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Case study of double skin façade in hot climates

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Abstract

This paper presents the findings of preliminary thermal analysis for a new building in central Abu Dhabi with double skin facade. The building is fully glazed and curved in shape. The study focuses on the thermal performance of the building's envelope and the analysis has been carried out using dynamic thermal simulations. Due to the high temperatures and intense solar radiation in the region, preliminary analysis showed that the air temperature in the double skin façade cavity would reach over 70 °C. This high temperature would not be optimal for the motors of blinds designed to operate within the gap. Occupants comfort is another key issue. High temperatures of the internal glazing could result in uncomfortable indoor conditions particularly for the spaces close to the perimeter of the building. A novel exercise was carried out to determine the optimum energy strategy to minimize the building overall energy consumption while maintaining indoor comfort and keeping the double skin cavity at acceptable air temperature for the blinds' motors.

1 Introduction

Double skin facade (DSF) is becoming a common architectural feature of commercial buildings. The challenge for DSF buildings is to maintain a balance between the aesthetic, acoustics insulation, and visual benefits against the performance of the building from energy point of view.

The general feature of DSF comprises an outer skin, a cavity, and inner skin of glazing. The outer skin and the inner skin can be either a single or double glazing layer. The structure of the DSF can also be associated with shading devices such as blinds to reduce solar gains and therefore the cooling demand of the building. During hot seasons, as a result of solar gains and outer skin thermal conduction, heat is trapped in the gap between

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the outer skin and inner skin of the DSF. Depending on the design, the gap of the DSF is commonly ventilated to drive out the excess of heat gained. There are several tools, such as computational fluid dynamics and dynamic thermal simulation tools that can be used to predict and analyse the performance of DSF. . In this paper, the predicted performance of the DSF has been analysed using a dynamic thermal simulation tool called Intergraded Environmental Solutions (IES). This software can be used to carry out steady state and dynamic thermal simulation using hourly weather data and detailed input for the services systems and building fabric.

2 Building description

The building considered in this analysis comprises a 17 storey office building (approximately 15,000 m^2 floor area) designed by Zaha Hadid Architects. The upper most floor of the building is designed as a special restaurant.

The outer skin is single glazed with special properties (see Table 1). The inner skin is double glazed and the gap in between includes motorized blinds to reduce the solar gains.

Figure 1. Two perspective views for the building

3 Objectives

The modelling of the DSF has been carried out aiming to provide the following preliminary studies:

- General analysis for 2 DSF gap cooling scenarios
- Analysis of the temperature variation along the DSF gap
- Possible effective ways for ventilating the DSF gap
- Sensitivity analysis for the outer skin glazing solar transmittance

These studies have been carried out to find reasonable solutions with the consideration of the following design constrains:

- Complexity of the building shape
- DSF with curved glazing structure

- Proprieties of the outer skin (golden mirror appearance)
- Use of motorised blinds (within the DSF gap) with limitations of operating temperature of the motors
- Totally sealed building due to sand storms in the region (no possibility for naturally ventilated DSF gap or enhanced/mechanically assisted naturally ventilated gap
- Maintenance/cleaning of the cavity and effect of sand on the blind motors

4 The approach of the thermal modelling

A typical mid-floor of the building has been selected for the thermal analysis. This is a simplified approach as the prediction of air temperature inside the gap, particularly for higher floor levels, is more complex due to the heat buoyancy effect.

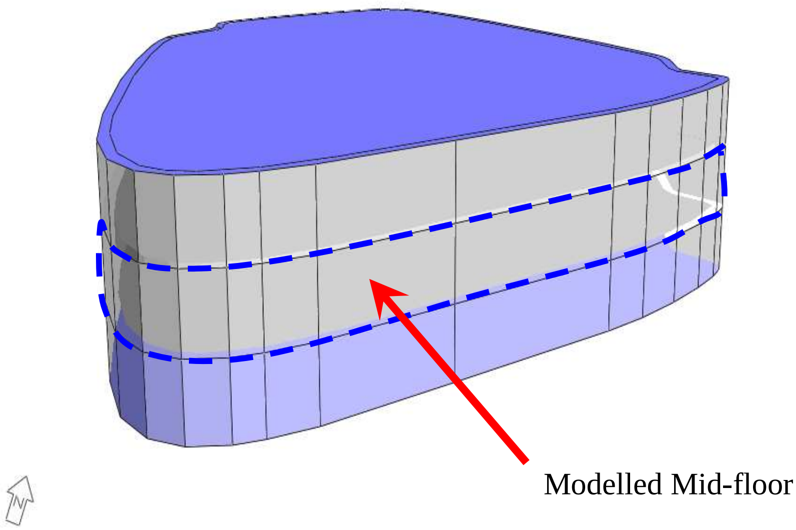


Figure 2. 3D render of the simplified model

The 3D model has been constructed using IES software with the thickness of the double skin gap considered in a range of 0.6 – 0.8 metre. Blinds have been considered within the gap. Abu Dhabi weather data has been used in this analysis and the properties of the glazing considered are as in Table 1.

