Design Procedures of Double-Skin Façades for Achieving Internal Thermal Comfort in Educational Buildings

Lina Natiq Yassen Kassab Bashy [*], Oday Qusay Abdulqader Alchalabi[**]

[*] Department of Architectural Engineering, College of Engineering, University of Mosul, Iraq
Email: lina.21enp31@student.uomosul.edu.iq
https://orcid.org/ 0009-0001-3085-9938

[**] Department of Architectural Engineering, College of Engineering, University of Mosul, Iraq
Email: Odaychalabi@uomosul.edu.iq
https://orcid.org/ 0000-0003-0556-9872

Abstract

The educational buildings within universities are the main spaces for students' academic activities and life during the daytime, students spend 80% of their time inside these buildings. Therefore, achieving student thermal comfort requires universities to spend time and cost to prepare these buildings to be comfortable. The University of Mosul (UoM) included 24 colleges with 117 scientific departments, which contained hundreds of educational buildings occupied by 65000 students in addition to 4099 faculty staff and 3170 administrative staff. The thermal comfortability in UoM educational buildings partially achieved using the traditional method of air-conditioning units and some of the buildings still use electrical and gasoline heaters, which cost and increase the air pollution with less efficiency function. Therefore, the study is a trial to find a guideline for designing and treating the educational building using the passive and active design focusing on the facades as most elements of the building facade the outside environments and affect the internal thermal comfortability. The methodology applied simulation and analysis of a successful double-skin façade to eliminate the main steps of the design. The case study selected the following criterion of uncomfortable buildings in the UoM considering the questionnaire thermal characteristics of educational buildings. The case study is the hostel building (Al-Zahraa residential Building) within the University of Mosul. The results show three main steps that should followed by the designers in the university to achieve thermal comfortability, additionally considering the possibility of redesigning the facades.

Keywords- Thermal comfortability, double-skin, dynamic façade, kinetic façade.

I. INTRODUCTION

Building façades are the main element affecting the internal environment. However, designers focus on the aesthetic factors in the design process more than the environmental effects. Designers in the contemporary era trying to follow the methodology of considering the functional, aesthetic, and environmental factors in the design of the façade to create integrated buildings. The challenges of rehabilitation, renovating, and developing existing buildings are faced by the needs of the users and function. However, planning to develop and change the façade design in the university building should follow the methodology of considering environmental needs. The educational buildings, especially within the university must provide a friendly environment atmosphere to create healthy educational space in terms of physical and psychological aspects. The University of Mosul is the second biggest university in North Iraq in terms of area and users. The average building age is between 25 – 30 years, which is old in addition to the architectural style. After the war between 2014 and 2017, 80% of the buildings were destroyed partially by ISIS. The university started to recover in 2018 and nowadays the remaining destroyed buildings are 7-10%. Therefore, the research problem is the non-consideration of environmental effects in the process of restoring the damaged building and treatment the existing buildings of the students' hostel. The research question is “What is the active method of treatment of the existing façade in educational buildings within the University of Mosul”.

The research objective is to identify the optimal application of new technology to existing façade treatments due to the partial thermal comfortability achieved in UoM using traditional methods such as air-conditioning units, electrical, and gasoline heaters, which cost and increased air-pollution with less efficient function. Therefore, the study aims to find a guideline for designing and treating the educational building using the passive and active design focusing on the facades as most elements of the building facade the outside environments and affect the internal thermal comfortability for the existing educational building. The users suffering from the lack of thermal comfort and the negative impact on their health without knowing the causes is one of the indicators of the sick building syndrome. The World Health Organization (WHO) report in 1984 mentioned that 30% of the building problems in the world are the low Indoor air quality that interferes with the comfort factors associated with the physical characteristics of buildings, and one of the most important reasons for this is the non-environmental design of the building's façade that causes the sick building syndrome. The relationship between the users and space is important to create an active interior space [1]. The façade design can affect air circulation by creating positive and negative areas, which make the indoor air fresh. Moreover, the successful treatment of the façade can reduce energy consumption in line with providing comfortable interior space. The architecture design can be integrated and harmonised with nature to create a sustainable space [2].

