THERMAL ACCEPTABILITY ASSESSMENT IN VERNACULAR BUILDINGS OF COLD AND CLOUDY REGION OF NORTH-EAST INDIA

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Abstract

Thermal performance study is one of the critical aspects of the natural ventilated vernacular buildings. Thermal comfort studies of built environment mainly focussed on two different approaches, one is heat balance approach and the other is adaptive approach. Thermal comfort survey has been carried out in 50 houses covering over 100 occupants of cold and cloudy climatic zone of North East India. This comfort study has been done in the form of long term thermal monitoring at outside and inside of a house, comfort survey based on ASHRAE thermal sensation scale for different seasons of the year. Comfort temperatures are calculated based on Humphreys and Auliciems comfort model. Neutral temperatures at which people feels comfortable in this natural ventilate buildings are obtained from the comfort survey. It has been found that the comfort temperature obtained from the Humphreys and Auliciems comfort model differs with the neutral temperatures obtained from comfort surevy. There are four major indicator like outdoor and indoor temperatures, relative humidity and clothing pattern of the peoples has direct impact on the peoples perception and acceptabilty on comfort situtaion. In this study, thermal comfort equations are developed based on these four indicator and validated with the neutral temperature obtained from comfort survey. It has been found that the comfort equation developed with all these four indicators has highest co-relation coefficient and provide the neutral tempartures values very close to thermal comfort survey results. However, these equations are valid only for similar kinds of natural ventilated buildings and also for similar kinds of building functioning management of this climatic zones. It is also not appropriate to obtaine a genralized thermal comfort model as the adpation process and the expectation and perceptation of the peoples are region specific and also differs with socio-cultural norms.

1. Introduction

Building, energy and environment are closely related and affect energy and environmental sustainability of a region. Buildings are generally synonyms of comfort as men spent about 90% of his life time in built environment. So, it becomes a pre-requisite to provide the desired level of comfort inside the building. The definition of acceptable indoor climate in building is very much important for not only making it comfortable, but also in deciding its artificial energy consumption. According to ASHRAE-55, thermal comfort is defined as '*the conditions of the mind in which satisfaction is expressed with the existing thermal environment*' (ASHRAE-55, 2010). This standard also states that if the combination of indoor environmental conditions and personal acceptance to 80% or more occupants, indoor environment is termed as comfortable. However, the standard never precisely defines '*acceptability*'. Thermal comfort research community commonly consider that '*acceptable*' is synonymous with '*satisfaction*' and thus is indirectly related to thermal sensation (Auliciems, 1981; Nicol and Humphreys, 2002; Singh et al., 2011). One of the major issues concerning thermal comfort is the conflict in conditioned buildings, where the indoor built environment is controlled to nearly constant levels of air temperature in accordance with the occupant's behaviour and clothing. On the other hand, in naturally ventilated buildings, where adaptive approaches are dominant and people has option to adapt a wider range of temperatures that compliment to their culture and climates and is less energy demanding (de-Dear and Brager, 2002). People have a natural tendency to adapt to changing conditions of their environment. It is also influenced by personal differences in habitant's mood, culture and other individual, organizational and social factors. Thus the definition of thermal comfort provides a broad perspective based on the judgement of mind which intern is influenced by various inputs such as physical, physiological, psychological and regional factors (like local climate, socio-economic, socio-cultural etc.) (de Dear and Brager, 2001; Singh et al., 2009b). Recent studies carried out on thermal comfort in different parts of the world conclude that there is no absolute standard for thermal comfort. This is because thermal comfort depends on local environmental as well as personal variables (Brager and de Dear, 1998). It is evident from the various studies that human thermal comfort is the main driving force behind the enormous increase in energy cost of buildings (Humphreys and Nicol, 2002). This is also intern responsible for huge economic and environmental cost due to high energy consumption. With the rising concern on environmental and economic sustainability, extensive study covering different aspects related to thermal comfort in the built environment has been carried out by large number of scientists for decades (de-Dear and Brager, 2001; Humphreys and Nicol, 2002; de-Dear and Brager, 2001; Singh et al., 2011).

