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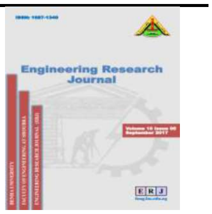

Performance Enhancement of Airflow Patterns of a Double Skin Facade in Hot Arid Climate

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Abstract. The great interest on the double skin facade innovation has been increasing worldwide , despite the advantages of using double skin facade technology, highly naturally ventilated double glazed office buildings which depend mainly on air speed and stack effect; can be overheated during the summer due to the coincidence of high outside temperatures, solar gains and internal heat gains. A comprehensive modeling of a multi-story double skin facade and forced ventilation is proposed. The modeling was done using ANSYS fluent program to measure the air movement within the ventilated facade cavity. In the simulation study, it is proposed to analyze the impact of a two main parameters affecting the airflow development: Cavity depth and cavity openings configurations. The obtained results of this research suggest that by modifying the parameters of DSF, airflow velocity within the cavity can be increased, and, consequently, high indoor tempperture and the need of energy consumption for cooling will be decreased.

This paper is a part of a sequenced simulation study that aims improving thermal performance of DSF office buildings in hot climate condition in Cairo, Egypt.

Keywords: Building Envelope, Double Skin Facade, Airflow, ANSYS.

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1. INTRODUCTION

A great motivation for using double skin facade (DSF) came from the desire of combining glass and transparent walls of modern buildings with energy efficiency. However, its implementation is accompanied by significant challenges due to the complexity of thermal phenomena and airflow involved in their behavior and adaptability of solutions to climate conditions in different geographic regions.

With greater awareness of DSF impact on the use of energy, it has become an attractive technique for reducing energy consumption and cost. Despite of the many advantages of natural ventilation system, in some climatic conditions and building types, natural ventilation is not enough to achieve the required thermal comfort for building users. So it needs to be enhanced by other mechanical sources.

Nowadays the main concept of architectural design is the 'western style' that may not be appropriate in climatic conditions other than cold climate. Therefore, architects must take into account the differences between the methods of construction in cold climates, and how to apply proper techniques in other climatic conditions such as tropical and hot climates.

DSF are still undergoing scientific analysis to optimize settings to improve its thermal properties, light transmission and acoustics. DSF system is not a new approach to sustainable building skin, they have actually gone through different stages from vernacular architecture in the past to modern glass architecture. The concept of DSFs was announced in the 20th century with a limited progress in the beginning .Then during the energy crisis, the importance was directed towards reducing energy consumption of the buildings using this system.[1]

2. OBJECTIVES

Estimating the airflow in the cavity (between the two glazing layers) is a critical for understanding DSF behavior, especially in hot summer conditions. This paper aims for testing how to improve DSF by changing the parameters affecting the airflow patterns in the DSF air cavity in a hot arid climate and to reduce the thermal load on the interior glass interface of the double glass facade. This necessitates testing the parameters of the DSF that influence system performance. The modeling is done using ANSYS fluent program to analyze the impact of two main parameters on the airflow development: Cavity depth and cavity openings configurations.

3. Double skin facade

Double skin facade is obtained by adding an additional layer of glass to the building exterior faced to provide additional ventilation or soundproofing to the building. This system can be implemented in different ways, depending on the building's function and the requirements established to the facade. Recently DSF is an architectural concept that is getting more acceptance and application throughout Egypt, especially in the area of commercial buildings and offices. Literature about double skin facade, revealed that the exterior facade would reduce energy consumption in buildings, but there are still some discussions about the effectiveness of these DSF systems in such dry and hot climate. This will be discussed further in this paper.

3.1. Double skin facade in hot arid climates

The envelope of a building in a hot arid climate is exposed to an aggressive environment for most of the year, leading to the consumption of a large amount of energy to operate the mechanical equipment to keep maintaining indoor comfort conditions.

The complexity and the adaptability of the double skin facade system to the different climatic conditions require accurate design. If the DSF designed properly, then the system is flexible enough to meet climate change for most types of building use.

Some researchers claims that DSF decrease buildings cooling loads (Chan, et al., 2009[2]; Hien, et al., 2004[3] ; Saelens, et al., 2007[4]). However, some other studies showed that DSFs often product a higher consumption of the cooling energy because of the system poor performance (Gratia & De Herde, 2007[5]; Stribling & Stigge, 2003[6]).

