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Control Mechanism and the Energy Performance of an Integrated Kinetic Façade System

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***Abstract*—This study is to suggest a kinetic shading system that can convert its formation and function intelligently according to the altitude of the sun. The proposed system works as an integrated light shelf in case the sun is positioned at high altitude and changes the form into a vertical louver to block direct sunlight when the sun is getting lower. Through this process, this system may increase the uniformity ratio of indoor space and decreases an indoor radiation causing cooling loads. The suggested shading system changes the function in respondent to exterior environment accordingly. Such a system, however, has various technical factors and is currently being utilized in some advancing countries only. For this study, a working prototype of a kinetic shading system has been suggested, and a series of mock-up experiments and simulation analyses have been performed for certifying its adaptability and practicability to the professions. In conclusion, it has been turned out that the proposed system has improved capabilities in aspects of both energy efficiency and spatial comfort, and the result of the study could successfully been patented for the working mechanism associated with integrative methods towards advanced building envelope technologies.**

***Keywords*—kinetic façade, integrative envelope, working prototype, light shelf, energy simulation**

I. Introduction

Energy shortage has been recognized as a major problem around the world. In architectural point view, energy used for building operation has occupied 40 percent of the total energy consumption, and especially lighting and air conditioning are being taken for approximately 50 percent of the total building energy consumption (Yoon, 2006); those are normally associated with a façade system and closely related with indoor illumination and cooling loads. So, it is necessary for investigating how to reduce energy consumption from the above two parts causing great amount of losses in the whole building energy usage. This paper presents an integrative method with a kinetic shading system not only to decrease building energy consumption and improve spatial comfort as well.

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This paper aims at proposing an adaptable shading system that can change its formation and function according to the position of the sun. The proposed system works as light shelf and vertical louver time to time and makes it possible for people to customize the indoor environment in aspect of spatial comfort. Also it contributes to save energies by blocking direct sunlight and getting natural light flown into the indoor space. This point of view is presented by the following process; first, the limits of conventional shading systems used for the present field are examined; second, a step by step design process applied with kinetic mechanism are suggested; finally, the proposed system is testified through mock-up experiments and simulation analyses. A series of sensors have been utilized for monitoring mock-up conditions such as temperature, humidity, ambient light and so on.

This procedure enables to verify the environmental impact of the system for indoor space. Solar radiation and daylighting ratio can be compared through combined use of a few simulation programs including Ecotect and Project Vasari based on the preliminary experiments. This paper, then, investigates the applicability of the suggested kinetic shading system responding to the external environment.

II. Research Background and Basic Theories

Shading system is an element for controlling the solar radiation to adjust an indoor environment. This component is normally fixed on the wall and unable to control the solar radiation effectively. In addition, a fixed vertical louver interferes for the outside views. So, a type of moveable louver seems available to be activated for the building façade in order to resolve mentioned problems.

On the other hand, a light shelf is an architectural element which allows the daylight to penetrate into the indoor space as deep as possible and blocks the direct sunlight to prevent a glare. This type of the shading system has been proven to decrease the artificial lighting consumption quite much. Thus, it improves the visual comfort to occupants, and may reduce cooling loads by blocking the direct sunlight.

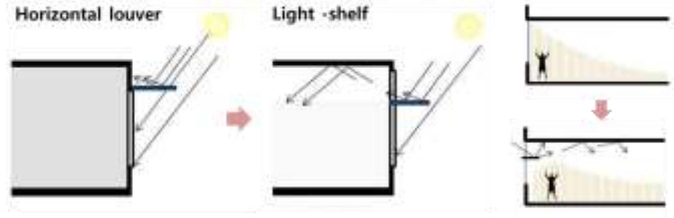


Figure 1. Comparison of horizontal louver and light shelf

As an advanced type of shading system, kinetic façade system is an active control system for making better indoor environmental condition by changing its function according to the exterior surroundings. This system is designed to move partial components for responding to environmental changes outside. Recently, practical implementations of the kinetic system are being realized with advanced technologies in mechanics, electronics and robotics, while those still have considerable problems in aspects of production and maintenance costs, because they require tight collaborations among various fields.

