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Performance Assessment of Double Skin Façade in Optimizing Building Energy Consumption (Case Study in Shiraz)

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Abstract

Reducing the energy consumption of the buildings in Iran is essential, since the building energy consumptions in the country are about 40% of the total energy consumption. Approaches and strategies to reduce the level of energy consumption in buildings can be investigated in two main parts: designing energy-efficient buildings and energy efficiency in existing buildings. With the advent of various technologies, complexity and administration costs are also increased. Therefore, the decision-making about the selection of optimal strategies and finding the solutions to reduce the energy consumption in buildings has become more important. On the other hand, the interaction between the design elements, climate, users, cooling, heating, ventilation, and lighting is very complex and can only be studied by simulating all of the influencing factors in the energy efficiency of the building. Since the building shell as the separator of the interior and exterior environment plays an important role in the thermal behavior of the buildings, in this article, the use of double skin facades was investigated, as a new technology that is designed as an obstruction which creates a balance between the interior and exterior environments. Based on the results of this study, it was concluded that if this technology is properly used and implemented in the designing process of the buildings, it could have an important role in reducing the energy consumption of buildings, as well as several side benefits.

Keywords: Double Skin Facade; Energy; Saving; Optimization

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1. Introduction

Saving energy in buildings and environmental pollution are two important concerns in architecture, which have attracted a considerable attention. The façade, as a part of the construction associated with external factors, plays an important role in the energy performance and comfort in the building. In fact, the facade is the common element that forms the interior and exterior of the building, and hence it is responsible for several concerns such as heat loss, solar heat absorption, daylight, and daze control (Heidari et al., 2013).

In general, thermal dissipation structure arises from two fundamental sources: first, the heat dissipation is due to the entrance of cold outside air into the building, through air infiltration and renewal. Secondly, the heat dissipation from the walls of the building where the outer shell exists and is related to all surfaces around buildings, including walls, ceilings, floors, openings, and light transmitting surfaces, which on the one hand are linked with uncontrolled space or outer space, and on the other hand, are linked to the controlled space within the building. Therefore, the outer shell will prevent the waste of the generated heat and cold, which will subsequently save a considerable amount of energy consumption (Shah Mohammadi, 2010).

In the contemporary world, with the use of new materials and intelligent technology, this idea is gradually taking shape that the facade of the building to be designed or implemented should be like a skin or intelligent shell which withstands some of the external factors, shows different actions, and takes advantage of some natural environment phenomena. It is possible to use glass that responds to light in accordance with the specified conditions. Similarly, it is gradually becoming possible to use openings which respond to outside air temperature and create a balance in the process of air exchange between the inside and outside of the building. Hence, one can use the textures and materials in façades, through which the energy of the sun and the radiant energy can be converted and used for another type of energy.

2. Literature Review

2.1. Intelligent Façade

Smart exterior architecture is a trend for energy waste reduction, air pollution reduction, usage of renewable energies, and the interaction between buildings, environments, and the users (Servatjoo & Armaghan, 2011). Intelligent facades can be divided into the following categories, based on the structure, the materials, and the performance: 1. Double skin façade 2. Smart material façade 3. Integrated intelligent system with façade (ventilation, solar, etc) and 4. Integrated intelligent façade (Servatjoo & Armaghan, 2011).

2.2. Double Skin Façade

The essential concept of the Double skin façade was first explored and tested by the Swiss-French architect Le Corbusier in the early 20th century; he called his idea “neutralizing wall”. American engineers studying the system in 1930 informed Le Corbusier that it would use much more energy than a conventional air system, but Harvey Bryan later concluded Le Corbusier's idea had merit if it included solar heating (Bryan, 1991).

Another early experiment was the Alfred Loomis’ house built in 1937 by architect William Lescaze in Tuxedo Park, NY. This house included "an elaborate double envelope" with a 2-foot-deep airspace conditioned by a separate system from the house itself. The objective was to maintain high humidity levels inside (Braham, 2005).

