

## Defining thermal comfort in residential buildings of North-East India

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### Abstract

Human spend most of time inside the buildings. It is an inherent nature of human beings to always look for an enhanced level of thermal comfort, which resulted in increased energy consumption of the buildings. Hence, it becomes a necessity to design building which provide optimal thermal comfort with minimum artificial energy consumption. North Eastern region of India is classified into three bioclimatic zones (*warm and humid, cool and humid and cold and cloudy*) at micro-climate level based on the 30 years climatic data. This classification provides specific information of each climatic zone. Different climate oriented features as well as solar passive features available in the vernacular architecture of the region along with their functionality are assessed. Thermal performance study is carried out into three vernacular houses one in each climatic zone. Detailed field study on thermal performances is carried out by measurements of environmental parameters, both at indoors and outdoors of the building, in the different seasons (January: winter season; April: pre-summer season; July: summer/rainy season; and October: pre-winter season) of a year. Simultaneously questionnaire based thermal comfort surveys have been carried out covering 300 subjects in all the seasons in these climatic zones. The comfort status and range of comfort temperatures are evaluated in these vernacular architectures bases on the field survey and thermal performance study. Detailed analysis of the data collected during comfort survey showed that PMV (Predicted Mean Vote calculated according to ISO 7730 standard) deviates from AMV (Actual mean vote recorded on 7 point ASHRAE sensation scale) for the same thermal environment. To explain this deviation a mathematical relation has developed to evaluate the corrective term called adaptive coefficient ( $\lambda$ ), which need to be added with PMV to get cPMV (Corrected Predicted Mean Vote). The value of " $\lambda$ " may be negative or positive depending on the adaptation level of the occupants. The information forthcoming from this study could assist in improving sustainable built environment design in North-East India.

### Introduction

Building energy consumption is increasing with the increasing demand for better thermal comfort inside the built environment. With rise in economic prosperity and changing lifestyle thermal comfort has become more prominent than ever before. It is an inherent character among the occupants that they try to achieve the desired level of thermal comfort by personal adjustments and mechanical means or both. Although personal adjustments are least energy consuming, mechanical means are energy intensive thus increasing the direct or indirect energy consumption of the building<sup>1,2</sup>. In today's scenario of global warming and climate change, the design of buildings which provide optimal thermal comfort by incorporating maximum flexibility for personal adjustments while minimizing the use of mechanical devices and thus the energy consumption has become critical<sup>2,3</sup>.

In India, with population growth, demand for housing and rapid urbanization has led to higher energy consumption in the building sector<sup>4</sup>. According to a Government of India report, 80% of the buildings that will exist by 2050 are yet to be constructed. In India building consumes around 35% of total energy with an annual growth rate of 8%<sup>5</sup>. At the same time, the market growth of air conditioning equipment is around 3% but its share of energy consumption is 31% in commercial buildings<sup>5</sup>. In North-East India, residential buildings are of vernacular architecture and mostly naturally ventilated. There are a very few buildings which operate on a mixed mode.

The use of vernacular architecture is very popular and widely used because it is economical and satisfies socio-cultural needs. In this context it becomes important to study the thermal comfort status of these residential buildings as well as characteristics of the occupant's interactions with the built environment.

### Methodology of the study

This study is done as a part of doctoral research (first author) covering different aspects of buildings. Each aspect is covered in a separate section. Specific climatic information plays an important role in designing climate responsive buildings. From the literature survey it was found that North-East India does not have a bioclimatic classification at micro-climate level. Therefore meteorological data for 30 years from 27 metrological stations across the region were collected from the Regional Metrological Centre, Guwahati and used to classify the region into different bioclimatic zones. Thermal performance study of the selected residential building was carried out by year-long thermal monitoring followed by a questionnaire based thermal comfort survey. Monitoring included measurements at 30 min interval of temperature (indoors and outdoors of the selected houses), relative humidity (indoors and outdoors of the selected houses) and illumination level (indoors of the selected houses) for 25 days in each of four seasons (January: winter, April: pre-summer/spring, July: summer/rainy and October: pre-winter/autumn) of a year using HOBO RH/Temp/Light/External Data Logger, USA. Questionnaire based thermal comfort survey were conducted in similar houses of each climatic zone to evaluate thermal comfort status in the residential houses and develop an adaptive thermal comfort model. Comfort survey was carried out in 150 households (50 houses in each climatic zones) covering 300 occupants (100

occupants in each climatic zone) following ASHRAE -55 Class II protocol.

