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Condensation resistance evaluation of a double-sliding window system for apartment buildings

Sihyun Park[a], So Young Koo[a], Jae-Han Lim[a] Yoon-Bok Seong[b], and Seung-Yeong Song[a,]*

[a]*Department of Architectural Engineering, Ewha Womans University, Seoul, South Korea*
[b]*High-tech Construction Materials Center, Korea Conformity Laboratories, Seoul, South Korea*

Abstract

In a cold climate such as Korea, the condensation risk is high for window systems. Condensation can lead to mold or mildew problems, thereby causing discomfort for building occupants. To evaluate the risk of condensation for residential apartment buildings, the most commonly used double-sliding window system with double glazing on a four-track polyvinyl chloride (PVC) frame was examined as a reference model. A variety of different frame profile options has been proposed as alternatives to existing window systems. The condensation risk from the reference model was compared to that of the alternatives using two-dimensional steady-state heat transfer simulations. The temperature difference ratio (TDR) was calculated for each case using the inside surface temperature determined at the evaluation locations by the simulation results. Then, these TDRs were compared to determine the most improved alternative.

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Keywords: condensation resistance; inside surface temperature; temperature difference ratio (TDR); double-sliding window system

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Nomenclature	
low-E	low emissivity
PVC	polyvinyl chloride
TDR	temperature difference ratio
T_i	the inside air temperature
T_o	the outside air temperature
T_{si}	the inside surface temperature of the evaluation locations

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* Corresponding author. Tel.: +82-2-3277-3913 Fax: +82-2-3277-2437.
E-mail address: archssy@ewha.ac.kr

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1. Introduction

Recently, residential apartment buildings have faced increased condensation risk caused by highly airtight building designs that are implemented to reduce building energy consumption. Characteristically, Korean apartment buildings are designed with a main living room and a bedroom with a large window area, as shown in Fig. 1. Thus, the window systems are considered to be the vulnerable element of the building envelopes because there is a high risk of condensation on the inside surface. In particular, during a cold winter, the condensation in apartment buildings can damage the interior surfaces and cause serious problems involving mold or mildew, which can lead to health problems, consequently causing discomfort for building occupants. To eliminate condensation risks and secure the well-being and comfort of building occupants, in 2014, the Korean government implemented the Design Standard for Preventing Condensation Risk in Apartment Buildings [1].

In this study, a double-sliding window system with an aluminum spacer was used as a reference model, and possible alternatives were analyzed using a two-dimensional steady-state heat transfer simulation. The lowest inside surface temperature was determined from the simulation results and used to calculate the temperature difference ratio (TDR) to evaluate the risk of condensation.

Fig. 1. Typical Korean apartment buildings.

2. Overview of the existing window systems in Korea

The Korean Design Standard for Energy-Efficient Buildings defines the minimum building envelope design requirements, such as those for walls, windows, and doors. To meet the required U-value of a window system, most residential buildings are designed with double glazing (5CL-12Air-5CL) on a polyvinyl chloride (PVC) four-track framed window system, although some use triple-glazing window systems. Usually, double glazing can be assembled using different glass types for the inner and outer layers and a gas fill. A low-emissivity (low-E) coating decreases the radiative heat transfer through the glazing unit. An argon-gas-filled double-glazing system for a 12-mm cavity provides a measurable improvement in the thermal performance compared to an air-filled cavity. Regarding the frame, PVC is the most popular, with steel reinforcement inside a large hollow chamber within the frame. Small extrusion details in the frame profiles are used to prevent the reinforcement steel surface from contacting the frame body; however, warped steel can make contact with the large frame area in practice. The creation of smaller cells within the frame reduces this conduction, as does the addition of an insulating material. To ensure air-tightness, the glazing and frame are sealed with silicone sealing, and a few weep holes are punched into the frame tracks to release accumulated condensed water. Typically, in a Korean apartment building, the walls are designed as an entire window adjacent to the living area and bedrooms. Many cases of condensation occur on the edge-of-glazing area; in particular, lower surface temperatures are measured near the jamb, and the sill overlaps the third and fourth tracks facing the building interior.

