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Research paper



Development of a Window-mounted Insulation Module using Blind Technology to Improve Comfort and Convenience

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Abstract

The increase in the amount of energy consumed by buildings has led to a growing number of studies that attempt to solve this problem. One approach that has been proposed in some studies is the use of air caps, a type of material that can be attached to the exterior surface of a building to improve its insulation performance and thus save energy. However, air caps are currently difficult to attach, and there has been a problem of deteriorating views caused by the attachment method, which applies the air caps to the front surface of windows. Therefore, the objective of this study is to develop blind-type window-attaching-type air cap modules and use a full-scale test-bed to verify the energy saving effects on lighting devices and air-conditioning appliances. The conclusion reached is as follows: 1) The blind-type window-attaching-type air cap module suggested in this study is designed to open and close the blind with its air cap attached to the wing plate of the blind in order to easily shift the status of air cap application and minimize the extent to which it interferes with the view. 2) The window to which the air cap is attached, compared to unattached ones, has a 3.9–12.8% increase in energy consumption for lighting, which makes it inappropriate for lighting energy saving. 3) The blind-type window-attaching-type air cap module, compared to the current air cap-related technology, is capable of achieving a 4.3–7.4% reduction in the energy used for air-conditioning. 4) The blind-type window-attaching-type air cap module, compared to current air cap technology, is capable of achieving a 3.7–1.3% reduction in the energy used for air conditioning and lighting, and is thus useful for saving building energy.

Keywords: *Air cap, Blind, Add-in type, Performance evaluation, Prospect right.*

1. Introduction

1.1. Background and purpose of research

With the increase in the amount of energy consumed by buildings that has been measured in recent years, a number of studies have been carried out and technologies developed to address this problem. In particular, the amount of energy consumed by building air conditioning systems is high; according to the Buildings Energy Data Book published by the U.S. Department of Energy, air conditioning systems were responsible for 53% of total building energy consumption in 2011 [1]. The amount of energy consumed by a building is highly connected with the performance of its exterior surface. To address concerns regarding heat loss through the exterior surface of a building, several studies have been conducted on means of increasing the insulation performance of building exterior surfaces. These include studies on double skins [2-10], PCMs[11-14], light duct [15], light shelf [16-18] and Automated blinds[19-28]. However, the application of such technologies has been limited to new buildings, and thus a study on approaches to improve the performance of the exterior surface of existing buildings is required [34,35].
The air cap was first developed by a U.S. company called the Sealed Air Corporation [29], and was designed by stacking up two pieces of polyethylene film together, with the gap between filled with air for buffer packing purposes. More recently, air caps have been filled with materials that improve the insulation capacity of windows in existing and new buildings. However, this air cap and those studies to improve the insulation capacity of windows [30, 31] have the disadvantage of deteriorating the view, which interferes with the window's original function. Besides, existing studies related to air cap [30, 31] have limited their examination of how air cap applications improve the insulation capacity of windows and save indoor air conditioning energy, and have not considered how applying the air cap to windows decreases indoor light inflow and thus increases the lighting energy requirement.
Therefore, this study intends to attach air cap blinds in order to develop a brand-new blind-type window-attaching-type air cap module, and use a full-scale test-bed to verify its performance and thus prove its usefulness.

1.2. Methods and Scope of research

This study was conducted in accordance with the procedure shown in <Fig. 1> to develop a blind-type window-attaching-type air cap module and verify its performance.

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First, we performed a literature review on the standards of proper indoor and outdoor temperature and illumination for air cap specification and performance tests.
Second, we developed a blind-type window-attaching-type air cap module and suggested a vertical and horizontal structure for the blind-type window-attaching-type air cap module.
Third, we examined the performance and verified the usefulness of the performance of the blind-type window-attaching-type air cap module suggested in this study, and proved its building energy saving performance compared to the air cap type that is attached to the front surface of a window.
Note that the performance test in this study was only conducted during summer (the time of year with the most sunlight hours) and winter (the time of year with the fewest sunlight hours) when the air conditioner was operated. Furthermore, in terms of the index to verify the energy saving performance, only electricity consumed by the air conditioner and lighting devices used to maintain the proper indoor temperature and intensity of illumination were taken into consideration.

