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Optimization of Wind Louver Angle By CFD Simulation

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Abstract The objective of this study was to determine the optimal angle of a wind louver that would induce the optimal wind speed for indoor. Being controlled to have an optimized angle depending on the direction from which wind is blowing and the wind speed, the wind louver to be installed on the building envelop comes to create indoor comfort through a constant wind speed using the function that reduces the indoor wind speed by changing the angle when the wind speed is not lower than a certain level and makes wind flow into the room to the maximum when the wind direction is adverse to catching the wind or the wind speed is not higher than a certain level. To determine the optimal wind louver angle, a core-centered office building with cross-ventilation problems in the climate of Seoul, Korea, which experiences four distinct seasons, was considered for analysis in this study. A module 1 office space model was used for the CFD simulation to analyze the average indoor wind speed with respect to the outdoor wind speed (varied between 1 and 8 m/s), the wind louver angle, and the outdoor wind direction (varied between 0°and 180°in steps of 10°).

Keywords: Wind, CFD, Wind Louver, Eco-friendly Architecture, Indoor Comfort

1. INTRODUCTION

The comfort of a building is an environmental assessment criterion that significantly affects the quality of life or the efficiency of the business conducted in it. This is because the comfort felt directly impacts the human sensory system. However, because the control of environmental factors such as light, temperature, and humidity is necessary for improving and maintaining the comfort of a building, considerable amounts of energy are expended on the required equipment. This has prompted the development of passive techniques for achieving indoor comfort and hence maximizing the energy efficiency of a building. Such techniques include temperature regulation by solar energy, the stack–effect ventilation technique, and the storage of heat in the walls or below a building. Natural ventilation, which has been utilized from ancient times, is another very common example. However, owing to the difficulty of controlling the wind speed and direction over different seasons, an indirect method of natural ventilation based on temperature difference has been developed more recently.

It is considered that, if the challenges of natural ventilation can be overcome by using real-time control to achieve effective flow of the outdoor air current into a room, or to cut it off when need be, the indoor air quality and comfort may be enhanced to reduce the cooling and heating energy consumption of the building.1 In the present study, we developed a system in which louvers are vertically installed in the building[1] envelop and controlled in real time with regard to the wind conditions and the prevailing season.[2] The system can be used to decrease or increase the indoor wind speed by varying the angle of the louvers. We particularly investigated the optimal angle of the wind louvers for achieving indoor comfort.[3]

When indoor air current speed exceeds a particular level, discomfort may be experienced by the occupants. Moreover, in the Korean climatic zone, there are three distinct seasons, namely, winter, summer, and spring/autumn, during which different indoor wind speeds are required for comfort. In the present study, the indoor wind speeds that are suitable for the different seasons were identified, and CFD simulation and analysis were used to determine the angles of the wind louvers for achieving these speeds with respect to the outdoor wind speed. Based on the outdoor wind speed, wind direction, and angle of the wind louvers, 2,888 (19 × 19 × 8) cases were simulated to determine the optimal average indoor wind speed. In addition, a function that can be applied to other climatic zones was derived by an analysis of the correlation between the outdoor and indoor wind speeds and the corresponding angle of the wind louvers for achieving indoor comfort in the Korean climatic zone.

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An example of a device that can be used to manipulate wind flow into a room is the wind catcher, which was used in the ancient Persian region. The device is used to lower underground indoor temperature by catching the wind with a cross-shaped wall at the top of a tower-type building and making it flow into the underground. It is particularly suitable for areas with a hot climate. In modern times, windows or forms of objet that receive wind have been used as wind catchers to improve ventilation performance under winds in specific directions. Moreover, while several studies have been conducted on the use of louvers to control solar radiation in buildings, rarely has the application of the device to wind flow into a room been considered. Because the element that catches the wind is always fixed in such applications, the effect is maximized by moving the actual device based on the prevailing conditions.

