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The Impact of Double Skin facade on the Energy Consumption of Offices Buildings under the Tropical Brazilian Climate

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ABSTRACT

Double skin façade (DSF) is an attractive architectural element in modern office buildings that, while giving a transparent appearance to buildings, can potentially be able to moderate the indoor thermal conditions and reduce energy demands. Developments in warmer climate countries such as Brazil are beginning to consider the application of DSF technology as a solution to improve thermal and energy performance in their buildings. Building upon the experience of a comprehensive research programme on the study of the thermal performance of office buildings with DSF, from which key design parameters affecting the thermal behaviour of DSF have been identified and evaluated, this study aims to examine the impact on energy consumptions. Using an office building model with an optimised DSF, this study assesses the energy consumptions when the building is fully air conditioned or operated under a mixed mode ventilation strategy. Models with similar characteristics but with single skin façade are also studied for comparison. Computational models developed for this study are evaluated using the dynamic simulation program IESVE which integrates building fabric thermal behaviour and environmental systems operating under the climatic conditions of the Brazilian city Rio de Janeiro. The results indicate that natural ventilation can provide the necessary thermal comfort in over 34% of the year in the building model with DSF under mixed mode ventilation strategy, that can potentially reduce 21% of annual cooling energy when compared to the fully air conditioned model. However, energy savings due to the addition of DSF alone are relatively small - 15% in full air conditioned model and 6% in mixed mode ventilation model. The benefit to thermal energy consumption is therefore marginal. However, comprehensive whole life evaluation is needed to provide a holistic assessment when other beneficial contributors, such as lighting, smart glazing and integrated PV are taken into consideration.

Keywords: Double Skin Façade; Tropical climate; Building Energy Simulation

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1. INTRODUCTION

Increasing environmental awareness and the need to reduce the energy consumption have encouraged researchers to focus on more efficient building envelopes. In this context, there is a growing interest in double skin facade (DSF) as a potential passive system to reduce energy consumption with the attraction of its modern transparent envelope. Although benefits such as ‘energy consumption reduction’, ‘increased ventilation and thermal comfort’, and ‘visual and aesthetic quality enhancement’ are reported in the literature, there is still little knowledge and experience available about the DSF’s operation, especially during hot seasons and under hot climates (Ghaffarianhoseini et al., 2016). Moreover, majority of the existing studies have focused on the DSF cavity as an ‘isolated’ structure, which is often treated as a local feature without taking into account its thermal interaction with the user space (Barbosa and Ip, 2014).

DSF consists of an additional external skin, usually made of glass, applied external to the conventional building façade so forming an air cavity between the two layers. Although DSF was developed as an effective enhancement to traditional façades for colder climates, its application has been reported as a potential technology for reducing cooling loads in hot climates such as in China (Zhang et al., 2010), Spain (Torres et al., 2007), Singapore (Chou et al., 2009), United Arab Emirates (Radhi et al., 2013) and Malaysia (Rahmani et al., 2012). Overcoming climatic variations has instigated recent investigations of additional features such as sun protection devices, modification of façade geometry, adaptive ventilation schemes and integration of photovoltaic systems (Agathokleous and Kalogirou, 2016).

Previous comprehensive research on the thermal performance of office buildings with DSF for tropical climate conditions (Barbosa and Ip, 2014; Barbosa et al., 2015a; b, Barbosa and Ip, 2016) has investigated the influences of architectural configurations and climatic conditions on the thermal performance of buildings with DSF and predicted the annual thermal acceptance levels of optimized naturally ventilated models with DSF under Brazilian climate conditions. Building upon these outcomes, this paper extends the study to incorporating mechanical ventilation. Using a building model under the climate of Rio de Janeiro, this study investigates the impact to the energy consumptions of using full air conditioning or mixed mode ventilation when applied to the cases with or without DSF.

1.1. DSF operation and energy consumption

The DSF can be considered as a type of thermal chimney that can promote natural ventilation in the building due to solar induced thermal buoyancy and pressure variations that resulted from the effects of wind around the building. The stack effect that occurs within the DSF is driven by the temperature difference between the warmer cavity air and the outside cooler air (Gratia and De Herde, 2007a; Kim and Sohn, 2009). The difference in temperatures is not only related to the model configurations - such as glazing type and area, presence of shading devices within the cavity and its materials - but also significantly to the level of solar radiation incident on the outer layer of the DSF.