II. LITERATURE REVIEW

The smart envelope of façades buildings is one of the smart system treatments of the façade. Façade treatment is an important part of the smart building, which can adapt itself to the surrounding environment through sensing, induction, and reaction. Smart facades can interact with climatic influences and solve problems that arise from interaction with the environment [3], [4]. A dynamic system is a successful strategy for controlling the façade envelope to reduce the heat gain in the buildings. However, the treatment of the dynamic facade can influence thermal comfort by controlling the sunlight and working as the second skin of the building to protect the building from heat loss. It can control the shape, orientation, and direction, or open and close it in response to climatic factors by a mechanical system depending on temperature, humidity, wind, and the intensity of lighting. It works to rationalize energy consumption by about 40% to 60% and achieve thermal comfort [5]. Some shapes used In animated facades inspired by nature, such as the use of leaf or flower shapes to provide effective shading and an aesthetic visual effect, and these shapes can move in ways that simulate the movements of plants or other living organisms [6]. Karanouh and Kerber (2015) mentioned that building envelopes has an important impact on energy saving and consumption, depending on the type of envelope and design. The dynamic facade is an effective way to design the building envelope to improve building performance and reduce energy consumption in hot climates to provide solar shading. It provides comfortable natural lighting and good ventilation. One of the important examples of the movable façade is the façade of the Sea Towers building, which represents the reinvention of the traditional 'Mashrabiya' by integrating with advanced technology. The mechanism of the triangular shading panels depends on the response of the linear actuator to the movement of the sun to provide protection from sunlight and maintain privacy, as well as reduce energy consumption by 50% and CO2 emissions carbon dioxide by 1,750 tons annually [7].

Youssef (2017) concluded that changes in the dynamic systems of the facades improve the quality of the internal environment. There are several ways to operate the dynamic systems according to the methods of movement pattern (Figure 1), which includes four movement types. The first type is 'Translation', which is the movement of an element on a regular flat path. The second type is 'Rotation' is the movement of an object around an axis, while 'Scaling' is the change in an object's mass by expansion or folding. The 'Convolution' is a mixed type of movement, in which façade elements can moved around the point by changes in the direction of the dynamic façade element [8].

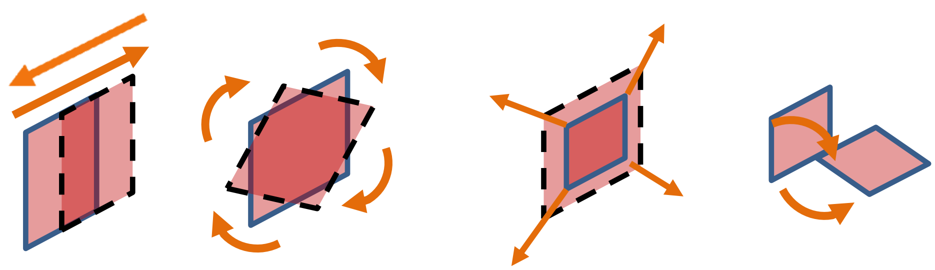

Fig. 1. The four-movement types used in the kinetic façade adapted by authors from [8]

Biomimetic methodologies for designing kinetic facades are characterized by the efficiency in achieving the quality of the internal environment [9]. The kinetic (dynamic) façade can be designed by simulating the behaviour of living organisms in the desert environment and transferring natural concepts to be applied in architecture to achieve thermal comfort. The behaviour of kinetic facades can follow the behaviours of many living organisms in the desert environment by adapting to the conditions internally, or externally to respond to the hot climate variables and reduce heat gain from the outside. Moreover, the ability to lose heat, raise their internal temperature, and protect their bodies with good insulation, which smart facades can include similar ability if it is designed to simulate nature [10]. The exterior material of the façade building has a role in improving the sustainability factors of the buildings in a positive way [11]. There are three types of simulating the façade envelope with a biomimetic system. The effective type is simulating a kinetic façade with an environmental system, in which facade design simulates nature in terms of form, materials, construction, process and function. A possible form that can be used in designing the kinetic façades to shade buildings are

- Shapes inspired by nature: leaf or flower shapes used to provide effective shading and an aesthetic visual effect. These shapes can move in ways that simulate the movements of plants or other living organisms. Simulating the idea of rotating the white Ipomoea plant (Figure 2), which opens in the morning and closes in the afternoon to adapt to the sun's rays and provide a suitable shading system to reduce heat gain during the day [12].

