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Research Paper

Simulation of thermal behavior of facades in order to optimal appearance in terms of energy consumption (Case Study: Office building in Tehran, Iran)

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Abstract
In contemporary contexts, optimizing energy consumption and ensuring thermal comfort for occupants in hot and arid climates necessitates prioritizing the shielding of buildings from solar radiation and heat. This study employed simulation techniques utilizing Rhino software, Grasshopper plugin, and Climate Studio plugin to determine the most suitable facade design in terms of energy efficiency, considering the thermal performance of office building facades in Tehran. The investigation evaluated the thermal performance of four facade systems: three variations of double-skin facade (Buffer system, Extract-air system, Twin-face system), and a kinetic facade. Detailed calculations were conducted for heating, cooling, and electrical energy consumption, with results compared using monthly and annual charts. Simulation outcomes indicate that, under constant conditions, the kinetic facade exhibits superior energy efficiency by dynamically adjusting its components, including rotation direction and opening/closing mechanisms, resulting in a 42.3% reduction in energy consumption compared to conventional double-skin facades. Furthermore, the analysis suggests that annual energy consumption, encompassing cooling, heating, and electric lighting, is lower on the southern facade than on the northern facade. Notably, the kinetic facade, with its adaptable design, demonstrates significant performance in energy reduction compared to other facade types, establishing it as the preferred option in this study. Employing intelligent self-adaptive systems, a portion of the facade is configured as a canopy, effectively mitigating building cooling and heating loads by regulating solar radiation, thus enhancing environmental comfort for occupants while minimizing energy loss.

Keywords: *Hot and Dry Climate, Energy Analysis, Thermal Performance, Office Building, Double-Skin Façade, Kinetic Façade.*

1. INTRODUCTION

The building envelope and facade represent critical factors in determining a building's energy consumption, contributing to both increased heating demands during cold seasons and elevated cooling requirements due to solar radiation and space heating. Serving as the interface between controllable indoor spaces and uncontrollable outdoor environments, this component is precisely where significant energy losses occur. Thus, effective control over energy loss and permeability in the exterior facade can substantially diminish a building's overall energy consumption. Furthermore, building envelopes, functioning as conduits for natural light, significantly influence the energy consumption of lighting systems. Comparative assessments of energy usage across various building types reveal that office buildings exhibit higher energy consumption levels compared to other structures, ranging between 100 to 1000 kWh per square meter, contingent upon factors such as location, dimensions, lighting and air conditioning systems, as well as the types and quantities of equipment (Burton & Sala, 2001).

Research conducted in the United States reveals that office buildings exhibit an average energy consumption of 300 kWh, with 70% allocated to lighting and air conditioning. In contrast, studies in the United Kingdom (Lombard et al., 2008) and Canada (N.R.C., 2005) indicate energy utilization rates of 72% and 60%, respectively, in this context. Notably, in Iran, cooling and air conditioning systems account for

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the highest share at 34%, followed by lighting, heating, and cooling systems at 25% and 21%, respectively, contributing to the energy consumption of office buildings, as reported during operational hours despite the relatively abundant daylight in the region (Energy Efficiency Organization Report, 2018). Globally, approximately 30% of electricity consumption in office settings is attributed to lighting (Lam W.M.C., 1986). Despite Tehran's annual average of 3025 hours of natural light, a significant portion of building areas remains deprived of adequate illumination, potentially due to factors such as increased urban density, varied building orientations, spatial design deficiencies, suboptimal use of openings, skylight inefficiencies, and inadequacies in facade systems (Heidari, 2012). Thus, with the hypothesis that altering facade systems and employing environmentally responsive solutions like kinetic facades could mitigate energy consumption, the current study endeavors to compare the energy performance of four distinct facade systems.

Hence, the primary objective of the current study is to examine and contrast the energy efficiency of four facade system models in Tehran. This research is motivated by the growing importance of energy considerations and the imperative to optimize renewable resource utilization, juxtaposed with the necessity to develop solutions for reducing building energy consumption.

2. LITERATURE REVIEW

Numerous studies have examined the thermal performance of facades, focusing on their suitability across various climates and the impact of different facade systems and parameters. These parameters include canopy type (horizontal or vertical, fixed or kinetic), orientation angle, and the operation of openings on thermal efficiency. For instance, Hussgen (2008) conducted simulations of single-shell and double-skin facades using ESP-r software, demonstrating that designing a double-skin facade can minimize a building's heating energy costs by up to 20% (Hussgen, 2008). A double-skin facade comprises two transparent surfaces separated by a cavity. This additional layer can mitigate both summer cooling demands and winter heating demands. Solar radiation penetrating the outer skin on the south-facing facade heats the air within the cavity. Depending on whether heating or cooling is required, this preheated air can be either drawn into interior spaces or ventilated out of the building (Ozdeniz, 2011).

Furthermore, Selkovitz (2001) concluded that advanced glass systems, when integrated with double-skin facades, offer dual benefits: shielding the building from harmful solar radiation and enhancing air quality while reducing cooling and heating loads as well as operational costs (Selkowitz, 2001). In Iran, Ghanbaran and Hosseinpour (2013) advocated for the adoption of double-skin facades in office spaces. Their study involved evaluating the energy performance of an office building in Tehran through simulations with both single-shell and double-skin facades. The findings indicated that compared to a single-shell facade, employing a double-skin facade resulted in a 16% to 20% reduction in the building's energy consumption for ventilation systems (Ghanbaran and Hosseinpour, 2013).

Additionally, the concept of adaptive kinetic facades has been explored through architectural conceptualization, mechanism design, evaluation, materialization, and maintenance processes, drawing upon various design frameworks for kinetic architecture as proposed by other authors (Asefi, 2012; Fouad, 2012; Werner, 2013; Alkhayyat, 2013; Megahed, 2017).

Furthermore, Taraz et al. (2015) conducted an investigation into the efficacy of a kinetic facade prototype in Tehran using both experimental methods and facade simulations. The primary focus of this research was to develop an opening and closing mechanism for a layered modular facade design, aimed at enhancing both the visual aesthetics and functional requirements of the building. Given the hexagon's flexibility in covering surfaces with diverse geometries, the final model was designed in the shape of a hexagon. Figure 1 illustrates the opening and closing phases of the designed facade. As depicted, closing the facade entails the expansion and opening of the hexagonal components from all sides to fully cover 100% of the facade space.