Another important parameter that contributes to the resulting air movement within a naturally ventilated building is the wind effect. When wind approaches a building, it creates a distribution of static pressures on its exterior surface, the magnitude of which depends on the wind direction, wind speed, air density and surrounding obstructions (ASHRAE, 2009).

In naturally ventilated buildings with DSF, fresh cooler outdoor air is normally drawn through openings from the opposite façade, which passes through the user space before being extracted into the DSF cavity. In air conditioned buildings, the windows are sealed. Use of DSF can reduce the cooling load by reducing the direct solar gain and buoyancy driven air movement in the cavity continuously removes the heat trapped within it (Chan et al., 2009).

Different architectural configurations have been tested to determine the reductions in energy demands of buildings with DSF, such as cavity depth (Rahmani et al., 2012), application of different materials properties on the façade layers (Chan et al. 2009, Mingotti et al., 2013), position and angle of shading devices (Gratia and De Herde, 2007b) and opening size (Chou et al., 2009). Recent review of studies on the performance of DSFs, mainly based on temperate climates, has concluded that the technology can potentially reduce the air conditioning consumption up to 50% when compared to conventional facades, as such DSF has been recognised potentially as an effective option for reducing the energy use in buildings (Sanchez et al, 2016).

2. METHODOLOGY

2.1. Models description

In this study, an optimized DSF base case model has been developed based on the outcomes of previous research on the performance of the DSF under tropical climate conditions. Its consists of an 11 storey open plan office building with dimensions of 12m x 16m and 3.5m floor-to-floor height. A fixed clear glass vertical DSF cavity was applied to the north face forming an air cavity of 1m.

The model considered the design parameters that maximize the annual acceptable comfort levels in the occupied space (Barbosa et al., 2015a) such as closure of the cavity bottom and its extension 3.5m above the roof of the building to avoid poor ventilation on the top floors. North windows, placed at the top of the walls, were sized to achieve similar flow rates across all floors levels. South windows, positioned at the bottom of the walls, were fully open. A concrete shading device was positioned within the cavity and a white masonry wall was used on the inner layer of the DSF. The longest sides, facing north/south orientations, were modelled with horizontal windows sized to achieve balanced flow rates across all floors and air buoyancy force is enhanced by concrete shading device within the cavity. The model also considered the influence of the surrounding environmental conditions on the thermal performance of the DSF of a naturally ventilated building such as orientation and predominant wind (Barbosa et al., 2015b). Building upon the base case model, four case study models have been established, which consider the use of full air conditioning or mixed mode ventilation with single skin façade (SSF) or DSF, as illustrated in Figure 1.