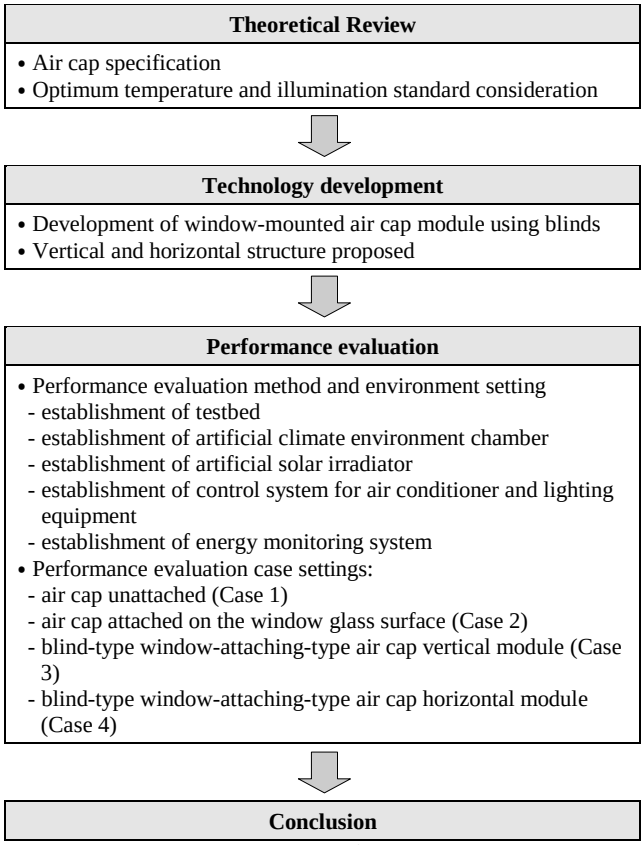


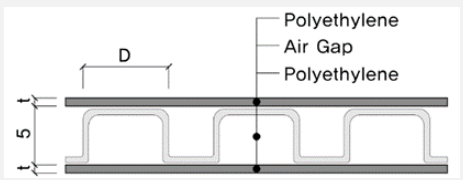
Fig. 1: Research flow chart

2. Air cap research trend and indoor illumination standard

2.1. Standard and research trend of air cap

As mentioned above, air cap has been used as a buffer in packing after stacking two pieces of polyethylene film and filling up the air between those; however, it has recently been attached to building windows and is used to improve building insulation performance. An air cap can have various specifications depending on the size of its air layer, thickness, and shape, but the performance test was conducted using the specifications from a related study [30] in which the air layer was shaped in a circle having a diameter of 10 mm and a thickness of 5.6 mm.

Table 1: Air-cap specifications as provided by the manufacturer

D	t	Air-cap section
10 mm	0.2 mm	
	0.4 mm	
20 mm	0.6 mm	
25 mm		
30 mm		

Regarding the method used to attach an air cap to a window, as shown in <Table 2>, which shows the result of a review on related preceding studies, water or vinyl double-sided tape is used; while vinyl double-sided tape is efficient in terms of improving insulation performance, considering the inconvenience when removing the air cap, the normal method is to use water to attach the air cap to the glass surface of a window. Moreover, according to preceding studies, attaching the air cap on the front surface of a window deteriorates the

view, which is a demerit of applying an air cap to a window. The study related to the energy saving performance test for a window to which an air cap has been applied is limited to the window's insulation performance and air conditioning energy saving, and does not consider the fact that attaching the air cap lowers indoor natural light inflow to the extent that it changes the light energy consumption; thus, a study to address this is needed.

Table 2: Air cap research trend

Title of study (Year)	Use of air cap	Material to attach air cap to window	View
A Comparative Evaluation on the Thermal Insulation Performance of Windows according to the Temporary Improvement Method (2015) [30]	Improved insulation performance of windows	Water- or vinyl-type double-sided tape	Not considered
Thermal Performance Evaluation of the Window Systems with Air-bubble Sheets (2015) [31]	Improved insulation performance of windows	Water	Not considered
Comparative Evaluation of Thermal Insulation and Solar Heat Gain in Bubble Wrap attached Window (2016) [32]	Improved insulation performance of windows	Water	Not considered
A Comparative Evaluation on the Thermal Insulation Performance of Windows According to the Air cap Adherence (2014) [33]	Improved insulation performance of windows	Water- or vinyl-type double-sided tape	Not considered
Development of Aircap Wall Module through the Lamination of Aircap (2015) [34]	Development of insulation material	String magnet	Not considered
Development of detachable air-cap module for improving the performance of windows (2015) [35]	Development of insulation material		Not considered

