Analysis of the Strategies for Designing Optimal Transparent Envelopes in High-Rise Office Buildings of Hamadan through Computer Simulation to Reduce Energy Consumption

Mahdi Sharifi
Faculty Member
Department of Art and Architecture
Doroud Branch, Islamic Azad University
Doroud, Iran.

Abstract

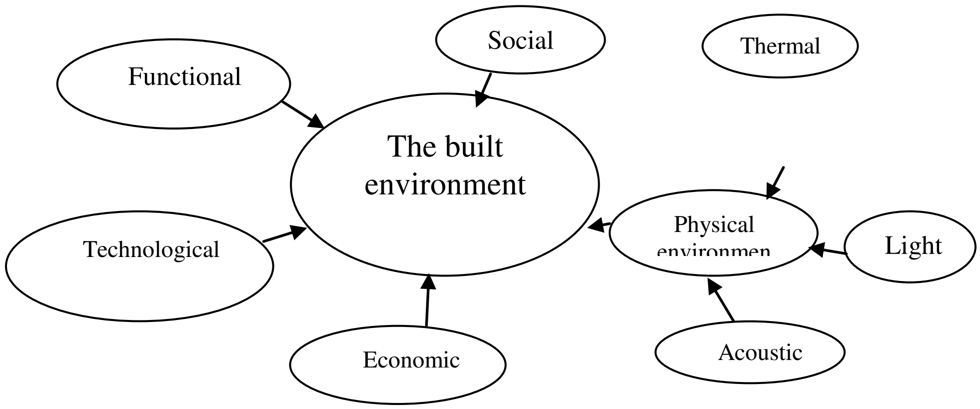
The envelope as the outer part of the building plays an important role in providing comfort conditions (in terms of view, acoustics and thermal comfort) for the building users. Appropriate thermal behavior as an important task of the envelope is very significant for energy consumption. The expansion of high-rise buildings in the past decade has led to the widespread use of resources which accordingly the production of carbon monoxide by these buildings is also growing. If the envelopes of high-rise-buildings are properly designed, annual and total energy consumption for heating and cooling will be reduced. In this paper, firstly different kinds of envelopes, their performance and their thermal behaviors have been evaluated through the computer simulation by the use of the Design Builder Software. So that, some kinds of transparent envelope with different specifications, including single-skin and double-skin facades with different thickness and materials have been simulated and it has been recognized that the increase of thickness and the number of layers in a single-skin facades and the increase of distance between two skins in double-skin facades lead to the decrease of energy consumption. The increase of the distance between the layers in a single-skin façade has no effect on energy consumption and among the studied envelopes; the single-skin facades in which two layers have a thickness of 6mmand there is a distance of 6 mm between them, and the double-skin façade with a distance of 100 cm between the two skins have had a better performance. The results of the present research can be used to better understand the behavior of envelopes and more appropriate climatic design in Hamadan.

Keywords: Building envelope, Thermal behavior, Energy consumption, Simulation

Introduction

In Amid encyclopedia, the envelope has been defined as "cover, shell, skin, and opposite to the core" (Amid, 2002,). In Moeen encyclopedia, the term means a part of plants' structure which constitutes the outermost part of the organs and in fact, it is a stratum that covers the other organs of the plant (Moeen, 2003).In their brief study of the envelope, Harold Dielmann et al referred to four functions that are expected from the envelope, these functions are:1. Protection, 2. Communication, 3. Introduction, 4. a part of the urban space. The most elementary and, even in terms of precedence, the first responsibility which the envelope assumed was the responsibility of protecting man against external threats. On the one hand to protect himself against climatic factors, and on the other hand to confront with insidious animals and nuisance people, human created a space called home (Pakzad, 2003). The envelope of the building, as an intermediary between interior and exterior spaces, plays a significant role in moderating climate conditions and providing comfort for residents and hence reducing heating and cooling loads, and the design and implementation of building envelopes which provide the highest thermal comfort in the interior space by an appropriate thermal behavior without the help of mechanical equipment can largely lead to savings in energy consumption (Mohammad, 2012).s The building envelope is designed considering various factors such as environmental, technological, cultural and social, functional and artistic factors. These factors are as follows (Ghiai and Tahbaz, 2011). Hamadan is one of the cold regions which have cold winters and hot summers. Therefore, proper design of envelopes seems necessary.

