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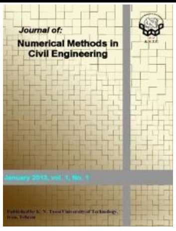

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Numerical assessment of natural air conditioning in a building with double skin facade in hot arid climate

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Abstract:

Today, there is more need for natural air conditioning, which means there is more demand for air conditioning by open windows. Perhaps this is a reaction to the "Sick Building Syndrome" which is frequently used to describe irregular HVAC use. In buildings, the implementation of these mechanical , increasing continuous comfort, shows the lack of awareness and consideration towards environmental issues, including the enormous amount of energy waste. The results of all the conducted research conclude the façades require a greater design which is well equipped to encountering the elements, including wind, rain, heat, and humidity. In this regard, Dual Skin Facades, which/ have recently become widespread in European architecture, provide the possibility of natural ventilation while regulating sound, wind, and rain. Heat, cold, light, wind, and outside noise may all be adjusted and compensated by Dual Skin Facades, allowing residents to be more comfortable without any energy loss. The purpose of the following paper is to perform a numerical investigation of natural air conditioning in various Dual Skin Façade systems. The buildings under consideration are located in Iran's "Hot and Arid" climate in the city of Kerman, and they will benefit from natural air conditioning in most months of the year. Also, the parameters impact the flow field, such as velocity and temperature in winter and summer, as well as throughout the day and night, were studied for various opening sizes. The results of modeling showed that regarding the climatic conditions, the appropriate selection of the dual skin facade system, the air-gap width, the ventilation method, the location, and the dimensions of the openings, significantly made the buildings with dual skin facade obviate the need for mechanical heating and cooling facilitieswhich leads to energy saving.

1. Introduction

Dual skin facades are defined as follows by the National Institute of Building Research in Belgium:
The Active Façade (Dual Skin) is a kind of façade which consists of several transparent skins, covering a story or more of a structure, whether the sheets are air isolated or not. The air gap between the two skins might be naturally or artificially ventilated. This gap's ventilation strategy changes by time. The amenities and systems of the façade, whether active or passive, are incorporated to improve the inner environment.
Automated control systems are used to manage such complexes in most cases [1].

Dual skin facades are an intricate part of office buildings that have been extensively considered and executed. The façade is designed in a way that the building's skins are made up of two layers (interior and exterior skins) of different glass materials separated by an air gap and enabling air ventilation. Not only does the building's exterior skin protects it from climate threats, but it may also considerably minimize noise pollution. Inhabitants might benefit from

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adjustable windows independent of climatic impacts such as wind and flurry, the negative effects of direct sunshine (glare), contamination of the environment, and so forth. The possibility of installing awnings protects the interior rooms of the building from direct sunlight while using daylight, which reduces the HVAC load in cooling the building in summer. In cold climates, the dual skin façade acts as a heat conserver, so that the radiant energy is stored between the two layers (in the gap), and its temperature is approximately the same as the building's interior temperature [2].

In addition to providing the required transparency, the dual skin facade can save the solar radiation absorbed by the external glass of facade in the winter or reduce it in the summer with the help of proper natural ventilation. Here's how the dual skin system contributes to improving the quality of the interior air as well as reducing the load on the air conditioning system [3].

Dual skin facade research is conducted in a variety of climes, including hot and humid [10], moderate [11,12], cold [13], and hot arid regions [14,17]. Simulations have been used in the most of these investigations. The technology was initially developed in cold climates, however beginning in the 1980s, dual skin technologies began to spread to Europe, North America, and Japan noticeably. The use of dual-skin facades in regions with extremely hot summers and cold winters (Hot and Arid Climates) is increasing as a result of recent economic developments [4]. However, field measurements have not frequently been carried out in these investigations.

