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Predicted thermal acceptance in naturally ventilated office buildings with double skin façades under Brazilian climates

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ABSTRACT

This study has predicted the annual thermal acceptance levels in naturally ventilated office buildings with double skin façade (DSF) under different Brazilian regional climates. It builds upon the outcomes of a comprehensive research programme on the study of generic thermal performance of naturally ventilated office buildings with DSF, which has identified and evaluated the key design parameters affecting the thermal behaviour of DSF through computational simulation models. Taking into account Brazil's bioclimatic zones characteristics, including the solar incidence and wind conditions, design configurations are adapted, optimized and embedded within computational models for analysis. Thermal acceptance levels of each region, using operative temperatures as the thermal comfort index, are illustrated. The highest levels of thermal acceptance, as high as 90%, are experienced in the south and southeast regions. Around 65% can be achieved in regions of centre-west, north-west and coastal areas, but only 20% in the arid region of the north-east. Significance of these thermal acceptance levels is discussed and comparisons to single skin façade (SSF) models highlight the benefits and constraints of the application of the DSF. The methodology and the results developed from this study enable initial assessment of application of DSF in naturally ventilated buildings under warm and hot climates.

1. Introduction

The double skin façade (DSF) is an architectural element that has gained recognition as a potential solution for reducing air conditioning loads of highly glazed office buildings. It consists of an additional fully glazed external skin installed over the conventional building façade, forming a normally ventilated air cavity between the layers [20]. The technology was originally developed for low energy buildings in European and other localities with moderate climates in order to enable the reduction of winter heating loads [23]. However, the early design often resulted in summer overheating that instigated research and development of remedial features such as sun protection devices, modification of façade geometry and cavity ventilation schemes in order to achieve effective thermal performance even during the hot summer periods [14,17]. The demonstrated ability of the DSF to reduce cooling loads has motivated its recent adoption by designers in many cities located in warm and even hot climates as showcases of iconic corporate buildings associated with sustainability. These impetuses triggered a number of studies on viability and implementation of DSF in countries with warmer climates such as in China [26], Spain [25] and Singapore [10]. Most of these studies are based on building models that are fully air-conditioned without considering further exploitation of the technology to enhance the energy performance through incorporation of natural ventilation to operate under a mixed mode ventilation strategy [6].

Although there is a growing interest to take advantage of the environmental and energy benefits of natural ventilation in buildings with DSF, the lack of performance prediction has been considered as a key barrier for its implementation especially in utilising the climate driven functionalities [12]. To fill this gap of knowledge, and in particular addressing the growing building and economic developments in warm and tropical climate countries such as Brazil, a comprehensive research programme that investigated the influences of generic architectural configurations and climatic conditions on the thermal performance of naturally ventilated buildings with DSF has been developed [6,7,8]). The findings from these studies enabled this current and more detailed study on predicting the levels of annual thermal acceptance in naturally ventilated office buildings with DSF in different regions of Brazil. The paper introduces the concept of DSF and provides the background on previous studies and relevant outcomes accomplished that underpin the methodology developed in the current study. The characteristics of regionals climates are classified and applied to simulations models which are individually optimized

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and adapted to the specific climatic conditions showing the predicted annual thermal acceptance levels. The findings support designers to assess the potential of DSF at the early stage of design.

2. Double skin façade in naturally ventilated buildings

The DSF can be regarded as a type of chimney attached to a building that can promote the natural ventilation using solar induced thermal buoyancy force and air pressure resulted from the effects of wind acting on the building surfaces. Thermal stack and wind effects seldom act in isolation so the magnitude and pattern of natural air movement through the building depends on the strength and direction of these combined natural driving forces and the resistances of the flow paths [11].

Fundamentally, with reference to Fig. 1, part of the shortwave solar radiations incident on the DSF is absorbed by the materials of the inner and outer layers of the façade. A portion of this radiation is converted into heat energy and stored in the materials, thereby raises its temperature. Part of this heat energy is subsequently transferred to the air in the cavity by convection and long wave radiations. The air in the cavity becomes then hotter and lighter than its surrounding environment resulting in air movement towards the top of the façade [21].

In naturally ventilated buildings air from the user room displaces the cavity air while fresh air from outdoor is drawn through openings on the opposite façade, which passes through the user space before being extracted into the cavity. The air in the cavity is further heated by the solar gains forming a continuous convection stream, as illustrated in Fig. 1 [13,22].