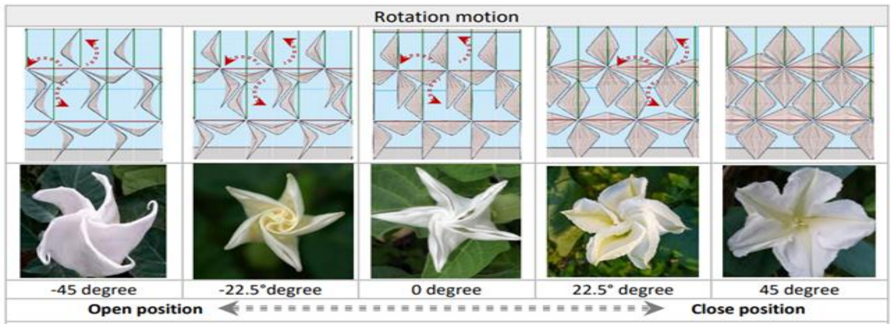

Fig. 2. The simulation of the kinetic façade with the shape of the Ipomoea flower [12, pA11]

- Transparent, semi-transparent, and non-transparent shapes: Translucent and overlapping shapes are usually used in the design of the kinetic building facades to achieve unique visual effects and activate the shading area, which is achieved by overlapping and moving the facades unite in ways that allow light to penetrate in different ways and modify the shadow levels inside [13].
- Complex geometric shapes: Kinetic façades can be designed based on complex and intersectional geometric shapes. These shapes are created from the overlay and interaction of various geometric shapes. By the movement of these shapes around various axes, the shading created diverse and interesting effects [13], [14].
- Dynamic geometric shape: Such as triangles, rectangles, squares, and curved shapes used to create dynamic facades Moving and changing their shape according to the needs. Geometric shapes can be moved in a variety of ways to adjust the direction of the shadow and the amount of sunlight [14].

The literature highlighted that the circle shape is not efficient to use in the design of the dynamic façade oppositely with Polygonal shapes. Polygonal shapes provided a covering for the overall façade without giving chance to the sunlight to pass it without control. Therefore, the triangle, square and hexagonal shapes are the most used shapes in the designing of a kinetic façade. A Hexagonal is the optimal shape because of the shortest sides compared with e triangular or square shape, although they are the same sizes (Figure 3).

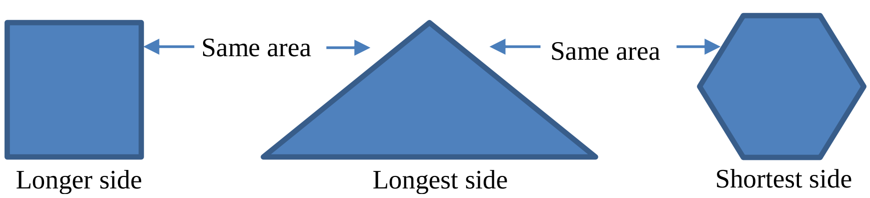

Fig. 3.. The optimal shape used in a kinetic façade depends on the length of the sides. (source: adapted by researchers from [14])

III. RESEARCH DESIGN, METHODOLOGY

The methodology of the current research applied a simulation approach by designing a kinetic façade for an existing building in the University of Mosul and comparing the results of the thermal behaviour of the building in two models (existing, after treatments). The case study selected according to the most consumed energy buildings that used during the year and used by students. The case study is a hostel building inside the university, which includes four levels. Moreover, the thermal comfort level in the building measured in two ways (thermal measurement, and energy consumption). Moreover, surveys and meetings with the students and managing staff of the hostel done to ensure that the hostel building and thermal comfort level not perfectly designed. Grasshopper software with the extension of DesignBuilder used in modelling and simulating the dynamic façade as an environmental solution for the existing façade. Octagonal and Hexagonal shapes applied in the current study to measure the reduction in energy consumption and increase of the thermal comfortability level. The octagon is characterized by eight sides and right angles (135 degrees), resulting in eight equilateral surfaces. The octagonal shape is used in the design of dynamic facades with fixed parts (the squares between the eight units) to form movable and fixed panels (Figure 4). The current study selected the important buildings that have a role in the high recorded of energy consumption in the University of Mosul, which is the hostel building for girls. The case study is located inside the main campus of

MoU with around 15 residential buildings. The users suffered from the uncomfortable interior environment although the high energy consumption. Therefore, this building selected as a case study and applied the treatment of the double-skin façade with a dynamic hexagonal shape as shown in Figure 8.

