An Adaptive Facade Configuration for Daylighting Toward Energy-Efficient: Case Study on High-Rise Office Building in HCMC

Van Tung Nguyen, Thi Hong Na Le, Hung Tien Le, and Phan Bao Long Nguyen

Abstract Natural daylight within buildings is one of the solutions to effectively reduce energy consumption in high-rise office buildings (HOB). The management of natural lighting depends largely on the characteristics of the building envelope (BE) in the building, especially the facade system. Adaptive facade (AF) is one of the solutions in the BE system of the building that helps to solve numerous problems in energy-efficiency and in particular, the balance of natural lighting. In this research, it is proposed that a kinematic AF system integrated onto the single-layer glass facade structure be implemented in HOBs in Ho Chi Minh City (HCMC), through the study of the typical case being the LIM Tower office building located in central HCMC. The kinetic AF system is integrated in order to improve the quality of natural lighting through 3 statistics: Annual Sunlight Exposure (ASE), spatial Daylight Autonomy (sDA), and Daylight Factor (DF). Results from simulations utilizing Rhinoceros-Grasshopper software (Computer-Aid Design) and Climate Studio plugin show that the AF phenotypes significantly reduce the luminance in the room—a reduction of appropriately 50% compared to the case without AF. In cases of the proposed AF phenotypes, the ASE index decreased below 10% compared to natural daylight conditions and achieved 3 points according to LEED V4.1. During the daily opening and closing cycle of the AF, the ASE and sDA indices don't observe many sudden fluctuations and remained stable within the allowed lighting range.

Keywords Adaptive facades · Daylighting · Energy-efficient · Office building

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V. T. Nguyen (✉) · H. T. Le · P. B. L. Nguyen
Faculty of Mechanical - Electrical and Computer Engineering, Van Lang University, 69/68 Dang Thuy Tram Street, Ward 13, Binh Thanh District, Ho Chi Minh City, Vietnam
e-mail: tung.nv@vlu.edu.vn

T. H. N. Le
Faculty of Civil Engineering, Ho Chi Minh City University of Technology, 268 Ly Thuong Kiet Street, 14 Ward, District 10, Ho Chi Minh City, Vietnam

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1 Introduction

Energy consumption in the industrial and building sectors as reported by IEA is the area with the highest energy consumption in the global economy [1]. In order to reduce energy consumption in buildings, the design forms of passive and active design are two main groups of solutions, in which passive design is the solution that is more often taken interest in because of its applicability. Passive design is a solution aimed at reducing energy consumption through the influence of the BE system such as the usage of shading devices.

The AF solution is one of the components of the building envelope system, whose function is interacting and responding to the natural environment in real-time [2]. AF is understood as a multifunctional highly adaptive system, the insulating system between the interior and exterior of a building, this facade is capable of changing features, functions, or behaviors by itself to meet the requirements of usage efficiency, with the aim of improving the energy-efficiency of the building. The AF helps to balance natural lighting and prevents radiation from transmitting into the building through mobile shading panels. The AF form is widely applied in many practical works and in researches, which shows the great potential that this system offers. Typical buildings with AF applied are presented in Fig. 1.

AF affects the issue of energy-efficiency through it is ability to adjust natural daylight to suit the internal occupational environment. Daylight indicators through simulation have the effect of establishing limits for lighting in accordance with design standards. Common daylight indicators include ASE, sDA, and DF. ASE being the proportional value of the locations with the number of hours receiving direct sunlight inside the room. In particular, ASE measures locations exposed to direct sunlight above 1000 lx and received over 250 h. sDA surveys locations achieved adequate sunlight exposure during standard working hours (8 am to 6 pm) in the workspace. To reach sDA requirement the surveyed positions must yield a minimum of 300 lx in half of the day's working hours (50% of the occupied period). According to the LEED V4.1 standard, buildings will be assigned 1 to 3 points for designs with appropriate ASE and sDA statistics (Table 1) [3]. Also according to LEED V4.1, the ASE index of below 10% needs to evaluate luminance inside the working plane. (iii)

