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INTERNATIONAL STANDARDS DON'T FIT TROPICAL BUILDINGS: WHAT CAN WE DO ABOUT IT?

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LOS ESTANDARES INTERNACIONALES NO SE ADAPTAN A LOS EDIFICIOS EN EL TRÓPICO: ¿QUE PODEMOS HACER AL RESPECTO?

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RESUMEN

Mediante estudios experimentales realizados en climas tropicales se ha llegado a la conclusión de que los Estándares Internacionales para la climatización interna de edificios, ISO7730 basadas en las ecuaciones PMV/PPD de Fanger, no describen adecuadamente las condiciones de confort. Este trabajo presenta algunas de las evidencias de esta afirmación y sugiere vías para que los Estándares Internacionales sean complementados usando la información obtenida a través de muestreos locales de condiciones de confort.

ABSTRACT

Field studies conducted in tropical climates have found that the International Standard for indoor climate, ISO7730 based on Fanger's PMV/PPD equations, does not adequately describe comfortable conditions. This paper presents some of the evidence and suggests ways in which International Standards might be complemented using the results of local comfort surveys.

PALABRAS CLAVES
Confort térmico, Estándares internacionales, Climas tropicales.

KEY WORDS
Thermal comfort, International standards, Tropical climates.

1. INTRODUCTION

International standards to describe comfortable thermal environments indoors (ISO 1994, ASHRAE/ANSI 1992) are based on theoretical analyses of human heat exchange with the environment calibrated using the results from experiments in special climate-controlled laboratories or climate chambers. ISO 7730 uses the Fanger (1970) Predicted Mean Vote (PMV) formula which predicts the mean subjective response to the thermal environment on the ASHRAE scale (table 1) from a knowledge of six thermal variables. These are the metabolic rate and clothing insulation of the subjects, the temperature of the air and surrounding surfaces (the radiant temperature), the humidity and the relative velocity of the air. The formula is based on the results of extensive work at Kansas State University and the Technical University of Denmark. Fanger was at pains to investigate the differences between groups including subjects who, though tested in Denmark, were straight from the tropics and so might have been physiologically adapted to the heat. He found no consistent difference between the 'tropical' and the 'non-tropical' subjects. Subsequent work by de Dear (1991) in Singapore confirmed this finding in a tropical context.

Table 1 The ASHRAE comfort scale

Description	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
Numerical value	3	2	1	0	-1	-2	-3

Surveys of thermal comfort in the field seem to bring these results in to question. Many surveys have been conducted using subjects in a tropical context and relating their observed sensation on the ASHRAE scale (or the similar Bedford scale) to the physical environment. Examples are Webb (1959), Nicol (1973), Sharma and Ali (1986), Busch (1992), Taki et al (1999) and Nicol et alt (1999), many others are quoted in the literature e.g. in Humphreys (1975) and deDear and Brager (1998). The results from these surveys give the subjects responses in situations they normally experience and not the results from the unfamiliar surroundings of the climate chamber or the predictions of the thermal comfort indices based on heat balance equations. The conditions which they find comfortable (or neutral on the ASHRAE scale) differ from the predictions of ISO7730 particularly in hot climates when buildings are not mechanically cooled (deDear and Brager 1998). ISO7730 overestimates the occupant response on the ASHRAE scale at high temperatures. It predicts discomfort at temperatures which subjects in field surveys find comfortable.

2. WHY ARE PREDICTIONS WRONG?

One problem for the prediction of comfort using ISO7730 in hot climates is the declared limitations to the applicability of the PMV, which are shown in Table 2. Air temperatures above 30°C and air velocities in excess of 1m/s are not uncommon in buildings in tropical countries. Conditions are often such that the formula predicts PMV over 2. Yet many field studies in hot climates have found that subjects can be comfortable at temperatures up to or even exceeding 30°C especially if they are using a fan.

Table 2 Limitations to the range of conditions over which PMV applies (ISO7730 1994)

Variable	Symbol	Units	Lower limit	Upper limit
Metabolic rate	M	W/m^2 (met)	46 (0.8)	232 (4)
Clothing insulation	I_{cl}	°C/W (clo)	0 (0)	0.310 (2)
Air temperature	t_a	°C	10	30
Radiant temperature	t_r	°C	10	40
Relative air velocity	v_{ar}	m/s	0	1.0
Water vapour pressure	P_a	P_a	0	2 700
Predicted Mean Vote	PMV		-2	+2

There are a number of other reasons why the heat balance approach gives the wrong predictions of thermal sensation. The formulae seek to predict the conditions which people are in equilibrium with their environment. They then assume that the sensation will be neutral if the values of the six variables are such that the heat lost to the environment by conduction, convection, radiation and evaporation balances the metabolic heat produced. The PMV then goes further and assumes that the thermal sensation will not be neutral if the body is not in equilibrium. Using results from thermal comfort experiments in climate chambers it predicts what sensation will result from a particular imbalance.

