Thermal comfort educational software for hot climates

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ABSTRACT

Thermal comfort studies have been developed all around the world by many authors and some adaptive comfort models have been proved specifically for warm climates.

An educational software developed some years ago for temperate climate, ACT (Program for the Evaluation of Thermal Comfort), by Isalgué and Serra, has been proved and used successfully by students in the Mediterranean climate of Barcelona, since 1992. This software uses an empirical model, based on Fanger’s PMV.

The purpose of this work in this first approach is to verify if one basic comfort model can be used for different climates, maintaining the simplicity of the original model, as a good approach. An adaptive factor has been added to the model, in order to take into account the acclimatization, not only around the year but also for different climates.

The accuracy of the model has been verified for the hot dry climate of Hermosillo city, in the Sonoran desert in Mexico, analyzing the comfort votes of people in indoor and outdoor spaces. The asked comfort votes and the calculated values by the software are compared and discussed.

The accuracy in prediction of the PMV 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.

1. INTRODUCTION

The design of the indoor environment for thermal comfort of the occupants and the knowledge of the variables that intervene in the thermal sensation are fundamental for the passive design of buildings and to control heating and air-conditioning systems. Different types of thermal methods have been developed in the last decades in order to know the variation of the thermal human sensation under different conditions.

Two approaches can be considered the most representative: the empirical and the analytical (Nicol, 1993). The empirical methods are based on field surveys where people are asked about their thermal sensation on a subjective scale from “too cold” to “too hot”. The answers are called the comfort votes and include the global thermal sensation involved in the complexity situation of the subjects. The most known analytical model is Fanger’s (1970) Predicted Mean Vote (PMV), which is the basis for the international ISO Standard 7730. These models have the difficulty that clothing and metabolic rate must be predicted, and that are steady-state models while the real situation is variable.

Adaptive models are not based on heat exchange between man and environment, but on the observation that there are some actions that people can and actually take to achieve the thermal comfort.

Field surveys allow predicting the people thermal sensation and the comfort temperature, which will vary at least with the climate and the season. Many authors have work in this kind of approaches such as Aluciems (1981), Nicol (1994), Fanger and Toftum (2001), Nicol and Humphreys (2000), González and Bravo (2003), and others. In field surveys, a close correlation between comfort temperature and mean outdoor temperature is found (Nikol and Humphreys, 2002).

An educational program ACT (Program for the Evaluation of Thermal Comfort) has been developed from 1992 by Isalgué and Serra, which scope was to show to Architecture students in Barcelona (Mediterranian temperate climate) how different parameters and factors can influence the thermal comfort (The program can be freely downloaded from www.upc.es/aie). The program contains an empirical model based on Fanger’s PMV method (Fanger, 1970) and physical approaches.

The scope of the present work is trying to extend the validity of comfort evaluations in different external conditions, especially in hot-dry climates. This has been implemented in the program adding a simple expression, related to long-term thermal adaptation, and making it useful to represent the people thermal sensation in different climates, verifying the results in the desert climate of northwest Mexico.

A field survey is applied to search an appropriate comfort model, which helps to understand how the comfort sensation and the adaptation mechanisms work in hot climates.

2. COMFORT MODEL

The program inputs are divided in two groups: Comfort parameters and Comfort factors (Fig. 1). The first are inputs related to the climatic conditions such as: air temperature, radiant temperature, relative humidity and wind speed. The Comfort factors are people data, such as activity, clothing level, and the month of the year (seasoning adaptation) at the time of the survey.

The outputs that can be obtained at the results screen (Fig. 2) are the equivalent temperature, the preferred temperature according to the parameters, the percentage of dissatisfied people and the global thermal sensation (PMV).

