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The impact of Double skin façade on thermal performance and thermal comfort in the hot dry climate of Egypt

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Abstract

The building Envelop plays an essential role in protecting the occupants from the outdoor environment. Appropriate Envelop design can contribute greatly to providing comfortable indoor climates and reducing Energy consumption. Regarding the environmental problems associated with shortage of resources of energy, it is essential to apply sustainable design strategies. Double skin façade is considered one of the energy efficient and sustainable systems. In this regard, the aim of this paper is to examine the effectiveness of applying Double skin façade in office buildings in the hot dry climate of Egypt. The influence of different design parameters on the performance of the double skin façade is explored. The impact of every parameter on Electricity consumption and thermal comfort was examined and compared to a conventional base case. The Designbuilder simulation software was used to conduct the simulations. The study findings indicate that the double skin façade is effective in hot dry climates since it reduces energy consumption and increases thermal comfort, however, additional techniques are needed to enhance it's performance specially in Summer.

Keywords: Sustainable design, Building Envelope, Double skin façade, Energy Efficiency, Thermal comfort.

1 Introduction

Building envelope significantly impacts the building energy consumption. High-rise buildings with glass curtain walls are extensively used recently. However, large glazing areas might result in increased heat gain and consequently, increased electricity consumption. The appropriate design of the building envelop can contribute to reducing the energy use and increasing thermal comfort. Several studies indicated the efficiency of double skin façade system.

It is a technique that first appeared in Europe to combat cold climates and reduce electricity consumed in heating. It has proven to be an energy efficient and sustainable design strategy. For this reason, other countries with various climates began to perform studies on Double skin façade adaptation in different climatic conditions. The DS requires a well designed construction to make significant energy reductions [1]. Designing DS system is complicated, particularly for structures that are naturally ventilated. One of the main obstacles to the advancement of DS system is the lack of common standards and guidelines for the design and assessment of the system in the majority of nations. [2]. Predicting the double skin façade performance is complex since it is determined by several design elements interaction. The proper combination of design parameters are crucial.

The DS system can contribute to energy reductions and thermal comfort achievement. In winter, the additional outer layer of the façade, will provide insulation when closing the cavity. It can contribute to decreasing the heat transfer rate and consequently heat loss through glazing. This is because the air flow speed will be reduced and the temperature in the cavity will be increased. In Summer, the solar radiation

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is absorbed through the construction and re-radiated as longwave infrared radiation. This energy could not pass back through the glazing, and the air inside the cavity warms by convection. This enhances the stack effect.
Interaction of several design variables impact the performance of DS. Therefore it is of great importance to evaluate the DS from a holistic perspective.
In the light of this facts, it is of great importance to examine the thermal performance of DS to provide recommendations on the most appropriate combination of design variables.
Several studies examined the performance of DS, however, few research examined it's impact on thermal comfort in hot dry climates. Integration of new techniques inspired by traditional architecture in DS design is not been sufficiently examined yet. These techniques have social and cultural benefits besides their environmental benefits, therefore, they need more investigation.

The study aims at:

1) Examining the viability of applying DS façade in hot dry climates and evaluating it's potential energy savings.
2) Assessment of the impact of several design parameters on thermal performance and thermal comfort.
3) Explore recent techniques inspired by traditional architecture like using wooden screens.

To achieve this aim, two Double skin models were assessed and compared to a base case model. The first model has a glazed outer skin while the other model has a wooden mesh screen as an outer skin. The assessment of the performance of the DS system was performed using Designbuilder Building energy simulation software. The results indicate reductions in Energy use and improvement in thermal comfort.

2 Literature

There are primarily four types of DS system: Multi-story, Corridor, Box window and Shaft box window. Alberto et al. (2017) [3].

- **Multistorey**: Cavity gap between interior and exterior skins is extended along the whole façade without any partitions. There are ventilation openings close to the roof and ground[4]
- **Corridor type**: horizontal partitions are utilized. The outer skin is single glazed and has apertures placed in a staggered pattern to stop stale air removed from one floor from reaching the cavity area of the floor directly above. This type is mostly utilized in high-rise structures.[5]
- **Box window type**: Vertical and horizontal partitions separate the façade to smaller boxes. The external skin is single glazed and has openings to permit fresh air to enter and stale air to exit. This configuration allows for natural ventilation in the interior spaces and through the cavity.
- **Shaft box window type**: Group of box window in the façade are joined by vertical shafts that are positioned within the façade. The shafts causes enhanced stack effect. This configuration is mostly used in low-rise buildings.

The most effective type is the multi-story, which makes about 30% reductions in energy requirements for HVAC. Several parameters impact the performance of DS system, mainly: depth of the cavity, Glazing properties, shading of the cavity, orientation and ventilation. Various researches studied the impact of these parameters on DS system performance.

