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The effect of window opening ventilation control on residential building energy consumption

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ABSTRACT

Occupant behavior in terms of the operation of natural ventilation is a significant parameter that affects the thermal performance of residential buildings. The objective of this study was to evaluate the influence of the occupant behavior regarding the window opening ventilation control and the building thermal mass on the energy consumption related to HVAC system in residential buildings in Brazil. The focus of the study was on analysing different natural ventilation operation scenarios: morning to night ventilation, automated ventilation control, and night ventilation. The combined use of a HVAC system and natural ventilation was applied using an Energy Management System that enables advanced controls during simulation in the EnergyPlus program. The results indicate that buildings with medium thermal capacity have a greater potential to provide thermal comfort for users, since using an appropriate building ventilation control. Also, appropriate building ventilation achieved through automated ventilation control combined with medium thermal inertia provided a reduction in the energy consumption for HVAC system.

1. Introduction

In recent years, many countries have developed regulations based on the energy efficiency of buildings to achieve a reduction in the energy consumption, such as Portugal [1], Brazil [2] and Australia [3]. Building energy consumption is dependent on environmental requirements aimed at providing appropriate comfort for users. Most of residential regulations take into account the energy consumption related to heating, cooling, ventilation, lighting and water heating to determine the building efficiency level. According to Olesen [4], energy savings should not affect people's comfort and health.

Buildings energy consumption can be reduced by taking into account passive strategies. In countries with tropical climates, the natural ventilation strategy can contribute to reduce the energy consumption associated with the artificial cooling of buildings. Natural ventilation in buildings presents important functions, such as ensuring air quality and providing thermal comfort to the users when the external climate conditions are favorable.

The thermal and energy performance of residential buildings is influenced by several factors including the architectural features, thermophysical properties of materials, orientation, equipment installed, lighting systems, ventilation, HVAC system, shading devices and external weather conditions [5–7]. Besides all of these factors, the influence of the occupant behavior on the thermal and energy performance of buildings also needs to be considered. The occupant behavior has a potential impact on the building performance through interactions with lighting systems, ventilation, HVAC system, window openings and window shading devices. The user interactions with window operation are important to achieve acceptable thermal comfort conditions for those buildings where passive strategies, such as natural ventilation, have been considered [8].

The need for thermal comfort in buildings is the predominant factor which motivates users to interact with ventilation devices present in buildings which operate in hybrid ways (mixed-mode ventilation) [8]. The user interactions are related to psychological factors (age, gender, health); social factors (number of residents); availability of resources (money, knowledge and lifestyle); characteristics of the house (openings, ventilation, HVAC system); and climate (temperature, humidity, radiation) [5]. Environmental variables are parameters that influence the decision making of users in relation to the building operation.

Researchers have investigated the influence of occupant behavior on the building performance by assessing the interaction of users to control systems in the building: environmental condition-

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ing (air conditioning system and natural ventilation), lighting and shading devices. Most studies present a common characteristic: a relation between the user actions and the environmental parameters measured inside (air temperature, humidity and illuminance) or outside the building [9–11].

The action of window opening is the most spontaneous and simple technique applied to control environmental overheating. However, this action requires user interaction in the application of a passive strategy to provide comfortable environments [12]. An understanding of occupant behavior is essential for the design and performance evaluation of naturally ventilated buildings.

Andersen et al. [13] studied some information concerning occupant behavior in the operation of residential buildings in Denmark. The authors concluded that the occupant behavior of opening the window is related to the external temperature. In addition, it was observed that building construction characteristics influenced the window-opening action.

Fabi et al. [14] developed a method to analyze the influence of occupant behavior in relation to the opening of windows on the energy consumption of residential buildings. The occupant behavior was based on statistics and probability algorithms obtained from a study of 15 residences in Copenhagen [13]. The method identified a diversity of occupant behaviors regarding window control, improving the performance of the building. Moghadam et al. [15] investigated two scenarios to also analyze the influence of occupant behavior in relation to the opening of windows on the energy consumption of residential buildings: “active” and “passive”. The results have shown the importance of occupant’s interactions with building control systems on the building energy consumption.