An empirical expression is presented in this work, which in addition to the original model, is able to represent the long-term adaptation of the people to the local climate. The first point is that, by long-term exposition to high temperatures, thermal sensation to changes becomes affected. The first approach is to have a linear dependence of the desired temperatures on the “historical” temperatures that the body has been exposed to. This has been approached by:

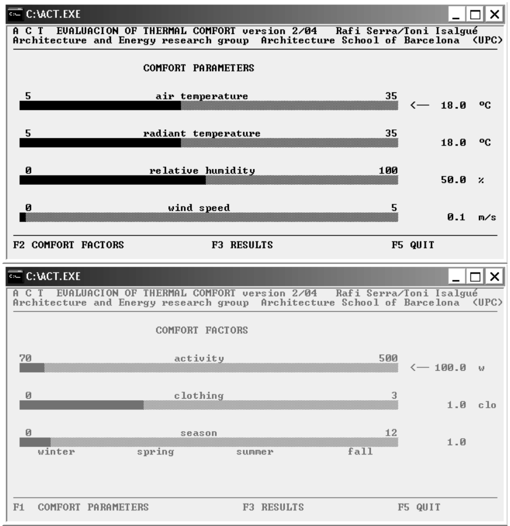

Figure 1: Comfort parameters and comfort factors screen.

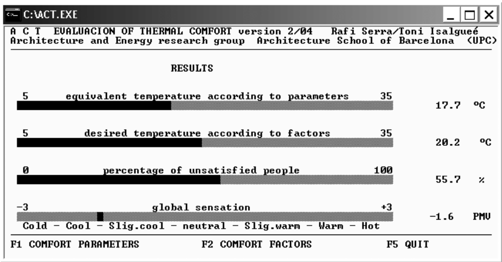

Figure 2: Results screen.

$$T_{be} = 25.5 + T_m/5 \qquad (1)$$

where:

- T_{be} is the new base reference temperature, and
- T_m is the mean annual temperature.

Effects of temperature oscillations, which have different amplitudes in this climate, are mostly included in the seasoning adaptation.

It is possible that this expression, firstly intended for hot climates, could be applied to any other climates because the mean annual temperature is included as variable. However, no validation for lower temperatures has been done yet.

The equation 1 intervenes in the last three mentioned outputs (preferred temperature, percentage of dissatisfied people and computed PMV value), modifying the people sensation because of the tolerance that gives their long-term adaptation to the local climate.

The obtained results, comparing with the real people sensation, present a similar pattern but are displaced to higher PMVs. Actually, the neutral (or comfort) temperature is displaced to higher values, according to the monthly mean outdoor temperatures, which intervene in the seasoning adaptation and the "historic" adaptation given by equation 1. That means that the model has underestimated the people adaptation capacity to very high temperatures. On the other hand, the thermal sensation range between the different people seams to be bigger. Because of these effects, the following equation is needed to a nearest agreement:

$$PMV\ (ajusted) = PMV\ (calculated) * 1.75 + 3.34 \quad (2)$$

The last two expressions constitute the added adaptive model, which gives a good accuracy for indoor and outdoor spaces, taking into account the simplicity of the expressions, as can be seem in the following paragraphs.

3. FIELD STUDIES

To verify the accuracy of the proposed model, field studies with Architecture students have been done. The experiment sample consist on a group of 56 students about 19 or 20 years old, habituated to the hot dry local climate (Fig. 3). They have been previously trained in these specific studies.

In the field survey, the asked thermal sensations were based on a seven-point scale, representing the people comfort votes. At the same time, the following thermal variables have been measured: air temperature, mean radiant temperature of the surrounding surfaces, relative humidity and wind speed, at different locations into and around the same building. Clothing and activity level have been reported in each case. The studies have been done at the end of summer.

Figure 3: Part of the field survey group and measurement devices.

The local climate is characterized by high solar radiation levels, clean skies the whole year and high temperature oscillations daily and in the different seasons. Summers are very warm, with daily temperatures between 25-30°C and 40-44°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 and 30°C. During 5 or 6 months per year it is almost constant (day and night) the use of air conditioning inside the buildings.

