Building Serv. Eng. Res. Technol. 11(3) 105–108 (1990) Printed in Great Britain

#4593

Technical Note

Summary In countries with hot climates, thermal comfort always depends on the acquired tolerance of people to the prevailing conditions, and from this stems their perceived comfort level indoors. Comfort evaluation must allow for acclimatisation if economic environmental control systems are to be specified. Previous comfort studies are critically evaluated for application to the Bangladesh climate. The most appropriate findings are summarised and considered in the context of local vernacular design and social requirements.

Thermal comfort studies and applications for Dhaka

Z N Ahmed BArch MPhil†, **A T Howarth** BSc MPhil PhD CEng MIMechE MCIBSE‡ and **J M Zunde** BA(Arch) MA RIBA HonBIAT

† Department of Architecture, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
‡ School of Construction, Sheffield City Polytechnic, Sheffield, S1 1WB, UK

Received 12 May 1989, in final form 6 April 1990

1 Introduction

Proper climatic design can be used as a tool to reduce superfluous heating and cooling costs which is of special significance in the countries of the Third World, where economic conditions dictate minimisation of such unnecessary expenditure. Fuel costs have grown with the realisation that energy resources must be conserved and thus the so-called 'energy crisis' continues. Designers do not all agree with the principle that the design of a space should encourage the use of available natural resources, climate in this case, to produce the desired interior environment.

Culture and social habits probably form the most important influence on the design of any type of building in a given region. Social habits originate from religious beliefs, as well as the inhabitants' adaptation to their unique surroundings and climate. It is therefore imperative for a designer to study the nature of the people for whom he designs in order to create successful buildings and to realise that this nature, to a great extent, springs from a direct response to the climate.

The traditional or vernacular house reflects the nature of its user. Rural communities are usually perfectly adapted to local needs, materials and climate as the result of many years or even centuries of optimising resources. Characteristically, they have developed materials and labour to suit the social organisation of a household, carried out in and around a building, and the climate.

In Dhaka, for instance, the prevailing wind direction during the hot months is principally from the southern side, so this side of the house is favoured for the most important rooms: bedrooms, living room and sitting room. Kitchens and toilets are almost never placed on this side, a northern location being preferred for the former, while a western one is found ideal for the latter. For the same reason, paved areas on the south are avoided if possible, so that overheated surfaces do not dissipate their heat into the house with the incoming breeze.

Humidity conditions in the warm-humid rainy season necessitate wide openings to let the breeze in and these must be shaded properly to keep out direct solar radiation and rain. Internal planning of houses is such that interior spaces may be linked directly with semi-external spaces, like covered verandahs, practically bringing outdoor conditions into the interior. The verandah may be used as circulation space and often as a clear weather lounge for the family. This creates permanent ventilation indoors, which may be seen as a disadvantage during the cold winter months. However, as the sun is considerably lower in the sky hemisphere in winter, southern verandahs are favoured by quite a large amount of solar incidence, and they form a welcome space for basking in the sun during the winter months.

Contrary to expectations, in view of the high levels of temperature and humidity experienced in Bangladesh, the acclimatised population feels thermal discomfort in only a small proportion of the year. This author's (Ahmed) experience of living and working in this climate may help in identifying the truly uncomfortable periods of the yearly cycle. It should be mentioned here that almost the whole urban population that can afford it uses mechanically induced air movement in the form of electric ceiling or lower level fans in the period March to November. Hardly any resort to the use of air conditioning, as this is not usually economically feasible. The thermal comfort evaluations which follow are made for indoor conditions considering the use of electric fans during this period and the lack of any form of heating during the winter.

The summer months of March and April are felt to be uncomfortably hot, as are periods towards the end of summer and just before the onset of the rainy season, when both temperature and humidity levels run high. The period May to September is normally tolerable if not pleasant, while late-September to mid-October again experiences spells of uncomfortably hot and sticky weather, usually lasting a day or two at a time.

This paper examines some of the previous research on thermal comfort and selects the results most likely to provide a satisfactory prediction of comfort conditions within buildings in the Bangladesh climate.

2 Studies of thermal comfort

The first step in any climatic design is the establishment of certain parameters, on the basis of which an environment may be judged as desirable. The environment parameters within these desirable limits may be collectively termed as the 'comfort zone'.

Studies to judge and evaluate thermal comfort and conditions that lead to it, have been undertaken in the Western World since the eighteenth century[1]. The most common factors known to affect human's perception of thermal comfort have been divided into two groups: environmental variables, which include air temperature, mean radiant temperature, the relative humidity of the surrounding air, the air velocity; and personal variables consisting mainly of activity level and clothing thermal resistance, the 'clo' value.

Most of the investigations were conducted on subjects placed in environmental chambers where the environmental variables can be adjusted. They were asked to vote on their thermal sensation on suitable psycho-physical scales, such as the one shown in Table 1, which is used by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE)[2].