	External skin	Internal skin external glass	Internal skin internal glass
Thickness (mm)	10	8	8.76
Conductivity (W/mK)	1	1	1
Type of glass	Pyrolitic coating with gold appearance on outer	clear glass with low-e coating	clear laminated glass

	surface		uncoated
Light Transmittance	38%	87%	87%
Light Reflectance (outside)	35%	5%	8%
Light Reflectance (inside)	45%	4%	8%
Solar Transmittance	46%	56%	70%
Solar Reflectance (outside)	21%	20%	6%
Solar Reflectance (inside)	30%	30%	6%
Outside emissivity	0.84	0.84	0.84
Inside emissivity	0.84	0.04	0.84
U-value (W/m^2K)	5.56	3.2	5.6
Refractive Index	1.5	1.5	1.5

Table 1. Properties of the glazing

Humidity in the offices space	minimum 40% and maximum 60%
Temperature of the internal office space	24 °C (constant)
Miscellaneous internal gains (e.g. small power)	15 W/m^2
Lighting internal gains	18.75 W/m^2
Occupancy density	9 m^2 per person
Infiltration	0.25 air change per hour
Simulation period	Whole year round

Table 2. Input parameters for the thermal model

5 General analysis for 2 DSF gap cooling scenarios

This study has been carried out to compare the cooling demand for the selected floor of the building the DSF gap temperature maintained at (i) 45 °C (the assumed design external temperature) and (ii) 60 °C (maximum operating temperature of the blind motors). This simplified analysis is focused on energy efficiency. Parameters such us occupant comfort have not been considered in this study, however it is discussed in the next section. Further analysis of these parameters will be required to determine the optimum solution.

5.1 Maintaining DSF gap temperature at 45°C

The ventilation flow rate of the selected floor is estimated as 1500 l/sec. To maintain the DSF gap temperature at 45°C, at least 3000 l/sec of cool return air (at ~ 27°C) from the inner spaces would be required to ventilate the DSF gap. The return air (i.e. 1500 l/sec) will not be enough to ventilate the gap cavity and additional air supply would be required. The internal office space cooling load of the selected floor can be estimated as 192.6kW, while the additional cooling load required to maintain the DSF gap at 45 C is estimated as 44 kW.

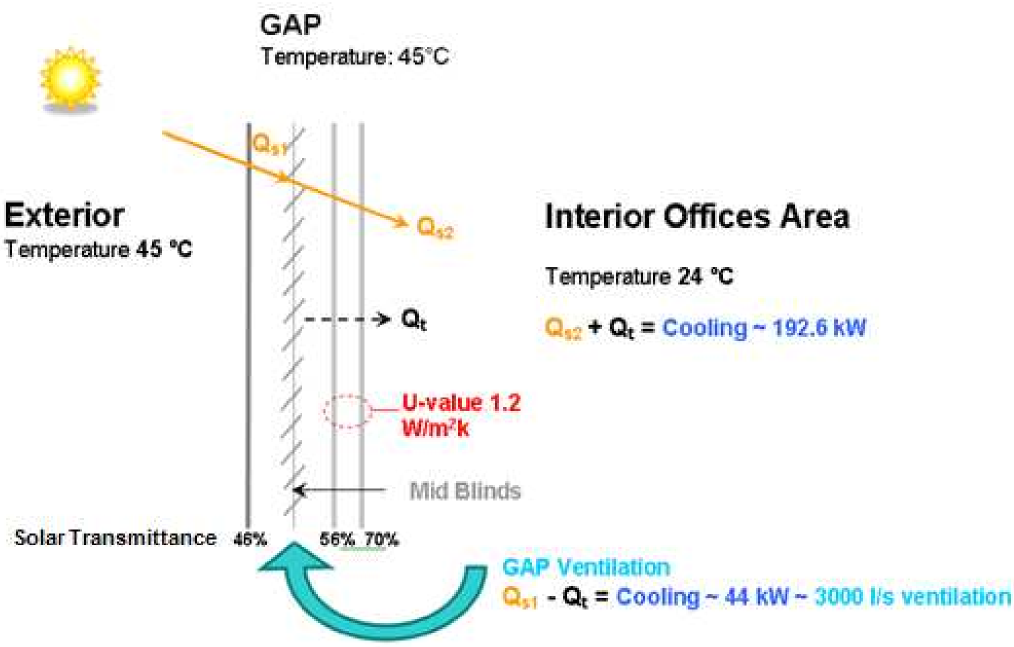


Figure 3. Cooling requirements when the DSF gap is kept at 45 °C

5.2 Maintaining DSF gap temperature at 60°C

If the temperature of the DSF cavity is kept at 60°C, the air flow rate from the inner spaces needed to ventilate the cavity is estimated as 800 l/sec (assumed supplied at 27 °C). This allows the cooling system to benefit from approximately 700 l/sec of cool return by means of coolth recovery and therefore assist in energy savings. The selected office cooling load can be estimated as 196.4kW, while the equivalent cooling load that would delivered to the DSF cavity can be estimated as 20.6 kW.