The air gap size, windows, construction material types, structure type, the direction of air current, shading devices, and intelligent controlling systems are some of the fundamental elements in designing dual skin facades [2,16]. The types of air ventilation in the air gaps of dual skin facades could be natural, mechanical, or a combination of both [15]. The natural ventilation takes place based on air buoyancy, which is the result of the potential difference between the external and internal temperatures, leading to the pressure differential is produced in the air gap. Other elements such as wind direction, speed, and the resulted air pressure, the building positioning, the size of the windows allowing the air in and out, and etc., could contribute to the performance of natural air ventilation [4].

It is possible to ventilate the airgap in-between two glass layers mechanically, which its intensity is adjustable. The ventilation of the internal air via windows (regardless of window type) depends on the air current and the difference between the inside and outside temperatures [5].

Since the 1980s, Dual skin facades have been installed in office buildings in Iran. Although the number of DSFs in Iran is currently limited, architects are increasingly turning to them. In this study, a structure in a hot arid climate is measured in summer and winter, throughout the day and night. Also in this research, the window sizes to induce the air intake to the building or output from it in terms of natural ventilation in the dual skin buildings are analyzed numerically as below.

2. Literature review

2.1 The Layers to Dual Skin Façade

The layers of dual skin façade include the External Skin, the Internal Skin, and the airgap in between the two.

The External Skin (Façade): Generally, it is a singular toughened (tempered) glass, and the external glass could be made entirely out of glass.

The Internal Skin (Façade): They are thermal insulating double pane (varieties of solar glasses may be applied) glasses and could be made entirely out of glass.

The air gap between two glasses: The air gap can be ventilated naturally or mechanically. Air gap sizes vary from 20 cm to 2 m thick and act as a support. Users can access the windows to ventilate. Shading can also be integrated and controlled by an automated system within the air gap [6].

The external skin is to protect the building against air hazards, and it also insolates external noise pollution. Usually there are openers which allow ventilation for the inner spaces and rooms. The air current is activated through the airgap of a dual skin façade by means of convection. To achieve further compatibility with the surrounding environment, it is also possible to close the external openings completely. The external skin of facades is generally constructed using tempered or laminated glasses. Some adjustable sun blockers are installed in the inner layer. The internal skin includes frames of dual-layer glasses that can prevent the thermal energy from escaping in the winter. In most cases, the inner layer could be adjusted to open for natural ventilation [7,18].

2.2 Façade Skin Structures

There is variety of construction materials to choose from/ . The types of glasses are either Tainted (LOW-E) or Toughened glasses and could be implemented in a variety of methods. The shade material could be either out of metal or plastic, painted or simply reflective high gloss, and also solid or porous. The layer setup depends upon the direction of the air current. If the air is to be ventilated outward, the isolation would be placed into the inner frame, and another glass would be placed on the outer side; otherwise, if the air is to ventilate inward, the isolation is placed into the outer skin [8,19].

2.3 Schemes of Air Current in ventilation

The façade has three various recommended air ventilation schemes. (see figure 1):

-Type A: The air enters the airgap from inside the building, and the air coming out of it returns to the central heating or A/C systems of the building.

-Combination of Ventilation (Type B & C): The air enters the airgap from inside or outside the building, and is directed outward to the opposite side.

-The B and C variants may pre-heat the air before it reaches the rooms in colder climes.

-In types A, B, and C, mechanical ventilation is used, which can be combined with the HVAC system of the building.

-Ventilation to the outside of the building (Type D): Fresh air enters from outside through the air gap and it is also ventilated outside. The D type is used in conjunction with a natural ventilation system as a breath for the dual skin façade. In this type, fresh air can be supplied to the interior of the building through open windows. Also, when the windows are closed, as a thermal insulator, it creates suitable thermal stability [8,2].

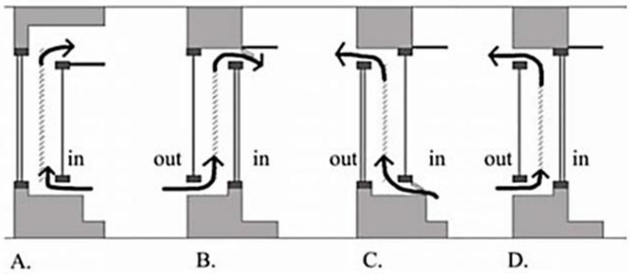

Fig.1: Types of ventilation plans [1]

2.4 Climatic Pointers in Designing Dual Skin Façades in Hot & Arid Climate

-The conducted research concludes that if the air-gap diameter is anything from 50 to 60cm wide, it may provide a more suitable result.