To assess the impact of the designed facade, simulation operations were conducted in both open and closed modes for each of the four primary directions (north, south, east, and west). Subsequently, the annual energy consumption was compared separately for each case. The findings demonstrated that implementing the modular system in the building facade could enhance energy efficiency by enabling intelligent control of light penetration throughout seasonal changes. When the designed facade is positioned on the north-facing side of the building, closing it during winter increases the building's heating load, while reducing cooling energy consumption in summer. Hence, it is advisable to close the facade during summer and open it in winter. Conversely, for the south and east orientations of the building, closing the facade during both summer and winter is preferable. Notably, energy savings are achieved by closing the facade in any mode, with a more pronounced effect observed during winter compared to summer (Taraz et al., 2015).

In a study by Rasouli et al. (2015), the performance of horizontal and vertical kinetic shutters within double-skin facades of office buildings was evaluated through parametric simulation. Their findings indicate that the kinetic canopies outperform their fixed counterparts, with the kinetic horizontal shutter canopy emerging as the most optimal option with the lowest annual energy consumption. Specifically, the total energy consumption of the kinetic horizontal shutter canopy was found to be superior compared to other configurations, achieving a reduction of 27.34% compared to fixed horizontal shutter canopies, 11.87% compared to fixed vertical shutters, and 1.37% compared to kinetic vertical shutters. Additionally, it demonstrated a 50% improvement over double-skin facades without canopies (Rasooli et al., 2018).

Previous studies on the thermal performance of facades predominantly focused on various types of double-skin facades or specific facade systems. However, a comprehensive comparative analysis in this regard has been lacking. Therefore, the aim of this study is to identify the most suitable facade system for hot and dry climates. To achieve this objective, an evaluation of the energy consumption of an office building in Tehran was conducted using four different facade system models. By comparing the thermal performance of these facades on the north and south aspects of the building, it becomes feasible to determine the most suitable facade system with regards to energy consumption.

3. RESEARCH METHOD

The current study employed software simulation and modeling, supplemented by data gathered from both library and field sources. The study area, Tehran, was defined within Climate Consultant 4 software to acquire fundamental climate data, encompassing parameters such as sunshine duration, temperature, and wind characteristics. Analysis revealed that Tehran experiences a maximum temperature of 39.4 degrees Celsius and a minimum of -7.4 degrees Celsius, with a monthly average of 29 degrees Celsius and a minimum of 0.1 degrees Celsius. Sunshine duration ranges from an average of 5 hours in February to over 12 hours in July. Additionally, characteristics of the target building were determined through on-site measurements of dimensions and observation of room illumination patterns throughout the day.

Subsequently, an office building was modeled using four facade systems: 1) Single-shell facade, 2) Double-glazed facade, 3) Double-skin facade with canopy, and 4) Kinetic facade, implemented in Rhino and Grasshopper software. The thermal performance of these proposed facade designs was evaluated using the Climate Studio plugin to simulate the building's response to Tehran's climatic conditions. Finally, the thermal performance of each facade system was compared to elucidate their respective impacts on the building's energy consumption.

The independent variable in this research is the type of facade system (comprising three types of double-skin facades and one type of kinetic facade), while the dependent variable is the annual energy consumption for cooling and heating purposes. Moreover, considering that the examined facades are positioned on the north and south orientations, room orientation (facade direction) is treated as an intervening variable in the research. Detailed steps of the research process are illustrated in Figure (1).

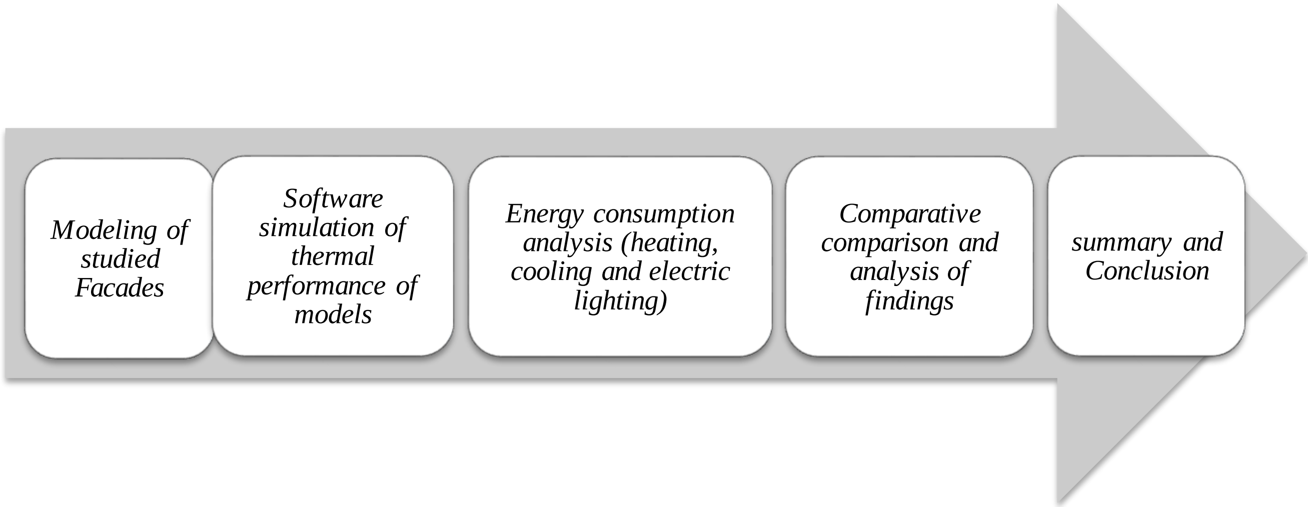


Fig 1. Research process and procedure

4. PROPOSED MODELS OF RESEARCH

Given the prevalent use of glass facades in contemporary office buildings, double-skin facades emerge as an optimal solution. Typically, a double-skin facade consists of two glass layers separated by an air corridor, with the main glass layer serving as insulation against temperature variations, wind, and sound. Sun-shading devices are commonly positioned between the two glass skins to regulate solar heat gain (Ding et al., 2005:37).

Considering the diverse construction types for double-skin facades, establishing a classification system becomes imperative to evaluate and compare their respective merits and environmental effectiveness (Popa et al., 2012). Lang and Herzog identify three fundamental system types:

4.1. Buffer system

The buffer system employs two layers of single glazing separated by a distance ranging from 250 to 900 mm. These layers are sealed to create an air corridor, allowing controlled fresh air entry into the building. This air exchange can be facilitated through additional means such as a separate HVAC system or box-type windows integrated into the overall double skin. Shading devices may also be incorporated within the cavity to regulate solar heat gain (Elzyadi, 2017).