### Results and discussion

#### Bioclimatic zones

The North-East region of India consists of eight states with an approximate area of 2,54,438 km<sup>2</sup>. Temperature, humidity and precipitation profile based on the 30 years data obtained from metrological stations were analyzed. Other parameters such as precipitation, wind direction, sky condition and vegetation were also considered for climate classification. On the basis of the present study North-East India is classified into three major bioclimates, a. Warm and humid, b. Cool and humid and c. Cold and cloudy as shown in Fig 1<sup>6</sup>. Specific information generated corresponding to each climatic zone is presented in Table 1<sup>6</sup>.

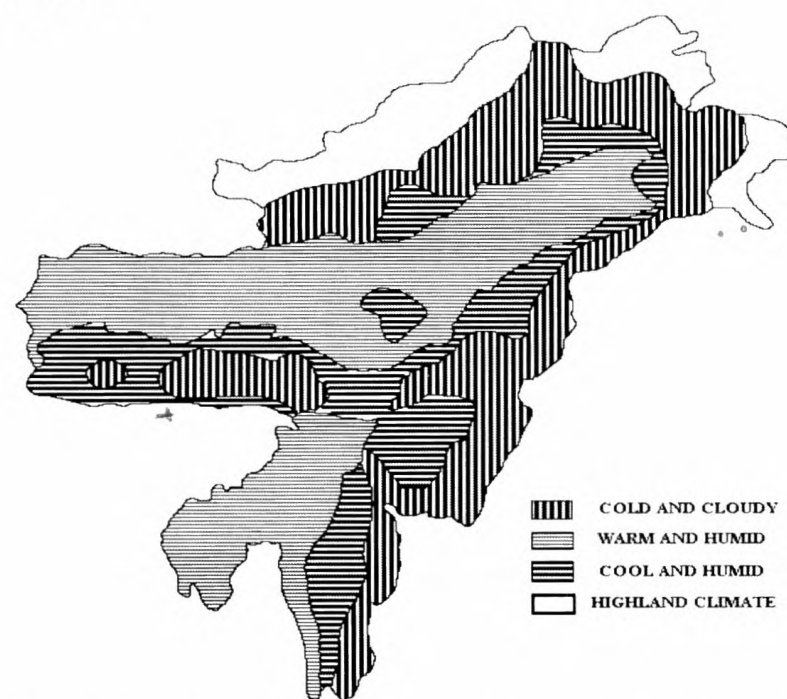


Fig. 1. Bioclimatic classification of North-East India<sup>6</sup>

Table 1. Specifications of bioclimatic zones of North-East India [6, 7]

Bio-climatic zones	Warm and humid	Cool and humid	Cold and cloudy
Temperature range	Summer Maximum 30° – 35°C Minimum 22° – 27 °C	Maximum 25° – 30°C Minimum 20° – 24°C	Maximum 20° – 25°C Minimum 14° – 19°C
	Winter Maximum 25° – 30°C Minimum 10° – 15°C	Maximum 20° – 25°C Minimum 10°C – 15°C	Maximum 15° – 20°C Minimum 5° – 10°C
Relative humidity (%)	75 – 90	75 – 95	80 – 90
Rainfall (mm)	1700 to 2100	1500 to 2000	>2000
Sky condition	Generally clear sky but overcast during monsoon	Generally clear sky but heavy overcast during monsoon	Occasionally clear sky but overcast sky rest of the year
Wind direction	Low wind during summer and from SE, N & NE direction	High wind during summer and from E, SW & W direction	Medium Wind from NE, SW & W direction
Vegetation	Heavy vegetation	Heavy vegetation	Heavy vegetation