Table 1. Technologies for thermally improved window design.

	Technology	Expected Effects
Glazing	Better insulating spacer 1) Thermoplastic compound (TPS) 2) Thick-walled plastic (Swisspacer) 3) Thermally broken aluminum spacer (Warm light) 4) Thin-walled stainless steel spacer (TGI)	Increase the inside surface temperature at the edge-of-glazing
	Spacer size optimization	
	Insulating cap on glazing end	
	Low-E coating	Increase the inside surface temperature of the glazing
	Argon-, krypton-gas fills	
Frame	Insulating cover	Increase the inside surface temperature at the edge-of-glazing and the frame
	Frame structure and size optimization	
	Smaller cells within the frame between the reinforcement steel and the frame Insulating cap on the frame extrusions	Increase the inside surface temperature of the frame

To resolve the current state of double-sliding window system problems, the condensation resistance at the edge-of-glazing and frame must be improved. In this study, the related drawings and warm-edge technology for the glazing are analyzed, and appropriate technologies are suggested, including the use of insulating glass and the adjustment of the structure and size.

3. Condensation resistance index

The occurrence of inside surface condensation depends on the inside air temperature, humidity, and outside air temperature. The Korean Design Standard for Preventing Condensation Risk in Apartment Buildings requires the allowed maximum TDR of building envelopes. The TDR is defined as the ratio of the difference between the inside air temperature (T_i) and the inside surface temperature of the evaluation locations (T_{si}) to the difference between the inside air temperature (T_i) and the outside air temperature (T_o) [2]. After obtaining the inside surface temperature of the evaluation locations, the TDR can be calculated using Eq. (1). This value is used to evaluate the level of condensation risk and ranges from zero to one. To evaluate the simulation results, the required TDR evaluation locations were referenced from the standard; the locations are shown in Fig. 2.

$$TDR = \frac{T_i - T_{si}}{T_i - T_o} \tag{1}$$

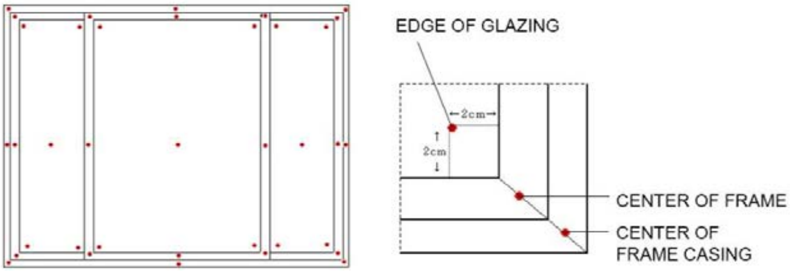


Fig. 2. Evaluation locations of a window system.

Table 2. Allowed maximum temperature difference ratio in different regions.

		TDR		
		Region I[a]	Region II[a]	Region III[a]
Window directly facing the exterior	Center-of-glazing	0.16	0.18	0.20
	Edge-of-glazing	0.22	0.24	0.27
	Frame	0.25	0.28	0.32

