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Integration of Shading Devices with Naturally Ventilated Double Skin Facades in Hotel Buildings

(With Special Reference to Greater Cairo, Egypt)

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Abstract: Studies have shown that using naturally ventilated double skin facades could enhance energy performance of buildings through heat dissipation. Also, using shading devices could lower down energy consumption by blocking undesired solar heat gain. This paper aimed at evaluating using shading devices with naturally ventilated double skin facades in hotel buildings in Greater Cairo as a passive technique to lower cooling loads in cooling seasons. Computational fluid dynamic simulations were done using DesignBuilder software to compare between three cases in the four orientations for three floors at day and at night. Case 1 was a single skin façade (reference case). Case 2 was a naturally ventilated double skin façade. And case 3 was highly reflective shading devices integrated with naturally ventilated double skin facade. The main goal of this study was not only to study the effect on thermal comfort, but also to study the effect on air ventilation rates and indoor air quality which could reflect on cooling loads needed to reach thermal comfort. Initial findings indicated that case 2 could enhance thermal comfort and indoor air quality by lowering down mean operative temperature and mean age of air values in comparison with case 1. Air ventilation rates were improved in North and East orientations only with higher mean air velocity values when compared to case 1. Results of case 3 showed significant enhancement in thermal comfort and indoor air quality in South, East and West orientations where difference between room's mean operative temperature and ambient operative temperature could reach 1.51C°, 1.85C°, and 1.78C° for the three orientations respectively. In North orientation, the difference could reach 1.31C°. Case 3 also showed enhancement in mean air velocity values. Last but not least, case 3 showed enhancement in mean age of air values.

Keywords: Passive Cooling, Double Skin Facades, Naturally Ventilated Walls, Shading Devices, CFD Simulations.

1. INTRODUCTION

Double skin façades are becoming a trend in architecture nowadays in terms of energy conservation and natural ventilation. Their different applications and types introduce a wide range of choices regarding energy conservation mainly. They can be used in different types of buildings to cool them naturally or with less possible use of mechanical ventilation. Double skin facades may be used as an interior space if used as a corridor. This could add a value to the design as well.

Nowadays, Egypt suffers from energy problems. Buildings are the most elements that uses electricity especially those which rely on HVAC systems for cooling in Egypt's hot climate [1]. HVAC systems may cause serious problems to the environment because of the radiations and the vapors that harm the ozone layer [2]. Due to these problems, architects need to consider designing buildings that are naturally ventilated where different passive cooling techniques are applied. These buildings should be designed to suite Egypt's climate and conditions and should be environment friendly.

Double skin facades are a proper solution that may work in Egypt that needs to be tested and considered in the design phase. This research aims at evaluating how the naturally ventilated walls may affect thermal comfort in hotel buildings in Greater Cairo, as the hotel buildings are considered a type of buildings that consumes a large amount of electricity.

2. LITERATURE REVIEW

A double skin façade is defined normally as a pair of glass walls which are separated by an air gap. This gap works as insulation against noise, wind with high velocity (especially in high rise buildings), and mainly temperature. It also forces airflow next to the exterior glazing that can be used as natural ventilation for the interior spaces [3]. Double skin facades differ in types. They are classified either according to the ventilation system (natural – mechanical – hybrid) or according to air movement (Corridor - Shaft box – Buffer – Extract Air – Twin Face - etc.).

A double skin facade can also be supported by shading device to control the heat gain. This adds a value to the environmental aspect where the double skin façade minimizes the heat gain of the interior spaces and help achieving natural ventilation.

2.1 Naturally Ventilated Double Skin Facades

An advantage of the double skin façade is that it allows natural ventilation if it was well designed because of the outer skin that protects from wind in case of high wind and allows operable windows in the inner skin to naturally ventilate the interior spaces. This can lead to reducing energy consumption. This also leads to reduction in CO2 emission in the operation phase.

Different types of double skin facades should be applied according to the climate, orientation, location of the building, and its type so that it can help providing fresh air [4]. There are some factors that controls achieving natural ventilation through double skin facades. These factors include difference in temperature that causes air changes. Also pressure difference is one of the factors which causes air flow and stack effect. Stack effect is defined as the movement of air into and out of the building and is driven by buoyancy. In hot weathers, these forces are not always enough for achieving natural ventilation [5].

Alahmed, Z., (2013), tested three types of DSF cavities in Riyadh, KSA and compared them to a base case and a base case with shading devices using IES software. Different parameters were studied like DSF orientation, cavity width and cavity shape in his study. The researcher concluded in his research that the wider the cavity, the lower energy the building will consume. Also, he concluded that at the western façade which had the best results, multistory type succeeded to reduce the energy by 5.02% compared to the base model and 4.05% when compared to the base model with shading devices. The corridor type façade results were 7.71% and 4.43% energy reduction when compared to the base model and the base model with shading devices respectively. While, the box window type showed 8.05% and 4.78% energy savings when compared to the base model without and with shading, respectively [6].

Rezazadeh, N., et al, 2017 investigated the total comfort hours of the different types of naturally ventilated walls in an office building located in Rasht, Iran where the weather is hot and dry in summer. The different models where modelled and tested on ECOTECT and the results were shown as the total comfort hours in each case The results showed that the shaft type had the highest total hours of comfort with a 75 cm wide cavity which were 677 Hrs. Box window type had slightly higher total hours of comfort than the corridor type but both with a 100 cm cavity width showed a high value of 643 total hours of comfort. Multistorey façade results were 640 total hours of comfort placing fourth [7].