Some researches examined the effect of the cavity depth. The cavity's depth impacted energy use, ventilation and stack effect. Radhi [6] stated that smaller cavity width increased stack effect and airflow. It was recommended that the depth should be within 0.7 and 1.2 m since it balances the heat transferred to the interior space and the extraction of air.
Preventing overheating is crucial. Therefore, solar protection is essential. Shading systems can be positioned outside, inside or within the cavity. It is preferred to install blinds inside the cavity.
Shameri et al. [7] examined the impact of glazing properties. the external layer was typically a single-glazed glass while the internal layer is often double glazed to decrease the amount of heat transmission. Natural or mechanical ventilation can be used to ventilate the cavity. The orientation of the DS system impacts its efficiency. Kim et al.[8]
Literature on previous studies conducted on DS in hot climates was reviewed thoroughly. Several studies investigated the applicability of DS in hot climates.
(Hamza, 2004) conducted a comparison of cooling loads in a single skin base case to a double skin case. The impact of altering the configuration of the façade on cooling load was examined. The study revealed that a transparent DS did not make significant energy reductions compared to a well designed single skin. However the study indicated that improving the properties of DS configuration can contribute to reducing electricity consumption. Cooling loads on the four main orientations were reduced by about 12%. The heat trapped in the cavity enhances natural buoyancy and consequently reduces heat gain. Utilizing reflective glazing on the outer layer achieved higher energy reductions . This is because direct solar radiation is blocked from entering the cavity and the interior spaces via inner glazing.[9,10]
(Alahmed, 2013)[11] examined the impact of several variables including installation type, depth of the cavity, the ventilation inside, and orientation, on DS performance using computer simulation. The study indicated significant reductions in electricity consumption compared to a base case building. The best performance was for the box window type with cavity depth 150 cm with mechanical ventilation on West and East facades. Energy consumption was decreased to 8% and 4.8% respectively when compared to the base case without and with utilizing shading.
Yagoub, et. al, 2010 [12] conducted a study on an office building in U.A.E. The research revealed very high temperature in the cavity as a result of high outdoor temperature. The study mentioned that in order to reduce the temperature of the cavity, ventilation flow rate should increase from 1500 l/s to 3000 l/s resulting in additional cooling loads.
A simulation analysis was performed by (Radhi,et al., 2013) [5] on an educational building in UAE. Rhadi examined the effect of using climate interactive façade systems on cooling electricity. The study indicated cooling energy reductions reaching 20%. Radhi stated that the most influential parameters were the floor level, properties of the glazing and the depth of the cavity.
(Hashemi, et al.,2010) [13] conducted field measurements for a DS building in Tehran. The study revealed that additional technologies such as shading and ventilation of the cavity are required to improve the efficiency of DS in hot climate. The efficiency of DS in hot humid climates was investigated [14]. The study indicated that energy savings could be achieved by proper parameter combination.

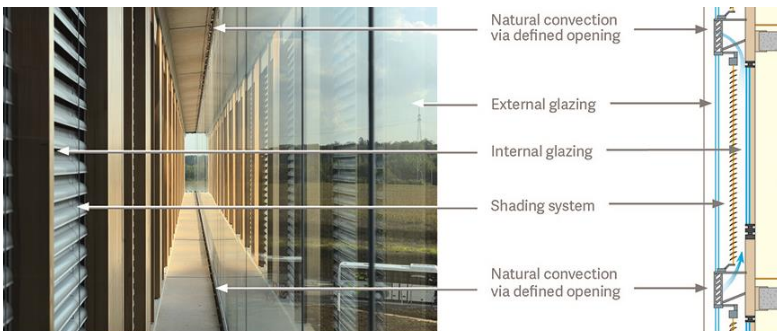

Fig. 2 Double skin Fcacde.

Fig. 1 modern interpretation of Islamic Mashrabeya,

Souq-Masdar Cityby foster and partners.

Recent techniques inspired by traditional Islamic mashrabiya have been utilized. A wooden mesh screen that permits air movement, blocks solar radiation and provides privacy. It can be considered as a second layer creating a new type of double skin façade system

DS designs that are inspired by vernacular architectural features is a good attempt to utilize regional specific vernacular architecture, specially, they are efficient in shading.

3 Methodology

Building energy simulation is an essential method to help better understand the behaviour of DS technology. It can predict the building's electricity consumption considering the various parameters influencing the thermal performance of the building such as the climatic conditions, materials of the envelop, orientation and occupancy.

In this study, the assessment of the performance of the DS system was performed using Designbuilder Building energy simulation software.

The main aim of the simulation was to examine the viability of applying DS façade in hot dry climates and evaluate it's potential energy savings. It aims also to assess the impact of several design parameters on thermal performance. It's impact on thermal comfort is assessed as well.

Two Double skin models were assessed and compared to the base case. The first model has a glazed outer skin while the other model has a wooden mesh screen as an outer skin.

In the first stage of simulation, the peak day with maximum air temperature in summer was identified, the annual electricity consumption for the four orientations was evaluated to determine the worst orientation.

In the second stage, the annual electricity use of the base model was evaluated and compared to that of the DS models, with the DS system installed on the orientation with the highest energy consumption determined in the previous stage. In the third stage, the impact of several design parameters on thermal performance on the DS model with the least consumption was assessed. The assessed design variables were glazing type, the cavity shading. In the fourth stage, the annual electricity consumption of the optimized DS model was calculated. The cooling electricity in peak summer day which was set to be 19 August as determined in stage one, was calculated and compared to the base case. In the final stage, the impact of the optimized DS model on thermal comfort was evaluated. The annual PPD and PMV was calculated and compared to the base case. PMV and PPD was evaluated in the peak summer Day and compared to the base case as well. The indoor air temperature was calculated and compared to the outside dry bulb temperature.

