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Adaptive thermal comfort in the main Mexican climate conditions with and without passive cooling

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ABSTRACT

The present work shows an adaptive thermal comfort modelling suitable for the main four climatic regions of Mexico, for cooling and heating seasons and for both air-conditioned and free-running buildings using passive cooling. The document has the aim of setting up an own thermal comfort criteria within the Mexican territory and thereby determining the upper limit of the indoor air temperature, for passive cooling, and the lower threshold, for active cooling. All this with the purpose of reaching the maximum of comfort with passive methods as well as minimizing the energy consumption when active cooling is on. The comfort model takes account of the main human and physical factors presented in previous surveyed studies. With this, it is found that for air-conditioned buildings the temperature set-point of the thermostat could be considerably raised and still maintaining indoor comfort. On the other hand, for free-running buildings, the sensation of discomfort could be decreased if the occupants are able to have the control of their environment by using controlling passive techniques namely natural ventilation and solar control systems.

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1. Introduction

In the recent years the subject of a proper indoor environment as well as the energy efficiency in buildings have become a very important task for architects and specialists related on construction [1–3]. The reason of that relies on the necessity of saving energy considering that a high energy consumption in buildings implies a waste of resources and thus the increase of the global warming [4].

On the other hand, proper levels of indoor environment are necessary in order to enhance the health and welfare of the occupants. The indoor environment is understood as the group of the following four parameters: thermal comfort, acoustical comfort, lighting comfort and indoor air quality (IAQ) [5]. When the high quality of one or more of these four parameters is missing, issues such as diseases, low levels of production and dissatisfaction might occur [5]. For example, high levels of indoor noise can cause headache, and a high indoor temperature might provoke health issues such as dehydration or a heat stroke [5].

Thermal comfort, understood as “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation” [6], is one of the most important characteristics when the indoor environment is estimated [5]. This comfort is even more important when the building is located at extreme-conditions zones such as northern Europe and northern Asia (cold conditions) [7,8] and tropical countries such as Cameroon, Singapore and Mexico (warm conditions) [9–11].

Thereby, for warm-to-hot conditions countries, the relationship between thermal comfort and energy consumption is given by the fact that, for achieving proper levels of indoor temperature, the use of air-conditioning (AC) systems is very wide [12]. Moreover, the AC might represent the half or more of the total energy consumption of a single air-conditioned dwelling in this kind of countries [13]. Therefore, if thermal comfort remains while not using AC, the building will be able to save energy and increase the wellness of the users.

Nevertheless, as the thermal comfort range depends of both physical and human parameters at each case study [14–18], this range has to be set up for every region or country in order to achieve both comfort and energy saving. Countries and regions such as USA (ASHRAE 55) and Europe (EN 15251) have already standards that delimit this range based on indexes such as the predicted mean vote (PMV) and the physiological equivalent temperature (PET) [19–21]. Also, other countries such as Malaysia, India, Australia, Nepal and

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Nomenclature

σ	Standard deviation of the sample [°C]
MAD	Median absolute deviation of the sample [°C]
n	Number of results of the sample [dimensionless]
x	Result of the questionnaire [°C]
$\ddot{x}$	Median of the sample [°C]
x_i	Result i of the questionnaire [°C]

Japan have studies of the thermal adaptability and perception of the people by using face-to-face surveys [22–26].

There are other countries, however, that do not have neither an own thermal comfort model nor field studies related to the thermal sensation and adaptability which help to drive the solutions of comfort and energy efficiency on the buildings. Mexico is amongst these countries, to our best of knowledge. Only an adaptive thermal comfort model has been developed proper for the city of Hermosillo, northwest Mexico (warm and dry conditions) [27,28].

Hence, this document has the objective of presenting an adaptive thermal comfort model for the four main climate regions of Mexico in cooling and heating seasons, for free-running and air-conditioned buildings. With this, it is expected to establish the criteria of thermal comfort for any season, air-conditioning status and region, therefore achieving energy savings and correct indoor environments when it is required.

2. Methodology

In order to establish a reliable thermal comfort model, both human and physical factors must be taken into account. Human factors (physiological and psychological) such as gender, age and psychological perception could be assessed by carrying out face-to-face surveys and experimental tests [29]. Physical factors such as indoor temperature, mean radiative temperature and relative humidity are measured by their correspondent gauge. With these factors, thermal comfort indexes such as the proposed by Givoni and Fanger have been developed [20,30].