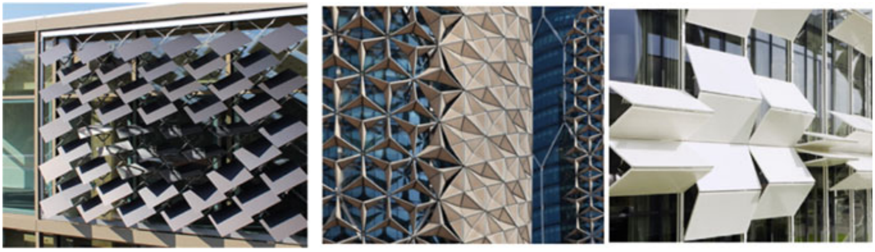

Fig. 1 Typical AF phenotypes in buildings, from left to right: House of Natural Resources in Zurich, Al Bahar Towers, Kiefer Technic Showroom (source: [8])

Table 1 Natural daylight rating scale in option 1 according to LEED V4.1 (source: [3])

New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		Healthcare
Percentage of regularly occupied floor area	Points	Points
The average sDA300/50% at least 40%	1	1
The average sDA300/50% at least 50%	2	2
The average sDA300/50% at least 75%	3	Exemplary performance

Daylight Factor (DF) is the percentage between indoor and outdoor illuminance as determined under CIE Overcast (lux) sky conditions. According to the United States Green Building Council (USGBC), DF must achieve a minimum of 2% in 75% used space.

The diversity of AF phenotypes has been presented in many previous studies [2, 4], some of which are interested in natural lighting issues such as [5, 6]. Research by A. Tabadkani et al. [4], presented analysis on the kinetic AF and natural lighting comfort through the Useful Daylight Illuminance (UDI) index. Kinetic adaptive facade are defined as complex mechanical systems in which a certain kind of motions like displacing, sliding, expanding, folding or transforming, ensure variable geometries and mobility of the system [2]. Research by P. Bakmohammadi [7] studied lighting and energy in classrooms through UDI, DA, ASE indices, concerning user comfort. When existing effects change the size or angle of the window, the illuminance and energy consumption index (EUI) also change simultaneously. However, there are yet no studies on the change of motion of kinematic AF affecting the lighting indices ASE, sDA, and DF in high-rise offices located in HCMC. At the same time, there are no proposed AF solutions following the new evaluation method of the LEED V4.1.

In this study, the kinetic AF model is proposed to be equipped on the northeast facade of the HOB which is the building's main facade. The case study used is LIM Tower HOB located in HCMC as it is typical for all buildings with a single-layered glass facade. The research focuses on the impact of structural design and motion of the mobile AF (kinetic facade) towards the ASE, sDA, and DF indices in accordance with the criteria for rating green-buildings such as LEED V4.1. The implementation process is divided into 3 main stages to enhance the efficiency of natural daylight. Of which, phase 1 is to build a HOB model consist of a typical floor for natural lighting simulation. There on, the survey of the typical floor natural lighting coefficient in the above HOB is taken. Phase 2 presents the survey of ASE, sDA, and DF coefficients in the room when equipped with the simultaneous AF system. Finally, stage 3 alters the design variable of the AF to find a suitable solution for the lighting problem according to LEED V4 standards.

The study was carried out using Rhinoceros-Grasshopper software, the plugin used in the analysis of daylight factors is ClimateStudio of Solemma. Climate Studio is an improved and updated plugin from DIVA-for-Rhino. Many studies on the accuracy of software DIVA-for-Rhino and ClimateStudio have also been taken in prior researches [6, 7]. This study provides AF solutions to the problem of natural lighting for HCMC, at the same time, building a design process towards lighting comfort adhering to LEED V4.1 standard.

2 Setup Experiment

2.1 Daylight Modeling

In order to properly apply AF to HOBs, it is necessary to investigate the daylight coefficients inside the workspace. Surveys on daylight quality in HOB in HCMC were carried out on the 25th floor of LIM Tower (Fig. 2a). The total floor area is 920 m^2, the height between floors is 3.2 m. The daylight factor is calculated on a grid plane with an area of 48 m^2. Each grid module is spaced 0.6 m apart (conforming to the calculation grid proposed by LEED) and the grid system is located 0.76 m above the floor, which coincides with the standard working position proposed by LEED V4.1.

