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Overall Thermal Transfer Value of Naturally Ventilated Double Skin Façade in Malaysia

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ABSTRACT

As one of the many paths to achieve a sustainable built environment, the Malaysia uniform building bye-law with the new amendment stipulates that the OTTV of a building envelope with a total air-conditioned area exceeding 4000 m2 should not exceed 50 W/m2. Although, the existing formulae provided for calculating OTTV is only applicable to a traditional single skin façade (SSF) building. Therefore, this paper seeks to investigate and evaluate how the natural ventilation in the cavity of a naturally ventilated double skin façade (NVDSF) will impact the OTTV of a building integrated with this façade typology. To achieve this goal, a hypothetical base-case was designed to represent a typical commercial building in Kuala Lumpur, Malaysia. The calculated OTTV value of the base case is compared with that of the same building integrated with naturally ventilated cavity using dynamic simulation software (EnergyPlus/DesignBuilder) tool. The result indicates that the annual heat transferred through the east orientation of the building is higher than all other orientations and by integrating a naturally ventilated cavity on all orientations would reduce the cooling load over traditional single skin building by a range between 46% and 84%. However, the cost implication of investing in buildings with this kind of façade require more exploration for a better understanding on the return of investment in Malaysia context.

Keywords:
Naturally Ventilated Double-Skin Facades (NVDSF), simulation (DesignBuilder), Overall Thermal Transfer Value (OTTV), thermal performance

1. Introduction

Building envelop performance is a function of its interaction between the internal and external environment with the envelop playing a mediatory role. The functional requirement includes the capacity to control heat flow, air and water vapour flow, control rain water movement, as well as to control the spread of fire while providing the necessary aesthetic value at the same time. However, Hutcheon and Lee and Tiong [1,2] describe other functional requirements of an efficient building envelope which include the resources consumption vis-à-vis energy consumption and possible negative environmental impact while ensuring a comfortable indoor environment. While achieving

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these, building envelop is also expected to efficiently resolve other performance issues such as thermal comfort, day-lighting, indoor air quality, fire safetyand carbon footprints.

Studies shows that in recent times, building energy consumption in Malaysia has been on an increasing trajectory as the country's economic continue to grow [3,4]. Lee and Tiong [2] documented a study conducted on building energy consumption which indicated that electricity consumption in residential sector in the year 2000 was 9,471 GWh which indicate an increase when compared to 326 GWh in the 1970s. Abdul Rahman and Keat [5] presented a statistic of increased energy demand of about 20% within three years and projected a 60% increase between 2002 to 2010 which was not achieved. Yet, energy demand continued to grow. The energy efficiency of commercial building on the other hand continue to generate increasing attention as air conditioning considered to generally accounts for about 30~50% of the total energy use. In Malaysia, air conditioners accounted about 42% of total electricity consumption for commercial building and 30% of residential building. The usage of domestic electricity in Malaysia has increased rapidly due to the enhancement in the standard of living of the household and these contribute to the overall performance of building.

Building performance is the level of services provided by its components measured against many of the parameters in relation to the expected quality stipulated on a measuring standard and overall thermal transfer value is one of such standard used to determine the performance of building envelop in Malaysia. OTTV is a measure of building energy consumption due to solar heat gain by building envelop. The measure was originally developed by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) as a thermal performance index for envelop of air-conditioned buildings. In Malaysia context however, OTTV formula has undergone reviews since the first version was launched [5] and was then a voluntary standard which has now been recently incorporated into the uniform building bye-Law (UBBL) with clause 38A under the amendment 2012 [7] which mean it is now a mandatory injunction for the building industry.

The earlier version of Malaysia standards [8] regarding OTTV stipulated that commercial building envelop having a total air-conditioned area exceeding 4000m^2 should not exceed 50 W/m^2 which was reviewed twice. First in the 2014 version of the MS 1525 and again in the final enforced version mentioned above. Upon reviewing all the available building energy code around, it can simply be stated that the smaller the OTTV the lesser the energy expended on cooling the interior space due to solar heat gain. [9] pointed out that OTTV standard and day lighting in buildings are two approaches to evaluate and control energy consumption in building. The regulation of energy end-use in residential building is important as studies show that it account for 65% of the global emission while commercial building account for 35% [10,11]. The thermal transmittance (U-value) of building envelope materials was the earlier evaluation tool but with the development of OTTV, it is considered a better performance index because the formula evaluates the impact of solar energy on all the envelop components [12]. The parameters in the Malaysia version of OTTV formula include the window-to-wall Ratio (*WWR*), Shading Coefficient (*SC*) of the window system, thermal Resistance of both the opaque (U_w) and Transparent material (U_f), the orientation factor (*OF*) as well as the absorptive property (α) of opaque material which is missing in the Hong Kong and Singapore version [6, 12, 13]. The OTTV expression is as given in the equation 1 below