4.2. Extract-air system

The extract-air system comprises a second single layer of glazing positioned on the interior of the main facade, typically consisting of double-glazing or thermopane units. The air space between these two layers of glazing is integrated into the HVAC system. Heated air between the glazing layers is extracted through the cavity using fans, thereby regulating the temperature of the inner layer of glazing, while the outer layer of insulating glass minimizes heat transmission loss. Fresh air is supplied by the HVAC system, precluding natural ventilation. As a result, these systems typically do not reduce energy requirements, as fresh air changes must be mechanically supplied. Occupants are unable to adjust the temperature of their individual spaces. Shading devices are commonly mounted within the cavity. The spacing between the glass layers ranges from approximately 150 mm to 900 mm, determined by the requirements for cavity access during cleaning and the dimensions of the shading devices (Nasrollahi & Hadianpour, 2013).

4.3. Twin-face system

The twin-face system comprises a conventional curtain wall or thermal mass wall system encased within a single-glazed building skin. The outer glazing, which may consist of safety or laminated glass, or insulating glass, serves primarily to shield the air cavity contents, such as shading devices, from weather conditions. This system requires an interior space of at least 500 to 600 mm to facilitate cleaning. Distinguished from both buffer and extract-air systems, twin-face systems include openings in the skin to enable natural ventilation. The single-glazed outer skin provides protection and insulation properties to minimize heat loss, while the internal skin serves to regulate thermal insulation. Additionally, the outer glass skin serves to impede wind flow in high-rise situations, while also permitting interior openings for access to fresh air without causing noise or turbulence (Boake et al., 2013).

The three systems differ markedly in their ventilation approaches and their capacity to decrease overall energy usage (Ahmed et al., 2022). Figure (2) illustrates the various types of double-skin façade systems.

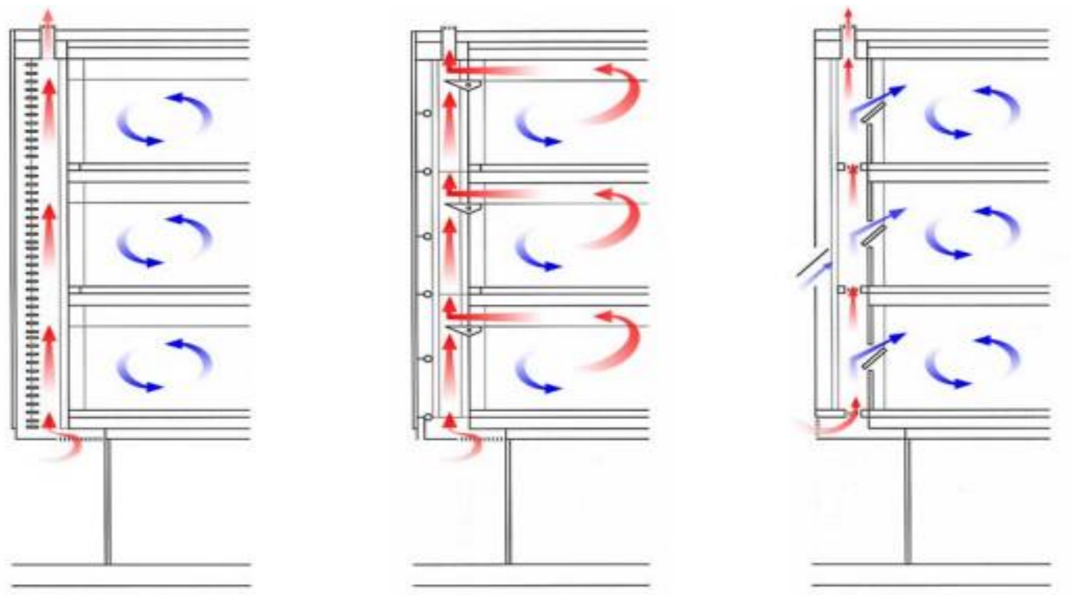
This type of façade, a suitable alternative in office building design for the past twenty years (Poirazis, 2004) have been selected as the primary research models.

Furthermore, double-skin facades exhibit adaptability to both cooler and warmer climates, rendering them highly versatile. This adaptability stems from their ability to undergo minor adjustments, such as opening or closing inlet or outlet fins or activating air circulators, thereby altering the façade's behavior.

In colder climates, the air buffer within the double-skin façade acts as a barrier against heat loss. Sun-heated air trapped within the cavity can warm spaces outside the glass, consequently reducing the demand for indoor heating systems. Conversely, in hotter climates, the cavity can be vented externally to mitigate solar heat gain and lessen the cooling load. Excess heat is expelled through a process known as the chimney effect, wherein differences in air density induce a circular motion, causing warmer air to rise and escape. As the air temperature within the cavity increases, it is pushed outwards, generating a gentle breeze in the surroundings while providing insulation against heat gain (Jankovic & Goia, 2021). Figure (3) illustrates the various airflow path alternatives within a double-skin façade.

4.4. kinetic facade

The fourth proposed model is a modular dynamic system that can be installed on the façade of the building (refer to Figure 4).



1) Buffer system 2) Extract-air system 3) Twin-face system

Fig 2. Types of double-skin façade systems (Boake et al, 2013)

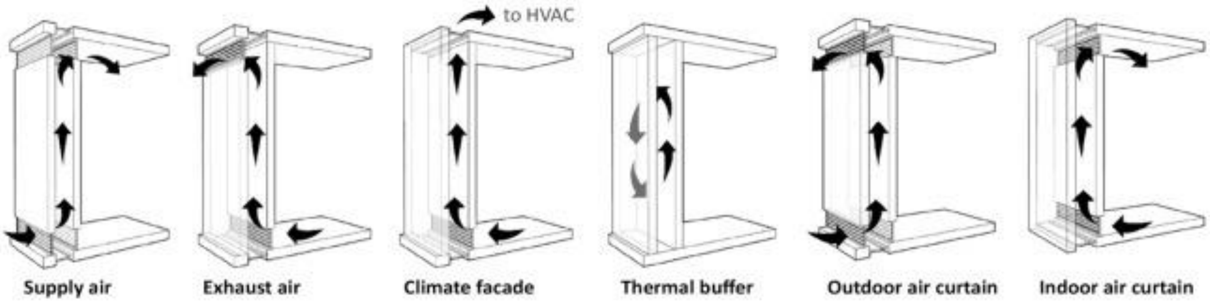


Fig 3. Double skin façade airflow path alternatives (Hachem- vermette, 2020)

