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Residential buildings' thermal performance and comfort for the elderly under climate changes context in the city of São Paulo, Brazil

Carolina A. Alves [a,*], Denise H.S. Duarte [a], Fábio L.T. Gonçalves [b]

[a] Faculty of Architecture and Urbanism, University of São Paulo, São Paulo, SP, Brazil
[b] Institute of Astronomy, Geophysics and Atmospheric Sciences, University of São Paulo, São Paulo, SP, Brazil

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ABSTRACT

The subject of this paper is the residential buildings' thermal performance and comfort in the city of São Paulo, taking into account the climate changes and the greater vulnerability of the elderly related to the environmental conditions. The aim is the evaluation of thermal performance and comfort in residential buildings under the RCP 8.5 scenario from the IPCC Fifth Assessment Report, as well as under the heat wave occurred in January and February 2014.

This study is based on real case studies and computer simulations carried out using EDSL TAS. Three elderly dwellings were surveyed and monitored aiming the comparison between measurements and computer simulation to calibrate the models. For the computer simulations, simulated and measured climate data were employed.

Results were analyzed comparing comfort conditions in the different climate scenarios and among the case studies, following two adaptive comfort indexes selected for this study.

Analysis revealed a tendency of change in comfort conditions following the progression of the climate scenarios, showing an increase in heat sensation and a decrease in cold sensation. The results show that the combination of both phenomena, climate change and heat wave, may lead to a potential effect of heat discomfort.

1. Introduction

The scientific community has seen changes in weather patterns in recent years. Although there is some uncertainty regarding projections of changes, most researchers accept their implications to increased emissions of greenhouse gases [1–3] resulting from human occupation on earth, especially after the 19th century, with the industrial revolution and its consequences, and evolved to the current situation. Over the period 1880–2012 the globally averaged combined land and ocean temperatures increased by 0.85 °C [4] and the warmest years are the latest ones.

Buildings are not isolated, but, generally, placed in an urban context, influenced by the urban heat island. The associated effect of urban heat island and global warming increase the near surface temperature in cities. Urban warming has serious consequences on the energy, environmental and social balance of cities [5] as well as human comfort and health.

Brazil has recently constituted the Brazilian Panel on Climate Change (PBMC), with the goal of studies compilation on the subject related to the country. According to PBMC, Brazil's climate will be warmer in the coming decades, with gradual and variable average temperature increase in all regions between 1 °C and 6 °C by 2100, compared to that recorded at the end of the 20th century [6–8].

Historically, Brazil has hydroelectricity as its main energy source. Recently, however, the participation of the thermal component is increasing [35] and, currently, issues as energy and agriculture are the main causes in the greenhouse gases' emission. The building sector electricity consumption is increasing in Brazil and worldwide, and in 2010 it was the largest consumer of electricity in the country [8].

Energy consumption in buildings occurs in every stage of its lifecycle, with the highest consumption, however, occurring during the operation phase, which is mainly due to cooling and heating [9,10]. Even though heating and cooling of residential buildings is somewhat inexpressive in Brazil, mitigation strategies should consider energy efficiency improvements in buildings, especially facing Brazilian poor people energy transition process, energy security and a gradual increase in temperatures caused by climate change in progress.

* Corresponding author.
E-mail address: carolina.alves@gmail.com (C.A. Alves).

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Adaptation is important for the purpose of keeping human life and health in Earth and even comfortable conditions for people. It is desirable that adaptation and mitigation have a complementary character; otherwise, or human comfort will be compromised, or there will be an increase in energy demand. Hence the importance of adapting buildings and its users to climatic parameters to which they are subjected and lowering energy consumption. Adaptation responds mainly by reducing or eliminating the risks of climate change impacts and gains relevance in the scenario that emerges. According to the 5th IPCC Report, the Earth will suffer an increase in the average temperatures surface from 0.9 °C to 1.7 °C in the most optimistic projection, and, from 2.6 °C to 4.8 °C in the most pessimistic until 2100 [1]. So, taking into account energy security and human comfort issues, it is important to seek means of obtaining favourable environmental conditions with the lowest possible energy use when not by passive means, with buildings prepared to operate in free-running mode or low-energy mixed-mode.

Adaptive comfort models can be successfully adopted to evaluate comfort conditions in free-running buildings. The use of an adaptive comfort model takes into account the tendency that people have to adapt to fluctuating environmental conditions [11]. Adaptation can be physiological, psychological or behavioural so, a wider range of thermal comfortable conditions and a closer relationship with the external climatic environment can be obtained. Those models apply very well to naturally ventilated buildings because they tend to encompass greater thermal fluctuations, according to external variations, likewise, the users' expectations, their adaptation and satisfaction with naturally ventilated environments are different if compared with air-conditioned environment users [12,13]. Therefore, different recommendations are proposed for air-conditioned and free-running buildings, because the thermal tolerance response has been shown to be different for building users under these two thermal conditioning alternatives. Following this approach, the user is no longer seen as passive to the surrounding environment, but as the controller of it, by the operation of simple mechanisms such as opening or closing a window, and, so, been able to increase their satisfaction.

