Adaptive Thermal Comfort in Warm Dry Climate:
Economical dwellings in Mexico

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ABSTRACT: Adaptive models are based on the observation that there are some actions that people can and actually take to achieve the thermal comfort. Studies regarding to thermal comfort conditions in economical dwellings are carried out simultaneously in six cities of Mexico, corresponding to warm dry and warm humid climates. In this work, case studies of economical dwellings in Hermosillo city (Northwest Mexico), are presented and analyzed. Field surveys have been carried out to obtain information about the physical characteristics of the dwellings and their occupants, and the indoor thermal environment. Neutral temperature has been obtained from the applied survey. The high neutral temperature allows visualizing the effect of the adaptation mechanism of people to extreme climates. People comfort votes as a function of indoor air temperatures have been analyzed, evaluating separately different people characteristics, such as age, size and gender. The results show the variability of the neutral temperature and the tolerance to temperature changes, depending on the population specific characteristics. In many cases, in which the population do not have access to artificial acclimatization devices, the neutral temperature values can guide the architects for choosing the most suitable thermal strategies for buildings design.
Keywords: energy in buildings, adaptive comfort, economic dwelling, warm dry climate.

INTRODUCTION

Thermal comfort studies have been developed all around the world by many authors and some adaptive comfort models have been developed and proved specifically for warm climates, such as Auliciems and de Dear [1], Heidari and Sharples [2] and other authors [3]. Adaptive models are based on the observation of actions that people can and actually take to achieve the thermal comfort.

The necessity of fast and economic construction of housings for poor people in Mexico, causes that in any climate, housing developments are design and constructed without regional adaptation, using almost the same model for the whole country. In extreme climates like in Northwest Mexico, indoor thermal conditions are not acceptable during the most part of the year and excessive energy for air conditioning is used, which lead to high acclimatization costs.

In the context of an inter-institutional project ("Comfort and thermal energy efficiency in low-cost dwellings in Mexico: regions of warm dry and warm humid climates"), supported by Mexican federal funds, the National Housing Council and the National Council of Science and Technology, many studies regarding to thermal comfort conditions in economical dwellings are carried out simultaneously in six cities, corresponding to warm dry and warm humid climates, all around the Mexican territory. In this work, case studies of economical dwellings in Hermosillo city, Northwest Mexico, are presented and analyzed. In this city, the climate is hot dry, and although of this condition, a huge number of houses are not designed nor constructed according to the local extreme climate. Carrying out field studies, physical characteristics of the houses and the people, indoor climatic variables and asked thermal sensation from the users have been sampled. Indoor thermal variables have been measured and simultaneously a questionnaire to house inhabitants has been applied. Most of the inhabitants are habituated to the local climate.

The neutral temperature Tn has been obtained from the applied survey, considering environmental conditions and particular peoples' characteristics. The high neutral temperature values, allows visualizing the effect of the adaptation mechanism of people to extreme climates.

LOCAL CLIMATE AND SURVEYS

Climate The local climate is characterized by high solar radiation levels, clean skies the whole year and large temperature oscillations daily and seasonally. Summers are very warm, with daily temperatures between 25-30°C and 40-45°C, and relative humidity between 50 and 15%.

Summer wind is usually warm, so it does not help for passive cooling or for a better outdoor thermal comfort. Winters are mild, with minimum temperatures from 0 to 7°C and maximum temperatures between 25-30°C. Because of the extreme conditions in summer, part of the population is habituated to air conditioning. But people with lower incomes have generally no access to these devices and cannot afford their operation costs. This society sector often lives in small houses in large developments, constructed in many cases without insulation. So, indoor thermal conditions, mainly in summers, are not comfortable at all.

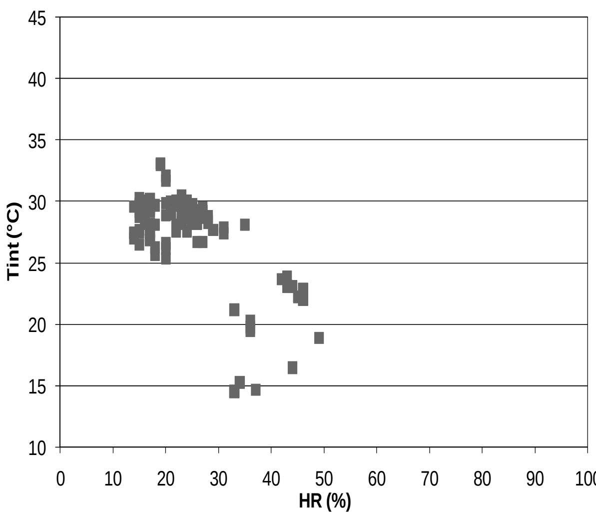

Figure 1: Relative humidity and air temperature indoors during the winter survey period

