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How Double Skin Façade's Air-Gap Sizes Effect on Lowering Solar Heat Gain in Tropical Climate?

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Abstract: The most pleasant architectures are known as systems which are able to maintain great correlation with nature. These systems make the best out of natural potentials to maintain thermal comfort for buildings occupants. To that aim, the first step is to manage the effect of outside weather condition on building's envelope. DSF is known as architects' solution to control incoming wind speed, manage the amounts of solar heat gains and reduce noise pollution in noisy city area. DSF is able to decrease cooling loads by ventilating away the solar heat built up in the cavity. However previous researchers have suggested that the risk of overheating within (DSF) envelope is high in tropical climate. This paper would aim to evaluate the effect of DSF's air-gap size on the amount of solar heat transferred through the façade envelope. CFD tool is applied to simulate 6 different strategies. While during each strategy 60 monitor point record accurate temperature data; the results of the simulations determines rooms' temperature for each strategy. In addition analyzing the result determines that DSF air-gap size is an important factor in order to reduce solar heat gains and reduction up to 3° centigrade is possible by well designed air-gap size.

Key words: Double-skin facade · Thermal comfort · Convection and radiation heat transfer · Ventilation systems · Tropical climate · CFD modeling

INTRODUCTION

Background of Study: The most pleasant architectures are known as systems which are able to maintain great correlation with nature. These systems make the best out of natural potentials to maintain thermal comfort for buildings occupants. To that aim, the first step is to manage the effect of outside weather condition on building's envelope. DSF is known as architects' solution to control incoming wind speed, manage the amounts of solar heat gains and reduce noise pollution in noisy city area. DSF is able to decrease cooling loads by ventilating away the solar heat built up in the cavity. However previous researchers have suggested that the risk of overheating within (DSF) envelope is high in tropical climate. Modern buildings are known with their fully glazed facades. Apart from facade aesthetic, the desire to have more transparent facade and get the best out of outdoor illuminate, encourage architects to increase the window to wall ratio in modern office buildings. However, considering thermal criteria, glass is the weakest point of building envelope both in summer and winter periods. According to Chan A.L.S [1] Double Skin Facade (DSF) is a building facade with multiple skins, the skins may be air tight or ventilated. DSF is mostly known because of its thermal performance which control solar heat gain and reduce energy losses [2-4]. In addition of thermal merits, DSF is useful design solution mostly in noisy city areas. DSF can also bring natural ventilation, improve user control and comfort and at the same time save the building energy consumption [5].

Earliest DSF systems were constructed during 1903 in Germany [6]. Until recently, wide series of researches were done to improve DSF's efficiency; however these researches had been focused on facades located in European climate [7-11]. Hien, W.N. *et al*. investigated the effect of double skin facade on lowering building's cooling load in tropical climate of Singapore [12].

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Gratia E. *et al*. examined the most appropriate ways of natural ventilation in office building with double skin facade in sunny summer days of Belgium [13]. Similarly Wong P.C. *et al*. studied the efficiency of DSF to naturally ventilate high rise office building in hot and humid climate of Singapore [14]. However DSF efficiency is not explored properly in tropical climate. Therefore a wide range of theoretical and experimental researches is needed to analyze the DSF performance in the tropical climate [15]. On the other hand, DSF has a potential to increase the solar heat gains. Previous researchers [12, 15] recommended that the risk of overheating within DSF envelope is high in tropical climate. However, Wong P.C. (2006) [14] suggested some strategies in order to improve thermal comfort criteria in tropics. Due to the high expenses of cooling loads in tropical climate, solar heat gain is not a desirable parameter. In order to reduce cooling loads, present study evaluates some design strategies to decrease solar heat gains throughout DSF envelopes.

Problem Statement: Buildings consume more than 40% of the energy globally and weakest points of building construction are windows because of their high U value. DSF could be applied to improve energy efficiency and occupants' thermal comfort both in cold and hot weather conditions. However DSF performance is mostly studied in cold climate and there are a lot of literature considering DSF in European and North American countries. But its application in tropics is not studied enough yet. This paper would aim to evaluate the efficiency of DSF in lowering solar heat gains in tropical climate of Malaysia.

Objectives of the Study: This research aims to evaluate the efficiency of double skin facade layering to decrease solar heat gains. In this regard the second layer of DSF is examined through five different air-gap sizes. DSF is considered for south facing facade and natural ventilation is allowed just throughout facade cavity during all mentioned strategies.

The objectives of this research are to: Investigate the effect of DSF glazing material on lowering solar heat gain in the context of Malaysia. Investigate the effect of DSF cavity depth on lowering solar heat gain in the context of Malaysia.