TABLE I. CASES FOR KINETIC FAÇADE SYSTEM

Case	Performance and Effectiveness
 GSW Headquarters, Germany	-Vertical louver angle adjustment through detection of solar light -double skin façade -Natural ventilation -50% energy saving
 ThyssenKrupp Quarter, Germany	-Solar radiation controller applying venetian blind -Angle adjustment form 0˚ to 90˚
 Kiefer Technique Showroom, Austria	-Lighting flow adjustment depending on the using intention -Opening and closing by rolling the frame
 Helio Trace, USA	-AIA R&D Award -80% reduction in the amount of solar radiation

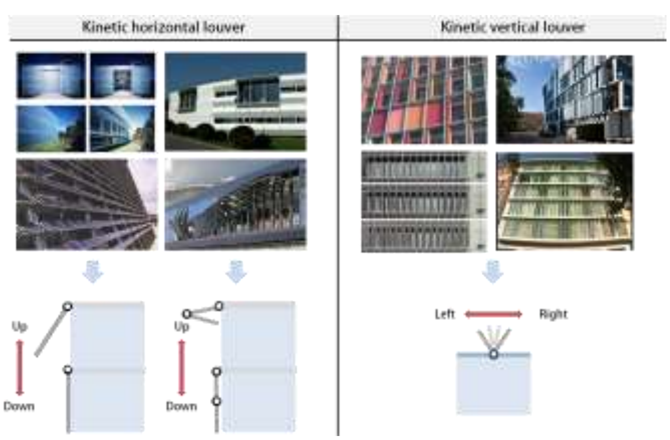


Figure 2. Conceptual diagrams for major mechanism of kinetic façade system

As shown on Table I, the mechanism of the kinetic façade system can be classified into two major types: horizontal and vertical. Although some of the kinetic façade systems are implemented in complex form, they have certain advantages in both economic feasibility and implementation flexibility. Figure 2 shows diagrams for the mechanism including its moving direction and method, and more effective operations can be carried out by combined use of those kinds of movements.

III. Design Process of the Proposed System and Implementation of a Working Prototype

This study proposes a working prototype of the modular system applied with integrative functions of vertical louver and light shelf. The suggested system can change the functions by the position of the sun. This unique combination has the distinction from the existing kinetic façade systems.

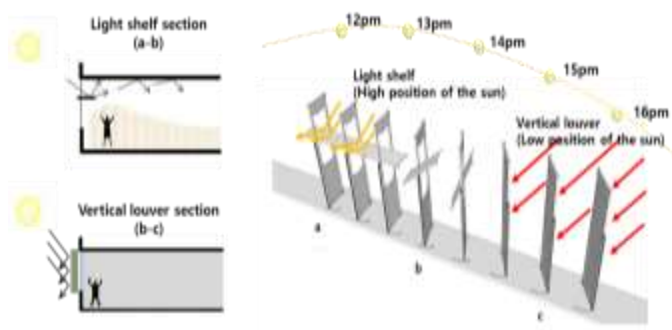
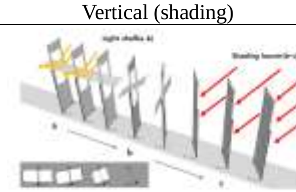
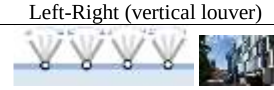


Figure 3. Transformation procedure of the proposed prototype

Two comparative functions such as penetrating natural daylight and blocking the solar radiation are embodied and optimized into the system, and the proposed mechanism has provided to support relatively enhanced environmental controls.