-As a part of climatic pointers, it is recommended to use very small openers in approximations of 10 to 20% of the surface, and also, to prevent the direct sunlight from shining through the window surfaces.

-The shading mechanisms (if any) are the best if they are installed to the internal layer near the exterior layer to reduce the thermal exchange.

-The arrangement and proper designation of the air intake windows are recommended to be facing south or southeast because that is the direction in which the agreeable air current often is in the summer, along with some measures to reduce the temperature of the incoming air, once it is to enter the building. Since the northern side of the building has minimal exposure to sunlight, it is the most appropriate side to designate the air intake windows in most climatic categories. It is recommended to avoid windows facing the west, or the southwest as much as possible due to the direction of cold air which often comes in the winter.

-To take advantage of the sunlight shining on the skin, and as a conclusion, the increased air buoyancy of the air-gap raises the air in it that produces suction power to move out the air inside the building. It also operates as an insulating layer in the winter; therefore, Dual skin facades out to be positioned facing the south side in the northern hemisphere [2].

3. Methodology

3.1 The process of the numerical study of natural ventilation in Dual Skin Façades

In order to investigate the performance of natural ventilation in the dual skin facade system, and the parameters which have effect on it, a three-story building in a hot and dry climate as a case study was numerically evaluated. The specifications of the case study and the climatic data are given in the next section.

In this study, FLUENT software was used to analyze the flow field of the dual skin façades numerically. FLUENT software solves the Navier-Stokes equations, which are a set of momentum and mass conservation equations. This software solves these equations on the grid of cells and estimates the parameters affecting the flow field.

GAMBIT software has also been used to create geometry and meshing. After meshing, the boundary conditions should be selected. For this purpose, the air inlet and outlet, the internal and external surfaces, and surrounding walls are determined, and finally, the resulting mesh is entered into FLUENT software. The most important point in numerical analysis is the correct choice of boundary conditions.

In this modeling, the inlet and outlet boundary conditions are determined based on wind speed and temperature of the flow of air.

After applying the meshing, boundary conditions and initial conditions on the desired geometry, the desired model is numerically simulated for a period of 24 hours in an hourly segment.

Finally, by solving the flow field, the distribution of velocity and temperature is obtained.

In the following the specifications of the case study and climatic data are described:

3.2 Case study

The case study in this research is a hypothetical 3-story building in which a single-room unit is considered on each floor. The second skin is installed on the south side of the building. The width of the airgap in this dual-skin facade is considered to be 50 cm. On each floor, an opening with variable dimensions of 0.4, 0.6, and 1 meter is placed on the inner and outer skin. The internal and external windows and the openings at the top and bottom of the airgap, can be opened or closed according to the position.

3.3 Climate data

The current model has been investigated in the hot and dry climate of Kerman city with latitude and longitude of 57° and 30°. Also, the required climatic data, such as wind speed and temperature, are collected in Table 1. The climatic data below is quoted from the book “Climate and Architecture” by Morteza Kasmaei[9].

Table 1. The climate data

	Summer		Winter	
	Day time	Nighttime	Day time	Nighttime
The average temperature of the exterior design (°C)	34	15 (the intended value is the lowest possible temperature)	15	0
The average temperature of the interior design(°C)	25		23	
The average wind velocity(m/s)	3		4	

In the following, according to the assumptions below, modeling, and analysis of the results have been done:

In all the figures, the first model from the left shows the 100cm sized window, the second model is the 60cm sized window, and the third model is the 40cm sized window .

In all models, the two lowest exterior windows are the air inflow, and the exterior window positioned on top is the air outflow.

