

Investigating Impact of Double-Skin Facades on Reducing Energy Consumption in Office Buildings (Case Study: Computer Center Building at Shahrood University of Technology)

F. Ahani, E. Sarkardehi *, M. Ansarimanesh, H. Moslehi

Faculty of Architectural Engineering and Urbanism, Shahrood University of Technology, Shahrood, Iran.

Received Date 17 January 2025; Revised Date 27 March 2025; Accepted Date 12 May 2025

*Corresponding author: ahanifatemeh7@gmail.com (F. Ahani)

Abstract

Approximately 40% of fossil energy consumption in Iran is attributed to office and residential buildings. Therefore, optimizing energy consumption and managing energy demand in these buildings is essential. A key aspect of this optimization is the building's outer shell, which plays a vital role in heat control. One effective method for reducing energy consumption in buildings is the implementation of double-skin facades (DSFs), which have demonstrated superior performance compared to single-skin facades. Considering the high energy consumption of office buildings in Iran, this research aimed to minimize energy use in the computer center building at Shahrood University of Technology. The research methodology consisted of a literature review, field measurements, and simulation. The validity of the research data was evaluated against field measurements, and its accuracy was confirmed. Using Design Builder version 7 simulation software, twelve models of double-skin facades were analyzed and categorized into box window facades and shaft boxes, both located on the southern elevation of the computer center building. The results indicate that the double-skin facade featuring a box window reduces the building's energy consumption by 6.4% to 9.7% compared to the single-skin facade. Additionally, the double-skin facade of the shaft box also decreases energy consumption, ranging from 5.5% to 9.3% compared to the single-skin facade.

Keywords: *Double skin facade, Office building, Reducing energy consumption, Simulation, DSF.*

1. Introduction

Currently, the construction industry is a major consumer of electrical energy generated from fossil fuels.[1]. Studies show that nearly one-third of global energy consumption is linked to the building sector, which accounts for almost a quarter of worldwide carbon dioxide emissions. [2,3]. According to the International Energy Agency, the building sector in the European Union is the largest consumer of energy [4]. Moreover, IBM¹ research shows that building energy consumption increases by 1% each year. This indicates that by 2060, buildings will consume 30% more energy. [5]. The energy consumption of a building is significantly influenced by its coverings, including walls, windows, floors, and ceilings [6]. The facade of a building serves a critical function in mediating the relationship between the internal and external environments and strongly affects the

building's interior temperature and energy consumption. [7,8]. In multi-story buildings, 40% of total heat loss occurs through the façade. Consequently, most energy exchanges in the building relate to its outer shell [9]. The building's facade facilitates heat exchange, solar energy reception, ventilation, and penetration of light and sound into the interior.[11]. Additionally, Office buildings are classified as high energy consumers due to their quantity, operating hours, and energy consumption patterns. [12]. To reduce energy consumption in buildings, significant efforts have been made to develop various types of sustainable structures, among which we can mention double skin facade (DSF) [13]. Considering that the highest energy consumption in Iran is associated with the building construction sector, utilizing a double-skin facade can be a crucial step in reducing energy use. The

¹ International Business Machine

selection of an appropriate double-skin facade from the extensive range of over 40 available types is crucial for optimizing energy efficiency in buildings. When a facade is misaligned with the specific environmental conditions, it not only fails to achieve the intended reduction in energy consumption but may also worsen energy wastage, resulting in an overall increase in energy use. Ultimately, choosing the right facade can make a significant difference in a building's performance and sustainability. The proper design and effective use of natural daylight can reduce building energy costs by up to 30%. [14]. So far, many studies have been conducted on the efficiency and performance of double-skin facades in different climates, and since most of the research on the performance of double-skin facades in Iran has been conducted in the climate of Tehran, this study examines the performance of double-skin facades in the climate of Shahrood. Also, considering the high energy consumption of office buildings in Iran, the limited fossil reserves, and the need to reduce energy consumption in these buildings, this research examines the computer center building of Shahrood University of Technology.

Research Question

- To what extent can the implementation of a double-skin facade in an office building located in the Shahrood region reduce overall energy consumption?
- It is hypothesized that incorporating double-skin facades will lead to a significant reduction in energy consumption, thereby decreasing the reliance on heating systems during winter and cooling systems in summer.

Research Purpose

- The primary aim of this research is to reduce energy consumption in the computer center building in the Shahrood region through the adoption of a double-skin facade.

2. Double-Skin Facade

A DSF² consists of one or more surfaces, featuring multiple layers of glazing separated by an air cavity. This air space between the two layers acts as an insulating barrier [15,16,17,18,19] (Figure 1). The air space between the shells can be ventilated either naturally or mechanically [5,20,21]. In mechanical ventilation, the volume of air being ventilated can be adjusted and controlled. In contrast, natural ventilation relies on wind and the thermal behavior of the building's facade. To enable effective natural ventilation, it is essential to create adequate openings in both the internal and external walls [22]. In these air cavities, the canopy device, typically of the blind type, can be installed along with systems that generate

electrical energy, such as photovoltaic cells [23,24]. The middle cavity collects solar radiation in winter through the greenhouse effect or releases it in summer via natural ventilation [25]. In double-skin facades, heat transfer occurs between the layers of glass, the canopy, and the facade surfaces through radiation [26,27]. The DSF has a higher saving capacity than the traditional SSF³. It offers better heat retention during winter and reduces internal heat through cavity ventilation in summer [28]. With proper design, double-skin facades can enhance visual appeal, reduce noise pollution, and control light and heat within the building [26,29]. The environmental and economic benefits of DSFs include reduced energy consumption, increased airflow, enhanced thermal comfort, improved daylighting and glare control, better sound insulation, noise reduction, enhanced aesthetic quality, and long-term cost savings [30]. of the constructional features investigated in this study (exemplified for the case of an outdoor air curtain DSF) [35].

Double-skin facades are generally divided into four categories: box window type, shaft box type, corridor type, and multi-story type [33] (Figure 2).

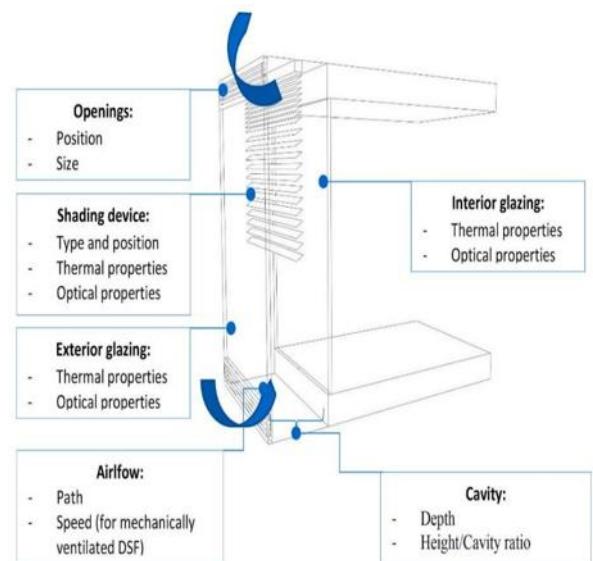


Figure 1. Schematic representations

² Double Skin Facade

³ Single Skin Facade

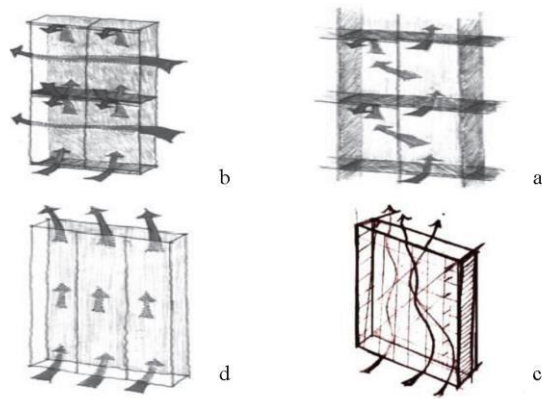


Figure 2. Types of double-skin facades based on the middle cavity.: a) box window, b) corridor, c) multi-story, d) shaft box [25].