In this document, the adaptive thermal comfort model for Mexico considers regular conditions of the PMV and the PPD (metabolic rate of 1.0–1.5 met, clothing of 0.5–1.5 clo, mean radiant temperature equal to indoor temperature, and wind speed at 0–6 m/s). Indoor temperature and relative humidity are considered as variables depending on the climate conditions of each survey.

2.1. Mexican climatic regions

Four great climates over the Mexican territory are identified (see Fig. 1). Arid conditions are predominant in the northern region, dry tropic in the west, temperate conditions are presented in the center and humid tropic in the southeast part. These four regions are differentiated by their average outdoor temperature and relative humidity as it can be seen in Fig. 2.

Fig. 2 shows that for arid conditions the average temperature is high in summer and the relative humidity (RH) is low (under 50%) almost all year long. The dry tropic climate presents a similar behavior as the mean temperature in arid regions (low in winter and high in summer) and a medium relative humidity (around 70%) during the year. Temperate conditions have low average temperatures (under 20 °C) and a relative humidity similar to dry conditions. Humid tropic has high mean temperatures (above 25 °C) and a high relative humidity (above 80%) during all year.

Thus, from Fig. 2 one can conclude that the four climatic regions are clearly defined: arid (high temperature in summer, low temperature in winter, low RH all year long); dry tropic (high temperature in summer, low temperature in winter, medium RH all ns are clearly defined: arid (high temperature in summer, low temperature in winter, low RH all year long); dry tropic (high temperature in summer, low temperature in winter, medium RH all year long); temperate (medium temperature all year long, low RH all year long); and humid tropic (high temperature all year long, high RH all year long).

2.2. Human factors

The human perception of thermal comfort is a subjective value that depends on the physiological and psychological status of the occupants. This status must take account of the gender, age and level of stress. Studies have found out that females, children, elderly and high stressed people are more prone to be in thermal discomfort and thus get a disease as a consequence of this [32–34].

Another important human factor that should be taken into account is the so-called long-term adaptation, understood as the ability of the human body to adapt on certain conditions of temperature and humidity over long periods of time [35]. Namely, when a person has spent a certain period on a constant climate is more capable of reaching thermal comfort than other person who has spent a shorter period. This ability also depends on such factors as the anatomy of the people and even their nutrition [36].

In this context, the adaptive thermal comfort for Mexico takes account of this long-term adaptation as there are four main climates varying in temperature and humidity. The comfort model is proposed for inhabitants of the regions that have already an adaptation to the climate. For people who is not yet adapted, active cooling and heating is proposed. Furthermore, as great part of the respondents claim that they have lived in two or more cities with different climates, hence depending on the availability of AC systems (many times with shortages according to some of them), they agree that their thermal comfort adaptability is less regarding the space conditioning and more regarding their behavior by clothing, exercising, drinking a hot/cold beverage etc.

2.3. Survey methodology

The methodology consists in a written questionnaire, where the answers drive to a vote of thermal comfort in the correspondent climate, with & without active cooling; and in winter (heating) and summer (cooling) season. Thereby, the questions were oriented to an indoor temperature that people are willing to stand under a certain outdoor temperature, with and without using AC.

The questionnaire was divided in four tables with seventeen rows and six columns each one. In each row the hour o'clock was set, starting at 7:00 h. until 23:00 h. Every hour o'clock, on the second column, the actual outdoor temperature had to be written, whereas in the third column the desired temperature of comfort according to the respondent had to be set down. The fourth, fifth and sixth columns were for the upper limit of comfort, lower limit of comfort and desirable temperature set-point, respectively.

The first table was for a winter day not using AC (heating), the second table for a winter day using a heating system. The third table is for a day in summer not using AC (cooling) and the forth one for a summer day using an AC system. The outdoor temperature was collected by the participants from the website of the Mexican Meteorological Center (SMN, initials in Spanish), where the data are hourly given for 189 meteorological stations located around the Mexican territory [37]. The indoor temperature was collected either from ambient-air thermometers previously given to the respondents (see Fig. 3) or from thermometers owned by the surveyed.

In addition, in the questionnaire it was asked the main physical characteristics of the building: materials of construction of the

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