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Estimation of degree-days for different climatic zones of North-East India

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ABSTRACT

Efficient use of energy in buildings has become a necessity due to increasing heating and cooling energy demand. Degree-days are a versatile climatic indicator that can be used to estimate the heating and cooling energy requirement for a building. In this study, heating degree-days (HDD) and cooling degree-days (CDD) are estimated for warm and humid, cool and humid and cold and cloudy climatic zones of North-East India. The daily maximum and minimum temperature data are collected from Regional Meteorological Centre, Guwahati. The degree-days are calculated by using three different methods, i.e. ASHRAE formula, UKMO equations and Schoenau–Kehrig method for different base temperatures. It has been found that there is a variation in degree-days obtained from the above methods in the respective climatic zone and also varies from zone to zone. The degree-days are also estimated on hourly basis based on Typical Meteorological Year (TMY) data for validation. Generalized equations are developed by using multiple linear regression technique to estimate the degree-days and those satisfied the statistical tests are proposed. The developed equations can be used to obtain degree-days of locations in same climatic zone for which daily temperature data are not available, with a fair accuracy.

1. Introduction

Buildings, energy and the environment are concurrent issues that the building professions have to understand and need to find a balance between these issues (Lam, 1999). Energy efficiency has become a prior condition in building design due to rise in energy consumption, consequent green house gas emissions, and cost of energy. It has been observed that more than 80% of total energy consumption occurs during the operation of buildings and around 20% during the construction (Liu, Zhang, & Zhai, 2010). Climate, socio-cultural setup, economy, building materials and available technologies are the main factors that greatly affect the building architecture and its sustainability (Sayigh & Marafia, 1998). Degree-days are versatile climatic indicator, used in building design and operation that estimates the energy consumption and consequently carbon emissions due to space heating and cooling (Aktacir, Büyükalaca, Bulut, & Yilmaz, 2008; Mourshed, 2012). It is a widely used method because it captures both the extremity and duration of ambient temperatures (CIBSE, 2006). Degree-day is calculated by the summation of temperature differences between the ambient or outdoor air temperature and a reference temperature known as the base or balance point temperature. Cooling degree-days (CDD) and heating degree-days (HDD) are determined by using the base temperature and outdoor temperature data and which can be used for forecasting the energy consumption for heating and cooling requirements of residential or commercial buildings (Yu, Yang, Tian, & Liao, 2009).

Walsh and Miller (1983) obtained a simple method for estimating the degree-days for a given period as a function of mean

Abbreviations: ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers; CDD, cooling degree-days (°C); CDD_d, daily cooling degree-days (°C); DD_a, annual degree-days (°C); DD_m, monthly degree-days (°C); HDD, heating degree-days (°C); HDD_d, daily heating degree-days (°C); HVAC, heating, ventilating and air conditioning; LINEST, linear estimation; N, number of days in a month; Sd, yearly standard deviation of average temperature; Sd_{max}, yearly standard deviation of maximum temperature; Sd_{min}, yearly standard deviation of minimum temperature; T, annual mean temperature (°C); T_b, base temperature (°C); T_d, daily average temperature (°C); T_i, outdoor air temperature at the i-th hour of the day (°C); T_m, monthly mean outdoor air temperature (°C); TINV, inverse of t-distribution; T_{max}, daily maximum temperature (°C); T_{min}, daily minimum temperature (°C); TMY, Typical Meteorological Year; TRNSYS, Transient System Simulation tool; UKMO, United Kingdom's Meteorological Office.

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and standard deviation of the daily average outdoor temperature in terms of graphical means. Büyükalaca, Bulut, and Yilmaz (2001) estimated HDD and CDD for 78 Turkish stations for different base temperatures and presented in the form of tables and contour maps. Day, Knight, Dunn, and Gaddas (2003) described the proper identification of energy/degree-day correlation considering the building energy balance which can be used to determine the building base temperature from reduced datasets. Mourshed (2012) developed a relationship between degree-days and annual mean temperature from low-resolution temperature data of 5511 locations around the world and sited the importance of specific geographical parameters on degree-days by using multiple non-linear regressions. Matzarakis and Balafoutis (2004) calculated the HDDs for 40 meteorological stations in Greece by means of special maps. The values calculated by the multiple regression analysis were found to be close to the measured values, which confirmed the statistical model used in the study to be accurate. Lam, Tsang, and Li (2004) examined the subtropical regions of Hong Kong for 40 years (1961–2000) and found slight increase in CDD for the last 20 years, and concluded that energy use for cooling would increase if the trend persisted. Mirasgedis et al. (2006) developed statistical models to estimate electricity demand in Greece using relative humidity, heating and cooling degree-days with R^2 above 96%. Christenson, Manz, and Gyalistras (2006) studied the climate change impact on the building design parameters and calculated the heating and cooling energy demand in highly insulated buildings of Swiss locations. The degree-day methods for the period 1901–2003 and 1975–2085 are used for this estimation. It is found that relative HDD values decreases based on base temperature and increases for CDD values. Bolattürk (2008) analyzed the Turkish buildings and optimized the insulation thickness on external walls to minimize the annual heating and cooling loads for energy savings. The annual energy consumption of buildings has been estimated by using degree-hours method. The use of insulation in buildings with respect to cooling degree-hours was found to be more significant for energy savings compared to heating degree-hours. Dombayci (2009) calculated the HDD and CDD values of Turkey by using daily maximum and daily minimum outdoor temperatures and observed the trends for various base temperatures for a period of 21 years in 79 city centers and have found that with increase in base temperatures, HDD and CDD values increases and decreases respectively on a linear basis.