In winter, it would be advantageous in terms of thermal comfort to close the openings since external temperature is always lower than inside the building. Existing studies and cases have shown that, as mentioned in the introduction, the static air buffer is the optimal type in winter because it acts as a thermal buffer (Figure 3). In summer, an airflow operating method should be used appropriately since the relationship among the temperature outside the cavity, inside the cavity, and inside the building changes over time. Within the duration of sunshine, in which the external temperature is higher than inside the building, closing the openings inside the building would be advantageous in terms of thermal comfort since the heat gained by solar radiation would be removed in the cavity before it enters the building (Figure 4).

Meanwhile, after sunset, when external temperature becomes lower than inside the building, natural ventilation, in which the openings of the cavity are opened, can emit heat inside the building. Therefore, to save cooling energy consumption, natural ventilation can be used according to specific circumstances [34] (Figure 3).

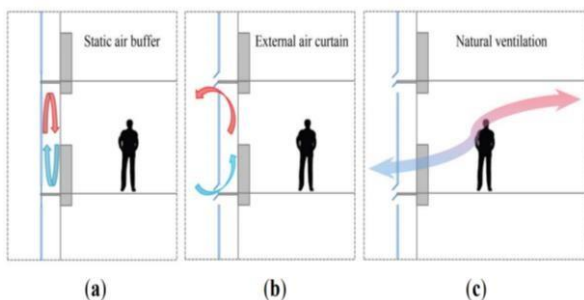


Figure 3. Seasonal airflow operating method of a DSF: (a) Static air buffer as winter airflow operating method; (b) External air curtain as summer airflow operating method; (c) Natural ventilation as summer airflow operating method [34].

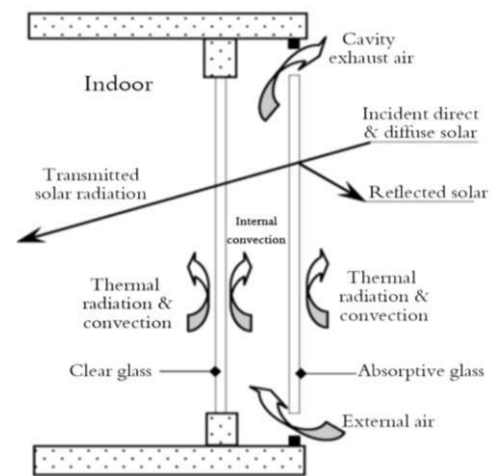


Figure 4. Heat transfer and air movement in DSFs [1].

Hafezi *et al.* [12] have investigated 4 double-skin facade models in an office building in Tehran. The results obtained from Design Builder software showed that the shaft box facade type, if no utility systems are used, and the box window facade type, if utility systems are used, showed the best performance. Siadaty *et al.* [26] studied the optimization of thermal performance of a box window type double-skin facade with natural ventilation in the summer season in Tehran. The results of the study showed that among 112 simulated double-skin facade scenarios, the best type of double-skin facade is one with a cavity width of 120 cm, a cross-sectional area of air inlet and outlet vents of 0.20% m², and low-emissivity interior and exterior glass and a canopy with an angle of 45 degrees. Tao *et al.* [36] have investigated double-skin facades with natural ventilation and adjustable louvers. The results of the study showed that the optimal louver angle at 45 degrees can increase ventilation. Su *et al.* [28] have researched on the optimization of double-skin facade design for different climatic regions in China. The results show that the structural parameters of the double-skin facade significantly affect the thermal performance of the double-skin facade. These parameters can include the type of opening, the width of the opening, and the width of the cavity. Naddaf and Yasin Bapar [7] studied the selection of the most appropriate type of doubleskin facade to optimize the energy performance of a building using Energy Plus and Climate Studio software. The building under study is located in Erbil and four geometric shapes of a double-skin facade with natural ventilation were evaluated. The software output results show that using DSF will

reduce the annual cooling demand by 9% to 14%, and that the shaft box double-skin facade and box window are the most effective double-skin facade types. Also the naturally ventilated 100 cm cavity depth, it shows the best feedback.

3. Methodology

In a double-skin façade, fluid flow occurs in the vertical directions of the cavity. Since Solar radiation goes in the fluid flow path, double-skin façade heat transfer theory reacting to the airflow of the cavity takes into account the direction of airflow. Airflow is taken into consideration in the one dimension of building height direction. Each one of the factors of cavity space-outer skin, space media (air, etc.), and inner skin-have constant physical and thermal properties and temperature. Figure 5 illustrates an overview of the basic theory of heat transfer in double-skin facades [36].

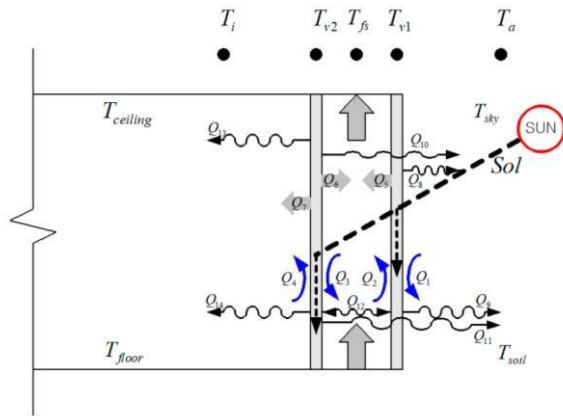


Figure 5. Overview of the basic theory of heat transfer in double-skin facades [36].

The heat transfer equation of the heat flow direction in each zone is presented as the Equations 1, 2, and 3, respectively, each of which is the formula of the outer skin, cavity flow space, and inner skin. In this case, the transfer rates of conduction, convection, and radiation coming to the inside from the inner skin are integrated into one coefficient. If the cavity is closed, $\square=1$; if it has the state of airflow, $\square=0$ [36].

$$K_{v1} \frac{\partial T_{v1}}{\partial t} = Q_1 + (1-\alpha)Q_2 + \alpha Q_5 + Q_8 + Q_9 + Q_{12} + \alpha_{v1} Sol \quad (1)$$

$$K_{fs} \frac{\partial T_{fs}}{\partial t} + V_{fs} \frac{\partial T_{fs}}{\partial Y} = -(1-\alpha)Q_2 - (1-\alpha)Q_3 - \alpha Q_5 - \alpha Q_6 \quad (2)$$

$$K_{v2} \frac{\partial T_{v2}}{\partial t} = (1-\alpha)Q_3 + Q_4 + \alpha Q_6 + Q_7 + Q_{10} + Q_{11} + Q_{12} + Q_{13} + Q_{14} + \tau_{v1} \alpha_{v2} Sol \quad (3)$$

The research methodology of this study employs an analytical-descriptive approach in its initial phase. To gather relevant information related to the topic, data was obtained from various books and publications and reliable websites. Next,

comprehensive maps of the building, including floor plans, elevations, and sections, were collected and analyzed using Design Builder software. To validate the data generated by DesignBuilder, the study referenced Mrs. Meysamipour's thesis, titled "Investigation and Evaluation of Thermal Comfort in Office Buildings (Case Study: Computer Center Building of Shahrood University of Technology)". This thesis investigated temperature variations both inside and outside the building during the hot season in June and July, as well as during the cold season in October and February. The output data obtained from Design Builder was then compared with the findings reported in Meysamipour's thesis to ensure consistency and accuracy.