There are also cases where summer overheating problems have to be compensated by unnecessary use of air conditioning systems (Streicher et al., 2007[7]).

Regardless of the cost and maintenance issues, double skin facades can provide the clients requirements in addition to the protection from the environmental issues. But still there is a big argument about the effect of using this facade in some hot climate conditions.

3.2. Concept and functionality of the double skin facade

Double skin facades can provide natural ventilation to the interior space and reduce the requirement for mechanical ventilation. For the naturally ventilated double façade system, the natural ventilation strategies are driven into the building by wind pressure effect and stack effect

3.3. Operation principle with natural ventilation

Natural ventilation allows the access to air flow that can be used to cool and ventilate the space through the exterior glazing of the double skin creating a buffer zone of air next to it when not affected by high speed wind. This technique of air reduces the energy consumption of the building and in turn reduces the CO2 output in the operational phase of the building.[8]

The phenomenon of thermal chimney within the DSF occurs due to the density difference between the warmer

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[1] Sinclair, R, Phillips, D, Mezhibovski, V., Ventilating Facades, 2009.

[2] Chan, E., Fong, K., Chow, T., Lin, Z., Investigation on energy performance of double skin facade in Hong Kong, 2009.

[3] Hien , N., Chandra, A., Liping, W., Pandy, A., Xialion, W., Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore, 2005.

[4] Saelens, D., Roels, S., Hens, H., , Strategies to improve the energy performance of multiple-skin facades. 2008

[5] Gratia, E., Herde, A., Greenhouse effect in double-skin facade. 2007

[6] Stribling, D.,Stigge, B., A critical review of the energy savings and cost payback issues of double facades,2003.

[7] Streicher, W., Heimrath, R., Hengsberger, H., Mach, T., Waldner, R., Erhorn-Kluttig, H., On the typology, costs, energy performance, environmental quality and operational characteristics of double skin facades in European buildings, 2007.

[8] De Gracia, A., Castell, A, Navarro L, Oró E, Cabeza, L., Numerical modelling of ventilated facades: a review, 2013.

air inside the cavity and the cooler air outside. The air inside the cavity is warmed up by the solar radiation and exhausted to outside from the top of the cavity. In naturally ventilated building, fresh air is often drawn from windows on the opposite side of the DSF, which passes through the occupant space before being extracted into the cavity of the DSF.

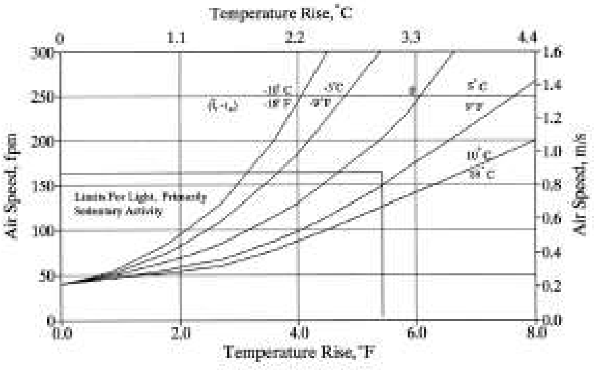
3.4. Natural ventilation for thermal comfort

Achieving acceptable indoor air quality by natural ventilation technique is based on the supply of the fresh air to the space and on the reduction of indoor pollution concentrations. When using natural ventilation for cooling, the upper limit of the thermal comfort zone can be overcome at any moment due to random variations in natural driving forces.

As there are many criteria linked to the natural ventilation performance, air quality control and thermal comfort. Criteria for air quality control are defined in terms of minimum ventilation rates, while criteria for thermal comfort depend on air velocity, indoor air temperature, and mean radiant temperature.[1]

Due to the multi-parameters of thermal comfort, precise value of ventilation rate required for achieving thermal comfort is hard to be determined. So, air velocity is more applicable parameter when talking about thermal comfort.

