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Analysis of the differences in thermal comfort between locals and tourists and genders in semi-open spaces under natural ventilation on a tropical island

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ABSTRACT

The adoption of natural ventilation is prevalent in semi-open hotel lobbies on the tropical island of Hainan, China. This paper presents the results of a thermal comfort study of such applications in ten luxury hotels in this region. Significant differences were found between the local residents and tourists in their thermal satisfaction and between the males and females in their thermal comfort. Moreover, the thermal satisfaction levels of the local residents and tourists showed significant correlations with the wind speed and air temperature considering the wind speed compensation, with regard to genders, the males' thermal comfort levels showed significant correlations with the wind speed and air temperature considering the wind speed compensation, while the females' thermal comfort levels showed significant correlations with air temperature, wind speed and the air temperature considering the wind speed compensation. And results of ordinal logistic regression show that the tourists are more sensitive to the wind speed and air temperature considering the wind speed compensation than the local residents, and the females are more sensitive to the air temperature, wind speed and air temperature considering the wind speed compensation than the males.

1. Introduction

Both human health demands and thermal comfort require sufficient amounts of fresh outdoor air [1], and natural ventilation is believed to be capable of enhancing indoor air quality through appropriate passive designs [2]. In the past few years, an effort has been made to exploit natural ventilation as much as possible in order to minimize energy consumption in buildings [3]. Many studies have shown reduced operating costs, better thermal comfort, and improved indoor air quality to be some of the advantages of the application of natural ventilation in buildings [4]. In naturally ventilated buildings, the occupants may tolerate higher temperatures than in air-conditioned buildings, and natural wind with a relatively high average velocity is more acceptable than mechanical wind in the summer [5]. Natural ventilation also solves some of the problems caused by mechanical ventilation systems, such as noise, maintenance, and energy consumption costs. It is used not only for maintaining the air quality inside a building, but also for thermal comfort, especially in hot-humid climates, and can produce important energy savings [6]. Overall, natural ventilation has the advantage of exploiting a free and abundant resource, while remaining easy to use. It improves occupant comfort by creating air movement within the building, and by cooling the building structure at night with the lowest outdoor temperatures [7]. However, significant barriers to the broad adoption of natural ventilation persist. For example, Brager identified several barriers in the U.S., including a general lack of familiarity with natural ventilation design, concerns about long-term maintenance, a lack of reliable and easy-to-use design tools, and, significantly, concerns about meeting current codes and standards for minimum ventilation rates and thermal comfort conditions [8].

Heating, ventilation, and air-conditioning systems and advanced technology are typically used to provide desirable indoor thermal environments for human occupancy [9]. Moreover, thermal comfort and indoor air quality (IAQ) have become topics of interest [10]. Human health and comfort have been perceived as the most important parameters during the evaluation of an indoor environment [11]. Although human performance depends on many things in addition to thermal comfort, reaching the best possible thermal environment improves the possibility for reach-

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ing the best performance or productivity [12]. From a physiological point of view, human thermal comfort is reached when the heat flows to and from the human body are balanced, and the skin temperature and sweat rate are within a comfortable range [13]. Proper indoor thermal conditions in buildings are important not only because the building's occupants will be comfortable, but also because the building's energy consumption and sustainability will be affected [14]. Both the thermal comfort of a building and energy savings are influenced by various factors, including the thermal physical properties of the building materials, building orientation, ventilation, building space usage, and the integration of modern and passive energy saving technologies [15].

The concept of thermal comfort is quite complex, and varies according to each subject; however, although many international standards have defined the range of comfort, opinions remain widely divided. Comfort has been defined as the state of mind that expresses satisfaction with the environment [16]. The assessment of the applicability of thermal comfort standards requires field data comprising both objective sensor data (air temperature, WBGT, relative humidity, and air speed) and subjective data (actual thermal sensations recorded at the same time as the objective data, thermal preferences, etc.) [17]. Thermal comfort has been discussed since the 1930s [18], and many models or indices to predict thermal sensation and comfort have been developed, especially for indoor conditions. The most popular of these include the Predicted Mean Vote (PMV) and Physiologically Equivalent Temperature (PET) [19]. The PMV is calculated on the basis of 4 measurable quantities (air velocity, air temperature, mean radiant temperature, and relative humidity) and 2 expected parameters (clothing and metabolic rate). The vote generated from the PMV is considered as an index value to determine the thermal sensation of the subject [20]. It seeks to assess the influence of the thermal environment using subjective judgment scales [21].