Problems arise for such prediction of comfort sensations, particularly in the real, variable situations that are found in the buildings particularly those in the tropics:

It is not possible for an imbalance to persist in the heat flow between the body and the environment, death would result. A dynamic equilibrium is essential and any imbalance in heat flow be must be corrected over time. A persistent positive or negative PMV is theoretically impossible, but in real situations (see e.g. Matthews & Nicol 1995) people can be hot over long periods of time.

People will take actions to ensure this dynamic equilibrium such as changing their clothing or their activity or where possible changing the environment to suit themselves.

These changes may take time to achieve and in addition the human body is relatively massive and will take time to respond to a change in the heat balance. Time is an important element in thermal comfort. It is important that any prediction takes it in to account. This is not be accounted for in climate chamber experiments.

There are other problems such as formulating the way clothes are used-which varies from climate to climate. Most theoretical formulae see clothes as having an insulating function but in many climates they are used to maintain an appropriate microclimate next to the skin (see e.g. Berger 1988).

Metabolic rate is assumed to be independent of the temperature of the environment, yet people may be adjusting their activity to take account of the temperature, changes in posture will also affect metabolic rate by changing the surface area for convective and evaporative heat loss.

Each of these effects may be a minor source of error in itself, but because thermal behaviour is essentially governed by the thermal sensation in a feedback relationship, they are often additive so can result in significant errors in the resulting prediction. A model which represents the thermal equilibrium as a heat balance at a point in time will not fully reflect thermal comfort in the field. Without full allowance for the dynamic nature of the human interaction with their surroundings, such a model is likely to have limited applicability. This is especially true in the conditions found in free-running buildings in hot climates. The inappropriateness of the existing International standards poses problems for Architects and engineers in tropical countries. How should they decide what temperatures to provide in their buildings?

3. DECIDING WHAT TEMPERATURES TO PROVIDE: THE FIELD SURVEY APPROACH

The problem of deciding what temperatures to provide in buildings is immensely complex. One way around this is to treat the process as a black box where the internal mechanisms of the relationship between comfort and the environment are less important that the outcomes. This is the approach taken by those who use field surveys to investigate the problem. In the field all the variables are in action-people are free to change their clothes, their activity, their posture, and when the building allows it, to change the temperature, air movement and even the humidity.

Nicol and Humphreys (1972) presented the results of field studies in the tropics (Webb 1959 and Nicol 1973) together with their own results from the UK. The results show that mean comfort vote changes little with the mean temperature experienced. A similar figure including the results from many more studies world-wide is shown as figure 1. Each point represents the mean values of comfort vote (on the scale shown in table 1) and the mean temperature the subjects experienced over a whole survey. Note that temperatures well above 30°C are considered comfortable in some cases.

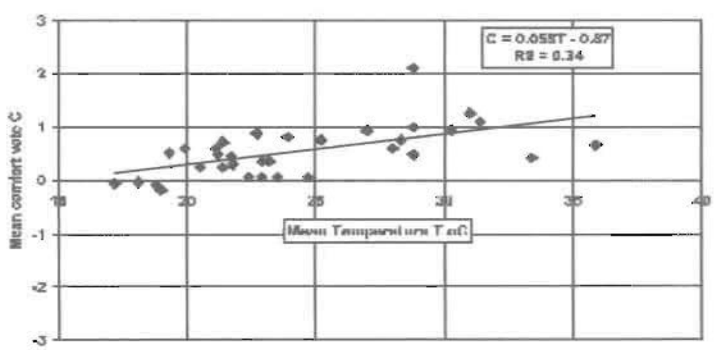

Fig. 1 Mean comfort vote on the ASHRAE comfort scale as a function of mean temperature experienced. Each point is the mean over a whole field survey.

Subsequent work by Humphreys (1975) showed the obvious deduction: that the temperature which people find comfortable is closely related to the mean temperature they experience. In other words people find ways in which to make themselves comfortable in the conditions they normally experience: they *adapt* to them physiologically and behaviourally.

In buildings which are free running (buildings which *at the time of the survey* are neither being neither heated nor cooled) the mean indoor temperature tracks the mean outdoor temperature. Consequently the temperature which people find comfortable also tracks the outdoor temperature. In heated or cooled buildings the relationship is more complex because the indoor temperature is, to a certain extent, independent of then outdoor temperature. Humphreys (1978) conducted a meta-analysis of the data from a large sample of comfort surveys world-wide and produced the relationships shown in figure 2.