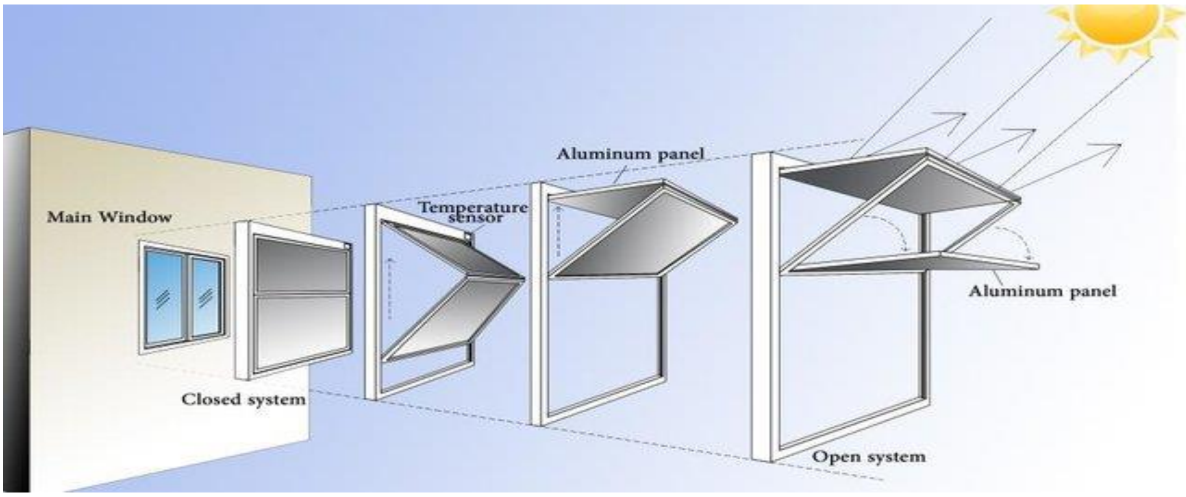


Fig 4. Stages of the operation of the kinetic system (Elkhayat, 2014)

The kinetic facade mechanism elevates the control of light to a more intricate level, reducing energy consumption and enhancing resident comfort. Referred to as a kinetic facade, this type of facade primarily focuses on controlling and enhancing four major environmental variables: solar thermal energy, sunlight, ventilation, and energy production within the building (Hensen et al., 2002). By effectively managing these variables, kinetic facades can significantly minimize energy consumption.

The kinetic facade dynamically adjusts the building's state and structure in response to changing external conditions, ensuring continuous comfort within the interior space. One of its primary advantages lies in its ability to regulate the amount of daylight entering the interior, thereby improving daylight quality and enhancing vision quality, particularly in office and public spaces (Sangtarash et al., 2022).

Geometric and kinematic models are pivotal in the design of kinetic facades. These models play a crucial role in understanding the facade's opening and closing mechanisms, controller functionality, material selection, and structural stability. The mobility of the facade or its modules necessitates the geometric integrity of its components to maintain structure and coherence while undergoing shape changes (Sharaidin, 2014). Unlike static facades, the design process for a kinetic facade involves an interactive approach, encompassing the selection of geometry, analysis of movement, creation of digital and physical models, and the design of connections and materials to accommodate movement mechanisms (Sangtarash et al., 2022).

5. SIMULATION PROCEDURE

The simulation procedure utilized meteorological data from the Shemiranat synoptic station, situated in the northern region of Tehran at an altitude of 1415 meters above sea level (TMY2). According to this data, the maximum and minimum temperatures recorded in Tehran are 39.4°C and -7.4°C, respectively. Additionally, the monthly average temperature is 29°C, with a minimum of 0.1°C (Heidari and Jahani Nogh, 2018).

The building under investigation is a four-story office-service complex situated in Zafaranieh, Tehran, with the ground floor designated for service provision. Further details about this building are depicted in Figure (5).