3.1 Climate

According to Köppen climate classification, Egypt lies in the hot arid desert climate. the annual outside dry bulb temperatute is presented in fig.3. The maximum recorded temperature was 32.4 ^{o}C in 19 August and the minimum recorded temperature was 10.8 ^{o}C in 25 Jan.

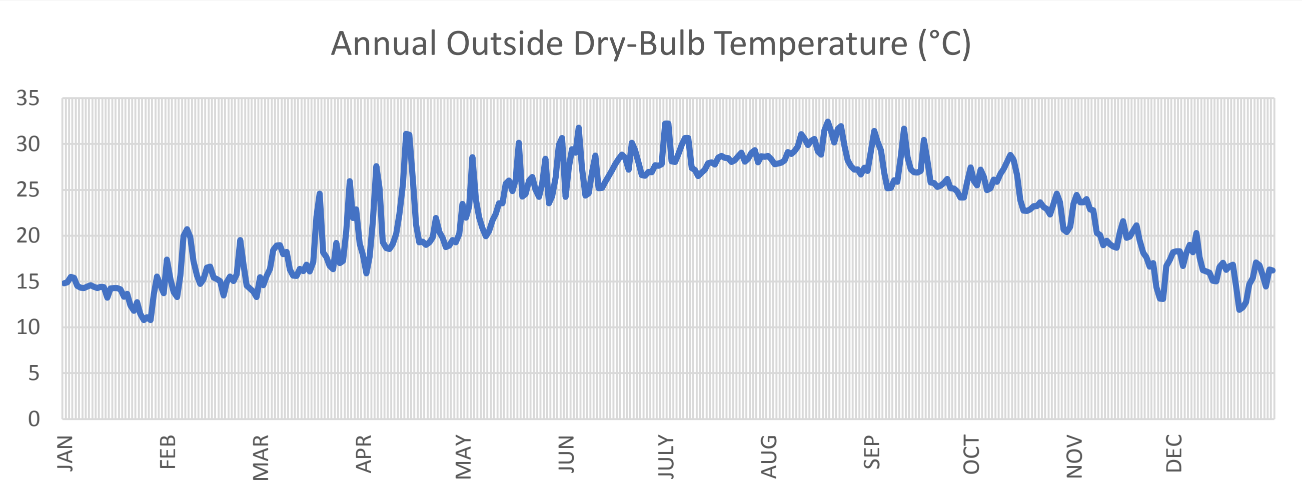

Fig. 3: Outside dry bulb temperature .

3.2 Base case description

3.2.1 Single skin Façade base case

A typical office building was chosen to conduct the simulations. The modelled building prototype was based on a survey on office building prototypes in 6 October city and new Cairo. The office building consists of six floors. The height of each floor is 3.5m. The plan is square with dimensions 30m x 30 m. The square shape was used to control the impact of orientation on simulation results. The plan is an open plan office with a central core. The building is Air-conditioned. The main building construction materials were selected according to common office building envelop materials. Double glazing with air gap 13mm is utilized for the internal skin, while single clear glass was utilized for the external skin, the window to wall ration is 60%. The walls were medium weight Concrete blocks. The properties of the building are listed in table 1. The occupancy schedule was set to 5 working days from 8:00 a.m to 5 p.m.

Table 1: Base case description.

Properties		
Building	Building shape	Square (30m x 30 m)
	Number of floors	Six floors
	Height	3.5 m
	Aspect ratio	1:1
	Area of floor	900 m^2
Envelop	WWR	60%
	Glazing: generic clear 3mm, air gap 13mm, generic clear 3mm. U value	U value: 1.96 W/m2K
	External walls: cement plaster 0.02m, medium Concrete blocks 0.2m, cement plaster 0.02m.	U value :1.6 W/m2K
	Roof Cast concrete(lightweight) 0.1m, extruded polystyrene 0.04, fiberboard 0.013, asphalt 0.019	U value :0.48 W/m2K
	U value Floor	2.9 W/m2K
	SHGC	0.691
	Single clear glass light transmission	0.744
HVAC	AC typpe	Fan Coil unit,Air cooled chiller
	Temperature set point (^{O}C)	24
	Relative humidity set point (%)	60
	Outside air (m3 /h per person)	20

Lighting	Installation power density (W/m^2)-100 lux	5
Plug loads	Power density (W/m^2)	11.7
Total consumption	Average annual energy use	210 KWh/m^2

3.2.2 Double skin Façade models.

Two Double skin models were constructed. The first model has a glazed outer skin while the other model has wooden screen mesh as an outer skin. The multi-storey type was selected for this study due to it's efficiency as indicated in the literature. The cavity depth is 1 meter as recommended in previous research. Vents at the bottom and top of the cavity were used to evacuate hot air. Single clear glass was utilized for the external skin.(fig.4). The second model is based on the single skin model as well. A wooden screen mesh was utilized as an outer skin .(fig.5)