Most of the time, the external window's inlet air temperature is 3 degrees colder than the outside air temperature, and the opener's inlet air temperature at the bottom half of the air gap is 1 degree colder. The inlet air velocity of the lower opener is intended to be 2.5$^{M/Sec}$.

3.4 The Glass Specifications

The characteristics of the glasses used in the inner and outer skin are defined in table 2 as default data.

Table 2. The Glass Specifications

	The Inner Glass	The Outer Glass
Thickness(mm)	150 (the double glass windows gap)	5
Coefficient of Heat Conductance(w/m².k)	2.9	5.9
Special Heat Capacity(j/kg.k)	2500	

4. Numerical results

Numerical analysis of Natural Ventilation in Dual Skin Façade

In order to analyze the results of flow field simulation, changes in velocity and temperature parameters for different dimensions of the opening, and at different times, such as night and day, summer and winter are given. It should be noted that in all diagrams, the first model from the left shows 100cm openings, the second model shows 60cm openings, and the third model shows 40cm openings.

4.1 Temperature Changes

Daytime temperature changes in summer are shown in figure 2. In this case, the inflow and outflow windows are open, and the upper opener is closed. Also, the inflow air temperature through the openers is set at 31 degrees Celsius, whereas the outside temperature considered to be 34 degrees Celsius.

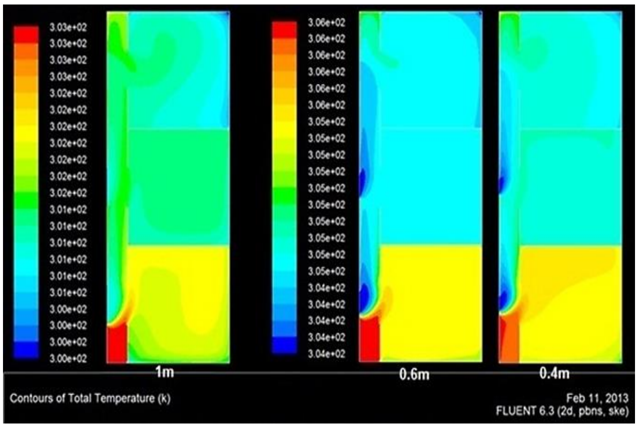

Fig. 2: Daytime temperature changes in summer; the inflow and outflow windows are open, and the upper opener is closed

Referring to the first model, the passing air through the airgap has changed the temperature of the first floor to 29○C, the second floor to 28○C, and on the third floor to 27○C, which indicates a 7°C drop in temperature relative to the outside temperature. It means 7○C less in temperature difference between the outside and inside, which allows less heat transfer between the two. It also means that with respect to comfort temperature of 25○C, there is at least a 2○C increase.

Referring to the first model, the passing air through the airgap has changed the temperature of the first floor to 32○C.and the second and third floors to 31○C, which indicates a 3°C drop in temperature relative to the outside temperature. It means 3○C less in temperature difference between outside and inside, which allows less heat transfer between the two. It also means that with respect to comfort temperature of 25○C, there is at least a 6○C increase.

The model experiment, in brief, shows that if the inner air inflow openers to the building are to be opened, the size of the openers will have significant improvements on the internal temperature of the building, and the model with a1-meter-wide opener would have a greater effect on balancing the internal temperature of the building.

4.2 Velocity Changes

The daytime wind velocity changes in summer are shown in figure 3. In this case, the inflow and outflow windows are open, and the upper opener is closed. Also, the inflow air temperature through the openers is set at 31 degrees Celsius, whereas the outside temperature is considered to be 34 degrees Celsius.