*Bioclimatism and vernacular architecture*

The scientific basis for passive solar building design has been developed from a combination of local climate, solar heat gain or loss and human thermal comfort. Residential buildings of North-East India are of vernacular architecture, naturally ventilated and widely constructed<sup>7</sup>. A survey of buildings was carried out in three different climatic zones across North-East India to identify the solar passive and climate oriented features that dominate their residential building design. They are highlighted in this section. Buildings of the vernacular architecture in warm and humid climate are "U" shape and of elongated plan. The shape of the building allows most of its surface area to be exposed to the prevailing wind direction<sup>7</sup>. Vernacular building envelopes in this climate are massive in construction (Fig. 2). The massive walls are made of either mud or baked bricks, but all roofs are of light weight. Since this region receives heavy rainfall, the entrances to the houses are pulled inwards. To overcome this climatic constraint, all vernacular houses have slanting roofs facing two or four directions. In most cases, roofs are extended to act as an overhang to protect the wall from rainfall and also from direct solar radiation<sup>7</sup>. Shading plays an important role in modulating heat gain of the building. Vernacular houses of this climate have overhangs (Chajja) on windows and their roofs are extended outwards to act as overhang (Fig 2). The height of the ceiling and openings help in the formation of natural draught<sup>7</sup>. The warm air escapes through the opening and finally through chimneys and vents provided on rooftops as shown in Fig 3.

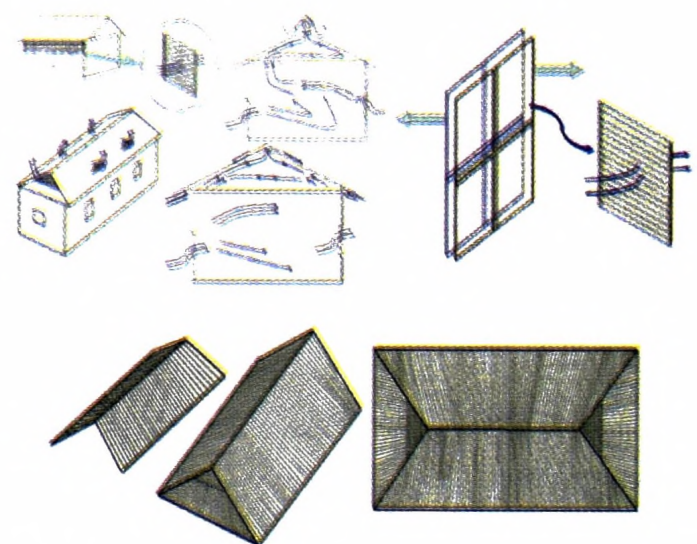
In cool and humid climate, the common layout of the vernacular architectures is 'L' shaped or

rectangular shaped (elongated plan). The orientations of houses are East-West and South facing to receive the maximum solar radiation<sup>7</sup>. L shaped house plans provide for a large veranda, which also acts as a buffer space and is easily modified to meet the requirements of different seasons of the year. Vernacular houses of this climate generally have light weight structures. Rural houses are on a wooden frame structure but urban houses have brick structures. The thickness of the external wall in urban house is 0.20 - 0.38 m but in rural houses, the external wall thickness is 0.07 - 0.13 m. Windows and doors in the vernacular architecture of this region are small. Ventilators are not present. Windows and doors are often completely made of wood<sup>7</sup>. Vernacular buildings use locally available building materials like cane, bamboo and wood.

In cold and cloudy climates, the layout of vernacular architecture is rectangular shaped with very few houses 'L' shaped<sup>7,8</sup>. Orientations of houses are a major concern in this climate. Almost all the houses are constructed on the southern slope of mountains, so as to receive the maximum available solar radiation. Houses are constructed in such a manner that they do not fall in the path of the prevailing wind. The external walls of buildings in this climate buildings are made up of rock slabs (cut in the shape of bricks). Thickness of the external walls is 0.25 - 0.30 m. The envelope is tightly constructed to minimize infiltration. Houses are generally constructed on a raised platform of wood and flooring is usually wooden. Vernacular houses of this climate also have slanting roof in two directions to overcome heavy rainfall as in other climates<sup>7</sup>.



