Impact of window spacers on condensation risk and heat transmittance of insulated glazing unit in residential buildings

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ABSTRACT

Insulating glazing units have been widely used to reduce condensation risks and heat transfer through building envelope. Nonetheless, window spacers are still weak points from the viewpoint of heat loss and condensation, due to relatively high thermal conductivity. For this reason, thermally improved window spacers are considered as alternatives to mitigate heat loss and condensation risk of insulating glazing units. However, it is a little tricky to expect how much condensation risk and heat loss would be reduced by applying thermally improved spacers, because they are usually composed of very thin foil and adhesive, aggravating difficulties in modeling spacers. In this context, simulation study was performed to investigate the impact of window spacers on condensation prevention and heat transmittance of insulating glazing unit in residential buildings. To do this, this study implemented a two-box model by which window spacer is replaced by imaginary rectangles with the equivalent thermal conductivity. For commercially available window spacers, temperature factors and overall heat transmittance were analyzed with THERM and WINDOW program. The results showed that temperature factors could increase from 0.59~0.72 to 0.66~0.80, depending on the window type, when applying thermally improved spacers. In addition, thermally improved spacers could prevent condensation at 4~16°C lower outdoor temperature than conventional window spacers. It was also found that the reduction in overall heat transmittance could be 0.07~0.12 W/m^{2}K, implying that thermally improved spacers could reduce heat loss by 2.8~8.2%. Based on the results, a design chart was suggested to help designers to select a proper window spacer which can mitigate condensation risk and heat loss through the window.

KEYWORDS

Window spacer, Condensation, Temperature factor, U-value

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INTRODUCTION

Windows are one of the weakest points in building envelopes with regard to thermal insulation (Gustavsen et al. 2011). 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 heat loss and condensation risk (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. 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. As a result, the TIS has been increasingly applied to IGU in residential buildings.

To consider the impact of 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 tricky to represent TIS because it is composed of very thin metallic foil, desiccant, sealant and so on. For this reason, this study evaluated thermal performances of IGUs by representing TIS with equivalent thermal conductivity (Gustavsen et al. 2011). Based on the evaluation results, this study suggested a design chart to determine an appropriate TIS with regard to condensation prevention and energy saving in residential buildings.

RESEARCH METHOD

In order to evaluate the thermal performances of TIS, two dimensional heat transfer simulation using WINDOW and THERM was conducted. A vertical section of the IGU (1m x 0.9m), which is widely applied to residential buildings in Korea, was modelled as described in Figure 1. Frame material was assumed as PVC (poly vinyl chloride) that is effective for reducing heat transfer through the frame section. Window spacer 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. 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 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).

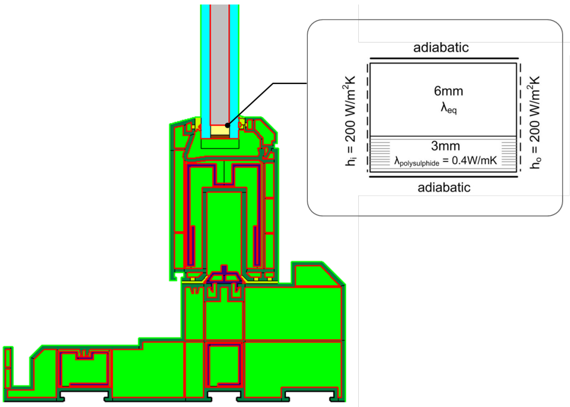


***Figure 1**. Vertical section of investigated IGU*

It should also be considered that 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 in terms of condensation prevention and energy saving when varying λ_{eq} of window spacers from 0.1 to 8.0 W/mK, 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 1.

***Table 1.** Simulation cases* for investigating thermal performances of TIS*

Low- e coating	*Infill gas*	*Glazing*	
		Double	*Triple***
No coating	Air	[1] D-Leno-Air	[7] T-Leno-Air
No coating	Argon	[2] D-Leno-Ar	[8] T-Leno-Ar
Soft coating	Air	[3] D-Les-Air	[9] T-Les-Air
Soft coating	Argon	[4] D-Les-Ar	[10] T-Les-Ar
Hard coating	Air	[5] D-Leh-Air	[11] T-Leh-Air
Hard coating	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 was same with that of double glazing, except the width of glazing.