$$OTTV = 15x\alpha x(1 - WWR)xU_W + 6xWWRxU_f + 194xWWRxSCxOF \quad (1)$$

As the construction industry experience transformation with the advent of technology and the availability of new materials are fast changing the industry landscape, Generally, the conclusion from the literature review conducted and presented by Gbenga *et al.* [13] to understand state-of-art on building energy standards in Malaysia indicates only few works are available on double skin facade

OTTV evaluation. In this study, the OTTV of buildings incorporated with naturally ventilated cavity is evaluated using DesignBuilder simulation tool and to achieve the goal in this study, the adopted methodology is explained in section three.

2. Literature Review

Lee *et al.*, [14] defined double skin facade (DSF) façades with a multi-layered which has external and internal layer serving as buffer to control both the ventilation and solar transmission. Study also indicates the use of multi-layered skins as external noise insulation potential [15]. DSF could provide outdoor air through openings where preheat or precool air is introduced into either the interior space for natural ventilation or the cavity to reduce solar transmission. It can integrate the mechanical ventilation with natural ventilation during the mild seasons.

There are studies over the years on DSF thermal performance which include the works documented by Baharvand et al., Shang, Saelens et al., Saelens and Hens and Manz and Frank [16-20] at different locations. In Malaysia climate context, the works of Hashemi *et al.,* [21] and Rahmani *et al.,* [22] considered DSF natural ventilation potential in Malaysia and the impact of cavity depth on the solar heat transfer through DSF system respectively. It was found that while the heat transferred through a ventilated cavity is much lesser than that of heat flow through a single skin, the impact of the ventilated cavity fades as it results to overheating in the adjacent space with increase in the cavity depth. Although, the conclusion given by Rahmani *et al.,* [22] can be considered credible yet, the calculated percentage difference between the air temperature of the single skin and the double skin cannot be taken as absolute due to the scheme of the building case simulated for the study. The ventilation in the cavity of a double skin facade creates stack effect that has the potential to reduce solar gains as the transmission though the internal skin can be reduced through the ventilated cavity. Despite the potentials of double skin facade there still exist the concern regarding the need for great care in its implementation, especially for high-rise buildings to achieve the expected results. Also, the result of the DSF typologies simulation presented by Azarbayjani [23] using DesignBuilder CFD shows its potential to lower the building heating demand even though the heating energy consumption was higher than cooling energy consumption. The reduction of energy losses and the possibility of providing a sunspace to take advantages of the solar heat gain caused the combined shaft-corridor DSF and the other two DSF alternatives to lower the heating needs more than the reference building.

The shading effects of different glazing material varies with orientation and the solar coefficients (CF) for building different orientations (North, North-East, East, South-East, South, South-West, and West) and that of different types of shading devices are given in the Malaysian Standard 1525:2014 for the evaluation of overall thermal transfer value [24]. Also, Capeluto [25] evaluated self-shaded/inclined facades and result from the study indicated that inclined facade gave a better energy saving compare to an ordinary vertical façade. Furthermore, Baharvand *et al.* [10] evaluated different building forms with different width-to-length ratio for optimum performance in Malaysia local context and the results reveals that that the circular shape with W/L ratio 1:1 is the most optimum shape in minimising total solar insolation. To justify and proof the energy efficiency of self-shaded building, [26] documented the OTTV calculation of the Malaysia energy commission building and the result from the parametric analysis shows that inclined transmitted lesser solar heat. However, the existing OTTV formulation in Malaysia would not be able to accurately predict the heat transfer through a building envelope with ventilated double skin façade or green roof because its derivation is based only on parameters of single skin and traditional roofing materials [2, 4-6, 26] although Hong Kong and other country have initiated OTTV calculation tool for both ventilated façade and green roof [27, 28]. The next section will describe the adopted methodology for the study.