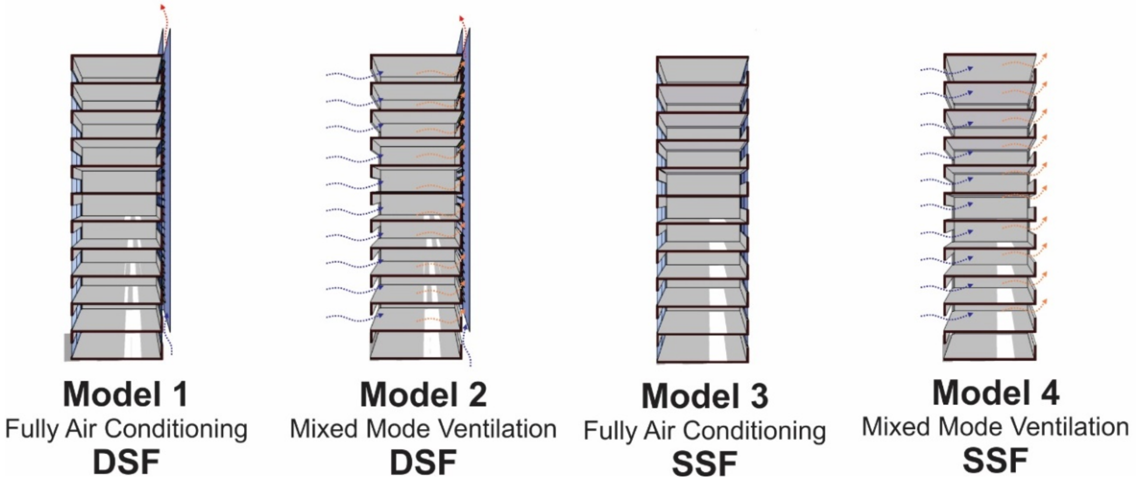

Figure 1 – Section of models used on the simulations

For the models 1 and 2 with DSF, a clear single glazing outer layer was applied to the north face forming an air cavity of 100 cm extending 3.5 m above the roof. The cases with SSF were modelled with an external concrete shading device. Table 1 shows the building model fabric material properties and the description of internal heat gains applied during the office hours for the whole year. Full internal gains were applied from 8 a.m. to 12 a.m. and from 1 p.m. to 5 p.m. and half capacity was considered for one hour during the lunch time, before and after working hours.

Table 1 - Building model fabric materials characterisation and description of internal heat gains

Building envelope	**U value**
Roof	0.18 W/m^{2}K
Ground floor	0.28 W/m^{2}K
Opaque part of façade (Thickness = 0.27m)	0.61 W/m^{2}K
Window (12mm clear single glass)	3.9 W/m^{2}K
Double skin	
Clear single glass (shading factor = 0.87)	5.04 W/m^{2}K
Shading device (Absorptance = 0.14)	
Use of the building	**Total gain**
Internal heat gains (People + Equipment + Lighting)	36.9 W/m^2

Inter-program comparison technique was used in this study as a viable means to validate the physical phenomena involved in the dynamic thermal behaviour of the DSF. Simulation models with similar geometry and fabric materials as well as internal heat gains and external boundary conditions, within the range of the operating parameters, were created and applied to another proprietary industry accepted CFD software Flovent (Mentor, 2014). Results of a series of 'snapshot' steady state quantitative outcomes and airflow profiles across the floors of the base case model were generated and compared to those obtained from the IESVE software, which showed close agreements. In the absence of a fully validated dynamic CFD simulation tool for a whole building, these consistent quasi-dynamic results were deemed to provide adequate evidence of confidence for the purpose of this preliminary study.

2.2. Modelling process and simulation analysis

The building's dynamic behaviour in conjunction with the prescribed ventilation strategies were simulated using the integrated simulation software IESVE (2016). The tropical climate of Rio de Janeiro city (latitude 22.9° S, longitude 43° W) was selected for this study. The climate diagnosis through the psychometric analysis (Schuch and Ono, 2010) indicated that the city was uncomfortable for 64% of the year, mainly due to the occurrence of high temperatures and relative humidity with annual averages of 27°C and 80%, respectively. In terms of wind speed, the city experiences lower than 4m/s for 81% of the year.

Both DSF and SSF have been considered to highlight the benefits and constraints of the application of the second facade layer on the building. Fan coil air conditioning system has been implemented during the working hours. When air conditioning is used, the windows are fully closed and no natural ventilation is allowed. Mixed mode ventilation with operation strategy based on comfort criteria has also been studied.

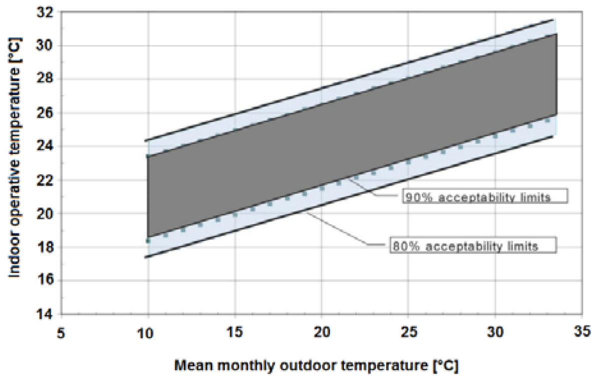

Figure 2 – *Acceptable operative temperature ranges for naturally ventilated spaces from ASHRAE 55 (2013)*

The graph of thermal acceptability in Figure 2 (ASHRAE 55 2013) shows the concept of the adaptive approach in which there are variations in acceptable indoor comfortable (operative) temperatures under different mean outdoor temperatures and acceptable limits. Thus, people in warm climate zones tend to tolerate higher indoor temperatures than people living in cold climate zones. Considering the range of outdoor temperatures in Rio de Janeiro, 27°C was defined as the maximum temperature allowed within the offices during the working hours.