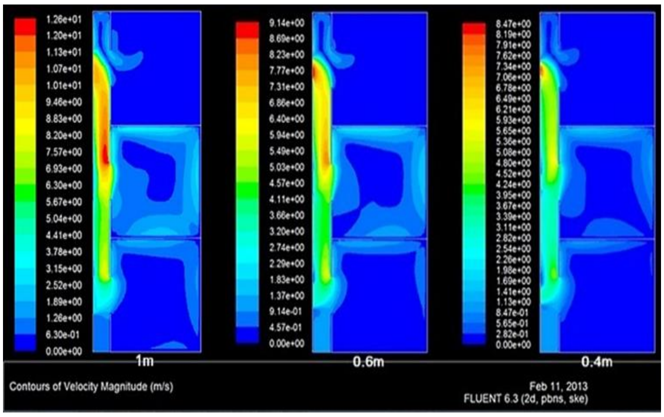

Fig. 3: The daytime wind velocity changes in summer: the inflow and outflow windows are open, and the upper opener is closed

In the first model, The velocity of the air inflow to some parts of the first and the second floor is increased from "0" to about 1.5 / 2.0M/Sec. The outflow velocity of air through the third-floor window due to the combination of suction power and higher pressure reaches 10M/Sec, and it does not produce a noticeable change to the air current of the third floor inside of the building.

In the second model, the velocity of the air inflow to some parts of the first and second floor is increased from "0" to about 1 / 1.5M/Sec. The outflow velocity of air through the third-floor window reaches 8M/Sec, and it does not produce a noticeable change to the air current of the third floor inside of the building.

In the third model, the velocity of the air inflow to some parts of the first and second floors is increased from "0" to 1M/Sec. The outflow velocity of air through the third-floor window reaches 6M/Sec, and it does not produce a noticeable change to the air current of the third floor inside of the building.

4.3 Temperature Changes

The nighttime temperature changes in summer are shown in figure 4. In this case, the inflow and outflow windows are open, and the upper opener is closed. Also, the inflow air temperature through the openers is set at 12 degrees Celsius, whereas the outside temperature is considered to be 15 degrees Celsius.

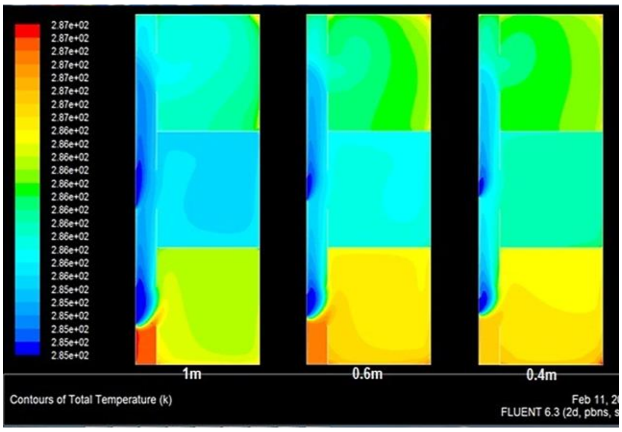

Fig. 4: Nighttime temperature changes in summer; the inflow and outflow windows are open, and the upper opener is closed

Referring to the first model, the passing air through the airgap has changed the temperature of the first floor to 13○C, the second floor to 12○C, and the third floor to 13○C. The analysis shows a maximum 3°C drop from the outside temperature. Additionally, it shows a 12°C drop from a 25°C level of comfort.

According to the second and third models, the passing air through the airgap has altered the temperature of the first floor to 14○C, the second floor to 12○C, and the third floor to 13○C. The results show a maximum temperature reduction of 3 degrees Celsius in comparison to the outdoor temperature. It also indicates a decrease of 11°C compared to a comfortable temperature of 25°C.

Briefly, the model result indicates that if the inner air inlet openers to the building on summer nights are to be left open, the size of the openers will have no significant improvement on the temperature inside the building. In the model, the air temperature of the second floor is slightly less than the first and the third floor. This is due to higher air circulation to the floor. The reasons are the choices made with respect to the inflow and outflow of the openers of the external façade, which produces a denser air to the section and an increased level of heat conductivity.

4.4 Velocity Changes

The nighttime wind velocity changes in summer are shown in figure 5. In this case, the inflow and outflow windows are open, and the upper opener is closed. Also, the inflow air temperature through the openers is set at 12 degrees Celsius, whereas the outside temperature is considered to be 15 degrees Celsius.