Figure 1: The Factors Affecting the Design of Building Envelopes



In the past, walls with high thermal mass were used, but today in the architecture of high-rise buildings, these materials have been replaced by materials such as multi-layered glass, clay hollow blocks, expanded clay aggregates, Hebel lightweight concrete with lower density and thermal capacity, which sometimes are combined with thermal insulations to form thinner structures as exterior walls. Promotion of beam and column system rather than load-bearing wall and also the increase of land prices have led to the desire for decreasing the thickness of the walls as much as possible, in addition the use of the view and landscape has caused the increase in the use of transparent envelopes, which in the present study, it has been tried to pay special attention to this type of envelopes. Envelope design aims to provide comfort conditions and energy savings in the life space of human. The parameters that affect the envelope design consist of two categories:1- parameters related to the external environment 2. Design parameters related to the built environment. Parameters related to the external environment involve several categories and are concerned with natural factors, these factors are: 1-External air temperature, 2-External humidity, 3- External wind flow,4- the level of external lighting, 5. Solar radiation, 6- the level of external sound (Oral, G., Yener, A., Bayazit, N., 2004).

But the built environment is defined as an environment which is designed and built by the human and can be studied under different conditions and scales. The parameters of this group can be defined at the scale of residential unit, a building or even a room. Also today, the shortage of land in urban areas is one of the problems which have led urbanization policy to the construction of high-rise building sat large-scale. Hamadan is also one of Iranian cities, which involves a vast bulk of the construction due to the increasing growth of the population and migration from neighboring provinces. High-rise buildings have been represented as a way to respond to this growing need. According to statistics published by Tavanir organization, buildings constitute about 40 percent of total energy consumption (Mohammad, 2013). These figures and statistics indicate the necessity of saving in fuel consumption in Iran and high potential in public buildings to achieve this goal. In the vernacular architecture of the cold regions which Hamedan is one of these regions, thick walls with high thermal mass could adjust the comfort conditions, but heat dissipation through the envelopes has increased with the expansion of high-rise buildings and glass facades. Providing comfort conditions by the consumption of fossil fuels lead to ecological imbalance and environmental pollution threatens human life. To reduce the negative effects of the issue, renewable resources should be used increasingly.

Literature Review

Only a few researchers have concentrated on the study of the effects of office building envelopes on energy consumption and air conditioning load and most of the previous researchers have worked on energy consumption in relation to residential high-rise buildings (Ghiai and Tahbaz, 2011). This kind of studies has been conducted mostly on the envelopes of office buildings in Hong Kong and there are only a few studies on building design and optimization of energy consumption in cold and temperate regions. Other studies related to cold and temperate climates have focused on the applied strategies of air conditioning systems in buildings and appropriate conditions for users (Bojic, M., Yik, F., Wan, K., Burnett, J. 2002),A study by Tahbaz and Jalilian(2005)has been related to the role of building walls in providing thermal comfort for residents, in which appropriate walls with special specifications has been demonstrated for the considered zone according to the given climatic zoning and the tables of the appropriate typology of each climatic zone have been represented.