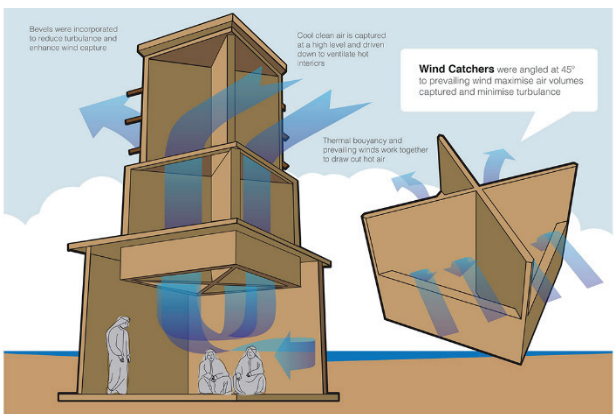

Figure 1. Passive Cooling Using Wind Catchers (Legion in Persia)
Source : http://www.customgreen.com.au

In the field of architectural environment, CFD simulations have been used to some extent in studies on buildings and wind. However, most of the studies considered natural ventilation methods such as cross-ventilation, as well as wind pressure and turbulence in a building or in an urban space. To the best of the authors' knowledge, no study has been found in which CFD simulation was used to investigate the achievement of indoor comfort through wind control. Through an experiment performed on the effect of the window opening position and roof inclination angle on cross-ventilation, J. Peren et al. (2015) confirmed that the roof inclination angle indeed affected the ventilation. H. Montazeri et al. (2013) noted that many studies have focused on the effect of simple external building forms, whereas the balcony of a building also affected the wind pressure and ventilation. T. Choi (2010) used CFD to analyze natural ventilation by wind pressure in a high-rise building using a window that they developed, with the purpose of determining the optimal indoor wind speed. Most previous studies on louvers and wind were conducted by private companies in the fields of machinery, and they mainly focused on the change in the pressure or flow rate. For example, Komastu and Nakanishi (2007) used CFD simulation and an experiment to establish the relationship between the shape of the louver on the front of a car and the wind inflow and pressure.

The objective of the present study was to determine the parameters for achieving indoor comfort by varying the speed of the wind blowing into the room through control of the angle of louvers attached to the building envelop. The study was thus different from previous relevant studies.[4]

2. SIMULATION SETUP

The wind speed required to achieve indoor comfort in each season relative to the outdoor wind speed in the Korean climate was established before the simulation. The 3D model and CFD analysis method were also established.

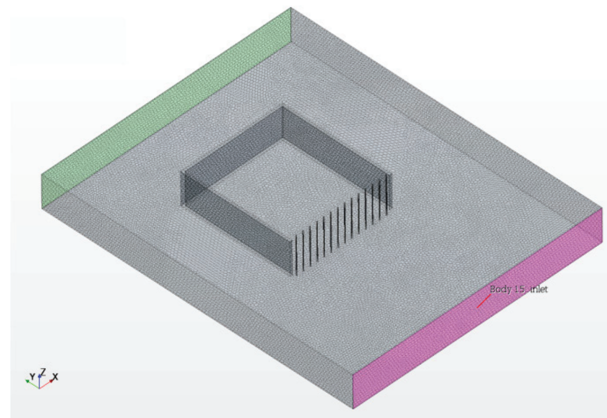

Figure 2. Simulation Model

The outdoor wind speed range for the simulation was set to 1–8 m/s, which had been determined by previous studies to be typical for the Korean climatic zone. The annual mean values of the wind speed and wind direction were calculated for different heights, and based on the wind pressure at each height, could be adjusted using the ASHRAE (2001) standard. Generally, half of the average wind speed for each season is recommended for use in the design of natural ventilation systems.[5] However, in the case of Korea, which has no outdoor wind speed standard for natural ventilation, the wind speed data for Seoul with respect to the height, as corrected by Jun et al. (2010), is used. In the present study, the wind speed for Seoul was calculated using the wind speed correction formula and meteorological data for between 1999 and 2008. By this means, the wind speed at heights between 0 and 50 m was determined to be 3.79 m/s, and that between 450 and 500 m was determined to be 7.18 m/s. A wind speed range of 0–8 m/s was thus used for the present simulation.[6]