For low air velocities, mean radiant temperature and room air temperature equally affect the comfort temperature (operative temperature). At relatively high air velocities operative temperature can be described as the room air temperature, reducing the impact of mean radiant temperature. On the other hand, when air temperature is within acceptable ranges for achieving indoor thermal comfort, natural ventilation by convection should be magnified to make best use of outdoor air temperature. Thus, by increasing air velocity, air temperature effect will be maximized to achieve required comfort temperature. The high air speed can be used to compensate for an increase in air temperature and average radiant temperature, but not above 3.0 ° C above the values for the comfort zone without high air speed, such as shown in Figure 1as shown in figure1. [2]



(Fig.1) Air speed required for offsetting increased temperature

(Source: ASHRAE Standard 55-2004, Thermal environmental conditions for human occupancy)

3.4.1. Natural ventilation potential in Egypt

In a study by Yujiao, et al., 2017[3], estimated the natural ventilation hours and energy saving potentials of the world's 60 largest cities, calculated with Building Energy Simulations (BES). In general, Egypt has a desert climate. The climate is moderate along the coast, while temperature can exceed 40C in the summer of the central and southern part of the country. Cairo has 4886 NV hours, and that is a good potential with Egypt's climatic conditions.

3.5. Components of double skin facades:

The BBRI, 2002[4] described the layers of the facade as follows figure 2:

- Exterior Glazing: It can be made of single or coated glass with exterior air inlet and outlet openings controlled manually or automatically or fully glazed.
- Interior glazing: Glazing unis varied from (clear, low E coating, solar control glazing). It consists of fixed or operable, double or single pane windows to allow natural ventilation to the interior space.
- The air cavity: It can be totally natural, fan supported or mechanically ventilated. The width of the cavity can vary as a function of the applied concept.

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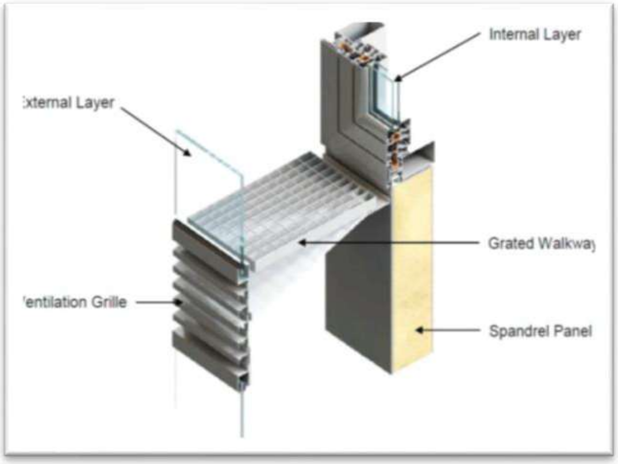
[1] Santamouris, M., Solar Thermal Technologies for Buildings, the State of The Art, 2003.

[2] ASHRAE-Standard, ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, 2004.

[3] Chen, Y., Tong, Z., Malkawi. A., Investigating natural ventilation potentials across the globe: Regional and climatic variations, 2017.

[4] Belgian Building Research Institute (BBRI), Source book for a better understanding of conceptual and operational aspects of active facades. http://www.bbri.be/activefacades/index2.htm , 2002.



(Fig.2) Double skin facade components
(Source: Thermal comfort of multiple skin facades in warm climate offices)

3.6. Classification of double skin facade

There are various approaches for classification of double skin facades, as we concentrate in this study to identify the parameters and factors that mainly affect DSFs building performance in hot arid climate. Three groups of parameters are identified that have major impact on DSF performance: first, the facade parameters which involves the features of the DSF structure, cavity and external layer of the facade; second, the building parameters which comprises physical configurations of the building, including inner layer of the DSF; third one is the site parameters, which are related to the effects of the outdoor surrounding conditions on the building thermal behavior. These are shown in table (1).

Table (1) DSF parameters classification

Parameters Classification	Parameters
Facade Parameters	• **DSF Structure** • **Cavity height** • **Cavity depth** • **Cavity opining** • **Shading device** • **Outer skin glazing properties**
Building Parameters	• **Window to wall opening ratio** • **Inner skin materials properties**
Site Parameters	• **Solar irradiance and orientation** • **Wind speed and direction** • **Outdoor air temperature and humidity** • **Type of ventilation**

3.7. Double skin facade performance

During the summer, it is important to design the DSF to prevent increasing the temperatures inside the cavity. The right combination between facade type and double skin geometry, the size of the openings and the position of the shading devices can assurance enhanced results for every type of building and climate.

3.8. Double skin facade and energy consumption

In principle, double skin facades can save energy when properly designed. According to Oesterle et al., 2001 [1] *"Significant energy savings can be achieved only where double skin facades make window ventilation possible or where they considerably extend the period in which natural ventilation can be exploited. By obviating a mechanical air supply, electricity costs for air supply can be reduced. This will greatly exceed the savings mentioned before"*.