2.2. Consideration of Optimum Temperature and Illumination Standards

Maintaining the proper indoor intensity of illumination and temperature helps residents to maintain a pleasant feeling and prevents unnecessary air conditioning and lighting energy consumption, contributing to energy saving.
This study considered KS A 3011[36], IES[37] and ISO 10211[38], as shown in <Table 3>, <Table 4> and <Table 5> to determine the proper indoor intensity of illumination and temperature. Based on this data, proper temperatures for the year's longest and shortest day based on hours of sunlight were set as 26°C and 20°C, respectively. In addition, the proper indoor intensity of illumination standard was set to 400 lx.

Table 3: Appropriate indoor illumination standard (KS A 3011)

Activity type	Scope [lx]		
	Min	Ave	Max
Visual performance according to the general brightness degree	150	200	300
Visual performance according to the general brightness degree	300	400	600
Visual performance according to the general brightness degree	600	1,000	1,500

Table 4: Appropriate indoor illumination standard (IES)

Task grade	Standard	Minimum allowed illumination	Standard allowed illumination	Maximum allowed illumination
General	IES (USA)	500	750	1000
	JIS Z 9110 (Japan)	300	500	600

Table 5: Appropriate indoor temperature standard (ISO 10211)

Summer	23.0–26.0℃
Winter	20.0–23.5℃

3. Development and Performance evaluation of window-mounted air cap module using blinds

3.1. Development of window-mounted air cap module using blinds

Regarding the blind-type window-attaching-type air cap module suggested in this study, as shown in <Figs. 2, 3, 4, 5, 6, 7 and 8>, vertical and horizontal types are suggested, and their details are as follows.

First, the air cap is attached to the wing plate of the blind structure. While the wing plate of the existing blind has a blocked structure for sun-blocking purposes, the blind-type window-attaching-type air cap module suggested in this study is produced in a "□" shape with a similar hole shape. This is a type of technology that opens and closes blinds with an attached air cap to enable the easy application of air caps to a window and minimize the interference with the view.

Second, a blind-type window-attaching-type air cap module form is suggested that is attached to the window frame; its structure is one of a guide frame of the blind-type window-attaching-type air cap module that is combined with the window frame. Furthermore, at the part where the window frame and the guide frame are combined, double-sided insulation tape was used to aid their combining, which enhances the sealing and insulation performance.

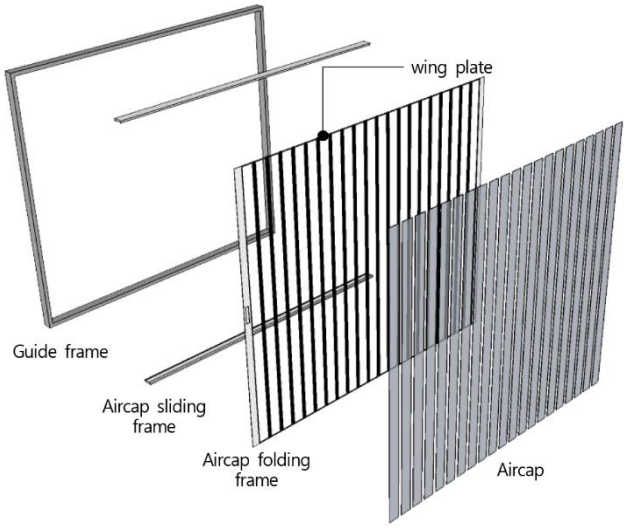


Fig. 2: Window-mounted air cap module using a blind (Vertical type)