But the most reliable definitions, which relate to the Belgian Building Research Institute, are as follows:

“A double skin façade can be defined as a traditional single façade doubled inside or outside by a second, essentially glazed façade. Each of these two façades is commonly called a skin. A ventilated cavity is located between these two skins having a width ranging from several centimeters to several meters.

Automated equipment, such as shading devices, motorized openings or fans, are most often integrated into the façade. The main difference between a ventilated double façade and an airtight multiple glazing, whether or not integrating a shading device in the cavity separating the glazing, lies in the intentional and possibly controlled ventilation of the cavity of the double façade”.

Another definition provided by this Institute focuses on ventilated facades and does not have the comprehensiveness of the previous definition. The definition is: "A two-shell view with at least two shells between the interior space and the external environment is distinguished from other views. Between these two shells, there is a gap for air flow. The width of this cavity can vary from a few centimeters (in the narrowest state) to several meters (in the broadest state). The outer shell is glass, which is usually made of hard glass. The inner shell is almost entirely of glass and the glass is used in the type of insulation (BBRI, 2002).

In recent years, in European countries, especially Germany, The Netherlands, and the United Kingdom, double skin facade solution is widely considered. This system has provided many fans with a significant reduction in energy consumption, natural ventilation in the building and a significant reduction of noise. The architecture is very transparent, providing comfort and convenience for the residents (Motiee & Nasiri, 2006).

One of the first modern examples to be constructed was the Occidental Chemical Building (Harrison & Boake, 2003). The Occidental Chemical building, especially the glass cube, included a 4-feet deep cavity between glass layers to preheat air in winter. This design has been used in buildings recently because it is useful in reducing energy consumption in buildings (Grondzik et al., 2009). The active facade (usually when mechanical ventilation is available), passive facade (usually when there is natural ventilation), dynamic facade, double sheet façade and the multi-chamber facade and smart glass facades were mentioned (Poirazis, 2004).

According to Claessens and DeHerde, a second skin façade is an additional building envelope installed over the existing façade. This additional façade is mainly transparent. The new space between the second skin and the original façade is a buffer zone that serves to insulate the building. This buffer space may also be heated by solar radiation, depending on the orientation of the façade. For south oriented systems, this solar heated air is used for heating purposes in the winter time. It must be vented in order to prevent overheating in other periods (Poirazis, 2006).

Double skin façade system was known by other names such as ventilated facades, façade wall ventilation, double façade, double cover, and facades glass two layers (Madahei et al., 2012). Accordingly, the simplest definition of Double-skin façade is based on the features it may offer. The Double-skin façade is sometimes a pair of glass skins separated by an air corridor. The main layer of glass is usually insulating. The air space between the layers of glass acts as insulation against temperature extremes, winds, and sound (Lang & Herzog, 2000).

About fifty percent of the global energy consumption is used in building areas. The savings of energy in this area could lead to significant decrease in global energy consumption. One way to reduce energy consumption in the building is using Double skin façade (Yazdizad et al., 2014). Recent studies showed that the energy performance of a building connected to a double-skin facade can be improved either in cold and warm season or in cold and warm climates by optimizing the ventilation strategy of the façade (Mingotti et al., 2011). Building facades in designing spaces could have an effective role in reducing energy consumption. According to the literature in the field of sustainability, the design of an efficient shell can significantly decrease the heat repulse in the winter and heat absorption in the summer (Hadianpour et al., 2014).

a. First Shell of the Double Skin Façade: The first shell can be any type of wall. However, in Iran, the glass facades are generally considered as the first shell. That is the single paneled window or the curtain wall (Yazdizad et al., 2014).

b. Second Shell of the Double Skin Façade: In the construction of the second shell, we should use a light material, such as metals with minimum thicknesses that do not reduce their strength and resilience due to applied pressures. Finally, the weight of the second shell is also imposed on the structure of the building. Such facades differ from other facades by placing at least two shells or walls between the interior and exterior space. Usually, the outer shell is the hardest kind of glass (Yazdizad et al., 2014).