The indoor average wind speed for human comfort with respect to the temperature and climatic zone has been determined by different studies, and is available in international standards such as ISO-7730 and ASHRAE. However, such standards, in addition to being concerned with other environmental conditions, sometimes conflict. In the present study, the climate was classified into three seasons, namely, spring/autumn, summer, and winter, and the corresponding optimal indoor wind speeds were set to not more than 0.5, 2.5, and 0.3 m/s, respectively, which are not significantly different from the values specified in the international standards. The minimum wind speed required for humans to perceive the air current and feel comfortable in an indoor space is generally 0.5 m/s at a height of 1.2 m, which is the height at which humans are generally positioned. This wind speed was set for spring/autumn, while a value of 2.5 m/s was set for summer because of the higher ventilation requirements during this season. Whereas it is desirable to cut off drafts or winds that are unusually colder than the room temperature owing to their general unpleasantness, especially in winter, the maintenance of a minimum amount of air inflow is considered desirable. Accordingly, the winter speed wind into the room was set to an average value of 0.3 m/s in this study.

Table 1. Simulation Settings

Area per Module		about 1,000㎡
Size of Model		10m(W)*10m(D)*3m(H)
Range of Wind Louver Angle		10° ~ 180° (10° increments)
Range of Outdoor Wind Direction		10° ~ 180° (10° increments)
Size of Wind Louver		600mm(W)*50mm(D)*3000mm(H)
Indoor Comfort Wind Speed	Spring/ Fall	0.5m/s
	Summer	2.5m/s
	Winter	0.3m/s
Analysis Range of Outdoor Wind Speed		1 ~ 8m/s (1m/s increments)
CFD Model Boundary Setting		Inlet, Outlet, Wall

With regard to the CFD simulation analysis method, a 3D module 1 office building model was developed and a wind-tunnel simulation was performed with the wind louver positioned in the opening. The optimal wind louver angle with respect to the wind direction was investigated. The considered office building had a total floor area of 10,000–20,000 ㎡, 15 stories above the ground, and of an average class in the Korean rental market. The model was developed with reference to the work of Geum (2013). Each floor had an area of about 1,000 ㎡, and, based on nine planar modules, each office module had an area of about 100 ㎡. This excluded the core space at the center, which was 10 m long, 10 m wide, and 3 m high. Both the outdoor wind direction and louver angle were varied between 0° and 180° in steps of 10°. Each wind louver was 50 mm thick, 600 mm long, and 3,000 mm high, and was installed vertically in an opening in front of a unit space.

In developing the CFD environment, the wall was made a slip wall to avoid friction when the wind collides with it. For accurate analysis, the size of the volume lattice was set to 50 mm, which was the length of the short side of the wind louver. The simulation model was developed as a k-ε model. The average speed of the wind blowing into the room, the outdoor wind speed and direction, and at the wind louver angle were all monitored. Table 1 outlines the simulation settings.

3. CHARACTERISTICS OF WIND LOUVER, WIND DIRECTION, AND WIND SPEED

The average outdoor wind speed and direction for each module and the wind louver angle were determined by CFD simulation analysis. Figure 3 shows the indoor average wind speed with respect to the outdoor wind speed for different wind directions and angles of the wind louver. The present analysis revealed that an increase or decrease in the average indoor wind speed was closely associated with the relationship between the outdoor wind direction and the wind louver angle, and that the maximum average indoor wind speed in the closed space depicted by the model was about 1/3 of the outdoor wind speed. It was particularly observed that the average indoor wind speed was higher when the wind louver was opened downwind, contrary to the expectation that more wind would flow into the room when the wind louver was opened to face the wind. The average indoor wind speed when the wind louver was opened frontward with angles ranging between 80° and 100° was found to be similar to that when the wind louver was opened by only about 10°. A diagonal opening of the wind louver was observed to accelerate the wind flowing inwards more than a full opening. Figure 4 shows the variation of the average indoor wind speed with the wind louver angle for an outdoor wind speed of 1 m/s.