In another research, considering the use of common materials in residential buildings of Tehran, thermal behavior of the envelopes has been studied and it has been found that the study of envelope in sustainable conditions doesn't provide appropriate and decisive results to examine the thermal behavior of the envelope (Shagayegh, M., 2012).Nielsen, Duer and Svendsen (2000) represented a simple method to obtain energy from the surface of the windows, a method which was based on the orientation, shading and transparency. Menzies and Wherrett (2005) have performed several studies on the issues of occupant comfort and environmental sustainability in the selection of multi- glazed windows. By a finite difference technique, Aydin (2000) analyzed numerically the heat transfer through a double-pane window. He also determined the thermally optimum air-layer thickness between the two panes for different climates. Ochoa et al (2012) studied design optimization criteria for windows providing low energy consumption and high visual comfort. They claimed that these two aspects cannot be met at the same time. Tsikaloudaki et al (2012) assessed cooling energy performance of windows for an office building in the Mediterranean zone. They recognized that the solar transmittance plays an important role in the envelopes transmittance; they also found that when solar transmittance is low, windows are not sufficiently important. Gasparla et al (2011) evaluated the impact of different kinds of glazing systems (two double and triple glazing), window size, orientation of the window and solar gains on the energy performance of residential buildings in the four central and southern European cities. They recognized that the large surface area of windows can affect the energy performance in the winter, but shading system prevents the penetration of solar radiation in the summer. They also discovered that heat transfer is an important factor affecting the windows' performance. Bojic et al (2002) studied the thermal performance of simple, colored and reflective glasses in high-rise residential buildings. They claimed that thermal conductivity should be examined before the reconstruction of residential buildings, reducing the annual cooling load and annual energy consumption and economic assessment.

Wong et al (2005) investigated the effects of double glazed facade with ventilation system on the energy consumption, thermal comfort and condensation in a typical office building in Singapore. They claimed that double glazed facade with natural ventilation is able to minimize energy consumption as well as to enhance the thermal comfort. They also concluded that turning the mechanical fans on can solve the condensation problem caused by high humidity. Arici and Karabay (2010) determined the optimum air layer thickness of double-glazed windows for the four climatic regions of Turkey. The results of their study showed that the optimum air layer thickness varies between about 12 to 15mm depending on the climatic zone and with a well-optimized glazed window; up to 60% energy savings can be achieved. In a simulation study, Ismail et al (2008) compared PCM filled glass windows and absorbing gas filled windows. They concluded that PCM filled glass windows has a better thermal behavior.

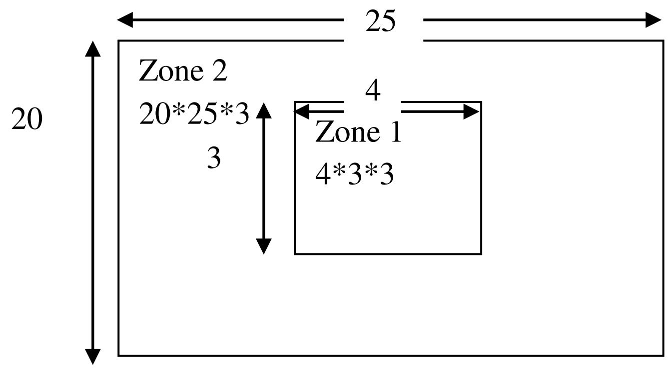
However, in the present paper, due to the expansion of the glazed high-rise buildings, it has been tried to study the transparent envelopes and to determine which envelopes have better thermal behavior and better performance in terms of the decrease of annual energy consumption and heating and cooling load. For this purpose, various envelopes, including single-skin facades with different number of layers and different distances between the layers as well as double-skin façades with different distances and different ventilation conditions and different kinds of profiles and glass, have been studied to represent the most optimum envelope among typical transparent envelopes considering the climatic conditions of the Hamadan and the given factors.

Research methodology

The method of computer simulation is commonly used in researches which examine the impact of environmental factors on the performance of building components and the impact of structural elements on the conditions and consumption of energy. In this method, the impact of environmental conditions on energy consumption is considered by computerized modeling in energy software. The software used in the present study has been Design Builder software which is one of the most powerful energy software in the field of building. The Independent variables of the research include thickness, the number of layers, the distance between the layers and the material of the envelopes. The thermal transmittance of envelopes and consequently its impact on heating and cooling load in the building are dependent variables of the research. For a more exact study and ease of simulation, some factors, such as climatic and environmental conditions, the position and orientation of building and the envelopes have been assumed constant. In the research method of simulation, while improved models are represented, a broader view is provided to reason logically and analyze deductively which are required for an academic study.