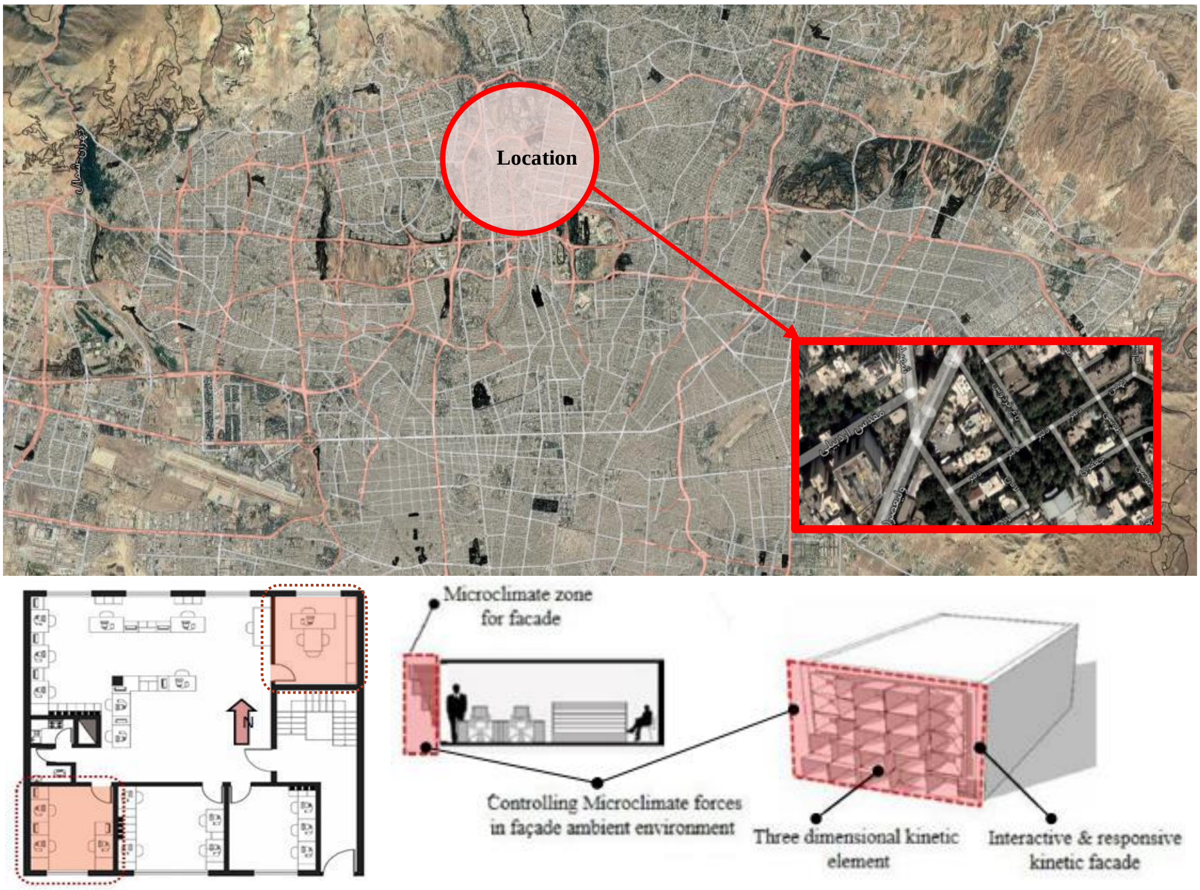


Fig 5. Information about the building under study (Location, plan, section and elevation)

The simulation analysis focused on an office space spanning 220 m2, comprising five distinct office areas. Among these areas, two rooms, each measuring 3 by 5 meters with a height of 2.80 meters, are positioned on the south and north sides of the building, respectively. Each room features a single wall, containing a window measuring 230 by 160 centimeters and situated one meter above the floor level, connecting to the external environment. The window is constructed with single-paned glass, 6 mm thick, and with a visible light transmittance of 60%.

The outer wall of the building is constructed using 30 cm thick brick, while the inner walls and roof are simulated with 5 cm thick white plaster. Additionally, the floor of the space is simulated with gray ceramics (Khatibi et al., 2022). Table (1) provides detailed characteristics of the materials utilized in the walls, along with the physical and thermal properties of various components comprising the basic model.

In the simulation process, the number of investigated parameters is crucial for determining the accuracy of the simulation. Generally, a higher number of parameters results in a more accurate simulation. To summarize, the simulation steps for both the south and north faces include driver parameters, digital model creation, and evaluation (refer to Figure 6). These steps were repeated for each of the three types of double-skin facades on both the north and south fronts.

Table 1. Specifications of the basic research model

General Features	land use	Office - Services
	Infrastructure area	220m^2
	Number of floors	4 floors
Outdoor space	Climatic characteristics	Hot and Dry Climate
	Location of the building	Tehran
Shell	external wall	Cement board with a thickness of 2cm, Concrete block 10cm, Gypsum board with a thickness of 1.3cm
	Opening	Single wall window with aluminum profile with dimensions of 230 × 160 and laminated glass with a thickness of 4 + 6 mm with a coefficient of temperature 3 (w/m^{2}k)
Internal space	Dimensions of the interior	Room 5 × 3 m to a height of 2.80 m
	Interior materials	White gypsum plaster with a thickness of 5cm with a heat coefficient of 0.25 (w /m^{2}k)
	Floor materials	Gray ceramics with a thickness of 1 cm, Concrete with a thickness of 20 cm And gypsum acoustic tile

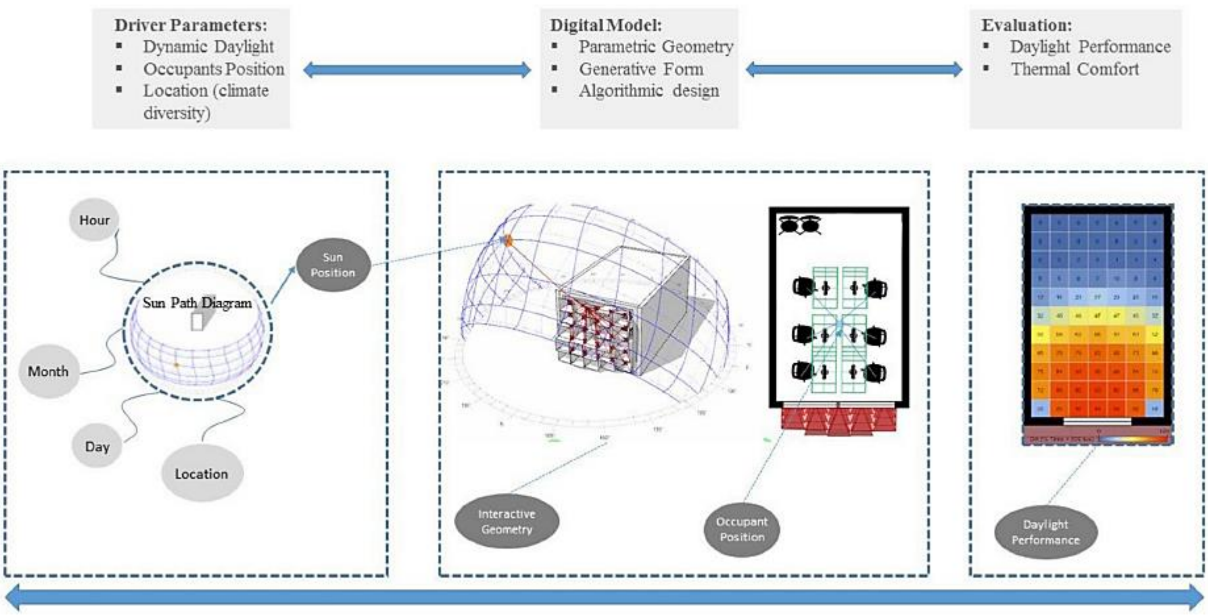


Fig 6. Algorithmic workflow for digital modeling and parametric evaluation in kinetic facade

The initial stage of the thermal analysis involved determining the annual energy consumption of the building, encompassing the cooling load, heating load, and electric lighting in the facades. For this research, the calculation of cooling and heating loads for the facades was conducted using energy modeling in Climate Studio software on a monthly basis. The analysis process was systematically executed on both the south and north fronts of the building.