In hot climatic regions, buildings will face additional heat and will feel physically uncomfortable if effective strategies are not implemented in their systems leading to greater energy consumption. When the problem is known, it is important to minimize the additional heat through optimized methods of energy consumption. Compared to this, air conditioning is not a required method, because of its high consumption and cost, which leads to more effective methods minimizing heat gain, knowing the behavior of solar radiation and the characteristics of building envelope.[2]

Based on the previous literature review, the DSF building thermal performance depends largely on the geometry of the facade and its configurations due to the

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[1] Oesterle, Lieb, Lutz, and Heusler.Double-Skin Facades – Integrated Planning, 2001.

[2] Faggal, A., Double Skin Facade Effect on Thermal Comfort and Energy Consumption in Office Buildings, 2014.

ventilation mechanisms and heat transfer processes that take place inside the cavity. Airflow, air velocity and air temperature distribution along the cavity height are influenced by a number of parameters such as shading device configurations, cavity configurations and glazed properties. The integration of all this into the chosen DSF structure and the optimized opening configuration are the key factors that will determine the effectiveness of DSF to improve internal thermal comfort. However, parameters point toward the need for a more investigation that recognizes how the design solutions interact with each other, contributing to the building thermal and ventilation performance.

4. Simulation study methodology and objectives

This simulation study deals especially with the analysis of the airflow parameters of a double skin facade cavity. The significance of the DSF as a thermal gain buffer and its overheating limitation is evaluated through a steps of analysis for a set of parameters mentioned before. The temperature and airflow are observed in the cavity of a DSF using a mechanical simulation program. The simulations are used to determine whether the airflow is sufficient for utilizing natural ventilation, and when it needs to be enforced with mechanical ventilation.

4.1. Simulation study boundaries

This paper is going to examine only the air flow in a DSF cavity for a typical office building in hot arid climates of Cairo in summer, with a double skin glazed façade. The work will not include explorations of winter days, daylight, cost and acoustics.

4.2. Air flow in the cavity

The dynamics of airflow in the cavity with natural ventilation is based on natural convection, especially on micro pressure caused by the gradient of temperature inside the cavity. As Shiou Li (2001) describes, *"The cavity on double skin facades is either naturally or mechanically ventilated. Natural ventilation can provide an environmental friendly atmosphere and reduce the requirement for mechanical ventilation. On the other hand, natural ventilation is not without risk. It may create a door-opening problem due to pressurization. Besides, if the air path is not appropriately designed, the solar heat gain within the facade cavity will not be removed efficiently and will increase the cavity temperature."*

When evaluating the speed of the airflow in a natural ventilated DSF cavity, the focus is on evaluating indoor air quality of the indoor spaces.

Depending on the outdoor climatic conditions and the way the double skin facade works, the air flow in a ventilated cavity can have a significant deviation in the order of magnitude and the appearance of a reverse flow. [1]

In view of that, double skin facade physics can be characterized by three main topics: optics, heat transfer and air flow[2].

In the modern science, there is a strong background for calculation of optical and heat transfer processes, but prediction of the air flow in the double skin facade cavity is still under research. It is explained by the complexity of natural air flow phenomenon, by the limitations described above and by the lack of the experience in measurements of air flow in the full scale DSF cavity in external environment.[3]

To conclude, and as it is mentioned before, ventilation is one of the most significant components of a double skin facade system. It helps to decrease the air temperature in the cavity and to extract undesired hot air. However, it is important to integrate other components such as the pane types and the type and location of shading devices to avoid overheating in the cavity and thus increasing the cooling loads.

To commit to the research aim and to limit the variables as possible to make the result more accurate, the variable list has been divided into two groups, constant parameters and variable parameters as shown in table (2).

Table (2) constant and variable parameters of the study

Constant Parameters	Variable Parameters
Cavity height	DSF structure
Outer/ inner skin facade properties	Cavity depth
Room area	Openings size / direction
Orientation	Window to wall ratio
Wind speed	Sun shades

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[1] Loncour, X, Deneyer, A, Blasco, et al., Ventilated Double Facades Classification and Illustration of facade concepts, 2004.

[2] Kalyanova, O, Poirazis, H and Heiselberg, P K. Literature Review of Double Skin Facades, 2005.

[3] Modelling Approaches: Report for IEA ECBCS Annex 43, Validation of Building Energy Simulation Tools, 2005.