Condensation prevention performance was evaluated with temperature factor as formulated by equation (1), where the surface temperature at 13mm from the sightline was used to calculate the temperature factor (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°C and -15°C respectively, considering the winter design condition in Seoul, Korea.

$$f_T = \frac{T_{si} - T_o}{T_i - T_o}, \qquad (1)$$

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

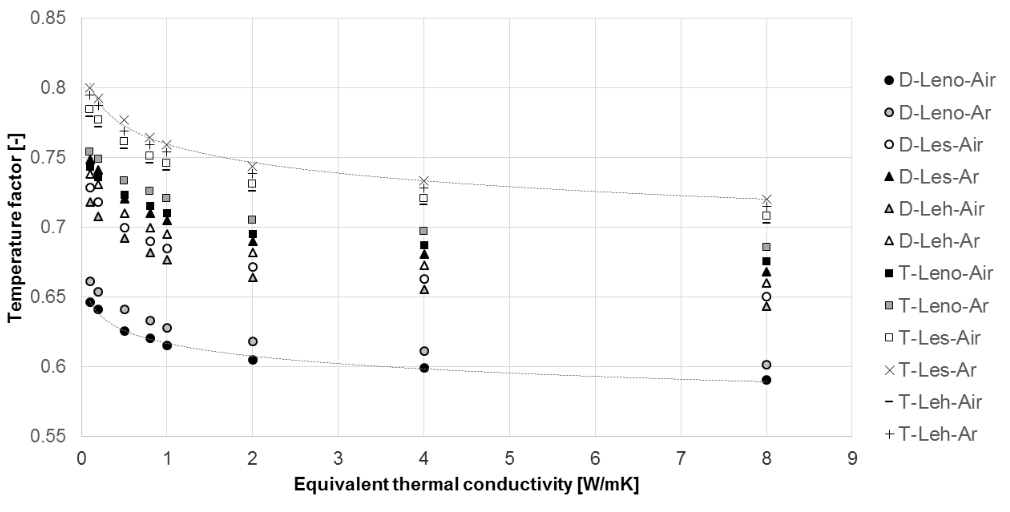
Energy saving performance was analyzed with total U-value of the IGU because it directly affects the heat transmittance and the consequent heating load of a building. Equation (2) was employed to calculate the total U-value (ASHRAE 2013), where center-of-glazing U-value was calculated by WINDOW program, while the frame and the edge section U-values were calculated by THERM program. The width of the edge section was assumed as 63.5mm from the sightline, as defined by NFRC 100.