For the mixed model ventilation cases, the windows were set to open when the room temperature is lower than 27°C and the outside air temperature is at least 2°C below the room air temperature.

The results are used to evaluate the impact of the application of the second layer on the building facade on the cooling energy demand. Moreover, it compares the energy consumption of a full air conditioning model with mixed mode ventilation option.

3. RESULTS

Figure 3 shows the sum of the cooling plant sensible loads for all rooms in the building over the months of the year during the working hours of cases 1 (fully air conditioning model with DSF) and 2 (mixed mode ventilation model with DSF), respectively. For the building with DSF, the mixed mode case consumes 21% less energy than the fully air conditioned case. This difference is up to 49% during the winter months, which indicates the potential of natural ventilation in meeting the thermal comfort.

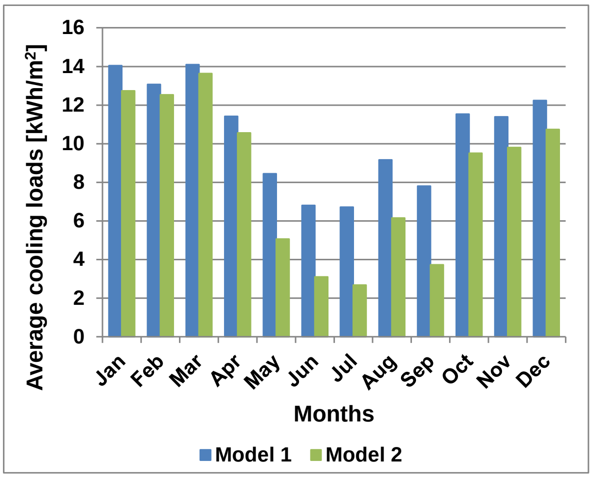

Figure 3 – Comparison of cooling loads of DSF models 1 (Fully air conditioned) and 2 (Mixed mode ventilation)

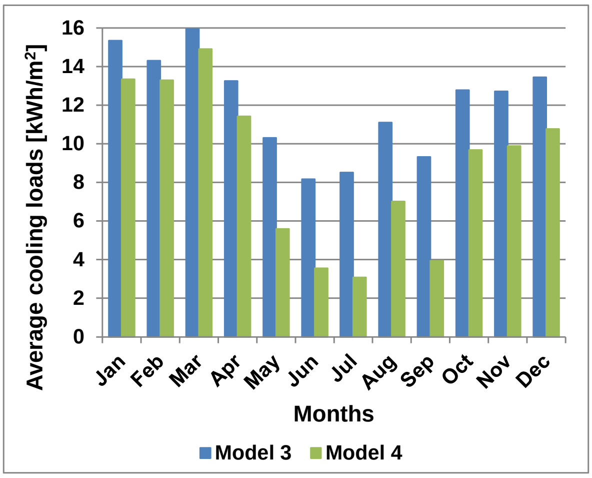

Figure 4 – Comparison of cooling loads of SSF models 3 (fully air conditioning) and 4 (Mixed mode ventilation)

Comparing the cooling loads of cases without the double skins, the results show that the mixed mode case consumes 27% less energy than the fully air conditioned case, as shown in Figure 4. The results illustrate that thermal acceptance can be achieved for significant part of the year without requirements of air conditioning under this climate condition. Such strategy gains energy and environmental benefits, resulting in improved indoor air quality, reduction in operational costs and higher occupant satisfaction.

For the models with full air conditioning, the case with DSF consumes 15% less energy than the case with SSF. This can be explained by the reduced solar gains as the double skin provides an additional filtration to solar heat gains. The moderation of temperature difference between the cavity and the room can also contribute to the lower energy consumption. For mixed mode ventilation models that allow natural ventilation, the results showed that the energy consumption for the building with DSF is on average only 6% lower than the SSF case. The building thermal performance is therefore not substantially enhanced with the application of the second skin, which can be partly due the overheating promoted by the DSF, especially during the hot days. Furthermore, the radiation emitted by the heated shading device can increase the heat gains into the building especially when windows are open.