In this study, given the climatic conditions of Hamadan, a sample building has been modeled and it has been tried to find an envelope which has a better performance in terms of all aspects (heat dissipation, receiving light and solar radiation, energy consumption for heating and cooling, etc.). In the present research, a base model of building with the following features was modeled. This base model was a building with dimensions of 20 * 25 meters and it was divided into two zones on each floor. Zone 1 was an office room with the plan dimensions of 5*4 meters and the height of 3 meters and zone 2 occupied the rest of the area of each floor, which has been considered as an adiabatic space. The following figure shows the manner of zoning the floors of the building.

Figure 2: **The Zoning of the Floors of the Modeled Office Building**



This room was located on the sixth floor of the building and its relationship with outside space was through the southern facade. In the modeling, it was assumed that the southern facade was completely glazed and the specifications of its parameters have been considered as the variables of the research and modeling was done based on these parameters. Other facades have been considered as non-transparent. The space of zone 1 was an office space, its working hours started from 8 am to 3 pm. The number of its working days in year was 250 days and the numbers of people who worked in zone 1 were 4 people. The equipment of this space included 4 computers, and its lightening was provided by 4 overhead fluorescent lamps and its air conditioning and heating and cooling were done by air handling unit. The details of the exterior walls on the eastern, western and northern facades have been represented in the following table.

Table 1: Details of Exterior Walls

Total thickness	External finishes	Main wall	Internal finishes	Facade
24 cm	Brick with the thickness of 3 cm + 3 cm mortar	15 cm reinforced concrete	2 cm plaster + paint	Eastern
24 cm	Brick with the thickness of 3 cm + 3 cm mortar	15 cm reinforced concrete	2 cm plaster + paint	Western
24 cm	Brick with the thickness of 3 cm + 3 cm mortar	15 cm reinforced concrete	2 cm plaster + paint	Northern

Also, the details of the interior wall between the space of zone 1 and zone 2 are as follows:

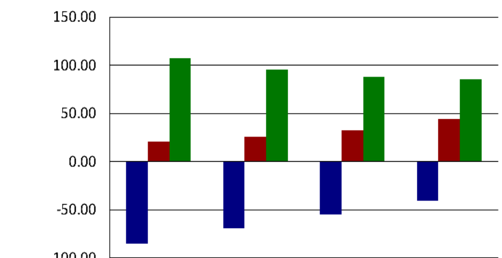
1. Earthenware with a thickness of 10 cm
2. Plaster of 2 cm along with paint on each side of walls as the finishes Ceilings used for the floors involved the following details.
1. The main structure of the ceiling composed of30 cm reinforced concrete
2. Suspended ceiling with the size of 25 cm
3.3 cm plaster as finishes below the ceiling

In zone 2of the office room, the operating temperature of cooling systems during the day and night were considered respectively as 24 ◦C and 26◦C. The operating temperature of heating systems was considered respectively as 22 ◦C and 18◦C for the day and night.

Results

To start the simulation, firstly the ratio of transparent surface to non-transparent surface was examined. The percentage of the ratio of these surfaces (transparent to nontransparent) was determined as 30, 50, 70 and 100% and according to the sepercentages; the simulation was performed to determine the optimum percentage. The following diagrams show the simulations of energy consummation for cooling and heating, the solar gains and the annual energy consumption considering these percentages.