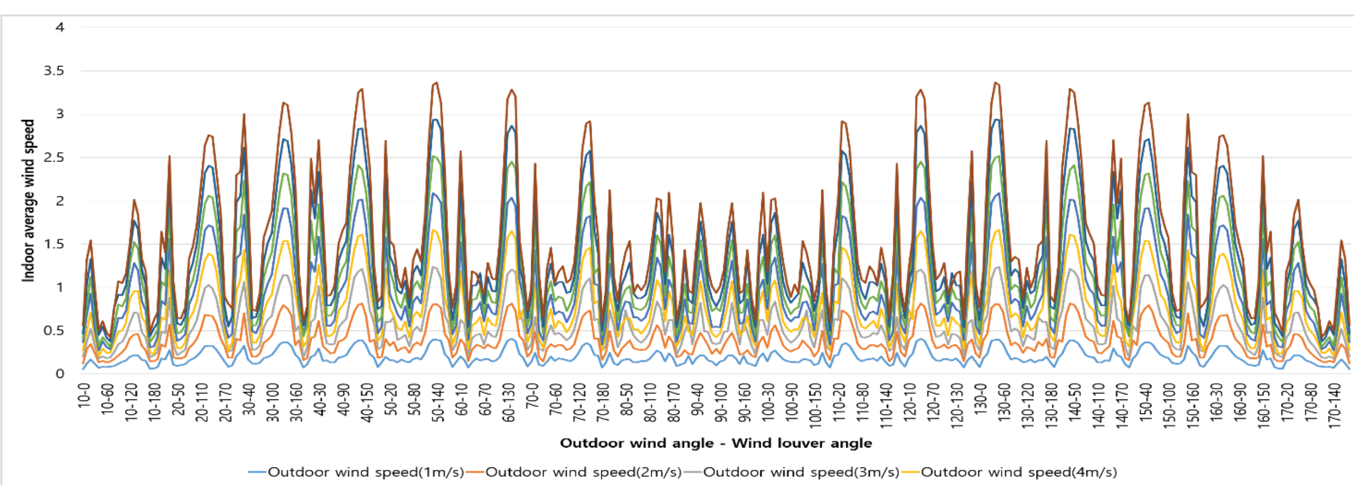

Figure 3. Graph of Indoor Wind Speed by Wind Direction and Angle of Wind Louver by Outdoor Wind Speed

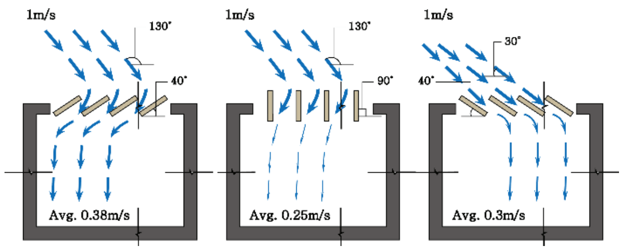

Figure 4. Diagram of Maximum Average Velocity for Each Degree Setting

An examination of the relationship between the wind louver angle between 0° and 90° and the wind direction between 0° and 180° reveals three types of wind flow into the room. To compare the three types of flows, the outdoor wind speed was fixed at 1 m/s, and the change in the average indoor wind speed with the wind direction angle was observed for a given wind louver angle. An analysis of the plotted results show that the highest average indoor wind speed was about 0.3 m/s, taking into consideration that the maximum value of the average indoor wind speed was 1/3 of the outdoor wind speed.

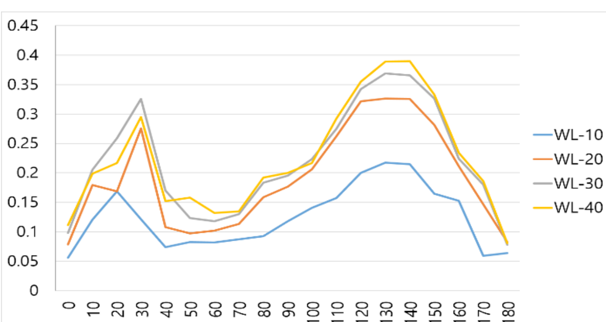

Figure 5. Pattern of Indoor Wind Flow - 1 (Wind Louver 10-40°)

For wind louver angles of 10°–40° (Figure 5), two undulations occur with increasing wind speed, specifically in the short range of 20°–30°. The undulation decreases as the wind speed exceeds this range, and begins to increase again over the wide range of 100°–150°. In the wind louver angle range of 50°–70° (Figure 6), there is one undulation and the speed increases between 110° and 140°, after which it decreases. For wind louver angles between 80° and 90° (Figure 7), the average indoor wind speed is irregular and also relatively low. The indoor wind speed is lowest when the outdoor wind blows in the same direction as the wind louver, or perpendicular to it.