The linear relationship which Humphreys derived between comfort temperature and mean outdoor temperature for free-running buildings (the straight line in Figure 2) is:

$$c = 0.534\,To + 11.9 \qquad (1)$$

where T_c is the comfort temperature and T_o is the mean outdoor temperature. Recent work by Humphreys and Nicol (2000b) using data collected by deDear and Brager (1998) almost exactly matches these earlier findings.

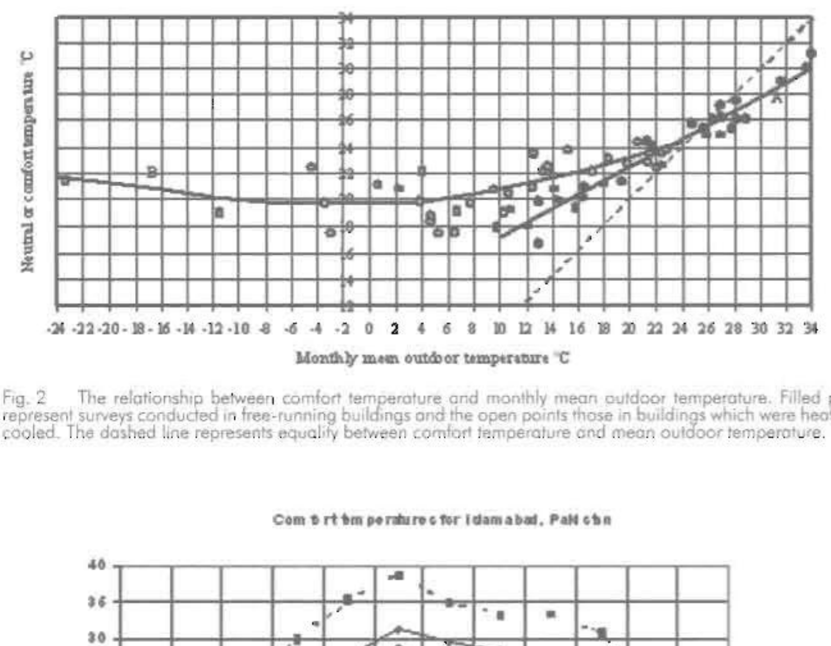

Fig. 2 The relationship between comfort temperature and monthly mean outdoor temperature. Filled points represent surveys conducted in free-running buildings and the open points those in buildings which were heated or cooled. The dashed line represents equality between comfort temperature and mean outdoor temperature.

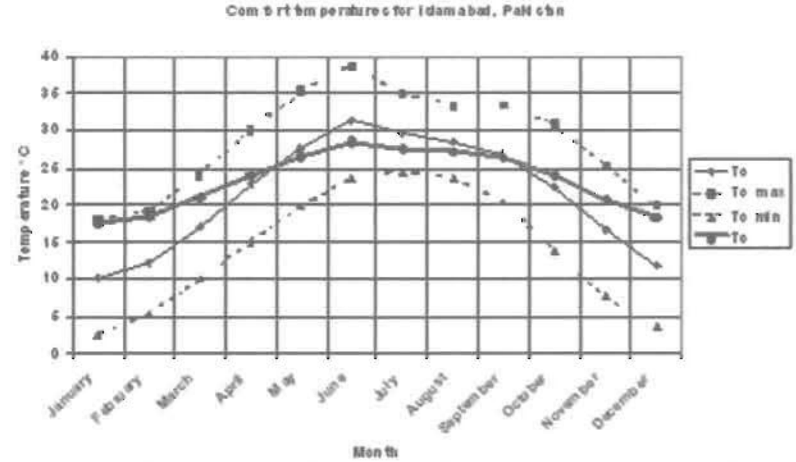

Fig. 3 Comfort temperature T_c for Islamabad Pakistan calculated from the outdoor temperature T_o using equation (1). T_o is calculated as the mean of the monthly mean maximum ($T_{o\,max}$) and Minimum ($T_{o\,min}$).

This relationship enables building professionals to predict the temperature which will be comfortable in buildings by calculation from the monthly mean outdoor temperature given by meteorological records. Results for Islamabad, Pakistan are shown in figure 3. The figure shows the comfort temperature overlaid on the outdoor temperature to indicate the temperature differential which the building must achieve to remain comfortable indoors. In this case the building must be warmer that the outdoors in winter and cooler in summer, but by amounts which it might be possible to achieve by passive means (certainly in winter). A comfort *zone* within which temperatures are generally acceptable can be taken to extend some 2-3 °C either side of this optimum temperature.