**Fig 2** Vernacular architectures and solar passive features in warm and humid climate<sup>7</sup>



**Fig 3.** Shading, ventilation techniques and common roof patterns<sup>8</sup>

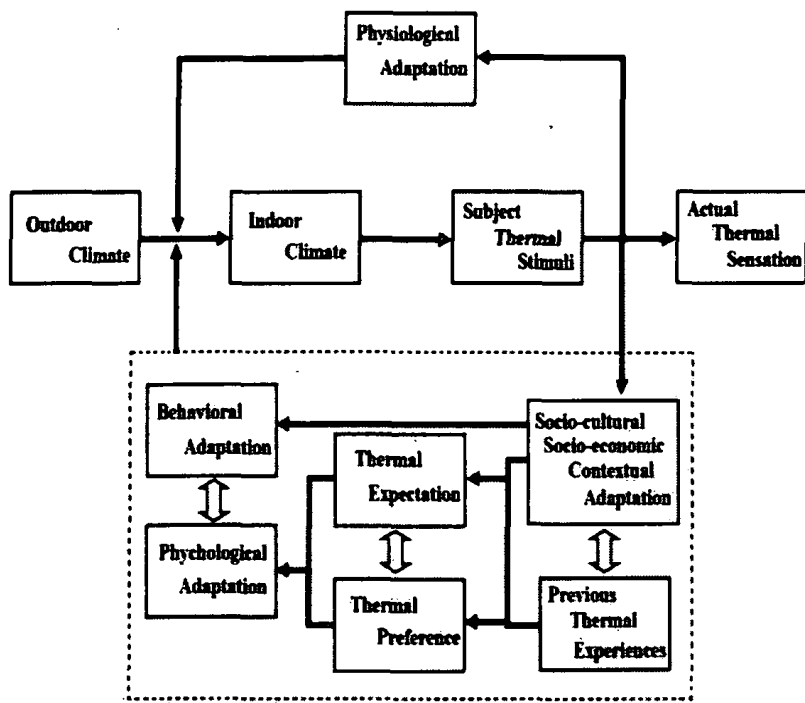


Fig. 4. Different adaptive actions interlinking<sup>12</sup>

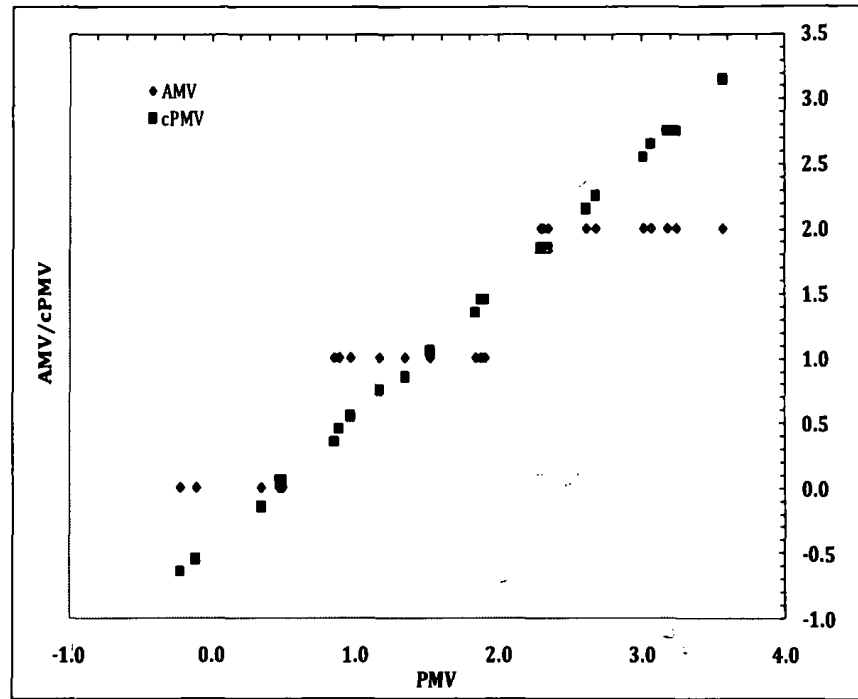


Fig. 5. Relationship between PMV, AMV and cPMV for warm and humid climate (summer)<sup>12</sup>