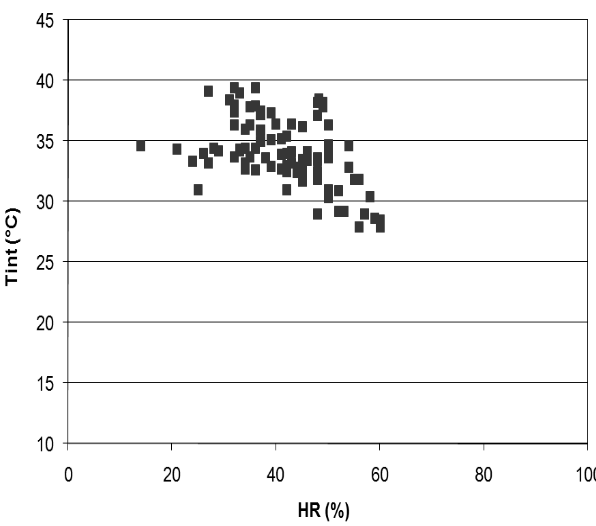

Figure 2: Relative humidity and air temperature indoors during the summer survey period

In Figs. 1 and 2, indoor temperature and relative humidity during winter and summer surveyed periods are plotted. The measures correspond to the surveyed houses analysed in next paragraphs.

At the next graph (Fig. 3), comfort votes for both periods are summarized, as a percentage of the total votes of each period. The percentage has been obtained considering the number of thermal sensation votes from each level (ASHRAE scale from -3 to +3) divided by the total number of people´s responses from each surveyed period. The periods have been calculated separately but the results have been plotted together in the graph.

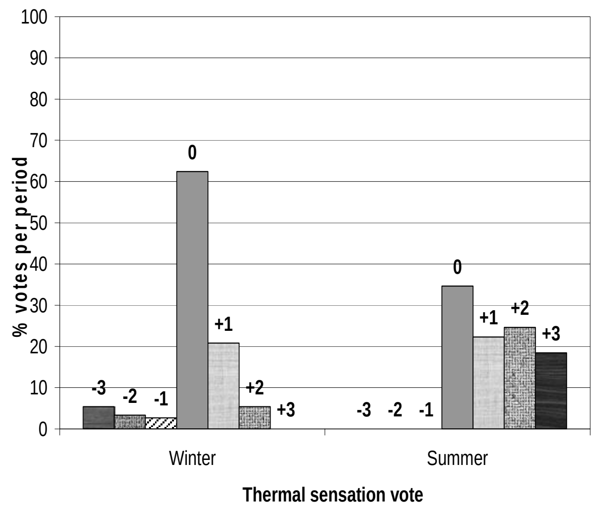

Figure 3: Thermal sensation votes during winter and summer survey periods (% of each vote level per period)

As can be seen (Figs. 1 and 2), winter indoor conditions are mild and it is not so difficult to adapt to indoor climate (in Fig. 3, more than 60% of sensation votes express comfort or zero value in the scale). Nevertheless, summer indoor conditions are not very friendly, as expressed also in the percentage of high sensation votes (from 0 to +3) at Fig. 3.

Field surveys By applying field surveys it is possible to analyze thermal sensations of people into their own environment, obtaining data in the site were they live or work. This type of comfort studies allow to evaluate the physiological and psychological responses of the people as a whole, including the actions that people take to achieve the thermal comfort. They allow predicting the people thermal sensation and the comfort temperature, which vary at least with the climate and the season.

The comfort studies presented here have been carried out by field surveys in several economical housing developments in Hermosillo city, Mexico (Fig. 4). Occupants of the surveyed houses are workers with very low incomes and the majority is habituated to the local climate. They are usually families compound by young couples with one or two children. Houses are constructed in 33.5 to 39 m^2, distributed in two main spaces (one bedroom and one multi-uses room) and one bathroom. The houses are made of concrete block walls and concrete slabs, without insulation.