The adaptive approach is based on statistical analysis of large number of thermal comfort field studies. Field studies have more immediate relevance to real thermal environment, which strongly depends on the context, the behaviour of occupants and their expectations. Humphreys and Auliciems both reported strong positive correlations between the observed comfort temperature and the mean temperature prevailing in indoors and outdoors during field studies (de Dear et al., 1997). However, in these studies, two other important parameters, relative humidity and clothing levels of the occupants based on traditional life styles has not considered (Franger and Toftum, 2002). Recent studies carried out on thermal comfort in naturally ventilated buildings states that adaptive actions and opportunities plays a major role in defining comfort status in naturally ventilated buildings. The adaptive factor and the extent of adaptation, an occupant goes through over a period of time and in different seasons of a year is very difficult to define and calculate mathematically (Singh et al., 2011). This is because of the complex interlinking of different adaptive opportunities and actions of the occupants. The flow of information that governs the actions of occupants is also influenced by perception and expectations. This makes the system more complex to formulate it in a mathematical model (Singh et al., 2011). However, this problem can be overcome by applying multiple regression technique to analyse the collected data during different field experiments and surveys. First of such attempt was being carried out by Humphreys on the available database of more than 30 comfort surveys done around the world (de-Dear and Brager, 2001).

In this study appropriate correlation among major factors (indoor and outdoor mean temperatures, clothing values and relative humidity) has been tried to develop by using multiple regression technique that primarily define comfort in naturally ventilated buildings. A detailed field study on thermal performances of typical traditional vernacular dwellings in cold and cloudy climatic zones of North-East India has been undertaken. This field study includes detailed survey of 50 vernacular dwellings, field tests and thermal sensation vote of 100 occupants on ASHRAE thermal sensation scale in this climatic zone. This work includes the analysis on different comfort models, predictive formulae development based on indoor and outdoor mean temperatures, relative humidity, clothing value, statistical analysis on calculated neutral temperature and thermal comfort acceptability based on comfort survey in the buildings for cold and cloudy climatic zone of North-East India.

2. Comfort models

Thermal comfort studies of built environment mainly focussed on two different approaches, one is heat balance approach and the other is adaptive approach. Heat balance study has been widely used but adaptive approach is also slowly getting acceptance. Various studies on thermal comfort have been done in the last decade is based on adaptive approach. However, both these approaches have their own advantages and limitations. An extensive study on thermal comfort was done by Fanger on large numbers of Danish students, subjected to controlled climate chambers. In this experiment, clothing level, activity level and thermal environment were pre-defined and closely monitored. This laboratory based study leads to the development of static heat balance model of human body (Franger, 1986). Fanger's model combines the heat balance theory with the physiology of thermal regulation to determine the range of comfort temperatures in which the occupants of a building would had feel comfortable. This model is described as a function of four environmental variables, i.e. temperature, mean radiant temperature, relative humidity and air velocity. Fanger's experiments concluded that activity level is the only physiological process that determines the sweat rate and mean skin temperature thus influencing the heat balance of the body. The mathematical relations lead to the development of seven point ASHRAE thermal sensation scale ranging from cold (-3), cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3). This scale is also known as Predicted Mean Vote (PMV) index and leads to the development of Predicted Percentage of Dissatisfied (PPD) index (ISO 7730, 1994).

PMV-PPD indices were first proposed in the form of standard ISO 7730 (ISO 7730, 1994). Laboratory studies support the validity of ISO 7730 but field study often deviates (Humphreys and Nicol, 2002). Field study conducted on thermal comfort by many researchers put PMV-PPD model into question (Brager and de Dear, 1998; de Dear and Brager, 2002; Humphreys and Nicol, 1998, 2002; Sharma and Tiwari, 2007; Sharma and Ali, 1986; Singh et al., 2011). The reasons behind this deviation is that the PMV-PPD indices calculation process require the knowledge of clothing insulation and metabolic rate which are very difficult to calculate because of complex calculation procedure. Also PMV-PPD model ignores the important parameters such as cultural, climatic, social and contextual dimensions of comfort and thus denying all processes of thermal adaptation (Olesen and Pearson, 2002; Singh et al., 2011). Though PMV-PPD method is a breakthrough in the understanding and defining the thermal comfort in built environment but has its own limitation. The PMV-PPD model is useful only for predicting steady state comfort responses (Franger and Toftum, 2002). In the recent time, number of studies conducted on naturally ventilated buildings (transient built environment) showed that the results obtained by adopting PMV-PPD method deviate widely in predicting the persisting thermal environment (Nicol and Humphreys, 2002; Singh et al., 2009b; Singh et al., 2011).