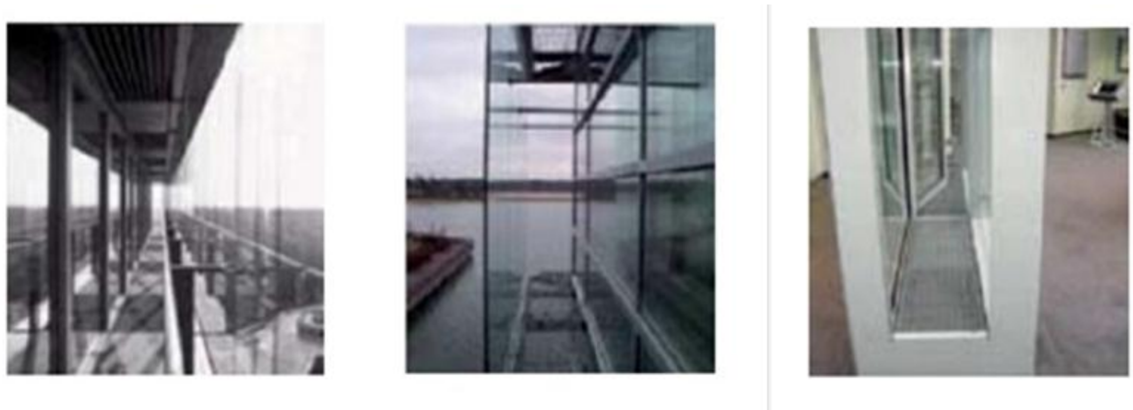

Fig 1 From left to right: the outer shell, the airspace, the inner shell, a double skin façade (Zolfaghari et al., 2013)

c. Air Space between Two Glasses: Air conditioning between two glasses can be natural or artificial. The width of the air gap between the glasses could vary from 2 to 60 cm (Zolfaghari et al., 2013).

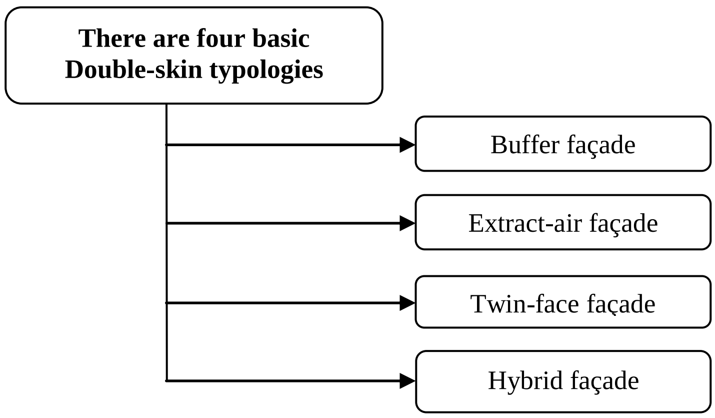

Fig 2 General classification of Double-skin façade (Emami Tabrizi, 2013)

2.3. Typologies

a. Buffer Façade: The buffer façade consists of two layers of glazing mounted, approximately 250 to 750mm (10” to 30”) apart, with the air space between the two sealed layers. This is the oldest typology which has been used for nearly 100 years (Lang & Herzog, 2001). The buffer façade was developed before the invention of insulating glazing to increase sound and heat insulation without reducing the amount of daylight entering the building. A contemporary example is the Occidental Chemical Centre (or Hooker Building) in Niagra Falls, New York (Emami Tabrizi, 2013).

b. Extract-Air Façade: The Extract-Air Façade consists of a main double-glazed skin of insulating glass with a second single-glazed skin placed inside. The air space between the two layers of glazing becomes part of the HVAC (Heating, ventilation, and air conditioning) system. The heated “used” air between the glazing layers is extracted through the cavity with the use of fans and thereby tempers the inner layer of glazing while the outer layer of insulating glass minimizes heat-transmission loss. This system is used where natural ventilation is not possible (for example in locations with a high level of noise, wind or fumes). Shading devices are mounted within the cavity. An example of an Extract-Air Façade is the Helicon Building, London (Ebrahimi et al., 2011).

