Effects of Kinetic Façades on Energy Performance: A Simulation in Patient's Rooms of a Hospital in Iraq

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Abstract

Hospital buildings are among the most energy-consuming types of buildings, due to their high occupancy especially in patient rooms, where the average occupancy rate may reach 24 hours / day. Large hospitals, depending on their functions require large amounts of energy, especially in hot, dry climates, to operate their ventilation systems of heating and cooling, which reduces the efficiency of the energy performance of the buildings.

This research evaluates the performance of a louver-type kinetic façade in increasing the efficiency of energy performance inside patient rooms by reducing energy consumption in hospitals. A 600-bed public hospital is selected in Iraq, specifically in the city of Najaf 32°15N,44°23 E to test this proposition. It is located in the central region with a hot dry climate.

Thus, the study evaluates the patient rooms in this hospital, which are located on the southern and northern facades. It is carried out in two stages: the first stage includes simulation and thermal analysis of the southern and northern parts of the patient rooms before adding the kinetic facades of the louvers-type. The second stage includes simulation and thermal analysis of the southern and northern parts of the patient rooms after adding the kinetic facades. Horizontal and vertical louvers are added to the southern facade and horizontal and vertical louvers to the northern facade of the hospital. The results of the analysis are compared before and after using the kinetic facades. Results were analyzed using Rhino Grasshopper program and Ladybug-Honeybee for simulation and thermal analysis.

The results show that the horizontal kinetic façade of louver-type reduces the radiation exposure levels: 75% when its angle of inclination was 45°, by 60% when the angle is 315°, and by 40% when the angle is ° 0. This directly and effectively reduces the temperature and thus reduces the energy consumption of the the HVAC systems. It proved that the kinetic facades achieve the efficiency of energy performance in the patient rooms.

Keywords: Kinetic façade, Energy performance, Hospitals, Hot dry climate, Thermal analysis, Simulation, Rhino Grasshopper.

Introduction

The use of innovative strategies based on adaptive solutions to improve the energy performance of buildings has become the most important goal at the moment. This is because of the fact that in high-performance buildings, the cover of the building has become the main component to achieve this goal. Thus, it is necessary to pinpoint that the cover of buildings is a sensitive and interactive extensions for those who are interested in this case rather than only a protection of Nature. Dewidar et al. (2013).

Nowadays, the design and construction of environmentally adaptive buildings represents a challenge that faces the architects, though, recent developments in Computer-Aided Design programs have enabled architects to explore new areas in building forms and influential treatments of building covers, in an attempt to solve the problems of this kind. Sheikh & Gerber (2011). The main global environmental problems that people face from the very beginning of the twenty-first century is the impact of global warming on climate. The cover of the building, which represents the barrier that separates the external environment from the protected internal environment, can reduce these environmental effects on the contents of a building. Therefore, the cover of the buildings represents 80% of the solution for the environmental problems. Etman et al (2013). Thus, the matter of keeping well energy and making solutions available to achieve it inside the contents of the building has become vital (Al-Ali & Kamoona, 2021).

Hospitals are buildings of specific importance in any society that need specific care in its design, and employing this type of buildings has a great effect on people’s health and environment. Alsawaf & Albadry (2022). Hospitals are the most important structures that have different. complexities. Among them are the medical developments such as the development in Medical sciences and technological developments, such as equipment and techniques used in surgery halls, diagnostic and intensive care rooms as well as rooms of continuous occupations like the sleeping rooms. Babbu(2016).

As mentioned earlier, hospitals are among the most complex types of buildings (Mahmood, 2021). Each hospital consists of a wide range of services and functional units, including diagnostic and therapeutic ones, such as clinical laboratories, radiology, emergency rooms and surgery. This diversity is reflected in the breadth and specificity of regulations, laws and controls governing the construction of hospitals (Carr,2017).

Usually, the complexity of hospital buildings makes it a subject for continuous development and change. This is part of its nature in involving an accurate coordination between its subsystems such as medical, nursing, engineering, and other services to reflect its jobs with high efficiency (Rasool,2015). In general, energy performance is a measure for the efficiency of the relative energy of a building, its equipment or components. This measure specifies the amount of energy necessary for the services of the building. That is, how the tools and equipment use the energy of the building (Nelson & Strarcher,2015). It is known that designers recognize that covers of buildings automatically reduce energy consumption but this is not always taken into consideration in the designer's early aims when attempting to design a hospital building (Grijalva, 2012).

In terms of kinetic facades, they have the ability to control their shapes and directions or open and close their openings as a reaction to environmental changes like temperature, humidity, air, and light. These kinetic facades are one of the vital means of reducing energy consumption (Abdul Jalil,2016). That is, they are one of the most eminent techniques of finding energy and that is why they are regarded as one of the components of the covers of buildings. Consequently, they have to be designed from the very beginning correctly to adapt to the local climate of the building spaces, in a way that achieves an efficient use of energy (Kamoona,2018).

Systems of shading such as kinetic facades reduce annual solar radiation and modify heat exchanges through the cover of the building. Hence, they positively affect the efficiency of energy performance in the building in term of lighting, ventilation, heating and cooling. Simultaneously, they affect people's visual and thermal comfort. Bellia et al (2014). Furthermore, the number of openings on the walls determine the level of daylight in the internal spaces. They also contribute in increasing the heat when the openings are not environmentally protected by systems that respond to various environmental conditions (Favoino et al.,2014). In other words, it is important to take into account the balance between the acquisition of solar heat and daylight because they have the same source (Modin,2014).