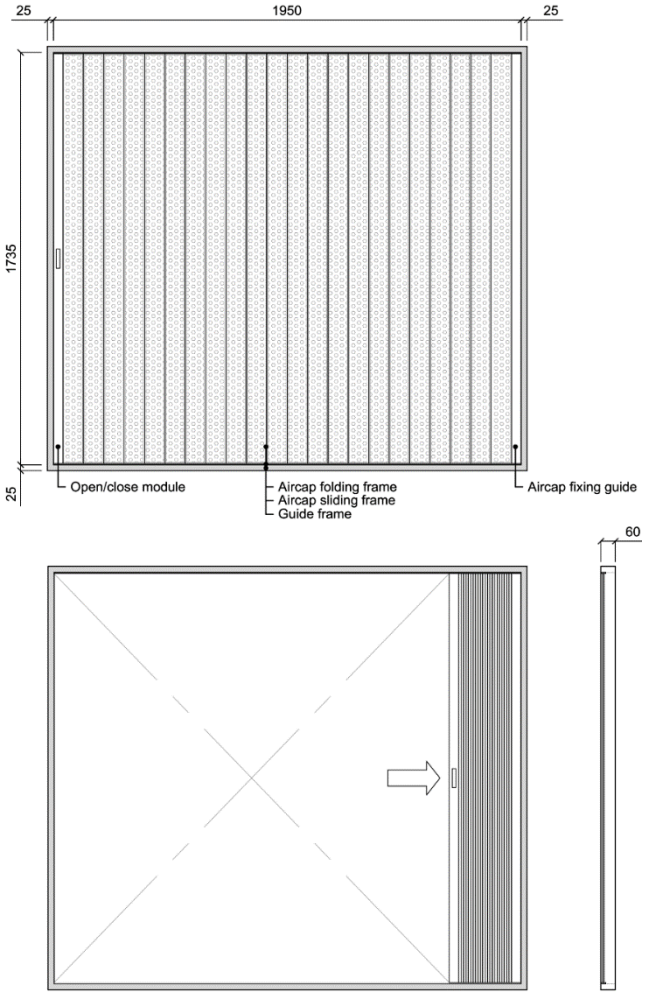


Fig. 3: Detailed drawing of window-mounted air cap module using a blind (Vertical type)

Third, the blind-type window-attaching-type air cap module for this study is suggested in either the vertical-type or horizontal-type form depending on the shape of the blind wing plate and whether it is an openable type. For the performance test on vertical and horizontal types, the image established in the test-bed is as shown in <Fig. 9> and <Fig. 10>. The number of wing plates of the vertical type and horizontal type are 22 and 18, respectively. These results were established after considering the size of the window.

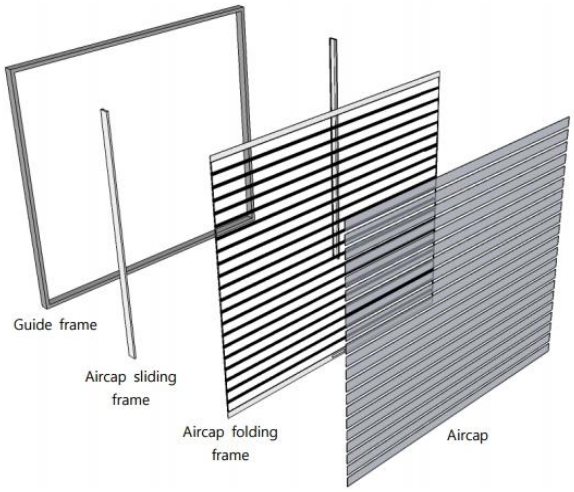


Fig. 4: Window-mounted air cap module using a blind (Horizontal type)

