). Higher temperature factors indicate that the window can endure condensation risks at lower outdoor air temperature. In this study, indoor and outdoor air temperatures were assumed as 24℃ and -15℃ respectively, considering the winter design condition in Seoul, Korea.

$$f_T = \frac{T_{si} - T_o}{T_i - T_o} \quad (-) \qquad (2)$$

where f_T is temperature factor, T_{si} surface temperature, T_i indoor air temperature, T_o outdoor air temperature.

In addition to the temperature factor, the annual time of condensation occurrence was estimated to compare the performance of condensation prevention. To do this, equation (2) was transformed to calculate the outdoor air temperature at which the condensation starts to occur, as formulated by equation (3)

$$T_o = \frac{T_{s,i} - f_T T_i}{1 - f_T} \quad (°C) \qquad (3)$$

If the T_{si} is substitued by the dew-point temperature at design condition (e.g. 13℃ at 24℃ DB, 50%RH), T_o can be considered as outdoor air temperature at which the condensation starts to occur. Then the annual occurrence time of condensation can be calculated by accumulating the number of hours when T_o is less than outdoor air temperature in typical meteorological data.

The impact of the TIS on the heat loss was analyzed with total U-value of the window because it directly affects the heat transmittance and the consequent heating load of a building. Equation (4) was employed to calculate the total U-value (ASHRAE 2013), where center-of-glazing U-value was obtained from the WINDOW program, while the frame and the edge section U-values were calculated with the THERM simluation. The width of the edge section was assumed as 63.5mm from the sightline, as defined by NFRC 100 (NFRC 2013).

$$U = \frac{U_{cg}A_{cg} + U_{eg}A_{eg} + U_f A_f}{A_{pf}} \quad (\mathrm{W/m^2K}) \qquad (4)$$

where U means U-value and A means Area, subscripts cg, eg, f and pf means center of glazing, edge of glazing, frame and projected area of fenestration, respectively.

Result and discussion

Condensation prevention (Temperature factor)

Simulation results showed that the λ_{eq} of the spacer has a clear relation between temperature factor, as shown in Figure 3. It can be found that temperature factor does not show much difference if the λ_{eq} is more than 2.0 W/mK, on the other hand, they showed a relatively large change when the λ_{eq} is less than 2.0 W/mK. This indicates that the TIS can be effective to increase temperature factor of the window, leading to the reduction in condensation riks.

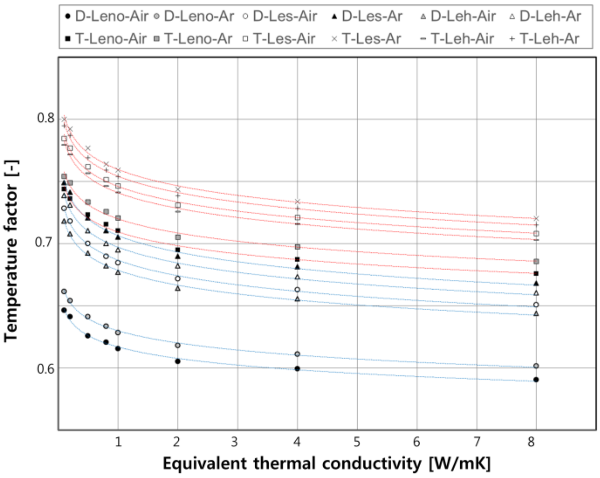


Figure 3: Temperature factors with equivalent thermal conductivity of spacers

The results showed that the temperature factors increases by 0.06~0.08, depending on the window type. The increased temperature factors indicate that the TIS can make the condensation occur at 4~16℃ lower outdoor temperature, compared with conventional spacers. Figure 4(a) shows the outdoor temperature at which the condensation starts to occur.

Using the typical meteorological data of Seoul, annual time of condensation occurrence was calculated as shown in Figure 4(b). It was found that the annual time can be reduced down to zero when applying the TIS to double glazing with low-e coatings.