Diagram 1: Energy Consumption for Cooling and Heating and Annual Energy Consumption Considering the Percentage of the Glass on the Southern Facade



	100.00	70.00	50.00	30.00
Total Cooling	-86.07	-69.78	-55.54	-41.14
Total Heating	20.68	25.23	32.49	44.07
Total Energy	106.75	95.01	88.03	85.21

In the next step, the southern facade was simulated with 100% glass and its different parameters were examined. Firstly the envelope was divided into two general states:

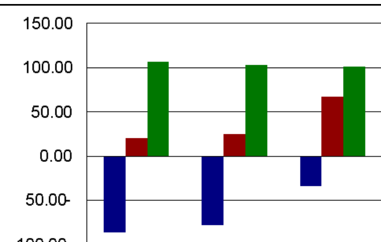
a. Single- skin façade

b. Double- skin façade

Then, single- skin façade was simulated in three different states as follows:

1. A single-skin façade with single layer of 12 mm tempered glass was simulated in which three different kinds of glass-simple, matt and reflective glass- was examined to obtain the optimum envelope. The diagrams of this simulation have been represented at below:

Diagram 2: Energy Consumption for Cooling and Heating and Annual Energy Consumption Considering the Kind of Single- Layered Glass on the Southern Façade



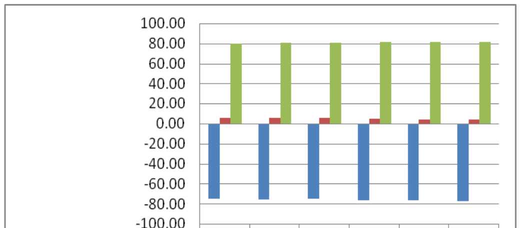
	Clear	Mat	Ref
Total Cooling kWh/m2	-86.07	-77.86	-34.14
Total Heating kWh/m2	20.68	25.41	67.44
Total Energy kWh/m3	106.75	103.27	101.58

Next, the single-skin façade was simulated with two layers of glass. Two different options were examined in this section:

1. An envelope with two glasses in which the thickness of external glass and internal glass were respectively 6 mm and 4 mm and the distance between two glasses was simulated in three different states of 6, 8 and 10 mm to find the most optimal envelope in terms of performance.
2. An envelope with two glasses in which the thickness of external glass and internal glass were respectively 6 mm and 6 mm and the distance between two glasses was simulated in three different states of 6, 8 and 10 mm to find the most optimal envelope in terms of performance.

The following diagrams show the various aspects of this simulation.

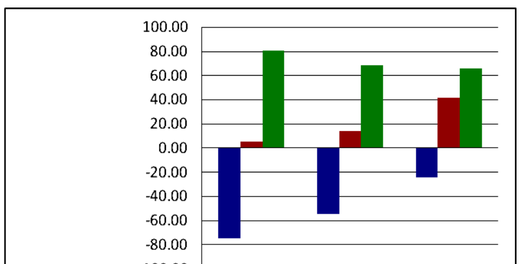
Diagram 3: Energy Consumption for Cooling and Heating and Annual Energy Consumption Considering the Distance and Thickness of Two Layers of Glass on the Southern Façade



	6mm -6-6	6 mm -6-4	8mm -6-6	8mm -6-4	10m m -6-6	10m m -6-4
Total Cooling kWh/m2	-74.88	-75.56	-75.06	-76.75	-76.82	-77.54
Total Heating kWh/m2	5.26	5.27	5.26	4.64	4.25	4.25
Total Energy kWh/m2	80.14	80.83	80.32	81.39	81.08	81.79

The optimum state was also obtained in this section, which due to lower annual energy consumption, the optimum state has been related to a façade in which the thickness of external glass and internal glass were respectively 6 mm and 6 mm and the distance between two glasses was 6 mm. Then, this state was simulated by simple, matt and reflective glass, which following diagram shows the energy consumption in this envelope.