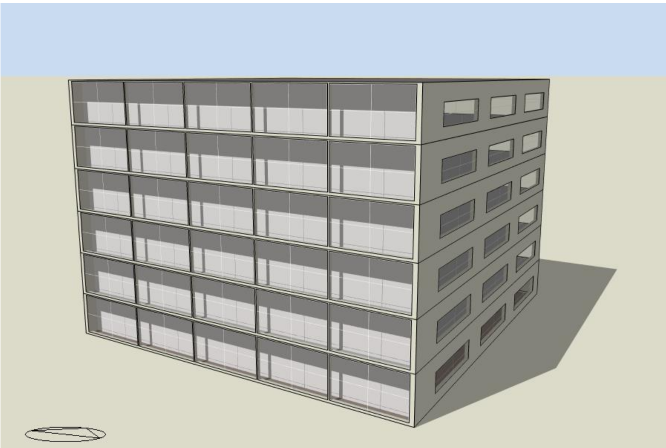

Fig. 4: Double-skin façade model with glazing

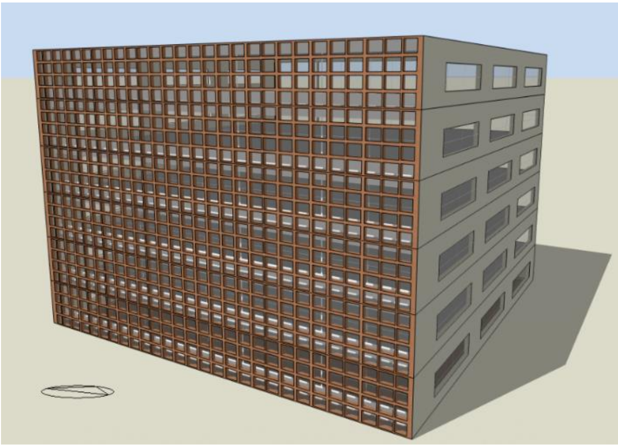

Fig. 5: Double-skin façade model with wooden screen

4 Results and discussion

4.1 Electricity use

4.1.1.Electricity use for the base case and DS models.

The two models were simulated in the four orientations and compared to the base case. The highest electric consumption was for the Double skin façade oriented towards North with a reduction of 3.6% than the base case. The highest reduction was for the Double skin oriented towards the south with reductions reaching 10 %. (fig.6). For this reason, the double skin will be installed on the south orientation.

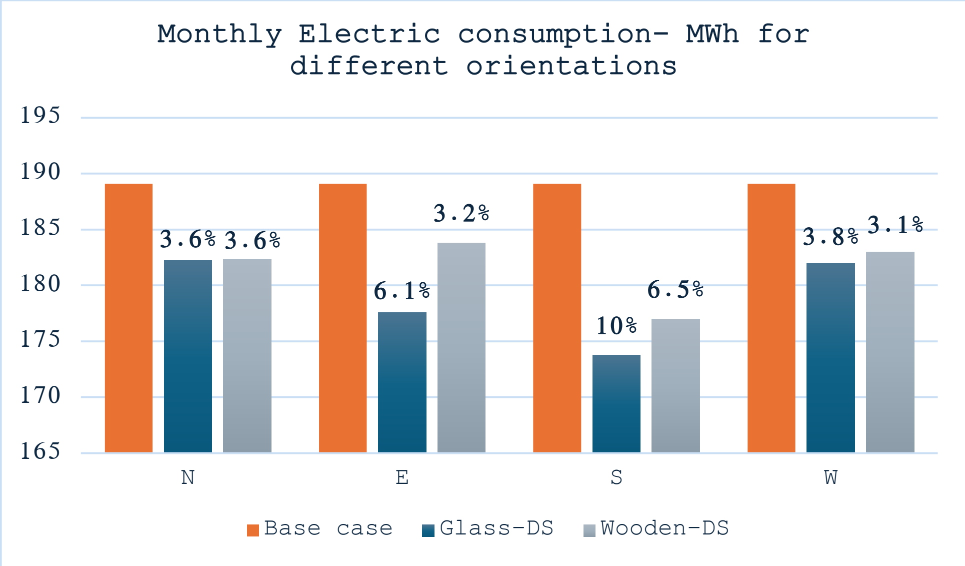

Fig. 6: Annual Electric use for different orientations.