3.1. Office building location

The case study is the computer center building at Shahrood University of Technology in Shahrood city. Shahrood is one of the largest cities in Semnan Province. In Shahrood, the summers are long, warm, arid, and clear and the winters are very cold, snowy, and partly cloudy [37]. The building is located in the eastern part of the campus, directly across from the men's dormitory. Figure 6 illustrates the computer center's location with the surrounding buildings and the university.

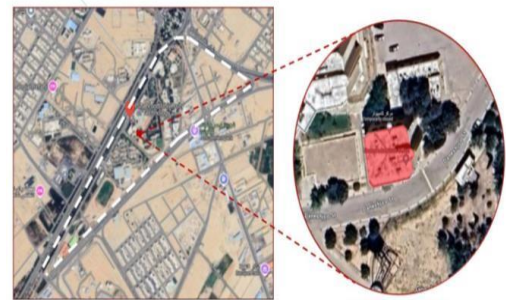


Figure 6. Location of the computer center building at Shahrood University of Technology.

3.2. Computer center building information The computer center building features three floors and includes various micro spaces such as a study hall for both men and women, office rooms, a pantry, and restrooms. The building's facade is constructed entirely of brick, while the windows are framed in aluminum. The HVAC system of the building is water cooler type and ceiling-mounted fans for heating. The system's engine room is situated outside the building, where hot water produced by the pumps is directed to the fan coils. In the Design Builder software, the windows of the computer center building are specified as Dbl blue 6mm/13mm Air. The entrance door is made of glass with aluminum framing; thus,

in the DesignBuilder software, this section is represented as glass instead of a traditional door.



Figure 7. South elevation of computer center building.

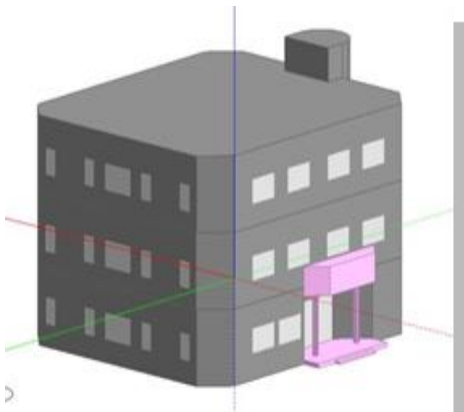


Figure 8. Computer center building simulated in design builder.

The construction materials utilized in the external walls of the computer center building are defined as five distinct layers in the Design Builder software. These layers, from the interior to the exterior, include plaster, cement mortar, brick, additional cement mortar, and a brick facade. For the building's roof, the materials, listed from the inside to the outside, consist of brick, plaster mortar, soil, sand, and asphalt. The flooring materials comprise ceramic tiles, cement mortar, and carcass stone, in that order. The partitions between spaces also consist of plaster, brick, and plaster. Additionally, the window profiles are made of aluminum. Table 1 provides detailed specifications of the materials used in both the internal and external walls, including their thickness, density, and thermal conductivity coefficients. Considering that the building is located in Shahrood City, all the relevant climatic data has been obtained from the official Climate One Building website. Additionally, all external openings, as well as the occupancy hours and lighting schedules, were defined based on the

building's operating hours, which extend from 7 a.m. to 4 p.m.

Table 1. List of materials defined in design builder software.

Material	Layer(kg/m ³)	Density(W/m.k)	Conductivity (cm)	Thickness
External Wall	Plastering Cement	1300	0.6	2
		1860	0.72	3
Mortar	Brick	1900	1	22
		1860	0.72	3
facade	Brick	1900	1	4
Roof	Brick	1900	1	10
		1600	1.10	5
	Mortar and soil			
	Sand	1950	2	3
	Asphalt	2330	1.15	4
Floor	Ceramics	1920	1.80	2
		1860	0.72	4
mortar	Carcass stone	2200	1.83	30
		2800	160	4
Opening	Aluminium window			
Partition	Plastering	1300	0.6	2
		1900	1	10
	Plastering	1300	0.6	2

the HOBO weather station and the building. Tables 2 present the findings from Meysamipour's thesis alongside the output data from the Design Builder analysis of the proposed building. The data are categorized into two groups, hot and cold seasons. As indicated in the table, the results obtained in this study closely align with those reported by Meysamipour during the hot season, exhibiting a maximum difference of only 10%. The results indicate a minimal discrepancy between the two data sets, further affirming the accuracy of the simulated model.



Figure 9. On the right side, The equipment placement inside the building. On the left side, The Hobo RX-3000 weather station [31].

Table 2. Validation of simulation results in comparison to meysamipour's Thesis data for hot and cold season.

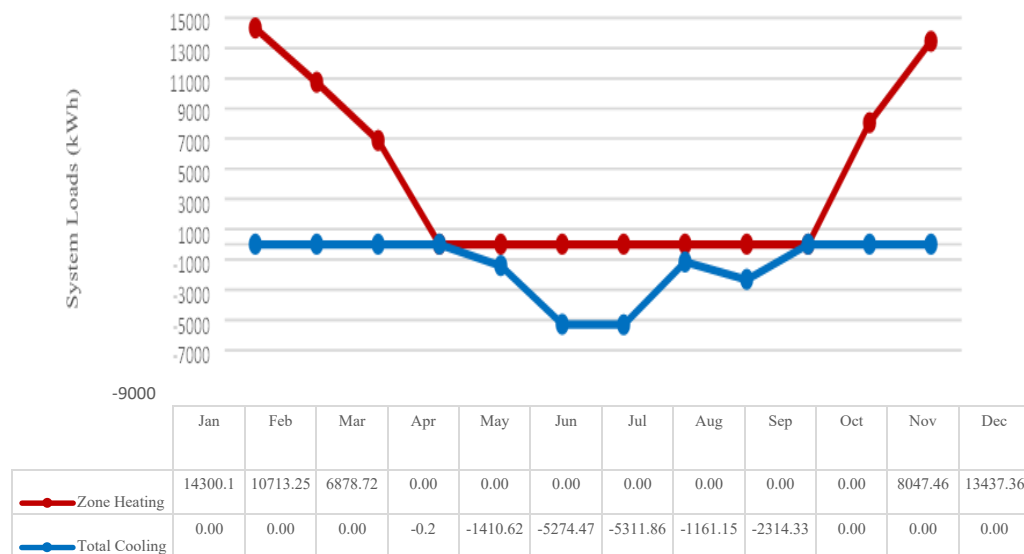
Season	Meysamipour's data			Simulation data		
		Men's site	Women's site	Men's site	Women's site	Difference
Hot	Operative Temperature	25.50	27.50	25.64	25.87	5.9%
	Radiant Temperature	25.58	27.54	26.83	27.06	4.8%
	Indoor air Temperature	25.43	27.45	24.44	24.68	10%
	Outside air Temperature	29.49	29.49	29.25	29.25	0.8%
Cold	Operative Temperature	21.92	23.31	21.34	23.53	2.8%
	Radiant Temperature	21.96	23.33	20.07	22.76	8.6%
	Indoor air Temperature	21.89	23.30	22.60	24.57	5.4%
	Outside air Temperature	16.35	16.04	16.05	16.05	1.8%

As shown in Figure 10, the building's total energy consumption is recorded at 68,849.52 kWh, excluding two weeks in August and two weeks in July due to the university's closure. The total annual heating load during the colder months is 53,376.89 kWh, with January representing the highest heating demand at 14,300.10 kWh. March, with 6878.72 kWh, has the lowest heating requirement among the cold months of the year. The total annual cooling load during the warmer months is 15,472.63 kWh, with June exhibiting the highest cooling demand at 5,274.47 kWh. April has the lowest cooling requirement among the warm months of the year, at -0.2 kWh. The average room temperature is shown in Figure 11, The highest average room temperature is in July with 25

°C. Figure 12 shows the general lighting of the building in different months of the year. March, October and December have the highest lighting requirement with 1915.37 kWh. And August has the lowest lighting requirement with 638.46 kWh.