Furthermore, adhering to Iranian national regulations, the simulated heating and cooling set points were established as 20°C and 28°C, respectively (National Building Regulations of Iran, 2014). Concerning double-skin facades with canopies operating under manual control, users activate the canopy from 10:00 AM to 4:00 PM during months when the building cooling system is active. Conversely, during months when the building heating system is activated, users close the opening from 6 PM to 6 AM. Moreover, the canopy automatically closes before the activation of the cooling system in summer and heating system in winter. Window protective covers also automatically close based on predefined set points in the installation system during the heating system operation, particularly during nighttime when the internal temperature reaches 20 degrees Celsius (heating system set point). Similarly, during the cooling system operation, when the internal temperature reaches 28 degrees Celsius (cooling system set point), the shade automatically closes with louvres positioned at a 45° angle (Vahhabi and Mahdavi Nia, 2018).

6. DISCUSSION

The research findings and results from the modeling process across various departments are detailed as follows. Initially, the cooling load analysis was conducted, comparing the cooling load for each facade on both the north and south sides. Subsequently, the heating load for the studied facades was examined on both the north and south fronts. Finally, an analysis of the electrical lighting load was presented. It's important to note that, as per the research method, the facade direction was treated as an intervening variable. Therefore, the cooling and heating loads for each of the four studied samples were calculated separately for the north and south facades, assuming a fixed facade direction.

6.1. Cooling load analysis

As depicted in Figure 7, the cooling load across all facade models is notably higher on the south side compared to the north side, which aligns with the expected direct sunlight exposure on the southern facade. Particularly, the extract-air system exhibits the highest cooling load on both the south and north sides, whereas the kinetic facade demonstrates the lowest cooling load, indicating the significant impact of facade system variation on cooling load reduction. For instance, in the southern zone, the first type of double-skin facade shows cooling loads of 959.56 kWh, reduced by 35% compared to the buffer system, while in the northern zone, it's 923.98 kWh, reduced by 25%. Similarly, the twin-face system exhibits a cooling load of 855.52 kWh in the southern zone, reduced by 42% compared to the buffer system, and 32% in the northern zone. The kinetic facade also shows considerable reductions, with cooling loads of 812.08 kWh and 800.73 kWh in the southern and northern zones, respectively, representing reductions of 45% and 35% compared to the buffer system. Overall, the impact of facade system variation on cooling load reduction appears to be more pronounced in the southern zone than the northern zone.

In summary, the extract-air system with a fixed canopy and the twin-face system with manual control canopy both aim to minimize direct sunlight penetration into the interior space, particularly during the warm season. By adjusting the canopy to absorb minimal light radiation, these systems effectively reduce the need for cooling system usage.

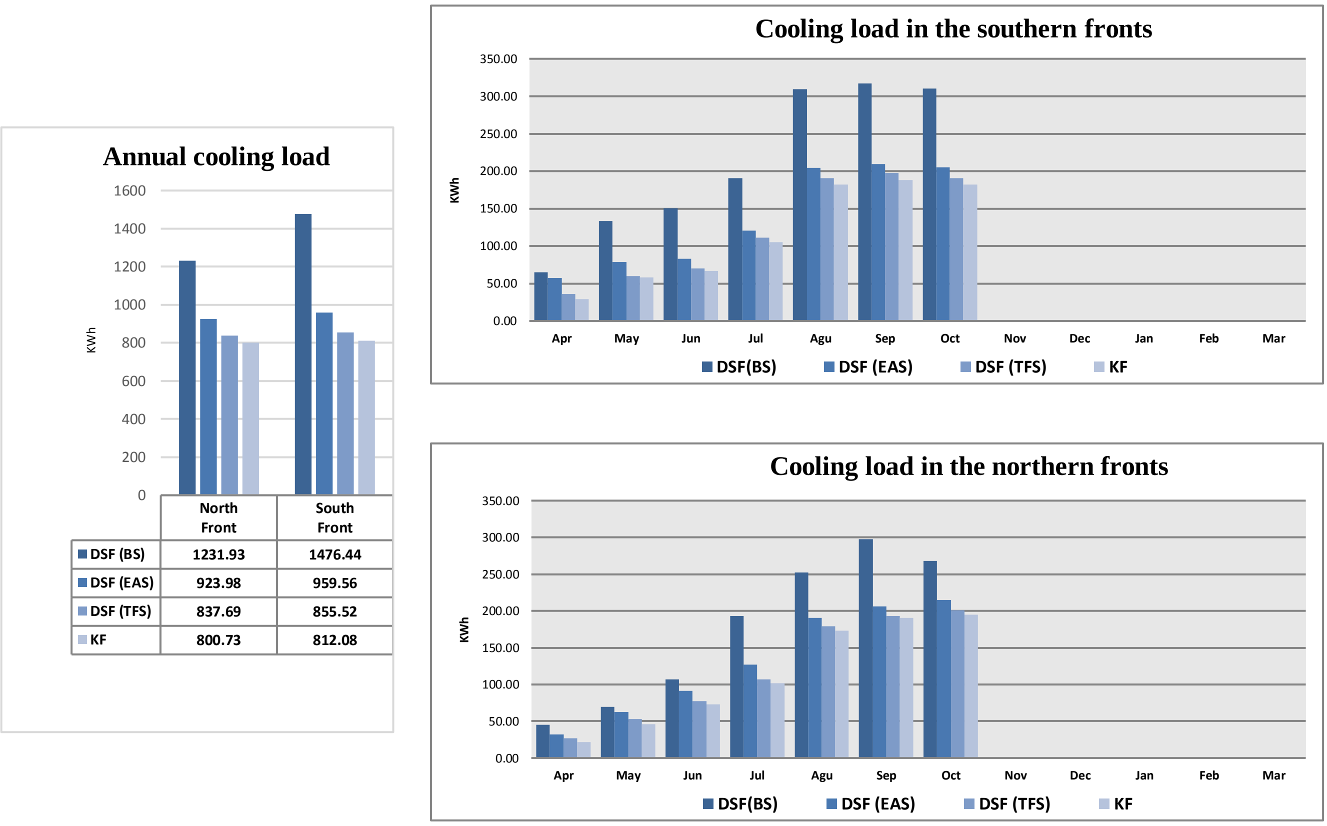


Fig 7. Comparison of cooling load in the façades on the south and north fronts on monthly and annual bases

6.2. Heating load analysis

The investigation into heating load for the rooms under different façade conditions reveals intriguing findings, as illustrated in Figure 8 depicting monthly and annual graphs for both the southern and northern fronts. Surprisingly, the annual heating energy consumption is observed to be higher on the northern front compared to the southern front. Regarding the impact of façade type on heating load, the extract-air system exhibits the highest heating load, while the kinetic façade shows the lowest. Meanwhile, both types of double-skin façades demonstrate equally effective reduction in heating load due to enhanced thermal insulation and solar thermal energy preservation within the cavity.