$$U = \frac{U_{cg} A_{cg} + U_{eg} A_{eg} + U_f A_f}{A_{pf}}, \quad (2)$$

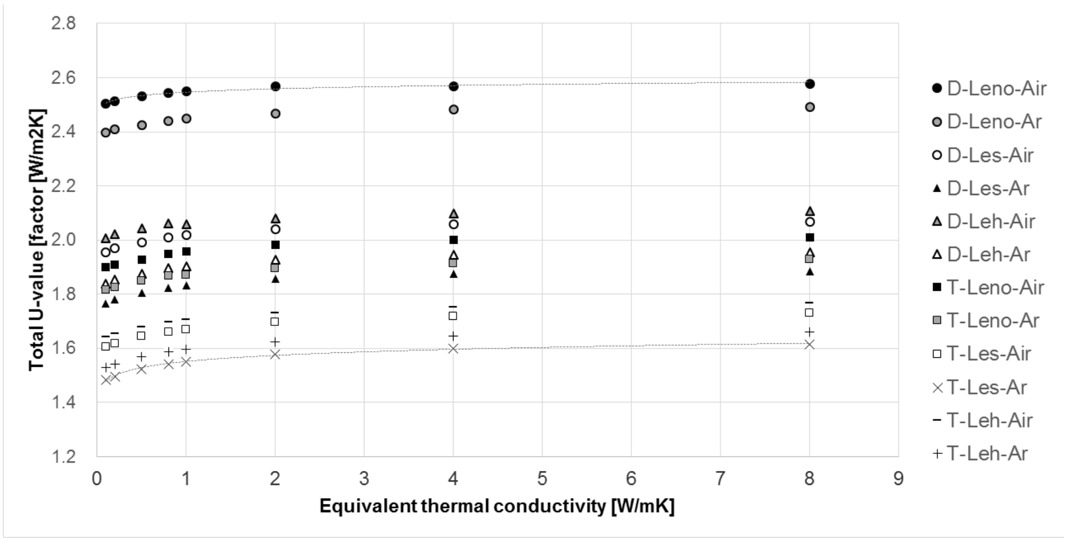
where subscript cg, eg, f and pf means center of glazing, edge of glazing, frame and projected area of fenestration, respectively.

RESULTS

Simulation results showed that the λ_{eq} of the spacer has a clear relation between temperature factor and total U-value respectively, as described in Figure 2. It can be found that temperature factor and U-value does not show much difference if the λ_{eq} is higher than 2.0 W/mK, on the other hand they showed a logarithmic change if the conductivity is lower than 2.0 W/mK. This indicates that the TIS can be effective to increase temperature factor and decrease total U-value of the window.



(a) Temperature factor



(b) Total U-value

Figure 2*. Thermal performance with equivalent thermal conductivity*

The results showed that the application of TIS can increase temperature factors from 0.59~0.72 to 0.66~0.80 depending on the window type. This indicates the condensation can be prevented at approximately 4~16°C lower outdoor temperature than conventional window spacers. It was also found that the reduction in total U-value could be 0.07~0.13 W/m^{2}K depending on window type, implying that the TIS could reduce heat loss by 2.8~8.2%. Based on the results, a design chart was developed to select an appropriate window spacer that can meet the required level of the condensation prevention and insulation performance. Figure 3 shows the developed design chart, where x-axis was transformed to a logarithmic scale.

This chart can be utilized to determine the λ_{eq} when there are performance requirements about condensation prevention (temperature factor) and U-value. For instance, if the window requires that U-value be 1.9 W/m^{2}K and temperature factor be 0.72, windows in the shaded region of Figure 3 can be one of alternatives to achieve 1.9 W/m^{2}K. Among these alternatives, 'D-Les-Ar' with λ_{eq} of 8 W/mK can be selected ((i) in Figure 3) because double-glazing window is usually less expensive than triple-glazing window. As for the temperature factor, λ_{eq} of 8 W/mK cannot meet the required temperature factor 0.72 ((ii) in Figure 3). Thus the proper λ_{eq} can be determined by finding the intersection of 'f_T=0.72' line and 'D-Les-Ar' line in the upper part of Figure 3(a). Finally, the 'D-Les-Ar' with the λ_{eq} of 0.6W/mK can be an alternative to meet the design requirement ((iii) in Figure 3).