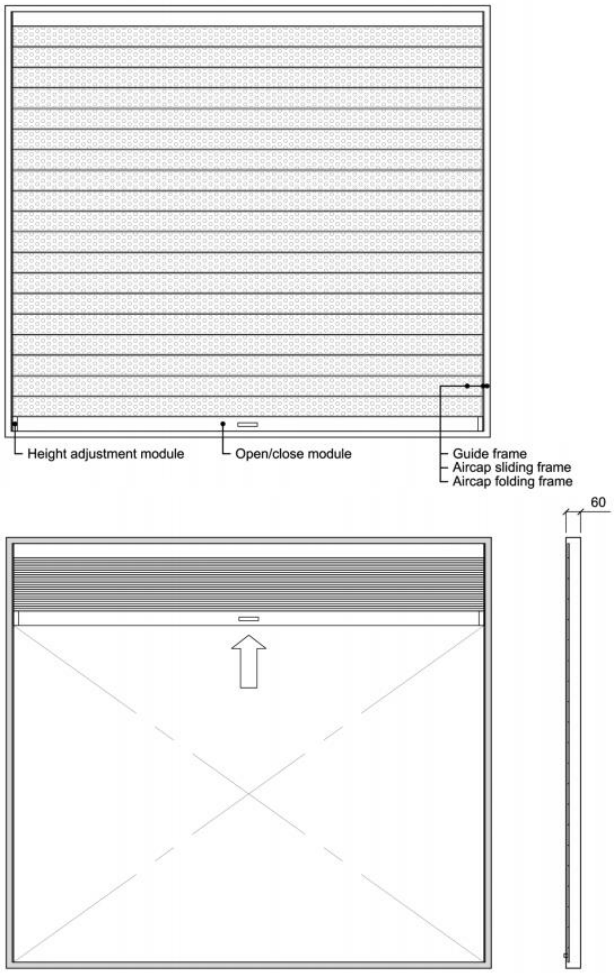
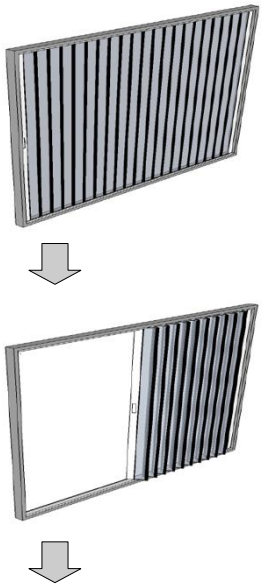
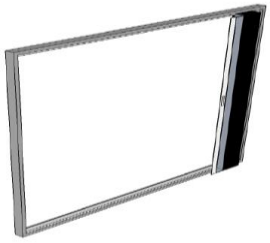


Fig. 5: Detailed drawing of window-mounted air cap module using a blind (Horizontal type)



100% air cap applied

50% air cap applied



10% air cap applied

Fig. 6: Opening and closing of a window-mounted air cap module using a blind (Vertical type)

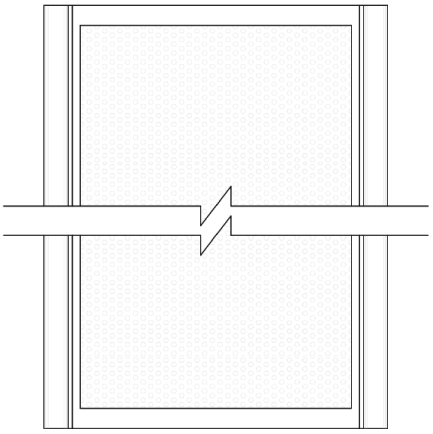


100% air cap applied

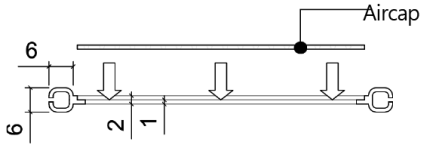
50% air cap applied

10% air cap applied

Fig. 7: Opening and closing of window-mounted air cap module using a blind (Horizontal type)



a) Shape of wing plate



b) Section of wing plate

Fig. 8: Shape and section wing plate



Fig. 9: Window-mounted air cap module using a blind (Vertical type)



Fig. 10: Window-mounted air cap module using a blind (Horizontal type)

3.2. Performance Evaluation Preferences

The window to which the blind-type window-attaching-type air cap module can be attached is 2.2 m wide and 1.8 m high, as shown in <Table 4>, <Fig. 10>, <Fig. 11> and <Fig. 12>. A chamber was constructed on the exterior of the test-bed to create an artificial weather environment, and was equipped with an artificial sunlight illumination device through which the light amount, height, and angle of the light source could be set. In addition, the chamber temperature can be set within the range of -20–40°C to create various outdoor environments. To ensure that the artificial sunlight illuminating the device in this study did not provide any setting for the sun's directory angle for each hour, the performance test was conducted based on a due south illumination direction. The outdoor intensity of illumination for the year's longest day and shortest day based on sunlight hours was set as 80,000 lx and 30,000 lx, respectively, based on a related study [39, 40]. The solar irradiance was set to a value derived using an artificial sunlight illumination device, and the temperature settings for the chamber contacting the window on which the air cap detachment-type module was attached were 34°C during the summer and -10°C during the winter for the performance test. In this study, as shown in <Fig. 6>, four sensors for light intensity and one temperature sensor were installed in the indoor space to collect the indoor light intensity and temperature information. The locations of the above sensors for light intensity were the result of coordination based on the study result, such that 4.4 m distance from the skylight window was appropriate to obtain the average indoor light intensity [41, 42] and the height of those sensors was set to 750 mm from the floor based on the height of the working surface. The temperature sensor was located at the center of the indoor space.