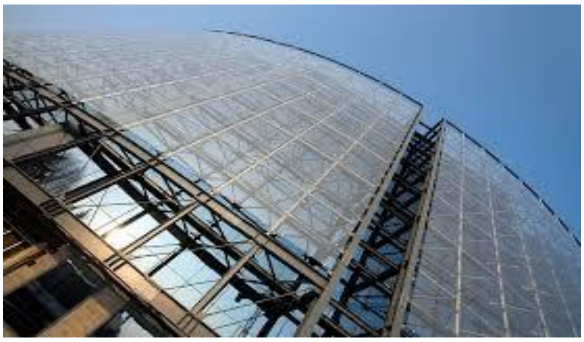

Fig 3 Close view of two shells of the Helicon building extractor in London (Emami Tabrizi, 2013)

c. Twin-Face Façade: The twin-face façade is comprised of a conventional curtain or massive wall system with an outer skin of single glazing (Lang & Herzog, 2001). The single-glazed outer skin is used primarily for the protection of the air cavity contents (shading devices) from the weather. With this system, the internal skin offers the insulating properties to minimize heat loss. This typology differs from the Extract-Air façade in that it permits openings in the skin, allowing for natural ventilation. Windows on the interior façade can be opened, while ventilation openings in the outer skin moderate temperature extremes within the façade. The use of windows allows night-time cooling of the interior, and thereby the cooling loads of the building’s HVAC system will be reduced. For noise control, the openings in the outer skin can be staggered or placed remotely from the windows on the interior façade. Some examples of twin-face façades are Telus William Farrell building, Vancouver, Debi's building, Berlin, and Das Dusseldorfer Stadttor, Dusseldorf (Lang & Herzog, 2001).

d. Hybrid Façade: The Hybrid façade is a system that combines one or more of the basic characteristics of the aforementioned typologies to create a new hybrid system. Examples of buildings with a Hybrid façade are the RWE building, Germany, ING Headquarters, Amsterdam and the Tjibaou Cultural Centre, New Caledonia (Boake et al., 2001).

2.4. Goals of Double-Skin Façade Design

The goals are categorized as;

- Providing acoustic targets for a glass view that increases transparency.
- Acoustics development in buildings located in a busy and polluted area.
- The use of natural ventilation instead of mechanical ventilation.
- Reduce the need for heat during the winter and reduce the need for cooling during the summer
- The maximum reduction in heating and cooling systems.
- Use natural light instead of artificial light as much as possible.
- Adjusting the optimum interior temperature of the building during summer and winter (Zolfaghari et al., 2013).

2.5. Advantages

One of the reasons for the use of double-skin facade, which has led to the rapid growth in its use, is the following: The building with this facade has lower energy consumption, for example, studies show that "Komertz Bank" in Frankfurt consumes about 30% less energy than similar buildings. This would be the best incentive for designers and users to use this type of façade. Cost savings as a result of reducing the number of mechanical facilities and reducing the dependence on artificial light are other benefits of the application of this system.

One of the most important reasons for the public interest in this face is the ability to open windows in the internal shell. This is easily possible, even in high-rise buildings where bodies are exposed to high wind pressure. This feature is also used to reduce noise, and the possibilities set by the user, to a large extent, provide comfort to the residents. Another benefit of this façade is avoiding contamination and providing night security for moving windows. Also, there is the possibility to use shade on the façade, even in bad climate conditions, where there is wind, rain, and polluted air. From the point of aesthetics, using this technology increases the architectural qualities. In some buildings, including the max Planck building and Stadttor building in Germany, using this facade displays advanced technology. Another aspect of the aesthetics of using this view is the achievement of transparent architecture. In this method, compared to the conventional method, the buildings mentioned have dramatically achieved this goal (Taghi & Montazer Motamedi, 2006).

