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Thermal monitoring and indoor temperature modeling in vernacular buildings of North-East India

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A B S T R A C T

Vernacular architecture is still very popular and constructed widely in North-East India. In this paper, the result of long-term monitoring of two vernacular houses selected one in Tezpur (warm and humid climate) and other one in Cherrapunjee (cold and cloudy climate) are presented. Long-term monitoring work includes the measurements of temperature (inside and outside house), relative humidity (inside and outside house) and illumination level (inside and outside house) for 25 days in all the seasons (January: winter, April: spring/pre-summer, July: summer/monsoon and October: autumn/pre-winter) of the year 2008. Temperatures profile across all the seasons represents strong daily and seasonal fluctuations. Formulae have been developed based on part of the monitoring data to predict the indoor maximum, average and minimum temperatures inside the same house occupied by the same family. The predicted formulae were developed based on the measured data for the month of January and July and were validated with the measured data of April and October months. It is found that the correlation coefficient (R^2 value) is above 0.96 for all the six formulae for the entire monitoring period.

1. Introduction

Vernacular architecture is a term used to categorize methods of construction which uses locally available resources to address the local needs [1]. These kinds of buildings are constructed using locally available materials and shows a greater respect to the existing environment and also takes into account the constraints imposed by the climate [2]. It is revealed from different studies on vernacular architecture that bioclimatism is a critical parameter for achieving sustainability of modern architecture and this concept takes into account the solar passive techniques and micro-climatic conditions in building design; which improves the building artificial energy efficiency and thermal comfort conditions in the built environment [3–5]. Vernacular houses of North-East India across the different bioclimatic zones are widely varied in their built forms and functionality. Entire region has more than 50 ethnic groups. Each ethnic group has distinct cultural and social setup. Vernacular houses constructed by these ethnic groups are in direct response to the local climate, social and cultural setup. This type of houses and design layout are still very popular and are widely constructed [6].

The existing thermal comfort standards is based on heat balance model of human body and derived from extensive laboratory experiments in different climatic chambers [7]. However, the conditions in a building are much more dynamic in terms of both thermal environment and occupants activities. This leads to deviation in the results when these thermal comfort models are applied to existing buildings [7]. So, there was a need of better understanding that takes into account of both dynamic thermal environment and occupants activities. Research on '*adaptive*' theory of thermal comfort first began in mid-1970s in response to the first oil shock with a prime concern to find out the human impact on the global climate environment. Adaptive theory primarily uses outdoor environmental variables to predict the indoor thermal environment [7]. This automatically takes into accounts of climatic conditions, social conditioning and other contextual factors.

Givoni presented formulas predicting daily maximum, average and minimum indoor temperature of two unoccupied buildings in Pala, California, with very scant climate data [8]. Krűger and Givoni reported long-term monitoring work of outdoor temperature measurement at seven houses in Curitiba, Brazil and they have generated such formulas for the occupied houses with correlation coefficients up to 0.9894 [9,10]. In this study, it has been demonstrated that the management of the houses by the occupants had larger impact on the indoor temperatures than the physical properties of the buildings. Krűger and Givoni have reported

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long-term thermal monitoring of an occupied passive solar apartment in an arid environment also with mathematical formulas predicting its indoor temperature [11]. Validation of the formulas showed a good agreement between measured and calculated indoor maximum, average and minimum temperature. These formulas are applicable, and can be used, only for the specific building that were monitored, occupied by the same family, or by a family with similar lifestyle and procedures for controlling the indoor temperatures.

No serious study has been done so far related to thermal monitoring or indoor temperature prediction of the vernacular houses of northeastern India. In this study, naturally ventilated houses are considered for detailed monitoring. Selection of vernacular houses for long-term monitoring is based on common building plan and functionality [6]. In this study, two fully operational naturally ventilated vernacular houses are considered. One is in warm and humid climate (Tezpur) and the other one is in cold and cloudy climate (Cherrapunjee) [12]. Houses considered for the study have number of solar passive as well as climate oriented design features. All these features are elaborated in later sections of this paper.

This paper presents a comparative study based on long-term thermal monitoring of these selected houses at two different climates. Long-term monitoring and extensive interaction work with the occupants of the selected houses is carried out to record the different climatic parameters like temperature, humidity and indoor lighting level and other behavioral patterns that affect the functioning of the buildings. Based on the collected data during long-term monitoring, mathematical formulae are developed for each climatic zone to predict the indoor temperature of the buildings. Indoor temperature profile is important to understand the thermal behavior of building. This is also one of the prime factors which influence the comfort status inside the buildings [8,9]. Since, it is practically impossible to record indoor temperature in every house, these developed predictive mathematical formulae can be used to predict the indoor temperature of the house of similar kind and activities with fair accuracy in the same climatic zone [9–11,13]. Finally a comparative study has done based on these predictive mathematical formulas on both the buildings at two different climatic zones.