2. Methodology

Several simulation tools have been adopted to study the thermal performance of DSF. Wen *et al.,* [29] adopted ANSYS software to simulate the velocity and temperature field in the DSF with different opening size. The results from the study indicate that openings between 0.3m and 0.45m provide the best choice and noted that, as the opening height varies from 0.1m to 0.6m, the air temperature in the layer decrease at first and later increase. However, Chan and Chow [27] used EnergyPlus to test the sensitivity of different in-let and out-let sizes of a ventilated double skin opening and the impact on the system overall performance. It was concluded that it has a very little significant. In another study Gan [30] predicted the convective heat transfer coefficient, thermal resistance, and thermal transmittance for a double-glazed unit using the CFD tool. It was noted that the unventilated air in the enclosed unit was driven by buoyancy- induced natural convection. Also, Baharvand *et al.,* [31] adopted the EnergyPlus and standard k-ε turbulent model in DesignBuilder software version 3.2.0.067 to examine the integration of DSF and solar chimney to enhance internal air velocity using computer simulation and in another study, the efficiency of the incorporated CFD in DesignBuilder was verified and validated [32], just as Campano [33] evaluated the accuracy of DesignBuilder natural ventilation result and was proven to be within the accuracy range.

Also, EnergyPlus has been extensively used in various building studies but unlike CFD tool, it is a whole building evaluation tool. EnergyPlus as a simulation engine has been validated under the comparative Standard Method of Test for the evaluating building energy analysis computer programs BESTEST/ASHARE STD 140.Chan and Chow and Atzeri *et al.,* [27, 28, 34] and Wang and Zhai [35] engaged EnergyPlus in their studies involving evaluating components of DSF performance. The study on thermal performance of DSF was conducted and recorded in Chan *et al.* [36] and Choi *et al.,* [37] among others, while Chan and Chow [28] employed EnergyPlus for formulating overall thermal transfer value equation for Hong Kong. The availability of additional add-ons in the EnergyPlus 8.3 version incorporated as one in DesignBulder has made the thermal simulation engine handy for both designer and researcher thus, suitable for this study.

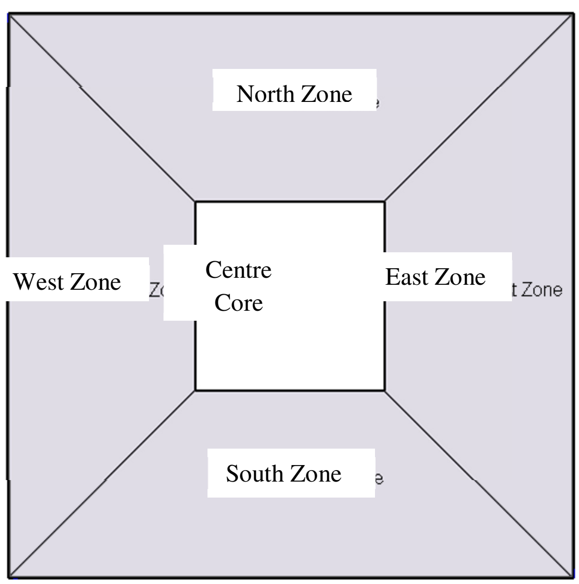

Fig. 1. Base Case Plan Building in DesignBuilder

The fact that DesignBuilder provides a user interface for the EnergyPlus with capacity to perform energy calculation (cooling and heating), daylight, carbon and cost analysis as well as provide defined boundary condition for the CFD calculation makes the tool handy for professionals other than engineers which was chosen for this study.

2.2 Building Base-Case and Model

The base-case building for this study is designed to represent commercial building type with averagely designed energy use. The building is about 5,769 square meters in five levels with the ground floor and 3.6m floor to ceiling height. It has a non-conditioned centre core area of 144m^2 thermally insulated from the indoor conditioned spaces on each floor. The building has 90% window-wall and the glazing shading coefficient for both the base case and the double skin case. The external wall is proposed to have lightweight plaster on both sides of a 100mm thick brick wall. The indoor air temperature is set to 24^{0}C and has 21 W/m^2 lighting power density installed in the conditioned area. At the second stage, the base case is incorporated with a varying ventilated cavity to compare the results of both the cooling load and calculated overall thermal transferred value. Other details regarding the base case envelope construction characteristics, indoor conditions and design data are given in the table 1 below. The weather data of Kuala Lumpur provided in the EnergyPlus data base was used for the DesignBuilder simulation.

There are many documented studies that evaluates the performance of different building simulation tools and their capabilities described in Wang and Zhai [35], Joe *et al.*, [38] Harish and Arun [39] and Attia *et al.,* [40]. The DesignBuilder was chosen however for this study due to its availability, user friendliness and availability of third-party modules. Also, this tool provides the integrated interfaces incorporated to provide tremendous complementary opportunity for building performance evaluation and provide a good accurate prediction of thermal and flow behaviours. The result and analysis of the simulation is as given in the section three below.