3.4. Single-skin Façade Analysis Energy Consumption of the proposed building.

Based on the aforementioned data, the energy consumption of the computer center building was analyzed using Design Builder software for one year. Figure 13 shows the natural ventilation of the building from April to September. The highest ventilation rate of the building is in April with 1.22 ac/h and the lowest ventilation rate is in July with 0.44 ac/h.

**Figure 10. Cooling and Heating load diagram of the computer center building in one year.**

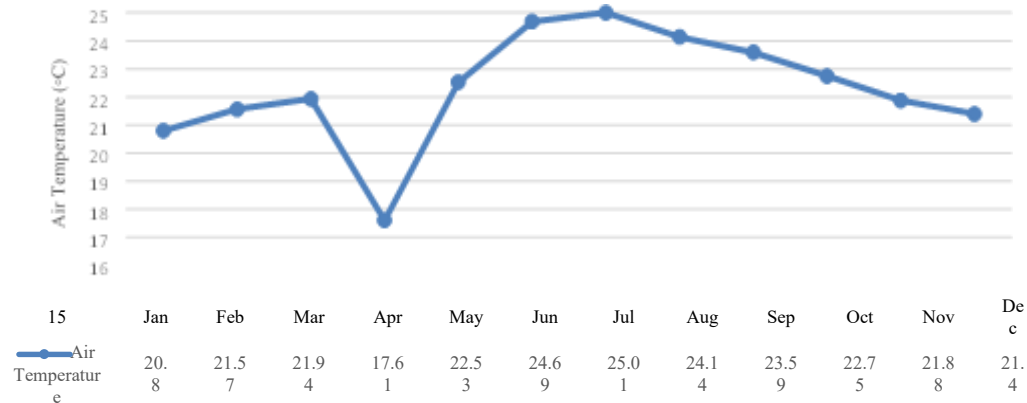


Figure 11. Air Temperature diagram of the computer center building in one year.

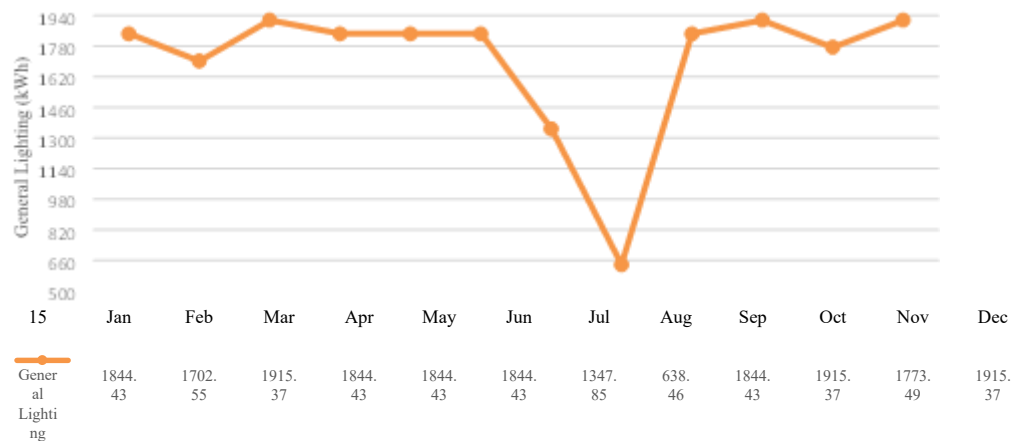


Figure 12. General Lighting diagram of the computer center building in one year.

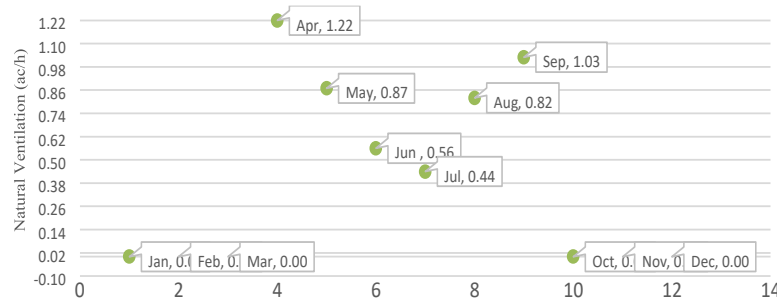


Figure 13. Natural ventilation diagram of the computer center building in one year.

3.5. Double-skin facade models Since there is currently no existing research on double-skin facades specific to the Shahrood region, studies conducted in climates with similar characteristics must be referenced. In 2015, optimal double-skin facade designs for the climate of Tehran were investigated by Hafezi et al, concluding that the double-skin facade featuring a shaft box and box window was found to outperform the other two models analyzed. In 2023, the most suitable types of double skin facades for the climate of Erbil

were examined by Naddaf and Yasin Baper, and it was found that the shaft box and box window configurations significantly reduced the building's annual energy consumption compared to the other models tested. Based on these findings, two facade models—box window and shaft box— have been selected to assess the impact of double skin facades on energy consumption reduction in the building.

Table 3. Parameters of the analyzed models.

Site Parameters	In Shahrood, the summers are long, warm, arid, and clear and the winters are very cold, snowy, and partly cloudy [37].
Building Parameters	Total height of the analyzed building is 14.60 m, with 3 floors. The exterior walls are made of brick with double-glazed aluminum windows. Double-skin facades will be located on the southern facade of the building The double-skin facades of the computer center building are the box window type and shaft box.
DSF Design Parameters	The width of the cavity: 20 cm- 40 cm. Shading devices: None- between the two shells- out of second skin. Type of ventilation: Natural

Table 4. Different scenarios of the simulation process

DSF Type	Cavity width (cm)	Shading devices location	Scenario Code	Number of DSF
No DSF used	-	-	C0	-
Box window	20	None	B1	1
		Between the two Shells	B2	2
		Out of second skin	B3	3
		None	B4	4
	40	Between the two Shells	B5	5
		Out of second skin	B6	6
Shaft Box	20	None	S1	7
		Between the two Shells	S2	8
		Out of second skin	S3	9
	40	None	S4	10
		Between the two Shells	S5	11
		Out of second skin	S6	12

Table 3 summarizes the parameters of the site, building, and double-skin facade. As the proposed building's structure is already built and it is planned to incorporate a double-skin facade on its southern elevation, two cavity depths of 20 cm and 40 cm will be evaluated, taking into account implementation constraints. Additionally, to mitigate excessive heat on the facade during the warm seasons, shuttered canopies will be installed between the double-skin facade and the exterior of the second skin, with the effects of each element to be measured separately. Table 4 provides a summary of the types of double-skin facade models specified for simulation in the Design Builder software.

