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Evaluation of strategies that improve the thermal comfort and energy saving of a classroom of an institutional building in a tropical climate

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ABSTRACT

The unsatisfactory thermal performance of buildings belonging to higher-education institutions in Brazil causes discomfort in classrooms and affects student performance. It is thus necessary to use mechanical systems that cool environments (e.g., air conditioners) to reduce the indoor air temperature, which increases the energy expenditure of the building by about 50%. This study analyses thermal comfort at the School of Civil and Environmental Engineering, Federal University of Goiás, by making in situ measurements, recording the perceptions of users, and conducting a computer simulation to develop an energy savings plan. The methodology involves: a) analysis of the architectural design; b) field measurements of the summer air temperature and humidity within the classroom and recordings of the views of users in three different situations (i.e., the use of an evaporative cooler with open windows and doors, natural ventilation with open windows and doors, and air conditioning with closed windows and doors); c) data processing in which thermal comfort is evaluated by the indices of the predicted mean vote and operative temperature; d) comparing the collected results and the perceptions of users; and e) evaluating thermal comfort in a computer simulation. We interviewed 200 users. Approximately 69.52% of respondents were dissatisfied with natural ventilation, 60.67% with evaporative cooling, and 70.18% with air conditioning. The neutral temperature was 25.90 °C. Although results show that the situation of the evaporative cooler was the most comfortable during morning, the number of users who felt uncomfortable was high in all situations and did not meet levels recommended by ISO 7730 (2005).

1. Introduction

Thermal comfort in the classroom is essential to academic performance [1–4]. Additionally, health and wellness issues need to be addressed for the classroom because students spend a third of their day in school. Promoting wellbeing in a scholar building environment with low energy spends is a challenge in tropical areas. Buildings adapted for thermal comfort, health, and best performance in daily activities can consume less energy and ensure the wellbeing of users [5]. There are close relations between thermal comfort and a building's architectural and constructional characteristics, such as the layout, spatial dimensions (including height), window–wall ratios, external shading, and properties of the building's thermal envelope (e.g., U values of building fabrics). However, in some climates, such as tropical climates, active strategies (e.g., the use of fans, air conditioning, and evaporative coolers) are needed in some seasons. High energy consumption by equipment overloads the energy system, which is generally not sufficient to meet demands. To ensure thermal comfort in an indoor environment and, at the same time, reduce the energy demand, passive strategies and adequate envelope treatment are required.

Studies on environmental comfort and educational buildings have suggested that new buildings provide better natural lighting, thermal comfort, and indoor air quality than old buildings [6]. The first Brazilian educational buildings were rooms adapted in parishes with poor conditions of ventilation and illumination. In 1894, educational buildings began to employ natural ventilation that met the standard at that time, namely the Sanitary Code, yet they were constructed with low-cost materials and rational construction systems of low environmental quality. In 1934, another standard, the Code of Savoy, defined the need for natural ventilation via openings and natural and artificial lighting of interior spaces, as well as a standardization of building materials [7]. In 1960, schools had natural ventilation systems comprising circular asbestos tubes embedded in walls, opposite windows. In 1976, a committee of the City Council elaborated a set of norms for school development, thus establishing mandatory parameters of natural lighting and cross-ventilation. Issued in 1994, Resolution SS-493 provided lighting and ventilation standards for different environments [8].

Many measures can be adopted to improve the thermal comfort of

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new and existing buildings, but it is important to combine energy spends with building envelope characteristics. Kowaltowski et al. [9] observed that classrooms of schools in the region of Campinas, Brazil, were more comfortable during the morning period than during the afternoon period in terms of air temperature. These results were related to the materials used in the roof (i.e., there was a lack of lining and fibro-cement tiles). Labaki and Bartholomei [10] observed the effect of arboreal shading on the wrapping of a classroom in terms of internal thermal comfort. The attenuation of solar radiation by trees reduces internal heat flow, providing better conditions of thermal comfort in the school environment.

Recently, policies such as High Environmental Quality, focusing on improving the quality of building environments and minimizing negative effects on the natural environment, have been implemented in the state of São Paulo, Brazil. Additionally, Brazilian standard NBR15575 [11] established technical envelope requirements, based on a climate zone, to promote good thermal performance. Although this standard provides a classification for the thermal performance of buildings, it does not address thermal comfort. This can be explained by a lack of research on methods adapted for use on Brazil realties.

There are different measures of improving the energy performances of new and existing buildings. On the one hand, the Buildings Directive of Europe proposed a 20% reduction in carbon emissions by 2020 [12]. On the other hand, the United States Department of Energy in partnership with the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and Internal Codes Council has developed and submitted code change proposals that strive to make economic and energy-efficient improvements to current model codes. Standard 90.1–2016 [13] establishes new technical envelope requirements including mandatory requirements for envelope verification, supporting reduced infiltration, and higher requirements for the leakage of air to winding doors; new regulatory requirements for metal construction roofs and walls, fenestration, and opaque doors; improved clarity of exterior wall definitions and building orientations; improved clarity around the effective value R of air spaces; and new requirements based on the addition of a climatic zone.