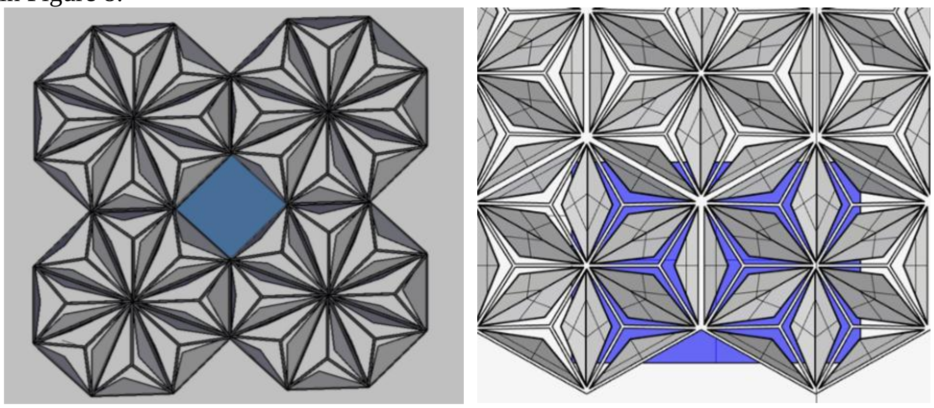

Fig. 4.. The Hexagonal and Octagonal shapes are applied in the double-skin of the buildings (Source: The researchers).

This treatment is adopted on the facades that contain openings or windows in the existing building due to the ability of the kinetic systems in the building envelope to work as an environmental mediator. The double-skin façade design depending on the control of four main variables supports the application of the principles of green architecture including, solar thermal control, daylight control, temperature control, ventilation, and power generation. The study focuses on the dynamic façade method with closing and opening control, which is the newest and effected method as mention by the previous studies.

IV. Results and Discussion

The results of simulating applying the treatment of the double-skin façade with the dynamic system using polygonal shape is more efficient as an individual treatment compared to other treatments, which the changes in the value of the variable positively validate this method (Figures 6,7, and 8). For the ventilation loads, the value improved by 1.94% as a result of the response to changes in the microclimate surrounding the building. The direct heat gain in the openings decreased by 26.04%. The generated heat remained from electrical devices and human behaviour remain at the same values. The value of lighting improved by 8.70% due to its effect on the passing of appropriate lighting in each facade and as needed by the dynamic movement. The result of providing a shaded area between the outer building envelope and the outer wall decreased the surrounding temperature from 31.87% to 24.54%, which decreased by 22.98%. This decrease reflected in the internal temperature of the hostel buildings from 28.94% to 26.02% at a rate of 10.10%. The simulation results show that the total cooling loads decreased by up to 49.64% compared to the cooling loads before treatment, and these results are close to the findings of the study of Abd El-Rahman et al. (2020) [12]. The application of dynamic facades inspired by nature in the treatment of the hostel buildings at the University of Mosul represented positive results, especially the decreasing of energy consumption, and the saving of cooling energy increased by 39%. The heating loads, the situation did not change much, and the percentage of reducing the total loads was approximately 22.66%, as shown in Figure (7).

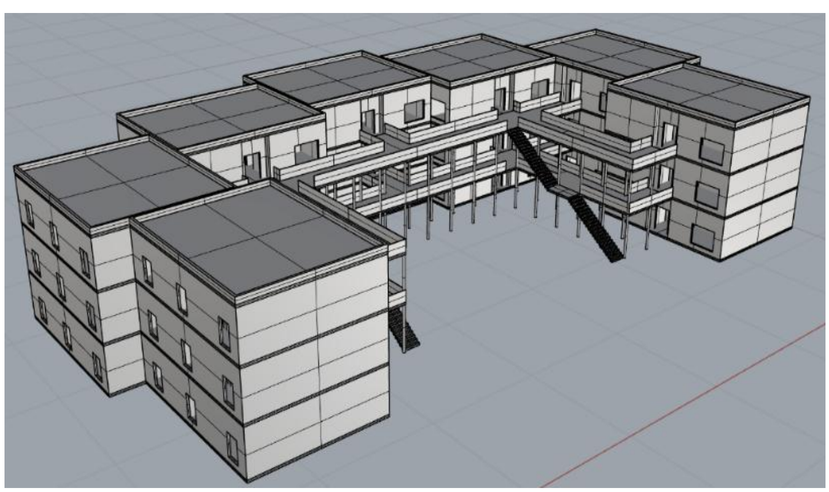

Fig. 5.. The simulation of the existing hostel building in the University of Mosul (Source: the researchers using DesignBuilder application).