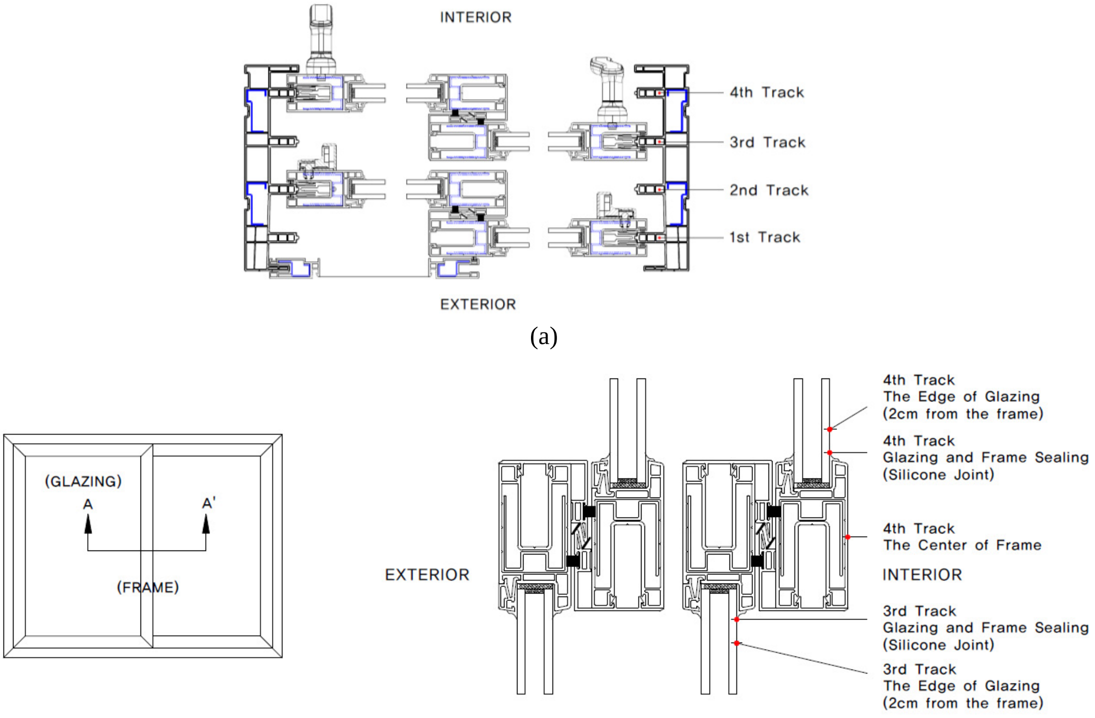
[a] Based on the monthly average daily lowest air temperature in January—the most extreme cold month in Korea, categorized regions by Region I: -20 °C; Region II: -15 °C; Region III: -10 °C [2].

4. Condensation resistance evaluation

4.1. Overview of the evaluation

This study analyzed the condensation resistance of double-sliding window systems consisting of double glazing on four tracks with PVC frames; the reference model was compared with alternatives with a similar window U-value. The U-value of the window system was set to 1.5 W/(m^{2}K) to meet the required window U-value for residential buildings according to the Korean Design Standard for Energy-Efficient Buildings, and each alternative composition is presented in Table 6.

A horizontal section, including all four jambs from the interior to the exterior, is chosen for the simulation, as shown in Fig. 3(a). The standard required evaluation locations are the edge-of-glazing that is 2 cm from the frame end and the center of the frame. However, to understand the simple and intuitive tendency of the occurrence of condensation, this study also examined the additional location of the glazing and frame sealing (Fig. 3(b)).



(a)

(b)

Fig. 3. (a) Simulated part of a double-sliding window system. (b) Simulated section (A–A') and evaluation locations.

4.2. Evaluated reference model and alternatives

The condensation resistance of a reference model and the alternatives were evaluated using a two-dimensional steady-state heat transfer simulation. Physibel TRISCO v.12 software was used to derive the inside surface temperature on the edge-of-glazing, the glazing and frame sealing, and the center of frame locations. All alternative cases were compared to the reference model to evaluate the increase in the inside surface temperature; as a result, better performing alternatives were suggested. Boundary conditions such as the setpoint temperature, the surface heat transfer coefficient for the inside and outside surfaces of the building, and the material properties are presented in Tables 3 and 4. The boundary conditions are referenced from the Korean Design Standard for Preventing Condensation Risk in Apartment Buildings. Frame cavities are modeled as the EQUIMAT type, which is set at the effective thermal conductivity. The large cavity between the two tracks and the air cavity between the double-glazing layers are modeled as BC_FREE, which calculates the radiative and convective heat transfer [3]. The simulated model is presented in Table 5.