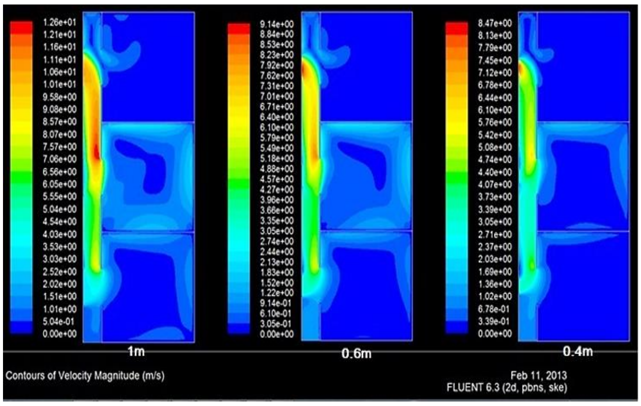

Fig. 5: Nighttime velocity changes in summer; the inflow and outflow windows are open, and the top opener is closed

In the first model, the velocity of the air inflow to some parts of the first and second floor is increased from "0" to about 2 / 2.5M/Sec. The outflow velocity of air through the third-floor window due to the combination of suction power and higher pressure reaches 11M/Sec, and it does not produce a noticeable change to the air current of the third floor inside of the building.

In the second model, the velocity of the air inflow to some parts of the first and second floor is increased from "0" to about 2 / 2.5M/Sec. The outflow velocity to the third-floor through the window reaches 9M/Sec, and it does not produce a noticeable change to the air current of the third floor inside of the building.

In the third model, the velocity of the air inflow to some parts of the first and second floors is increased from "0" to 1.5M/Sec. The outflow velocity of air through the third-floor window reaches 7M/Sec, and it does not produce a noticeable change to the air current of the third floor inside of the building.

With respect to the obtained results, the best size for the openers in the summer is 1 meter in dimensions.

With reference to the best model picked above, a model is set up and analyzed for winters, daytimes, with the internal windows closed, the top opener closed, and the external windows open to ventilate the airgap as it was set and evaluated for summer.

4.5 Temperature Changes

Daytime temperature changes in winter are shown in figure 6. The outer windows should be left open; however, in this case the interior windows and top opener should be closed. Additionally, it is planned for the outside temperature to be 15 C.

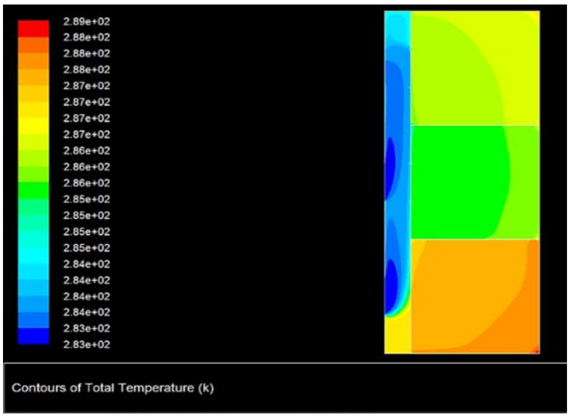

Fig. 6: The daytime temperature changes in winter; the interior windows and the top opener are closed, but the outer windows are to be left open

In this model, due to the closed inner windows and as a result of the circulation of air inside the airgap, the temperature inside the building reaches 15 degrees Celsius on the first floor, 13 degrees on the second floor, and 14 degrees on the third floor. Compared to the outside temperature, we see a temperature drop of at most 2 degrees, and in comparison with the comfort temperature, which is equal to 25 degrees Celsius, we are facing a temperature drop of at least 8 degrees.

Briefly, the simulation study demonstrated that, in the conditions of closing the inner windows of the air entering the building, the air circulation in the airgap has a negative effect on the temperature inside the building during the day in winter, so this model is not suitable for the winter season under these conditions.

4.6 Velocity Changes

Daytime wind velocity changes in winter are shown in figure 7. In this case, the top opener and interior windows should be closed, but the external windows should be kept open.