In tropical humid climate zones, ventilation is especially important to accelerate the heat exchange between a person and the environment, thus promoting an adequate temperature [22]. Buildings are a heat source, mainly in summer conditions, and the use of natural ventilation is very efficient for removing part of the thermal load of a building [23]. Therefore, natural ventilation is increasingly being seen as a sustainable solution to maintaining healthy and comfortable environmental conditions indoors [24]. Recent years have seen issues related to thermal comfort gaining more momentum in tropical countries [25]. Moreover, many studies have involved thermal comfort adaptation, based mainly on the theory of the human body adapting to its outdoor and indoor climates [26]. The definition of "thermal comfort" differs depending on behavior patterns, psychological conditions, climate, race, age, gender, and the degree of fatigue that subjects experience [27].

In southern China, it has been demonstrated that the occupants of sub-tropical climates had higher temperature tolerances, and many of them still felt comfortable with higher surrounding temperatures [28]. It has been proven that, within an environment with the same characteristics and climate, the thermal sensations and preferences differ among individuals. This preference always varies according to the place of study and its climatic conditions [29]. While the PMV index is very effective and reliable in buildings provided with HVAC systems, field studies in warm climates in naturally ventilated buildings have shown that it predicts a warmer thermal sensation than the occupants actually feel [30].

At present, China has no specific research on thermal comfort under natural ventilation conditions in tropical island regions. Since Hainan is striving to become a world-class resort island by 2020, tourists from all over the world, whose psychological expectations of thermal comfort are all quite different, will become the main subjects for the thermal comfort environments that Hainan hotels wish to provide. Therefore, it is important to carry out a study on the thermal comfort of natural ventilation for persons in Hainan hotel lobbies.

Table 1
Age and Body Mass Index (BMI) distribution of samples.

	Groups	Number of samples
Age	10–20	24
	20–30	218
	30–40	95
	40–50	41
	50–60	15
	>60	9
BMI	15–20	148
	20–25	187
	25–30	59
	30–35	8

The main purpose of this study was to determine the thermal comfort differences between local residents and tourists, and males and females, in semi-open buildings in an early summer climate on this tropical island.

2. Methods

2.1. Samples

In this article, the research objective of determining the thermal comfort of natural ventilation was aimed mainly at hotel tourists and work personnel, such as receptionists and servers, in semi-open buildings on a tropical island. Both sitting and standing personnel were selected for this investigation. The main research methods included conducting a survey questionnaire of thermal comfort, and measuring the thermal comfort parameters in the semi-open lobbies of ten luxury hotels in Sanya. The investigators conducted the field questionnaire surveys and environmental testing from May 21 to 31 in 2013. When choosing samples, the factors of gender balance and age distribution were considered, with an attempt to make these as uniform as possible, and a random sampling method was used. The sample sex ratio was essentially 1:1, with 209 males and 193 females being investigated, including 115 local residents and 287 tourists (all from different areas of China). Tables 1 and 2 show the basic information about the samples.

2.2. Test parameters and test methods

Four kinds of environmental variables related to indoor thermal comfort were tested and recorded in this field survey, including the air temperature, relative humidity, air speed, and wet bulb globe temperature (WBGT). The test instrument used was the Richter thermal comfort test system ISO7730, with a sensor designed according to the ISO7726 standard. It can monitor, record, calculate, and display various data about indoor and outdoor environments, and it is used as an environmental monitoring system for a thermal environment evaluation. The technical parameters of the test probe in the Richter thermal comfort test system are shown in Table 3.

The outdoor environmental variables included the air temperature, relative humidity, and air speed, and they were mainly tested using the portable climatic station H21-002 produced by the American company Onset. The outdoor meteorological parameters were continuously monitored throughout the day, and automatically recorded once every minute.

The outdoor mean temperature was in the 24.51 °C to 34.52 °C range, and the mean relative humidity was in the 59.9% to 94.8% range during this period of early summer on a tropical island. In the Hainan province, May and September belong to this climate zone in which the weather is warmer, but not very hot. Moreover, the hotter days in April and October and the cooler days in June through