In particular, the heating energy consumption for an office building equipped with the first type of double-skin façade (without canopies) is virtually zero annually, indicating that the interior temperature remains above 22 °C, thereby negating the need for heating system activation. However, the introduction of canopies in double-skin façades increases heating energy consumption, albeit effectively reducing heating load by preventing direct solar radiation absorption during colder seasons. Notably, kinetic canopies outperform fixed canopies by maintaining louvers at a closed, zero-angle position based on predefined set points, minimizing air penetration through seams during winter and cold nights.

In the case of twin-face systems with manually controlled canopies, minimal utilization during autumn and winter leads to a 24% reduction in room heating load compared to buffer system façades. Conversely, intelligent utilization of kinetic façades yields a more significant reduction of 39% in heating load.

6.3. Lighting electrical load analysis

In the third phase, the electrical load for the rooms was assessed across four scenarios involving single-shell façade, first and second type double shells, and kinetic façade. Figure (9) depicts the electric lighting load of the façades on both the southern and northern fronts through monthly and annual graphs.

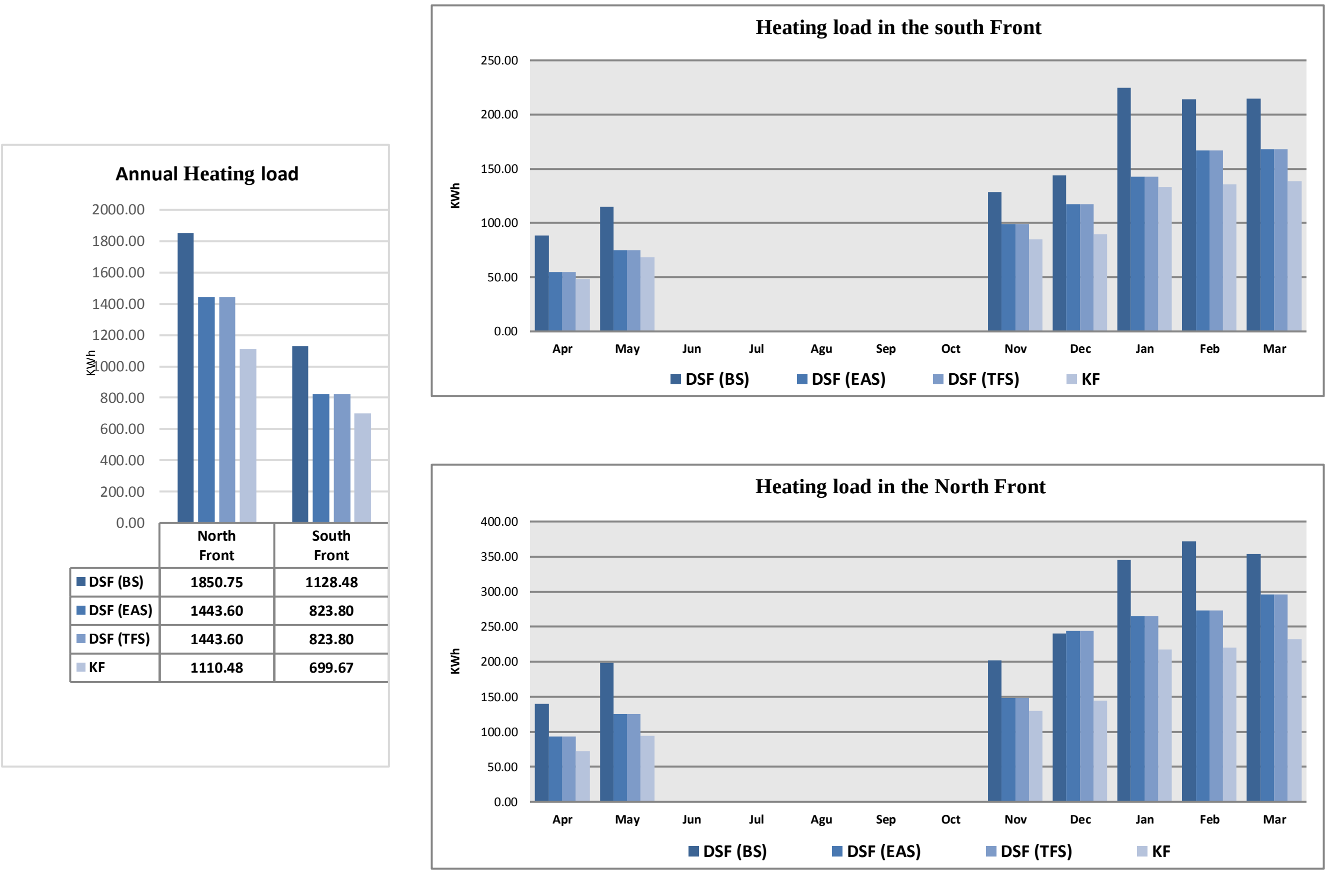


Fig 8. Comparison of heating load in the façades on the south and north fronts on monthly and annual bases.