The variables will include the following properties:

- Double skin facade structure: Shaft box facade, multi-story façade. Other two types of structures will be neglected since they don't work effectively with natural ventilation.
- Cavity depth : It verifies between 0.5m, 1m, 1.5m and 2 m
- Opining size :Includes 0.5m, 1m, 2m
- Opining direction : Leeward side, windward side

Fixed data will include the following properties:

- Cavity height : 3.6 m each floor (11 floor)
- Sun shades : without sunshades
- Window to wall ratio: without open windows (to maintain concentrating on the air flow without any additional declarations).
- Outer skin facade/inner skin facade properties: as mentioned before the simulation program deals with some material properties, as the main material is glass, so the glazing properties will include :
  - ❖ Conductivity (k) : 1 W/mk
  - ❖ Specific heat : 750 J/kg-k
  - ❖ Emissivity : 0.5
  - ❖ Density :2000 kg/m3
- Room area : 4*4 m
- Wind speed : 5 m/s

5. Simulation process

Using ANSYS:

- Measure air flow motion in the cavity with the changeable parameters.
- Calculate the average air speed in the cavity of the DSF.

5.1. Modeling a hypothetical building:

The model will concentrate on the cavity; it will consist of a section in the DSF cavity with a single office room behind it, with 11 floors height above ground floor as shown in figure 3.

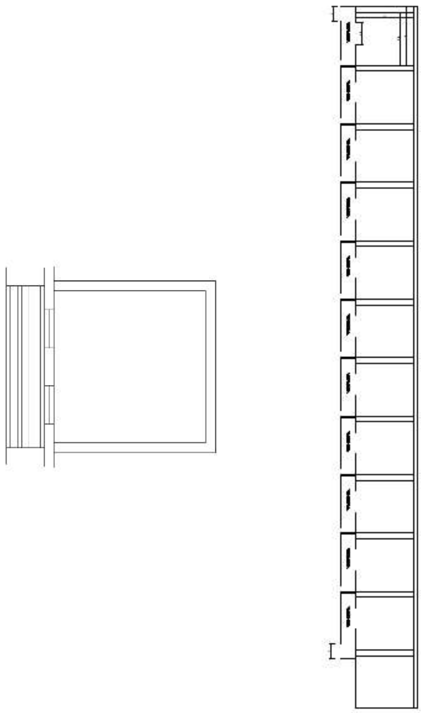


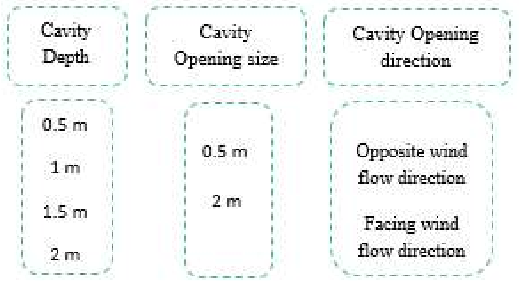
Fig.3 Plan &section of the hypothetical base case model by the researcher

Re-modeling the building

The result of the first base case leaded that, vertical divisions inside the DSF cavity provide no positive accurate results. The facade structure selected for the base case model is the multi-story facade, it delivers a greater absolute temperature difference along the cavity due to its height, to prevent resistance to air flow, the top and bottom of the cavity were modeled as fully open. The model has no shading devices or mechanical systems in order to provide a baseline to assess what extent the provision of natural ventilation for thermal comfort can be exploited merely due to the DSF.

5.2. Alternative cases

The final variable of the alternatives cases include:



Cavity Depth	Cavity Opening size	Cavity Opening direction
0.5 m	0.5 m	Opposite wind flow direction
1 m	2 m	Facing wind flow direction
1.5 m		
2 m		

Fig.4.The alternative cases

6. Result and Desscision

6.1. Airspeed average

The average air speed inside the cavity for each variable is shown in next figure 5.