The kinetic AF system is integrated on the northeastern facade of the building (Fig. 2b). The integration of Kinetic AF into the building is intended to solve lighting

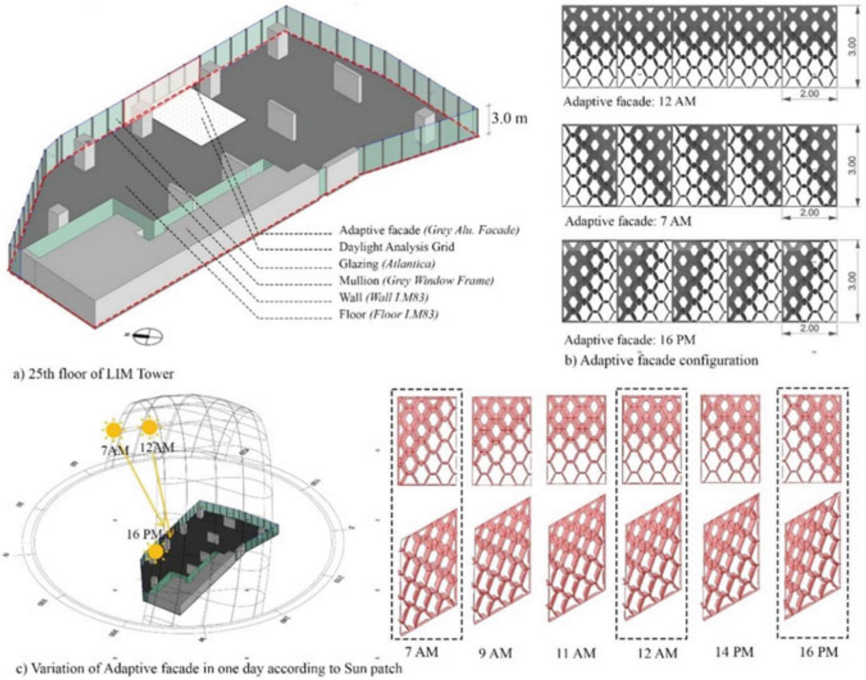

Fig. 2 Case study for daylight simulation and adaptive facade phenotypes (source: [8])

Table 2 Material system setup for daylight simulation (source: authors)

Construction	Type	Roughness	R_{vis} (tot)	R_{vis} (diff)	R_{vis} (spec)	T_{vis} (tot)	T_{vis} (diff)	T_{vis} (spec)
Ceiling LM83	Matte ceiling	0.10	70.0%	70.0%	0.0%	0.0%	0.0%	0.0%
Floor LM83	Matte floor	0.00	20.0%	20.0%	0.0%	0.0%	0.0%	0.0%
Grey Window Frame	Glossy others	0.20	18.1%	16.9%	1.2%	0.0%	0.0%	0.0%
Wall LM83	Matte wall	0.20	18.1%	16.9%	1.2%	0.0%	0.0%	0.0%
Grey Alu. Facade	Glossy ext. build	0.10	37.2%	34.7%	2.5%	0.0%	0.0%	0.0%

Glazing	Layers	T_{vis}	R_{vis} Front	R_{vis} Back	U value	SHGC
Atlantica	Single	66.3%	6.4%	6.4%	5.82	0.53
Atlantica-solarban 60 (3)	Double	45.9%	8.1%	8.3%	1.66	0.30
Atlantica-solarban 67 (3)	Double	40.2%	10.8%	18.1%	1.66	0.29

problems such as reducing the ASE index below 10% while keeping the sDA above the 50% threshold as announced by LEED shown in Table 1. The AF is composed of sheets of hexagon cells. In each AF there are 8 cells vertically and 5 cells horizontally. The inside of the hexagon cell sheets are then divided into small surfaces and are capable of rotating around the attraction structure from 0 to 80% according to the solar pattern. The orbit of the sun was determined on three marks: 7 am, 12 am, and 16 pm on June 15 (Fig. 2c). The simulation of the sun's orbit is done through the Ladybug plugin that operates on the Rhinoceros-Grasshopper platform [9].