Figure 4: One of the economical housing developments surveyed

Figure 5: Field surveys in houses. A student is applying a questionnaire and is measuring thermal conditions.

Field studies consist in sampling physical characteristics of the houses, social and physical characteristic of the people and asked thermal sensation from the occupants. This has been achieved by applying a questionnaire specially designed for these purposes. During this procedure, indoor thermal variables have been measured (Fig. 5).

The obtained information about dwellings and their users was: house orientation, physical characteristics and geometry, materials, air conditioning and ventilation devices, shadow devices. Information about the occupants such as age, gender, weight, high and social-economical data (such as education, salary, etc.) was also collected. Clothing and activity level have been reported in each case. In the field survey, the asked thermal sensations are based on a seven-point scale (ASHRAE scale from -3 to +3), representing the people comfort votes. At the same time, the following thermal variables have been measured indoors: air temperature, globe temperature, relative humidity and wind speed. Considering the local climate characteristics, the survey has been carried out in two extreme periods, winter and summer, which are the most relevant. The survey questionnaire and the application have been designed according to standards ISO 7730 and ISO 10551 [4, 5]. The measurement devices are according to standard ISO 7726 [6]. Based on statistical data, we determine that the database must include almost 150 persons per period. The indoor climatic variables have been obtained with the thermal environmental monitor QUESTempº 36 (Fig. 6), which is a datalogger with several sensors able to measure the following variables: dry bulb temperature, wet bulb temperature, black globe temperature, relative humidity and wind speed. The meteorological data have been obtained from the meteorological station of the Energy, Environment and Architecture Laboratory from the University of Sonora, located in Hermosillo city.

Figure 6: Thermal environmental monitor

Indoor thermal measurements have been taken after few minutes remaining in the same environment, so that devices could be ready to take appropriate data, according to their permanence in the site.

RESULTS AND INTERPRETATION

Sensation votes and neutral temperature Analyzing the five measured indoor variables, we have seen that air temperature and globe temperature were the most relevant variables able to modify the sensation votes. We have compared both at Fig. 7, in order to select the most appropriate to work with it. Although the field surveys have been carried out in two periods (summer and winter), in the next graphs are presented results only for the most critical adaptation period: summer.

In Fig 7, indoor air temperature Tint vs. globe temperature Tg are plotted. Each pair of simultaneous data is represented by black triangles, and the black line is the linear regression of these data. The gray line has been plotted to compare both variables, and is a hypothetical line where both temperatures are equal.

Fig. 7 is plotted in order to compare how much air temperature differs from globe temperature. As can be seen, during this period both are almost proportional, which indicate that both are able to be used as the most relevant indoor variables which impact on thermal sensations. We have chosen air temperature, because it is easier to compare our results which those corresponding to other authors, which mostly use air temperature.

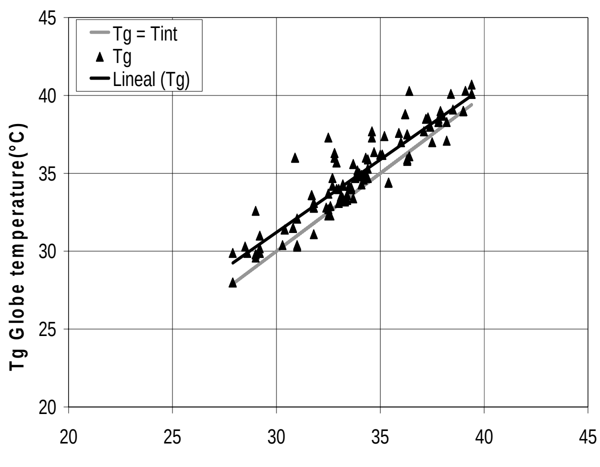

Figure 7: Air temperature vs. globe temperature indoors during the summer survey period (black triangles and black line). Gray line is Tg = Tint

Hermosillo's climate can be considered as "asymmetric", according to Nicol [7]. In such climates, thermal sensation responses during field studies show a tendency to only one extreme of the sensation scale. In this case the "warm" votes have no symmetric response at the opposite side of the scale (could). So, the conventional regression method distorts the results. In order to estimate the neutral temperature Tn and their limits, a method of statistical regression by layers has been applied, to avoid the characteristic bias of asymmetric climates [8]. The method is based on the proposal of Nicol for "asymmetric" climates [7]. The fundamental difference with the conventional method is that instead of obtaining the regression line that characterizes the complete sample studied, several layers are grouped by level of thermal sensations expressed. Later, the average of temperature and standard deviation per layer is obtained. The intersection of the regression line obtained with the average values and the 0-line sensation vote (sensation of thermal neutrality), determine the value of the neutral temperature Tn.