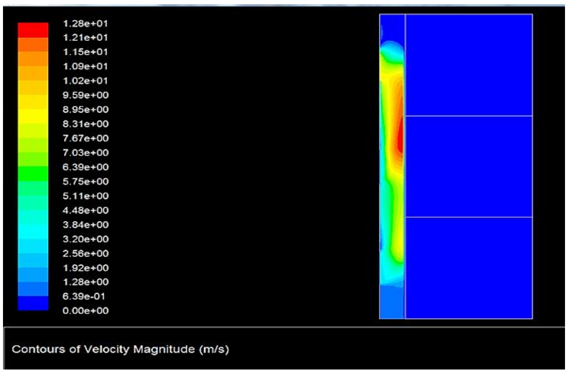

Fig. 7: Velocity changes in winter daytime; the interior windows and the top opener are closed; the external windows are kept open.

In this model, the inflow wind velocity is considered to be 4 meters per second, and due to the closed windows of air entering the building, the wind velocity has no effect on the in-building airflow.

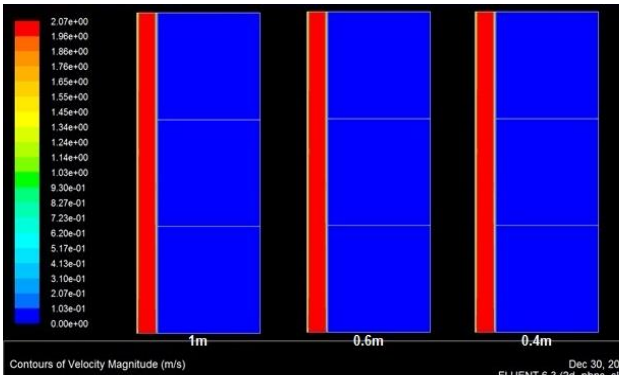

Fig. 8: Daytime velocity changes in winter; the inflow and outflow windows are closed, and the upper and the lower openers are opened.

Although the results of the daytime winter temperature alteration in the model of the figure 4 have been negative, we proceed with analyzing the temperature and velocity alterations in winters per model below: the inflow and outflow windows are closed, and the upper and lower openers are opened.

4.8 Temperature Changes

Daytime temperature changes in winter are shown in figure 8. The temperature outside is considered to be 15○C, and the air through the lower opening of the airgap is supposed to be 14○C. In the following model, the three openers located on the external skin closed, and in order to let the air in and out, certain openers on the top and at the bottom of the airgap are allocated.

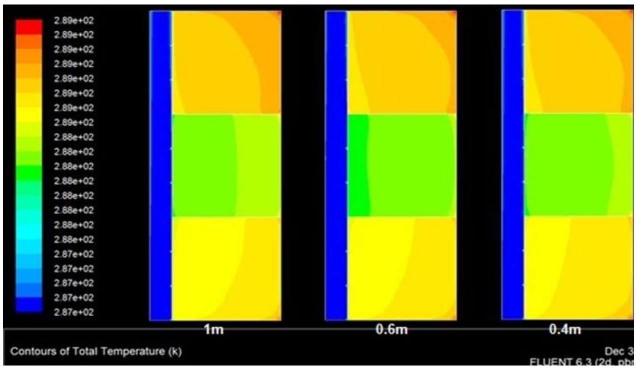

Fig. 9: Daytime temperature changes in winter, the inflow and outflow windows are closed, and the upper and lower openers are opened

Although the inner and the outer openers, set in all the three models, have been closed, but the results have been similar. In this position, the flowing (Air) has greater contact with the inner skin ,and thus, it allows a higher level of heat conductivity. As a result, the movement of the flowing air in the airgap affects the air temperature inside the building; Therefore, the first floor reaches 16○C, the second floor reaches 15○C, and the third floor reaches 16○C. In comparison to outside temperature, a 1○C increase is observed. In other words, the value of the outside temperature has approached the building's internal temperature by 1○C which translates to a lesser heat conductivity between the outside and inside.