Figure 6. Pattern of Indoor Wind Flow - 2 (Wind Louver 50-70°)

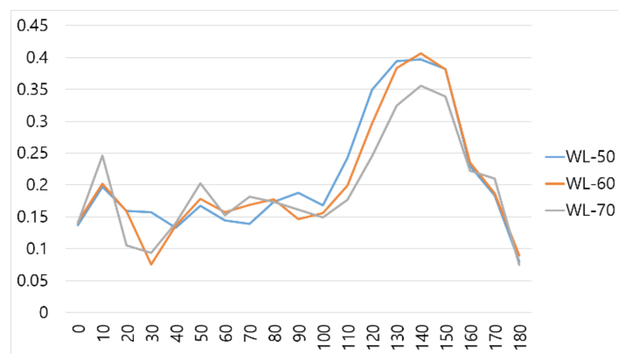

Figure 7. Pattern of Indoor Wind Flow - 3 (Wind Louver 80-90°)

A common feature of the three types of wind flow is that the average indoor wind speed is highest when the angle between the wind direction and the wind louver is about 70°–110°, beyond which the indoor wind speed decreases. The difference between the angle of the wind louver and the wind direction was found to be correlated to the indoor wind speed with a significance level of 0.01 for outdoor wind speeds of 1–8 m/s. Based on this correlation,

Table 2. Correlation of indoor average velocity and outdoor velocity 1~8m/s

	AIWS (OWS=1)	AIWS (OWS=2)	AIWS (OWS=3)	AIWS (OWS=4)	AIWS (OWS=5)	AIWS (OWS=6)	AIWS (OWS=7)	AIWS (OWS=8)
AIWS(OWS=1)	1							
AIWS(OWS=2)	.984**	1						
AIWS(OWS=3)	.976**	.980**	1					
AIWS(OWS=4)	.969**	.974**	.977**	1				
AIWS(OWS=5)	.963**	.968**	.972**	.994**	1			
AIWS(OWS=6)	.958**	.960**	.965**	.987**	.995**	1		
AIWS(OWS=7)	.953**	.953**	.958**	.987**	.992**	.995**	1	
AIWS(OWS=8)	.950**	.950**	.955**	.983**	.990**	.993**	.997**	1

**. Correlation is significant at the 0.01 level (2-tailed).
AIWS : Average of Indoor wind Speed, OWS : Outdoor Wind Speed

the following function that describes the relationship between the outdoor wind speed and the average indoor wind speed was derived:

$$Y_{(x)} = (1.095X - 0.126) \cdot Y_{(1)} - 0.01X - 0.004$$

where X denotes the outdoor wind speed ($2 \leq X \leq 8$), and $Y_{(x)}$ denotes the average indoor wind speed with respect to the outdoor wind speed.

Using the above function, the average indoor wind speed can be predicted based on the outdoor wind speed. The function can also be used to determine the wind speed on a specific floor based on the height of the floor above the ground. From the predicted average indoor wind speed, the angle of the wind louver can be calculated using available, and adjustment can be made to achieve the desired indoor comfort. The wind direction is taken into consideration for this purpose.

4. DETERMINATION OF THE OPTIMIZED WIND LOUVER ANGLE

The angle of the wind louver required to achieve the indoor wind speed necessary for comfort in the Korean climatic zone can be determined using the results of the simulation analysis. The variation of the average indoor wind speed with the outdoor wind speed and direction and the wind louver angle was established using the data presented in the appendix. The data can be applied to other climatic zones.

In this section, we examine the relationship between the wind direction, the average indoor wind speed for the three seasons (0.5 m/s in spring/autumn, 2.5 m/s in summer, and 0.3 m/s in winter), and the wind louver angle. It can be observed from Figure 8 that, while the indoor wind speed in spring/autumn is uniform, it is either high or low in summer and winter. The optimal wind louver angle and wind direction for the average indoor wind speed of 0.5 m/s in spring/autumn is presented in Table 3. The table indicates a tolerance band of 0.5±0.05 m/s and also gives the required change in the wind louver angle for the achievement of indoor comfort when the wind direction changes.