Most often, the traditional covers of buildings have stable features that cannot adapt to the environmental conditions. In contrast, resorting to modern buildings that have environmental adaption raises the benefit of climate changes (Loonen et al.,2013). The internal and external thermal loads can be reduced by using equipment that are efficient in the use of thermal energy and its lighting. This can usually be done by getting the benefit of natural daylight, effective solar shading methods, and the use of strategies of cooling, heating and ventilation (Kamoona,2016).

In regard to kinetic buildings, there is a growing concern about them, especially kinetic facades, where the many challenges lie in creating a cover of the building that can adapt to different environmental conditions (Alkhayyat,2013). Kinetic facade systems that react to different levels of solar radiation are exceedingly the most efficient solutions in hot and dry environments. These adaptive systems can take many different forms and configurations, such as external and internal systems, as well as different types of horizontal, vertical and hybrid louvers (Weston,2010). Vertical louvers are used for both the Northern and Western facades while the horizontal louvers are used for the Southern façade. On the other hand, vertical louvers are structured on the Western and Eastern facades (Dagher et al.,2022). Thus, vertical curtains are so effective if they are structured on the Eastern and Western side of buildings in order to be as a barrier or buffer of wind to protect the façade in winter (Kirimtat et al., 2016).

Adaptive systems use less energy, and provide more control over the thermal comfort level. It also leads to significant savings in energy consumption by its current energy-saving design strategies together with building covers. Besides that, the covers of traditional buildings which have stable features are not good solutions for various types of buildings. Various studies show an increasing interest in the techniques of kinetic facades to improve energy performance and interior comfort (Wang et al., 2012). There are a large number of systems for kinetic facades and adaptive covers of building. Yet, the decision on how to design, operate, maintain and evaluate them remains a great challenge (Attia et al., 2015).

In this context, this Paper aims to demonstrate the types of kinetic facades and their importance in reducing energy consumption, thus achieving the concept of energy efficiency within patients' rooms in hospital. Its objectives are:

1. To achieve a strategy that can be applied, and explore the kinetic facade that is efficient in achieving energy performance efficiency within the patient rooms in Iraqi public hospitals.
2. To test the hypothesis that the use of kinetic facades with louvers (horizontal or vertical), in a dry hot climate improves energy efficiency of the interiors.

Literature Review

This review examines the architectural studies that have dealt with Kinetic Façades and energy performance efficiency of buildings; it reveals numerous significant studies focusing on this intriguing subject. Global research indicates that the design of kinetic facades plays a prominent role in improving energy consumption efficiency and overall building performance in healthcare facilities. Previous studies have shown the influence of various elements of kinetic facades, such as utilizing natural light, effective ventilation, and other environmental factors, in reducing energy consumption while enhancing comfort and well-being for patients and staff within hospitals.

Matin et al. (2022) show that kinetic facades incorporate movable elements, such as louvers, that can respond to environmental conditions and adjust accordingly. Seyrek et al. (2021) revealed that kinetic facades with louvers have been utilized to address various factors including daylight control, interaction with human occupants, reaction to wind, energy generation, adaptation to seasonal changes, indoor comfort, glare reduction, controlling solar radiation, and natural ventilation.

Karaseva (2021) explains and develops systems of kinetic facades is ongoing in Europe and the United States, in addition examining about the efficiency of energy performance in buildings, as well as relying on innovative solutions for reducing the consumption of energy in buildings.

Romano et al, (2018) point out that kinetic façades, built during the last few years, are distinguished for the integrative systems between technologies of construction and the presence of controlling and monitoring systems that make them an essential element of a complex construction system.

Choi et al. (2017) point out exterior dynamic shading devices, integrated into "kinetic façades," possess the capability to create varying shaded regions on windows through the manipulation and movement of their shading elements and the precise calculating the shaded area is of utmost significance as it directly influences the process of assessing solar heat gain in building energy evaluations.

According to Aydin and Mihlayanlar (2020), research findings have led to the implementation of louver facades in building envelopes, particularly in hospitals, has the potential to yield significant benefits in terms of energy efficiency and occupant comfort. These kinetic facades can effectively control daylight levels, reducing the need for artificial lighting and improving energy efficiency.

Lee and Chang (2015) have given an overview of louvers, that adjustable louvers can regulate solar radiation, preventing overheating in warmer months and reducing the reliance on air conditioning systems. By adapting to seasonal changes, the kinetic facades with louvers can optimize indoor comfort levels by allowing for natural ventilation when suitable and providing insulation when necessary.

Sadegh et al. (2022) provide a conceptual framework for the louvers in hospital kinetic facades to emerge as a promising solution to improve visual comfort and energy efficiency in healthcare buildings, as the demand for sustainable and adaptable building designs increases in healthcare facilities, kinetic facades incorporating louvers have gained attention for their potential to address various factors.

Li, Liu and Peng (2020) point out that the vertical louvers in kinetic facades of buildings have gained significant attention in recent years due to their numerous benefits and ability to enhance the overall performance and aesthetics of the building. These louvers, which are movable and adjustable, play a crucial role in regulating the amount of natural daylight entering the building, controlling solar radiation and heat gain, and improving energy efficiency by utilizing vertical louvers in kinetic facades, building owners can effectively reduce the dependence on artificial lighting and minimize the energy required for heating and cooling systems.

Boer et al. (2011) show that Developments in computer technology has improved the ability to process complex simulation models and has enabled more accurate calculations of energy performance. These tools can be used as design tools at an early stage, which makes it possible to design an ideal cover for a building.