TABLE II. COMPARISON OF MECHANISMS FOR MAJOR SHADING SYSTEMS

Existing Shading Mechanism	Proposed Shading Mechanism
Open-Close (horizontal louver)	Horizontal (light shelf)-Vertical (shading)
	
Left-Right (vertical louver)	
	
Blocking direct sunlight-According to the sun's position	Horizontal (Using sunlight)-Penetrating natural light into indoor Vertical (Blocking sunlight)-Blocking the side direct sunlight

The design process shown on Figure 4 has been conducted to implement the suggested working prototype. The first step is for determining the formation of the main frame. Then, the second step is to consider the height of the light shelf and the width of its main frame. The third step is to arrange the frame unit and to remove conflict parts when rotating the frame. And, the last step is for configuring the mechanism to convert the formation to proper combination of the components.

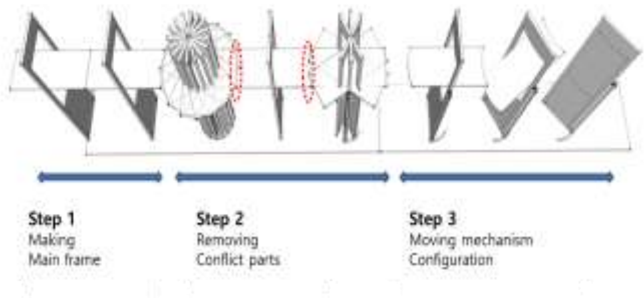


Figure 4. Design process of the proposed prototype

This system should meet the requirements for both fundamental mechanisms accordingly to execute expected performance successfully. First, a light shelf needs the appropriate width and the reflectivity. To calculate the width of the shelf, the extension line should be considered from bottom of the window up to the position of the sun in summer. The angle decided by two elements is normally set as 20 to 25 degrees. And the light shelf is placed above the eye-level. In case of a vertical louver, it can be rotated to any direction for blocking direct sunlight from the east or the west side.

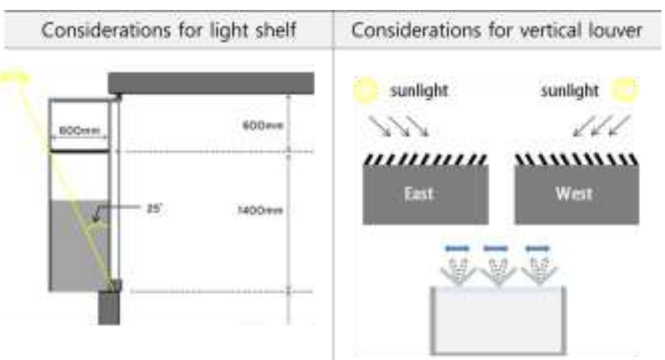


Figure 5. Overall system configuration

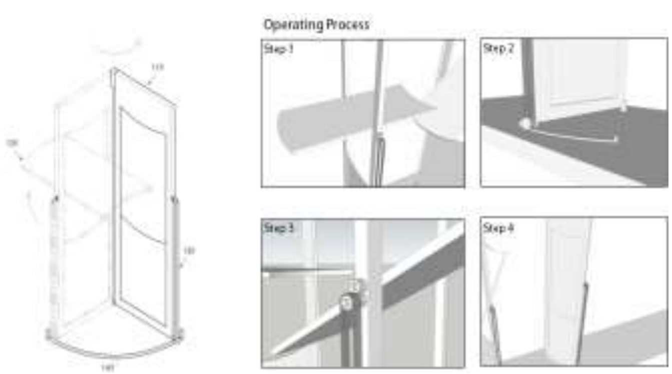


Figure 6. Working steps of the proposed system

Figure 6 shows the operation phases form the formation of the light shelf (Step 1) to the configuration of the vertical louver (Step 4). Main frame of the system is moved along the rotation axis when the altitude of the sun is changed from high to low. The movement of the rail makes the light shelf to be changed into the vertical louver, and so it is important for the movement to apply exactly how many times the gears rotate. It should be considered from the time this system is installed on the façade of the building.