2. Climatic conditions and vernacular houses in North-East India

North-East India is classified into three bioclimatic zones; *warm and humid*, *cool and humid* and *cold and cloudy* [12]. Two vernacular buildings are selected based on common layout and functionality [6]. One house is located at Tezpur, Assam in warm and humid climate and other one is at Cherrapunjee, Meghalaya in cold and cloudy climate (Fig. 1). The latitude of Tezpur is 26°37′N and longitude is 92°47′E and for Cherrapunjee latitude is 25°17′N and longitude is 91°44′E [12]. Most of the houses of the region are constructed in direct response to the climatic constrains. Houses of each climatic zone are distinct in its built form. Building materials and their processing is also different in each climatic zone. Baked bricks, processed mud, bamboo (sandwiched between two layers of processed mud), cane and wood, stone chips and rock slabs are the main building materials [6]. Mud processing is done by adding beaten straw, chopped jute and lime. All the building materials used to construct the vernacular houses in this region are available locally. This provides an edge on environmental front as less energy is involved in processing and transportation and henceforth minimal environmental degradation [6].

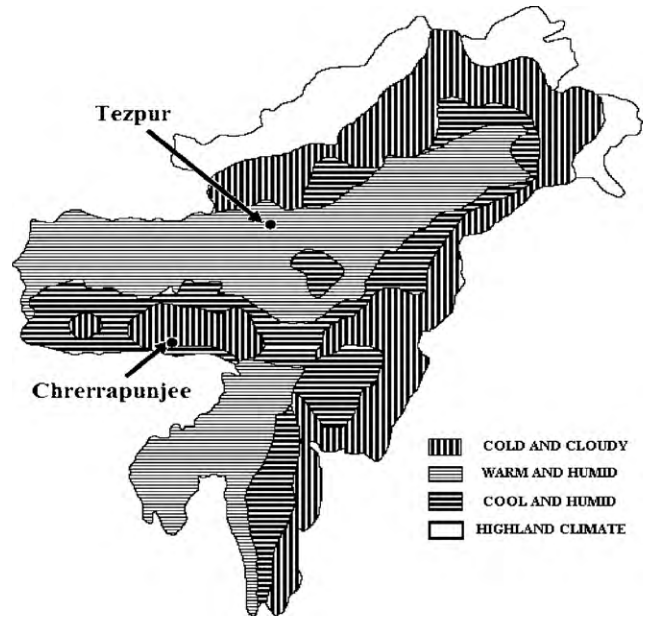

Fig. 1. Tezpur and Cherrapunjee location in bioclimatic zone.

3. The monitored houses and the families in Tezpur and in Cherrapunjee

In this section, the selected house for monitoring at Tezpur (warm and humid climate) and at Cherrapunjee (cold and cloudy climate) is described in detail including construction materials and their thermo-physical properties. Since the occupants tend to modify the indoor environments by their adaptive actions to restore comfort, details of family members and list of their probable adaptive actions taken are also reported.

3.1. The monitored house and the family in Tezpur

The vernacular house selected for long-term monitoring is based on common building plan and functionality of this climatic zone. This is a single storey house and five family members are living in this house; two males, two females and one female child. Two males are of age 65 and 37 years and females are of age 60 and 32 years. Female child is 9 years old.

The house is constructed in such a way that it has open space in all the four directions and the external walls are exposed to ambient air. Ventilators are constructed just above the windows but below the ceiling. The house has inclined roof and extended on both sides. Extended roofs protect the wall during heavy rainfall and also function as overhang. Roof is constructed of galvanized tin sheet. Due to tin roofing, all the houses have false ceiling made up of either wood or asbestos sheet. False ceiling separates the living space from being directly exposed to roof. Ceiling also plays important role in minimizing the heat gain during summer and loss during winter.

The building built area is 94 m^2 and the house is oriented in NE–SW direction. Openings in the form of windows and ventilators are evenly distributed throughout the exterior wall of the house. Window to wall ratio is 0.216 of this house. Net opening in the form of windows, ventilators and doors is about 50% of the floor area [14]. Windows and doors of all other rooms are made up of wood without any glazing. All the rooms has ventilators and are single glazed.

Building external and inter-room partition wall (plaster, brick and plaster) thickness is 13.4 cm. No insulation is present at the inside surface of the external walls. Over all heat loss coefficient