The fundamental assumption behind the adaptive approach is that *'if a change produces discomfort, people reacts in ways which tend to make them restore their comfort'* (Humphreys and Nicol, 2002). The definition of adaptive principles points towards the need of thermal comfort study based on field surveys conducted in wide range of environments. The meta-analysis of such data were reported by Humphreys (1976, 1978), Auliciems and deDear (1986) and de Dear and Brager (1998) (de Dear et al., 1997). Meta-analysis of data helped to link comfort vote to the respective adaptive actions of the occupants in particular context. The occupants with more adaptive opportunities to adapt themselves to the environment will feel less discomfort (Humphreys and Nicol, 1998). Humphreys developed a model using the available database of more than 30 comfort surveys done around the world. Humphreys proposed a series of simple correlations of thermal comfort prediction. The comfort temperature (T_{co}) can be estimated from mean monthly outdoor temperature (T_m) in °C, using the following equation for naturally ventilated buildings. The prediction claims to have a standard error of 1°C and applies to temperature range of $10°C < T_m < 34°C$.

$$T_{CO} = 11.9 + 0.53 \times Tm \qquad (r=0.97) \qquad (eq. 1)$$

Auliciems tried to reanalyze the Humphrey's data by removing some incompatible information. These results are based on more recent field studies and combined the data for both types of buildings with active and passive climate control. The absence of thermal discomfort is predicted by simple equation in terms of mean indoor (T_i) and outdoor temperature (T_m) in °C (Auliciems, 1981; Nicol and Humphreys, 2002).

$$T_{CO} = 9.22 + 0.48 \times T_i + 0.14 \times Tm \qquad (r=0.95) \qquad (eq. 2)$$

Adaptive thermal comfort approach put-forth the need of an alternative standard that would have more relevance to the variable indoor environment like in naturally ventilated building with hybrid ventilation and other contextual adaptation in which occupants have better degrees of control over indoor climate (Milne and Givoni, 1979). Variable temperature standard like adaptive model links indoor climatic condition with outdoor climatic context of the building and takes care of the past thermal experiences and current thermal expectations of the occupants (Singh et al., 2010). Although these field study on thermal comfort does validate adaptive thermal comfort in conditioned building but the question remains as how long this adaptive model will continue to suit in the new buildings where occupants clothing patterns, activity patterns and expectations levels are changing continuously and rapidly (Humphreys and Nicol, 2002). Adopting adaptive thermal comfort approach, it is also may not be possible to assign a single value to adaptive comfort standard because the adaptation is region specific and highly influenced by the local climatic conditions and socio-cultural setup (Bouden and Ghrab, 2005; Singh et al., 2011).

3. Methodology

North-East region of India is classified into three bioclimatic zones: *warm and humid, cool and humid and cold and cloudy* (Singh et al., 2007). Vernacular houses of North-East India across the climatic zones are widely varied in its built forms and functionality. The methodology of this study includes the thermal monitoring of vernacular houses of cold and cloudy zone in all the seasons and simultaneously carrying out the questionnaire based thermal comfort survey. Questionnaire based thermal comfort survey has been conducted in similar houses of this climatic zone followed by extensive interaction with the occupants of these buildings. Comfort survey for this study has been carried out in 50 houses covering over 100 occupants. The questionnaire was prepared based on ASHRAE 55-2004 Informative Appendix E '*Thermal Environment Survey*' (ASHRAE 55, 2010). The regional parameters like socio-economic and socio-cultural setup that affects the thermal comfort perception were also added as necessary modification in the questionnaire. This addition makes the study more relevant and appropriate to this region. The respondents were asked to vote on ASHRAE 7 point thermal sensation scale followed by extensive interaction and filling up the questionnaire. This interaction helped us to record the common behavioural adaptations. Before recording thermal sensation, the respondents were advised to sit ideal for about 20 minutes. This is necessary protocol to minimize the error and to maintain uniformity throughout the study. The surface temperatures of the enclosure surrounding the respondent (i.e. if the respondent is sitting in the living room on wooden chair then the surface temperature of chair, surface temperatures of nearest wall, floor temperature, if the window is closed then temperature of curtain) were recorded by non contact infra-red thermometer and air temperatures (five times) by digital thermometer during this survey process. The average of these five measured temperatures is used for the analysis. Similarly, the relative humidity, clothing level and illumination level were also measured. The temperatures corresponding to comfortable thermal environment are not fixed but are continuing response to changes in both indoor and outdoor environmental condition modified by climate and social custom. Sudden changes in the ambient temperature imposed on the occupants actually lead to discomfort (de Dear et al., 1997). Respondents are allowed to wear the normal clothing according to their cultural, social and traditional setup. The opening and closing of doors and windows are not controlled but the operation of fan is not allowed during the thermal sensation vote recording.