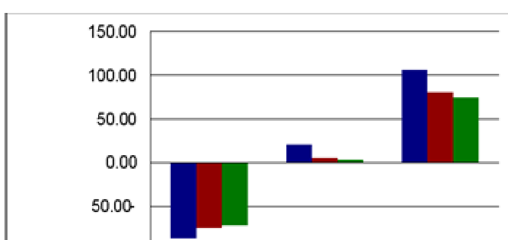
Diagram 4: Energy Consumption for Cooling and Heating and Annual Energy Consumption, Considering the Kind of Two-Layered Glass on the Southern Façade



	Clear	Mat	Ref
Total Cooling kWh/m2	-74.88	-54.55	-24.51
Total Heating kWh/m2	5.26	13.53	41.16
Total Energy kWh/m2	80.14	68.09	65.67

Next, a single- skin facade with three layers of simple glass with the thickness of 6 mm and the distance of 6 mm between layers was simulated and compared with previous ones. The following diagram shows the thermal behavior of this envelope.

Diagram 5: **Energy Consumption for Cooling and Heating and Annual Energy Consumption, Considering the Number of Glass Layers on the Southern Façade and the Comparison of Single, Double and Triple-Layered Glazing**



	kWh/m2 Total Cooling	kWh/m2 Total Heating	kWh/m2 Total Energy
Single Glazing	-86.07	20.68	106.75
Double Glazing	-74.88	5.26	80.14
Triple Glazing	-71.70	3.20	74.90

In the next step, a double- skin façade was simulated with the specifications of previous optimum state in each of the envelopes and the distance between skins was considered as 20, 60 and 100 cm. This simulation was performed once with exhaust fan and once with natural ventilation on the exterior skin, which its result can be seen in the following diagrams. The rate of intended openings on the exterior skin was considered as much as 5% of the envelope.

Diagram 6: Energy Consumption for Cooling and Heating and Natural Ventilation and Solar Gains in Double-Skin Façade with the Natural Ventilation Considering Different Distances between Two Skins

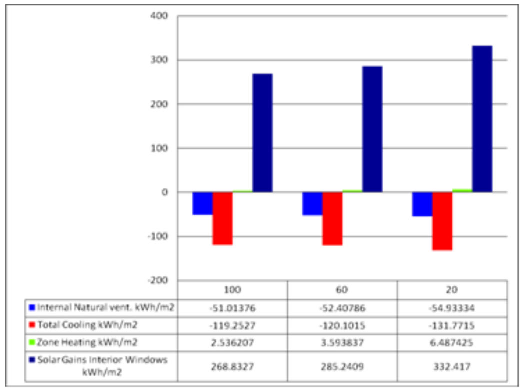
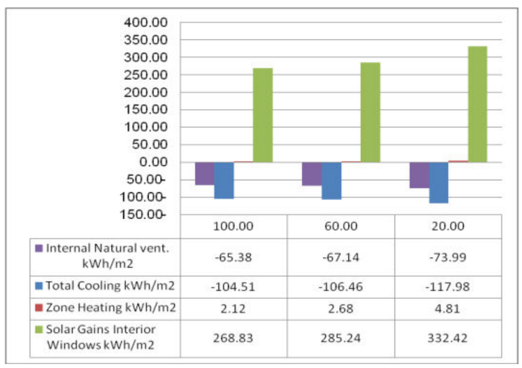


Diagram 6: Energy Consumption for Cooling and Heating and Natural Ventilation and Solar Gains in Double-Skin Façade with Exhaust Fan Considering Different Distances between Two Skins



Discussion

By analyzing the diagram of the ratio of transparent surfaces to non-transparent surfaces (diagram 1), it has been recognized that in the southern façade, with the increase of the glass percentage (from 30 to 100%) on the facade, solar gains increase significantly (from 171/17 to 577/99 kWh / m2) which leads to the increase of the cooling load of the building. Also, due to suitable insulation in the given room and appropriate radiation in the southern side in the winter, heating load decreases (from 44/07 to 20/68 kWh / m2) with the increase of the glass percentage (because of more radiation). But on the whole, among the percentages of 30, 50.70, a façade in which the ratio of transparent surfaces to nontransparent surfaces was 30% has had better performance in terms of energy consumption, because it involves less annual energy consumption (85/21 kWh/ m2).