A study developed by Hoes et al. [16] showed that occupant behavior has less influence in buildings with low thermal capacity and a large open area, for those located in a temperate climate. However, it was noted that occupant behavior affects the thermal and energy performance of buildings which have components with high thermal capacity and small openings. Hoes and Hensen [17] evaluated the potential to reduce building energy consumption, but preserving the comfort conditions by applying a hybrid adaptable thermal energy storage on building materials. The results indicate that it is possible to reduce the heating energy consumption by using a hybrid adaptable thermal energy storage in building materials instead of a construction with low and high thermal capacity. Also, the use of a hybrid adaptable thermal energy storage in building materials improves the building comfort conditions when compared to a construction with low thermal capacity. The maximum potential was observed for those building with an intermittently pattern of use.

Several studies have been developed considering models for the windows based on the relation between the external and internal temperatures of the environment [9,10,12,18–22]. Some studies assumed stochastic methods to predict the user presence and behavior through Markov and Monte Carlo method [12,22–24]. These studies present different solutions to estimate the user interaction in relation to window opening. It was observed that it is not appropriate to generalize regarding the occupant behavior, especially for different climates.

Many studies have shown that occupant behavior can have an impact on building energy consumption [25–29]. Factors that may influence the building energy consumption are family composition, age, habits, customs, lifestyle, health and safety of users; and thermal, visual and acoustic comfort.

Jiang et al. [30] analyzed the energy consumption of an artificial air conditioned building with 25 apartments located in Beijing. The envelope of all apartments had the same thermal properties. The results for the energy consumption ranged from no consumption to 14 kWh/m^2, with an average of 2.3 kWh/m^2, the difference being due to occupant behavior.

In Brazil, most residential buildings are naturally ventilated. Brazil’s territory comprises a very wide climatic variation that follows the opposite of the northern hemisphere. Most regions in Brazil have mild winters and hot summers, including an abundant wind velocity. The use of natural ventilation during the day helps users to achieve thermal comfort without the need of mechanical cooling. Brazilian people have a cultural habit of opening the windows during the daytime and to use artificial conditioning at night. Unfortunately, Brazil does not have any official standard regarding Indoor Air Quality.

Another feature of Brazilian buildings is the thermal inertia of the components. The Brazilian standards [31,32] recommend a minimal thermal capacity of 130 kJ/m^2 K. Thermal inertia is an important strategy for providing passive thermal comfort in naturally ventilated buildings in climates with a large temperature range, and the result of the effect will depend on the occupant behavior [33]. In warm seasons, users can explore the use of ventilation during periods when the outdoor temperature is lower than the internal temperature of the building. The choice of thermal properties for the building components should be made considering the occupation and user’s behavior. Moreover, the presence of air conditioners in Brazilian residential buildings has been increasing in recent years. According to the Brazilian Association of Refrigeration, Air Conditioning, Ventilation and Heating (ABRAVA), air conditioner sales increased by 33.5% for split-type and 15% for window-type during the period of 2012 to 2013. A total of 4.3 million of air conditioners were sold for the residential sector in 2013. The large number of air conditioners being sold for residential buildings is due to a combination of factors: easy access to credit; reduction in the cost of air conditionings and raised standards of living for social classes in Brazil resulting in increased purchasing power [34].

In Brazil, people have a cultural habit of allowing natural ventilation through windows for the whole day, without any criteria. This concern significantly impacts on the building energy consumption when the building is artificially conditioned. In this context, the objective of this study is to evaluate different scenarios of occupant behavior in relation to natural ventilation and the thermal mass on the energy consumption associated with air conditioning system in a residential single-family building, located in a subtropical climate. The study focused on analysing different operating scenarios of natural ventilation. It is important to mention that the ventilation cooling strategies used in this paper is to cool the building. While the results from this study are encouraging important observations are worth highlighting to improve significant opportunities to reduce energy consumption in residential buildings.

The paper is divided into 5 sections. Section 2 describes the methodology used in the simulations, the different occupant behavior scenarios and the outputs analyzed. The results are presented in Section 3, followed by the discussion in Section 4. The conclusions are presented in Section 5.

2. Methodology

2.1. Typology

In Brazil, approximately 88.6% of households are single-family residences [35] and 54.3% of Brazilian residential buildings have an average constructed area of approximately 75 m^2 [36]. For this study, a real single-family residence with an area of 63 m^2 was considered. The residence has two bedrooms, living room, kitchen and bathroom [37]. The dimensions of the residence are 7.0 m × 9.0 m × 2.8 m. The volumetric 3D model is shown in Fig. 1(a) and the floor plan can be observed in Fig. 1(b). The building was modeled using the EnergyPlus program, version 8.1 [38].