Albadry & Jafer (2015) mention that developments in techniques and technologies have led to reduction of some hospital spaces, especially the diagnostic and therapeutic departments, there are fixed spaces that must exist in any hospital. For example, patient's rooms, information rooms, registration rooms, waiting rooms, services and other public spaces are all indispensable in a hospital in spite of their differences from one to another. Hijeat & Husain (2012) explain the computer-aided design processes are helpful in the design and demonstration of the initial model of a specified idea reaching to final models with an integrative holistic vision of design and construction. Exploiting such processes can help in choosing the best alternative.

According to Iraqi thermal insulation blog (2013) horizontal louver-type kinetic facades block direct sunlight at times when the sun's altitude angle is high and the horizontal shadow angle is small. It is preferably used in the southern direction between two azimuth angles, 225°-135 ° and it can be stable or movable. As for the kinetic facade of vertical louvers, it works to repel direct sunlight at times when the sun's elevation angle is low and the horizontal shadow angle is large. It is preferable to use it in the direction between 0 ° to 90 ° from the North and between 360° - 270 ° in the North direction and it also can be stable or movable.

The Research

Given this context, this research engages a simulation and thermal analysis of two types of kinetic facades: a kinetic facade of the type of horizontal louver towards the South and a kinetic facade of the type of vertical louver towards the North. The research then compares the results to choose the best system for each facade.

Research Methodology

This paper is based on simulation, analysis and comparison to investigate the impact of kinetic facades on the efficiency of energy performance in patients rooms in public hospitals. The simulation is carried out through a case study in two stages:

1. Modeling environmental simulation and thermal analysis before installing the façade.
2. Environmental simulation and thermal analysis after using the louver type horizontal and vertical kinetic facades. The research compares the results before and after their use.

The research aims to achieve the highest efficiency of using energy in the patients' rooms by engaging the external environmental effects upon the hospital building at different times of the year. It also aims to make recommendations to achieve similar outcomes in the future to reduce the consumption of energy in patients' rooms; hence, increase efficiency of energy performance.
This research thus adopts the following steps (Fig. 1).

1. Describing the nature of the study and the climatic conditions in the area of the study.
2. Modeling the study by using Autodesk Revit.
3. Simulating the external environment to the internal environment of the selected sample using Rhino Grasshopper program before and after making the environmental treatment or balance to the façade.
4. Measuring and analyzing the results to arrive at correct recommendations that can be applied in the future on similar projects and in similar circumstances.

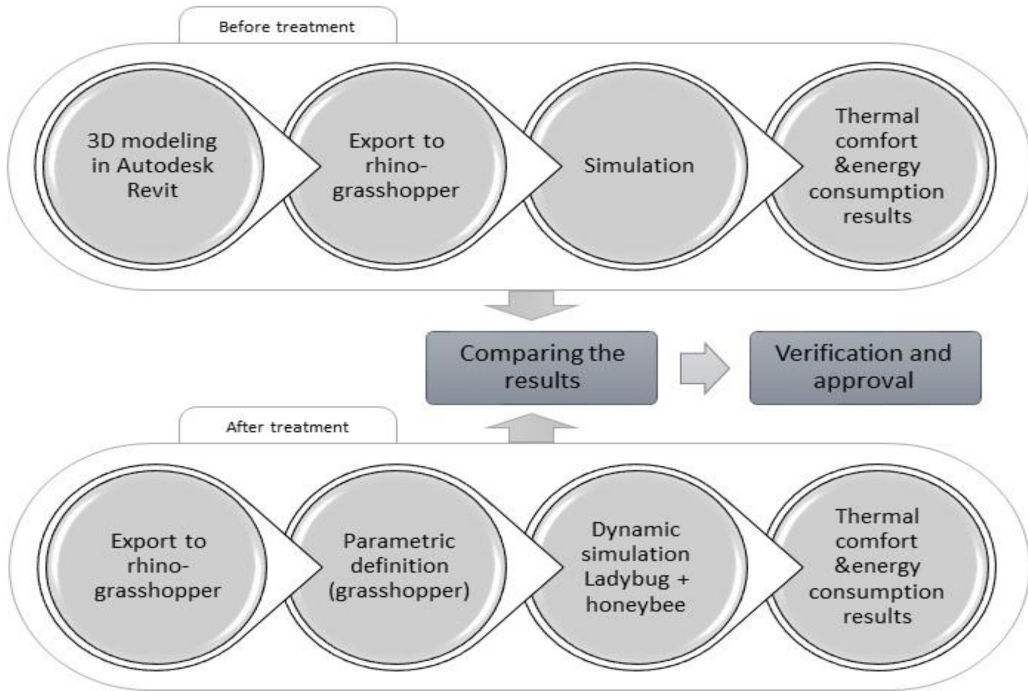

Fig. 1: Research Process
Source: authors

Case study

This research focuses on the public hospital in Najaf, Iraq. The city lies within the climate of the mid area of Iraq 32°15 N; 44°23 E. Climate of Iraq is divided into three main types and regions as follows:

1. Dry climate is present in the western desert and in South and Southeast Iraq.
2. Semi-tropical and semi-dry climate present in the Najaf city.
3. Mediterranean climate, which prevails in the Northern mountainous area of Iraq.