Table 5 presents the cross-section, elevation, and perspective views of the box window and shaft box types with cavity width of 20 cm and 40 cm are presented. The height of the double-skin facade vents is considered to be 20 cm and its width is the same as the width of the facade itself. windows and vents are opened during the building's occupancy hours (7 a.m. to 4 p.m.) in the warm months and closed during the cold months. In the box window

double-skin facade, the facade consists of horizontal and vertical divisions, each divided space containing two vents. In the warm months of the year, clean air enters the cavity through the lower vent and exits through the upper vent. This airflow leads to ventilation and cooling of the interior spaces. In the colder months of the year, the vents are closed. As sunlight hits the glass surface of the facade, the air in the cavity is heated, and this heated air acts as an insulator and prevents the building from losing heat. The shaft box facade is actually a box window facade that consists of air channels. These air channels start from the lowest floor and extend to the top floor. Clean air enters the cavity through the facade vents, enters the air channel through the middle vents, and exits the cavity through the top vent of the channel. For better performance of double-skin facades in the hot seasons, a shutter canopies is used between the two shells and outside the second shell. The canopies are opened during the hot season between 5 am and 7 pm to prevent the intense sunlight from entering the interior space. In the cold season, the canopies are opened from 7 pm to 5 am to prevent heat loss

from the building. The canopy is made of aluminum and is 10 cm wide, the blades are 1 cm thick, and the distance between the blades is 20 cm. The angle of the canopy blades is 45 degrees Celsius. Table 4 lists the specifications of 12 double-skin facade models in two groups of box window facades and shaft box, two cavity depths of 20 and 40 cm, and three modes of no canopy, middle canopy and external canopy, along with their codes.

building's cooling, heating and total load was reduced compared to the single-skin facade. In box window facades with a cavity depth of 20 cm, which include scenarios B1, B2, and B3, the heating load reaches 48,000 kWh. In this case, the building heating load is reduced by 8.5 to 8.8%. In box window facades with a cavity depth of 40 cm, which include scenarios B4, B5, and B6, the heating load reaches 49,000 kWh. In this case, the building heating load is reduced by 7.6 to 7.8%.

Table 5. Sections, Elevations, and 3D View of double-skin f dçade.

N	Double Skin Facade	Section	Elevation	3D View
1	Box window20 cm			
2	Box window40 cm			
3	Shaft box-20 cm			
4	Shaft box-40 cm			

4. Results Analysis

In this section, the outputs of the double-skin facades for the box window and shaft box have been analyzed using the Design Builder software.

4.1 Box window facade

As seen in Figure 14, The results from the simulation of box window facades showed that the

The building's cooling load in scenario B1 is 15175.21 kWh, which does not change much compared to the single-skin facade of the building. In scenario B2, due to the use of intermediate canopies, the building's cooling load reaches 13,907.72 kWh, which is a 10.1% reduction compared to the single-skin facade. The building

cooling load in scenario B3 is 13562.02 kWh, which has decreased by 12.5%. In scenario B4, the building's cooling load is 15,083.37 kWh, which has not changed much compared to the single-skin facade of the building. However, after adding the middle and outer canopies in scenarios B5 and B6, the building's cooling load is 13,974.44 kWh and 13,618.29 kWh, respectively, which results in a

reduction of 9.6% and 11.9%. The total building load in the box window facade type is between 62,000 kWh and 64,000 kWh. Scenario B3 has the kWh, which reduces the total building load by best performance among the other 6 models. In this 9.7% compared to the single-skin facade.

model, the total building load reaches 62,169.72

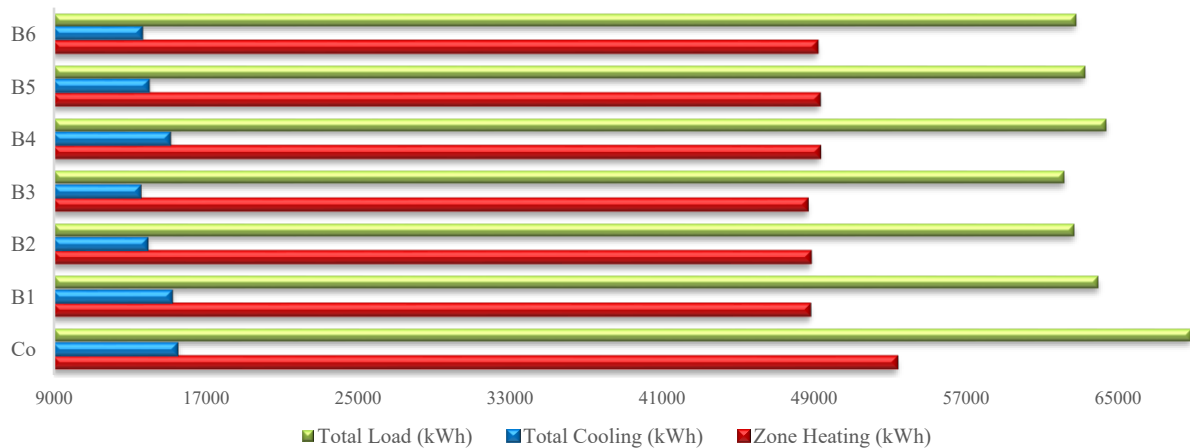


Figure 14. Comparison of heating, cooling and total load of six cases of box window facade.

4.2. Shaft Box Facade

As seen in Figure 15, The results from the simulation of shaft box facades showed that the building's cooling, heating and total load was reduced compared to the single-skin facade. In shaft box facades with a cavity depth of 20 cm, which include scenarios S1, S2, and S3, the heating load reaches 49,000 kWh. In this case, the building heating load is reduced by 7.8 to 8.1%. In shaft box facades with a cavity depth of 40 cm, which include scenarios S4, S5, and S6, the heating load reaches 50,000 kWh. In this case, the building heating load is reduced by 5.5 to 5.9%. The building's cooling load in scenario S1 is 14577.31 kWh, which is 5.7% less than the single-skin facade. This indicates that natural ventilation in the shaft box facade is better than the box window facade. The building's cooling load in scenario S2 is 13816.84 kWh, which is a 10.7% reduction compared to the single-skin facade. In

scenario S3, by adding an external canopy to the double-skin facade, the building cooling load reaches 13374.9 kWh, which reduces the building cooling load by 13.5%. In scenario S4, the building's cooling load is 14,597.04 kWh, which is a 5.6% reduction compared to the single-skin facade of the building. By adding a middle canopy in scenario S5, the building's cooling load reaches 13,807.53 kWh, which is a 10.7% reduction compared to the singleskin facade of the building. In scenario S6, by adding an external canopy to the double-skin facade, the building's cooling load reaches 13,487.23 kWh, which is a 12.8% reduction. The total building load in the 6 types of vertical axis facades is between 62,000 kWh and 64,000 kWh. Scenario S3 shows the best result compared to the other models. The total load in the scenario S3 is 62,388.98 kWh, which reduces the total building load by 9.3% compared to the single-skin facade.

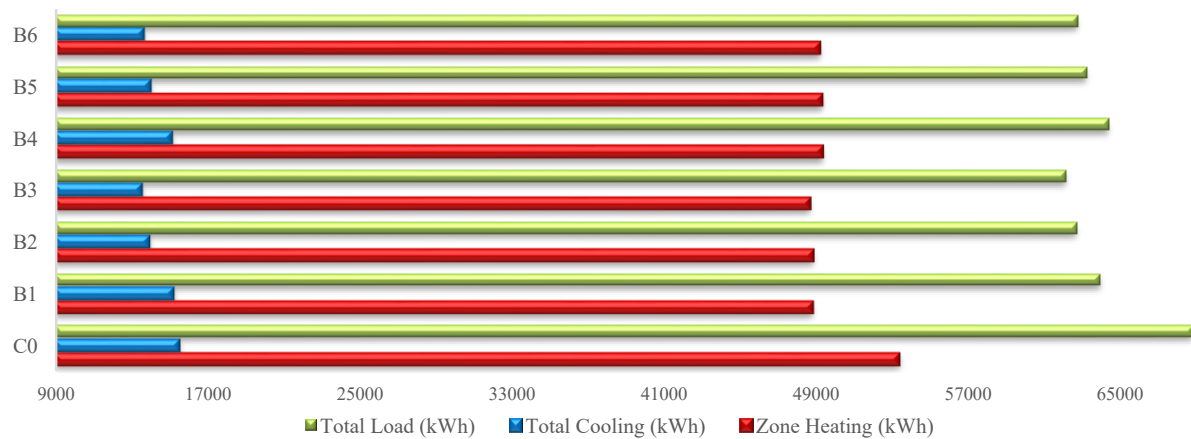


Figure 15. Comparison of heating, cooling and total load of six cases of shaft box facade.