4. Thermal monitoring and comfort survey

This section explains about the various analyses that have been carried out on the collected data. Long term thermal monitoring is being carried out at outside and inside of a house at cold and cloudy climate for the months of January (12^{th} January to 6^{th} February), April (6^{th} April to 30^{th} April), July (8^{th} July to 6^{th} August) and October (14^{th} October to 8^{th} November) of the year 2008. The outdoor temperature swing for the months of January, April, July and October are 16°C, 19°C, 10°C and 7°C respectively. Similarly indoor temperature swings for the months of January, April, July and October are 11°C, 10°C, 7°C and 7°C respectively (Singh et al, 200b). It is observed that for all the four months the indoor temperature swing lies in permissible range for naturally ventilated buildings. The time lag in this kind of vernacular house is 5 to 6 hours. Relative humidity is always high throughout the year in this climatic zone. These high values of relative humidity also affect the thermal comfort perception of the occupants. Clothing level adjustment is the important adaptation process to maintain the comfort at different temperature. During the comfort survey, it has been found that clothing values are largely scattered from 0.3 clo in summer to 1.5 clo in winter in this climatic zone (Singh et al, 200b).

Comfort temperature is calculated based on Humphreys and Auliciems adaptive comfort model. However, in the case of naturally ventilated buildings, it is always advisable to apply the concept of *range of comfort temperatures*. Here the term '*range of comfort temperature'* is used because it involves the physiological, psychological and behavioural adaptations of the habitants. It is found that in vernacular buildings, when a respondent votes -1 on thermal sensation scale it actually means that; though respondent is feeling slightly cool but he/she can make himself/herself comfortable by putting on some warm cloths (increasing clothing insulation), closing window (minimizing air movement) and so on. And if a respondent votes +1, means he/she will opt for decreasing clothing level, drinking water, opening window, running ceiling fans etc. The temperature values corresponding to -1 and +1 sensation are always ±3-3.5°C of neutral temperature. Neutral temperature is defined as the temperature at which a person feels thermally comfortable at fixed variables like environmental parameters, clothing and activity level. Since clothing and activity levels are region specific and driven by socio-cultural setup and climate, it is very difficult to find a single value for comfort temperature universally. Different respondents vote according to their own physiological, psychological and behavioural adaptations. Because of this fact, it has been found that at same temperature; different respondents have different thermal sensation or same thermal sensation at different temperatures. The neutral temperatures are calculated by using linear regression analysis between observed thermal sensation votes (TSV) as dependent variable on Y-axis and dry bulb temperature (DBT) as dependent variable on X-axis. In most of these regression plots, the R^2 value is close to 0.9 representing a strong positive correlation between these two parameters. Table 1 represents the comfort temperature based on adaptive comfort models, neutral temperature based on the regression analysis and also based on the comfort survey and also represents the range of comfort temperature based on the comfort survey for various seasons (Singh et al, 200b). It is also observed that the range of comfort temperature in this climatic zone is approximately 7.2°C i.e. minimum temperature corresponding to -1 sensation is 19.0°C in winter season and maximum temperature corresponding to +1 sensation is 26.2°C in summer season. So, for comfortable indoor environment the indoor temperature fluctuation should not be more than 7.3°C.

Table 1 Comfort and neutral temperatures at different seasons (Singh et al, 200b)

Season / month	Temperature swing (°C)		Comfort temperature (°C)		Neutral temperature (°C)		Range of comfort temperature (°C)
	Outside	Inside	Humphreys	Auliciems	Comfort survey	Regression analysis	
Winter /January	16	11	18.0	18.1	20.8	22.2	19.0 - NA
Pre-summer /April	19	10	21.8	23.9	22.4	22.2	21.3 - 24.1
Summer/July	10	07	22.7	23.7	23.2	23.4	22.1 - 26.2
Pre-winter/October	07	07	22.3	23.3	22.4	22.2	19.8-24.3