Temperatures, Heat Gains and Energy Consumption - Lena - Mosul, Building 1

EnergyPlus Output — 1 Jan - 31 Dec, Monthly — Licensed

Month												
Room Electricity (kWh)	12354.57	10794.78	11413.74	11834.64	12354.57	10893.81	12354.57	11884.16	11364.22	12354.57	11364.22	11884.16
Lighting (kWh)	17938.39	15598.60	16378.53	17158.46	17938.39	15598.60	17938.39	17158.46	16378.53	17938.39	16378.53	17158.46
Heating (Gas) (kWh)	1.97	3.75	96.50	717.21	3081.56	6824.78	11339.29	5388.29	3601.79	437.91	240.91	0.00
Cooling (Electricity) (kWh)	35551.32	28748.87	26682.66	14542.28	7006.86	1315.62	2487.57	4459.86	6006.83	14891.03	19550.85	32646.53
DHW (Electricity) (kWh)	1123.10	976.61	1025.44	1074.27	1123.10	976.61	1123.10	1074.27	1025.44	1123.10	1025.44	1074.27
Air Temperature (°C)	26.20	25.78	25.19	23.75	22.53	20.94	21.03	21.69	22.56	23.95	24.60	25.97
Radiant Temperature (°C)	28.51	27.96	27.17	25.34	23.70	21.75	21.71	22.80	23.83	25.69	26.51	28.19
Operative Temperature (°C)	27.35	26.87	26.18	24.55	23.12	21.34	21.37	22.25	23.19	24.82	25.56	27.08
Outside Dry-Bulb Temperature (°C)	23.69	22.56	20.65	16.70	13.19	10.30	9.76	11.25	13.02	16.40	18.77	22.76
External Infiltration (kWh)	-5065.17	-5801.36	-9039.66	-13677.93	-18956.13	-21023.04	-23121.82	-21343.70	-18751.56	-15101.36	-11264.07	-6418.98
General Lighting (kWh)	17938.39	15598.60	16378.53	17158.46	17938.39	15598.60	17938.39	17158.46	16378.53	17938.39	16378.53	17158.46
Computer + Equip (kWh)	12354.57	10794.78	11413.74	11834.64	12354.57	10893.81	12354.57	11884.16	11364.22	12354.57	11364.22	11884.16
Occupancy (kWh)	5079.90	4435.28	4668.64	4930.20	5250.50	4762.05	5443.67	5104.17	4803.83	5120.83	4673.37	4881.67
Solar Gains Exterior Windows (kWh)	24706.50	22053.29	23059.23	19890.63	17298.04	14039.64	15952.98	18268.85	20891.31	22476.73	23001.91	23615.05
Zone Sensible Heating (kWh)	1.71	3.21	81.45	503.18	1793.63	3504.35	5712.90	2952.92	2098.84	368.27	201.47	0.00
Zone Sensible Cooling (kWh)	-48773.67	-39646.08	-36685.68	-25682.85	-17259.55	-9188.66	-10364.70	-14241.49	-16595.31	-27528.79	-31804.11	-44201.77
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.03	1.02	1.05	1.05	1.02	1.06	1.04	1.03	1.05	1.03	1.03

Fig. 6.. The result kit of the simulating the existing hostel (Source: the researchers using DesignBuilder application)

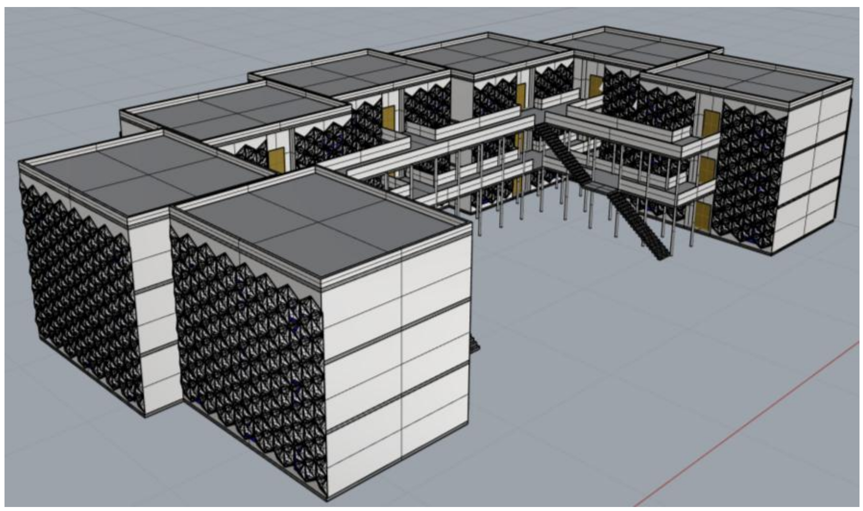

Fig. 7.. Using polygonal (Hexagonal) in the design of the double-skin dynamic façade (Source: The researchers using DesignBuilder application)