The voting results on this scale of 1 to 7 were subsequently treated statistically with the object of supplying an optimum temperature for the whole group. From many of these studies, attempts have been made to develop thermal indices, so that the effect from a combination of the environmental variables on the subjective thermal sensation, or comfort, of people in various levels of activity and clothing could be established.

A study was recently conducted by this author[3] on a few of these established thermal indices, among which were: predicted mean vote (PMV) and predicted percentage of disatisfied (PPD); effective temperature; resultant temperature; heat stress index; index of thermal stress (ITS); predicted four hour sweat rate (P4SR). Available climatic data on Dhaka, obtained from the Bangladesh Meteorological Department[4], were studied in the context of these indices in order to evaluate how the climate is rated and the extent of discomfort predicted by these indices.

Consistent with the requirement of analysing indoor climate in Bangladesh, the following assumptions were made in the process of this evaluation.

(*a*) Indoor air temperature and humidity levels were taken to equal average outdoor shade conditions. This seems likely as openings are wide and there is usually no clear division between interior, semi-exterior and exterior spaces, these spaces often flowing into one another.

(*b*) Average values were used for temperature, as extreme conditions do not portray the true picture of existing conditions.

(*c*) Indoor air movement during the months March to November was equated to airspeeds typically found in rooms with electric ceiling fans: 0.5 to 1.5 m s^{-1}[5].

(*d*) The insulation of the lightweight, light-coloured clothing worn in Dhaka, is likely to resemble the unclothed body.

Table 1 ASHRAE psycho-physical scale

	Thermal sensation
1	Cold
2	Cool
3	Slightly cool
4	Comfortable
5	Slightly warm
6	Warm
7	Hot

Application of climatic data to each individual index studied on the basis of these assumptions revealed that it is never possible to be truly 'comfortable' in the climate of Bangladesh. Almost all the predictions pointed to overheated conditions throughout the year. One particular index predicted severe heat stress involving a threat to health in the warm-humid and hot-dry seasons.

Experience of living in Dhaka suggests that this cannot be the true picture of the comfort conditions. The inhabitants do feel 'comfortable' or 'neutral' at times when the thermal indices would strongly suggest that discomfort should be prevalent.

3 Discrepancies between thermal indices and field evidence

Thermal comfort and sensation, and the development of the various indices[6], have largely resulted from experimental investigations and research conducted in climatic chambers where the physical environment can best be controlled. There remains no doubt that such studies have provided us with a sound understanding of how the different factors, environmental and personal, affect the physical environment and man's sensation of it. However, there is the growing realisation that field evidence points out discrepancies between these laboratory predictions and actual comfort responses.

The work of Fanger[7] is currently widely used in comfort assessments in European and American buildings. Fanger has produced a comfort equation applicable primarily to persons of college age but also to other groups.

Fanger acknowledges that the comfort equation may not be directly applicable at geographic locations outside the temperate zone. Acclimatisation is accepted as an important factor which almost certainly contributes to the ability of natives of tropical countries to be comfortable at higher temperatures. Additional factors may be diet, clothing and activity levels which are adjusted by a way of life which has been adapted to the climatic conditions.

This is confirmed by McIntyre[8] in his explanation of actual results as opposed to climatic chamber results, who says that culture and climate definitely affect people's description of sensation, though not necessarily the sensation itself.

McGreevor[9] suggests that in cold climates, the primary goal when seeking comfort is the avoidance of feeling cold, not the achievement of an abstract 'comfort' condition. This again points to the cultural difference in the definition of comfort. Likewise, in hot-dry climates, it would be the avoidance of dry heat and with it the absolute exclusion of the heated air. In warm climates comfort would be the avoidance of feeling hot and sticky, encouraging as much air movement as possible.

Studies in thermal comfort have now led researchers to believe that adaptation and acceptance are strongly related to the perception of comfort. According to Cooper[10], designers and researchers are placing too much importance on environmental factors, aiming to create steady-state conditions, and are less concerned with providing the occupants with those means which would enable them to create for themselves a broadly based range of conditions which lie supposedly within the comfort zone. Occupants now expect, after their experience in the days before the energy crisis, improved and optimised conditions. Comfort is not totally physiologically based, nor is it based totally on what is technically feasible with energy conservation in mind, but rather it is mostly based on what is socially acceptable, and this in turn depends on the ideas and assumptions designers, researchers and occupants have about the nature of the preferred environment.

Humphreys and Nicol[11] suggest that the globe temperature alone can better indicate thermal comfort, rather than a multi-variable index. They show that although the basic ideas behind the achievement of comfort conditions are universal it is the actual design values which may be quite different and depend ultimately on the climate of the country. In low latitudes, temperatures in the range of 31–38°C may be quite acceptable, whereas in the higher latitudes of UK or USA, a much lower range of 18–23°C is required.