In the sequel, the proposed methodology is described, firstly. The results and discussion are introduced in Section 3. Finally, conclusions are given in the last part of the paper.

MATERIALS AND METHODS

Methodology Description: This research aims to analyze the effect of DSF glazing material and DSF cavity depth on lowering solar heat gain in south facing DSF office building in tropical climate. In order to understand the effect of glazing types and air-gap depths on internal temperature of office building, the CFD (FLoVent) simulation is used. The simulation covers 6 different strategies. During each of these strategies 60 monitor points are positioned in different locations of building to record accurate temperature data. Apart from south face of the Building, three other faces designed with thermal resistant materials to minimize the effect of those faces. An internal fixedflow of 3 m/s flowed equally in all strategies. Consequently, the solar heat gains through DSF are the main effective factor on rooms' temperature.

AS the first step of simulation, the 10 stories office building was designed in FloVENT. In this case the building facade was considered to have single typical glazing. The air temperature at each level of building was measured by 6 monitor points, located in different X, Y and Z positions of each floor. As the second step of simulation, the typical glazing was replaced with reflective glazing and the result of all monitor points was collected again. In the next level, the simulation had been run with an extra glazing facade. In this case the second facade had been located in 10 cm distance from first glazing. On the basis that the air gap size was remained at its fixed depth, the simulation was run again. In the next step the air gap size was increased to 0.3m and all the different glazing types were applied as the second facade layer again. The same strategies were followed for the facade with the air-gap sizes of 0.5m, 1m and 1.5m.

The FloVENT Software: FloVENT is CFD software developed by Mentor Graphic to simulate the air flow and heat transfer within rooms or buildings. FloVENT is a powerful airflow modeling analysis tool designed to determine the effect of design parameters on air behavior [16].

The Climatic Data Assumption: Input climate data of simulation considered as Malaysian weather climate of Johor Bahru during the hot summer day of June 21 at 10 am. The weather temperature is 31°C, relative Humidity is 87% and wind direction of 1 m/s is toward the south.

Table 1: The geometric and thermal data of studied building

Building properties:	Glazing properties:
Office room width: 10m	1. Typical glass
Office room depth: 10m	Conductivity: 1.05w/(mk)
Office room height: 3m	Density: 2300 kg/m3
Total numbers of floor: 10	Special heat: 836 j/(kg k)
Building height 30	2. Anti-sun glass
DSF height: 33 m	Conductivity: 1.05w/(mk)
DSF air gap size: .1m-1m	Solar absorption coefficient: .99 1/m
Wall properties:	Refractive index: 1.525
Material: UF foam	Density: 2500 kg/m3
Conductivity: .04 w/(mk)	Special heat: 750 j/(kg k)
Density: 10 kg/m3	3. Reflective glass
Special heat: 1400 j/(kgk)	Conductivity: 1.05w/(mk)
Cavity depth: .1m-1.5 m	Solar absorption coefficient: .3 m
Roof:	Refractive Index: 2.35
Material: UF foam	Density: 2500 kg/m3
Conductivity: .04 w/(mk)	Special heat: 750 j/(kgk)
Density: 10 kg/m3	4. Plexi glass
Special heat: 1400 j/(kg k)	Conductivity: .2w/(mk)
Fixed flow:	Density: 1190 kg/m3
Velocity: 3 m/s temperature: 20	Special heat: 1500 j/(kgk)

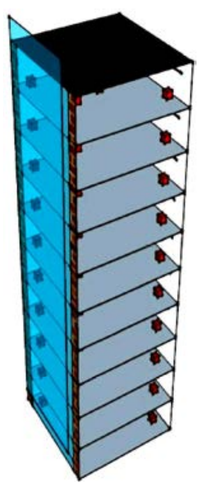

Fig. 1: Schematic design of simulated building

The Studied Building: The simulated building is a 10 stories air-conditioned office building (Figure 1). To simulate air-conditioning, the air flow of 3m/s with the temperate of 20° was flowed into the building through back wall. The geometric and thermal data of office building are described in Table 1.