The mid area of Iraq and Najaf in particular has a hot and dry climate with average temperatures ranging from (9.5) °C in January to (35) °C in July. The maximum-average temperature reaches up to (44) °C. Summer, in the mid area of Iraq, is hot and dry with clear sky most of the time which makes the sun light falls direct. There, temperature becomes (50) °C and this makes Najaf as one of the most heated cities in the world. In winter, on the other hand, most days are mild and at night the temperatures are lowered to a few degrees below freezing. Abdulla (2020).

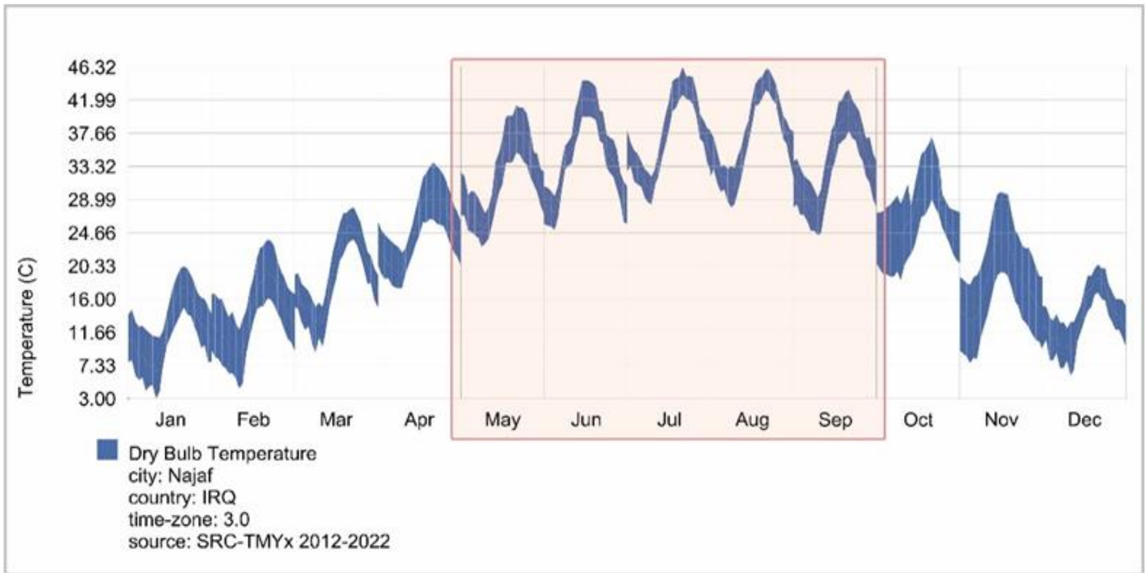

Fig. 2: Average Temperature in the Najaf City, using Ladybug Tool in Rhino-grasshopper.
Source: Authors

This research examines a public hospital with a capacity of 600 beds, located in the northern part of Najaf consisting of three floors (Fig. 3-a). It focuses on the patients' rooms because these rooms are occupied continuously 24 hours/day. They are distributed on each floor in three departments and in each department the rooms are distributed facing the Southern and Northern facades (Fig. 3-b). Each room is 21m^2 and has a volume of about 56.7m^3 (Table. 1). The hospital has 250 patients' rooms, 130 of which are placed towards the southern facade and 120 towards the northern façade.

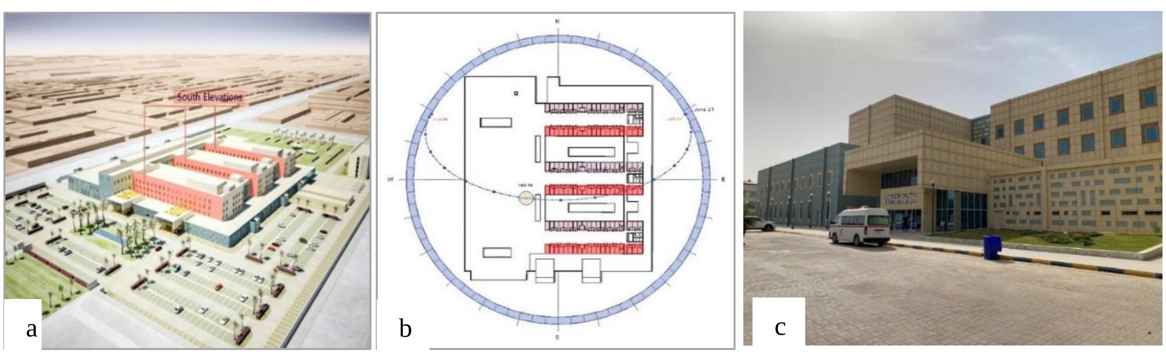

Fig. 3: Plan and views of the Hospital.
Source: authors

Table 1: Details of the patient's room
Source: Authors

Space type	area	volume	window	Window area	doors	No. of Occupants
Patient room	21m2	56.7m3	1	1.2×1.6=1.92 m2	2	2

The Simulation

Developments in computer technologies have improved the ability to carry out simulations. Hence, the possibility of getting more accurate calculations regarding energy efficiency of buildings. The simulations are useful as a design tool at an early stage, which makes it possible to design an ideal cover of a building to be suitable for a specific climatic condition. Boer et al (2011). The computer neither invents the design process, nor redefines architecture or the profession. On the contrary, it provides a valuable tool that enables architects to design and build innovative buildings with more efficient facades that face the external environmental influences. Bacha & Bourbia (2016). Tools of analysis and computer simulation are very helpful in digital design, specially the process of differentiating between alternative designs by a variety of analytical tools and techniques. Figliola & Rossi (2016). In order to explore the difference in the results of analysis and their effects on the energy performance in patient's rooms, this study uses digital design by various tools. One of them is Ladybug & Honeybee, which are tools for simulation and analysis to evaluate energy performance in terms of radiation exposure and energy consumption. These tools can be linked to the Rhino program through various components of Grasshopper (Fig. 4).