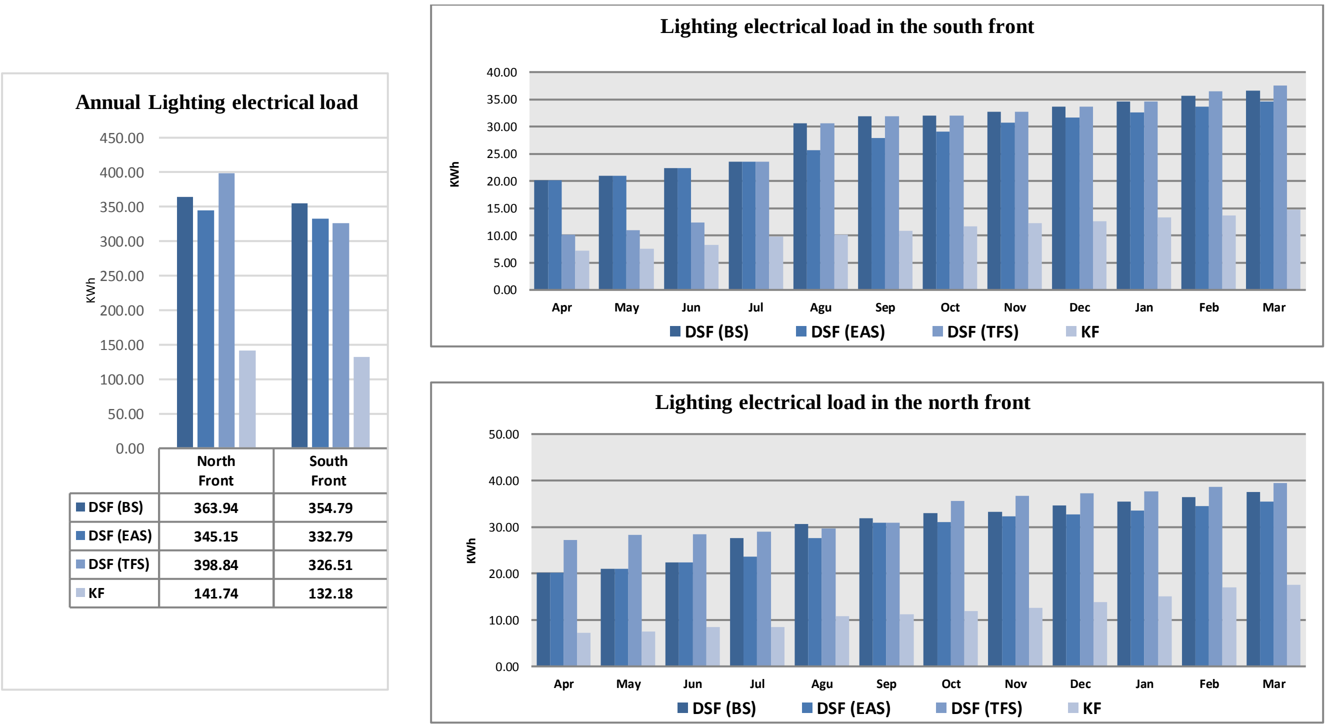


Fig 9. Comparison of the electric charge of lighting in the façades on the south and north fronts on monthly and annual bases.

The annual comparison of lighting electricity consumption on both the southern and northern fronts reveals similar consumption levels. Further comparison among the four scenarios—single-shell façade, double-glazed façade, double shell with canopy, and kinetic façade—indicates the most significant disparity in lighting electricity consumption occurs with the kinetic façade. By controlling the amount of light and heat entering the space based on the façade's open or closed mode, the kinetic façade substantially reduces lighting electricity consumption. Additionally, it effectively prevents undesirable light emissions during sunrise and sunset on both the eastern and western fronts through intelligent settings.

Considering the heating and cooling loads in the façades and the canopy's impact on light penetration, it's expected that canopies increase natural light penetration into the space. However, the diagrams illustrate a reduction of 62% in lighting electricity consumption with the kinetic façade compared to the buffer system. Conversely, there's a 12% increase in lighting electricity consumption with the third type of double-skin façade (TFS) compared to the second type (EAS). This increase may be attributed to the canopy's angled placement in the summer to mitigate heat absorption, thereby reducing the amount of light entering the space and necessitating the activation of lighting equipment for standardization and optimization.

7. FINDINGS

The energy consumption simulation of the office building's façades reveals higher energy consumption in rooms located in the northern zone compared to those in the southern zone, assuming a 70% window-to-wall area ratio. The type of façades significantly influences cooling and heating loads, with double-skin building façades exhibiting notable heat capacity and insulation properties. The kinetic façade, replacing the double-skin type, notably reduces cooling loads while double-skin façades demonstrate greater impact on heating loads.

Canopies integrated into the façades affect annual heating energy consumption, with double-skin façades without canopies experiencing zero consumption during cold periods. However, double-skin façades with canopies increase heating energy consumption due to reduced direct solar absorption by the inner shell. During heating periods, canopy adjustment by users contributes to thermal comfort, yet may intensify internal heat and cooling costs. Conversely, kinetic façades intelligently adjust canopy environments to mitigate glare and cooling loads, thereby reducing cooling and heating loads.

Regarding lighting electrical energy, the first type of double-skin façade exhibits 12% higher annual consumption than the twin-face system, despite canopy integration increasing heating and lighting energy consumption. Ultimately, canopies reduce overall energy consumption, with kinetic canopies allowing optimal angle adjustments to minimize cooling and lighting loads during heating periods. Overall, kinetic façades prove more efficient than fixed canopies in annual energy consumption, assuming constant operating conditions.

8. CONCLUSION

In today's context, shielding buildings from sunlight and heat is crucial for ensuring thermal comfort, especially in hot and arid regions. Consequently, identifying the most suitable façade system for office buildings to minimize energy consumption was the primary objective of this study. To determine the optimal solution, the thermal performance of four façade systems, including three types of double-skin façades and a kinetic façade, was meticulously assessed to gauge their impact on the building's energy consumption. Through simulation of these façades under Tehran's climatic conditions and conducting thermal analyses on both the northern and southern fronts of the building, the study outcomes were portrayed through monthly and annual graphs detailing cooling, heating, and electrical lighting loads.

The results gleaned from these analyses indicated that both double-skin and kinetic façades contribute to reducing energy consumption in the building, with the kinetic façade demonstrating a notably superior performance compared to double-skin counterparts. Although all types of double-skin façades led to an increase in lighting load, they substantially mitigated heating load. This characteristic allows double-skin façades to effectively meet heating requirements during cooling periods, offering more favorable conditions compared to extract-air systems.

Furthermore, the kinetic façade showcased its adaptability by enabling precise adjustments of its components, such as rotation direction and opening/closing, effectively controlling the influx of light and heat into the building. This ability not only enhances environmental comfort by minimizing light and energy waste and glare but also reduces overall energy consumption by optimizing solar energy absorption in winter and minimizing it in summer.

Additionally, the study highlighted the significant impact of canopies on reducing energy consumption, with kinetic canopies proving to be more efficient than fixed ones. Overall, the thermal performance of the kinetic façade was deemed desirable compared to other façades evaluated in the study.

In conclusion, it is recommended to conduct further numerical studies and simulations to explore the thermal performance of façades. These studies should focus on evaluating the impact of various factors such as the number of shells, shell types, opening and closing degrees, and geometric patterns employed in kinetic façades. It is essential to address research limitations, including utilization types, climate conditions, and specific façade configurations.

Moreover, future research should delve into the energy efficiency of kinetic façades across different climates and usage scenarios. This entails considering factors such as construction, production, installation, and maintenance costs.

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