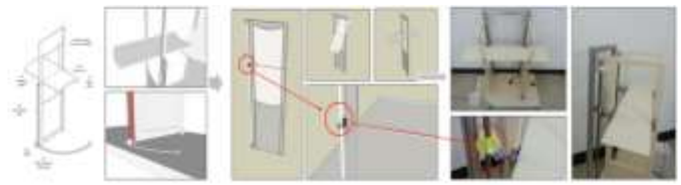


Figure 7. Improvement process of the suggested mechanism

Figure 7 demonstrates the improvement process of the small-scale mock-up as a working prototype. The initial alternative model was designed to be moved by a timing belt which connects the main frame to the gears of the light shelf. It causes, however, some problems in aspects of the durability and the simplicity of the structure. This is because the timing belt can be easily worn out and the complex structure tends to be malfunctioned easily. So the mechanism of the system was required some improvements.

Figure 8. Consecutive operations of the fabricated prototype

IV. Performance of the Proposed System

The next step is to evaluate the impact and the effectiveness of the proposed system for the indoor environment by experiments with the fabricated mock-up. Table III shows fundamental data setting for operating experiments like scale, location, test period, used sensors, materials of the prototype and so on.

TABLE III. CASES FOR KINETIC FAÇADE SYSTEM

Division	Contents			Remarks
Location	Longitude : 126.9˚, latitude : 35.1˚			
Test period	Nov 5, 2013 ~ Nov 11. 2013			
Mock-up size	1000mm x1400mm x 900mm			Picture attached
Used materials	Window	Color	Clear glass	6mm flat glass
		Heat transmission coefficient	5.1	
		Shading coefficient	0.8	
	Outer wall	Thickness (MDF:8mm*2/styrofoam:100mm)	116 mm	Picture attached
Used sensor	Illuminance sensor			Picture attached
	Temps sensor			

As shown on Figure 9, two mock-ups have been installed as the same scale to perform comparative analyses for the performance of the proposed system. The one has the suggested kinetic shading system on the front of the façade. And the other has an ordinary window module without any installation. Temperature and illuminance sensors are placed on the bottom of the mock-ups to monitor the change of the indoor environment. Then, obtained data are collected and sent to MS-SQL solution for analyses.

Figure 9. Mock-up and sensor settings for performance analyses

Figure 10 shows the distribution of the hourly illumination. The red line on the graph indicates the basic mock-up and the blue line presents the other mock-up with installation of the kinetic shading system. Green line means the external environmental changes. The left graph indicates the illumination on the front surface of the mock-up and the right shows that of the back face. First, it is turned out that illumination of the basic mock-up (A) is higher than the prototype of the kinetic system (B) in terms of the front-side illumination distribution.

This is because excessive solar radiation is absorbed in basic model without any shading device. It generates severe glare to occupants and this eventually reduces the visual comfort. In addition, excessive solar radiation causes cooling loads. However, the proposed system indicates better condition because it can be functioned both as a light shelf and a horizontal louver simultaneously. On the other hand, as shown on the right graph, both mock-ups show similar patterns in terms of temperature, and it means that uniformity ratio of the kinetic system can be improved by controlling external sunlight.