Table 6. Results of Heating, Cooling and total loads of double-skin facades.

Number of DSF	Code	Heating load (kWh)	percent	Cooling load (kWh)	percent	Total energy load (kWh)	Percent
-	C0	53376.89	-	15472.63	-	68849.52	-
1	B1	48790.26	8.5%	15175.21	1.9%	63965.47	7%
2	B2	48814.01	8.5%	13907.72	10.1%	62721.73	8.9%
3	B3	48643.7	8.8%	13526.02	12.5%	62169.72	9.7%
4	B4	49316.51	7.6%	15083.37	2.5%	64399.88	6.4%
5	B5	49285.5	7.6%	13974.44	9.6%	63259.94	8.1%
6	B6	49166.07	7.8%	13618.29	11.9%	62784.36	8.8%
7	S1	49176.73	7.8%	14577.31	5.7%	63734.04	7.4%
8	S2	49080.41	8%	13816.84	10.7%	62897.25	8.6%
9	S3	49014.08	8.1%	13374.9	13.5%	62388.98	9.3%
10	S4	50400.98	5.5%	14597.04	5.6%	64998.02	5.5%
11	S5	50290.13	5.7%	13807.53	10.7%	64097.66	6.9%
12	S6	50217.87	5.9%	13487.23	12.8%	63705.1	7.4%

Classification of heating, cooling and total load of double-skin facades.

Final Classification of heating load of DSFs

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13
Scenario	B3	B1	B2	S3	S2	B6	S1	B5	B4	S6	S5	S4	C0
Heating load (kWh)	48643	48790	48814	49014	49080	49166	49176	49285	49316	50217	50290	50400	53376

Final classification of cooling load of DSFs

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13
Scenario	S3	S6	B3	B6	S5	S2	B2	B5	S1	S4	B4	B1	C0
Cooling load (kWh)	13374	13487	13526	13618	13807	13816	13907	13974	14577	14597	15083	15175	15472

Final classification of total load of DSFs

Rank	1	2	3	4	5	6	7	8	9	10	11	12	13
Scenario	B3	S3	B2	B6	S2	B5	S6	S1	B1	S5	B4	S4	C0
Total load (kWh)	62169	62388	62721	62784	62897	63259	63705	63734	63965	64097	64399	64998	68849

4.3. General classification of DSF

Table 6 shows the results of the heating, cooling, total loads and their percentage reduction

compared to the single-skin facade. Also, the rankings of box window and shaft box facades are also specified in Table 7. As seen in Table 7,

Scenario B3 has the highest reduction in heating and total load compared to the single-skin facade. And scenario S3 has the highest cooling load reduction compared to other models.

4.4. Analysis of optimal model outputs

4.4. Analysis of optimal model outputs

As seen in Table 7, the most optimal double-skin facade in this study is scenario B3, which is actually a box window facade with a cavity depth of 20 cm and an external canopy. In Figure 16, the heating load of Scenario B3 is compared with the single-skin facade of the building. As seen in the graph, the cold months of the year are from November to March. The heating load of this building in the double-skin facade mode is reduced by 8.8% compared to the single-skin facade. In Figure 17, the cooling load of a building with a double-skin facade is compared with a single-skin facade. The warm period of the year begins in May and lasts until September. The cooling load of this building in the double-skin facade mode is reduced

by 12.5% compared to the single-skin façade. In Figure 18, the average room temperature of a building with a single-skin facade is compared with Scenario B3. The average room temperature in scenario B3 is slightly higher than the single-skin facade in different months of the year and has not changed much. Figure 19 compares the general lighting required for a building with a single-skin and double-skin facade in different months of the year. As seen in the Figure 19, the amount of light required by a building with a double-skin facade is slightly higher than single-skin facade due to the use of external canopies. However, in general, they are not much different from each other. In figure 20, the natural ventilation rate of a building with a single-skin and double-skin facade is compared. Natural ventilation in the building continues during the warm months of the year from April to September. The natural ventilation rate of the building with a double-skin facade is 132% higher than single-skin facade.

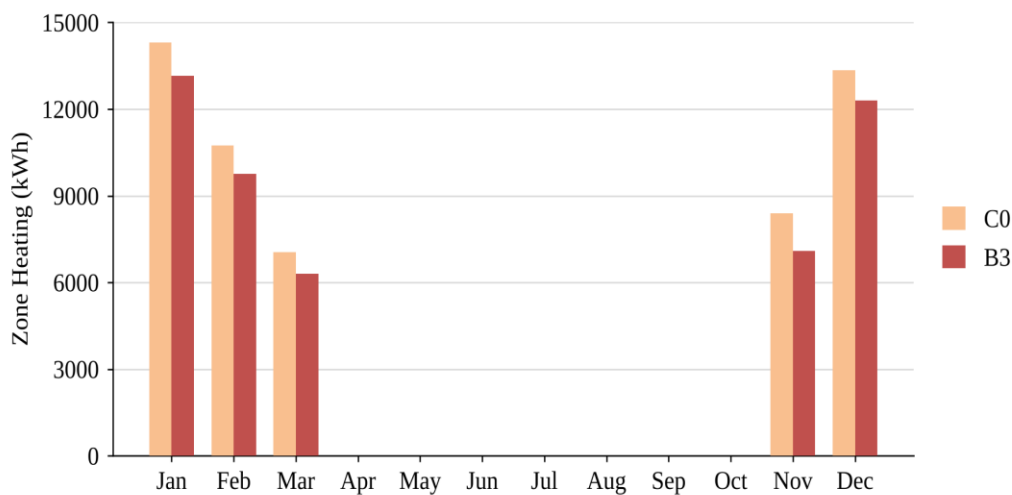


Figure 16. Comparison of the heating load of a box window (B3) and a single-skin façade (C0) of a building.

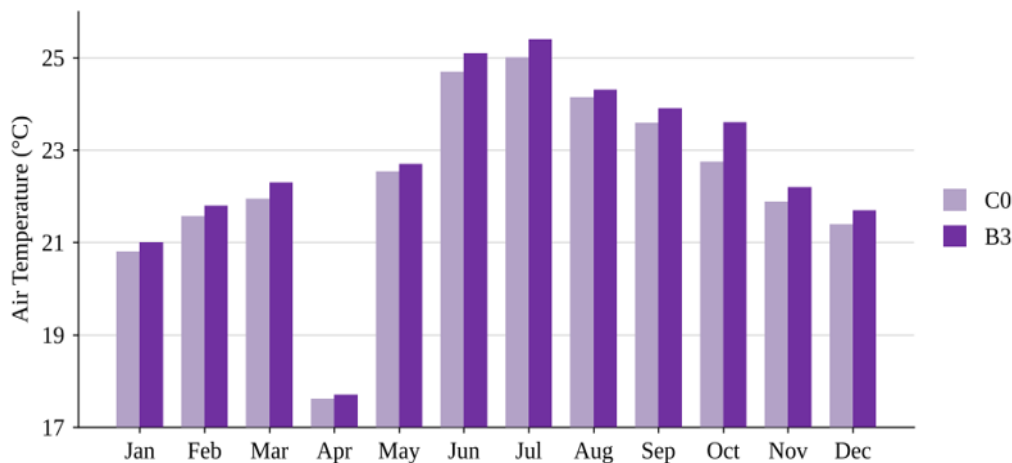


Figure 18. Comparison of the Air temperature of a box window (B3) and a single-skin façade (C0) of a building.