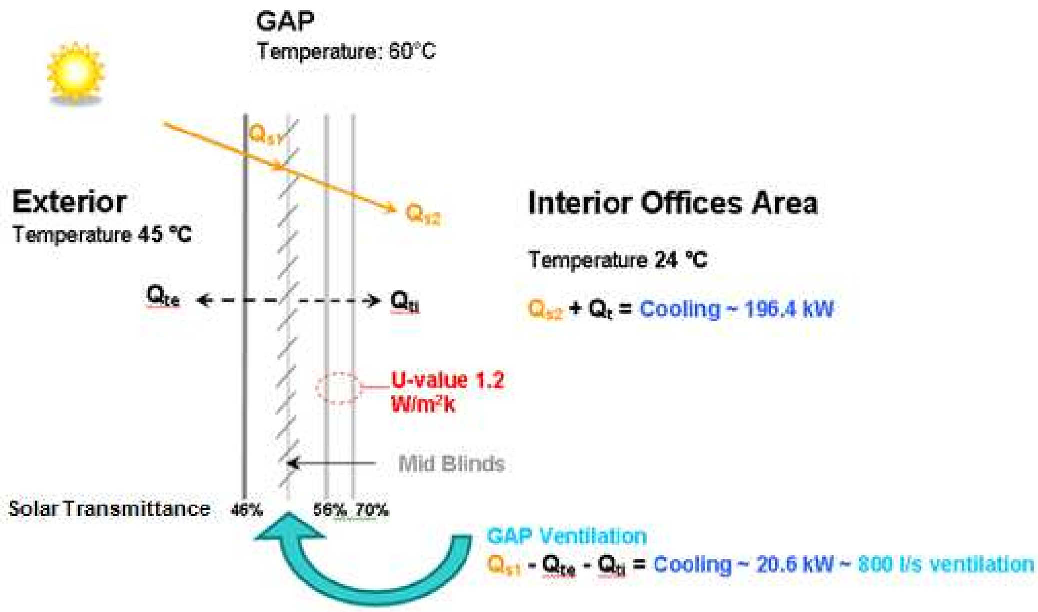


Figure 4. Cooling requirements when the DSF gap is kept at 60 °C

5.3 Outlines of this study

- From the energy efficiency point of view, it is beneficial to maintain the temperature of the DSF cavity at same external air temperature (~ 45 °C), however this would require all return cool air from internal spaces to be supplied to the cavity in addition to extra cooling load.
- Maintaining the DSF cavity at 60 ° C allow for partial heat recovery. This would also allow for the motorised blind to operate with minimum risk.

6 Analysis of the temperature variation along the DSF gap

6.1 Dividing the DFS gap into multiple sectors

Similar to other thermal modelling software, IES software has limitations. As an example, if the DSF gap is considered as one zone, the software will predict an average air temperature for the whole gap. The DSF gap of the selected floor has been divided into 14 sectors[†], considering the orientation (see Figure 5), to allow for better representation of the temperature variation along the gap.

[†] It must be noted that the 14 sectors considered as 'testing areas' considering the different orientations to increase the accuracy of the results, and that effectively do not represent real partitions.

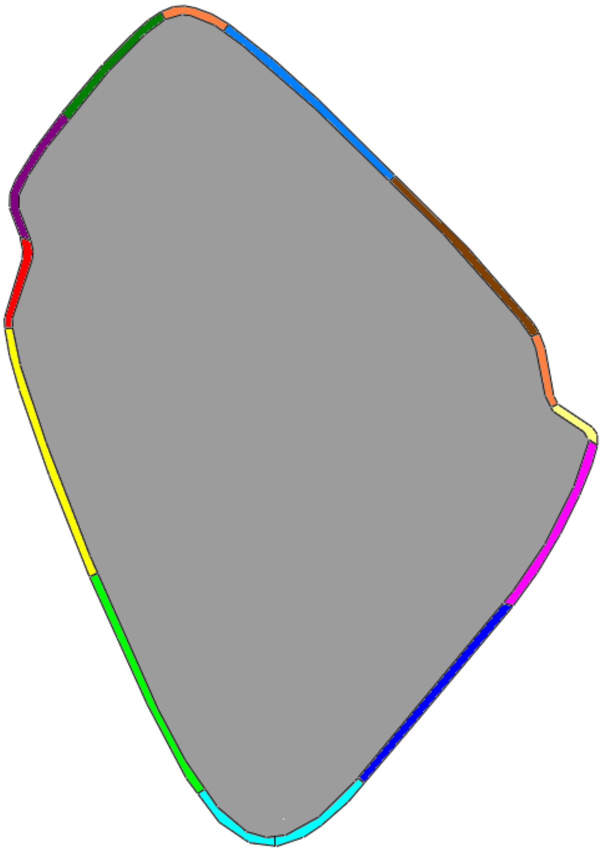


Figure 5. Plan view of the modelled mid-floor with speculative sectors

6.2 Internal surface temperature of the glazing

One of the key parameters that can affect comfort of the building users is the internal glazing surface temperature, particularly for the building users who are located close to the internal glazing of the building. The other building users, who are distant from the façade internal glazing, may not be affected.

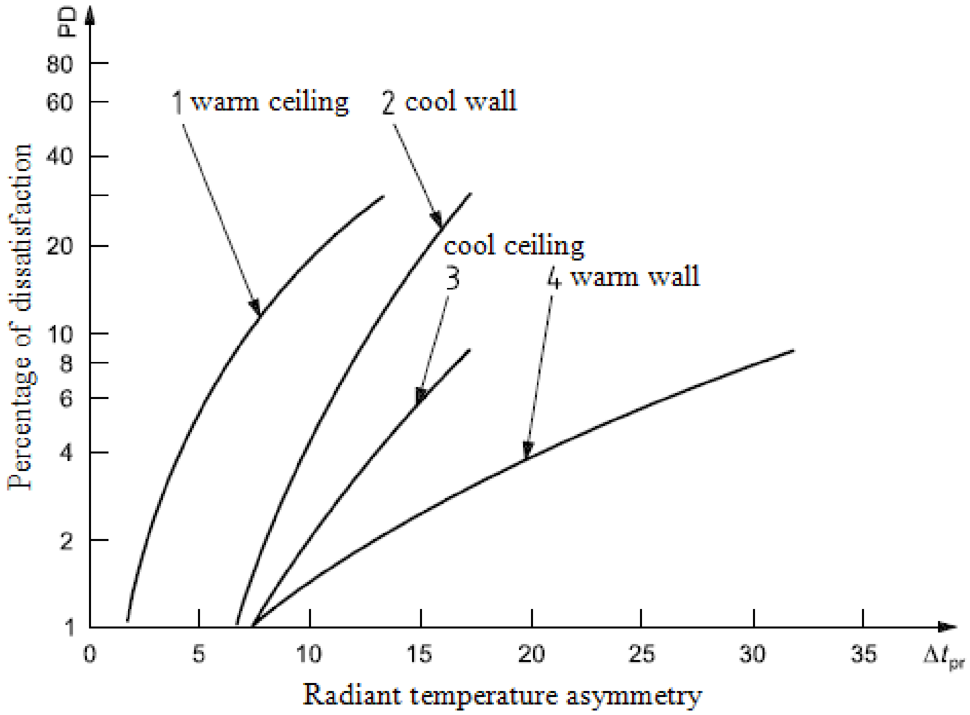


Figure 6. Local thermal discomfort caused by radiant temperature asymmetry (ISO7730:2005)