To verify whether the school environment is comfortable, it is necessary to evaluate the thermal comfort according to climatic variables and to evaluate how satisfied people are with the thermal environment. The first studies on human thermal comfort focused on the safety of workers [14] and adapting educational environments from the point of view of environmental comfort to promote student performance [15]. Thermal comfort studies can be divided into two main categories according to the approach they are based on: studies using a rational thermal comfort (RTC) model, such as the predicted mean vote (PMV) model [16], and studies using an adaptive thermal comfort (ATC) model, such as the operative temperature (To) model [17–19]. Although the Fanger model was based on studies of university students within climate-controlled contexts, several studies have argued that the model cannot predict the level of thermal comfort for real classroom conditions accurately, even in the case of higher-education institutions [20]. With the introduction of the adaptive model, several studies have proposed updates and established quantitative indices that allow the individual to improve his or her comfort conditions. For example, ASHRAE 55 considers combined effects of the mean radiant temperature and airflow that increase the upper limit of temperature of the comfort zone through physiological cooling [21a]. However, in real classroom conditions, students are unable to make environmental changes to achieve the necessary conditions for comfort [21].

Several studies on thermal comfort within educational buildings in different climates were conducted, mainly using an RTC or ATC model. In India, a study carried out in a university classroom reported a neutral temperature of 29 °C for both natural ventilation and the use of fans. However, 80% of users were satisfied with the use of fans [22]. That study suggested that the ATC model performs well for natural ventilation assessment and can be used in tropics and that students can adapt to the temperature range. In a study conducted in Australia, students attending a school were exposed to different situations (i.e., natural ventilation, the use of an evaporative cooler, and the use of an air conditioner) and the observed neutral temperature was 22.58 °C, which falls below predictions of both the RTC and ATC [23]. That study suggested that the student group exposed to more diverse indoor and outdoor thermal environments had greater degrees of thermal adaptability. In northeast Brazil, it was observed that users could adapt to an air temperature up to 26 °C with a minimal air velocity of at least 0.4 m/s [24]. That study suggested that the user acceptance of higher air velocities increased to compensate for elevated temperature and humidity.

Public institutions of higher education in Brazil, having both old and new buildings, are currently looking to improve thermal comfort interior spaces for the wellbeing of students and professors. It is thus necessary to adopt mechanical systems for cooling, which will increase energy consumption. According to the Center of Management of Physical Space at the Federal University of Goiás, the incorporation of air conditioners in classrooms has raised electricity costs by about 50%. One air conditioning unit, for example, consumes about 2.4 kWh, while an evaporative cooler consumes about 0.38 kWh. Assuming that the equipment is used 8 h a day during class (for 20 days per month), the energy consumption will be 384 kWh/month while that of the evaporative cooler will be 60.8 kWh/month.

Considering the context presented, the present study analyzed the thermal comfort and thermal perception of users for three distinct ventilation systems (air conditioner, evaporative cooler, and natural ventilation), according to in situ measurements and interviews, and evaluated which ventilation strategies have your use indicated during the year to develop an energy savings plan according to three scenarios proposed. The case study chosen was a classroom, in Block B of the School of Engineering, belonging to the Federal University of Goiás.

2. Methodology

Thermal comfort, achieved by a thermal body balance, is affected by human factors (i.e., physical activities and clothing patterns) and indoor environmental parameters (i.e., air temperature, mean radiant temperature, air velocity, and relative humidity) that depend on the local climate and building envelope. The methodological procedure used in this study to predict thermal sensations was

- to describe the climate and thus clarify the local climate background and relation between users and buildings;
- to describe all elements of the building envelope in a case study;
- to take anthropometric data, clothing preferences, and activities of users as user features, considering the number of questionnaire respondents, and to evaluate thermal preferences;
- to describe equipment used to collected meteorological data;
- to calculate thermal comfort using RTC and ATC models;
- to obtain the behavior of a building during the year in three-dimensional modelling and simulation; and
- to develop an energy savings plan.

2.1. Goiânia climate

Goiânia (16° 40′ S; 49° 15′ W; 749 m) is located in the center-west region of Brazil and is the state capital closest to the federal capital Brasília (about 200 km distant). It is the second most populous capital of the midwest, surpassed only by Brasília. The city has about 1.4 million inhabitants [25] and housing density of 1782.5 inhabitants per square kilometer. The Goiânia climate is classified as high-altitude tropical [Aw, [26]]. The average temperature over the last 10 years has been 23.59 °C and the highest temperature recorded during that time was 40.1 °C, recorded in October 2015. Rainfall is 1570 mm per year and concentrated in the months of October to April. Goiânia has a well-