Local people adapt their way of life to these circumstances: the siesta during the afternoon hours is very common and in general the necessary physical activities and movements such as to walk are done very slowly.

Measurements and surveys have been done in indoor spaces, with and without air conditioning and in confined outdoor spaces under microclimatic conditions, such as patios and outdoor corridors.

In the next paragraph, the results of the survey are presented, analyzing the effect of the climatic variables on the comfort votes, and a comparison between the asked comfort votes and the calculated by the adaptive model is shown.

4. RESULTS AND DISCUSSION

4.1 Influence of climatic variables

We have analyzed which of the measured climatic variables (comfort parameters) has in our case more influence on the comfort sensation of the surveyed persons. In Figure 4 it is possible to appreciate that air temperature and especially radiant temperature are the most important variables.

Relative humidity has less influence and

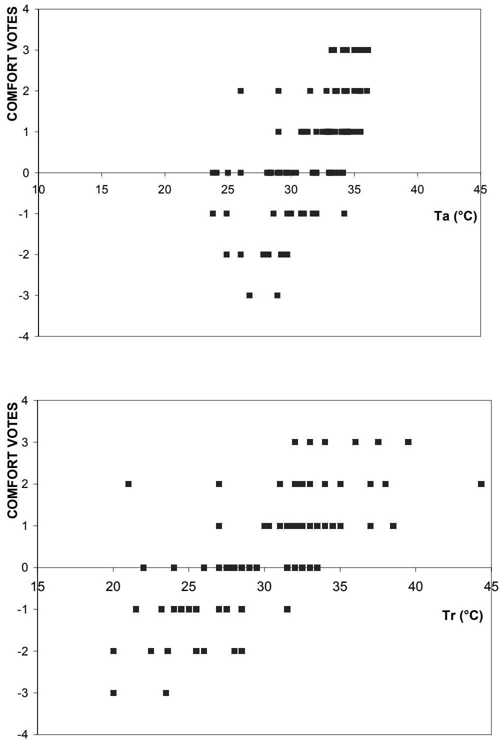

Figure 4: Air temperature T_a and mean radiant temperature T_r vs. asked comfort votes.

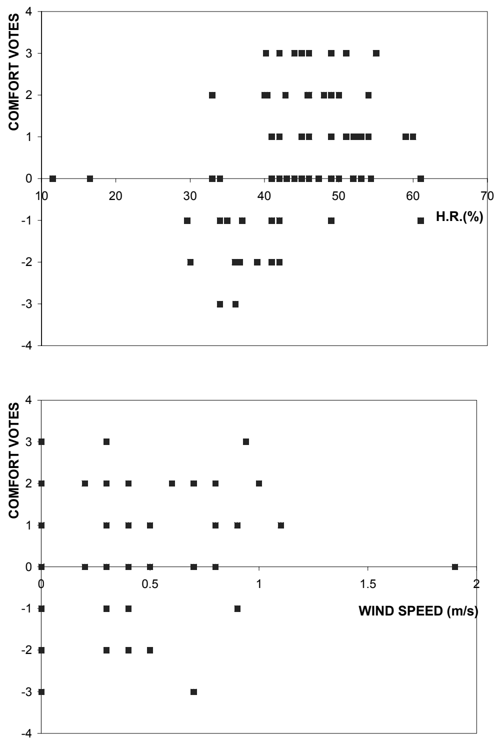

Figure 5: Relative humidity H.R. and wind speed vs. asked comfort votes.

wind speed seems not to have a clear relation with people thermal sensation (Fig. 5). We think the reason could be that the occasionally wind gusts are very warm and cause a higher comfort vote.

4.2 Model results

Because the surveyed comfort votes in air-conditioned spaces differ very much from not-air-conditioned spaces (indoor and outdoors), we have analyzed these two groups separately. We have seen that indoor spaces without air-conditioning and outdoor spaces are in our case not very different. Our results into air- conditioning spaces were not very useful. The comfort votes obtained from air-conditioned indoors were so spread, that we could not find a clear tendency. The different people reported a variety of sensations under the same thermal conditions.

