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Energy Sustainability of an Integrative Kinetic Light Shelf Unit

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ABSTRACT

Purpose: Suggesting a working prototype of a kinetic light shelf unit and revealing its energy efficiency by a series of building performance simulations were presented. Recently, kinetic building envelope has been an emerging technology as an innovative way to control exterior building environment, but products from many researches about the façade could not been reached to the industrialization so far. That is because its initial installation, operation and maintenance costs are still too high to use for the practical field, although buildings using kinetic envelopes could decrease their energy consumption significantly. This narrow point of view needs to be reconsidered, since buildings require great amount of energies to run their functions through the whole life and using better building components can lead to achieve much more benefits in aspects of the lifecycle cost (LCC). **Method:** A series of certified simulation tools like Ecotect and Green Building Studio that are normally used for researches and developments in the field of architecture were utilized. **Result:** Based on simulation analyses, the result of the study has showed that the proposed system definitely has adaptability to the professions and positively shows practicability as advanced integrative building envelopes with renewable energy association.

KEYWORD

Kinetic Envelope
Building Façade
Building Information Modeling
Energy Simulation
Sustainability

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1. Introduction

The issue of energy sustainability is one of the biggest concerns in the field of architecture, engineering and construction (AEC) these days, and many researches and developments are handling innovative processes and methods to decrease energy consumption using in buildings. Buildings, in fact, are using about forty percent of the entire energies consumed in the Earth, and especially eighty percent of the total amount is needed for building maintenance and fifty six percent occupies for operating lighting, heating and cooling. In other words, applicable suggestions in the architectural field could help resolve problems mentioned above. [1]

Building energies used for utilities such as heating, ventilation and air-conditioning (HVAC) and lighting are deeply related to the envelope system that causes severe energy loss depending on its configuration. For example, there is not only a sort of conventional method to compose the façade like either horizontal or vertical louver, but also an integrated way to cover multiple functions such as light shelves. [2] Light shelf is especially known as one of efficient eco-friendly lighting technologies. Furthermore, building design including light shelf is acceptable for the Leadership in Energy & Environmental Design (LEED).

Currently, further innovated envelope systems have been suggested, and one of the representative instances is the kinetic façade that is added to the above basic components and motorized to operate them by programmed logics. [3] In this sense, this paper proposes a prototype of the kinetic envelopes derived from existing standard formations, examines the mechanism and analyzes its building energy performance in comparison to the previous cases.

This study aims to investigate a new kind of the kinetic building envelope operated along the path of the Sun and to reveal its energy efficiency through relevant analyses. The process to achieve the goal is as follows; first, conventional fixed-louver types are reviewed through previous studies, second, an integrated kinetic envelope system is proposed and its configuration is assumed as a motorized type added to the conventional specimen, third, the most suitable method for simulation analyses is selected with comparing normal tools used currently, and finally, required simulations for the suggested envelope are performed in comparison to the conventional cases.

Through this study, it is expected to examine a possible resolution to reform fundamental functions of building envelopes, adaptability to the façade design, energy efficiencies through the lifecycle by comparative analyses, and so on.

2. Settings and Procedures

2.1. Classification of the Shading Devices

Shading device is an important building component to prevent

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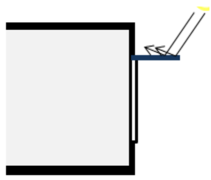
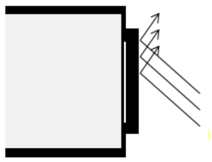
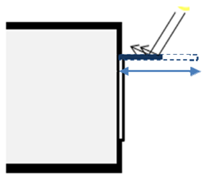
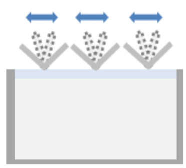
direct insolation from the outside, decrease heating and cooling loads, and make comfort indoor environment by controlling natural lights and air flows. The type of the device is various for those reasons, and there are own characteristics depending on the operation mechanism that makes possible to get energy consumption down. [4] Table 1 shows the comparison between the fixed shading devices and the motorized kinetic components.