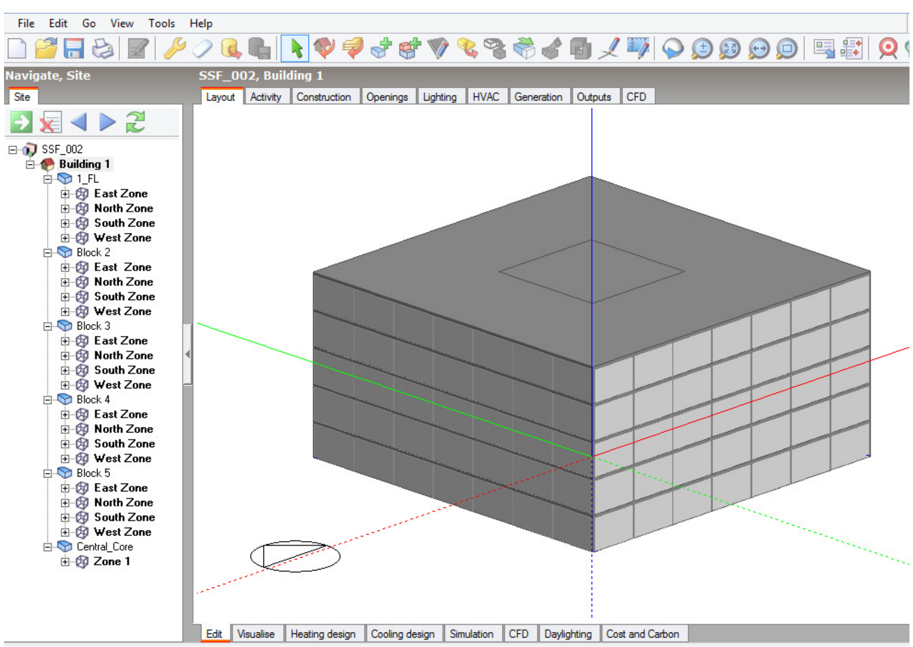

Fig. 2. Base case created in DesignBuilder

Table 1
Base-Case commercial building Specifications

Description	Solar Absorptance	Emissivity	Resistance (m2K/W)
Outer Surface	0.7	0.9	0.0299
Inside Surface	0.55	0.9	0.1198

Window:	**Parameter Ranges for Facade Variables**
Window-wall ratio = 0.4	Solar Absorptance = 0.7
Shading coefficient = 0.69	Window to wall Ratio = 90% WWR
Glass U-value = 5.79	U-Value Opaque wall = 0.346 W/m2/k
No shading devises	U-Value Glass = 5.84 W/m2/k
Lighting:	Shading Coefficient (SC_i) = 0.5
Lighting load = 21W/m^2	Shading Coefficient (SC_o) = 0.9 (for DSF)
Space Condition	Cavity Depth = (0.2, 0.4, 0.6 & 0.8) m
Outside Ventilation air = 3.3	Air Inlet and Outlet Opening = 0.3m
Infiltration when there is no fan = 1.0	
Occupancy density = 8m^2/person	
Cooling set point = 24^{0}C	

3. Results and Discussions

The performance of a double-skin façade like the traditional single skin depends on the building material properties and in DSF case, the facade configuration with respect to the cavity depth is of great added importance. The results and analysis of the simulation showed that the ventilated cavity is a major factor to determine the amount both heating and cooling load.

As mentioned earlier, five different façade configurations including the base case was simulated to evaluate the annual cooling of a representative commercial building using Kuala Lumpur weather data. The profile illustrated in figures 3 to 6 show the impact of the incorporated ventilated cavity on the base case cooling load in terms of the percentage differences on four orientations in all the cases (SSF, DSF with 200mm, 400mm, 600mm and 800mm cavities). The simulation results show that the east orientation receives more solar heat and hence recorded the highest cooling load of 418.16 W/m^2 in the base case. The north orientation however, transmitted the least solar heat with 400.32 W/m^2 cooling load – a percentage difference of 4.26%. The west orientation on the other hand gave a percentage difference of about 1.93% in cooling load when compared to the east orientation. Yet, the results of the cooling loads from building with ventilated cavities showed about fifty percent reduction in the cooling loads on all orientations. The figure 3 below show the percentage differences between the cooling loads of single façade and the ventilated double façade on all the four orientations (north, east, west and south). The east and south results are plotted on primary axis while north and west are plotted on the secondary axis to avoid overlapping of the data for visual representation. To calculate overall thermal transfer value of the building base case from the DesignBuilder simulations output, the calculated cooling load taken from the plant is related to the OTTV by expression 2 given below

$$\text{Chiller Load} = k_1 + OTTV_f \quad (2)$$

where k_1 is the coefficients that represents the internal gains from lights, occupants and equipment while OTTV amount to the thermal transmitted contribution to the building which the chiller would have to work on in terms of the cooling load. Also, the simulated output is in kilowatt hour (kWh) and are converted to watts (W) to conform with the OTTV units which is in watts per square meter (w/m^2).