5. Analysis

Humphreys comfort model uses mean monthly outdoor temperature to predict comfort temperature whereas Auliciems comfort formula consider mean indoor temperature and mean outdoor temperature (Auliciems, 1981; Nicol and Humphreys, 2002). The comfort temperatures are calculated based on these two models and presented in Table 1. It is found that the comfort temperatures calculated by using Humphreys and Auliciems deviates from experimental values (neutral temperatures obtained through comfort survey) and also predict low percentage of comfort time in these houses (Singh et al., 2009b). Recent studies also conclude that comfort temperatures of the occupants are largely governed by local parameters like local environmental parameters, socio-cultural setup, behavioral action, activities and clothing etc (Nicol and Humphreys, 2009). The probable reasons behind this deviation are due to the difference in local environmental parameters and other associated parameters. This demands development of new set of comfort relations which includes the local parameters of a particular climatic zone. In this study, it has been tried to use the experimental data and derived different thermal comfort equations to predict comfort temperatures for different seasons of a year for this particular climatic zone. The predicted equation with highest correlation coefficient is found to be the best in representing the experimental values.

Figure 1 represents the average indoor and outdoor temperatures, average relative humidity, clothing value and neutral temperature from comfort survey for the different seasons. In developing these formulas, the first issue was to find out, which parameters could be the best serve as a basis for the prediction? This involves the analysis of the patterns of the relationship between the neutral temperature and the parameter of interest. This analysis is performed by plotting the different parameters of interest over the background of the neutral temperatures. Once this pattern is found satisfactory, then it is a relatively simple matter to express it in a mathematical relation. The constants of the formulae are specific to particular building or group of similar kinds of buildings and the similar functional management of the houses for a particular climatic zone. Figure 2 represents the neutral temperatures obtained by using the different parameters of interest such as average of indoor and outdoor temperature, relative humidity and clothing value. Multiple regression analysis on the collected data of January and July month is performed to develop the predicted formula and validate with the neutral temperature for April and October months. The following combinations are used for the regression analysis.

The predicted formula is developed by using the 24 hrs average outdoor temperature (T_0) and presented in equation 3. The coefficient of co-relation for this regression analysis is 0.89.

$$T_n = 17.86 + 0.22 \times T_0 \qquad \text{(eq. 3)}$$

The predicted formula is developed by using both 24 hrs average outdoor and indoor temperatures (T_i) and presented in equation 4. The coefficient of co-relation for this regression analysis is 0.89.

$$T_n = 17.91 - 0.03 \times T_i + 0.25 \times T_0 \qquad \text{(eq. 4)}$$

The predicted formula is developed by using both 24 hrs average outdoor and indoor temperatures (T_i) along with the average relative humidity (Rh) and presented in equation 5. The coefficient of co-relation for this regression analysis is 0.92.

$$T_n = 17.27 - 0.07 \times T_i + 0.26 \times T_0 + 0.02 \times Rh \qquad \text{(eq. 5)}$$

The predicted formula is developed by using both 24 hrs average outdoor and indoor temperatures (T_i) along with the clothing level (*clo*) and presented in equation 6. The coefficient of co-relation for this regression analysis is 0.94.

$$T_n = 15.69 - 0.14 \times T_i + 0.42 \times T_0 + 1.55 \times clo \qquad \text{(eq. 6)}$$

The predicted formula is developed by using both 24 hrs average outdoor and indoor temperatures (T_i) along with the clothing level (*clo*) and relative humidity and presented in equation 7. The coefficient of co-relation for this regression analysis is 0.97.

$$T_n = 15.15 - 0.18 \times T_i + 0.43 \times T_0 + 0.02 \times Rh + 1.51 \times clo \qquad \text{(eq. 7)}$$