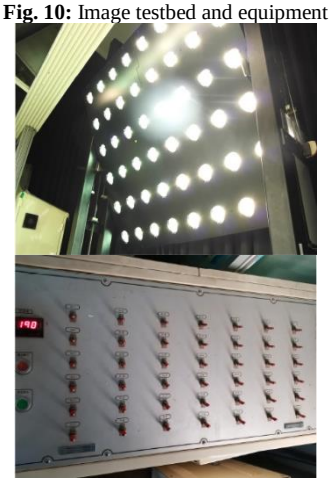
Table 6: Overview of the testbed

Room size	4.9 m (w) × 6.6 m (D) × 2.5 m (H)
Wall material	Insulation panel (Thk 100 mm)
Window size and material	· Size: 1.9m(W) × 1.7m(H) · Type: Pair glass 24 mm (6 + 12 + 6 mm) · Thermal transmittance - Summer : 2.83 W/m²K - Winter : 2.69 W/m²K · Transmissivity: 80%
Air conditioner	· Model: AP-SM302(EHP) · Capacity - Heating : 13,200 w - Cooling : 11,000 w

	· Consumption - Heating : 3.90 kw - Cooling : 3.90 kw · COP - Heating: 3.38 - Cooling: 2.82
Lighting	· Dimming control (eight levels), LED type · Energy Consumption for Phased Light Dimming - Level 1 : 12.3 kWh - Level 2 : 18.3 kWh - Level 3 : 22.0 kWh - Level 4 : 27.7 kWh - Level 5 : 34.0 kWh - Level 6 : 38.5 kWh - Level 7 : 42.6 kWh - Level 8 : 50.8 kWh.
Energy monitoring system	· Model : SPM - 141 · Measurement capacity : Single phase (220 V, 1–50 A) · Error rate : Within 2.0% · Measurement items : Power / voltage / current, real-time, and accumulated amount
Temperature sensor	· Sensing element: Silicon photo sensor with filter · Detection range: 0–200,000 lx (Precision: ±3%)
Illuminance sensor	· Sensing element: NTC 10KΩ: AN Type · Detection range: -40–90°C (Precision: ±0.3°C)
Directions	South aspect



Fig. 10: Image testbed and equipment



a) Artificial sunlight illumination device and controller



b) Lighting controller (8 step dimming switch)