2.2 Integrating Shading Devices with Naturally Ventilated Double Skin Facades

A lot of studies of shading devices inside DSFs cavities showed that shading devices affect thermal comfort for the occupants by reducing the amount of direct solar gain reaching the indoor spaces. Thus, shading devices highly affect energy performance of buildings where double skin facades are applied, especially in hot climates, where overheating can occur inside the cavity because of the high solar radiations transmission through the DSF glazing which leads to high air temperature inside the cavity [8].

Shading devices positions, size and angle are the main parameters that affect energy saving which could reach 23%. Although shading devices are installed to control direct solar gains and thus reduce energy consumption, placing them inside the cavity may affect the air flow speed and pattern which needs to be studied in the early design stage for the shading devices placement and angles.

Oesterle, et al, 2001 investigated the integration of shading devices inside the air cavity and stated that the exterior skin can reduce a minimum of 10% of solar irradiance while the integrated shading devices could reduce around 50% to 60% of solar irradiance when compared to interior blinds. Therefore, the optimal integration of shading devices with DSFs can show up as a solution that overcomes disadvantages of DSF concepts in hot climates [8].

While shading elements act as heat collector, the part of heat they absorb stays inside the cavity and therefore it enhances the cavity's buoyant flow. And with sufficient natural ventilation, the performance of DSF systems in hot climates will be enhanced. In this case, the quality of natural ventilation is a key factor that decides whether the system will succeed or not [8].

3. METHODOLOGY

Three cases were used to investigate the effect of integrating shading devices with naturally ventilated double skin facades on Hotel Buildings in Greater Cairo:

a) Case 1: single skin façade (reference case).
b) Case 2: naturally ventilated double skin façade
c) Case 3: naturally ventilated DSF with shading devices.

3.1 Hotel Room Design

The reference case used in the study was a generic plan arrangements for a 36 m^2 hotel room (8x4.5 m). Figure 1 shows the plan and section of the room.

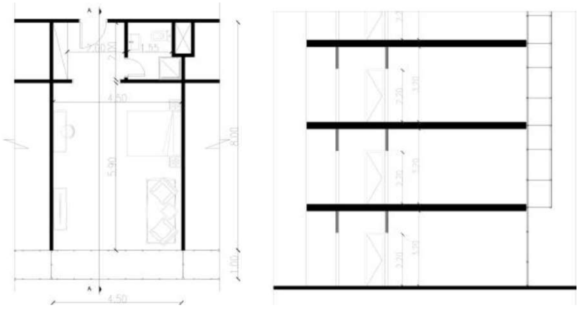

FIGURE 1. Plan of Naturally Ventilated Wall Case (Left) and Section (A-A) (Right)

3.2 Simulation Software

DesignBuilder V4.6.015 was used for simulations for its user friendly interface and computational fluid dynamics (CFD) simulations capability. Simulation engine of DesignBuilder is energy Plus which has been validated by Energy Efficiency and Renewable Energy (EERE) program, U.S. Department of Energy (DOE). Energy plus provides access to mostly all the required simulation capabilities of thermal performance including natural ventilation, shading systems, glazing, thermal mass, building fabrics and HVAC systems [9].

3.3 Simulation Day and Hours

According to thermal simulations done on DesignBuilder, August had the highest mean site temperature all over the year. Figure 2 shows thermal simulation results all over the year.

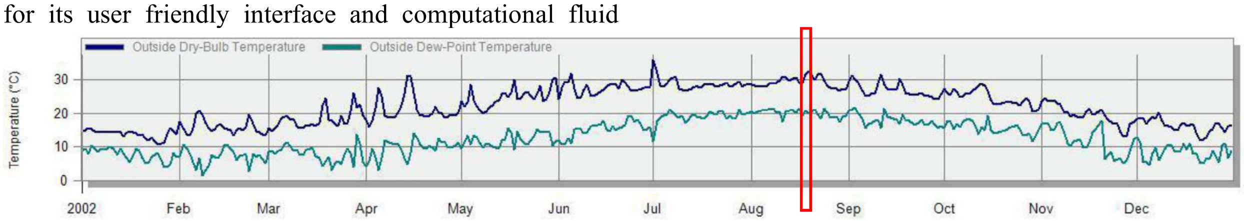

FIGURE 2. Average Site Year Temperature

Thermal analysis were simulated for August to detect the highest day in the South orientation which is the extreme condition for operative temperatures. The simulations were done for the three selected floors: 5th floor, 20th floor and 35th floor. The three floors showed that the temperature at the 23rd of August is the highest with 33.78 °C, 33.37 °C and 33.39 °C, operative temperatures respectively.

In order to choose simulation hours, thermal simulations were done for the four orientations at the 23rd of August. The results showed that 2 PM had the highest operative temperature (OT) at day and 6 PM had the highest OT at night. So later CFD simulations were done at 2 PM and 6 PM.

3.4 Simulation Floors

Three floors were chosen for simulation which are the 5th, 20th and 35th floors in South orientation at 2 PM. The choice was based on changes in operative temperatures at floor 5 and 35 and then another average floor was chosen between them which is floor 20. Figure 3 shows floor numbers and their corresponding operative temperature at the chosen time.