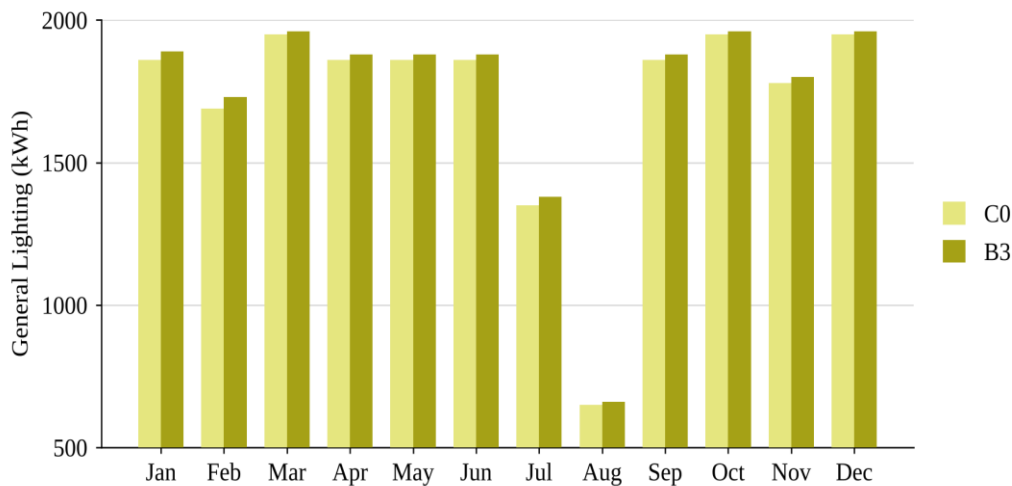


Figure 19. Comparison of the general lighting of a box window (B3) and a single-skin façade (C0) of a building.

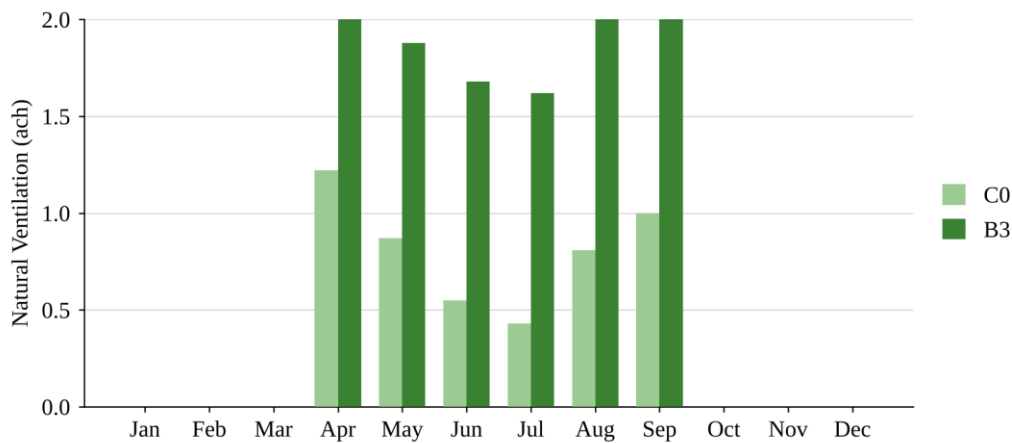


Figure 20. Comparison of the natural ventilation of a box window (B3) and a single-skin façade (C0) of a building.

5. Conclusion

This study was undertaken to minimize energy consumption in the administrative building of the Computer Center at Shahrood University of Technology. The methodology employed includes three elements: a literature review, field investigations, and simulations utilizing Design

Builder version 7 software. The findings have been validated by comparing the research conducted by Meysamipour, which confirms their accuracy.

Two models of a double-skin facade featuring a box window and shaft box, with cavity depths of 20 cm and 40 cm, have been examined. In hot seasons, the temperature increases within the middle cavity of the double-skin facade prompts the installation of canopies both between and outside the facade. Initially, the impact of the double-skin facade, without the canopies, was assessed for both cavity

depths. The results indicated an insignificant effect on reducing the building's cooling load. Consequently, the investigation extended to the additional shutter canopies and their influence. Simulation results across 12 models of the double-skin façade revealed that as the cavity depth increases, the facade's capacity to heat the middle cavity diminishes and the building's heat loss increases. Therefore, in this climate, a cavity depth of 20 cm is more suitable than 40 cm.

The double-skin facade of the box window decreases the building's heating load by 7.6% to 8.8%. As noted, a cavity depth of 20 cm has a more favorable impact than a depth of 40 cm. Additionally, the cooling load for this model is reduced from 1.9% to 12.5% compared to the basic building model. Overall, the total energy load of the building is lowered by 6.4% to 9.7% with the box window configuration.

Furthermore, the shaft box facade reduces the heating load by 5.5% to 8.1% relative to the singleskin model and achieves a cooling load reduction ranging from 5.6% to 13.5%. Similarly, the total energy load of the building is diminished by 5.5% to 9.3% when compared to the base model in the case of the shaft box design.

In conclusion, the most efficient type of doubleskin facade is the double-skinned box window facade, which features a cavity depth of 20 cm and an external canopy, achieving a 9.7% reduction in energy load. In contrast, the facade type with the least reduction in energy load is the shaft box facade, with a cavity depth of 40 cm, resulting in a 5.5% reduction.

In the best case, the double-skin facade in this study reduces the heating load by 8.8% and the cooling load by 12.5%. The double-skin facade also increases the natural ventilation of the building by 132%.

The results can be summarized as follows:

- Implementing double-skin façades on the southern front of the building effectively reduces the heating and cooling loads.
- The inclusion of a shutter canopy between and outside the double-skin façade enhances the ventilation rate within the cavity.
- The chimney effect created inside the cavity enhances natural airflow.
- The amount of lighting required by the building is increased by adding a double-skin facade and canopies.
- Adding shutters to both façades contributes to a reduction in the building's total energy load.
- External canopies outperform middle canopies in their effectiveness.
- As the cavity depth increases, the façade's ability to heat the central cavity decreases.
- By adding a double-skin facade, the average room temperature has increased slightly in all months.