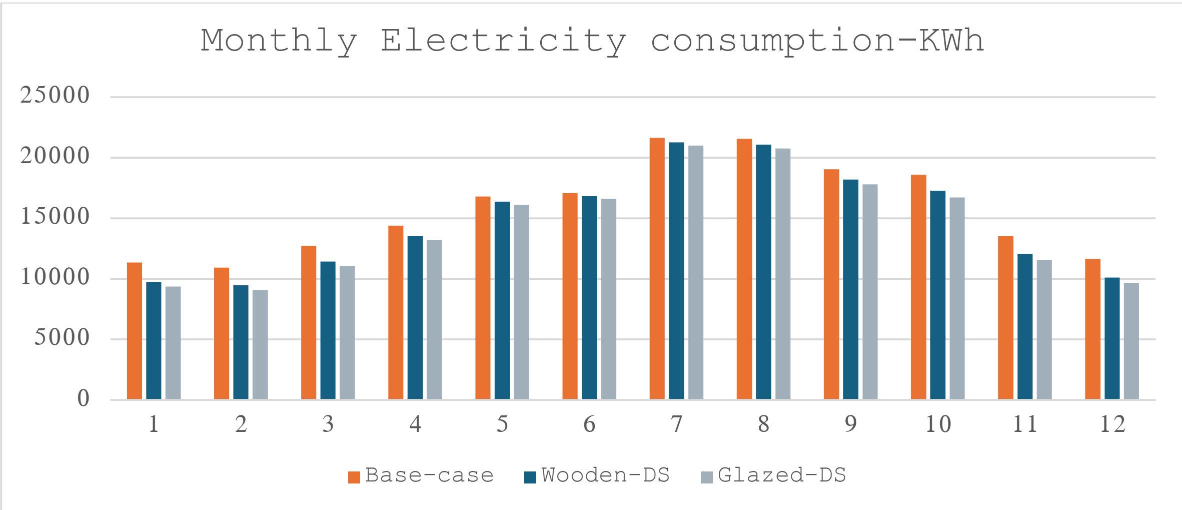

Fig. 7: Monthly Electric consumption.

The average electricity use of the base case in August is around 21,558 KWh for each floor, while it was around 20,4 KWh and 21,0 KWh for DS model with glazing and the DS model with the wooden screen respectively. (Fig.7). It is observed that the energy consumption of the DS models is lower than that of the base case, however, the reductions was not significant. This is attributed to the warm air accumulated in the cavity which is difficult to get rid of specially with high outdoor temperatures.

Fig.6 presents the monthly Electric consumption for every floor.

In case of the Glazed DS model, the annual electric consumption for one floor dropped from 189 MWh to 172 MWh with reductions about 10 % . while in case of the wooden DS model, the annual electric consumption for one floor dropped to 177 MWh with reductions about 6.5 % It is obvious that the DS system has resulted in Energy saving, however, these savings could be increased by thermal properties improvement. This is in accordance with [9,14]. Since the Glazed double skin façade resulted in higher electricity reductions, it will be the model chosen for optimization.

4.1.2.Energy consumption for the optimized DS model.

The main aim of optimization is to decrease the energy consumption and improve indoor thermal comfort. This could be achieved by altering the properties of some variables like glazing, shading inside the cavity and the orientation of the cavity. Since the DS model with glazing resulted in lower electricity consumption, it was selected to perform the optimization.

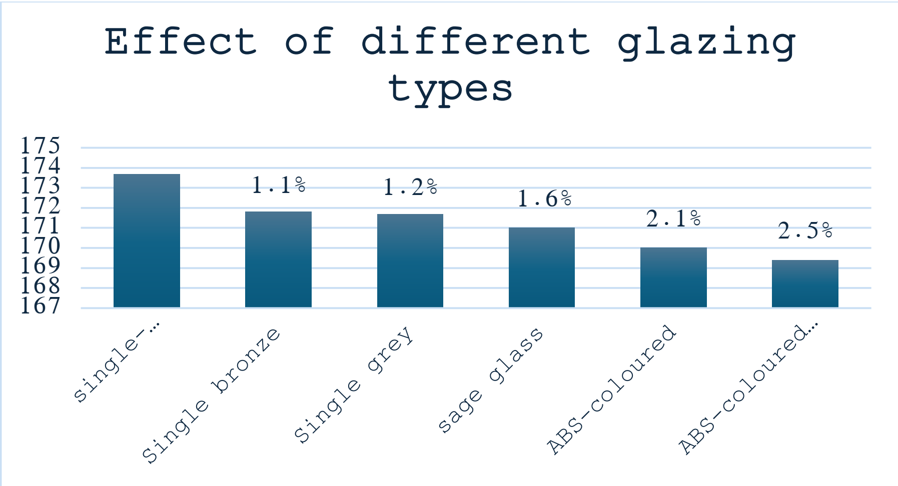

Fig. 8: impact of various glazing types of DSF on Electricity use.

Six glazing types were simulated including single clear glass 6mm, single bronze, single grey, sage glass and the electric Abs coloured single glazing. The Electric Abs coloured double glazing had the best performance compared to other glazing types. The results are shown in fig.8.

The glazing type of the DS skin was changed from single glazing to Electric Abs coloured double glazing. The annual electric consumption for one floor dropped from 189 MWh to 168.3 MWh. The cooling load was reduced from 94 MWh to 80 MWh per floor.

By using high reflectance-low transmittance blinds, the annual electric consumption for one floor dropped to 168 MWh resulting in reductions by about 300 KWh annualy per floor.

The total electric consumption reductions for the optimized model reached 11%.

Fig.9 shows the monthly cooling load. The max. load in August was 13,540 KWh and it dropped to 12,640 KWh in case of the optimized DS.