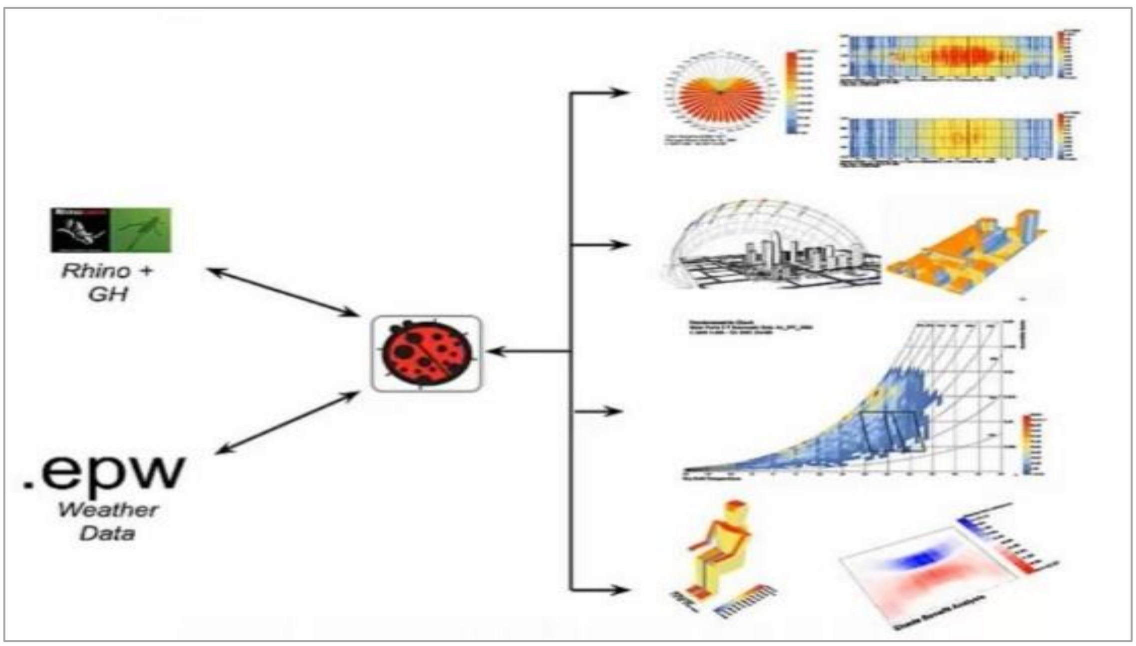

Fig. 4: Components of Grasshopper.

Results and Discussion

After conducting the analysis and environmental simulation on the pinpointed study, the results of the analysis show that the most heat load on the facades of the building of the hospital is between May to August as shown in the Fig.2.

The maximum temperature are between 12 and 6 pm, ranging from 38-49°C, as in Fig.5&6 and a highest thermal load is on the southern facade between, 800-640 kwh/m^2 whereas the lowest thermal load is on the northern facade between 230-320 kwh/m^2.

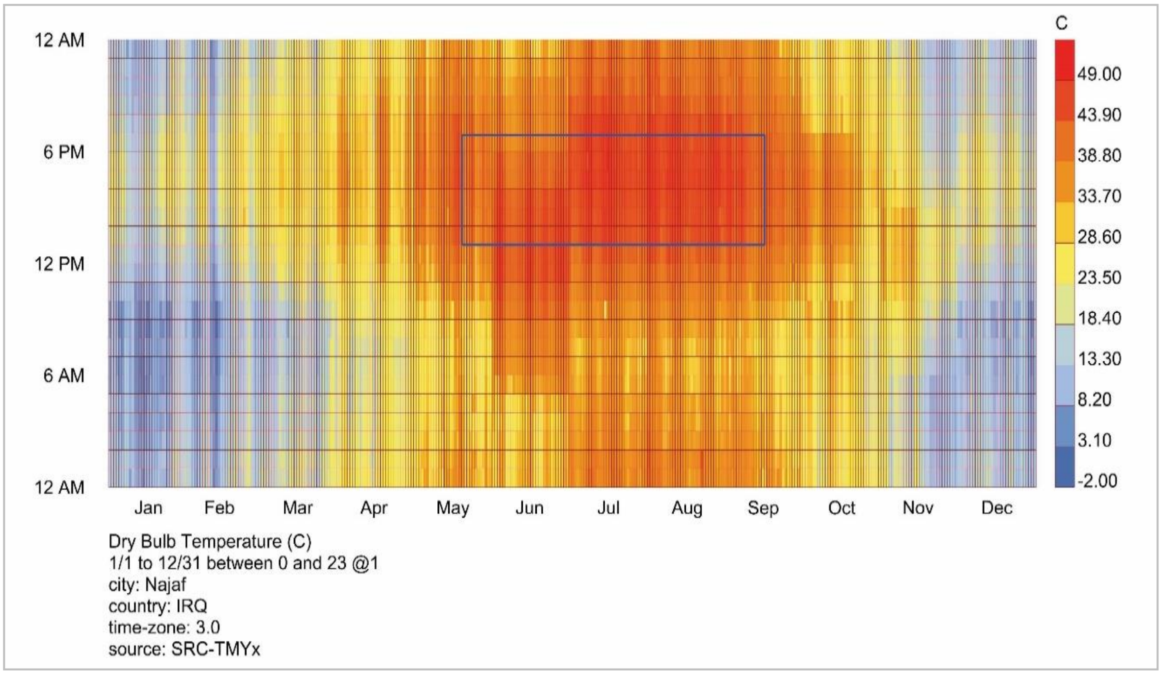

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Fig. 5: Temperatures during days in the Najaf City, using Ladybug Tool in Rhino-grasshopper
Source: author