In Iran, a significant portion of energy is spent on cooling or heating the buildings. A new solution with a sustainable architecture approach is required for reducing energy consumption. The proper use of light and solar energy in buildings is one of the most basic principles of optimal use of energy in architecture. The application of canopies and double-skin facade are an appropriate response to the use of energy resources (Mohammad Khani, 2012).

The advantages of double skin facades over conventional single skin facades are not clear-cut; similar isolative values may be obtained with conventional high performance with fewer windows. The cavity causes a decrease in usable floor space and depending on the strategy for ventilating the cavity, it may lead to problems with condensation, and subsequently exposure to outside noise. The construction of a second skin may also present a significant increase in materials and design costs. Building energy modeling of double skin facades is inherently more difficult because of varying heat transfer properties within the cavity, making the modeling of energy performance and the prediction of savings debatable (Penić et al., 2014).

There are other advantages of the double-skin facade:

- Low construction costs compared to other similar methods.
- Sound insulation.

- Thermal insulation.
- Natural ventilation.
- Reducing the effect of wind pressure.
- Transparent designing.
- Escape from fire.
- Solar performance.

On the other hand, the important question is the impact of using these shells to reduce energy consumption in buildings. The Design Builder software was used for thermal simulation; the result verified that the total amount of energy consumption of the models with an optimized double-skin facade for warm and dry climates was 14.4 kW-hr/m^2, which is less than the energy consumption of the models without the double-skin facade. Although energy consumption for lighting throughout the room with optimized double-skin facade was higher, the impact of the double-skin facade to reduce energy consumption for heating and cooling is more tangible. This shows the high-potential of using these optimized shells for hot and dry climates to reduce energy consumption in buildings (Hadiyanpour et al., 2014).

Indeed, nowadays the use of natural ventilation in buildings, in order to ensure the welfare and convenience of the users, needs to be considered in building design. Taking advantage of natural ventilation will decrease the indiscriminate use of HVAC in buildings. Double-skin facade will provide noise, wind, and rain control. Double-skin facades have the possibility to protect and adjust the heat, cold, light, wind, and the outside noise condition, as well as providing comfort and well-being to residents without wasting energy (Ghadimi et al., 2013). Challenges carried out in buildings with double-skin façade cause the creation of balance between performance aesthetics, acoustics solutions, and visual efficiency in construction of the building from the point of view of energy supply (Afshin Mehr et al., 2015).

2.6. Disadvantages of Double Skin Façade

Despite the huge benefits of this technology, double skin façade system has some disadvantages, some of which are mentioned below:

- High manufacturing costs compared with conventional façades.
- Reducing the usable valuable space.
- Excessive cost of maintenance.
- Accumulation of warm air in the upper classes.
- Welding problems.
- Increasing the heat of structures (Servatjoo & Armaghan, 2011).

2.7. Double Skin Façade and its Role in Energy Efficiency in Buildings

According to studies and real examples, double skin facade system, in addition to having a positive impact in the field of aesthetics, saves 30% of energy consumption. Furthermore, it also provides natural ventilation, reduces the dependency of the building on natural light, and significantly reduces noise pollution. Moreover, the upper floors of the building also show good resistance against wind-power (Shahriari & Karimzadeh, 2012).

In a study of thermal behavior of single skin and double skin glass façade conducted by Ghanbarian and Hosseinpour, using simulation-based samples with double skin facades, it was observed that the "double skin glass separated by air gap”, in other words, the so-called double skin façade, can reduce energy consumption by 16 to 20 percent HVAC system in the building.