Table 1. Classification of enveloped by shading devices

Category		Mechanism	Characteristics
Fixed	Horizontal		- Prevents the insolation at the time with the highest temperature - Suitable for the south direction
	Vertical		- Prevents the low Sun in the early morning or the late evening - Suitable for either the east or the west direction
Kinetic	Horizontal		- Controls the amount of insolation by length of horizontal louvers
	Vertical		- Controls the amount of insolation by movement of vertical louvers

2.2. Kinetic Light Shelf Unit

The light shelf system has two major functions; it can reflect light deeper into interior space and block the direct light as well. When the reflected light on light shelf comes into the deeper interior space, the lighting energy will be decreased during a day time. Moreover, the solar radiation will be blocked by the light shelf as a shading device. These two functions are deeply related to the use of energy. [5]

For this reason, this proposed device is considered as a promising and practical skill. But this device is significantly affected by the altitude and motion of the sun, so it may have a limitation about the range of use. Accordingly, the purpose of this study aims at suggesting a kinetic light shelf makes the functions to be formed according to the altitude of the sun.

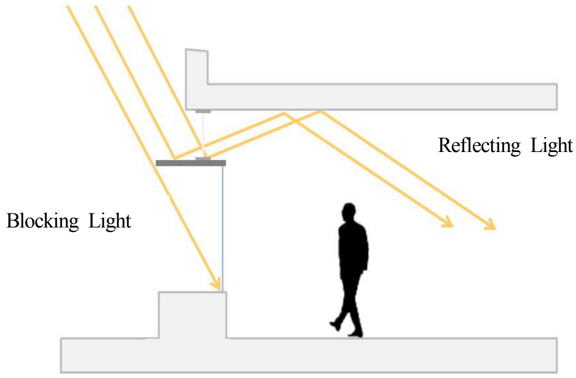


Fig. 1 Concept and function of the light shelf

In order to the function shown on Fig. 1, the position of the sun should be located between 11 AM and 1 PM (See Fig. 2). This is because the light generated from the higher altitude of the sun can be reflected by light shelf. But when the sun set down into the ground, this function of light shelf will become dwindle. [6] And the sunlight that penetrate window will have an impact on the indoor environment.

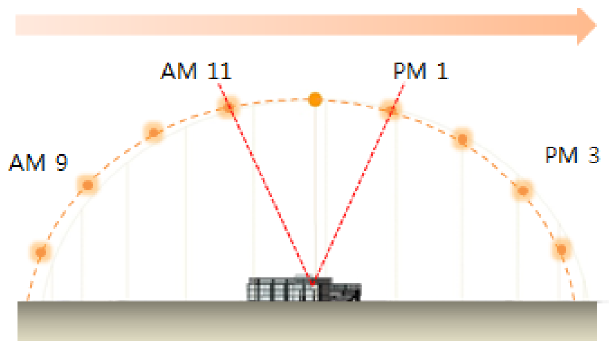


Fig. 2 Performance section of light shelf

The most important feature of the kinetic light shelf unit is possible to adjust in the altitude of the sun. When the sun is located between a and b including meridian transit altitude (lower-left corner), the kinetic light shelf unit works as a light shelf. Through this a to b course, indoor space can get the natural light reflected by surface of the light shelf.

The surface of the shelf is covered with high reflectance material. And when the sun is located between b and c (red part, lower-left corner), the kinetic light shelf unit operates as a vertical louver to block out the direct light. Two types of the function are shown on Fig. 3 which represents the changing course from horizontal (light shelf) to vertical (louver). Like this, the kinetic light shelf unit can be changed light shelf into vertical louver and it works to fit in each situation. [7]

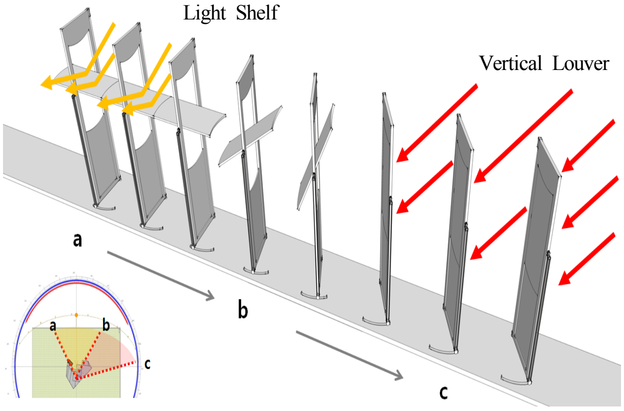


Fig. 3 Exemplar prototype of the kinetic light shelf unit

This unit should meet the requirements for both fundamental mechanisms accordingly to execute expected performance successfully. First, a light shelf needs the appropriate width and the reflectance. 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.