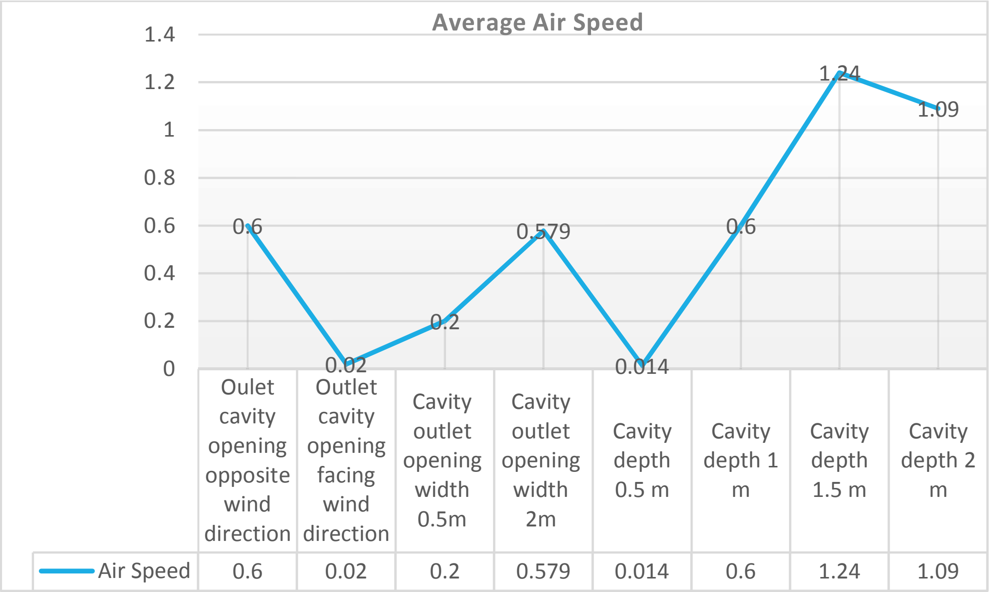


Fig.5. Average air speed inside the cavity

6.2. Air Temperature average

The two layers of the cavity have a 45°C as surface temperature from outside solar heat gain, as shown in figure 6. The temperature in the cavity drops to 42°C, but still the highest floor level remain at 45°C.

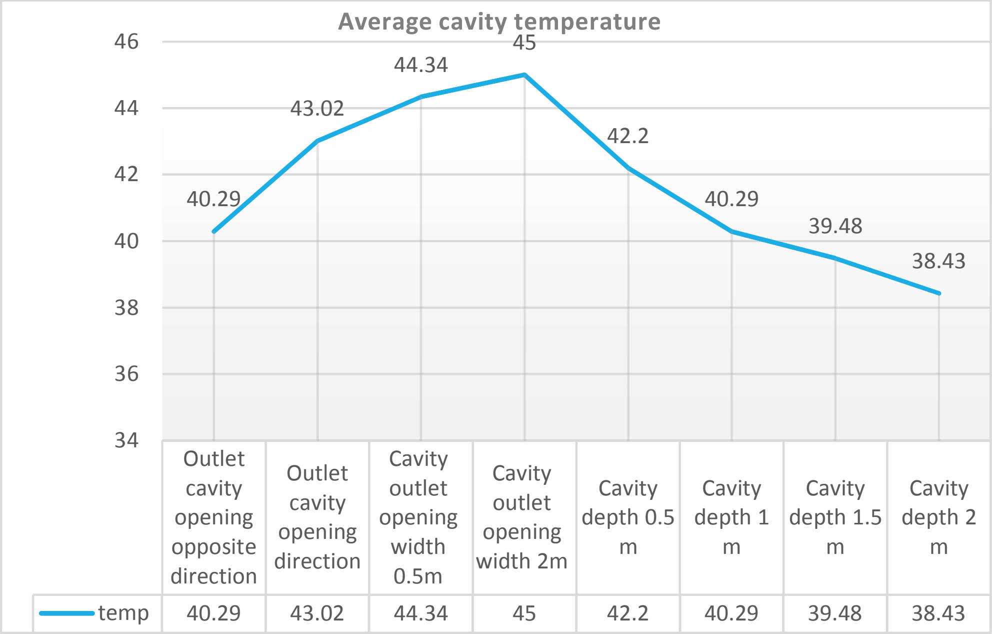


Fig .6 average temperature inside the cavity

Discussion:

- **Cavity outlet opening direction**

The result of the air flow distribution affirms with the result of the air speed average , as the case facing the wind direction made the air dwell through the air cavity, otherwise when it is on the opposite side of the inlet opening enhanced the air flow speed in the cavity.