In the Figures 6 and 7 the calculated PMVs with the adaptive model according to Eq. 1 vs the asked comfort votes (square points) are plotted. The plotted line represents the regression (equation 2) between these values. We have taken the same line for the outdoor and indoor surveys. The R^2 values are 0.43 for the indoor survey and 0.60 for the outdoor one. Taking into account that the resolution of the experimental comfort votes is 1 (seven-point scale from -3 to 3), we consider that the R^2 errors are quit acceptable for a rough model.

In general, we can observe that the calculated PMVs are higher than the real thermal sensation (with the exception of the very high +3 vote). We have seen, that the model overestimates the sensation of warmth. In the model (equation 1), the real T_{be} has been actually displaced to higher values, as a result of long-term adaptation to warm climates.

The people adaptation to temperature changes is better than expected, with the exception of very high thermal conditions, which are

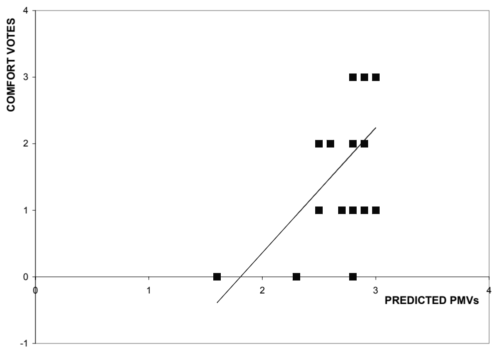

Figure 6: Asked comfort votes and predicted PMVs indoors.

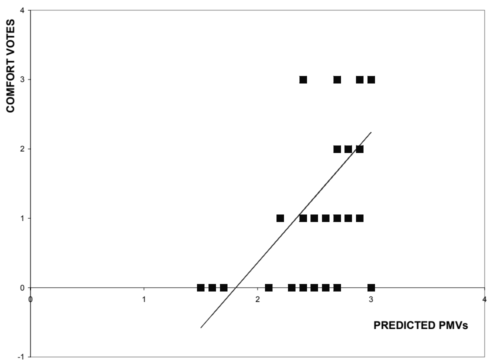

Figure 7: Asked comfort votes and predicted PMVs in confined outdoors.

probably near of the limit of tolerance.

Although the people are habituated to air-conditioned buildings, their thermal expectation is in our case not very high and they judge the environment less unacceptable than would people from other climates. A probable reason for the better tolerance is that people are adapted to the great temperature oscillation of the local climate, daily and along the year. Additionally, the reduction of the metabolic heat rates, by lowering the activity levels, is very probably in our case the key of this adaptation.

Although there are always constraints limiting the ability to take actions to avoid discomfort, such as extreme climates, the energy costs and the fashion, people find ways to adapt to climatic conditions (Nicol, 1993; Fanger and Toftum, 2001).

5. CONCLUSIONS

An empirical comfort model has been presented which is part of an educational software used for Architecture students.

The proposed comfort model, which is a combination of a Fanger-based PMV with an adaptive adjustment, is able to represent the comfort sensation in not-air-conditioned indoors and confined outdoors. The variables that intervene in this model are the clothing, the activity level and the mean annual and monthly outdoor temperature, which dimension the local climate adaptation of the people.

Model results for air-conditioned spaces were not good, probably because one of the intervening variables, the mean outdoor temperature, has no relation with this kind of artificial indoors, with sudden temperature variations and too fast adaptation requirements.

The field survey presented in this work, which includes the response of the subjects, gives a good idea of the full complexity of the people sensation and helps to develop the model and to understand the mechanisms that intervene in the thermal comfort in extreme climates.

Field studies about the adaptation of people to the local climate are useful to set air-conditioning set points, as well as the ranges of indoor temperature variations, in order to predict the changes in the energy use and for the conscious use of energetic resources for cooling.

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