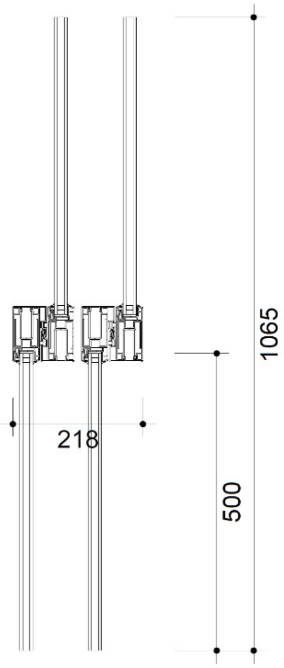
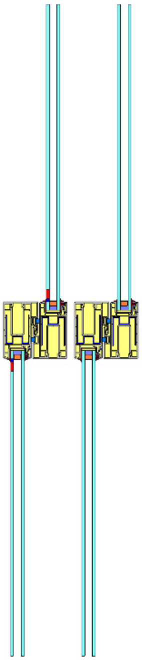
Table 3. Boundary conditions.

	Temperature (°C)	Surface Heat Transfer Coefficient (h) (W/(m^{2}K))
Inside	25.0	9.09
Outside	-15.0	23.25

Table 4. Material properties for the simulation.

	Materials	Thermal Conductivity (W/(mK))	Emissivity (ε)
Glazing	Glass	1.0	0.9
Frame	Steel	45.3	0.12
	PVC	0.17	0.9
	Glazing Beads	0.17	0.9
	Silicone	0.35	0.9
	EPDM	0.25	0.9
	Mohair	0.14	0.9
Spacer	Aluminum	221.0	0.09
	Sealant	0.35	0.9
	Desiccant	0.13	0.9
Insulating Spacer	TPS	0.25	0.9
Additional Insulating Material	Polystyrene	0.038	0.9

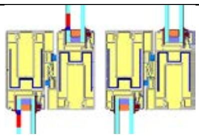
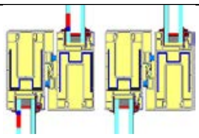
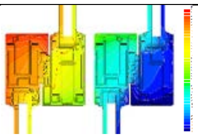
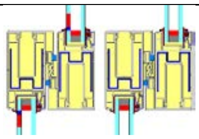
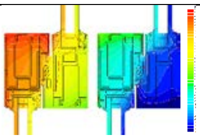
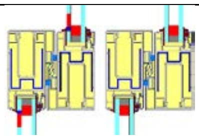
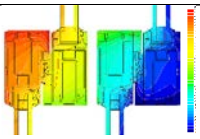
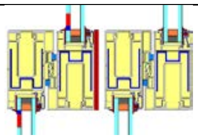
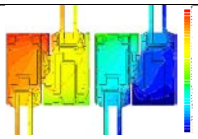
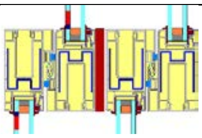
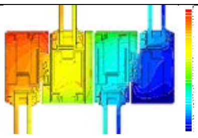
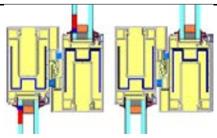
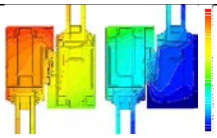
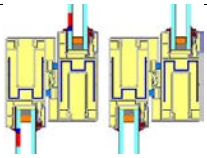
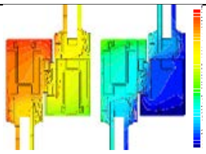
Table 5. Simulation model.

	Drawing	Simulation Model
Reference Model		

4.3. Evaluation results

The evaluation results of the condensation resistance for the simulated reference model and all alternatives are summarized in Table 6. The previously mentioned applicable technologies in Table 1, thermoplastic spacer applications, and the size optimizations (Cases 1-1–1-3); the addition of an insulating cover on the frame (Cases 2-1 and 2-2); and the frame-size optimization (Cases 3-1 and 3-2) are selected for the evaluation.

Table 6. Reference model and alternative simulated models and results.