The effect of the building fabric on the radiant temperature asymmetry can be shown in Figure 6 (ISO 7730:2005). For a warm wall, a radiant temperature asymmetry (Δt_{pr}) between 30 – 35 °C would approximately lead to 8 – 10 % of dissatisfied people.

Calculating the radiant temperature asymmetry can be a complex exercise considering the irregular shape of this building, as it requires determining temperature of surrounding surfaces. The crucial part would be the temperature of the perimeter glazing surface, which is facing the warm double skin and the outdoor environment.

In this study, the maximum surface temperature of internal glazing was predicted to be approximately 33 °C. This is deemed reasonable in terms of causing significant impact on comfort. Detailed calculations and modelling will be required to determine the impact of this suggested internal glazing temperature particularly for building in hot climates.

Figure 7 shows the incident solar radiation on the façade. The air and glazing surface temperatures vary along the DSF gap depending on the sector orientation. With the DSF gap being unventilated, the highest air temperature inside the double skin is expected in the southern and west southern sectors, reaching up to 73 °C as shown in Figure 8. The temperature of internal glazing is expected to vary between 31 – 33 °C, while the air temperature of the inner spaces is maintained at 24 °C (design temperature internal temperature).

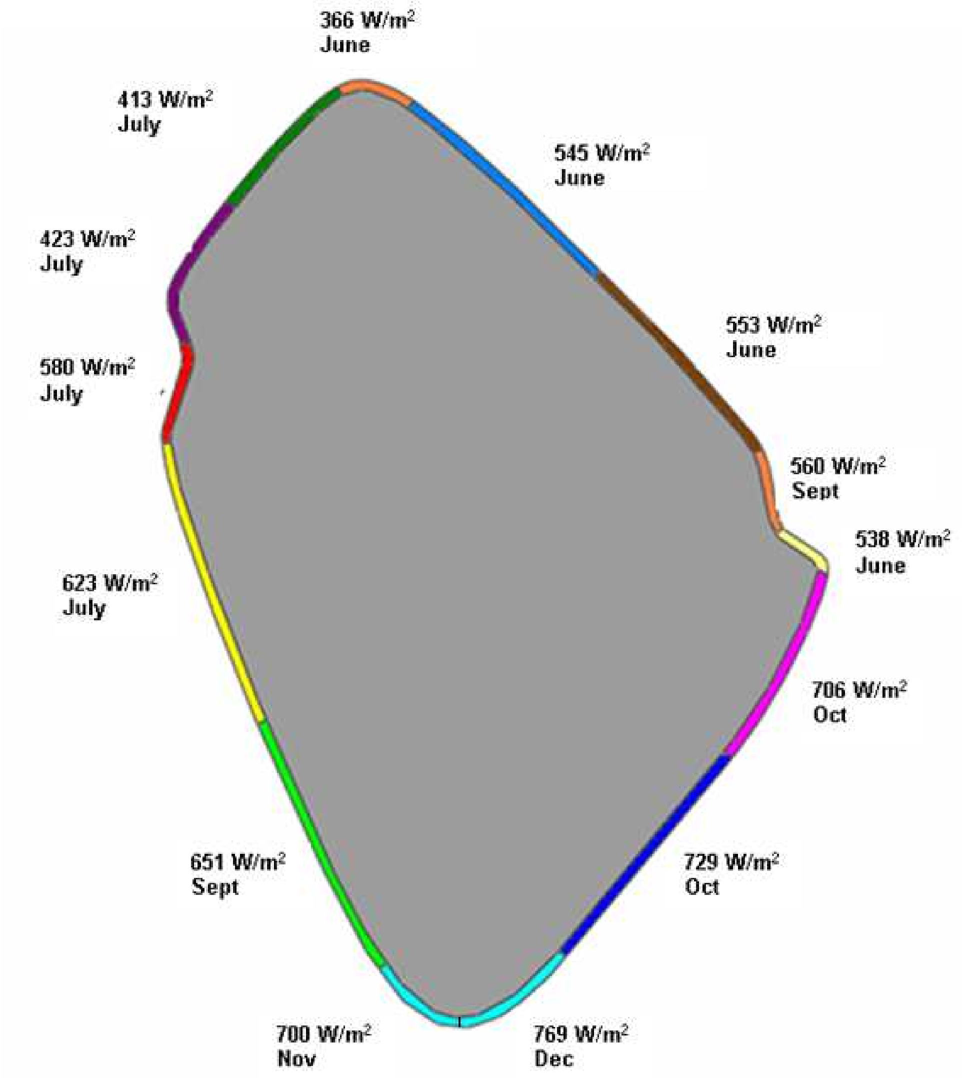
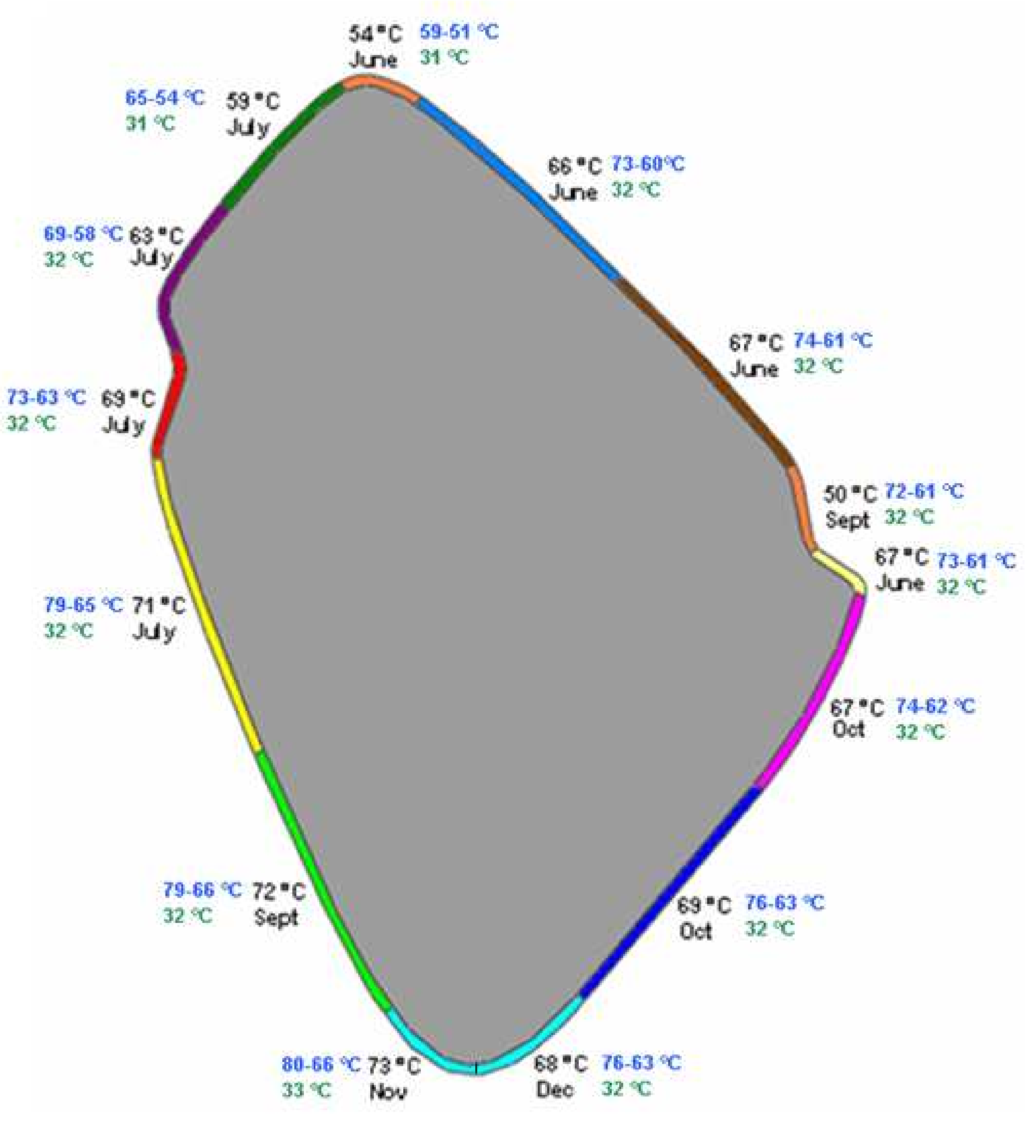