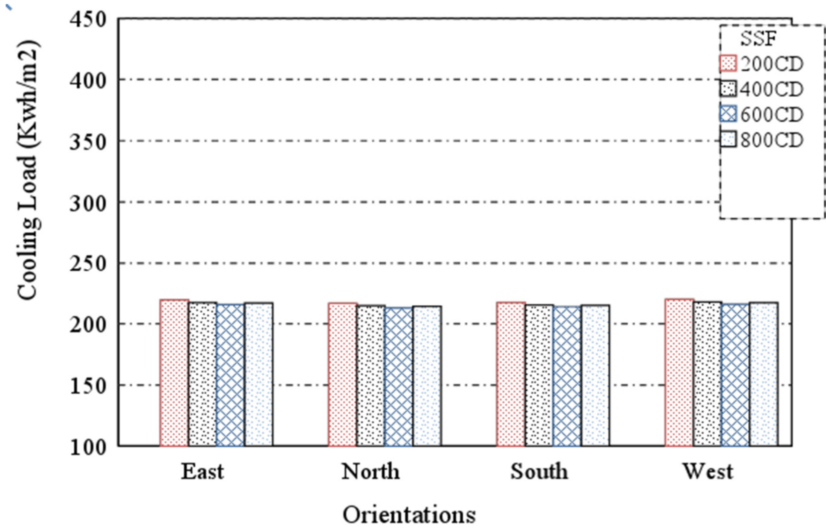

Fig. 3. Summary of annual thermal performance of various cooling load with different cavity depths

Table 2
Summary of simulated cooling load (kWh/m2) and overall thermal transfer value (W/m2) on all the four orientations (N, E, S, W)

	Cooling Load (kWh/m^2)				Overall Thermal Transferred Value (W/m^2)			
	East	**North**	**South**	**West**	**East**	**North**	**South**	**West**
SSF	418.16	400.32	406.95	410.11	150.90	133.07	139.69	142.85
200CD	219.45	216.68	217.42	219.96	106.97	104.19	104.93	107.47
400CD	217.35	214.75	215.41	217.73	106.07	103.48	104.13	106.45
600CD	215.65	213.02	213.87	216.02	105.56	102.93	103.78	105.93
800CD	216.97	214.36	215.01	217.17	108.04	105.43	106.08	108.23

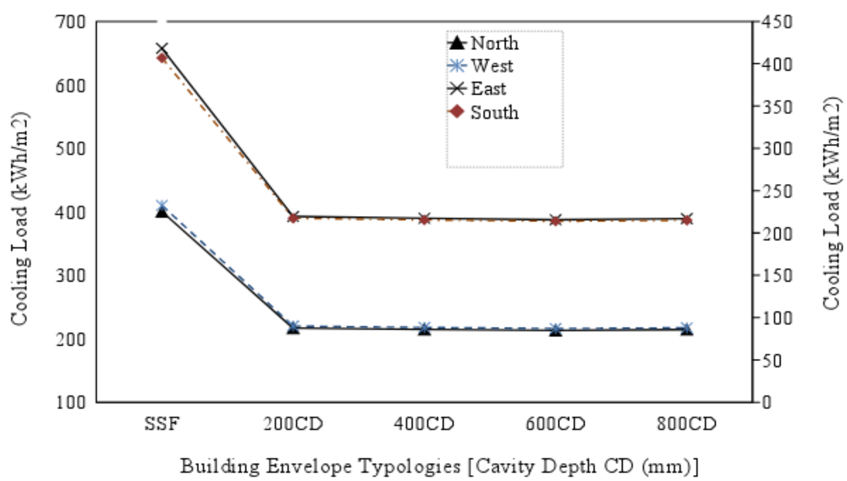

Fig.4. Percentage differences in the annual cooling load with different cavity depths