- **Cavity depth**

A depth of 0.5m achieves the lowest values of air speed. While the wider the cavity width the better the average air speed. However a decrease in the air speed level was observed in the 2m cavity width when compared with the narrower one

- **Cavity outlet opening width**

Airflow distribution over the outlet opening width has shown that a low air speed average was obtained in case of the opening width 0.5 m, while when the opening width was 2 m it gives a better air speed average.

Conclusions and Recommendations

Double skin facades for office buildings were mainly developed to achieve acceptable indoor environment with reduced energy consumption. However, the main disadvantage of this system is that in countries with high solar gain and a lack of high ventilation rate, the air temperatures inside the cavity are increased during periods of hot weather, leading to overheating problems.

The present work specifically studied and analyzed the air flow characteristics in a double skin facade cavity. The study aimed at testing how to improve DSF by changing the parameters affecting the airflow patterns in the DSF air cavity in hot arid climate. In conclusion, the issues observed from the simulation are:

- Cavity depth has a main effect on airflow pattern of the DSF cavity. Temperature in deeper cavities is slightly lower than temperature in lower depth cavities. Air speed in the cavity does not vary in a linear way with the caviry depth. It decresed as it reaches the width of 2m.
- Althoug double skin airflow in the cavity has been enhanced with wider cavity opening in the top, temperature increses in the same dimention. This may be attributed to the height of the cavity as it is 2 m above the building height. Narrow cavity enhances the stack effect, but it creates higher resistances to the airflows in the cavity.
- Low air speed in the cavity, resulting in low airflow through the rooms. Strategies are needed to maximize the absolute airflow within the cavity and, consequently, in the rooms.
- High level of discomfort conditions due to high temperatures. Controlling solar gains can improve acceptable temperatures and minimize discomfort periods.
- Vertical divisions within the DSF cavity do not provide a positive improvement because they act to disturb air movement within the cavity and involve only additional costs.

The results of the research confirms the DSF system disadvantage that keeps the hot air inside the cavity creating a greenhouse effects. There are many solutions to reduce stored hot air. However, in this study, the air flow in the cavity has been confirmed as an important factor with respect to heat reduction in the cavity. The correct design and the consideration of the climatic parameters make the double skin facades effective in every climate and solve the challenges to a large extent. Furthermore, there appears to be a need for further research with the DSF system.

References:

[1] Sinclair, R., Phillips, D., Mezhibovski, V., Ventilating Facades, 2009.

[2] Chan, E., Fong, K., Chow, T., Lin, Z., Investigation on energy performance of double skin façade in Hong Kong, 2009.

[3] Hien, N., Chandra, A., Liping, W., Pandy, A., Xialion, W., Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore, 2005.

[4] Saelens, D., Roels, S., Hens, H., Strategies to improve the energy performance of multiple-skin facades, 2008

[5] Gratia, E., Herde, A., Greenhouse effect in double-skin facade. 2007.

[6] Stribling, D.,Stigge, B., A critical review of the energy savings and cost payback issues of double facades,2003.

[7] Streicher, W., Heimrath, R., Hengsberger, H., Mach, T., Waldner, R., Flamant, G., Erhorn-Kluttig, H.,On the typology, costs, energy performance, environmental quality and operational characteristics of double skin façades in european buildings, 2007.

[8] De Gracia, A, Castell, A, Navarro, L, Oro, E, Cabeza, LF., Numerical modelling of ventilated facades: a review, 2013

[9] Santamouris M., Solar Thermal Technologies for Buildings - The State of The Art, 2003.

[10] ASHRAE-Standard, ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, 2004.
[11] Chen, Y., Tong, Z., Malkawi. A., Investigating natural ventilation potentials across the globe: Regional and climatic variations, 2017.
[12] Belgian Building Research Institute (BBRI), Source book for a better understanding of conceptual and operational aspects of active facades. http://www.bbri.be/activefacades/index2.htm , 2002.
[13] Oesterle, Lieb, Lutz, and Heusler, Double Skin Facades, Integrated Planning, 2001.
[14] Faggal, A., Double Skin Facade Effect on Thermal Comfort and Energy Consumption in Office Buildings, 2014.
[15] Loncour, X, Deneyer, A, Blasco, et al., Ventilated Double Facades. Classification & Illustration of façade concepts, 2004.
[16] Kalyanova, O, Poirazis, H and Heiselberg, P K. Literature Review of Double Skin Facades, 2005.
[17] Modelling Approaches: Report for IEA ECBCS Annex 43, Validation of Building Energy Simulation Tools, 2005.