Figure 7. Incident solar radiation distribution around the perimeter of the façade



Sectors peak temperature (°C)
DSF gap: outer skin - inner skin (facing the gap) surface temperature (°C)
Glazing surface temperature (facing the internal office space) (°C)

Figure 8. Air and glazing surfaces temperature variation along the double skin gap

6.3 Outlines of this study

- The DSF gap of the selected floor has been divided into 14 sectors to allow for more accurate analysis.
- The DSF gap has been considered as unventilated in this study to determine the peak DSF gap temperature
- Peak air temperature the southern sector of the DSF gap can reach up of 73 °C.

- Environmental design guidance has been considered to maintain the inner space at comfort air temperature (24 °C). The predicted temperature of the internal surface of the inner skin glazing is in range of 31 – 33 °C and the impact of this glazing surface temperature on comfort of the perimeter areas needs further investigation.

7 Possible effective ways for ventilating the DSF gap

This study focuses on the possibility of independent ventilation arrangements for the Eastern and Western grouped sectors of the DSF sectors of the selected floor (see Figure 9). If feasible, this arrangement could lead to significant minimization the peak temperatures and homogenizing the temperatures variation in the DSF gap throughout the day (see Figure 10 and Figure 11). This would also allow for energy savings as a result of partial coolth recovery and from the structure point it would improve the durability of the DSF structure.

