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RESEARCH ARTICLE

A simplified tool for building layout design based on thermal comfort simulations

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Abstract
Thermal comfort aspects of indoor spaces are crucial during the design stages of building layout planning. This study presents a simplified tool based on thermal comfort using predicted mean vote (PMV) index. Thermal comfort simulations were performed for 14 different possible room layouts based on window configurations. ECOTECT 12 was used to determine the PMV of these rooms for one full year, leading to 17,808 simulations. Simulations were performed for three different climatic zones in India and were validated using in-situ measurements from one of these climatic zones. For moderate climates, rooms with window openings on the south façade exhibited the best thermal comfort conditions for nights, with comfort conditions prevailing for approximately 79.25% of the time annually. For operation during the day, windows on the north façade are favored, with thermal comfort conditions prevailing for approximately 77.74% of the time annually. Similar results for day and night time operation for other two climatic zones are presented. Such an output is essential in deciding the layout of buildings on the basis of functionality of the different rooms (living room, bedroom, kitchen) corresponding to different operation times of the day.

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1. Introduction

As per ASHRAE 55 (RAA-C.E, 2013), thermal comfort is defined as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation." The human body is in the process of constant heat exchange with the environment. This heat balance of the human body governs the thermal comfort experience of individuals. As such, many variables affect human thermal comfort, and research has organized the most prominent variables into three sets (Table 1). This section provides a short description of the concepts of thermal comfort, including the predicted mean vote (PMV) scale, often used to measure thermal comfort (Rupp et al., 2015). The PMV, which was developed by Ole Fanger, is a seven-point scale ranging from −3 to +3 and is the most commonly used thermal comfort index (Fanger, 1970). PMV is the mean vote that one would expect to obtain from averaging the thermal sensation votes of a large group of people in a given environment. The PMV is a complex mathematical expression that involves activity, clothing, and four environmental parameters, namely, air temperature, mean radiant temperature, humidity levels, and air velocity. However, thermal comfort temperature ranges are specific to types of buildings and climatic conditions of the location (Toe and Kubota, 2013). On the same lines, the predicted percentage dissatisfied (PPD) gives the percentage of people who are dissatisfied with the thermal environment. When PMV is zero, PPD is at five percentage, which means that when the sensational level of cold or hot is zero, five percentage votes are for discomfort. This study utilizes PMV as the thermal comfort indicator for an optimized layout design of buildings during the design stage.

Optimum thermal comfort levels are basic requirements for any space design and research. For example, Han et al. surveyed 110 occupants in residential buildings and found that energy consumption could be reduced if thermal comfort conditions are considered (Han et al., 2007). However, a dearth of research in this field pertains to hot and humid climate locations. Furthermore, Barbosa et al. proposed design parameters that can help in evaluating and optimizing design options to maximize annual acceptable comfort levels in occupied space of up to 70% (Barbosa et al., 2015). As global interests turn toward energy efficiency in buildings in the wake of climate change, thermal comfort studies are gaining immense importance. A growing number of studies in the field of thermal comfort in tropical climates for indoor and outdoor spaces are evident with the increase in the number of published research and review articles. Deb and Ramachandraiah investigated thermal comfort conditions for indoor environments and concluded that occupants exhibited varying degrees of adaptability (Deb and Ramachandraiah, 2010). However, thermal comfort varies with different times within the day (Gupta et al., 2015). This effect is due to the thermal mass of building materials and the nighttime urban heat island (UHI) effect outdoors. An elaborate study on the effect of outdoor UHI on indoor thermal comfort in one of the test locations in this study (Chennai) is presented by Deb and Ramachandraiah (Deb and Ramachandraiah, 2011).

Indraganti (Indraganti, 2010a; Indraganti, 2010b) conducted a field experiment in naturally ventilated apartment buildings in Hyderabad. Responses from approximately 100 subjects were collected, which generated a dataset of 3962 values. In the month of May, most of the subjects were uncomfortable due to high air temperature. Thermal comfort increased in June and July as air temperature decreased. Humidity was not an important factor because the climate was hot and dry. Clothing adaptation was impeded by many socio-cultural and economic aspects. PMV was always higher than the actual sensation vote. Singh et al. (2010) conducted detailed field studies on the thermal performances of typical conventional vernacular dwellings in different bioclimatic zones in India. A survey was conducted on 150 different vernacular dwellings, and field tests with thermal sensation vote were conducted among 300 occupants. ASHRAE thermal sensation scale was used as a benchmark for the survey. The thermal performances of these vernacular dwellings were investigated for winter, pre-summer, summer-monsoon, and pre-winter months for 2008. The study attempted to determine the variation of comfort temperature in these vernacular buildings for different seasons of the year. These vernacular dwellings performed quite comfortably throughout the year except during winter months, when occupants were slightly less comfortable.

Table 1 Most prominent variables influencing thermal comfort.

No.	Set	Variables
1	Environmental	Air temperature, air movement, humidity, and radiation
2	Personal	Metabolic activity (Met value) and clothing (Clo value)
3	Contributing factors	Food and drink, acclimatization, body shape, subcutaneous fat, state of health, age, and gender

Thermal comfort in residences accounts for the well-being of the occupants and the impact on energy consumption (Yoshino et al., 2006). However, once the building is built, altering the building structure/system elements to cater to thermal comfort needs will be difficult. Retrofitting studies often investigate improvement in thermal comfort and energy savings that involve retrofitting costs (Takashi et al., 2013). Therefore, considering thermal comfort aspects of indoor spaces is crucial during the design stages of planning a building layout. Many studies propagate passive cooling strategies to improve thermal comfort in residential buildings (Taleb, 2014). An effective selection of the building layout in the early-design stage prevents more complex solutions that are often employed during the post-design stage. In general building design practice, building simulation software is employed to study the thermal comfort behavior after finalizing the space design and layout. For example, ECOTECT, EnergyPlus, and IES (Integrated Environmental Solutions) (Attia et al., 2012a, 2012b) are used to model thermal comfort and other indoor environmental variables in buildings, and they mainly focus on energy demand and consumption. However, these software are employed only once the building design is finalized. Along with this practice, only persons with expert knowledge about these simulation software can perform