Materials for daylight calculation are presented in Table 2. Accordingly, the materials used for ceiling, floor, and wall are Ceiling LM83, Floor LM83, and Wall LM83, respectively. The material for the AF uses a gray aluminum façade and the mullion uses a gray window frame material. Glazing materials were surveyed on three types of materials: Atlantica, Atlantica Solarban 60 (3), and Atlantica Solarban 67 (3) to evaluate daylight performance.

Table 2 presents the material properties used in the simulation. The material data is extracted from ClimateStudio v1.0. In which, materials are divided into two main groups of glazing materials and construction materials. For construction materials, the listed material parameters include the coefficient of surface roughness, Visual Reflectance (R_{vis}) which includes Specular Reflection (R_{vis}-spec), Diffuse reflection (R_{vis}-diff), and Total Reflectance (R_{vis}-tot). Indicators of construction materials are not capable of transmitting light (Visual transmittance-T_{vis}). For glazing materials, interfering indicators of lighting calculations include T_{vis}, front and back Visual reflectance, heat transfer coefficient (U-value), and Solar Heat Gain Coefficient (SHGC). The SHGC, U_{val} and R_{vis} indices of the three glazing materials is provided by the International glazing database (IGDB). The material parameters will directly interfere with the calculation of the ASE, sDA, and DF illuminance factors.

Table 3 Surveying the daylight of HOB LIM Tower through glass materials (source: authors)

	Atlantica single glazing	Atlantica-solarban 60 (3)	Atlantica-solarban 67 (3)
ASE	33.7%	33%	32.3%
sDA	100%	96.15%	87.69%
Mean DF	5.97%	4.31%	3.8%
LEED V4.1	3	3	3

3 Results and Discussion

3.1 *Case Study*

In hot and humid areas like HCMC, buildings using glazing often have inappropriate daylight intensity. In order to evaluate the daylight ability of the LIM Tower case study, the lighting indicators including ASE, sDA, and Mean DF (Average DF) were surveyed on many different types of glazing (Table 3). The results from Table 3 show that all glazing phenotypes achieved 3 points of LEED V4.1. A high sDA index from 87.5% to 100% indicates that the room receives a good amount of light for working processes. However, the ASE index is still marginally higher than the regulation of less than 10% of LEED. A high ASE number suggests that the luminance in the room is too high and needs to be managed. At the same time, a high DF index (from 3.8 to 5.97%) also shows that the room receives more natural light than allowed. From the results, the problem to be solved is to reduce the ASE index below 10% to ensure the balance of the glare control in the room while keeping the sDA at high levels to achieve 3 points of LEED V4.1.

3.2 *Adaptive Façade Parameters*

Based on the inadequacies in ASE index encountered by HOB LIM Tower as presented in Table 3. The kinetic AF in the form of the hexagon cells model is integrated to satisfy the natural daylight criteria. Surveys were performed on six different scales of the hexagon structure as shown in Fig. 3.

The resulting daylight indices are presented in Table 4. From those, it can be seen that the ASE index is significantly lower than the single glazing phenotypes of the

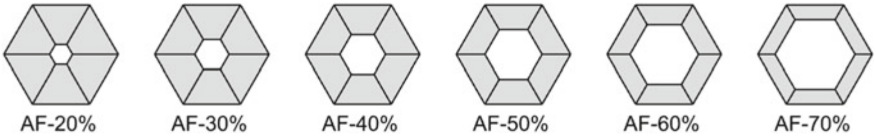

Fig. 3 Scale changes of hexagon cells (Source: authors)

Table 4 Investigate the change in the ratio of hexagon cells affecting natural daylight (source: authors)

	AF-20%	AF-30%	AF-40%	AF-50%	AF-60%	AF-70%
ASE	0.7%	3.8%	6.92%	11.54%	15.38%	15.38%
sDA	66.92%	70%	71.54%	72.51%	73.85%	74.62%
Mean DF	0.88%	0.9%	1.06%	1.2%	1.36%	1.64%
LEED V4.1	3	3	3	2	2	2

case study. Surveying on 6 scales of AF, the ASE index ranged from 0.7 to 15.38%, of which 3 cases met the ASE condition under 10% were AF-20%, AF-30%, and AF-40% and had ASE figures of 0.7, 3.8, and 6.92% respectively. The DF index was also significantly lower than the case study. However, with DF index of less than 2%, it is necessary to equip additional lighting equipment to enhance artificial lighting. As recommended by LEED V4.1, the ASE index should be less than 10% to ensure the quality of natural daylight, according to which three cases of AF are proposed to be suitable for lighting conditions are AF-20%, AF-30%, and AF-40%.