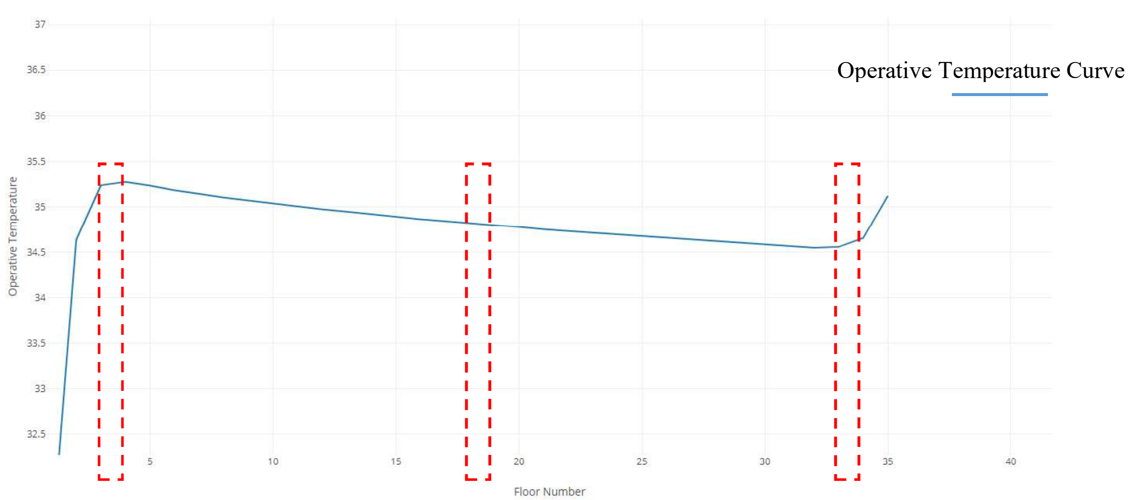

FIGURE 3. Operative Temperatures of the whole Floors of the building in South Orientation

3.5 Models' Parameters

The base case was a double glazed reflective single skin façade where the outer glazing is 0.80 cm and the inner glazing is 0.60 cm separated by 1.00 cm air gap. Those parameters are added to the DesignBuilder model for simulations. Figure 4 shows the model of the single skin façade on DesignBuilder.

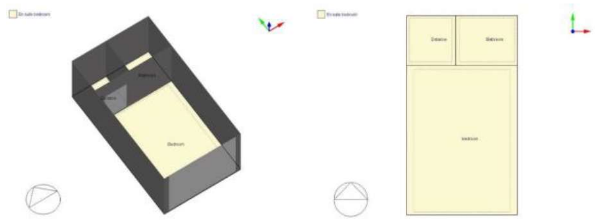

FIGURE 4. Reference Case Thermal Study Unit Axonometric (Left) and Plan (Right) on DesignBuilder

Table 1 shows glazing specifications.

TABLE 1. Glazing Material Specifications

Element	Conductivity (W/m-K)	Specific Heat (J/Kg-K)	Density (Kg/m^3)
Glazing	1.00	750	2500
Double Glazing	Emissivity	Solar Absorptance	Visible Absorptance
	0.90	0.70	0.70

3.5.1 Naturally Ventilated Wall Double Skin Façade Parameters

The naturally ventilated wall used in the simulations is a shaft type double skin façade with 1 m chimney at the top of the cavity. The width of the cavity is 1 m and the two layers of glazing are the same as the layers used for the single skin façade case. Figure 5 shows the model of naturally ventilated wall on DesignBuilder.

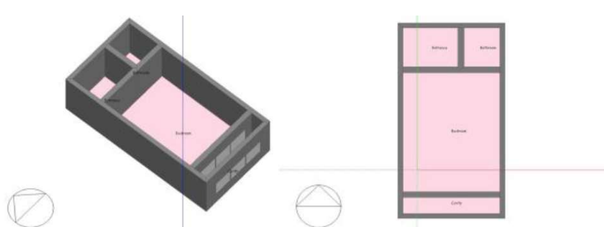

FIGURE 5. Model of Naturally Ventilated Wall on DesignBuilder

3.5.2 Shading Devices Parameters

The shading slats material is Aluminum. And they are placed 25 cm from each other. They are placed 20 cm away from the external skin. Their depth is 5 cm, their width is 40 cm and they are horizontally placed. Figure 6 shows the detail of used shading slats.

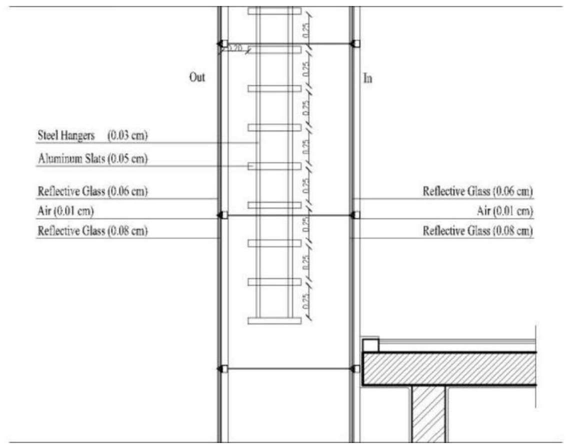

FIGURE 6. Detail of Shading Devices

The 24 cm separation distance was chosen based on sun angle in the 23rd of August at 4 PM which is 31 degrees as the sun's radiation strength will start to lower down after that.

3.6 Weather Data File

The weather data file of Cairo used in this research is based on Egyptian Typical Meteorological Year (ETMY) which was developed by Joe Huang from data provided by U.S. National Climatic Data Center for 12 to 21 years ending in 2013 for standards development and energy simulation. And this weather data was arranged by World Meteorological Organization.

Table 2 shows details for the weather data file of Cairo used in this research.