c) air-conditioning equipment

Fig. 11: Performance evaluation equipment

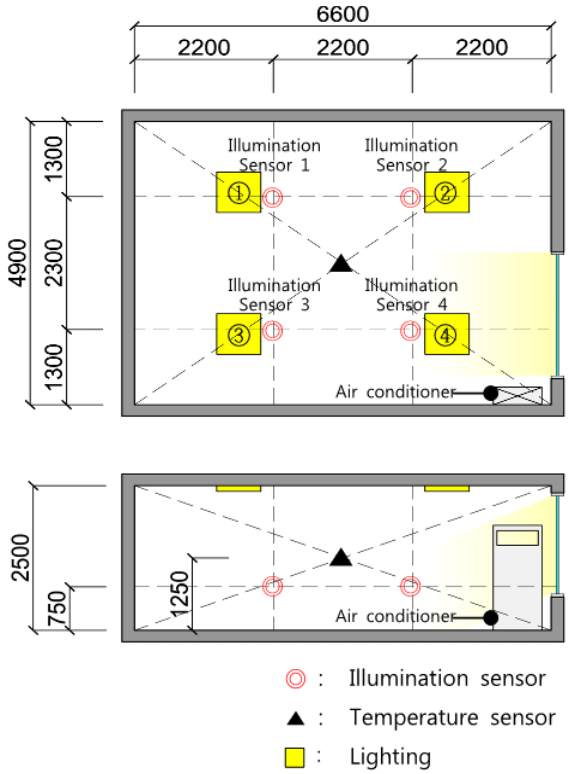


Fig. 12: Testbed plane and section

3.3. Performance Evaluation Methods

The performance test method used in this study is as follows:
First, several configurations of the blind-type window-attaching-type air cap module were tested: the air cap unattached case (Case 1), air cap attached on window glass surface (Case 2), blind-type window-attaching-type air cap vertical module (Case 3), and the blind-type window-attaching-type air cap horizontal module (Case 4). Note that water was used to attach the air cap to the window glass surface and double-sided insulation tape was used to attach the air cap to the window frame.
Second, air conditioners were set to maintain the indoor temperature for the year's longest day and the year's shortest day based on sun-light hours to be automatically controlled, and the power consumption was calculated depending on how they were controlled to conduct the energy performance test. The air conditioners' power consumption was checked for five hours during the day and the night.
Third, this study performed lighting control to set the indoor light intensity to 400 lx for each case, and a calculation of lighting energy consumption was then made depending on the lighting control. Lighting control was performed through the following procedure. Light intensity sensors 1, 2, 3, and 4 set in this study were linked to lightings 1, 2, 3, and 4, and the auto-dimming of each light was controlled by measurements first collected by those light intensity-linked sensors. If there was any value below 400 lx based on measurements first collected by light intensity sensors, lighting control was performed and dimming control was set to be sequentially done from the lighting linked to the one with the lowest light intensity. Note that lighting dimming control was set to interrupt the lighting control when all light intensity sensor measurements were > 400 lx and the light intensity reference value for lighting control; 400 lx was set based on the above contemplated KS A3011. Thereafter, the lighting energy consumption was calculated based on the measurement at the time of

lighting control interruption, and for the air conditioner's power consumption, performance test was conducted for five hours during the day and the night, respectively, but the day and night performance tests were performed separately. This element shows the limitation in this study due to the performance test based on an artificial weather environment.

3.4. Performance evaluation results and discussion

This study performed an energy saving performance test using lighting devices and air conditioners with the blind-type window-attaching-type air cap module; its results and a discussion are as follows.

First, Cases 2, 3, and 4 with the air cap attached had a 3.9–12.8% increase in lighting energy consumption to maintain an appropriate indoor light intensity due to the decrease in indoor light inflow compared to Case 1 without the air cap. This is connected to the deterioration of the window view caused by the air cap attachment.

Second, the blind-type window-attaching-type air cap module suggested in this study can reduce air conditioning energy use by 20.0–22.7% and 4.3–7.4%, compared to Case 1 without an air cap and Case 2 with air cap attached to the window glass surface, respectively. In particular, the blind-type window-attaching-type air cap vertical module could achieve a 3.3% in air conditioning energy compared to its horizontal module, and it is determined that this is because the vertical module has many joints to connect compared to the horizontal module, but appeared to be less affected by the horizontal load, which leads to less space between the blind wing plate and the frame.

Third, the blind-type window-attaching-type air cap module can save 14.1–16.3% and 3.7–1.3% of lighting device and air conditioner energy compared to the case in which no air cap is attached (Case 1) and the case in which air cap is attached to the window glass surface (Case 2), respectively, proving the usefulness of the blind-type window-attaching-type air cap module suggested in this study for building energy saving performance.

Table 7: Performance evaluation results (Indoor illumination Sensor value)

Case	Season	Time	Illumination Sensor (lx)			
			1	2	3	4
1	Summer	(day) 10:00-15:00	85.7	210.1	114.1	429.5
		(night) 19:00-24:00	0	0	0	0
	Winter	(day) 10:00-15:00	417.1	607.3	714.5	25499.3
		(night) 19:00-24:00	0	0	0	0
2	Summer	(day) 10:00-15:00	76.3	185.0	98.5	384.3
		(night) 19:00-24:00	0	0	0	0
	Winter	(day) 10:00-15:00	392.1	558.7	657.3	23459.4
		(night) 19:00-24:00	0	0	0	0
3	Summer	(day) 10:00-15:00	62.9	150.8	80.3	316.0
		(night) 19:00-24:00	0	0	0	0
	Winter	(day) 10:00-15:00	330.3	457.2	539.5	19397.2
		(night) 19:00-24:00	0	0	0	0
4	Summer	(day) 10:00-15:00	59.31	142.03	75.63	297.4
		(night) 19:00-24:00	0	0	0	0
	Winter	(day) 10:00-15:00	310.9	430.4	507.8	18256.2
		(night) 19:00-24:00	0	0	0	0