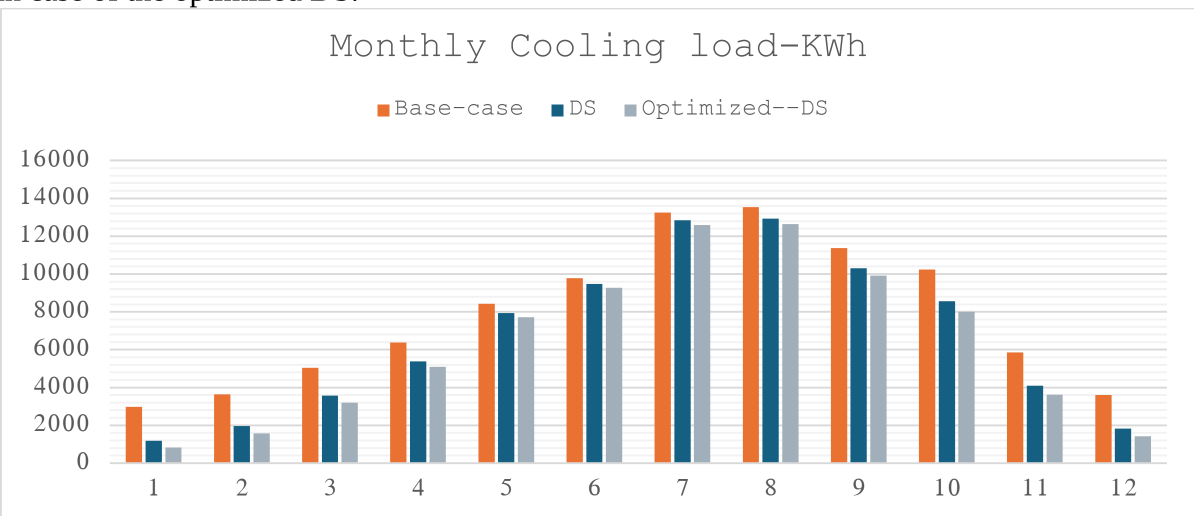

Fig. 9: Monthly cooling load KWh

In August 19, the cooling electricity dropped from 646.5 KWh to 593 KWh with a reduction of 8.3 % in cooling electricity.Fig.10 shows the cooling electricity in the peak summer day.

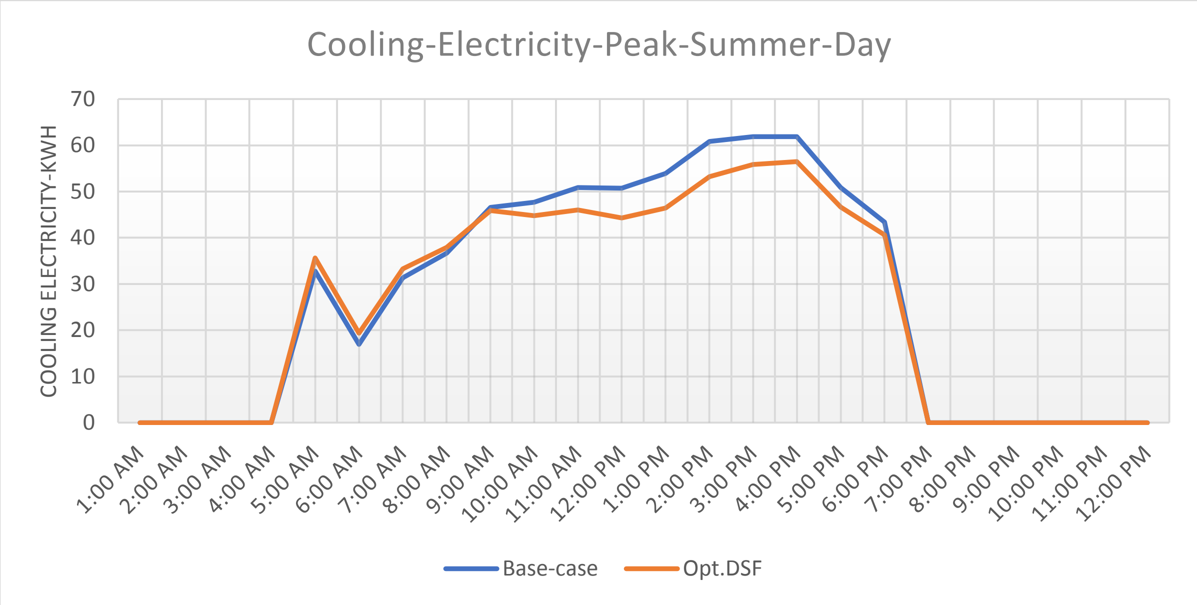

Fig. 10: Cooling electricity in Summer peak day..

4.2 Comfort`

Figure 11 presents monthly PMV values. The maximum PMV reaches a value of 1.42 for the base case and +1.14 for the DS model in August, while the minimum PMV in winter is -0.11 and -0.43 for the Base case and DS model respectively. According to the ASHRAE 55 standards, .the acceptable PMV comfort range is between -1 and +1. This indicates that by applying the optimized DS, thermal comfort is almost achieved.