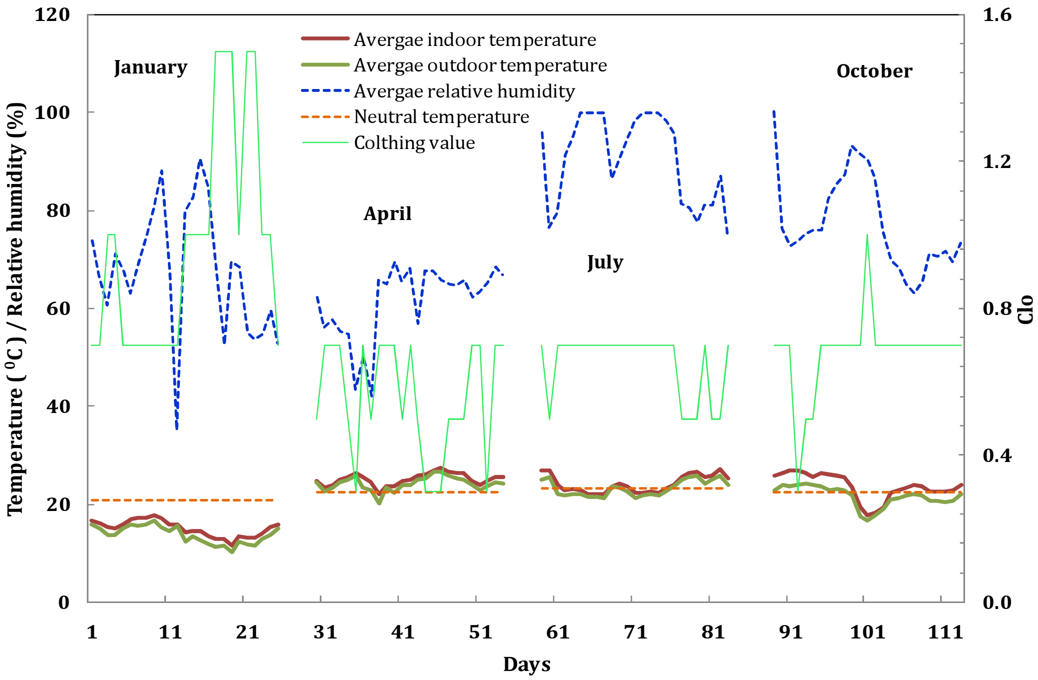

Figure 1 Average indoor and outdoor temperatures, relative humidity, clothing value and neutral temperature (comfort survey)

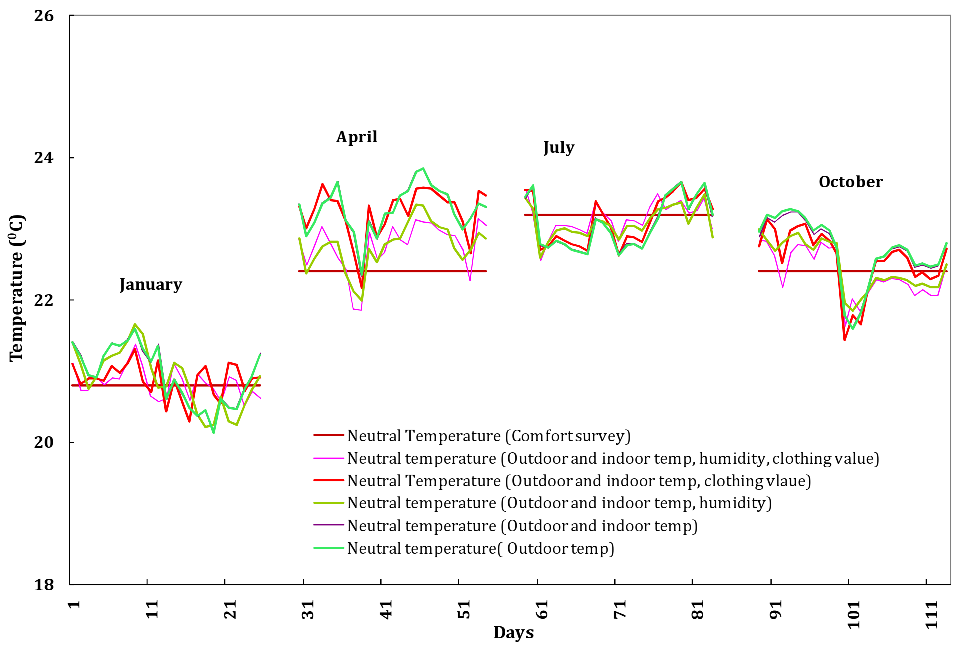

Figure 2 Computed neutral temperatures and from comfort survey

6. Results and discussions

Thermal performance study is one of the critical aspects of the vernacular buildings. Thermal performance study is carried out by recording temperature data both inside and outside of the houses and monitoring the functioning of various adoptions adapted by the occupants in all the four seasons. From the temperature profile, it is observed that the maxima of outdoor temperature and maxima of indoor temperature have a time difference of 5 to 6 hours (Singh et al, 2009b). This time difference or time lag provides critical information regarding the insulation level of the house. It is observed from the thermal profile that in winter months the outdoor maximum and indoor maximum temperature difference is less, which predicts that the building is using maximum available sunlight to increase heat gain inside the built space. In summer months it shows that the thermal capacitive effect affecting the sensitivity of indoor temperature to the outdoor temperature because difference between indoor maximum to that of outdoor maximum temperature and indoor minimum to that of outdoor minimum temperature has increased. Relative humidity data collected during the monitoring work is presented in Figure 1.