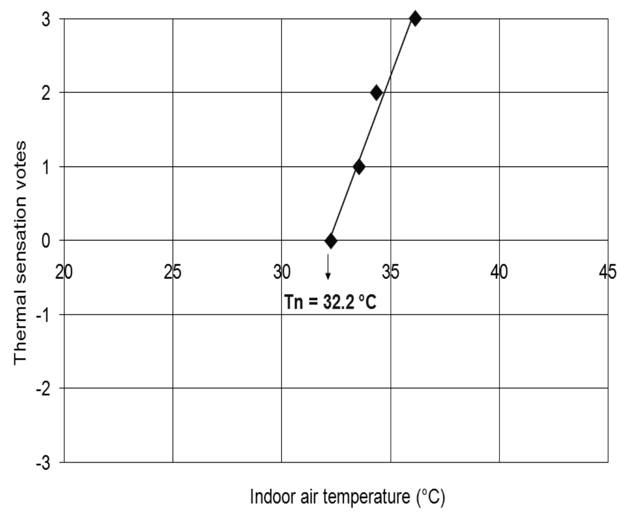

Figure 8: Thermal sensation votes as a function of indoor air temperature during summer survey period

At Fig 8, sensation votes from the whole survey are plotted with the corresponding indoor air temperatures. The figure shows the comfort or neutral temperature Tn, which in this case is 32.2 °C for summer. The calculated comfort range (close range) is Tn ± 2.45 °C. For the winter period (not presented here) we obtained Tn = 26.9 °C.

Although many variables are not easy to isolate, at the next paragraphs we present the comfort votes as a function of indoor temperature, depending on different people characteristics, such as age, size and gender.

Age For determining the influence of people's age on sensation votes, we have plotted Fig. 9. The most usual inhabitants of these houses are young couples with 1 (more frequently) or 2 children. Particularly in comfort surveys, no children intervene in the applied questionnaire. People younger than 40 represent 85% of this population sample and 15% are older than 40 years. Considering the people age distribution in this population, we have split them into two groups: the younger, which age is under 40 years and the more grown up group, older than 40 years. The tendency in Mexico is the inversion of the population pyramid, which leads in the future to a higher number of more adult people. In order to analyse almost two different age groups, we set the limit in 40 years to have enough data in both groups. Sensation votes from both groups are plotted separately in Fig. 9.

The two age groups seem to have similar responses to thermal effects (similar slope in the regression line), but the more grown up group seem to feel more comfort with higher temperatures. In older people, thermoregulatory mechanisms are less efficient, and they also decrease their activity habits and capacity. In our survey, this last factor was probably the most relevant and explains our results, because less activity is associated with lower thermal sensations.

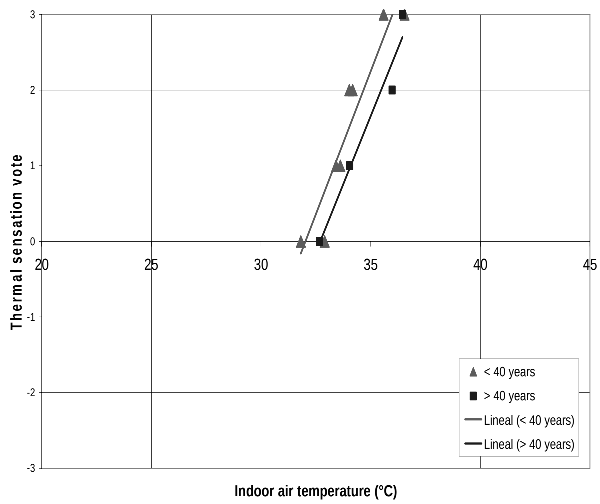

Figure 9: Thermal sensation votes as a function of indoor air temperature during summer survey period (depending on people´s age)

People's size The surveyed houses users, and in general local people, are stout people. We have used the body mass index BMI as indicator, instead of only the people's weight. In our case, 58% of the occupants have a body mass index higher than 25 (25 BMI is usually considered as the upper "normal" size limit). Official population data report in the region (Sonora State, Mexico) 67.6% of men and 77.5% of women older than 20 years have BMI > 25 [9].