This study lays on three residential real case studies with non-uniform typologies, internal loads, orientation, location, floor area, openings, etc., besides the urban context. Therefore, it is difficult to precisely identify the performance difference reasons. The aim was not to compare the three residential units among themselves, but, the study proposes an overview about how each one of the three examples perform under different climate condition, taking into account the climate changes in progress.

2. Adaptive thermal comfort indexes

Adaptive thermal comfort indexes propose a behavioural approach. They are based on individuals' adaptation to the environment, both physiologically, psychologically and behavioural. By incorporating the concept of variation in comfort temperature as a function of the external temperature, adaptive parameter approximates both and may entail even in energy demand reduction (in opposition to the static comfort models).

Initially, five adaptive thermal comfort indexes were considered for this study [14–16,42,17–19]. The neutral/comfort operative temperature equation of all of them is presented in Fig. 1. The graph shows the common relationship of increasing the internal neutral/comfort operative temperature as the external temperature increases. The similarity among the regressive equation presented models is evident and supports each other, in all cases it is perceived strong linear connection of indoor and outdoor temperatures in naturally ventilated buildings.

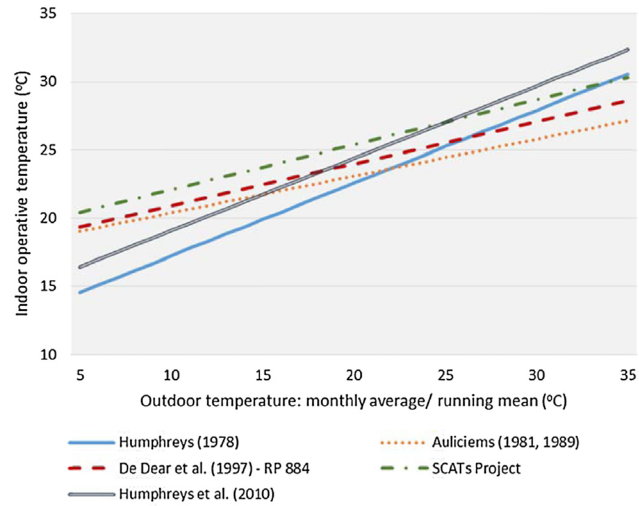

Fig. 1. Adaptive comfort model equations overlapped. Elaborated by the authors.

Among the five raised indexes, it is observed that both Humphreys team's equations present a stronger relationship between external and neutral/comfort temperatures when compared to the other indexes. The Humphreys [14] index is described by:

$$Tn = 11.9 + 0.53To \quad (1)$$

(Tn = neutral or preferred operative temperature, °C; To = Mean monthly outdoor air temperature, °C).

On the contrary, while four out of those five indexes take only free-running buildings into account, the only index considering a building sample in assorted operation systems (free-running and air-conditioned) is the one developed by Auliciems [15,16] and, therefore, it presents the lower internal/external temperatures correlation. It is defined by the following equation:

$$Tn = 17.7 + 0.27To \quad (2)$$

(Tn = neutral or preferred operative temperature, °C; To = Mean monthly outdoor air temperature, °C).

The index developed by De Dear et al. [42] was settled in the 1990s as part of the American Society of Heating and Air-Conditioning Engineers' (ASHRAE) research programme named RP-884 Adaptive Model Project. This index is defined by the equation:

$$Tn = 17.8 + 0.31To \quad (3)$$

(Tn = neutral or preferred operative temperature, °C; To = Mean monthly outdoor air temperature, °C).

The result of that work constituted the basis for the ASHRAE Standard 55 [20,21,39] adaptive comfort index, the standard's parameter for free-running buildings, with acceptable comfort ranges for 80% and 90% of satisfied people:

$$\text{80\% satisfied people condition}: (Tn - 3.5) \leq \text{Top} \leq (Tn + 3.5) \quad (4)$$

$$\text{90\% satisfied people condition}: (Tn - 2.5) \leq \text{Top} \leq (Tn + 2.5) \quad (5)$$

As well as the American Society of Heating and Air-Conditioning Engineers' (ASHRAE), the European Committee for Standardization (CEN) developed a project, based on a new database, collected specially for this project to be incorporated in a specific standard, the SCATS (Smart Controls and Thermal Comfort) Project. The project lasted one year and raised environmental offices condition data from five European countries (France, Greece, Portugal, Sweden and the UK) [17,18] (Fig. 2).