TABLE 2. Details of the EnergyPlus Weather Data File of Cairo, Egypt.

Weather File	Type	Coordinates	Elevation	Data Record End
EGY_Cairo.Intl.Airport.623660_ETMY.epw	Hourly weather data file	30.13° north ,31.4° east	74 m above sea level	2003

The .epw are energy plus weather data files.

3.7 Evaluation Criteria

The evaluation was based on a comparison between the three cases that shows which case enhances indoor air quality (IAQ) represented by mean age of air (AOA), air ventilation rates represented by mean air velocity (AV) and thermal comfort represented by mean operative temperature (OT).

Mean AOA is defined as the average time that air spends in a space.

OT is defined as a uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment [10].

Mean AV is the mean speed of the air.

According to ASHRAE Standard 55, air velocity that falls in comfort zone falls between 0.05 and 0.25 m/s while temperature in summer should range between 22.5 °C and 26 °C falls in comfort zone. However, it was not expected that operative temperature would fall in the comfort zone before the simulations and the aim was to reduce cooling loads needed to achieve thermal comfort [11].

The case which had the lowest mean OT and mean AOA and highest mean AV was considered better in terms of thermal comfort and ventilation rates.

3.8 Measurement Units

In the whole study, the following units are used:

TABLE 3. Measurement Units

OT	AV	AOA
Celsius Degrees (°C)	m/s	Seconds (s)

4. RESULTS AND DISCUSSION

The results of applying naturally ventilated double skin facade showed that mean operative temperature (OT) could be reduced by 3.07 degrees compared to case 1 at 6 PM and could be reduced by 2.71 degrees at 2 PM. However, mean age of air (AOA) increases and mean air velocity (AV) decreases in West and South orientations where AOA increases by 177.55 s and AV decreases by 0.06 m/s.

The results showed that North orientation had the lowest mean OT followed by East, West and South respectively. Also, West orientation had the lowest mean AOA and the highest mean AV followed by North, East and South.

Figures 7-12 show differences in mean OT, AOA and AV between case 1 and case 2. Results with negative mean that in case 2 mean OT increased, mean AV decreased or mean AOA increased.