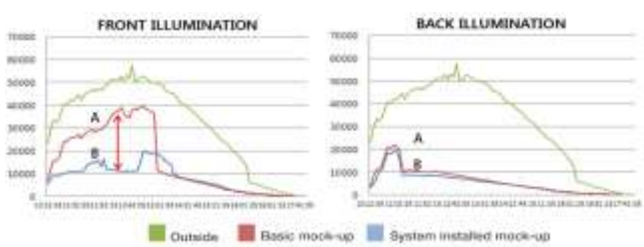


Figure 10. Analysis for hourly illumination

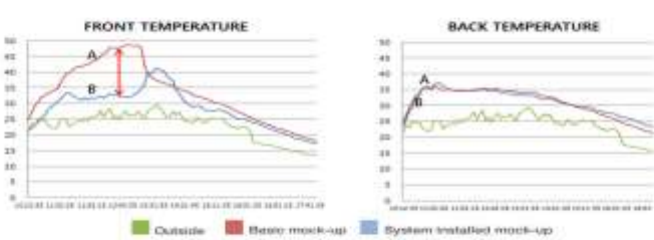
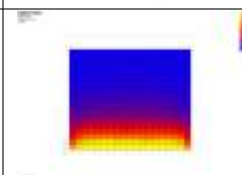
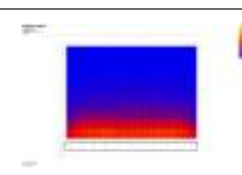
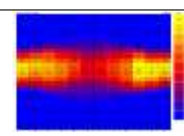
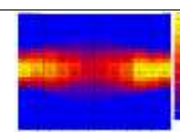


Figure 11. Analysis for hourly temperature

Figure 11 shows the distribution of the hourly temperature. As a preset condition, it is assumed that the indoor temperature is higher than outside, because there is no any ventilation device installed in the mock-ups and radiant heat absorbed into the indoor space could not be released to the outside. Basic mock-up (A) absorbs the outside sunlight without any shading system, so the indoor temperature became very high; this will cause great amount of cooling loads, especially in summer. But the other mock-up shows lower temperature than the previous case, because the proposed system can be functioned as a louver when needed. These results tell that the kinetic shading system could possibly provide significantly positive effects for two mentioned points of views.

TABLE IV. RESULTS IN SIMULATION ANALYSES

Division	Contents	
Mock-up size	W:12,000mm D:7,000mm h:3,2000mm	
Opening size	W:11,600mm H:2000mm	
Indoor reflectivity	Ceiling : 74.99% Wall:55% Floor:25.1%	
Lightshelf	Reflectivity:80% Width : 600mm	
Weather data	Gwang-ju(longitude:126.9˚, latitude:35.1˚)	
Orientation	Southward	
External illumination	8000 lux (overcast)	
Simulation Results		
	Basic mock-up	System installed mock-up
Model information		
Daylight rate		
	10.50%	8.33%
Solar radiation		
	$799,150 wh/m^2$	$650,530 wh/m^2$

Simulation results shown on Table IV indicate that the mock-up installed with the kinetic façade has better capabilities of controlling indoor environment than the basic formation in aspects of both daylight rate and solar radiation. More specifically, it will be able to find more concrete information when comparing the amount of energy consumption in various conditions as monthly, seasonal and annual usages; this part remains as a future study.

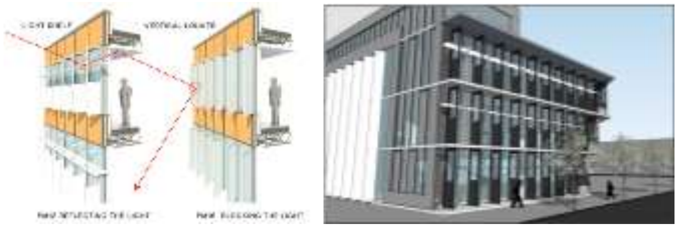


Figure 12. Application for the Prototype to the Building Façade

V. Conclusion

This study proposed a kinetic shading system that can control its formation and function along the position of the sun. It was turned out that the suggested system would improve weaknesses found from the existing systems through a unique mechanism.

A series of experiments were performed to demonstrate the effectiveness of the system, and they were divided into two main parts: making a small-scale working prototype as mock-up used for verification for performance of the system and examining its effectiveness by using two comparative mock-ups with the same basic configuration. Through this process, this study could verify the performance of this shading system, and especially, it was recognized that uniformity ratio could be improved and excessive solar radiation decreased by the system.

Based on simulation results, this study has concluded that the proposed system definitely has adaptability to the AEC (Architecture, Engineering and Construction) professions and positively shows practicability as advanced integrative building envelopes with renewable energy association.

Acknowledgment

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