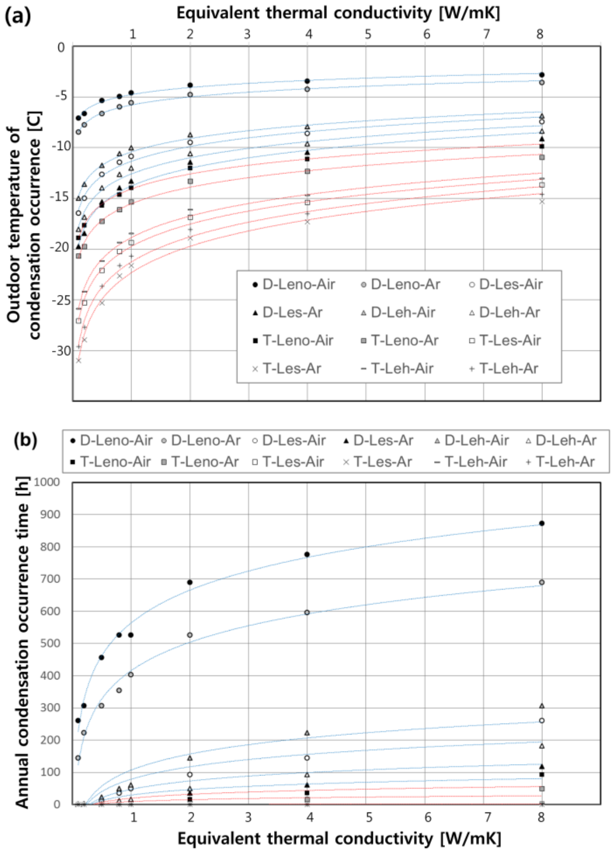


Figure 4: Condensation prevention performances (a) Outdoor temperature of condensation occurrence, (b) Annual time of condensation occurrence

Heat loss (Total U-value)

It was found that the reduction in total U-value could be 0.07~0.13 $\mathrm{W/m^2K}$ depending on window type, as shown in Figure 5. The result implies that the TIS can reduce the heat loss through the window by 2.8~8.2%.

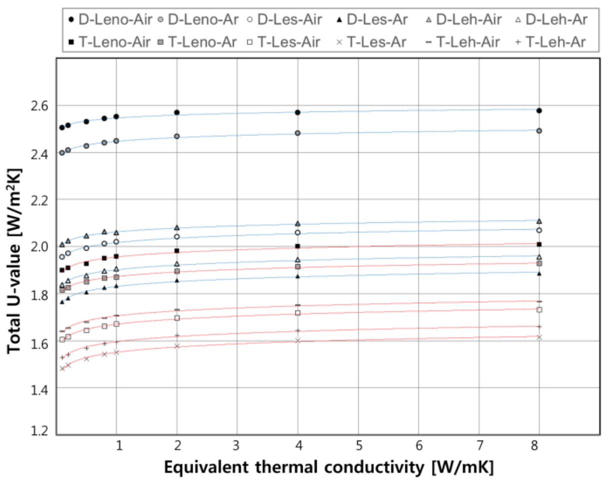


Figure 5: Total U-value with equivalent thermal conductivity of spacers

It was also found that the impact of the TIS on the U-value reduction increases when it is appied to the higher-performance glazing (e.g. triple glazing). Figure 6 shows total U-value reduction ratio when applying the infill gas or the TIS to various glazing systems. In each case, the effect of the TIS increases when low-e coatings are applied. In addition, the contribute of the TIS becomes more than the infill gas when it is applied to the triple glazing. Therefore, the TIS can be an effective measure to reduce the heat loss as the higher-performance glazing is increasingly applied to residential buildings.