In brief, when the air inflow and outflow openers to the building are closed, the tunnel-like flow of air through the airgap will have some favorable effects on balancing the air temperature inside of the building on winter daytime.

4.9 Velocity Changes

Daytime velocity changes in winter are shown in figure 9.

Although the inflow and outflow windows to the building are closed, the air current velocity remains constant in the airgap, and the air current velocity in the building is "0". Also since the air flow windows to the building are closed, the outside wind velocity will not affect the air current velocity inside the building.

5. Conclusion

Although preventing the sunlight from shining into the building directly would reduce the cooling load in summer, and appropriate ventilation would reduce the effect of the absorbed sunlight in the glass layer of the dual skin façade buildings, but it is the natural ventilation that would be the most advantageous in reduction of cooling load and heat reduction it also contributes to providing fine quality air entering the building.

A glance at the conducted research would reveal that natural ventilation takes place in dual skin façades based on the buoyancy resulting from the potential difference in temperature (producing the potential difference of air pressure in the airgap); therefore, the less the "air pressure potential difference" is in the airgap, the better the natural air ventilation would be. It is possible to produce a thermal difference between the outside and inside of the airgap by reducing the temperature of the exterior surface of the inner layer of the building. In other words, at this stage, the delay time needs to increase. The fact that suction power onto the airgap is controllableallowing us better air ventilation.

With reference to the modeling and the consequent figures, the best way to take advantage of dual skin façades in hot and arid climate, whether in summer or winter, the dimensions and the positioning of the openers are as follow:

Winters: The dimensions of the openers are 1 meter when ventilating the airgap in a tunnel shape (the air enters from the lower opener to the airgap, and exits from the opener located on top of the airgap). When both the inner skin and the outside skin of the building's inflow and outflow windows are closed, it may create some positive consequences. It is reasonable to Concisely, when the outside temperature is considered to be 15○C, and the inside comfort temperature is at 23○C, the model has shown a 1○C increase with respect to the outside temperature and still needs a 7○C to reach the comfort temperature inside the building. One of the effective parameters for balancing room temperature in winter is the radiation effect, which is skipped because the topic is too complex and also it is outside of the research scope. With respect to the influence that radiations can have on improving the model's result, therefore, the model of choice is recommended best for winter. (Figure 8 analysis)

Summer daytimes: "1" meter sized openers with ventilations in the airgap in a way that the air enters through two windows located at the bottom of the external skin at first and the second floor. The passing air exits through the upper window located on the external skin near the third floor to the building. Meanwhile the inflow windows of the building are to be left open. When the outside temperature is to be 34○C and the inside comfort temperature is 25○C, the model shows a 7○C decrease with respect to the outside temperature which requires only a 2○C to reach the comfort temperature inside. (Figure 2 analysis)

Summer nights: Due to the velocity and thermal resemblance of summer nights with one of winter daytimes in the intended climate, one meter-sized openers, a tunnel-like ventilation system in the airgap (the air enters from the lower opener to the airgap, and exits from the opener located on top of the airgap), closed inflow and outflow windows to both the inner and the outer skins of the facades, and with regard to the fact that other models failed to show desirable results, also since the wind velocity in the summer is less than the winter; therefore, better results are achieved from the said model in summer in comparison to the winter. This is recommended for summer nights. (Figure 4 and 8 Analyses).

According to the conducted research on Dual skin façades and its many advantages, this type of facade is widely used in office buildings. This type of facade plays a significant role in adjusting the temperature inside the building in summer and winter by using weather factors as much as possible and using natural ventilation. Also, using this facade and natural ventilation in buildings reduces the use of mechanical heating and cooling facilities in buildings, so this model is recommended as the preferred model in hot and dry climates, even for residential buildings.

6. Conflict of Interests

The author declares that there is no conflict of interest regarding the publication of this paper.

7. Data Availability Statement

All data used to support the findings of the study are included in the article.

8. Funding Statement

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