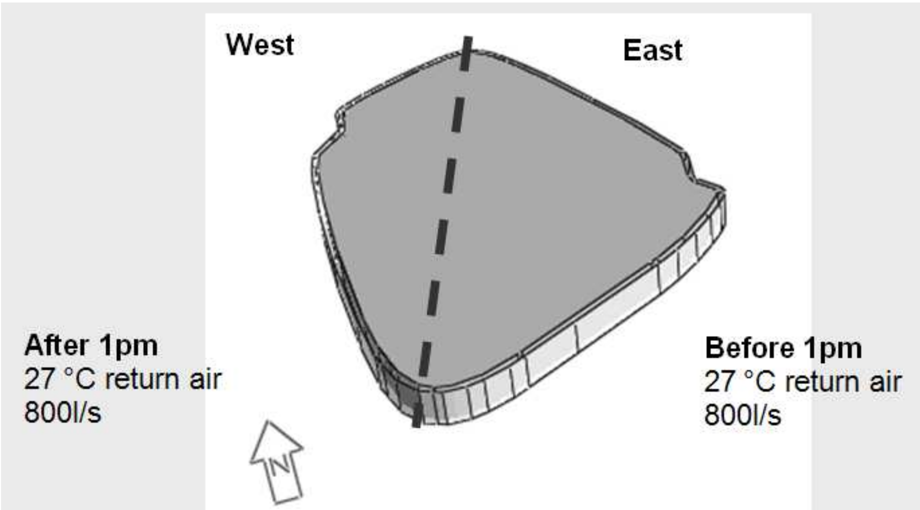


Figure 9. Potential morning and afternoon ventilation flow rate distribution for the Eastern and Western sectors of the DSF gap