Temperatures, Heat Gains and Energy Consumption - Lena - Mosul, Building 1

EnergyPlus Output — 1 Jan - 31 Dec, Monthly — Licensed

Month												
Room Electricity (kWh)	12354.57	10794.78	11413.74	11834.64	12354.57	10893.81	12354.57	11884.16	11364.22	12354.57	11364.22	11884.16
Lighting (kWh)	17938.39	15598.60	16378.53	17158.46	17938.39	15598.60	17938.39	17158.46	16378.53	17938.39	16378.53	17158.46
Heating (Gas) (kWh)	13297.20	7928.26	4362.68	869.32	0.14	0.00	0.00	0.00	0.00	145.33	2418.58	9721.38
Cooling (Electricity) (kWh)	215.08	2032.49	5873.48	15051.11	29011.52	32997.69	42832.59	40777.25	31548.36	20628.16	6643.13	1033.38
DHW (Electricity) (kWh)	1123.10	976.61	1025.44	1074.27	1123.10	976.61	1123.10	1074.27	1025.44	1123.10	1025.44	1074.27
Air Temperature (°C)	19.69	20.78	22.18	23.97	26.02	27.30	27.46	27.42	26.62	24.46	22.42	20.33
Radiant Temperature (°C)	20.21	21.81	23.68	26.07	28.69	30.07	30.47	30.25	29.25	26.64	23.70	21.05
Operative Temperature (°C)	19.95	21.29	22.93	25.02	27.36	28.68	28.97	28.83	27.93	25.55	23.06	20.69
Outside Dry-Bulb Temperature (°C)	6.33	7.46	10.06	14.74	21.05	24.54	26.34	26.29	23.41	17.66	12.28	7.50
External Infiltration (kWh)	-25787.69	-23135.76	-23103.96	-16799.16	-9289.78	-5006.53	-2246.53	-2322.25	-5869.98	-12689.82	-18667.56	-24719.38
General Lighting (kWh)	17938.39	15598.60	16378.53	17158.46	17938.39	15598.60	17938.39	17158.46	16378.53	17938.39	16378.53	17158.46
Computer + Equip (kWh)	12354.57	10794.78	11413.74	11834.64	12354.57	10893.81	12354.57	11884.16	11364.22	12354.57	11364.22	11884.16
Occupancy (kWh)	5551.75	4699.47	4810.01	4905.08	5112.87	4445.45	5112.27	4889.99	4667.72	5115.41	4729.82	5207.21
Solar Gains Exterior Windows (kWh)	13593.90	18257.62	26009.00	28654.40	32575.06	34338.59	35098.73	32821.25	28953.26	25353.24	17774.63	15963.86
Zone Sensible Heating (kWh)	7553.73	4810.14	2991.32	721.00	0.12	0.00	0.00	0.00	0.00	122.01	1929.34	6192.25
Zone Sensible Cooling (kWh)	-7623.21	-10417.72	-17370.05	-30538.90	-50771.69	-54565.18	-66602.95	-62296.96	-51472.72	-37508.15	-16990.74	-9257.55
Mech Vent + Nat Vent + Infiltration (ac/h)	1.06	1.05	1.03	1.05	1.05	1.01	1.04	1.02	1.02	1.05	1.04	1.05

Fig. 8.. The result kit of the simulation after applying the dynamic facade (Source: the researchers using DesignBuilder application)

ISSN: 2710-2165

The results show that the Hexagonal shape in the dynamic façade in comparison with the Octagonal reduced energy consumption by around 20%, which referred to the fixed area produced from the synthesis of the Octagonal shape. Therefore, the study recommended a Hexagonal shape in the designing of the dynamic façade unit.