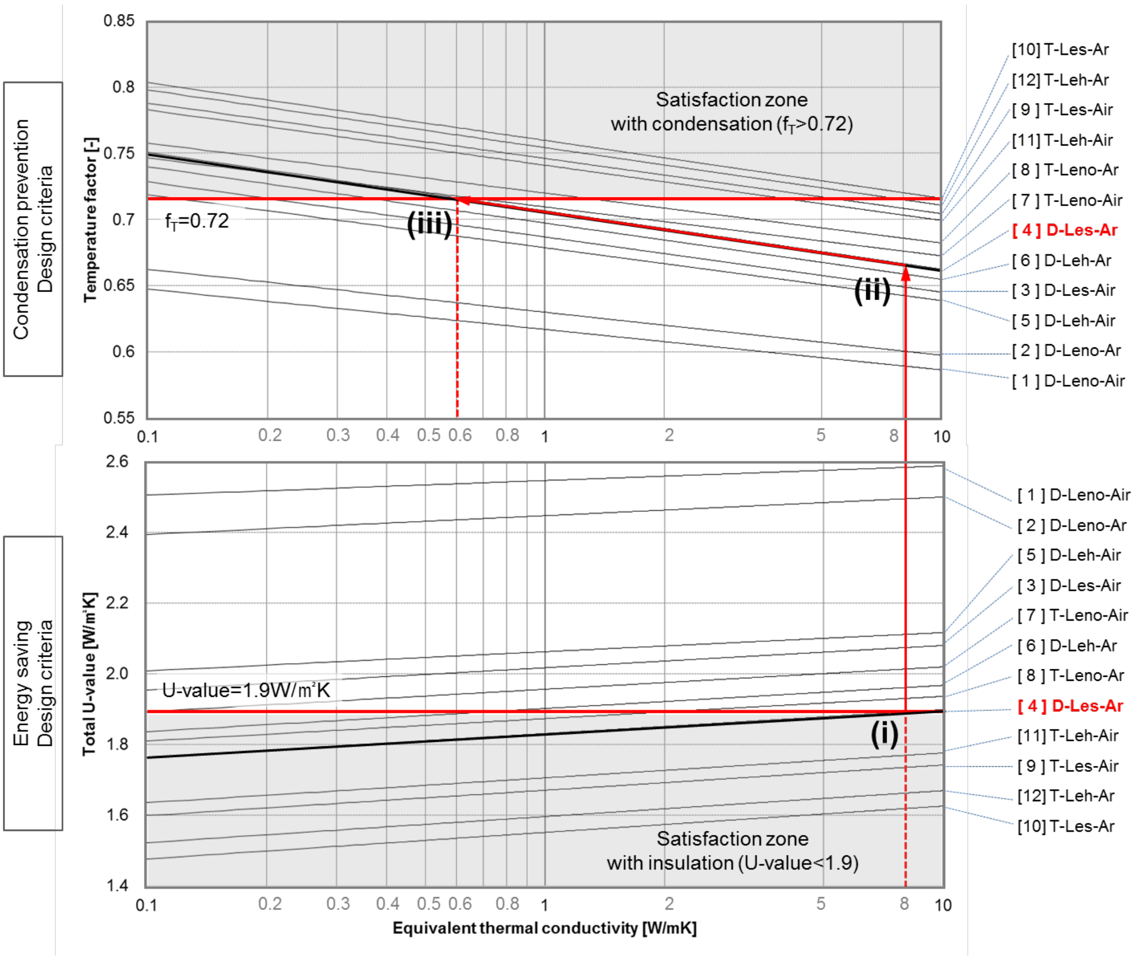


Figure 3. Design chart for determining an appropriate window spacer

DISCUSSION

The developed design chart can be implemented to select an appropriate window spacer when two design requirements (U-value and temperature factor) are given. In general, much attention is paid to determine 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 3. 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.

The design chart has limitation that it is based on the analysis results of the window with 1m x 0.9m size. It should be noted that the variation of the window size will affect the total U-value because the portion of edge region is dependent on the window size. Therefore, the design chart needs to be improved by applying a kind of compensation factor with regard to the window size. In addition, this study assumes a PVC frame to analyze the residential windows; however, total U-value and temperature factor might 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.

CONCLUSION AND IMPLICATIONS

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 simulation. Simulation results showed that the thermally improved spacer (TIS) can reduce the total U-value by 0.07~0.13 W/m^2K, implying 2.8~8.2% reduction of heat loss through the window. It was shown that the TIS can increase the temperature factor by 9.4~12%, resulting in the significant improvement of condensation prevention.

Based on the results, a design chart was suggested 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 would be helpful for engineers, designers and construction practitioners who want to reduce heat loss through the window and to minimize the condensation risks in the window.

ACKNOWLEDGEMENTS

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