However, it was recommended that even in the case of using double skin facade, the façade itself should not be fully covered by glass, and some opaque parts should also be considered. In total, the first option of double skin facade with glass surface 70% could be a good choice as an alternative to single-skin glass facades which causes 20% reduction in energy consumption of HVAC systems in office buildings. Indeed, it was found that these facades show better performance on energy savings during the cold season (Ghanbaran & Hosseinpour, 2013).

Another study has reviewed the cooling energy consumption and the percentage of energy efficiency for warm months in Tabriz. It was determined that the use of the double skin façade, with internal ventilation in the space between the skin, had a significant dominance for the city of Tabriz. It could reduce energy consumption from 100 percent to zero percent in October, whereas energy consumption was reduced by about 98 percent in May. This means that there is no need to spend money and energy on buildings for cooling in these two months. The consecutive results in reduced energy consumption belong to September with 83 percent, June with 63 percent, July, and August with about 44 percent, respectively. The reason is that the average temperature in the city of Tabriz in the summer is slightly higher than the comfort temperature, and double skin facade with natural ventilation could easily control the indoor temperature. Indeed, using internal sheds in the space between double skin facades does not let direct sunlight enter the building while the natural outdoor light is used. As a result, the indoor temperature is kept low and the need for cooling is reduced (Zolfaghari et al., 2013).

The simulation results conducted in the Design Builder software by Hadipour et al. (2014) in a room with an improved double skin facade (equipped with the best results of the previous calculations) showed that total energy consumption of the room with double skin facade is 4.14 kWh / m2 less than that of the room without double skin facade. This result shows the potential of using this type of facade in the reduction of energy consumption of the buildings in hot and dry climate (Hadiyanpour et al., 2014).

Research conducted by Zolfaghari et al. (2015) indicates that the use of double skin facades generally could reduce the building energy consumption in the cold season with a greenhouse-like performance which is stronger in cooler months. The double skin phase-change facades, in addition to utilizing a greenhouse-like performance, could save the energy during the warm periods and release it to the building during the night with the aid of their phase change to prevent the cold to enter the building (Zolfaghari et al., 2015).

In recent years, the interest in double skin facades has increased because of esthetic reasons and for its use as a passive system to save energy. Some authors have investigated their behavior related to thermal performance and energy efficiency in comparison with single skin facades. The aim of this work is to identify more efficient double glazed facade configuration that improves energy efficiency and indoor comfort conditions in buildings, and to study natural ventilation due to buoyancy-driven flow and heat transfer, including solar radiation, as compared to a single skin facade. A simplified model was simulated using a computational fluid dynamics software to investigate the effects due to different cavity widths in winter and summer conditions, with opened and closed vents, and whether there is solar radiation or not. The main results obtained were that in winter closed vents are always efficient and ventilating is never beneficial. In summer, closed vents are efficient in the absence of solar radiation, and in its presence opened vents are favorable. Results showed the optimum air cavity width, and it was concluded that these double skin facades reduce the heating and cooling demands of a building, being more efficient compared to single skin facades (Sanchez et al., 2016).

3. Methodology

In this study, descriptive, analytical, and simulation with software were used. It was also tried to use a comparative approach to identify and assess some indicators to provide some solutions for more energy efficiency.

3.1. Site Location

Shiraz is situated in Fars, Iran, its geographical coordinates are Latitude: (29°32′37″ N) Longitude: (52°36′52″E) Elevation above sea level: 1545 m = 5068 ft.

Evaluation of the performance of double-skin facade in Shiraz climate: To accurately evaluate the performance of double skin facades in the city of Shiraz, the Design Builder software was used for the simulation process. In the first step, the energy plus weather data related to Shiraz, according to table 1, were imported into the software.

Table 1 Energy Plus Weather Data of Shiraz.

General	
Name	**IRN_SHIRAZ_ITMY**
Source	ITMY
Country	IRAN (ISLAMIC REPUBLI
Filename	IRN_SHIRAZ_ITMY.epw
Details	
Latitude (°)	29.32
Longitude (°)	52.36
WMO station identifier	408480
ASHRAE climate zone	3B

In the next step, two buildings were designed in the software environment.