The airflow in such thermal chimney can be quantified by the following empirical equation (ASHRAE, 2009):

$$Q = C_D A \sqrt{2g\Delta H_{NPL}(t_i - t_o)/t_i} \qquad (1)$$

where Q=air flow rate, m3/s; A=area of the opening, m2; CD=discharge coefficient of the opening; g=acceleration due to gravity, m/s2; ΔHNPL=vertical distance from the neutral pressure line (NPL) to the aperture, m; ti=air temperature in cavity (higher temperature), K; to=outdoor temperature (lower temperature), K. This equation shows that in buildings with DSF, the key variables determining the thermal airflow through a building are the cavity height and cross-sectional area, the position and area of the window's openings and the temperature difference between the air inside the cavity and the external air. Secondary and interacting factors such as the building compartmentation, the thermal properties of building fabric and glazing, and the internal heat gains may affect how the heat is exchanged and the consequent path of airflow in the building.

Another important parameter that contributes to the resulting air movement within the building is the wind effect that varies according to the external surface pressures acting across the building envelope [5]. The airflows in the cavity reach their minimum when the wind direction is parallel to the façade but they increase when perpendicular, especially if the DSF is located at the leeward side of the building, which reinforces the cavity's stack effect [16,19]. As weather files are often based on data measured from open spaces, it is important to consider that temperatures may vary in urban central areas, which tend to experience higher temperatures due to the nature of materials usually applied to buildings and roads. It is also important to note that the local wind speed and direction may be affected by the density and height of constructions or topography surrounding the building (e.g. open country or city centre). Slower speeds will in reality occur relative to the quoted meteorological wind speed in dense terrains. The wind can be redirected by obstacles such as topography or large vertical constructions which can have significant effect on the wind speed profile. Additionally, street canyons may modify wind magnitude and direction and therefore, wind pressure coefficients experienced in different building faces can either pronounce or decrease the airflow through the building (Figs. 2 and 3).

The key drawback of DSFs is their high investment, the design and installation costs had been reported to be as much as 60–80% higher than conventional façades [3]. Additionally, cleaning, operation, inspection, servicing and maintenance costs also contribute to higher costs relative to the single skin facades, however, some studies have demonstrated their potential cost efficiency over a longer period of time with higher level of durability [15].

3. Previous and current studies

This study builds upon the outcomes of a comprehensive research programme on the prediction of the thermal performance of naturally ventilated buildings with DSF. Their relevance to this study can be described under 4 stages.

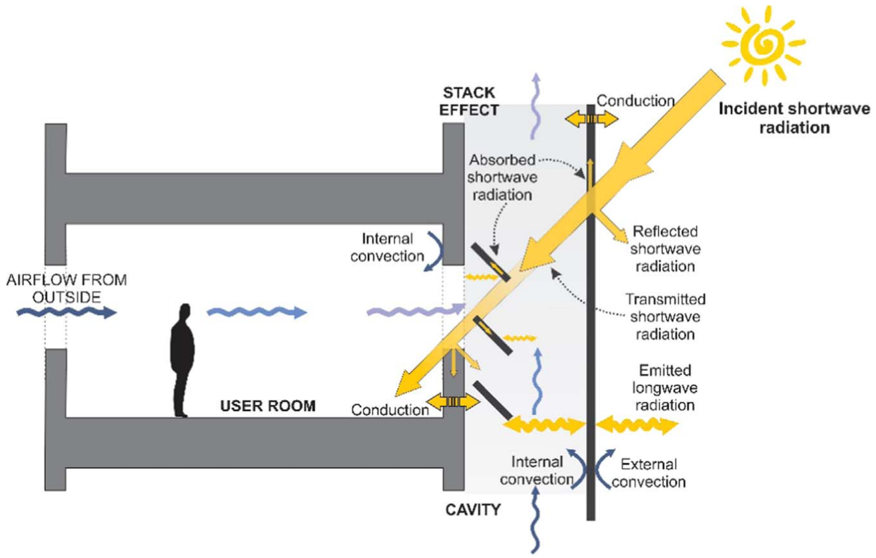

Fig. 1. Heat transfer and airflows in the DSF and the adjacent office.