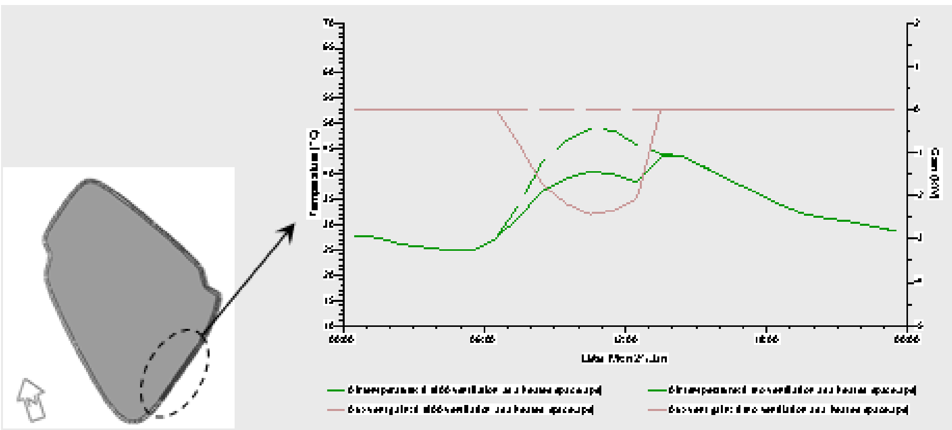


Figure 10. A sample south-eastern façade sector ventilated between 7am and 1pm

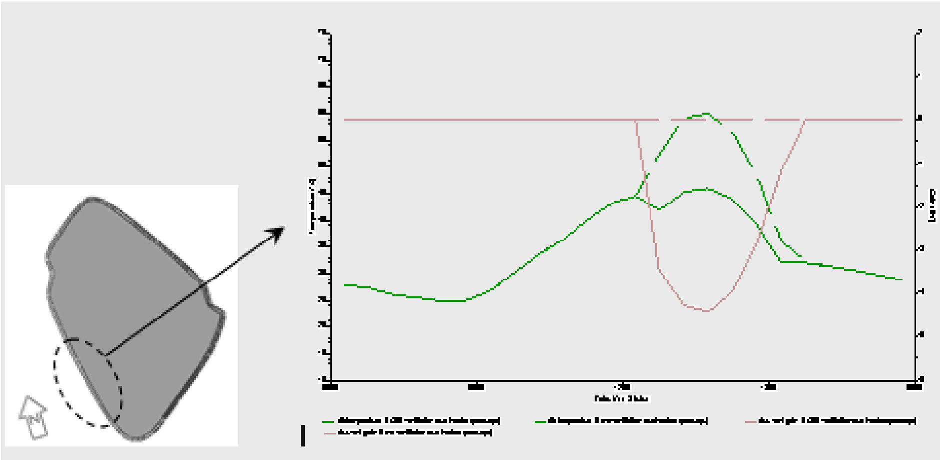


Figure 11. A sample south-western façade sector ventilated between 1pm and 7pm

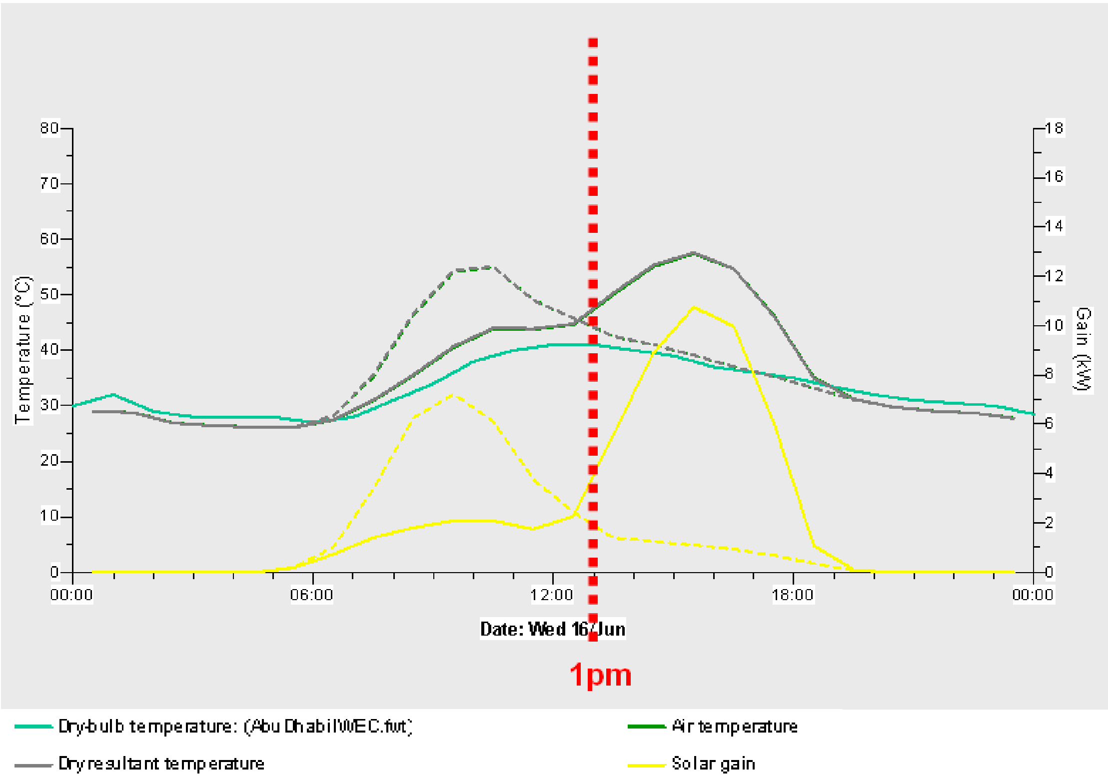


Figure 12. Temperature variation of ventilated DSF (800 l/sec supplied separately for Eastern and Western zones)

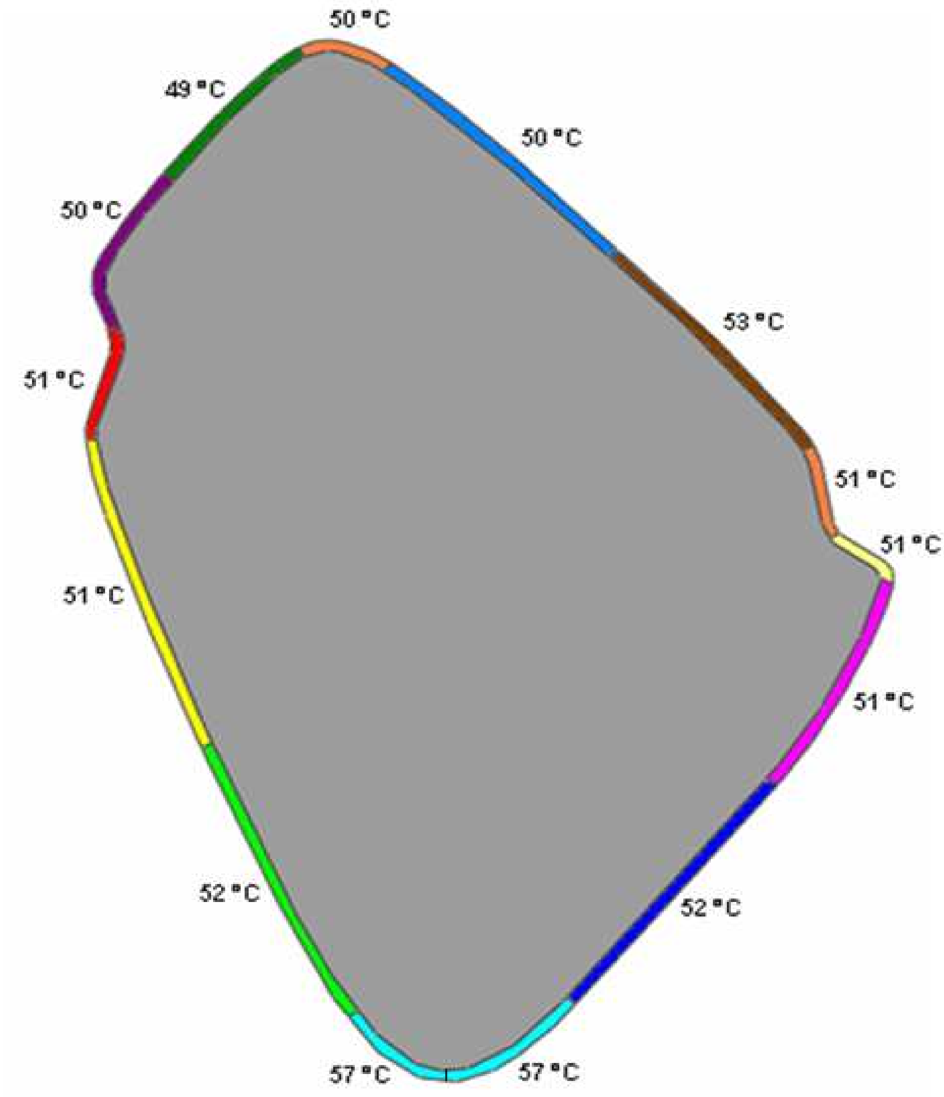


Figure 13. Air temperature of the 14 sectors with DSF gap being ventilated with 800 l/sec of air from internal spaces

7.1 Outlines of this study

If feasible, independent ventilation of the DSF gap (potentially for East and West areas) during day and afternoon time of the day would have several benefits that can be summaries as the following:

- Harmonizing the temperature variation along the gap by reducing the peak temperatures
- Allowing for partial coolth recovery
- Peak air temperature in the southern part of the DSF gap is reduced to ~ 57 °C

- Maintaining the temperature of the DSF structure would improve the durability of the structure

8 Sensitivity analysis for the outer skin glazing solar transmittance

For highly glazed buildings in regions such as Abu Dhabi, solar transmittance of the outer skin glazing is a key parameter to reduce the solar gains. A sensitivity analysis has been carried out to evaluate the variations of the solar gains for a range of external glazing with solar transmittance values from 46% down to 13%. The results show an estimated annual reduction of the solar gains from 140 MWh to approximately 117 MWh (~ 16% reduction) could be achieved by improving the performance of the external glazing transmittance.