Humphreys[12] has compared field studies of thermal comfort and notes that simple measurements such as air or globe temperature are often not inferior to the more complex composite indices in their ability to explain the subjective warmth response in field studies. He describes a 'neutral temperature' at which the occupant experiences thermal neutrality, a condition when he is neither aware of warmth not chill. Comparing 40 field studies in a wide range of climatic conditions, Humphreys concludes that the neutral temperature T_n for adults ranges from 17 to 35°C, depending on the mean temperature, T_m, experienced by the population. This suggests that acclimatisation indeed affects the temperature required for thermal neutrality. Normally a band of 4°C (±2°C), centred around T_n comprises the comfort zone. Humphreys puts foward the following formula to predict neutral temperatures:

$$T_n = 2.56 + 0.831\, T_m (°C) \qquad (1)$$

On the basis of the above equation a comfort zone has been suggested by this author for the inhabitants of Dhaka. These results are displayed in Table 2. The standard error of prediction has been put down as 1.1°C.

Although Humphreys[12] intends the above equations to form the basis of further research, their simple conclusions still lead to a satisfactory application to the Dhaka climate.

4 Application

In view of the inherent allowance for acclimatisation in Humphreys' work, it is now proposed as the best model for application to the Dhaka climate. Table 2 shows the daily mean temperature each month in Dhaka[4]. Using equation 1, the neutral temperature based on Humphreys' results has been calculated and included in the table. Using the tolerance band of ±2°C, the final column of Table 2 shows the proposed comfort zone. In fact these figures show reasonable agreement with the findings of Fanger[7] which demonstrate that a lightly clothed person can be comfortable at 29°C when the air speed is 1.5 m s^{-1} and an unclothed person can be comfortable at 32°C. Thus light, loose fitting clothing worn in Bangladesh may well give results in the range between 28°C and 32°C.

5 Conclusions

The derived comfort limits are of value to designers in predicting the possible extent of discomfort in any particular month. It is emphasised that the purpose of the above temperature limits is to provide a guide to likely tolerance of the climate within non-air conditioned buildings in Bangladesh.

Other significant factors (including respect of privacy, living patterns, window design, lighting, insulation and aesthetics) must also be considered and the experienced designer will balance the demands of many requirements according to the conditions of a particular brief.

Vernacular design is generally an evolved response to the overall basket of conditions in well established building types. It is where new building types are needed, or where less favoured sites must be used, that particular care must be taken to respond to the climatic and social requirements perceived.

An important role of the designer of buildings in Dhaka is to attempt to ensure that the building is able to modify the climate sufficiently to prevent the occurrence of temperatures outside the comfort zone without resorting to air conditioning.

Table 2 Monthly comfort zones in Dhaka, Bangladesh†

Month	Average temperature T_m (°C)	Neutral temperature T_n (°C)	Comfort zone (°C)
January	18.7	18.0	16.0–20.0
February	21.2	20.2	18.2–20.0
March	26.3	24.4	22.4–28.4
April	29.0	26.6	24.6–28.6
May	28.9	26.6	24.6–28.6
June	28.6	26.3	24.8–28.8
July	28.6	26.3	24.8–28.8
August	28.6	26.8	24.8–28.8
September	28.7	26.4	24.4–28.4
October	27.2	25.1	23.1–27.1
November	23.4	22.0	20.0–24.0
December	19.7	18.9	16.9–20.9

† Data of hourly variations of temperature are sparse, but assessments of outside peak temperatures suggest discomfort in the afternoons throughout the year. These effects may be moderated by the living patterns of the occupants and by the thermal inertia of the building structure.

References

1 Markus T A and Morris E N *Buildings, climate and energy* (Pitman) (1980) p 37
2 *ASHRAE Handbook and Product Directory: Fundamentals* (New York: American Society of Heating, Refrigeration and Air-conditioning Engineers (1985)
3 Ahmed Z N *The effects of climate on the design and location of windows for buildings in Bangladesh* MPhil Thesis Sheffield City Polytechnic (1987)
4 Private communication Bangladesh Meteorological Department, Dhaka, Bangladesh (1985)
5 Ali M M *Problems of ventilation in high density low-rise housing in Bangladesh (not humid)* MPhil Thesis, Newcastle-upon-Tyne University (1978)
6 Ahmed Z N op cit pp 42–58
7 Fanger P O Thermal comfort, analysis and applications in environmental engineering (London: McGraw Hill)
8 McIntyre D A *Chamber studies—reductio ad absurdum?* 5 (1982)
9 McGreevor P A The active pursuit of comfort; its consequences for energy use in the home *Energy and Buildings* 5 103–107 (1982)
10 Cooper I Comfort and energy conservation, a need for reconciliation? *Energy and Buildings* 5 83–87 (1982)
11 Humphreys M A and Nicol J F *J. IHVE* 38 181 (1970)
12 Humphreys M A *Field studies of thermal comfort compared and applied* BRE Current Paper 76/75 (Garston: Building Research Establishment) (1975)