According to LEED V4.1 an sDA greater than 50% is counted as 2 points and greater than 75% is counted as 3 points for natural lighting (Table 1). In Table 4, the sDA index of all the AF cases is above 50% and below 75%. This shows that all the surveyed cases of AF got 2 points of LEED V4.1. However, all cases with ASE index under 10% are added 1 point.

3.3 Adaptive Facades Daylight Performance Throughout the day

Table 4 has shown 3 suitable AF phenotypes including AF-20%, AF-30%, and AF-40%. A study based on three AF phenotypes is proposed to investigate the daylight quality through the opening and closing movements of hexagon cell sheets (Fig. 2). The survey results show that there are no significant changes in daylight indicators in the three-time marks of 7 am, 12 am, and 16 pm (Table 5). All cases had ASE of less than 10%, the highest was 8.4% as in the case of AF-40% (12 am) and the lowest was 0.77% as in the case of AF-20% (7 am). The sDA index is always above 50% with the lowest case being 60.77% (AF-20%) and the highest case being 99.23% (AF-40%). From the simulation data, all movements in all day of the AF achieved the maximum score for natural lighting according to LEED V4.1. The survey on the DF index shows that all cases are below 2% and need to be equipped with additional lighting equipment to ensure the necessary amount of light. The AF phenotypes consistent with LEED V4.1 are shown in Fig. 4.

Table 5 Investigation of natural daylight indices in all day of selected AF phenotypes (source: authors)

	Adaptive façade scale								
	AF-20%			AF-30			AF-40%		
	7 AM	12 AM	16 PM	7 AM	12 AM	16 PM	7 AM	12 AM	16 PM
ASE	0.77	5.38	3.08	3.8	7.6	3.8	6.92	8.4	6.92
sDA	66.92	60.77	66.92	70	63.85	64.62	71.54	95.3	99.23
Mean DF	0.88	0.79	0.9	0.9	0.83	0.97	1.06	1.39	1.56
LEED V4.1	3	3	3	3	3	3	3	3	3

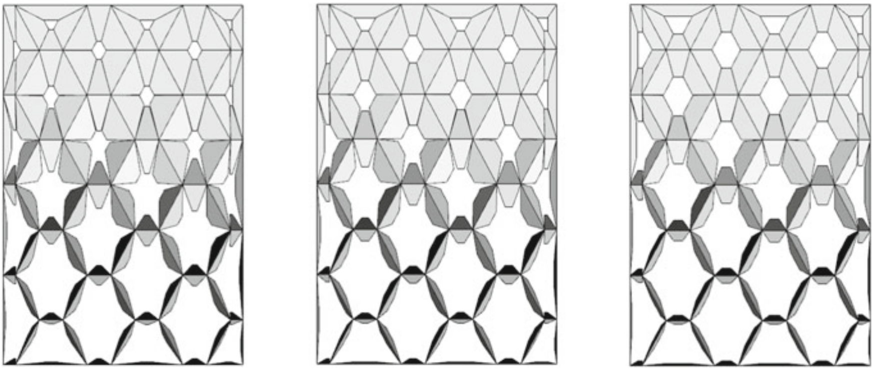

Fig. 4 The proposed AF phenotypes fit LEED V4.1 criteria, from left to right: AF-20%; AF-30%; AF-40% (source: authors)

4 Conclusion

The AF phenotype shows significant improvements in enhancing the efficiency of natural daylight energy-efficiency. Research on the AF phenotypes applied to HOB in HCMC has achieved positive results for natural daylight through the ASE, sDA, and DF indices. The proposed AF phenotypes have an ASE index of less than 10%, an sDA of more than 50%, and a score of 3 for LEED V4.1. The study's result opens up a system of solutions suitable for conditions in hot and humid climates such as HCMC and is a basis for designers and architects to apply in construction projects with an emphasis on energy efficiency and sustainable development.

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