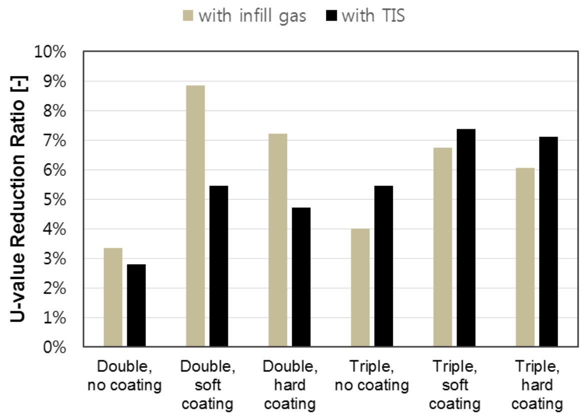


Figure 6: Total U-value reduction ratio

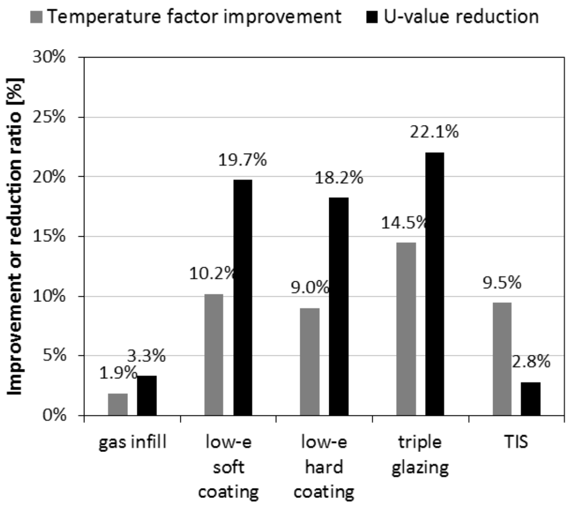


Figure 7: Comparison of insulation improvement

Figure 7 shows the comparison of the insulation performance in terms of temperature factor and total U-value, when thermal improvement alternatives are applied to the reference window (“D-Leno-Air”). It can be found that the TIS (spacer) can improve the temperature factor by 9.5% and can reduce the total U-value by 2.8%. The total U-value reduction by the TIS is less than those by other improvement measures; however, the TIS can result in the similar level of the reduction by the gas infill. The TIS can therefore be recommended as an alternative energy saving measure when it is difficult to apply the infill gases to the multiple glazing. Moreover, its contribution to the improvement of the temperature factor is far more than that by gas infill, even similar with that by low-e coatings. Therefore, the application of the TIS is particularly effective to reduce the condensation risk, while it can provide the modest improvement of insulation performance in terms of the total U-value.

Design chart for window spacers

Based on the results, design charts were developed to select an appropriate window spacer that can meet the required level of the condensation prevention and energy saving performance. Figure 8 shows the developed design chart, where x-axis represents λ_{eq} in a logarithmic scale. As the total U-value is dependent on the area of window elements (center-of-glazing, window edge, and frame), it was plotted with frame area ratios of 20%, 30% and 40%, respectively. For the sake of simplicity, cases for hard coating were not plotted in the design chart.

This chart can be utilized to determine the λ_{eq} when there are performance requirements about condensation prevention (temperature factor) and total U-value. For instance, if the window requires that U-value be 2.0 W/m^2K and temperature factor be 0.70, ‘D-Les-Air’ with λ_{eq} of 5 W/mK can be one of alternatives, as shown in the lower part of Figure 8(a). Regarding the temperature factor, λ_{eq} of 5 W/mK cannot meet the required temperature factor 0.70. Therefore, the proper λ_{eq} can be determined by finding the intersection of ‘temperature factor=0.70’ line and ‘D-Les-Ar’ line in the upper part of Figure 8(a). Finally, the ‘D-Les-Ar’ with the λ_{eq} of 0.5W/mK can be an alternative to meet the design requirement.

If the window requires that higher insulation (total U-value=1.6W/m^2K) and condensation prevention performance (temperature factor=0.72), ‘T-Les-Air’ with λ_{eq} of 2 W/mK can be one of alternatives, as shown in the lower part of Figure 8(b). In this case, the spacer (λ_{eq}=2W/mK) can also meet the required temperature factor 0.72, as shown in the upper part of Figure 8(b).

The developed design chart can be implemented to select an appropriate window spacer when two design requirements (total U-value and temperature factor) are given. In general, much attention is paid to determine total U-value of the window in order to cope with energy-saving regulations. However, the window can be exposed to condensation risks even though the U-value is determined to meet the energy-saving regulations, as exemplified in Figure 8(a). To deal with this problem, the TIS can be implemented as an alternative to mitigate condensation risks and the developed design chart can be applied to determine the proper λ_{eq} of the TIS.

This study assumes a PVC frame to analyze the residential windows; however, total U-value and temperature factor can be varied with the frame structure and/or material. Thus, the impact of various frame type on the thermal performance needs to be investigated to extend the applicability of the design chart. In addition, this study aims at developing a design chart which can be applied to Korean climate, where the total U-value for windows should be less than 1.5 W/m^2K for central