4. SOME PROBLEMS

4.1 ACCOUNTING FOR AIR MOVEMENT AND HUMIDITY

The results presented by Humphreys refer only to temperature, air movement is assumed to be small and humidity is standardised at 50%. In tropical climates air movement and humidity will be important factors in achieving comfort. Nicol (1973) showed that in the hot dry climates of Northern India and Iraq, the presence of air movement can be equivalent to a reduction in temperature of as much as four degrees, and this is more or less in line with theoretical expectation. Sharma and Ali (1986) found a similar effect. At hot times of year ceiling fans are used in almost all buildings in the tropics, and this can be assumed to allow higher temperatures that equation (1). It is more difficult to account for the effect of humidity. Whilst humidity has been investigated in a number of field surveys in hot climates, and found to have a significant effect, the size of the effect is uncertain, and further research is probably needed.

4.2 DIFFERENCES BETWEEN CLIMATES

Nicol et alt .(1999) conducted a survey throughout the year in Pakistan and found that the relationship between comfort temperature outdoor temperature was difference from equation (1) found by Humphreys. The relationship they found was

$$\mathbf{T_c = 0.36\,T_o + 18.5} \qquad \mathbf{(2)}$$

A similar survey throughout Europe found the relationship

$$\mathbf{T_c = 0.28\,T_o + 18.2} \qquad \mathbf{(3)}$$

Figure 4 compares these relationships to equation (1). It appears that the generally cooler climate of Europe results in lower comfort temperatures in free-running buildings and suggests that the climate may have an overall effect on the comfort temperatures, maybe as a result of physiological adaptation or behavioural adaptation which has become culturally based.

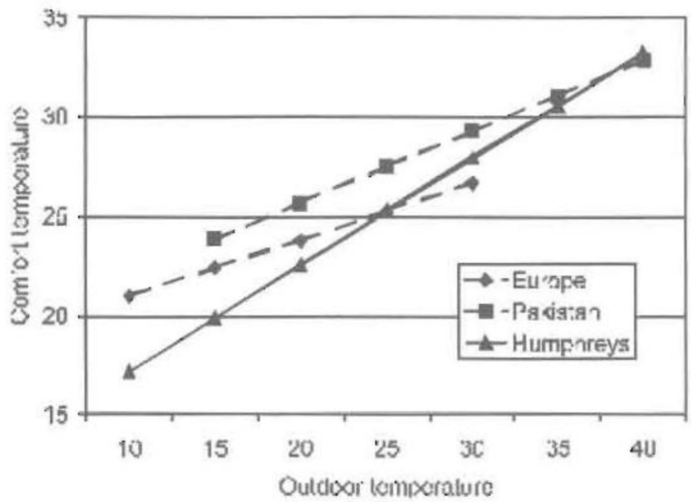

Fig. 4 Comparison of the Humphreys relationship in different climates

5. CONCLUSIONS

In theory at least the PMV should predict the temperature at which people are comfortable regardless of the local conditions. The equations on which it is based take account of changes in clothing and activity and so it should be able to predict thermal sensation irrespective of where it is used. In tropical conditions it fails to give accurate information about the temperatures which people will find comfortable.

It is particularly unfortunate that PMV predicts that people will feel hotter than they actually do and therefore tends to encourage the use of lower temperatures than necessary. In addition, because ISO 7730 does not provide information about clothing use there is a tendency to assume a particular clothing level and the need for a constant indoor temperature, thereby encouraging the use of mechanical cooling.

International standards which take account of the evidence from field studies in the tropics are urgently needed. ASHRAE, on the basis of work by deDear and Brager (1998) among others, are seriously looking at the possibility of incorporating the information derived from field surveys into American standards. Moves are afoot towards similar changes in ISO standards. Eventually it is to be hoped that these can be based on theory which has been successfully tested against empirical data. The cultural element and the allowance for time means that comfort surveys are needed in every area of the world, particularly in the tropics where current standards are weakest.

Meanwhile the empirical findings of field surveys can be used as a guide for informing the design of buildings to provide comfortable conditions. In the first instance according to equation (1), which can be taken as an international generalisation of field studies throughout the world. Wherever possible this can be improved by the conduct of local field surveys to fully reflect climate and culture in relationships such as those given in equation 2 and 3 for Pakistan and Europe.

Figure 3 shows the way in which the results can be used to calculate the optimum comfort temperatures at different times of year. A *comfort zone* of 2-3 degrees either side of the optimum can be taken as acceptable. If fans are available to building occupants another two or three degrees can be added to the predicted comfort temperature in the hottest time of year.

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