Clothing level adjustment comes under behavioral adaptation process. Behaviour adjustment includes all the actions taken by the occupant consciously or unconsciously which intern affects the heat and mass flow fluxes of the governing body. The behavioral adjustment acts on three levels namely: personal level, technological level and cultural adjustment. Out of these adjustments, personal level and cultural adjustments regulate the clothing level of the habitats. Figure 1 presents the variation of clothing value with the different seasons during the comfort survey. In other way, this profile clearly states the relationship between the clothing level and outdoor temperature in cold and cloudy climatic zone. This profile helps us to identify the most preferred clothing level according to the local climates, socio-cultural and traditional setup in this climatic zone. From the regression analysis, it has been found the most preferred clothing level for cold and cloudy climatic zone is 0.7clo for all the different seasons.

Table 2 Calculated neutral temperatures for different season

Month / season	Neutral temperature (^{0}C)						
	Comfort survey	Computed					
			OIHC	OIC	OIH	OI	O
January/ Winter	20.8	Average	20.8	20.9	20.9	20.9	20.9
		SD	0.22	0.24	0.42	0.41	0.41
		Range	20.5 - 21.4	20.7- 21.3	20.5 - 21.7	20.8 - 21.6	20.8 - 21.6
April/ Pre-summer	22.4	Average	22.8	23.3	22.8	23.3	23.3
		SD	0.35	0.35	0.32	0.33	0.33
		Range	21.9 - 23.2	22.2 - 23.6	22.0 - 22.9	22.3 - 23.4	22.4 - 23.4
July/ Summer	23.2	Average	23.2	23.1	23.1	23.1	23.1
		SD	0.23	0.34	0.22	0.36	0.36
		Range	22.6 - 23.6	22.7 - 23.6	22.6 - 23.4	22.8 - 23.4	22.8 - 23.5
October/ pre-winter	22.4	Average	22.4	22.6	22.5	22.7	22.7
		SD	0.35	0.44	0.35	0.45	0.47
		Range	21.6 - 22.9	21.4 - 22.8	22.0 - 23.0	21.8 - 22.9	21.8 - 23.0

It is found from the analysis that Humphreys and Auliciems model predict neutral temperature quite well for summer months. However, for winter months, it fails to predict the neutral temperature. To judge the effectiveness of Humphreys and Auliciems comfort model in determining the comfort duration in different seasons of the year, it is found that both the model predicts low percentage of comfort in the vernacular buildings of this region. In this climatic zone, Humphreys and Auliciems adaptive comfort model predicts 5% comfort time for the month of January. For the month of April, both models predicts about 70% of the time comfortable. But for the month of July, Humphreys model predicts 25% of the time comfortable and Auliciems model predicts 15% of the time comfortable. Again for the month of October, Humphreys and Auliciems model predicts 10% and 15% time comfortable respectively (Singh et al, 2009b). This is obvious because, as we know that comfort is governed by local parameters and personal controls and the relation developed by Humphreys and Auliciems are based on the data collected during different field surveys on European subjects. This discrepancy leads us to develop new set of co-relations based on the major influencing parameters. However, one interesting pattern is observed in the neutral temperature across all the seasons of the year that the neutral temperature assumes lower value in winter month and higher value in summer months. This trend is observed because comfort is a subjective response and is greatly affected by perception and expectations of the occupants about the indoor environment and subsequently indoor environment is influenced by the persisting outdoor environment in case of naturally ventilated building. This point also validates the adaptive thermal comfort study.

Comfort temperature is an important parameter which has far reaching effect on the function and running cost of the buildings. It is generally assumed that comfort temperature is same as neutral temperature. But in our previous study, it is successfully reported that neutral temperature and comfort temperature can be treated as separate entity (Singh et al., 2009b). The occupants in naturally ventilated building go through a wide range of adaptations mechanism, in comparison to the occupants of conditioned buildings. Because of this the occupants of naturally ventilated buildings vote towards comfort over a range of temperatures. In the comfort survey, it has found that the people tend to make themselves comfortable even if they have voted –1(slightly cool) or +1(slightly warm) on the ASHRAE seven point thermal sensation scale. This is where the occupants of naturally ventilated building use their adaptive opportunity to great extent. This interesting trend is observed during the interaction with the occupants. So, it can be conclude that the neutral temperature can be assigned to a particular temperature but the comfort needs to be represented over a range of temperature. From the analysis, it is found that for cold and cloudy climatic zone the range of comfort temperature is 7.2^{0}C.