	Glazing	Frame		Simulated Model	Temperature Distribution
	Spacer	Frame Insulated Cover	Frame Length	(Inside - Outside)	(Inside - Outside)
Reference Model	Aluminum Spacer	X	92 mm		
Case 1-1	TPS Spacer 3 mm	X	92 mm		
Case 1-2	TPS Spacer 6 mm	X	92 mm		
Case 1-3	TPS Spacer 12 mm	X	92 mm		
Case 2-1	Aluminum Spacer	Polystyrene 5 mm	92 mm		
Case 2-2	Aluminum Spacer	Polystyrene 10 mm	92 mm		
Case 3-1	Aluminum Spacer	X	84 mm		
Case 3-2	Aluminum Spacer	X	100 mm		

The edge-of-glazing and silicone sealing locations for the reference model and all of the alternatives resulted in temperatures that are 2–7 °C lower than the frame center; therefore, these areas are more vulnerable to condensation. All of the simulated cases including the reference model have lower surface temperatures on the third track, which is located closer to the outside than the fourth track; thus, the glazing on the third track is more prone to condensation. The inside surface temperature of the frame center is about the same for the reference model and the alternatives.

The simple substitution of a thermoplastic spacer (Cases 1-1–1-3) instead of the aluminum spacer increased the surface temperature by 0.4–0.7 °C at the edge-of-glazing and by 1.2–1.9 °C at the glazing and frame sealing compared with the reference model. This behavior occurs because the TPS has a lower thermal conductivity of 0.25 W/(mK), which resulted in a thermal improvement for the edge-of-glazing. By changing the thickness of the TPS for optimization, the thinnest insulation spacer resulted in a higher surface temperature around both the edge-of-glazing and the glazing and frame sealing. Characteristically, a spacer acts as a heat flow path between the glass layers of a double-glazing unit, even with a lower thermal conductivity. Therefore, the use of a spacer with a smaller area and a larger air cavity between the glass layers of the double glazing provides better thermal performance.

By adding an insulating cover on the frame (Cases 2-1 and 2-2), the temperature increased by 0.1–0.2 °C at the edge-of-glazing and by 0.1–0.6 °C at the glazing and frame sealing. These results indicated that the addition of thin insulating materials to the frame is not effective. A thicker insulating cover appears to be helpful but does not provide a notable effect. The addition of insulating materials also has limits in the thickness of the insulation between the sliders.

In the case of the frame-size optimization (Cases 3-1 and 3-2), the extended frame height improved the thermal performance for all evaluation locations. However, lowering the frame height worsened the thermal performance compared to the reference model. A longer frame not only moves the evaluation location of the edge-of-glazing closer to the center-of-glazing but also extends the heat flow path by covering a larger area of the glazing edge to reduce condensation risk.

Table 7. Evaluation results.

	Glazing								Center of the frame	
	3rd track of the window facing the interior				4th track of the window facing the interior				4th track of the window facing the interior	
	Edge-of-glazing		Glazing and frame sealing		Edge-of-glazing		Glazing and frame sealing			
	T_{si} (°C)	TDR	T_{si} (°C)	TDR	T_{si} (°C)	TDR	T_{si} (°C)	TDR	T_{si} (°C)	TDR
Reference Model	17.0	0.20	14.8	0.26	17.9	0.18	16.7	0.21	20.7	0.11
Case 1-1	17.7	0.18	16.7	0.21	18.6	0.16	18.4	0.17	20.7	0.11
	(+0.7)[a]	(-0.02)[b]	(+1.9)	(-0.05)	(+0.7)	(-0.02)	(+1.7)	(-0.04)	(0.0)	(0.00)
Case 1-2	17.6	0.18	16.5	0.21	18.5	0.16	18.3	0.17	20.7	0.11
	(+0.6)	(-0.02)	(+1.7)	(-0.05)	(+0.6)	(-0.02)	(+1.6)	(-0.04)	(0.0)	(0.00)
Case 1-3	17.4	0.19	16.0	0.23	18.4	0.17	17.9	0.18	20.8	0.11
	(+0.4)	(-0.01)	(+1.2)	(-0.03)	(+0.5)	(-0.01)	(+1.2)	(-0.03)	(+0.1)	(0.00)
Case 2-1	17.2	0.20	15.2	0.25	18.0	0.18	16.8	0.21	20.8	0.10
	(+0.2)	(0.00)	(+0.4)	(-0.01)	(+0.1)	(0.00)	(+0.1)	(0.00)	(+0.1)	(-0.01)
Case 2-2	17.2	0.19	15.4	0.24	18.0	0.18	16.8	0.21	20.9	0.10
	(+0.2)	(-0.01)	(+0.6)	(-0.02)	(+0.1)	(0.00)	(+0.1)	(0.00)	(+0.2)	(-0.01)
Case 3-1	16.1	0.22	13.7	0.28	17.4	0.19	16.1	0.22	20.7	0.11
	(-0.9)	(+0.02)	(-1.1)	(+0.02)	(-0.5)	(+0.01)	(-0.6)	(+0.01)	(0.0)	(0.00)
Case 3-2	17.5	0.19	16.2	0.22	18.3	0.17	17.6	0.18	20.7	0.11
	(+0.5)	(-0.01)	(+1.4)	(-0.04)	(+0.4)	(-0.01)	(+0.9)	(-0.03)	(0.0)	(0.00)