Air conditioning is not required in about 34% of the working hours in a building with DSF adopting mixed mode ventilation. However, it increases to 41% in the model with SSF (Figure 5). Although the DSF works as a thermal chimney promoting air movement under low wind speeds, the solution was unable to significantly improve the building's thermal performance. Therefore, if the building thermal performance only is considered, the conventional less costly and simpler single skin façade (SSF) is more appropriate to be implemented in this tropical climate.

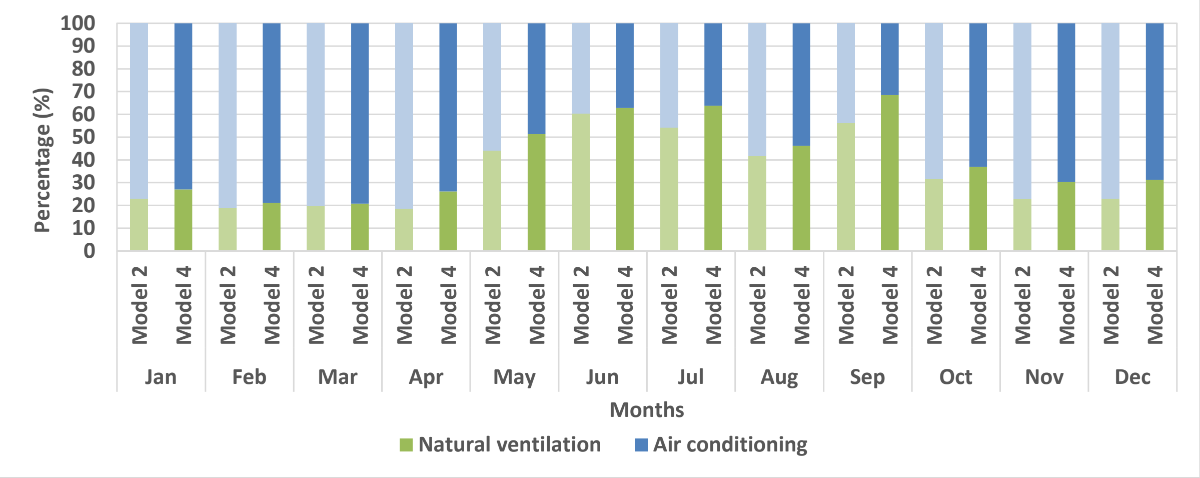

Figure 5 – Percentage of time with mechanical and natural ventilation for models 2 and 4

4. CONCLUSION

This study examines the energy consumption of a building with or without an optimized DSF under tropical climate. The models are tested under fully air conditioned and mixed mode ventilation strategies. The results indicate that for the building with DSF, indoor comfort conditions can be met by using naturally ventilation in nearly 34% of the time in the year. Conceptually there is potential energy saving opportunity which should be considered before committing to full air conditioning. Energy savings of 21% can be achieved in mixed mode ventilation systems when compared to fully air conditioning buildings with DSF. However, when considering models with and without DSF, the energy savings are small – 15% in fully air conditioned model and 6% in mixed mode ventilation model. Prior to adopting DSF, simpler and less costly options such as shading devices, strategic openings and fabric materials should therefore be considered.

Within the constraint of necessary assumptions, simplifications and limitations of simulation tools currently available, results of this research have demonstrated that thermal acceptability in a naturally ventilated building with DSFs under Brazilian climates is similar to its single skin counterpart; the benefits of the thermal performance alone can therefore not sufficiently justify such an expensive design feature. However, application of DSF is still at its infancy and, with the advances in technologies, its full potentials are yet to be explored. With the likely increasing use of glazed façades in office buildings in Brazil, there is a clear necessity to develop guidelines and performance data related to DSF and to develop detailed methodology for its evaluation. Comprehensive whole life evaluation is recommended to provide a holistic assessment when other beneficial contributors such as lighting, smart glazing and integrated PV are taken into consideration.

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