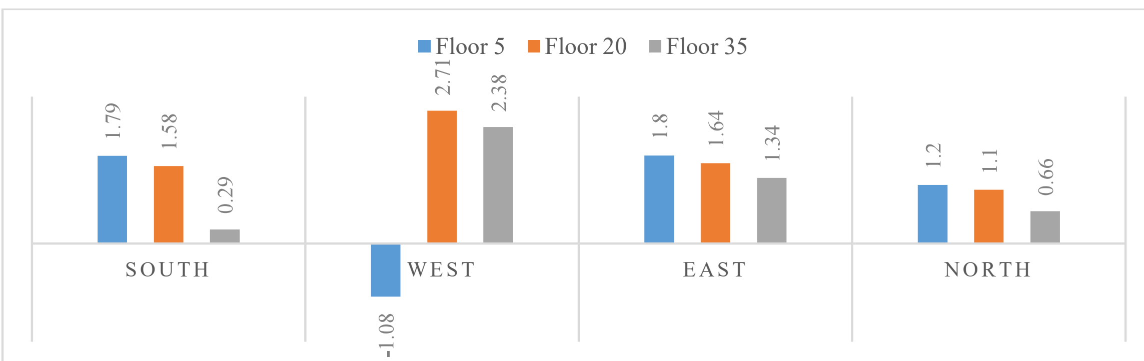

FIGURE 7. Mean OT Difference between Case 2 and Case 1 at 2 Pm

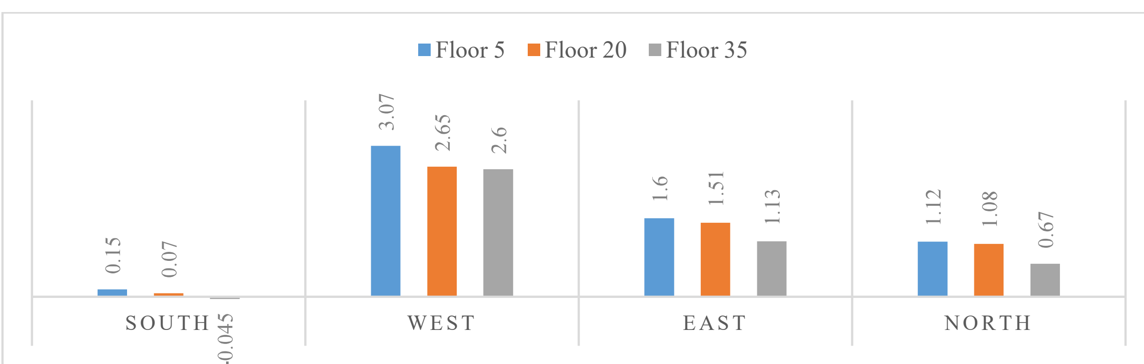

FIGURE 8. Mean OT Difference between Case 2 and Case 1 at 6 Pm

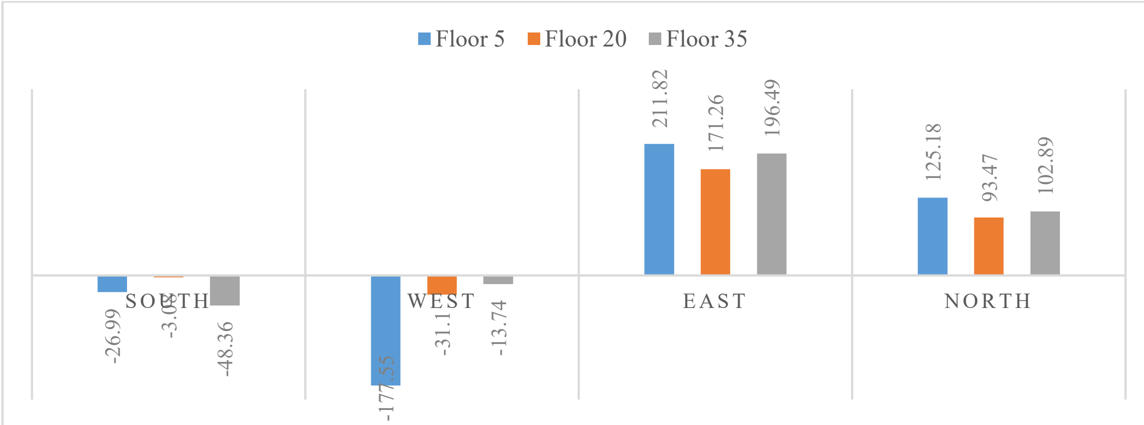

FIGURE 9. Mean AOA Difference between Case 2 and Case 1 at 2 Pm

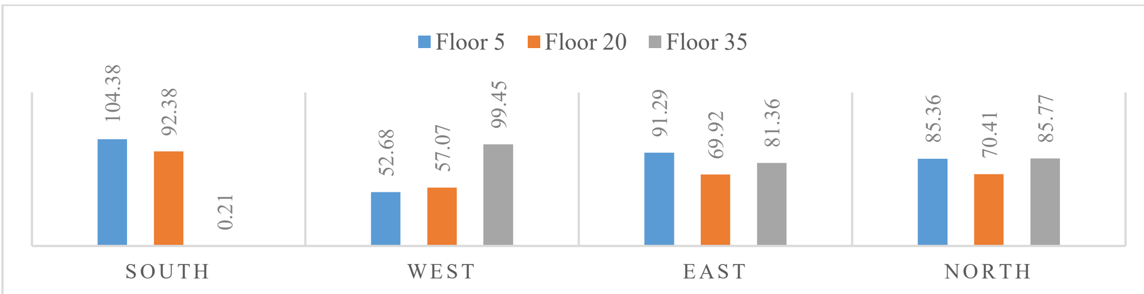

FIGURE 10. Mean AOA Difference between Case 2 and Case 1 at 6 Pm

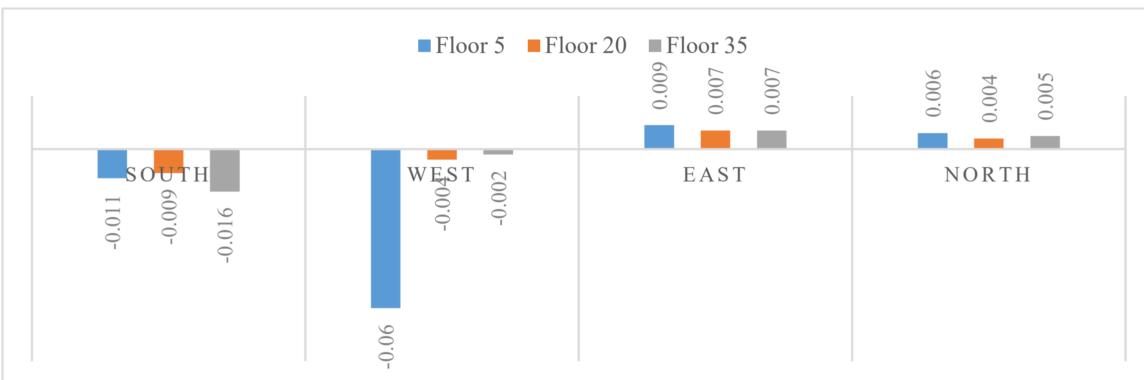

FIGURE 11. Mean AV Difference between Case 2 and Case 1 at 2 Pm

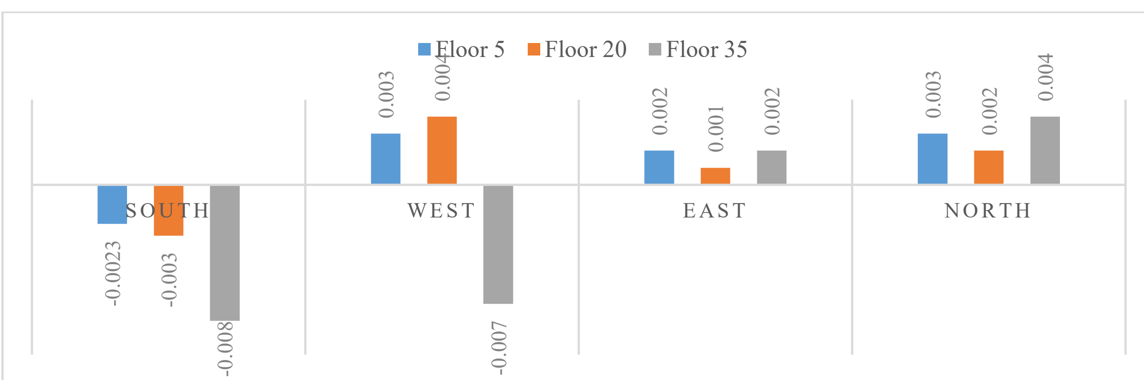

FIGURE 12. Mean AV Difference between Case 2 and Case 1 at 6 Pm

Figures 7-12 show that floor 5 had the lowest mean OT followed by floor 20 and 35 respectively. This could be resulted from the direct exposure of floor 35 to direct solar gains. Also mean AOA is lowest in floor 5 followed by floors 20 and 35 respectively. While mean AV in floor 5 had the highest value followed by floor 35 and floor 20.