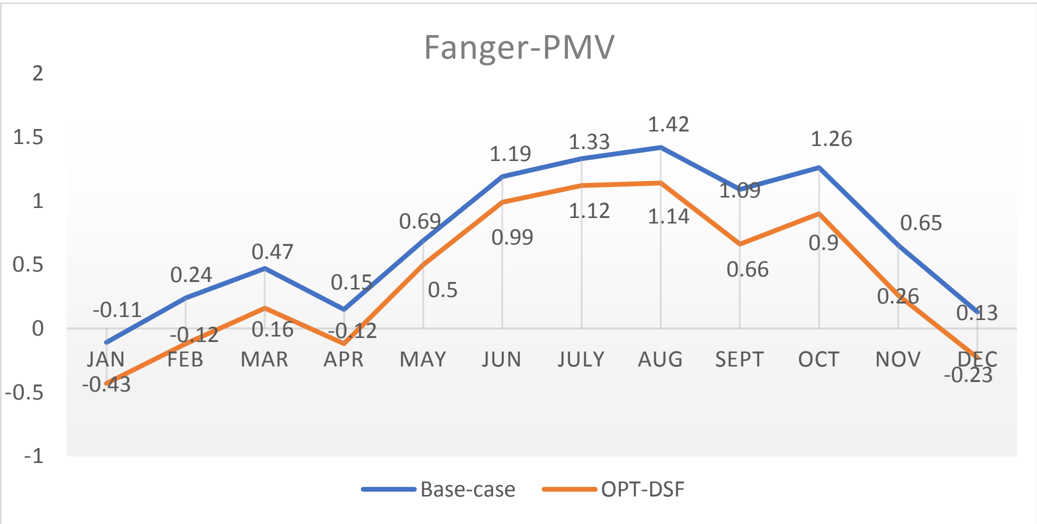

Fig. 11: Monthly PMV..

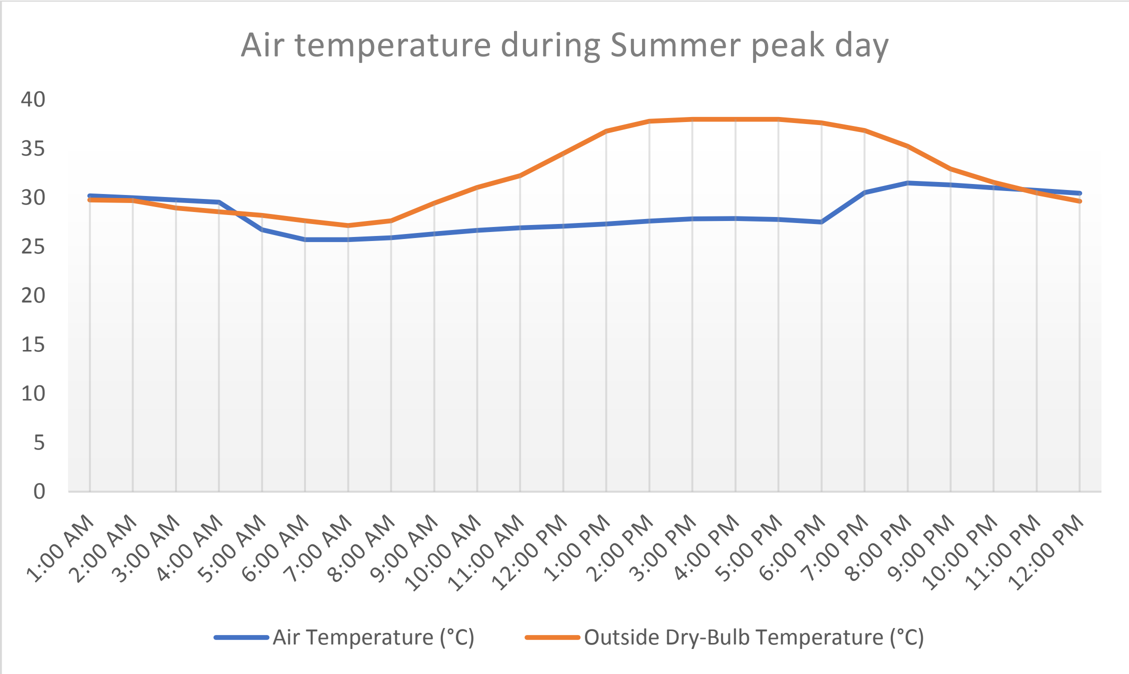

Fig. 12: Air temperature in Summer Peak day.

Maximum recorded temperature during the occupancy hours was 28ºC at 4:00 p.m. with a drop about 10 ºC than the outdoor temperature. (Fig.12)

In 19 August, the average Predicted Mean vote is 1.08 and the PPD is 37% for the base case, while for the optimized DS, the Predicted Mean vote is 0.9 and the PPD 31%. There was a decrease in the PPD by about 6%. The highest PMV during the occupancy hours was 0.6 at 4 p.m.(fig.13)

In 19 August, the maximum PPD recorded during the occupancy hours was at 4:pm with value 23% and 12.7% for the base case and the optimized DS respectively.(fig.14). This indicated that by applying the Opt.DS, the PPD became within the ASHRAE standards for office buildings. (5% minimum and 15% maximum)