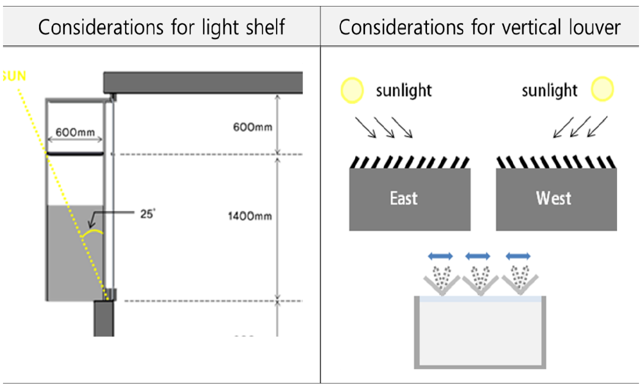


Fig. 4 Overall system configuration

2.3. Selection of Simulation Tool

This section is to discuss the procedure of selecting simulation tools to analyze the sustainability of the suggested façade system on the basis of comparative investigations.

EnergyPlus, first of all, provides a precise way to analyze indoor and/or exterior environmental factors in detail. But, this tool also has disadvantages that data input process requires complicated professional skills, additional modeling tool and converter are needed since its interface doesn't allow to make a target model for itself, and the analysis process takes long relatively. [8] Project Vasari uses DOE-2 analysis engine provided by the Department of Energy in the U. S., and produces pretty exact simulation results by loading the parameters defined in the ASHRAE (Standard supported by American Society of Heating, Refrigerating and Air-conditioning Engineers). In addition, this tool can easily be linked with Green Building Studio (GBS) and provides a well-organized analysis report about the energy performance. But, this method also has a shortcoming that analyses for specific time periods are not easy, because it takes a given broad range for input parameters instead of the modifiable input by users. [9]

Ecotect is being developed by Autodesk. This simulator can predict results for environmental settings simply and make data individually per experiment. This program also can estimate various elements such as radiation from the sun, natural lighting, air flow, heating, shade and shadow, building heating and cooling load, and so on, from the pre-design phase to the design development process for designers. The weather tool and the solar tool are also provided by Ecotect, and make possible to interpret weather situation and solar movement for the loaded building model. Analysis data generated by this tool can easily be exported to various formats for interlocking with more applications. [10]

For this study, Ecotect and GBS are selected for simulation to compare indoor environment and energy efficiency of the target buildings.

2.4. Scope and Detail Levels

Since there are no specified guidelines about detail levels of building models for performance evaluation, Level Of Development (LOD) 100 suggested by American Institute of Architects (AIA) has been used for modeling in this study. LOD 100 is known as an equivalent level of the conceptual design in Korea that volume of the building mass and the building type are defined and overall modeling process is established with fundamental building parameters such as area, height, volume, place, axis and so on. [11] In addition, this detail level determines not only a type of the project procurement as suggested by Integrated Project Delivery (IPD) and an initial step for design process with Building Information Modeling (BIM) as well; The AIA documentation, E202TM-2008, includes all the steps of the IPD design process and their detail levels towards BIM. [12]

This study has utilized LOD 100, because the target for the performance evaluation is not for building equipment and utilities, but for building façade as an architectural component. [13] Then, building performance focused on environmental and energy factors would be reviewed with a few alternatives of building skins chosen from both general curtain walls and kinetic façade components for comparison.