On the other hand, the results of integrating shading devices with the naturally ventilated double skin facade showed great enhancement in mean OT in all orientations except North. While mean AV and mean AOA were enhanced in all of the other orientations generally. The difference between mean OT in case 3 and case 2 reached the highest value of 1.68 Celsius degrees in South orientation. West and East orientations came second and third respectively in enhancing mean OT. While North orientation showed increment in mean OT with a maximum of 0.45 Celsius degrees. The reason behind this could be the reflection of solar gain from surroundings in North direction which is not highly affected by direct solar gain.

Mean AOA difference was at its highest value in South orientation where a decrement of 163.93 seconds appeared. East, West and North orientations followed that with a maximum decrement of 17.66, 13.67 and 13.86 seconds respectively.

Figures 13-18 show differences in mean OT, AOA and AV between case 3 and case 2. Results with negative mean that in case 3 mean OT increased, mean AV decreased or mean AOA increased.

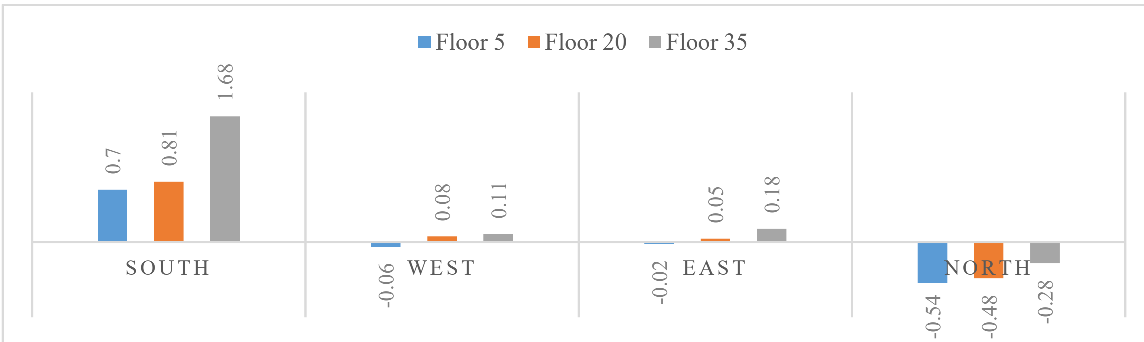

FIGURE 13. Mean OT Difference between Case 3 and Case 2 at 2 Pm