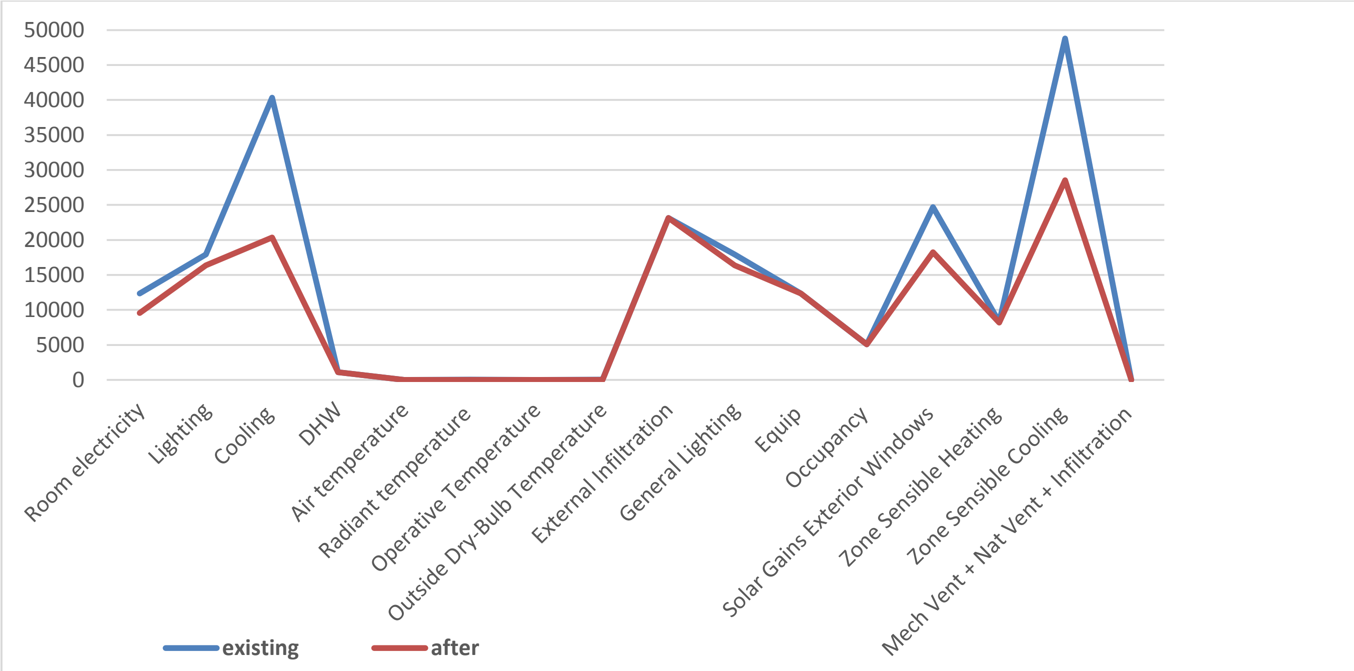

Fig. 9. The comparison between the two simulation models (existing and after treatment) (Source: the researchers).

The application of the dynamic façade for the hostel building in the University of Mosul shows that there are some variables affected positively and decreased the value, which makes the thermal comfort and air quality more suitable and acceptable in this type of building. Moreover, energy consumption reduced and develops the façade form is a results of using the dynamic façade in the simulation models of the hostel building in the UoM.

I. CONCLUSION

The hostel building considered an important building in the university, and students use it during the academic year. If the thermal comfort of this building is below the needs of the users, the students will lose their quality of study and will get an unhealthy environment. Therefore, the treatment of the façade is an emergency solution to restore a healthy environment. The treatment should include the methodology of a double-skin dynamic façade by following a natural system using a polygonal shape of the unit to provide an efficient environment. Controlling the sunlight and ventilation surrounding the building is important to save energy and create a healthy interior space for the students. The research concluded that the movement types of the units in the dynamic façade should controlled smartly according to the needs using a smart system effected by the density of the sunlight and indoor indicators, which opening and closing the units work individually wherever the building needs. The research recommended three steps can be followed by the designers to achieve thermal comfortability in the internal environment of the University of Mosul buildings (Student –Hostel) considering the possibility of redesigning the facades. The first step is to select the shape of the unit that is used in the dynamic façade. The second step is the selection of which side of the building needs this treatment. Finally, the smart technology controls the opening and closing of the units according to the interior space thermal comfort variable. Moreover, the visual appearance of the façade should be considered in the design to create an integration value between the dynamic façade, building type, and architectural appearance. These steps and dealing with architectural form is guideline recommended to the University construction department to apply for the hostel buildings inside the University of Mosul main campus.