References

- [1] Ahmed, M. M., Abel-Rahman, A. K., Ali, A. H. H., & Suzuki, M. (2016). Double skin façade: the state of art on building energy efficiency. *Journal of Clean Energy Technologies*, 4(1), 84-89.
- [2] Kariminia, S., Rezaie, M., Farokhi, M., Shooshtarian, S., Shamshirband, S., & Mosavi, A. (2022). Impact of double skin façade constructional features on heat transfer and natural ventilation of highrise residential buildings. Available at SSRN 4054206.
- [3] Nasir, O., & Kamal, M. A. (2023). An Appraisal of Double Skin Facade in Building Design: Architectural Intervention and Sustainability. *International Journal of Architecture and Urbanism*, 7(1), 158-172.
- [4] Silva, T., Vicente, R., Rodrigues, F., Samagaio, A., & Cardoso, C. (2015). Performance of a window shutter with phase change material under summer Mediterranean climate conditions. *Applied Thermal Engineering*, 84, 246-256.
- [5] Pelletier, K., Wood, C., Calautit, J., & Wu, Y. (2023). The viability of double-skin façade systems in the 21st century: A systematic review and meta-analysis of the nexus of factors affecting ventilation and thermal performance, and building integration. *Building and Environment*, 228, 109870.
- [6] Zhang, Y., Zhang, Y., & Li, Z. (2022). A novel productive double skin facades for residential buildings: Concept, design and daylighting performance investigation. *Building and Environment*, 212, 108817.
- [7] Naddaf, M. S., & Baper, S. Y. (2023). The role of double-skin facade configurations in optimizing building energy performance in Erbil city. *Scientific Reports*, 13(1), 8394.
- [8] Pomponi, F., Piroozfar, P. A., Southall, R., Ashton, P., & Farr, E. R. (2015). Life cycle energy and carbon assessment of double skin façades for office refurbishments. *Energy and Buildings*, 109, 143-156.
- [9] Qurraie, B. S., & Kıraç, B. (2023). Evaluation of energy efficiencies of double skin façade systems and double skin green façade systems in Turkey. *International Journal of Environmental Studies*, 80(3), 777-791.
- [10] Majid, A. H. A., & Ghazali, A. (2021, November). Hybrid system strategy on double skin façade to optimize thermal performance on research building. In *IOP Conference Series: Earth and Environmental Science* (Vol. 881, No. 1, p. 012048).
- [11] Anđelković, A. S., Gvozdenac-Urošević, B., Kljajić, M., & Ignjatović, M. G. (2015). Experimental research of the thermal characteristics of a multi-storey naturally ventilated double skin façade. *Energy and Buildings*, 86, 766-781.
- [12] Hafezi, M. R., Zomorodian, Z. S., & Tahsildoost, M. (2017). The process of achieving a double skin façade with suitable energy efficiency, a case study of an office building in Tehran. *Two quarterly magazines of Iranians architecture*, 10, 101-122.
- [13] Li, Y. and Darkwa, J. & Su, W. (2019). Investigation on Thermal Performance of an Integrated Phase Change Material Blind System for Double Skin Façade Buildings. *Energy Procedia* (158), 5116–5123.
- [14] Haghani, M., Mohammadkari, B., & Fayyaz, R. (2018). Investigating the impact of shuttered canopies on saving energy consumption in office buildings in

Tehran. Modares Mechanical Engineering Journal, 17(4), 17-28.

[15] Ghaffarianhoseini, A., Ghaffarianhoseini, A., Berardi, U., Tookey, J., Li, D. H. W., & Kariminia, S. (2016). Exploring the advantages and challenges of double-skin façades (DSFs). *Renewable and Sustainable Energy Reviews*, 60, 1052-1065.

[16] Jankovic, A., Siddiqui, M. S., & Goia, F. (2022). Laboratory testbed and methods for flexible characterization of thermal and fluid dynamic behaviour of double skin facades. *Building and Environment*, 210, 108700.

[17] Cherecheș, M. L., Cherecheș, N. C., Ciobanu, A. A., Hudișteanu, S. V., Țurcanu, E. F., Bradu, A., & Popovici, C. G. (2021). Experimental study on airflow and temperature predicting in a double skin façade in hot and cold seasons in Romania. *Applied Sciences*, 11(24), 12139.

[18] Sanchez, E., Rolando, A., Sant, R., & Ayuso, L. (2016). Influence of natural ventilation due to buoyancy and heat transfer in the energy efficiency of a double skin facade building. *Energy for sustainable development*, 33, 139-148.

[19] Lee, J., Chang, J. D., & Coffeen, R. (2020). Acoustical Evaluations of a Double Skin Façade as a Noise Barrier of a Naturally-Ventilated Facade. *Journal of Acoustics*, 2(1).

[20] Anđelković, A. S., Gvozdenac-Urošević, B., Kljajić, M., & Ignjatović, M. G. (2015). Experimental research of the thermal characteristics of a multi-storey naturally ventilated double skin façade. *Energy and Buildings*, 86, 766-781.

[21] Pomponi, F., Piroozfar, P. A., Southall, R., Ashton, P., & Farr, E. R. (2016). Energy performance of DoubleSkin Façades in temperate climates: A systematic review and meta-analysis. *Renewable and Sustainable Energy Reviews*, 54, 1525-1536.

[22] Kazami, M., & Maztarzade, H. (2023). Comparative investigation of double-glazed windows and double skin facades on the optimal temperature of the building. Case study: high-rise residential building of Chamran campus complex, Shiraz. *Scientific Journal of Modern Architecture Research*, 2(3), 23-35.

[23] Conceição, E., Gomes, J., Lúcio, M. M., & Awbi, H. (2021). Development of a double skin facade system applied in a virtual occupied chamber. *Inventions*, 6(1), 17.

[24] Jafari, L., Khyrossadat, A., & Mirhosseini, S. M. (2017). Performance Assessment of Double Skin Façade in Optimizing Building Energy Consumption (Case Study in Shiraz). *International Journal of Applied Arts Studies (IJAPAS)*, 2(3).

[25] Rasouli, M., Shahbazi, Y., & Matini, M. R. (2019). The performance of movable horizontal and vertical

shutter shades in the double skin façade of office buildings, Parametric evaluation and simulation. *Naghsh Jahan scientific research quarterly*, 9(2), 135144.

[26] Sayadati, F. S., Fayyaz, R., & Nikghadam, N. (2022). Optimizing the thermal performance of the box window double skin façade with natural ventilation in the summer season in Tehran. *Scientific journal of hot and dry climate architecture*, 13, 155-174.

[27] Joe, J., Choi, W., Kwak, Y., & Huh, J. H. (2014). Optimal design of a multi-story double skin facade. *Energy and Buildings*, 76, 143-150.

[28] Su, Z., Li, X., & Xue, F. (2017). Double-skin façade optimization design for different climate zones in China. *Solar Energy*, 155, 281-290.

[29] Hay, R., & Ostertag, C. P. (2018). Life cycle assessment (LCA) of double-skin façade (DSF) system with fiber-reinforced concrete for sustainable and energy-efficient buildings in the tropics. *Building and Environment*, 142, 327-341.

[30] Ahriz, A., Mesloub, A., Djeflal, L., Alsolami, B. M., Ghosh, A., & Abdelhafez, M. H. H. (2022). The use of Double-Skin Façades to improve the energy consumption of high-rise office buildings in a Mediterranean climate (Csa). *Sustainability*, 14(10), 6004.

[31] Meysamipour, Sh., Taheri, M., Chaozhay, Y., & Shahsooni, D. Investigation and evaluation of thermal comfort in office buildings (case study: Shahrood University of Technology computer center building. Master thesis, Department of Architecture and Urban planning, Shahrood University of Technology. (2020).

[32] <http://climate.one.building.org> [33] Azarbayjani, M. (2010). Beyond arrows: energy performance of a new, naturally ventilated, double-skin facade configuration for a high-rise office building in Chicago (Doctoral dissertation, University of Illinois at Urbana-Champaign).

[33] Hong, T., Kim, J., Lee, J., Koo, C., & Park, H. S. (2013). Assessment of seasonal energy efficiency strategies of a double skin façade in a monsoon climate region. *Energies*, 6(9), 4352-4376.

[34] Jankovic, A., & Goia, F. (2021). Impact of double skin facade constructional features on heat transfer and fluid dynamic behaviour. *Building and Environment*, 196, 107796.

[35] Sung, U. J., & Kim, S. H. (2019). A study on the improvement of double-skin facade operation for reducing heating load in winter. *Sustainability*, 11(22), 6238.

[36] <https://weatherspark.com/y/105379/Average-Weather-in-Shahrud-Iran-Year-Round>."