The calculated OTTV for the base case and the ventilated cavity cases is presented in the table 2 below and the data presented on the figure 5 shows the percentage difference between that of the single skin and the various double skin facades. The calculated OTTV of the base case on all the orientations shows that as indicative in the cooling load, the east orientation has the highest OTTV with a 12% difference from the north orientation which is the least value of OTTV of 133.07 W/m^2 as shown in the table 2. The south and west orientations transmitted higher solar heat than the north which resulted into a higher OTTV however much lesser than the transferred solar heat on the east orientation by a percentage difference of 8% and 6% on the south and west orientations respectively. On the impact of varying ventilated cavities on the overall thermal transfer value, the figure 5 below shows the percentage differences between the traditional single skin and ventilated double skin. The simulation results show about 46% and 48% reduction in the total however, the 600mm cavity depth gave the most efficient results on all four orientations (east, south, north, and west).

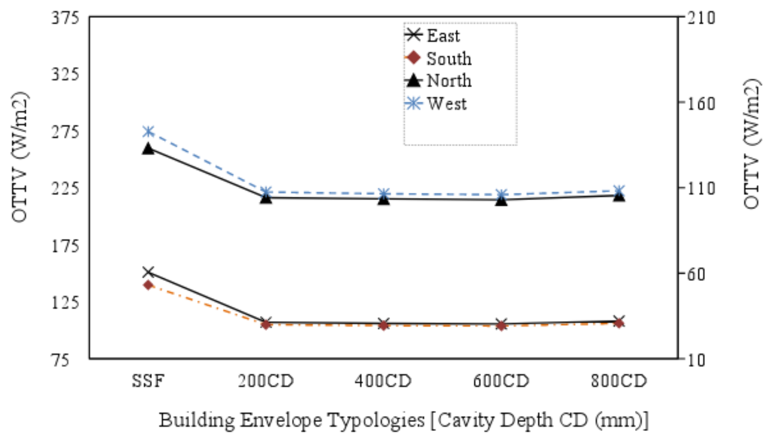

Fig. 5. Percentage differences in the overall thermal transfer value in different cavity depths and on four orientations

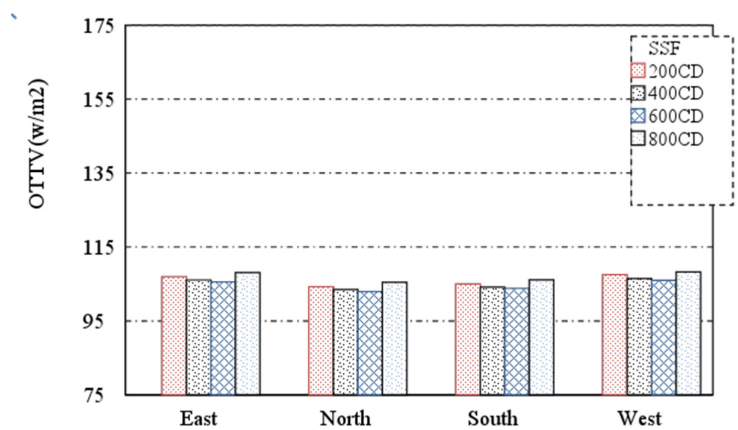

Fig. 6. Summary of annual thermal performance of various cooling load with different cavity depths

The result from the 800mm cavity depth predicted a higher overall thermal transfer value which corroborates most of the past studies that the efficiency of the ventilated cavities reduces as the cavity increases. Figure 6 on the other hand is an illustration of how the estimated thermal transfer value through the single skin varies compared to that through the simulated façade cases with ventilated cavities.

Future study should include the impact of the analysis and the effect of double skin facade on the interior spaces daylighting. Also, the environmental impact of the façade typology in the terms of co^2 emission from the building and its construction cost in Malaysia is important for future study to understand the return of such investment.

4. Conclusion

In this paper, the impact of incorporating ventilated cavity on the overall solar transmission through the envelop of building with ventilate cavity and the eventual cooling load has been evaluated. The calculated overall thermal transfer value in each of the cases shows a reasonable reduction in cooling load and the resulting thermal transfer value as discussed in section 3. However, the calculated overall thermal transfer values in each of the cases are higher than the required standard of 50 W/m^2, it can safely be stated that the stipulated standard can easily be achieved with improvement on both the façade elements, lighting features and the cooling plants system for the building construction. Therefore, incorporating a ventilated cavity is a good design strategy even in the tropical climate like Malaysia hence, provide a substantial opportunity to achieve a low energy use and sustainable building.

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