ACKNOWLEDGEMENT

The researchers acknowledged the University of Mosul, College of Engineering, Department of Architectural Engineering for registering the article under the research plan (2022-2023), which was approved by the scientific committee and allowed the researchers to use the software and instruments provided by the College of Engineering.

REFERENCES

[1] A. M. Hindi and Y. M. A. Alharayri, "The Harmony Effect between Changeability and Steadiness on Human in the Interior Spaces," *J. Specif. Educ. Res.*, no. 51, pp. 85–101, 2018, doi: 10.21608/mbse.2018.136532.

[2] H. A. S. Al-Alwan and yasamin H. H. Bege, "Harmony of architecture with nature, sustainable design towards human health and well-being," *Emirates J. Eng. Res.*, vol. 22, no. 1, pp. 37–55, 2017.

[3] M. Aladawi, "Passive Techniques in Architecture," *Arch Dewanya*, 2022. https://www.archdiwanya.com/2022/04/Passive-Techniques.html.

[4] G. Datta, "Effect of fixed horizontal louver shading devices on thermal performance of building by TRNSYS simulation," *Renew. Energy*, vol. 23, no. 3–4, pp. 497–507, 2021, doi: https://doi.org/10.1016/S0960-1481(00)00131-2.

[5] F. Isaia, M. Fiorentini, V. Serra, and A. Capozzoli, "Enhancing energy efficiency and comfort in buildings through model predictive control for dynamic façades with electrochromic glazing," *J. Build. Eng.*, vol. 43, p. 102535, 2021, doi: https://doi.org/10.1016/j.jobe.2021.102535.

[6] W. S. M. Abdel-Rahman, "Thermal performance optimization of parametric building envelope based on bio-mimetic inspiration," *Ain Shams Eng. J.*, vol. 12, no. 1, pp. 1133–1142, 2021, doi: https://doi.org/10.1016/j.asej.2020.07.007.

[7] A. Karanouh and E. Kerber, "Innovations in dynamic architecture The Al-Bahr Towers Design and delivery of complex facades," *J. Facade Des. Eng. 3*, vol. 3, no. 2, pp. 185–221, 2015, doi: https://doi.org/10.7480/jfde.2015.2.1017.

[8] M. M. Youssef, "Kinetic behavior, the dynamic potential through architecture and design," *International Journal of Computational Methods and Experimental Measurements*, vol. 5, no. 4. pp. 607–618, 2017, doi: 10.2495/CMEM-V5-N4-607-618.

[9] A. M. A. Faragalla and S. Asadi, "Biomimetic Design for Adaptive Building Façades: A Paradigm Shift towards Environmentally Conscious Architecture," *Energies Rev.*, vol. 15, no. 5390, pp. 1–21, 2022, doi: https://doi.org/10.3390/en15155390.

[10] S. E. Khalaf, M. A. Abdelmohsen, and A. Shamseldin, "Simulating the natural environment to achieve thermal comfort in the desert environment," in *Third International Conference on Creativity, Innovation and Development "Future visions in the civilizations and cultures of the Arab world 28 - 30 April 2018 and the countries of the Mediterranean basin,"* 2018, pp. 429–449.

[11] S. M. Talee, "Using Intelligent Techniques in Sustainable Buildings - Buildings' External Form of Arabian Gulf Region as a Case Study –," *Al-Rafidain Eng. J.*, vol. 24, no. 2, pp. 39–55, 2019, doi: 10.33899/rengj.2019.164354.

[12] S. M. Abd El-Rahman, S. I. Esmail, H. B. Khalil, and Z. El-Razaz, "Biomimicry inspired Adaptive Building Envelope in hot climate," *Eng. Res. J.*, no. 166, pp. A1–A17, 2020, doi: 10.21608/ERJ.2020.135274.

[13] A. Shafaghat and A. Keyvanfar, "Dynamic façades design typologies, technologies, measurement techniques, and physical performances across thermal, optical, ventilation, and electricity generation outlooks," *Renew. Sustain. Energy Rev.*, vol. 167, p. 112647, 2022, doi: https://doi.org/10.1016/j.rser.2022.112647.

[14] W. Y. H. Alhamedan, H. S. Mansur, and M. A. Alhfnawe, "Nature simulation techniques to produce sustainable residential buildings in the Eastern Province of the Kingdom of Saudi Arabia," *Int. J. Sci. Stud. Publ.*, pp. 1–31, 2020.