As the diagram related to the kind of glass (diagram 2) makes clear, simple glass involves the highest solar gains, then its cooling load in comparison with two other kinds of glass (matt and reflective) is far more (cooling load of 86/07kwh / m2), but in terms of heating load, the simple glass has better performance due to involving the lowest consumption. Finally, on the whole, the reflective glass with the lowest annual energy consumption (101/58 kWh / m2) is the best kind of glass among the others. In the case of the diagrams related to the thickness and the number of layers (diagram 3), due to the different behaviors of the envelope in different seasons, the energy consumed for cooling increases by the increase of the distance between two layers which is because of the increase of dissipation through convection between the layers in the winter, but the energy consumed for heating has also been reduced which is due to the decrease of heat dissipation through conduction and the decrease of radiation from inside to outside in the winter.

Finally, an envelope with a thickness of 6 mm on the internal side and 6 mm on the external side and a distance of 6 mm between the two layers consumes lower annual energy (80/14 kWh / m2) in comparison to other distances (8 and 10 mm).Due to higher thickness of layers, this envelope involves less dissipation compared with an envelope with the layers of 4 and 6 mm. By the analysis of the diagram related to the kind of glass with optimum previous state (diagram 4), again, it has been recognized that the reflective glass involves the lowest energy consumption for cooling and the simple glass involves the lowest energy consumption for heating, but generally, an envelope with reflective glass has the lowest annual energy compared with matt and simple glass. The diagram related to the number of the layers (diagram 5) shows that an envelope with three layers involves the lowest energy consumption for cooling and heating and the lowest annual energy consumption in comparison with other envelopes, which is due to the decrease of heat dissipation through the increase of the thickness, distance and thermal resistance.

The analysis of the diagrams related to the double-skin facades (diagrams 6 and 7) shows that the heating energy decreases by the increase of the distance between the skins, which is due to the decrease of dissipation through convection. In addition, cooling energy decreases also by the increase of the distance between the two skins which is due to the decrease of the solar gains. The natural ventilation also decreases, which is because of the increase of the volume of the space between two skins and the least number of air changes per hour. When the space between the two skins is ventilated by the exhaust fan instead of natural ventilation, similarly the cooling and heating load of the building decreases and the amount of air changes per hour also increases due to the higher power of exhaust fans and compared to the previous double-skin facade with natural ventilation, the cooling load decreases which is due to the increase of air changes by the exhaust fan. Heating load also decreases, which is due to the decrease of heat dissipation through the skins.

Conclusion

In this study, the conditions and specifications of glazed envelopes in high-rise buildings have been studied considering the climatic conditions of Hamadan. For this purpose, energy simulation software such as Design Builder software has been used and the following conclusions have been obtained.

1. The optimum percentage of the ratio of the transparent surfaces to the nontransparent surfaces in terms of energy consumption in these buildings has been 30%.
2. Among single-skin facades of simple, matt and reflective glass, reflective glass has had the lowest energy consumption.
3. Among single-skin facades with two layers of glass with the thicknesses of 6 mm and 4mm and the distances of 6, 8 and 10 mm between the layers, a façade in which the distance between layers was 6 mm has involved the most optimal energy consumption, and among the facades with two layers of glass with the thicknesses of 6 mm and 6mm and the distances of 6, 8 and 10 mm between the layers, a façade in which the distance between layers was 6 mm has had the lowest energy consumption. Comparison of the facades with the thicknesses of 6 m and 4m and the facades with the thicknesses of 6 mm and 6mm shows that the latter involves the lowest annual energy consumption.
4. Among double-skin facades with the distances of 20, 60 and 100 cm between the two skins, a façade with the thickness of 100 cm has had the lowest energy consumption, also when exhaust fans were used, the amount of consumed energy decreased.

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