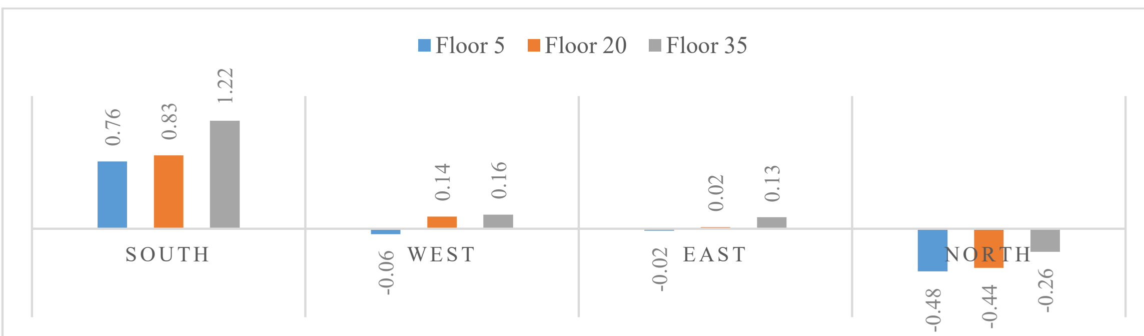

FIGURE 14. Mean OT Difference between Case 3 and Case 2 at 6 Pm

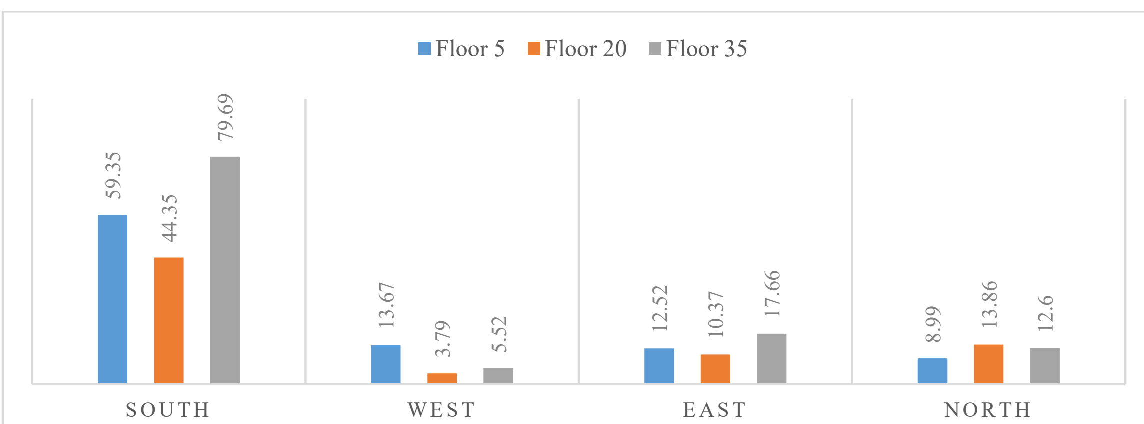

FIGURE 15. Mean AOA Difference between Case 3 and Case 2 at 2 Pm

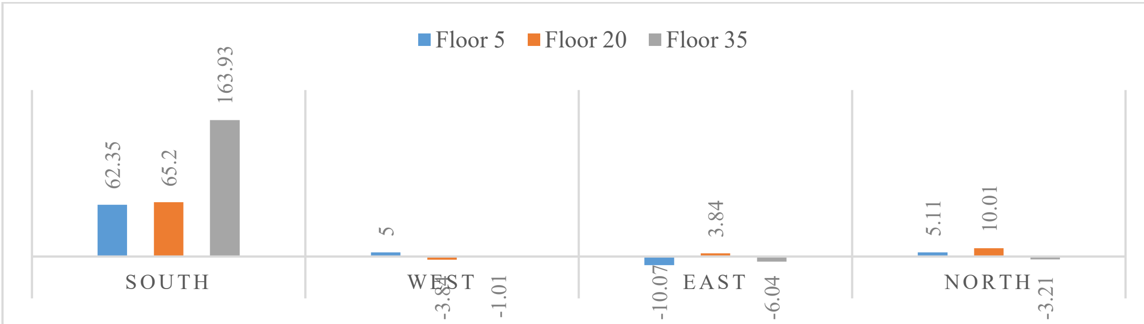

FIGURE 16. Mean AOA Difference between Case 3 and Case 2 at 6 Pm

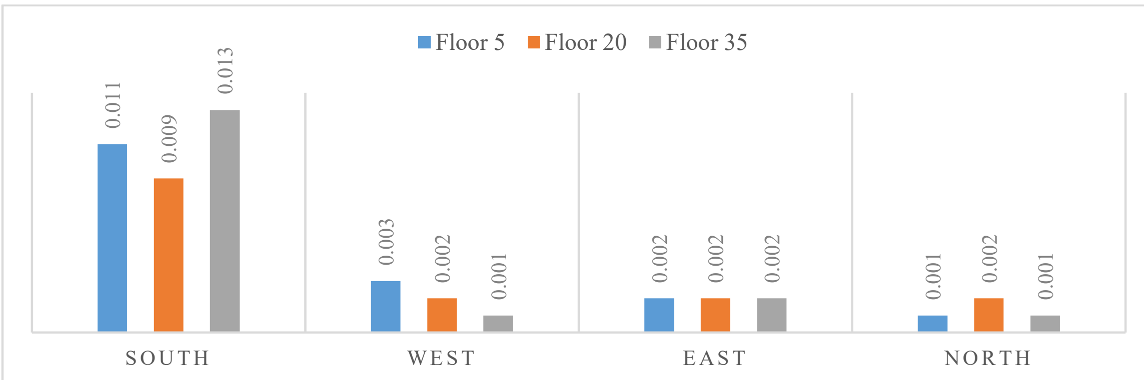

FIGURE 17. Mean AV Difference between Case 3 and Case 2 at 2 Pm

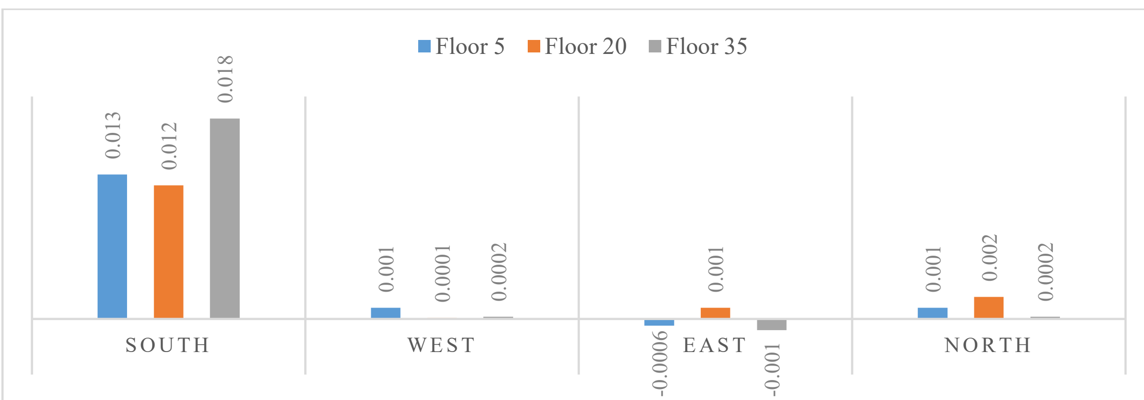

FIGURE 18. Mean AV Difference between Case 3 and Case 2 at 6 Pm

Figures 13-18 show that floor 35 had the lowest mean OT followed by floor 20 and 5 respectively. Here, the effect of shading devices appears in reflecting direct solar gains in floor 35. Also mean AOA is lowest in floor 35 followed by floors 5 and 20 respectively. While mean AV in floor 35 had the highest value followed by floor 5 and floor 20 in Southern façade while other orientations results showed that floor 20 had the highest mean AV value followed by floors 5 and 35 respectively.

Table 4 compares between the three cases' (case 1 – case 2 – case 3) highest and lowest mean operative temperatures (highlighted sections show the best proposal).