Table 2. Comfort survey indicators<sup>9</sup>

Climatic zone	Warm and humid	Cool and humid	Cold and cloudy
Clothing level (clo)	0.3	0.5	0.7
Metabolic rate (met)	1.0	1.0	1.0
Number of subjects	100	100	100
Number of houses	50	50	50
Survey time	January (winter), April (pre-summer), July (summer / monsoon) and October (pre-winter) months of 2008		
Respondent age (%)			
< 20 years	11	12	14
>20 – 40 years	77	70	63
> 40 years	22	18	23
Respondent gender (%)			
Male	65	51	42
Female	35	49	58

Table 3 Neutral temperatures and range of comfort temperatures based on survey in different climatic zones<sup>9</sup>

Station	Months	Neutral temperature (°C) (Regression analysis)	Neutral temperature (°C) (Survey)	Range of comfort temperature (°C)
Tezpur	January	26.0	NA	22.8 - NA
	April	26.1	26.1	24.0 - 28.4
	July	26.3	27.1	NA - 29.1
	October	26.1	26.1	23.7 - 28.4
Imphal	January	28.9	NA	21.1 - NA
	April	24.2	24.2	22.2 - 26.2
	July	25.5	25.2	23.5 - 27.6
	October	24.3	24.2	21.8 - 26.5
Cherrapunjee	January	22.2	20.8	19.0 - NA
	April	22.2	22.4	21.3 - 24.1
	July	23.4	23.2	22.1 - 26.2
	October	22.2	22.4	19.8 - 24.3

NA: Not available

*Thermal comfort assessment*

Objective and subjective measurements were carried out simultaneously during thermal comfort

surveys in four seasons of a year. Analysis of data was performed to assess the comfort status of the occupants living in these residential houses.

Thermal comfort indicators are shown in Table 2. Questionnaire for the comfort survey was designed following the informative index of ASHRAE standard 55. It was found that temperatures corresponding to comfortable thermal environment were not fixed but were a continuing response to changes in both indoor and outdoor environmental condition modified by climate and social custom (Table 3)<sup>9-12</sup>.

Neutral temperature is defined as the temperature at which a person feels thermally comfortable at fixed variables like environmental parameters, clothing and activity level<sup>9</sup>. Different respondents vote according to their own physiological, psychological and behavioral adaptations. Since the study is carried out on vernacular residential houses, it is found that when a respondent votes -1 on thermal sensation scale it actually means that although the respondent is feeling slightly cool, he/she can make himself/herself comfortable by putting on some warm cloths (increased clothing insulation), closing window (minimized air movement) and so on. If a respondent votes +1, it means that he/she will opt to decrease clothing level, drink water, open window, switch on ceiling fans etc. The temperature values corresponding to -1 and +1 sensation are always  $\pm 3^{\circ}\text{C}$  of neutral temperature<sup>9</sup>.

#### *Adaptive thermal comfort model*

According to ASHRAE 55-2013, thermal comfort is a subjective response and is defined as the '*state of mind that expresses satisfaction with existing environment*'<sup>12</sup>. A state of mind is widely driven by the perception and expectations of the occupants. So, the same thermal environment may be perceived differently by different occupants or different occupants may perceive the same thermal comfort level at different thermal environments<sup>12</sup>. The thermal sensation votes recorded on the ASHRAE 7 point scale during comfort survey is considered as the actual mean vote (AMV). The same sets of indoor environmental conditions are used to calculate Predicted Mean Vote (PMV). It has been found that there is a discrepancy between AMV and PMV values. The adaptive approach concept is based on the fundamental assumption that '*if a change produces discomfort, people reacts in ways which tend to restore their comfort*'<sup>12</sup>. The heat balance approach assumes occupants are passive to changes in the thermal environment while the adaptive model assumes that occupants are active in the built environment. Interlinking between different adaptive

opportunities and adaptation process is shown in Fig. 4<sup>12</sup>. Adaptive opportunities are broadly classified into three modes, namely a. behavioral adjustments, b. physiological adaptation and c. psychological adaptation. To develop an adaptive model, a correction factor called adaptive coefficient ( $\lambda$ ) is derived mathematically, calculated for each season and for each climate and added to PMV to match AMV values. The following equation shows the proposed adaptive thermal comfort model for North-East India.

$$\Rightarrow cPMV = \frac{PMV}{1 + \lambda \times PMV} \quad (\text{Eq. 1})$$

$$\text{where } \lambda = \frac{P_{\delta}}{\delta \times M} = \frac{P_{\delta}}{M} \left(\frac{1}{\delta}\right) = K \left(\frac{1}{\delta}\right)$$