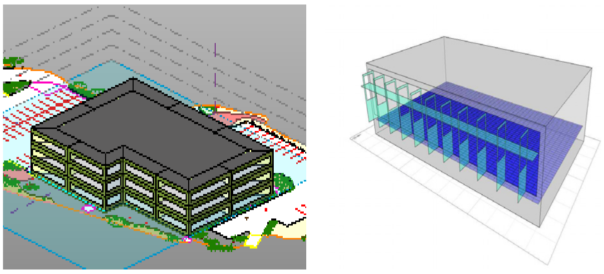
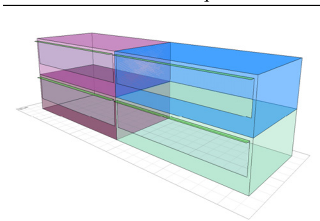
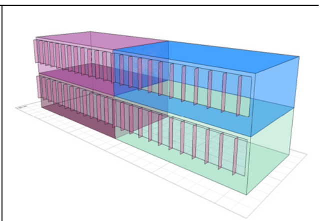
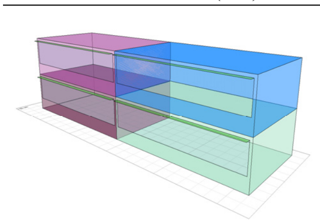
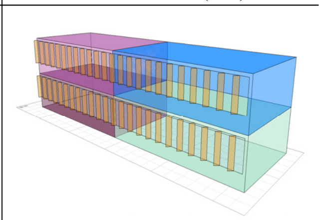


Fig. 5 Building model for simulation on LOD 100

2.5. Data Type

Simulation data can be categorized with four types such as general/fixed horizontal, general/fixed vertical, kinetic horizontal and kinetic vertical, and this study performs analyses for insolation, illuminance, radiation, and heating & cooling loads for each of those. [14] The fundamental simulation settings are described in Table 2.

Table 2. Outlines of simulation settings

Category	Contents
Unit Size	Four unit set (1 unit=W: 12,000mm, D: 7,000mm, H: 3,200mm)
Opening Size	W: 11,600mm, H: 2,000mm
Indoor Reflection Rate	Ceiling : 74.99%, Wall : 55%, Floor : 25.1%
Weather Data	Gwangju (Latitude: 35.1°N, Longitude: 126.8°E)
Orientation	South
Comparative Models for Simulations	
	
Fixed Horizontal (F-H)	Fixed Vertical (F-V)
	
Kinetic Horizontal (K-H) - Controlling the length of the louver every hour	Kinetic Vertical (K-V) - Controlling the angle of the louver every hour

3. Analyses for the Sustainability

3.1. Comparative Analyses with Kinetic Envelopes

Simulation analyses for four different types performed in this study include the effectiveness from the Sun, such as insolation, illuminance, radiation, and heating & cooling loads. The step-by-step simulations has measured the amount of energy gained through windows to conclude the insolation and the radiation first, and then monthly energy consumptions to maintain the indoor comfort have been examined for heating and cooling requirements. The simulation results have been summarized in Table 3 through Table 5.

Table 3. Radiation simulation result (Wh/m^2)

Category		Summer			Winter		
		Total	Direct	Diffuse	Total	Direct	Diffuse
F	H	5785098	2051243	3733852	10041021	7136692	2904320
	V	6645815	2940824	3704983	10696276	7814398	2881868
K	H	7207136	2962084	4245053	11348611	8056822	3291796
	V	6253155	2643482	3609671	9360611	6562107	2798501

Table 4. Heating and cooling loads

Category		Monthly Load					
		Month	Heating Load (Wh)	Cooling Load (Wh)	Month	Heating Load (Wh)	Cooling Load (Wh)
F	H	Jan	2224659	0	Jul	0	265625
		Feb	1723834	0	Aug	0	351754
		Mar	981021	0	Sep	0	0
		Apr	401727	0	Oct	159068	0
		May	70607	0	Nov	947441	0
		Jun	0	0	Dec	1826501	0
		SUM	8952237				
	V	Jan	2224884	0	Jul	0	265427
		Feb	1724083	0	Aug	0	351499
		Mar	981317	0	Sep	0	0
		Apr	401912	0	Oct	159160	0
		May	70657	0	Nov	947674	0
		Jun	0	0	Dec	1826728	0
		SUM	8953341				
K	H	Jan	2224884	0	Jul	0	265499
		Feb	1724083	0	Aug	0	351558
		Mar	981317	0	Sep	0	0
		Apr	401912	0	Oct	159153	0
		May	70657	0	Nov	947584	0
		Jun	0	0	Dec	1826584	0
		SUM	8952846				
	V	Jan	2224480	0	Jul	0	265788
		Feb	1723643	0	Aug	0	351951
		Mar	980803	0	Sep	0	0
		Apr	401589	0	Oct	159007	0
		May	70567	0	Nov	947279	0
		Jun	0	0	Dec	1826328	0
		SUM	8951435				