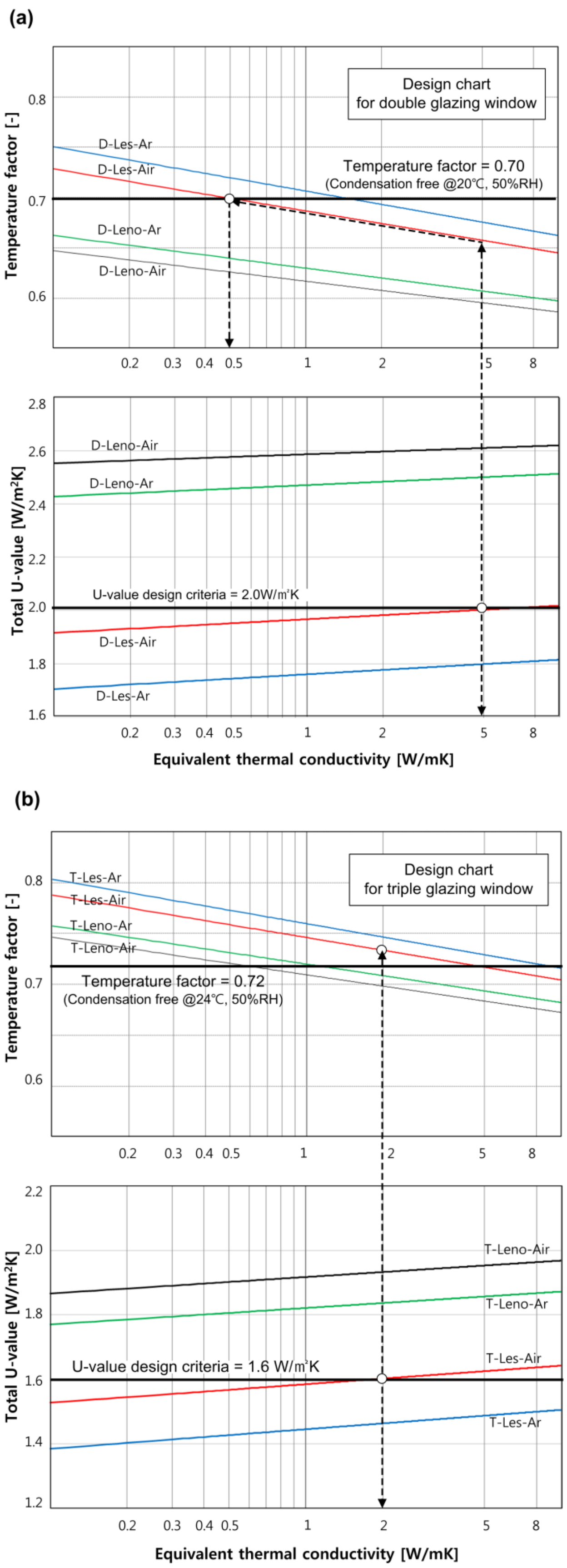


Figure 8: Design chart for determining a window spacer (a) For double glazing (b)For triple glazing

region, 1.8 W/m^{2}K for southern region, and 2.6 W/m^{2}K for Je-ju Island (MLIT 2015). However, further studies are necessary to extend the applicability of the developed design strategy, by investigating the effects of the TIS on the thermal performance in different climate zones.

Conclusions

In this study, the impact of window spacers on total U-value and temperature factor of the residential window was investigated by using two-box model for THERM simulations. Simulation results showed that the thermally improved spacer (TIS) can increase the temperature factor by 0.06~0.08, resulting in the significant improvement of condensation prevention. It was shown that the TIS can reduce the total U-value by 0.07~0.13 W/m^{2}K, implying 2.8~8.2% reduction in heat loss through the window.

Based on the results, design charts were proposed so that a designer can select an appropriate window spacer in terms of energy saving (total U-value) and condensation prevention (temperature factor). The analysis results and the suggested design chart will help engineers, designers and construction practitioners to reduce heat loss through the window and to minimize the condensation risks in the window.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No.2016R1C1B2010955), and a grant(16CTAP-C114863-01) from Infrastructure and transportation technology promotion research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

References

AAMA. 2009. AAMA 1503-09 Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections. USA: American Architectural Manufacturers Association.

ASHRAE. 2013. Chapter 15.3 Fenestration, ASHRAE Handbook Fundamental, Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Baker J. 2005. Spacer Thermal Performance Study, WESTLab Canada, National Fenestration Rating Council (NFRC) Accredited Simulation Laboratory, prepared for Insulating Glass Manufacturers Alliance (IGMA)

Bundesverband Flachglas. 2013. BF data sheets http://www.bundesverband-flachglas.de/shop/datenblaetter/bf-data-sheetsenglish/datenblaetter_engl.html, last accessed on 20 July 2016

Gustavsen A, Grynning S, Arasteh D, Jelle B and Goudey H. 2011. Key elements of and material performance targets for highly insulating window frames, Energy and Buildings, 43: 2583-2594.

MLIT. 2015. Appendix 1, Building Design Standards for Energy Saving: the Notification of Ministry of Land, Infrastructure and Transportation. (in Korea)

Lu, X. 2003. Estimation of indoor moisture generation rate from measurement in buildings. Building and Environment, 38(5): 665-675.

Mitchell R., Kohler C., Zhu L., Arasteh D., Carmody J., Huizenga C., and Curcija D. 2011. *January."THERM 6.3/WINDOW 6.3 NFRC Simulation Manual."*. Technical Report LBNL-48255, Lawrence Berkeley National Laboratory, Berkeley, CA.

NFRC. 2013. ANSI/NFRC 100-214: Procedure for determining fenestration product U-factors. National Fenestration Rading Council

Song S, Jo J, Yeo M, Kim Y and Song K. 2007. Evaluation of inside surface condensation in double glazing window system with insulation spacer: A case study of residential complex, Building and Envrionment, 42: 940-950.

van den Bergh S, Hart R, Jelle B and Gustavsen A. 2013. Window spacers and edge seals in insulating glass units: A state-of-the-art review and future perspectives, Energy and Buildings, 58: 263-280.