There can be three different conditions for the adaptive coefficient ( $\lambda$ ). When the adaptive coefficient is positive, the indoor temperature is greater than comfort temperature. This is generally common in summer for naturally ventilated buildings. From Eq. 1, it is clear that when  $\lambda > 0$ , the value of cPMV is lower than that corresponding to PMV. From this, it can be concluded that cPMV gives a feeling of being cooler than PMV i.e. cPMV votes are towards comfort to that at same PMV. At  $\lambda < 0$  i.e. negative, it means the indoor temperature is lower than comfort temperature. This condition occurs in winter season for naturally ventilated buildings. From Eq. 1, it is seen that cPMV is giving a warmer feeling than that corresponding to PMV. Or, it can be conclude that the cPMV votes are towards comfort to that at same PMV. At  $\lambda = 0$ , it means the indoor temperature is equal to comfort temperature. This condition is practically impossible but theoretically possible. In this case, the cPMV is equal to PMV. Equation 1 used to calculate the corrected PMV values for three climatic zones are presented in Table 4. When this is corrected and PMV is plotted against AMV, it is found that the deviation that was appearing due to adaptation is not present (Fig. 5).

#### **Conclusions**

The north-east region of India is classified into three major climatic zones: warm and humid, cool and humid and cold and cloudy. This classification provides better representation and the required information to engineers, architects and designers about the potential of passive design strategies with respect to climatic zones. The buildings in a warm and humid bioclimatic zone show a number of solar passive features such as enhanced air circulation,

Table 4. cPMV formula at different climatic zones for various seasons<sup>12</sup>

Seasons	Climatic zone		
	Warm and humid	Cool and humid	Cold and cloudy
Winter (January)	$\frac{PMV}{1 - 0.9 \times PMV}$	$\frac{PMV}{1 - 1.68 \times PMV}$	$\frac{PMV}{1 - 0.9 \times PMV}$
Spring / pre-summer (April)	$\frac{PMV}{1 - 0.324 \times PMV}$	$\frac{PMV}{1 - 0.6 \times PMV}$	$\frac{PMV}{1 - 0.7 \times PMV}$
Monsoon / summer (July)	$\frac{PMV}{1 + 0.444 \times PMV}$	$\frac{PMV}{1 + 0.2 \times PMV}$	$\frac{PMV}{1 + 0.1 \times PMV}$
Autumn / pre-winter (October)	$\frac{PMV}{1 - 0.268 \times PMV}$	$\frac{PMV}{1 - 0.4 \times PMV}$	$\frac{PMV}{1 - 0.7 \times PMV}$

promotion of natural ventilation, reduced heat gain and effective shading mechanisms, etc. In vernacular architecture of cool and humid zone, transition spaces in terms of verandas, corridors, etc. have very limited use. Vernacular architecture of cold and cloudy climate zone is greatly influenced by the prevailing climatic conditions. Minimizing heat loss features are dominant in building plans in this zone. From the comfort study results, it can be observed that the neutral temperature corresponding to each month in each climatic zone varies by  $\pm 2^\circ\text{C}$  in comparison with the same month in other climatic zones being of higher value in warm and humid climate and lower value in cold and cloudy climate. It is also found that, in all three climatic zones the range of comfort temperature lies between  $6^\circ\text{C}$  and  $7.3^\circ\text{C}$ . This allows greater flexibility to engineers and architects to design buildings with more energy saving

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options by introducing solar passive features in the building. It is also observed from the adaptive comfort study that PMV underestimates and overestimates the indoor thermal environment compared with that of AMV in winter and summer respectively. Theoretical adaptive thermal comfort models have been developed and the corrected predicted mean vote (cPMV) is calculated. The different values of the adaptive coefficients suggest that the occupant adopts different level of adaptations in different climatic zone and in different seasons of the same climatic zone. These adaptive coefficients also take into account the local climate and socio-cultural setup. The authors expect that the outcome this study will help in understanding the complexity of residential buildings and the comfort expectations of occupants. It will also help in designing sustainable buildings in North-East India.

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