Gelegenis (2009) presented a second-degree equation for the estimation of annual HDD at various base temperatures with quite accuracy for many Greek cities and other countries. Jiang, Li, Wei, Hu, and Li (2009) observed the heating and cooling degree-day trends in Xinjiang Province of China for 51 stations during 1959–2004. This study observed decreasing trends in annual heating degree-days for all the stations for base temperature of 18 °C and significant increasing trends in annual cooling degree-days for the base temperature of 24 °C for 23 stations in the western parts of Northern Xinjiang. Papakostas, Mavromatis, and Kyriakis (2010) evaluated annual heating and cooling degree-days for base temperatures of 15 °C (HDD) and 24 °C (CDD) for Athens and Thessaloniki, Greece. It is observed in this study that the heating energy demand decreases by 11.5% and 5% and the cooling energy demand increases by 26% and 10% respectively for Athens and Thessaloniki. Priya, Premalatha, Rajkumar, and Thirunavukkarasu (2011) calculated CDDs for Tiruchirappalli (India) for eleven base temperatures ranging from 18 °C to 28 °C and investigated the impact of degree-days on building design parameters. It is suggested in this study that correction in base temperature or improvement in overall heat transfer coefficient for the air conditioned buildings can save up to an extent of 80% of energy. OrtizBeviá, Sánchez-López, Alvarez-Garcìa, and RuizdeElvira (2012) investigated the evolution of heating and cooling degree-days for 31 stations of Spain, for the period of 1958–2005 and estimated the trends and inter-annual variability in the degree-day values. Carlos and Nepomuceno (2012) presented a simplified spreadsheet to evaluate building energy demand by applying the seasonal mean values of solar radiation and degree-days, useful for the early design stages for the initial decision on building design and materials etc. of a residential building. Al-Hadhrami (2013) calculated the annual and seasonal degree-day values of 38 meteorological stations of Saudi Arabia by using the long-term daily average temperatures for a base temperature of 18.3 °C.

Degree-day method is a simple and powerful method of analyzing climate related energy consumption in built environment. This method has been successfully used for estimation of heating and cooling energy demands of buildings in many studies reported earlier. It is also used to correlate the energy demand in a building as a function of external environmental parameter (primarily external temperature). North-Eastern region is in development process and the construction sector is rising in unprecedented way. However, no attempt has been made to estimate the heating or cooling degree-days and energy consumption or scope for energy conservation in buildings of North-East region of India. In this study, heating and cooling degree-days are calculated for three different climatic zones viz. warm and humid (place: Tezpur), cool and humid (place: Imphal) and cold and cloudy (place: Shillong) climatic zones of North-East India. The degree-day values are estimated by using different methods for variable base temperatures for each climatic zone and the variation in the degree-day values are analyzed. Generalized equations are developed by using multiple regression technique to estimate the degree-days and those satisfy the statistical tests are proposed.

2. Climate of North-East India

North-East India is the eastern-most region of India extended between 88 degree to 97.30 degree East longitude and 21.57 degree to 29.30 degree North latitude with an approximate area of about 262,185 km^2 (Singh, Mahapatra, & Atreya, 2007). The region has distinct and sharp climate variations within short distance due to uneven topography. Generally the daily average temperature in the plains of Brahmaputra and the Barak Valley, Tripura and in the western parts of Mizo Hills is approximately 15 °C in the month of January. However, it is observed that in other parts of the region, the daily average temperature is between 10 °C and 15 °C (Singh et al., 2007). The temperature rises from the month of April and in July the daily mean temperature ranges from 25 °C to 27.5 °C, excluding the south-eastern region of Mizo Hills and Shillong (Singh et al., 2007). During the month of October, decrease in daily mean temperature is observed in the hilly areas that range between 20 °C and 25 °C, whereas in Brahmaputra and Barak Valley, Tripura and the western region of the Mizo hills, the mean temperature is found above 25 °C (Singh et al., 2007). Further, it is observed that the upper Himalayas in Arunachal Pradesh has the lowest daily mean temperature which is below freezing point. The weather of a place is the integrated effect of all atmospheric variables over a brief period of time and climate is the average weather over a period of many years. Both the weather and climate are described by the climate factors such as solar radiation, ambient temperature, air humidity, precipitation, wind profile and sky condition. Singh et al. (2007) studied the bio-climatic zones of North-East India and classified it into three climatic zones viz. warm and humid, cool and humid and cold and cloudy based on ambient temperature, humidity, rainfall, wind speed, altitude and solar radiation and also taking into consideration the physical topography of the region. The characteristics of each zone differ and hence thermal comfort levels vary from one climatic zone to other. Fig. 1 shows the various bio-climatic