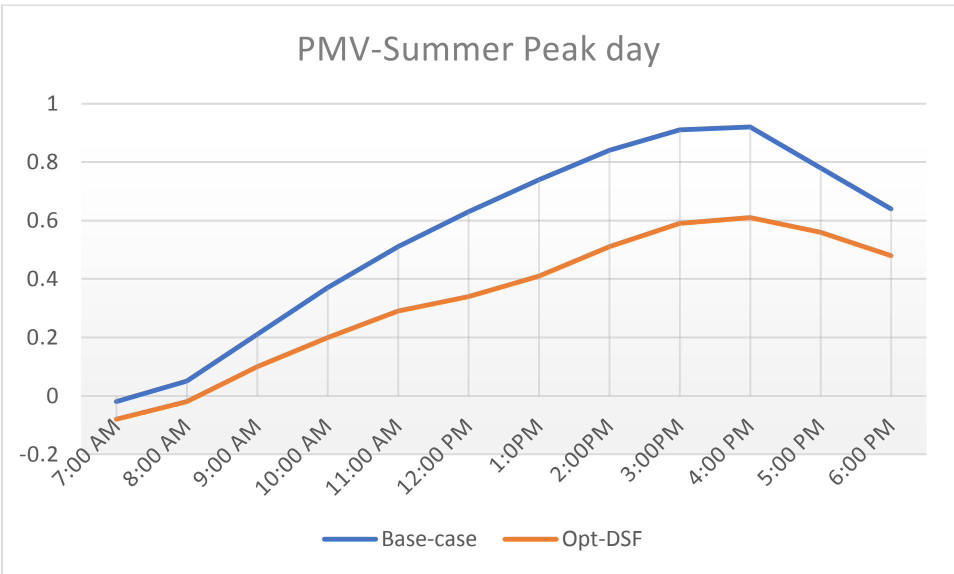

Fig. 13: PMV during occupancy hours in Summer Peak day.

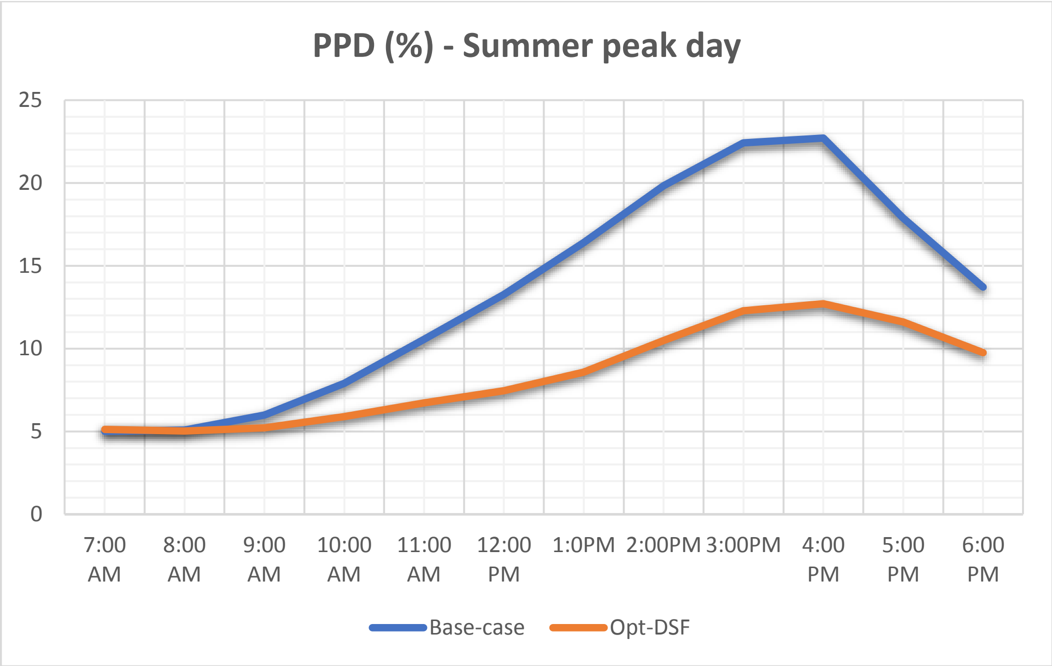

Fig. 14:PPD during occupancy hours in Summer Peak day.

Conclusion

The main aim of this study was exploring the viability of applying Double skin façade system in hot dry climates. The efficiency of this system is highly impacted by the climate and the design. For this reason, the study aimed at exploring the effect of different design parameters on the efficiency of the system in terms of energy saving and thermal comfort achievement.
The research indicated that applying the DS system on the southern façade resulted in the highest energy savings compared to the base case. Two models were assessed and compared to the base case. The amount of saved energy reached about 6.5% in the model with the wooden mesh screen and 10% in the model with glazing. By optimizing the DS system with glazing, annual reductions in electricity consumption reached 11%. The efficiency of the DS system could be enhanced with the proper combination of design parameters. Changing the glazing type and adding shading were the most influential parameters. The Elec.Abs coloured glazing had the best performance among other glazing types. Using High reflectance and low transmittance blinds was efficient in decreasing the solar gains.
Regarding comfort, the average annual PMV ranged between 1.14 in August and -0.43 in January, which lie in the comfort range.
Inspirations from vernacular architecture in DS design like using wooden screens inspired from mashrabya are promising solutions. Besides their environmental advantages in blocking solar radiation and providing visual privacy, they have the advantage of creating specific regional architectural identity. However, further investigation is required to improve it's efficiency.

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