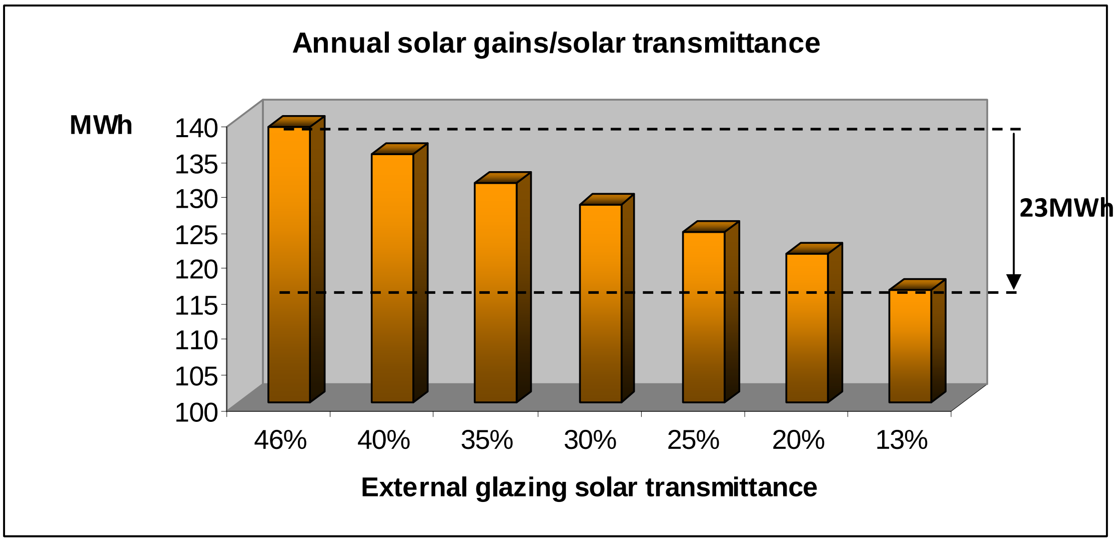


Figure 14. Variation of the peak annual solar gains of the selected floor with the solar transmittance of the outer layer external glass

9 Comparison of the predicted results with similar studies

The studies in this paper are limited to the thermal analysis of a mid-floor of the building and therefore does not consider the microclimate of the whole façade cavity particularly the vertical thermal behaviour of air movement. Computational fluid dynamics tools are suitable to model the behaviour of such air movement within the DSF cavity [Laouadi, 2009]. Testing experiments show that the air movement inside DSF cavity is not simple to predict [Manz, & Frank, 2005].

Due to the aesthetic demands, there are different designs for DSF. Depending on the design of the DSF and the cavity, the air movement in the cavity could have different behaviour and that result in range of temperature differential for the surfaces and the air within the cavity.

Results of coupling functions of CFD and building simulation show that, for a naturally ventilated DSF cavity, the air temperature difference between ambient and inside the cavity would reach up to 5 °C. This had been estimated for DSF cavity at a typical second floor level modelled with 800 W/m^2 solar irradiance [Manz, & Frank, 2005]. Abu Dhabi weather data shows the ambient air temperature can reach up to 45 °C. The air temperature difference between ambient and inside the DSF cavity for the study discussed in Section 7 is approximately 12 °C (see Figure 13). This air temperature difference is higher than that predicted by the model; however the solar irradiance for regions such as Abu Dhabi would reach level higher than 800 W/m^2 and that would lead to higher air temperature difference results.

Monitoring results for a DSF building in Lisbon had been discussed to show the glazed surface temperatures. This building is a multi storey commercial and office building with mechanically ventilated DSF. The DSF cavity is horizontally partitioned on every three or four storey. The monitoring results that had been discussed are for the 9th to 11th floor part of the building, which has an estimated height of 9.8 metre. The DSF gap is 0.83 metre wide, while the gap width for the building assessed in this paper varies in the range of 0.6 – 0.8 metre. The monitored results show that in a sunny day (13 Sep) at late afternoon (17:00- 18:00), the internal glazing surface (facing the internal surfaces) is 30 – 35 °C [Haase *et al,* 2009]. In this study, the predicted results for the internal glazing surface temperature (facing the office space), is 31 – 33 °C. These results are comparable however it must be noted that the predicted results are for a typical one floor (~ 3.5 metre high) and the monitored results are for 3 storeys part of the building (~ 9.8 metre high).

10 Conclusion

DSF is becoming a common architectural feature; however its performance from an energy point of view is debatable. In most of the DSF design, the cavity is naturally ventilated or in some cases, assisted with element of mechanical ventilated to minimize energy consumption.

The building analysed in this study is located in Abu Dhabi, which can be considered as a hot climate (desert/arid climate). Designing DSF in such climate needs careful considerations. Some of the predicted results from this study are comparable with those from sophisticated models and monitored results, the actual performance of the meant building will be needed to validate the predicted results. This is due to fact the building is in hot climate and DSF buildings vary in geometry and design.

It is possible to achieve comfortable internal conditions; however it is unavoidable to allow for an element of energy consumption dedicated to maintain the temperature of DSF cavity. This impacts the overall building energy consumption leading to higher running costs, and that would not rank the building very high amongst comparative energy efficient and sustainable buildings. From another point of view, acoustic comfort is an advantage for DSF buildings, in addition to visual and transparency features that can have aesthetic benefits particularly when developing iconic buildings in a region such as Abu Dhabi.

11 References

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