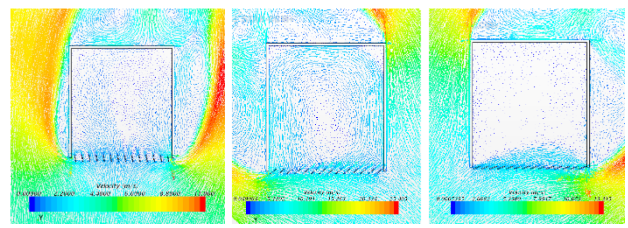

Figure 8. Example Results of Indoor Wind Speed and Direction according to Optimal Wind Louver Angle for Each Season Spring/Fall: Avg. 0.5m/s (Left), Summer: Avg. 2.5m/s (Mid), Winter: Avg. 0.3m/s (Right)

Table 3. Optimization of Wind louver Angle in the Spring/Fall (Outdoor Wind Speed: 4.0m/s)

Outdoor Wind Direction	Angle of Wind Louver																		
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
0							●	●	●										
10		●															●		
20		●								●									
30		●								●									
40						●													
50						●													
60								●											
70				●	●				●										
80									●	●	●	●						●	
90		●						●	●		●	●							
100		●						●	●	●	●								
110											●				●	●			
120												●							
130														●					
140														●					
150										●								●	
160										●									
170																		●	
180											●	●	●						

● : Optimization of Indoor Velocity

Table 4. Maximum Velocity for each Indoor Wind Louver Angle and Outdoor Wind Direction in the Summer (Outdoor Wind Speed: 4.0m/s)

	Angle of Wind Louver																		
Outdoor Wind Direction	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
0								◎											
10						◎													
20				◎															
30													◎						
40													◎						
50														◎					
60															◎				
70															◎				
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100				◎															
110					◎														
120					◎														
130						◎													
140							◎												
150							◎												
160																		◎	
170																◎			
180														◎					

◎ : Maximum Velocity for each Indoor Wind Louver Angle

Table 4 gives the optimal wind louver angle with respect to the wind direction for an average indoor wind speed of 2.5 m/s in summer. However, considering that the maximum average indoor wind speed is only about 1/3 of the outdoor wind speed, the indoor wind speed required for comfort cannot be achieved when the outdoor wind speed is 4 m/s. In this case, the louver angle that maximized the indoor wind speed was calculated. In the case of an outdoor wind speed of 7.0 m/s, the indoor wind speed is sometimes ≥3 m/s, and the optimal range of the louver angle that produces an indoor wind speed of 2.5 m/s is determined. For louver angles that produce insufficient wind speed, the maximum possible wind speed is used as an alternative.

With regard to the winter season, the wind should be made to flow into the room at the minimum speed of 0.3 m/s. The wind louver angle and wind direction for this speed are given in Table 5. The table indicates a tolerance band of 0.3±0.05 m/s and also gives the required change in the wind louver angle for indoor comfort when the wind direction changes. However, as in the case of summer, if the wind louver angle does not fall below the range required to achieve an indoor wind speed of 0.3±0.05 m/s, the angle that produces the minimum wind speed is selected.

The wind louver angle required for indoor comfort can thus be determined as described above. When the minimum or maximum wind speed is desired, such as in winter or summer, respectively, if the indoor wind speed is outside the optimal range, the angle corresponding to the minimum or maximum indoor wind speed should be applied.

5. DISCUSSION OF ANALYSIS RESULTS

This study was based on the idea that the average indoor wind speed impacts human comfort, and that a constant average indoor wind speed can be achieved by installing and adjusting a wind louver with respect to the wind direction. This concept enables real-time variation of the wind speed for maximum effect using minimal energy.

By simulation analysis, we not only confirmed that the use of a wind louver affected the indoor wind speed, but also determined the wind louver angles that maximized and minimized the indoor wind speed. The main finding of the analysis was that the average indoor wind speed decreased to 1/3 of the outdoor wind speed. This is because the considered indoor space was closed with the exception of the opening used to catch the wind.