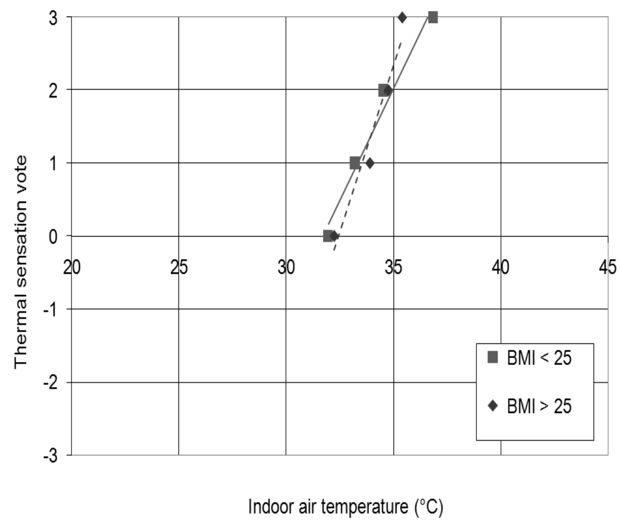

Figure 10: Thermal sensation votes as a function of indoor air temperature during summer survey period (depending on people´s body mass index)

At Fig. 10, both groups are plotted separately. At relatively moderate temperatures, both groups seem to have similar sensations to thermal conditions (thinner people prefer slightly lower Tn), although the different slopes in the regression lines indicate that bigger people have less tolerance to temperature changes. At temperatures higher than about 34 °C, as expected, bigger people prefer lower temperatures, and they arrive at the sensation of "hot" (+3) at lower temperatures than thinner persons. The reason is that in bigger people, the increase of the metabolic rate (due to the increase of volume) is proportionally higher than the increase of their skin surface, which allows not enough heat dissipation that could balance the heat exchange.

Gender The gender distribution in the field survey was almost a half and a half between females and males. At Fig. 11, females and males are plotted separately, showing slight different responses to temperature.

The graph shows that at relative moderate temperatures, females and males have a similar response to temperature. As temperature increases, females prefer lower temperatures (in warm climate) than males and show less tolerance to temperature changes. Women are physiologically more sensitive to temperature changes and have slightly lower thermal adaptation capacity.

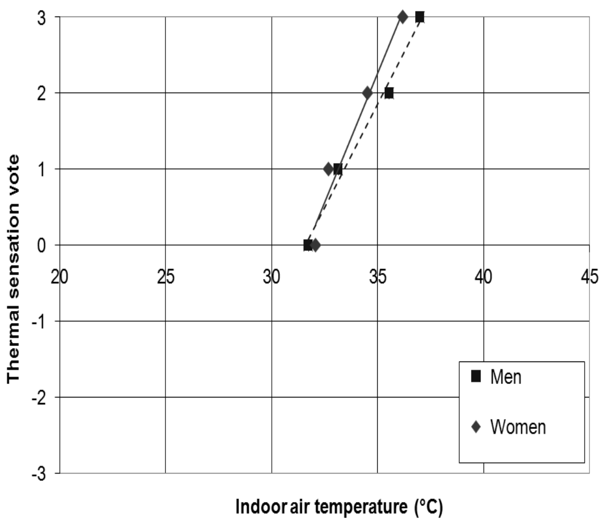

Figure 11: Thermal sensation votes as a function of indoor air temperature during summer survey period (depending on people´s gender)

CONCLUSION

The results of the field surveys presented in this work give a good idea of the complexity of people's sensation to thermal environments and can help to determine neutral temperatures under different circumstances. They are also helpful to develop models to understand the mechanisms that intervene in the thermal comfort in extreme climates.

In this work, results show the variability of the neutral temperature and the tolerance to temperature changes, depending on the population specific characteristics. Field surveys are a useful methodology to detect and to study thermal adaptation phenomena. The knowledge of neutral temperatures, according to many variables involved in human sensation, is useful for an optimal control of air conditioning systems, which leads to better thermal conditions of the occupants and to the conscious utilization of energetic resources for cooling. In many cases in Mexico, in which the population do not have access to artificial acclimatisation devices (although the extreme conditions), the neutral temperature values can guide the architects for choosing the most suitable thermal strategies for buildings design, helping to obtain indoor thermal conditions nearest to the comfort conditions of the specific population and climate, trying to achieve better quality of life for the occupants.

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