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ScienceDirect

Energy Procedia 115 (2017) 183–194

Energy Procedia

www.elsevier.com/locate/procedia

International Conference – Alternative and Renewable Energy Quest, AREQ 2017, 1-3 February 2017, Spain

Evaluation of thermal comfort and occupant satisfaction in office buildings in hot and humid climate regions by means of field surveys

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Abstract

Energy-efficient buildings of the public and commercial sector challenge significantly future infrastructure projects in Brazil. The cooling of buildings is an important contribution to the overall electricity consumption of the country and its continuous growth is motivated mainly by the rising standard of living and working. At the same time, people's requirements on comfort have increased. This paper presents how real occupants in office buildings perceive and assess the higrothermal comfort. Results of the field study are compared towards the requirements in the Brazilian (NBR 16401) and European Standards (EN 15251) in office buildings in hot and humid climate regions.

Peer-review under responsibility of the organizing committee of AREQ 2017.

*Keywords:*thermal comfort; energy comsumption; energy standards.

1. Introduction

Energy-efficient buildings and the initiation of the use of renewable energy in private and commercial sectors challenge significantly future infrastructure projects in Germany and also in Brazil. Economic expansion and regional integration in Brazil is leading to a rising demand for energy. The "Brazilian National Energy Plan 2030" predicts an

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1876-6102
Peer-review under responsibility of the organizing committee of AREQ 2017.
10.1016/j.egypro.2017.05.017

increase of 300 % on energy demand forecasts for the period 2005 to 2030 [1]. In Brazil, the building sector was responsible for more than 50.8 % of the total electrical energy consumption in 2015: residential buildings 25.1%, office buildings 17.5%, and public buildings 8.2 % [2]. Energy is used to cool, ventilate, illuminate and provide many other services in buildings. In Brazil, values of annual energy consumption of nonresidential buildings in different climate zones are hardly available. A study analyzing the energy consumption in hotels presents values between 58 $kWh_{el}/(m^2y)$ to 193 $kWh_{el}/(m^2y)$ in 2005 for cooling, ventilation and lighting [3]. In Rio de Janeiro city, the average annual energy consumption of nonresidential buildings attributed to 213 kWh_{el}/m^2 per year in 1997 [4].

In the last 10 years, the share in electricity consumption of building sector grew by 6.1 % over the decade. The energy consumption growth has expanded more rapidly than the GNP. In 2013, the electricity consumption in the commercial sector grew by 5.7 % and in the residential sector by 6.1 % whereas the GDP grew only 2.3 % [5]. Much of this growth was attributed to the maintenance of income and employment conditions, which led to the expansion of the population owning appliances related to comfort, especially air conditioning, whose retail sales last summer exceeded any expectations. Among 2008 and 2013, the sell of residential air conditioners grew up 64 % and the sell of commercial and service buildings grew up 140 %. In the built stock, decentralized air-conditioning units dominate the distribution systems (74 % split units, 14 % window room air-conditioning systems, 1 %VRF systems) and central cooling accounts with 11 % of the cooling market [6]. The majority of energy consumption (64 %) in nonresidential buildings in Brazil is used for air-conditioning and lighting [7].

The environmental comfort parameters and the thermal comfort requirements for cooling buildings in Brazil can be found in the Brazilian standard NBR 16401-2 [8], published in 2008. In contrast to the DIN EN 15251:2012-12 [9], this standard defines the acceptable thermal comfort range using operative room temperatures depending on the prevailing relative humidity of the indoor air. Based on the Predictive-Mean-Vote (PMV)-Model, the thermal comfort zone is defined to be between 22.5 °C to 25.5 °C operative temperature when relative humidity is above 65%, and 23.0 °C to 26.0 °C operative temperature when relative humidity is above 35 %. The differentiation of these two temperature ranges neither considers the prevailing ambient air temperatures, as is done in ASHRAE55 [10], DIN EN 15251, ISO7730:2006-05 [11], nor the type of cooling system employed in the building, as is used in the DIN EN 15251.

2. Objective

The study was conducted in three office buildings, one of them is located in the city of Niteroi (NAB) and the other two are in Rio de Janeiro (COPPE and CISCEA). One office building (CISCEA) is conditioned using a central system (air-cooled chillers), the others (COPPE and NAB) employ decentralized systems (split units with condensers under the roof). In all buildings, the occupants can influence the indoor environment, i.e. occupants can individually open/close windows, control the interior solar shading system, and a dress code is not observed.

The key objectives of the study are: 1) monitoring of indoor temperature and humidity in office rooms during occupancy, 2) analysis of occupant perception of and satisfaction with thermal comfort in office buildings, and 3) discussion of measure for increasing user satisfaction in office buildings in hot and semi-humid climate regions in Brazil depending on the cooling system employed. The investigation is intended to answer the following questions:

- How do occupants in office buildings perceive and rate the air temperature and the humidity?
- How satisfied are the occupants with the thermal room conditions?
- Do occupants in office buildings tolerate higher operative room temperatures with rising outdoor temperatures, if the occupant can influence the indoor environment?
- Does the user's satisfaction with thermal comfort change depending on the cooling concept? How is the comfort temperature determined for different cooling concepts, considering the relationship of room temperature, room humidity, ambient air temperature, and occupant satisfaction?
- How can cooling concepts be allocated to the defined comfort models in the standards? Should the Brazilian standard NBR 16401-2 be extended or complemented?
- Do occupants in hot and humid climate regions have an altered perception of indoor temperature and humidity and altered expectation on thermal interior comfort compared to occupants for example Central Europe with moderate ambient conditions in warmer season?