RESULT AND DISCUSSION

Here, 6 different cases are simulated to examine the effect of DSF glazing materials and air-gap size on lowering the solar heat gains. Based on the result obtained from the monitor points, it can be concluded that:

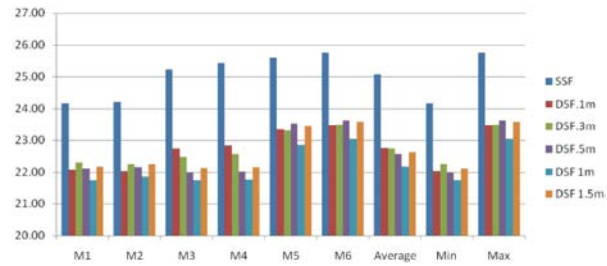

Fig. 2: Temperature of all monitor points located in 4th floor

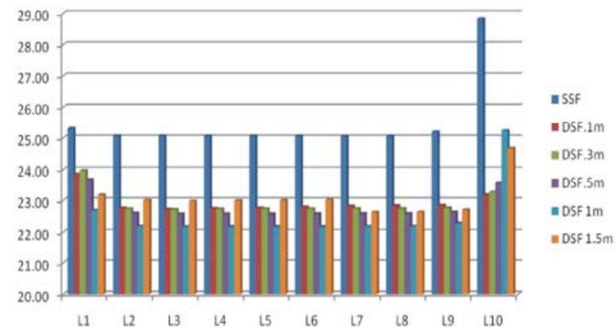

Fig. 3: Average of all monitor points for each floor

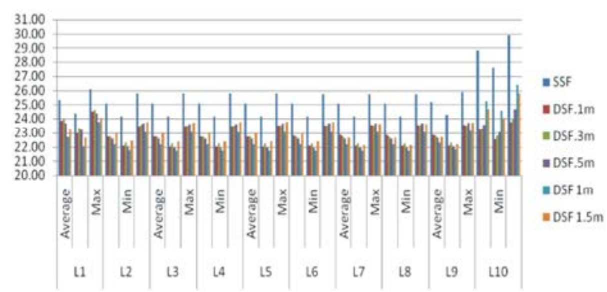

Fig. 4: Average, minimum and maximum of recorded temperature data in all floors

According to the finding of this research well designed DSF performs better than Single Skin Facade (SSF). AS an example, comparing the result taken from monitor points located in the fourth floor, the average temperature data in the case of DSF with the air gap size of 1 meter is 3° cooler than room's temperature in the case of SSF.

Analyzing the simulation result determine that the best air-gap size for the context of this study is 1m. Increasing the air-gap size up to 1 meter enhance DSF performance, however for the amount more than 1 meter the DSF efficiency in lowering solar heat gains decreased. The enhancement in DSF efficiency in first part can be interpreted as the effect of increasing the air gap-size in decreasing conduction heat transfer. Moreover the reduction in DSF efficiency for the air-gap sizes more than 1m meter could be because of reduction in stuck effect throughout DSF envelope (Figure 3).

Table 2: Average of Monitor Points for Each Floors

Strategy	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
SSF	25.31	25.07	25.07	25.07	25.07	25.06	25.05	25.06	25.20	28.83
DSF.1m	23.85	22.77	22.73	22.76	22.77	22.80	22.83	22.84	22.86	23.19
DSF.3m	23.97	22.75	22.73	22.74	22.74	22.75	22.75	22.75	22.77	23.27
DSF.5m	23.68	22.61	22.57	22.58	22.58	22.58	22.59	22.59	22.64	23.57
DSF 1m	22.69	22.19	22.18	22.18	22.18	22.18	22.18	22.19	22.28	25.24
DSF 1.5m	23.19	23.01	22.98	23.00	23.01	23.02	22.63	22.64	22.71	24.68

Independent of DSF air-gap size the highest temperature data is recorded in monitor points located in level 10 which are, followed by first floor (Table 2). The high temperature in level 10 could be related to solar absorption throughout roof. And the high temperature in level 1 could be because of DSF design preference (the second skin starting from 1m height of the building to facilitate air circulation within facade envelope).

Based on result presented in graph 5, same quantities have not been recorded in monitor points located in the one floor during one strategy. It could be related to the building's design, the heat gains mostly come from the front wall and fixed flow enter via back wall. As an example The range of difference in each room temperature is 1.5° in the case of typical SSF; 1° in the case of reflective DSF; and 2° in the case of anti-sun SSF. As it is presented in (Graph 5) In those cases which DSF strategies were applied, the room's temperature remained in a limited range of difference comparing to those cases of single skin facade. It should be because of the effect of DSF on decreasing overall thermal conduction of building facade.

CONCLUSION

Previous researches [12, 15] have suggested that the risk of overheating within DSF's envelope is high in tropical climate. Therefore, accurate planning strategies must be followed in order to reduce overheating and get more benefit out of DSF layering. This research evaluated the efficiency of different DSF glazing types and air-gap depths to minimize solar heat gains throughout glazing envelope. This research was done in a fully air-conditioning office building in tropical climate of Malaysia. Based on the data presented in Table 2 the reduction in solar heat gain is possible through optimizing glass properties and air-gap sizes. According to the finding of this research increasing the air-gap size up to one meter will reduce solar heat gains; but for the amounts more than one meter.

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