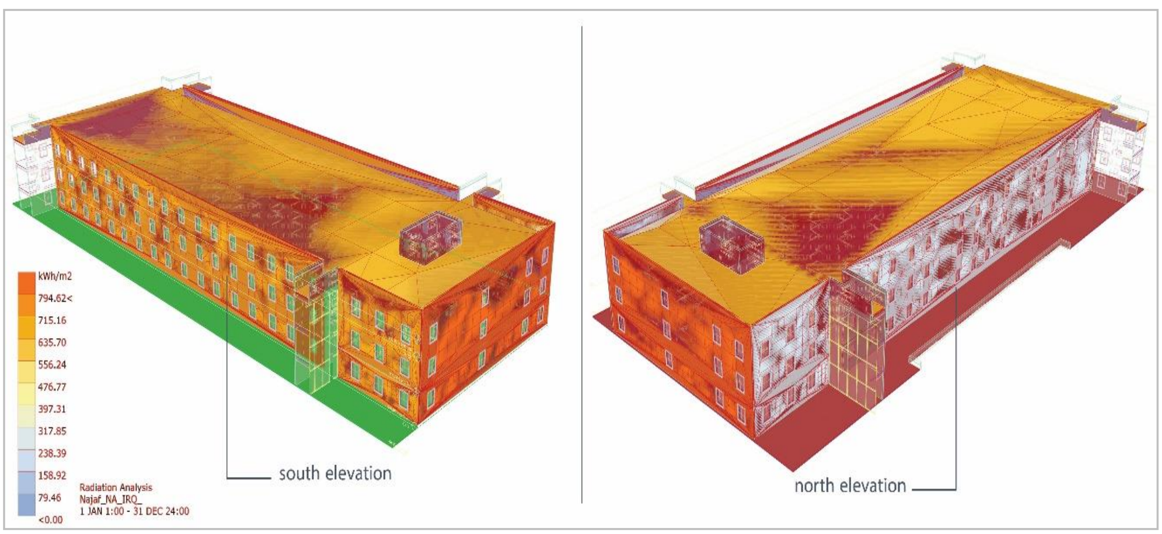


Fig. 6: Thermal loads supporting the cover of the building for both the southern and northern facades using honeybee – radiation analysis Tool in Rhino-grasshopper Program
Source: authors

Table 2: Details of the horizontal and vertical louvers used in this study
Source: Authors

Axis	Width	Length	Thickness	No. of louvers	Distance from facade	Distance between louvers	Total area of louvers
Horizontal	0.5 m	62 m	0.05 m	11	0.6 m	0.8 m	342 m
Vertical	0.5 m	9.5 m	0.05 m	72	0.6 m	0.8 m	340 m

When using the kinetic facade system with horizontal louvers on the southern rooms (Table. 2), the results of thermal analysis show as follow:

1. After using the angle of louvers is 45°, Fig 7, the level of radiation exposure has been reduced by 75 % (Table. 3).
2. After using the angle of louvers is 315°, Fig 7, the level of radiation exposure has been reduced by 50 % (Table. 3).
3.