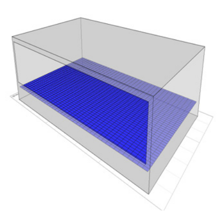
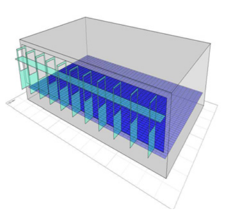
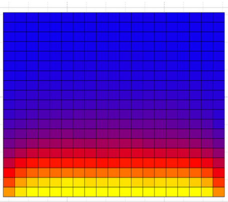
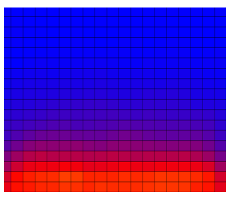
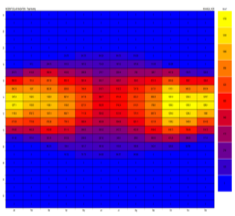
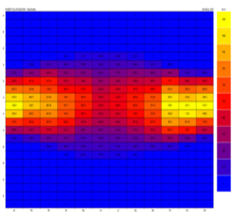
Table 5. Cumulative sunlight hour (h)

Category		Summer	Winter
F	H	33135.949	53377.715
	V	43761.484	56102.477
K	H	43242.611	60480.75
	V	39774.372	47479.583

3.2. Analyses for the Proposed Unit

Two models have been made to perform comparative analyses for the performance of the proposed unit. The one has the suggested kinetic light shelf unit on the front of the façade. And the other has an ordinary window module without any installation. The same simulation processes have been performed for those models.

Table 6. Results in simulation for the kinetic light shelf unit

Category	Contents	
Model Specification	W:12,000mm D:7,000mm H:3,200mm	
Opening size	W: 11,600mm, H: 2,000mm	
Indoor Reflectance	Ceiling : 74.99%, Wall : 55%, Floor : 25.1%	
Light Shelf	Reflectance:80% Width : 600mm	
Weather data	Gwangju (Latitude: 35.1°N, Longitude: 126.8°E)	
Orientation	Southward	
External Illumination	8000 lux (overcast)	
Simulation Results		
	Basic	Kinetic
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 6 indicate that the model installed with the kinetic light shelf unit 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.

4. Conclusion

This study has executed major analyses for the building energy performance applied with the kinetic envelopes comparatively. Through this process, this study could also verify the performance of a working prototype of the kinetic light shelf unit as an advanced intelligent shading device, and especially, it was recognized that uniformity ratio could be improved and excessive solar radiation decreased by the unit. Autodesk Ecotect and GBS were utilized for energy simulations and findings from those can be summarized as follows;

First, both types of kinetic envelopes including the proposed light shelf unit took less heat gains regardless of the season than any type of fixed façade systems. The horizontal envelope gained less insolation than the vertical type of the façade.

Second, the horizontal kinetic façade guaranteed the most illuminance in aspect of the time period. But, the type of vertical kinetic shows lacks of iluminance period in comparison to both fixed-envelope types.

Third, the above results were used for finding relationships to the energy performance; the horizontal kinetic façade achieves more insolation and illuminance than other types, and there was no such difference in aspects of heating and cooling loads; on the other hand, vertical kinetic envelope showed less insolation and illuminance, but it could save 1,906 Wh of the electrical energy.

In sum, kinetic façades as the proposed unit took benefits or broke disadvantages selectively, and it is assumed that kinetic type of envelope has a more controllability for the Sun. Furthermore, the most effective combination between horizontal and vertical kinetic algorithms could be found by a variety of simulation analyses.

This study has proved the energy sustainability of the kinetic envelope and its applicability as a building envelope. It could be possible that building energy performance would be much better, if the kinetic envelopes can be moved with intelligently motorized logic and operated perfectly with the certified program that is responsive to solar movement.

Based on simulation results, this study has concluded that the proposed system definitely has adaptability to the AEC professions and positively shows practicability as advanced integrative building envelopes with renewable energy association. The integrative way with more innovative mechanism such as the renewable energy technologies can suggest more productive alternative to optimize the architectural environment, and it remains as ongoing research.

Acknowledgements

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