Figure 2 represent the computed neutral temperatures from regression relations. The four major variables indoor and outdoor house temperature, relative humidity, clothing value for all the seasons are used to develop these regression analyses. The correlation coefficients (CC) are calculated for each case. The experimental data for January and July months are used to develop this regression equation. And later these regression analyses validated with the April and October months. It is observed that the relations are quite good agreement with the results of April and October months. High CC value indicates the existence of strong positive correlation among the variables.

Table 2 represents the computed average neutral temperatures, range of the neutral temperature and standard deviation of these temperature data for each season. The neutral temperature based on indoor and outdoor temperatures, relative humidity and clothing value (OIHC) is obtained by using equation 7. The computed neutral temperature and the neutral temperature from the comfort survey are fairly has good agreement. The range of variation of computed neutral temperature is 0.9 - 1.3^{0}C for all seasons. The neutral temperature based on indoor and outdoor temperatures and clothing value (OIC) is computed by using equation 6. The range of variation of the computed temperature is 0.6 - 1.9 ^{0}C for all seasons. The neutral temperature based on indoor and outdoor temperatures and relative humidity (OIH) is computed by using equation 5. The range of variation of the computed temperature is 0.8 - 1.2 ^{0}C for all seasons. The neutral temperature based on indoor and outdoor temperatures (OI) is computed by using equation 4. The range of variation of the computed temperature is 0.6 - 1.1 ^{0}C for all seasons. The neutral temperature based on only outdoor temperatures (O) is computed by using equation 3. The range of variation of the computed temperature is 0.7 - 1.2 ^{0}C for all seasons. The CC for the regression equation considering all the variables (OIHC) is 0.97 and for only variable outdoor temperature is 0.89. Similarly, the standard deviation in case of OIHC is minimum in comparison to other cases. So, it can be conclude that the predicted relation for neutral temperature based on all four variables provides better results in compare to other cases. However, in real situation, it may not be always possible to have database for the entire major variable for a climatic zone.

Table 3 Comfort and neutral temperatures at different seasons

Month / season	Comfort temperature (°C)		Comfort survey (°C)	Computed neutral temperature (^{0}C)				
	Humphreys	Auliciems		OIHC	OIC	OIH	OI	O
Winter /January	18.0	18.1	20.8	20.8	20.9	20.9	20.9	20.9
Pre-summer /April	21.8	23.9	22.4	22.8	23.3	22.8	23.3	23.3
Summer/July	22.7	23.7	23.2	23.2	23.1	23.1	23.1	23.1
Pre-winter/October	22.3	23.3	22.4	22.4	22.6	22.5	22.7	22.7

Table 3 represent a comparison of neutral temperatures calculated by different comfort equations including the comfort equations proposed in this paper. From the table, it can be concluded that the neutral temperature value calculated by equation 7 under column OIHC (which includes indoor and outdoor temperatures, relative humidity and clothing value) provides the closest values to that of found in comfort survey. Hence it can be concluded that the argument put forth by us to include all the four parameters in the comfort equations as it provides more acceptable and better results.

7. Conclusion

This study is being carried out to develop thermal comfort equation based on four major variables like indoor and outdoor temperatures of the house, relative humidity and clothing pattern at different seasons for vernacular houses of cold and cloudy climatic zones of North-East India. It has been found from the analysis that the parameters like indoor and outdoor temperatures; clothing value and relative humidity are the most important parameters that influence the thermal comfort of the occupant. These parameters are localized and thus suit the argument that comfort is governed by local environmental parameters and socio-cultural setup. These thermal comfort equations are developed by multiple regression method. Validation of the developed equations against the data collected during the comfort survey shows high fair of agreement. This provides better accuracy over Humphreys and Auliciems comfort model for predicting the comfort status in the built environments of this climatic zone. It is also tried to match the comfort temperature obtained from these equations with the neutral temperature obtained from comfort survey. However, to improve the accuracy of the results from the developed equation, it is required to carry out comfort surveys in large numbers of vernacular buildings along with extensive thermal monitoring. Moreover, this methodology overcomes the complex calculation procedures associated with comfort variables stated in heat balance method. In this method most of the parameters associated with thermo-physical properties of the building material and other regional factors are automatically taken care of by the coefficients of the developed equations.

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