A building without double skin façade, as building A, and a similar type building with an exterior double skin façade (building B).

Building A Building B

Fig 4 The schematic construction of building A and building B.

The characteristics of the four profile layers of building A are shown in Fig (5).

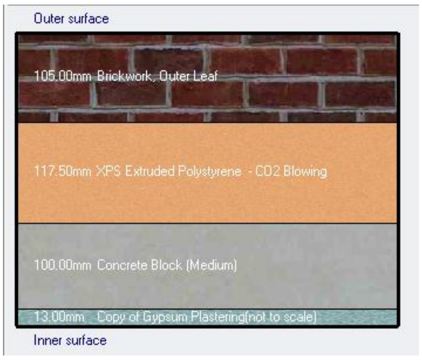

Fig 5 Layout of Building A, defined in the project.

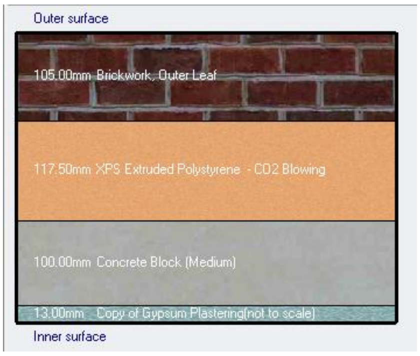

Fig 6 The outer skin defined for the building with double skin façade.

The design of the double skin facade building was carried out in two stages. The first stage, the outer skin designed with the specifications listed in fig (5), as shown in fig 6, and then the inner skin was designed with the specifications listed in fig (7).

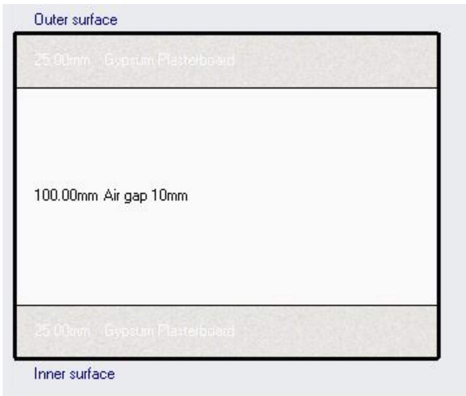

Fig 7 The inner skin defined for the building with double skin facade.

4. Results and Discussion

Annual energy loss was studied in the main parts of the building. The results were obtained on the basis of figures (7) and (8).

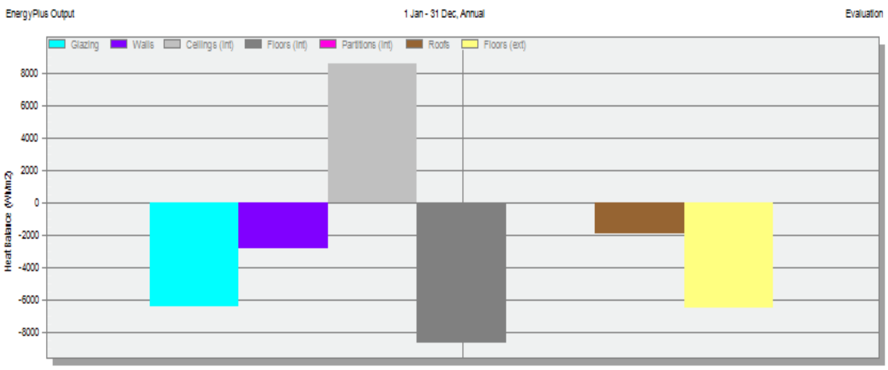

Fig 8 Amount of energy loss in terms of Watt-hours per square meter in building A.