[a] Surface temperature increase and decrease variation compared to the reference model: + performance improvement, - performance decline

[b] TDR increase and decrease variation compared to the reference model : - performance improvement, + performance decline

Shaded Box: Better performance improvement compared to the reference model (an increase >0.5 °C in the surface temperature)

5. Conclusions

On the basis of the current state of double-sliding window systems in Korea, applicable thermally improved technologies are investigated. The application of a thermoplastic spacer and the optimization of the size (Cases 1-1–1-3), the addition of an insulating cover to the frame (Cases 2-1 and 2-2), and a frame-size optimization (Cases 3-1 and 3-2) were evaluated in this study. An evaluation method for the inside surface condensation based on the TDR was used according to the Korean Design Standard for Preventing Condensation Risk in Residential Buildings.

1. The edge-of-glazing and silicone sealing locations for all of the alternatives and the reference model resulted a temperature that was 2–7 °C lower than the temperature at the frame center; therefore, these areas are more vulnerable to causing condensation. In addition, all of the simulated models, including the reference model, have a lower surface temperature on the third track; hence, the glazing on the third track has a higher condensation risk.
2. The substitution of a thermoplastic spacer (Cases 1-1–1-3) instead of the aluminum spacer increased the surface temperature by 0.4–0.7 °C at the edge-of-glazing and also increased the temperature by 1.2–1.9 °C at the glazing and frame sealing compared to the reference model. By changing the thickness of the TPS for optimization, the thinnest insulation spacer resulted in a warmer surface temperature for both of the evaluated glazing locations. Therefore, a smaller area for the spacer with a larger air cavity between the double glazing was found to have better thermal performance.
3. By adding an insulating cover onto the frame (Cases 2-1 and 2-2), an increase in the temperature of 0.1–0.2 °C at the edge-of-glazing and 0.1–0.6 °C at the glazing and frame sealing was observed. These results demonstrated that the addition of insulating materials to the frame is not effective.
4. In the case of the frame-size optimization (Cases 3-1 and 3-2), an extended frame height provided better thermal performance for all evaluation locations. A longer frame not only moves the evaluation location of the edge-of-glazing closer to the center of the glazing but also lengthens the heat flow path by covering more area of the glazing edge to reduce condensation risk

For the edge-of-glazing, the reference model and all alternatives resulted in TDRs in the range of 0.16–0.22; these results satisfy the requirement that the edge-of-glazing TDR be less than 0.24 for Region II in the standard. For the center of frame, the reference model and all alternatives have TDRs in the range of 0.10–0.11. These results easily satisfy the requirement of the standard that the TDR be less than 0.28 in Region II. However, this study was performed to understand the tendency of the vulnerable locations in a double-sliding window system in terms of the condensation resistance. For further research, the edge-of-glazing, where the jamb and the head/sill meet towards the interior, must be evaluated using a three-dimensional steady-state simulation and compared with mock-up tests.

Acknowledgements

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