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# Development of thermal comfort models for various climatic zones of North-East India

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ABSTRACT

Thermal comfort study provides crucial information about thermal performance of naturally ventilated buildings. Humphreys and Auliciems comfort model uses indoor and outdoor temperatures to predict comfort temperatures. It is found that the comfort temperatures obtained by using these methods do not take into account the occupant behavioural adaptability to a particular climatic zone. This demands development of new set of comfort models based on local environmental parameters, socio-cultural setup and behavioural action. Analysis shows that four major variables like indoor and outdoor temperature, relative humidity and clothing pattern plays an important role in defining comfort and greatly influence the occupant's perception and acceptance on thermal comfort. In this study, comfort models are developed based on these variables. The computed neutral temperatures based on the models are compared with the comfort temperatures obtained through comfort survey. The models are developed using the measured data of January and July months and validated with the measured data of April and October months. This study also concludes that it is not possible to obtain a generalized thermal comfort model for all climatic zone because adaptation process, expectation and perception of people are region specific and governed by local socio-cultural requirement.



## 1. Introduction

Thermal comfort is one of the most important indicators to analyze the indoor thermal environment of residential buildings. The rise in the expectations of occupant's thermal comfort has considerably increased the energy consumption of buildings. Typically more than 80% of total energy consumption occurs during the operation of buildings and around 20% during construction of buildings (de Dear & Brager, 2002; Peeters, de Dear, Hensen, & D'haeseleer, 2009). This is also in turn responsible for huge economic and environmental cost (Olesen & Parsons, 2002). With rising environmental and economic sustainability concerns, extensive study covering different aspects related to thermal comfort in the built environment has been carried out by large number of scientists for decades (Nicol & Humphreys, 2007; Rajasekar & Ramachandraiah, 2011; Sharma & Ali, 1986). ASHRAE 55-2013 and ISO-7730 standards are widely used for assessment and prediction of the relation between thermal comfort and indoor thermal environment. The sustainability of building sector and effectiveness of the widely accepted (ASHRAE 55-2013 and ISO-7730) thermal comfort standards has become an important topic of discussion (Brager & de Dear, 1998; de Dear & Brager, 2002; Humphreys & Nicol, 2002; Peeters et al., 2009). Thermal comfort has been defined by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) through ASHRAE-55 Standard as "*the state of mind that expresses satisfaction with existing environment*" (ASHRAE 55-2013). This definition clearly states that thermal comfort is a subjective response and a specific value cannot be assigned to it. This standard also states that if the combination of indoor environmental conditions and personal acceptance is 80% or more, indoor environment is termed as comfortable (ISO 7730, 2005; Olesen & Parsons, 2002). 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 votes (Auliciems, 1981; de Dear & Brager, 2001). Also recent studies carried out on thermal comfort in different parts of the world conclude that there cannot be generalized standard for thermal comfort (Nicol & Humphreys, 2009; Nicol & Stevenson, 2013; Singh, Mahapatra, & Atreya, 2011a). It is being widely accepted in the thermal comfort research community that

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state of mind is widely driven by perception and expectation of the occupants. It is also influenced by occupant's personal differences in mood, culture and other individual, organizational and social factors (Katafygiotou & Serghides, 2014; Nicol & Humphreys, 2002; Singh et al., 2011a; Villadiego & Velay-Dabat, 2014). So, it is evident that 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 (Nicol & Humphreys, 2002; Singh et al., 2011a). Thus, the definition of thermal comfort provides a broad perspective based on the judgement of mind which in turn is influenced by various inputs such as physical, physiological, psychological and other regional factors (like local climate, socio-economic, socio-cultural etc.) (Indraganti, Ooka, & Rijal, 2013; Katafygiotou & Serghides, 2014; Nicol & Humphreys, 2002; Villadiego & Velay-Dabat, 2014). There are numbers of factors that influence the comfortable thermal environment e.g. indoor temperature, radiative temperature, relative humidity and wind velocity, residents' living habits including clothing pattern and activity state (metabolic rate), adaptive behaviour, human physiology such as age, gender etc. Amongst these the indoor and outdoor climate are the primary factors that influence the human thermal sensation.