Table 8: Performance evaluation result (Calculating the power consumption of the lighting equipment)

Case	Season	Time	Lighting dimming control: Lighting Number (Dimming level)	Lighting Electricity consumption (kWh)
1	Summer	(day) 10:00-15:00	1(8) → 3(3)	0.364
		(night) 19:00-24:00	1(8) → 3(8) → 2(8) → 4(3)	0.900
	Winter	(day) 10:00-15:00	-	0
		(night) 19:00-24:00	1(8) → 3(8) → 2(8) → 4(3)	0.900
2	Summer	(day) 10:00-15:00	1(8) → 3(4)	0.392
		(night) 19:00-24:00	1(8) → 3(8) → 2(8) → 4(3)	0.900
	Winter	(day) 10:00-15:00	1(8)	0.062
		(night) 19:00-24:00	1(8) → 3(8) → 2(8) → 4(3)	0.900
3	Summer	(day) 10:00-15:00	1(8) → 3(5)	0.424
		(night) 19:00-24:00	1(8) → 3(8) → 2(8) → 4(3)	0.872
	Winter	(day) 10:00-15:00	1(8) → 3(1)	0.316
		(night) 19:00-24:00	1(8) → 3(8) → 2(8) → 4(3)	0.872
4	Summer	(day) 10:00-15:00	1(8) → 3(5)	0.424
		(night) 19:00-24:00	1(8) → 3(8) → 2(8) → 4(3)	0.872
	Winter	(day) 10:00-15:00	1(8) → 3(1)	0.316
		(night) 19:00-24:00	1(8) → 3(8) → 2(8) → 4(3)	0.872

Table 9: Performance evaluation results (Calculating the power consumption of cooling and heating equipment)

Case	Electricity consumption of cooling and heating equipment (kWh)				Sum of the electricity consumption of cooling and heating equipment (kWh)
	Summer (Day)	Summer (Night)	Winter (Day)	Winter (Night)	
1	2.378	1.153	3.466	3.580	10.576
2	2.345	0.864	2.749	2.877	8.834
3	2.124	0.801	2.653	2.598	8.176
4	2.235	0.831	2.713	2.678	8.457

Table 10: Electricity consumption of cooling, heating, and lighting equipment for each case

	Case 1	Case 2	Case 3	Case 4
Electricity consumption of the cooling, heating and lighting equipment (kWh)	12.740	11.080	10.660	10.941

4. Conclusion

This study developed a blind-type window-attaching-type air cap module to improve the convenience of air cap attachment on windows and insulation performance, and used a full-scale test-bed to confirm its usefulness in building energy saving.

First, the blind-type window-attaching-type air cap module was designed to make a hole in the blind wing plate to enable the insertion of an air cap, and vertical-type and horizontal-type modules were suggested depending on the shape of the blind. This makes it easy to secure a window view and apply an air cap to windows if necessary by opening and closing the blind with the air cap.

Second, compared to the case in which no air cap is applied, the case with an air cap applied showed a 3.9–12.8% increase in lighting energy consumption, making it inappropriate for lighting device energy saving. This was because air cap application decreased indoor natural light inflow.

Third, the blind-type window-attaching-type air cap module suggested in this study was compared to the case in which no air cap was attached (Case 1) and the case in which an air cap was attached on the window glass surface (Case 2); the result showed that this can save 20.0–22.7% and 4.3–7.4% air conditioning energy, respectively, and in particular, it is determined that the blind-type window-attaching air cap vertical module was more appropriate for building energy saving than its horizontal module.

Fourth, the blind-type window-attaching air cap module was compared to the case in which no air cap was attached (Case 1) and the case in which an air cap attached on the window glass surface (Case 2), and was found to reduce lighting device and air conditioner energy consumption while maintaining proper indoor temperature and light intensity by 14.1–16.3% and 3.7–1.3%, respectively; this is a result that confirms the efficiency of energy saving using the blind-type window-attaching-type air cap module.

This study suggests and verifies a novel blind-type window-attaching module to improve the application and insulation performance of window-attached air caps. A limitation of this study is that it relied on an artificial environment. In the future, it is necessary to verify performance through various methods that include the use of energy simulation programs capable of considering diverse environmental variables.

Acknowledgements

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