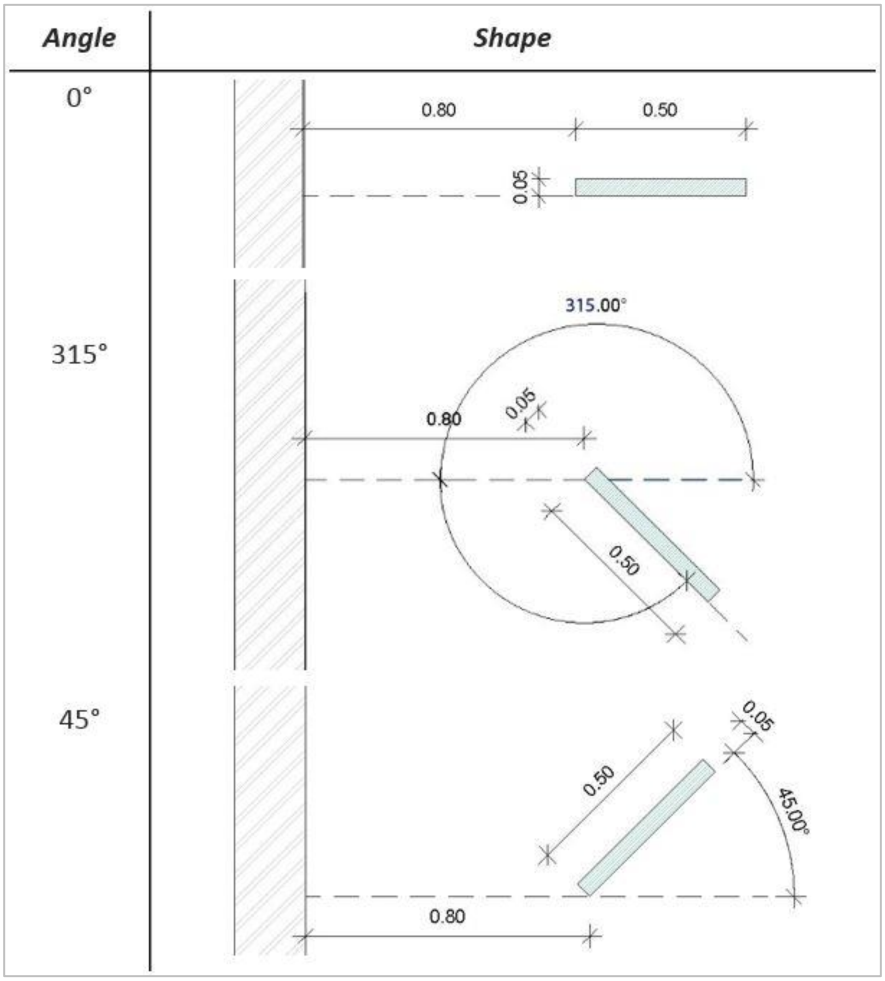


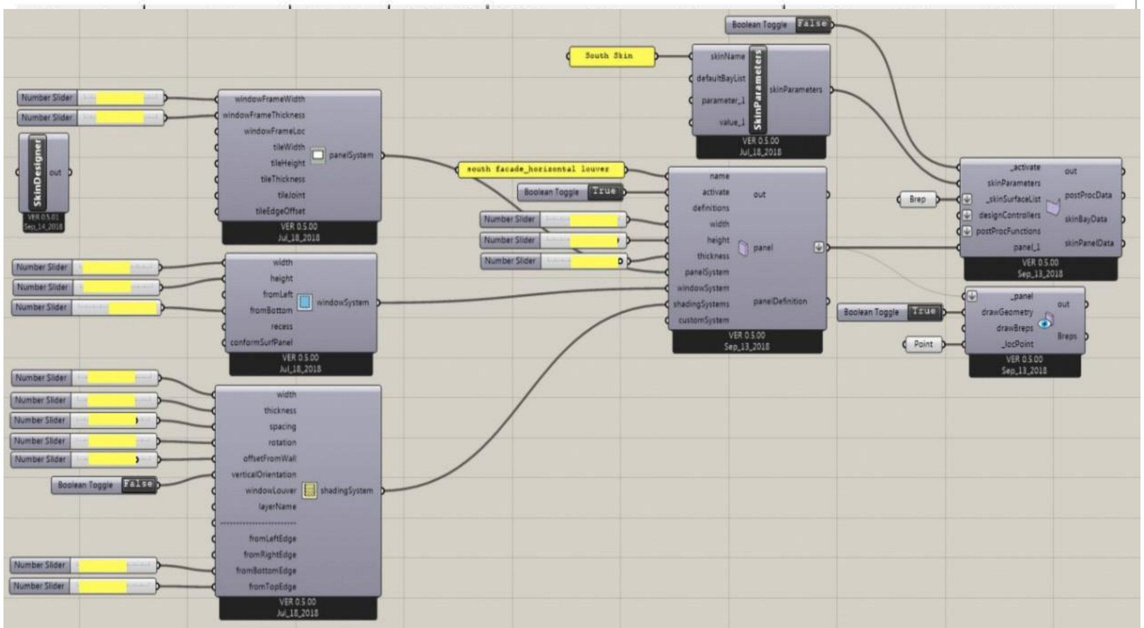
Fig. 7: Degree of angles of the louvers used in the dynamic facade system
Source: authors

Table 3: Results obtained from the thermal analysis process
Source: Authors

Direction	Axis	Angle	Thermal load reduction ratio
South	Horizontal	0°	30 %
		315°	50 %
		45°	75 %
	vertical	0°	15 %
		315°	20 %
		45°	25 %
north	Horizontal	0°	2 %
		315°	5 %
		45°	5 %
	vertical	0°	5 %
		315°	10 %
		45°	12 %

This directly and effectively leads to reduce temperature transferred into the patients' rooms. This also reduces energy used in the automation of the systems of ventilation, cooling and heating (HVAC) and ensures that it reaches the levels of heat in those rooms (24-21) °C HVAC Design Manual (2022). This successfully achieves efficiency of energy performance in the patients' rooms.

Table 4: The Results of Thermal Analysis Process
Source: Authors



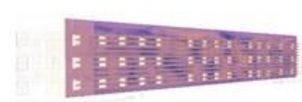
		45°	30 %		
	horizontal	0°	2 %		
		315°	5 %		
		45°	5 %		
north	vertical	0°	5 %		
		315°	10 %		
		45°	12 %		

Fig. 8: The Specific Identifier of Constructing the Horizontal and Vertical Louvers by using Skin Designer tool in Rhino-grasshopper program
Source: authors