Thermal comfort studies are generally based on field surveys or experiments conducted on subjects in climate chambers. These studies brought out numbers of thermal comfort models and indices to predict thermal comfort in either conditioned environment or naturally ventilated environments (ASHRAE 55, 2013; Fanger, 1986; ISO 7730, 2005; Tanabe & Kimura, 1994). The database created from these studies around the world brings out the comfort standards like ASHRAE-55 and ISO-7730 (ASHRAE 55, 2013; ISO 7730, 2005). These standards are now extensively used to define comfort in built environment. However, the results obtained from climate chamber experiments and that from field surveys, often deviates widely in defining comfort conditions in naturally ventilated buildings (Humphreys & Nicol, 1998; Milne & Givoni, 1979; Nicol, 2004). One of the major issues concerning thermal comfort model is the generalization of occupant's preference, expectation and acceptance in conditioned buildings, where the built environment is controlled to nearly constant levels of air temperature in accordance with the occupant's activity and clothing (Humphreys & Nicol, 2002). On the other hand, in naturally ventilated buildings occupant's adaptive approaches are dominant and have various options to adapt to a wider range of temperatures that is complement to their culture and climates and thus less energy demanding (Brager & de Dear, 1998; Olesen & Parsons, 2002; Singh, Mahapatra, & Atreya, 2009b). It is also important to note that people have a natural tendency to adapt to the changing conditions of the local environment. This leads to the development of adaptive thermal comfort concept. This includes experiments conducted on subjects and recording their preferences without imposing any artificial environmental conditions on them (Singh et al., 2011a). The result obtained from these types of studies automatically takes care of behavioural, physiological and psychological adaptations (Nicol & Humphreys, 2009; Peeters et al., 2009).

Thermal comfort studies in naturally ventilated buildings states that adaptive actions and opportunities play a major role in defining comfort status (de Dear & Brager, 2001). The adaptive factor and the extent of adaptation of an occupant vary over a period of time and even in the seasons of a year. However, this variation of adaptive factor is very difficult to define due to its complex interlinking between various adaptive opportunities and actions of the occupants. The flow of information that governs the actions of occupants is also influenced by perception and expectations (Fanger, 1986; Singh et al., 2011a). This makes the system more complex to formulate in a mathematical model. However, the problem can be overcome by applying suitable mathematical technique to analyze the collected data of field experiments and comfort surveys and to draw correlations to estimate the comfort in naturally ventilated buildings (Singh et al., 2009b). Such an attempt was first made by Humphreys on the available database of more than thirty comfort surveys done around the world (Humphreys & Nicol, 1998; Nicol & Humphreys, 2002; Nicol & Humphreys, 2009). This study developed simple correlation to predict the comfort temperature in naturally ventilated buildings. However, there was incompatible information, which was subsequently improved by Auliciems for buildings with active and passive climate control (Auliciems, 1981). Auliciems in his correlation used both indoor and outdoor temperature for predicting the comfort temperature (Auliciems, 1981). It is now well established fact that thermal comfort and thermal performance of buildings are function of regional parameters as well as occupant's behaviour. Hence, there is a need for a scientific study to improve the understanding on the functioning of a building. Author's previous study shows that Humphreys and Auliciems adaptive thermal comfort model failed to predict comfort temperature for North-East India (Singh et al., 2009b). Humphreys and Auliciems thermal comfort model always over estimated or under estimated the comfort temperatures of this region. The reason behind this is that these models did not consider the variables like behavioural adaptation, physiological adaptation and psychological adaptation. Four major factors (indoor and outdoor temperatures, relative humidity and clothing level) that primarily control the comfort in naturally ventilated buildings and their different combinations are considered in this analysis. Comfort survey as well as long term thermal monitoring data of the vernacular houses has been used to develop these thermal comfort models for all the climatic zones of North-East India. These thermal comfort models are developed by using multiple regression technique. Developed comfort models upon validation show good results and predicted neutral temperature with fair accuracy. This co-relations successfully accommodated the adaptation processes thus suggesting a new approach towards adaptive thermal comfort model. Data used in this study was collected during thermal monitoring and questionnaire based comfort survey that has been carried out in naturally ventilated vernacular buildings of North-East region of India in different climatic zones.

## 2. Comfort models

Thermal comfort models of built environment are based on two different approaches. One is heat balance approach and the other is adaptive approach (Singh et al., 2011a). Heat balance approach is widely used but adaptive approach is slowly gaining acceptance. Large number of thermal comfort studies has been carried out in the last decade are based on adaptive approach (Singh et al., 2011a). However, both the approaches have their own advantages and limitations and these are discussed in this section. Various recent studies also reported the discrepancy in the results obtained from conditioned and naturally ventilated buildings (de Dear & Brager, 2002; Singh et al., 2011a).

An extensive study on thermal comfort was done by Fanger on 1296 numbers of Danish students, subjected to controlled climate chambers (Fanger, 1986). In this controlled climate chamber, clothing level, activity level and thermal environment were pre-defined and closely monitored. This laboratory based study resulted to the development of static heat balance model of human body (Fanger, 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 will feel comfortable (Fanger, 1986). This model is described as a function of four environmental variables, such as; temperature, mean radiant temperature, relative humidity and air velocity. Apart from these