It was also confirmed that the average indoor wind speed was higher and the wind flow into the room was more stable when the wind louver was opened downwind compared to when it was opened facing the wind. This was particularly so for a wind louver angle of about 90°±20°. In addition, contrary to the expectation, the maximum average indoor wind speed when the wind louver was fully open was lower than that for other angles. The change in the indoor wind speed, which appeared to depend on the opening angle, was correlated and constantly varied with the outdoor wind speed. This enables the accurate prediction of the indoor wind speed and the required wind louver angle using a function that

Table 5. Maximum Velocity for each Indoor Wind Louver Angle and Outdoor Wind Direction in the Summer (Outdoor Wind Speed: 7.0m/s)

Outdoor Wind Direction	Angle of Wind Louver																		
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
0								◎											
10					●	●	●	●											
20				●										●	●				
30			●	●	●							●	●	●	●	●	●		
40												●	●	●	●	●	●		
50												●	●	●	●	●	●		
60														●	●	●	●		
70															●	●			
80																◎			
90																◎			
100				◎															
110				●	●														
120			●	●	●	●													
130			●	●	●	●	●	●											
140			●	●	●	●	●	●											
150			●	●	●	●	●	●							●	●	●		
160					●	●										●			
170												●	●	●	●				
180												◎							

◎ : Maximum Velocity for each Indoor Wind Louver Angle ● : Optimization of Indoor Velocity

describes the relationship between the outdoor and indoor wind speeds.

By the simulation analysis of this study, the indoor wind speeds required for comfort during the different seasons of the Korean climatic zone were determined. The ranges of the wind louver angles that produced these speeds were also determined with respect to the outdoor wind speed and direction. The same method can be applied to other climatic zones using the data presented in the appendix.

The data required for the utilization of the wind louver system presented in this paper are the characteristics of the wind louver and the wind, the equation of the average indoor wind speed, and the optimal louver angle for each season. The wind louver system enables energy saving through the utilization of wind energy to achieve indoor comfort, especially in situations where cross-ventilation is difficult, such as in one-room houses and core-centered office buildings.

However, the present study has some limitations considering that there are other environmental factors that affect indoor comfort apart from the indoor wind speed. Indeed, it is difficult to ensure perfect indoor comfort by only adjusting the wind speed without considering other factors such as humidity and temperature. In addition, the relationship between the wind direction and the wind louver angle obtained in this study was based on the average indoor wind speed. In reality, the wind speeds at local parts of an enclosed space differ.

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ENDNOTES

1 Relative humidity, air temperature, air speed, radiant temperature, clothing insulation, and metabolic rate are the six thermal environment factors of the Predicted Mean Vote (PMV) of P.O. Fanger (Denmark, 1970) that generally determine indoor comfort. However, this study considers only indoor air speed.

2 The louvers used to control wind flow into the room are referred to as "wind louvers in this paper."

3 Although people tend to believe that more comfort is achieved when the window is completely open than when a wind louver is installed, a wind that blows from an adverse direction can be made to flow into the room by the installation of a wind louver. In addition, comfort can be achieved in some cases by using a louver to reduce the wind speed.

4 Several studies have been conducted on human comfort. For example, V. Orgay reported that, to establish a pleasant environment in a building, harmony with the surrounding environment should first be ensured. Secondly, comfort should be secured through the design of the building. Thirdly, a pleasant environment should be maintained with minimum energy consumption. The present study particularly considered the maintenance of comfort by controlling the flow of wind into a room through the installation of a wind louver.

5 The relationship between the wind pressure Pv and the wind speed at a given height, UH, can be determined by Bernoulli's principle as follows: $P_v = 0.5P_a U_H^2$

6 For correction of the wind speed using the Deacon equation, we referred to the work of Jun et al.. The wind speeds over a height range of 0–500 m were classified in 50-m intervals. In addition, the wind pressure difference generated by the wind was calculated using the Bernoulli equation, and was defined by the wind pressure coefficient as in the following formula of building surface pressure difference: $\Delta P_s = C_p \cdot \Delta P_v = C_p \cdot \frac{P_a U_H^2}{2}$, where ΔP_s is the surface pressure difference [pa], C_p is the wind pressure coefficient, ΔP_v is the wind pressure difference [pa] , and U_H is the wind speed [m/s] at height H.

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