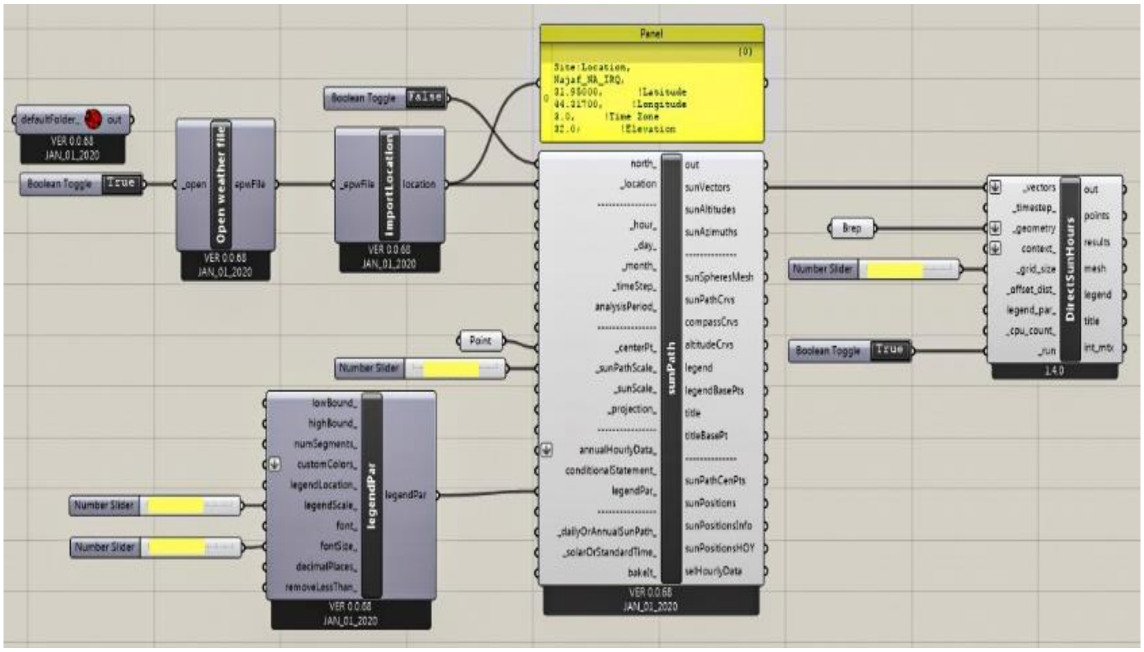


Fig. 9: The Specific Identifier of the Thermal Analysis Tool "Honeybee-Radiation Analysis" in Rhino-grasshopper program
Source: authors

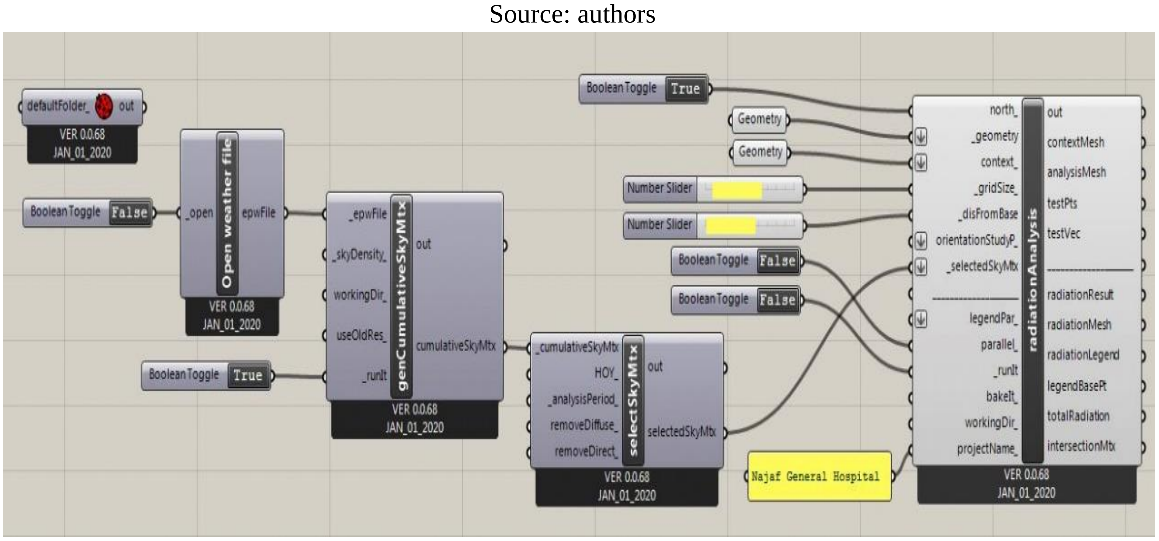


Fig. 10: Specific Identifiers of thermal analysis after using the Kinetic Façade by the Honeybee Tool in Rhino-grasshopper Program
Source: authors

Conclusions

This research thus concludes the following.

1. The use of the kinetic facades influence the reduction of temperatures transmitted to the patients' rooms directly and effectively. As a result, it reduces the consumption of energy in ventilating and cooling of these rooms, thereby increasing the energy performance in the hospital.
2. The kinetic façade of the horizontal louvers type used towards the South at an angle of 45 ° has reduced the level of thermal load in the patients' rooms inside the hospital by 75%. Moreover, it is found that this kinetic façade has achieved an acceptable level of thermal comfort since it reduces the energy consumption that leads to raise energy performance in the patients' rooms.
3. Using the kinetic facade of either the horizontal or the vertical louver type when the patients' rooms are on the Northern facade, leads to lower the rate of thermal load effect.
4. It is found that it is possible to have more accurate calculations for the efficiency of energy performance in hospitals besides evaluating this performance and choosing the best alternatives by using the rhino-Grasshopper program, as well as the simulation and thermal analysis using the Ladybug and Honeybee program.
5. Digital design helps in designing and building hospitals to be efficient in energy use.

Programs used in the study

1. Autodesk Revit 2020
2. Rhino grasshopper 7
3. Skin designer
4. Ladybug & honeybee tools

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