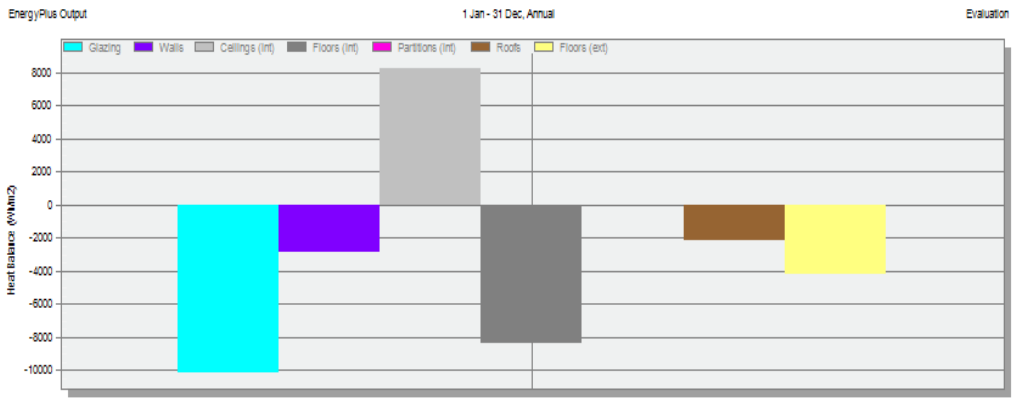

Fig 9 Amount of energy loss in terms of watt-hours per square meter in building B.

As it was expected, in the building designed with double skin facade a reduction in thermal dissipation was observed in all parts. For example, in the external floors, heat balance was significantly decreased compared to a standard building with only one shell. The reduction was about 1000 [Wh/m^2], which is a considerable decrease in annual energy consumption of the building as it can be seen in Fig (9).

Table 2 Annual building energy performance in building A

Site and source Energy

	Total Energy [kWh]	Energy per total building area [kWh/m^2]	Energy per conditioned building area [kWh/m^2]
Total site energy	6214822.01	349.39	349.39
Net site energy	6214822.01	349.39	349.39
Total source energy	13071643.41	734.86	734.86
Net source energy	10231241.66	575.18	575.18

Table 3 Annual building energy performance in building B

Site and source energy

	Total Energy [kWh]	Energy per total building area [kWh/m^2]	Energy per conditioned building area [kWh/m^2]
Total site energy	5876135.67	329.99	345.21
Net site energy	5876135.67	329.99	345.21
Total source energy	12363448.31	694.31	726.33
Net source energy	9687479.71	544.03	569.12

The further results indicate that the total energy in the building designed with double skin facade was significantly decreased compared to a standard building, which the only reduction of one shell was from 6214822.01 - 5876135.67 [kWh]. Also, Energy per total building area reduction and Energy per conditioned building area reduction were from 349.39 - 329.99 [kWh/m^2] and 349.39 - 345.21 [kWh/m^2], respectively. Finally, by comparing Tables 2 and 3, it can be concluded that the double skin facade design decreased the energy consumption significantly.

5. Conclusion

Due to the limited resources of fossil energy, energy crisis, environmental pollution, as well as consumption of 40% of energy by the construction sector, attention to different active and passive methods is of utmost importance in order to optimize energy consumption in the building sector. Low cost of energy and fuel is the reason for insufficient attention to national capital preservation and its wastage, which is especially observed in the construction industry and building engineering.

Suitable design in architecture, along with the use of new equipment and materials, create a competition between the manufacturers, as well as engineers. Implementation of energy management and the use of new methods and technologies in buildings like double skin facade are the ways which reduce the costs and increase the welfare of the users.

It is important that the outer shell in the single shell have high heat dissipation. To fix this problem, the design and implementation of intelligent facade and the inclusion of double skin facade are quite useful in optimizing energy consumption in buildings. The fact is that the air between the shells is an appropriate thermal insulation. Double skin facade has many advantages, such as light weight, high strength, and the possibility to simultaneously run with brickwork. In addition, if the cavity space is properly controlled in this type of Façade, it will play a very effective role in building energy efficiency.

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