TABLE 4. Comparison between mean highest and lowest OT of the three cases

	Hour	2 PM		6 PM	
South	Ambient OT	33.89		33.96	
	Mean OT	Highest OT	Lowest OT	Highest OT	Lowest OT
	Single Skin Façade (Case 1)	35.23	34.77	34.40	32.64
	DSF Case (Case 2)	34.83	33.19	34.85	33.57
	Integration between Shading Devices and DSF (Case 3)	33.15	32.38	33.63	32.74
West	Ambient OT	33.79		34.93	
	Mean OT	Highest OT	Lowest OT	Highest OT	Lowest OT
	Single Skin Façade (Case 1)	35.13	31.11	36.35	35.60
	DSF Case (Case 2)	32.75	32.02	33.75	32.96
	Integration between Shading Devices and DSF (Case 3)	32.64	31.94	33.59	32.82
East	Ambient OT	33.05		33.74	
	Mean OT	Highest OT	Lowest OT	Highest OT	Lowest OT
	Single Skin Façade (Case 1)	33.96	33.73	33.84	33.15
	DSF Case (Case 2)	32.39	31.32	31.84	31.64
	Integration between Shading Devices and DSF (Case 3)	32.21	31.27	32.58	31.62
North	Ambient OT	33.27		33.73	
	Mean OT	Highest OT	Lowest OT	Highest OT	Lowest OT
	Single Skin Facade	33.18	32.58	33.69	33.04
	DSF Case	32.53	31.48	33.02	31.96
	Shading Devices	32.81	31.96	33.28	32.40

Table 5 compares between the three cases' highest and lowest mean air velocity (blue color shows the best proposal).

TABLE 5. Comparison between mean highest and lowest AV of different cases

	Hour	2 PM		6 PM	
South		Highest AV	Lowest AV	Highest AV	Lowest AV
	Single Skin Facade	0.041	0.039	0.032	0.029
	DSF Case	0.031	0.024	0.030	0.021
	Shading Devices	0.041	0.037	0.042	0.039
West		Highest AV	Lowest AV	Highest AV	Lowest AV
	Single Skin Facade	0.090	0.039	0.038	0.031
	DSF Case	0.040	0.037	0.041	0.039
	Shading Devices	0.042	0.040	0.042	0.040
East		Highest AV	Lowest AV	Highest AV	Lowest AV
	Single Skin Facade	0.029	0.025	0.037	0.035
	DSF Case	0.037	0.036	0.040	0.037
	Shading Devices	0.038	0.035	0.039	0.030
North		Highest AV	Lowest AV	Highest AV	Lowest AV
	Single Skin Facade	0.033	0.029	0.037	0.035
	DSF Case	0.038	0.033	0.041	0.039
	Shading Devices	0.040	0.035	0.042	0.039

Table 6 compares between the three cases' highest and lowest mean age of air (blue color shows the best proposal).

TABLE 6. Comparison between mean highest and lowest AOA of different cases

	Hour	2 PM		6 PM	
South		Highest AOA	Lowest AOA	Highest AOA	Lowest AOA
	Single Skin Facade	412.26	394.58	523.69	519.62
	DSF Case	451.18	415.34	523.48	416.81
	Shading Devices	371.49	362.22	362.04	354.46
West		Highest AOA	Lowest AOA	Highest AOA	Lowest AOA
	Single Skin Facade	359.66	193.49	455.42	399.15
	DSF Case	373.40	371.03	346.47	345.86
	Shading Devices	367.88	357.36	349.70	341.47
East		Highest AOA	Lowest AOA	Highest AOA	Lowest AOA
	Single Skin Facade	610.08	577.32	451.05	448.27
	DSF Case	406.06	398.25	379.47	359.76
	Shading Devices	395.69	385.73	375.63	369.83
North		Highest AOA	Lowest AOA	Highest AOA	Lowest AOA
	Single Skin Facade	514.05	496.08	443.01	445.38
	DSF Case	402.61	388.87	372.60	357.30
	Shading Devices	389.93	379.88	692.59	354.91

5. CONCLUSION

The purpose of this simulation study was to evaluate the use of shading devices within a naturally ventilated DSF's cavity. The results showed enhancement in thermal comfort when integrating shading devices with naturally ventilated DSF. This enhancement includes lower mean OT compared to ambient OT that could reach 1.85 Celsius degrees difference in West facade. It also includes relatively higher mean AV in the space than the other 2 alternatives which could reach a highest value of 0.042 m/s which is close to the required AV that achieves indoor air quality (IAQ). The proposed configuration shows the best results regarding mean AOA with a lowest value among the 4 cases which is 349.70 m/s in West façade.

This proposal achieved acceptable and noticeable results in South, West and East facades. While using naturally ventilated DSF without shading devices showed the best performance only in North façade.

Although the mean OT is out of the comfort zone, results of mean AV and mean AOA could enhance ventilation rates and IAQ. Also, the reduction in mean OT could lower down the consumption of energy using HVAC systems.

However, the ambient temperature which is higher than comfort range will always affect the mean OT of the indoor space. This is because the temperature of incoming air could affect thermal comfort because the air flow will be hot and will not necessarily enhance IAQ. This problem needs more studies regarding applying another passive cooling techniques and more studies need to be done regarding changing the other parameters of shading devices.

To summarize these results, it is noticeable that integrating shading devices with naturally ventilated DSF could enhance thermal comfort in the hotel room in the hot arid climate of Greater Cairo in West, South and East facades while the use of naturally ventilated DSF was more effective in North orientation.

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