Weather Data for Building Simulation: Grid Resolution for Climate Zone Delineation

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Abstract

Classification of climate zones for building design and energy assessment purposes plays a vital role in aiding building engineers and architects in achieving energy efficiency in buildings using building performance simulation. Previous studies highlighted the need for climate assessments at higher resolutions for the purpose of climate classification but failed to infer the resolution requirement. In this study, climate zones of Kerala (one of the 29 States in India) are defined and delineated with climate data from grid resolutions of 10, 15, 20 and 25 km. The delineated zones are then assessed by comparing them with the thermal performance of a building representative of building typology of Kerala to identify the grid resolution necessary for zone delineation.

Introduction

The International Energy Agency (IEA) estimates that, of the total housing stock that would exist in India by 2030, only one-fourth has been built as of 2015 with the rest yet to be constructed (IEA, 2015). This is in marked contrast to developed regions such as Europe and the US. The energy use in the residential building sector in India is expected to undergo a drastic change with an anticipated rise in energy use of about 65% to 75% of 2005 levels by 2050 (van Ruijven et al., 2011). Thus, performance evaluation of proposed designs becomes an increasingly important consideration. Classification of climate zones for building design and energy assessment purposes plays a vital role in aiding building engineers and architects in achieving energy efficiency in buildings (Walsh et al., 2017).

The National Building Code (NBC) of India classifies the country for building design purposes into five major climatic zones (BIS, 2016). The classification is based on the study conducted by Ali et al. (1993) in which mean monthly maximum temperature and humidity data from 225 stations were used to delineate the zones.

The ASHRAE climate zone classification method classifies the country into different zones based on

heating and cooling degree days and precipitation. The climate zones in India were defined with data from a combination of ground station data (51 stations) and remote sensing data (Standard 169, 2013).

A number of studies (Bansal and Minke, 1995; Singh et al., 2007; Pawar et al., 2015) investigated the climate data in different magnitudes to classify and delineate the climate in India into different zones. Though these studies highlighted the need for location-specific climate assessments, the grid resolution required to delineate climate zones was not inferred.

Figure 1: Location of Kerala with respect to the other 28 States of India.

This study aims to identify the appropriate grid resolution required to classify and delineate climate zones for building design and performance assessment. The study focuses on the State of Kerala (Figure 1) which is one of the 29 States in India, located in the South Western part of the country between the Arabian Sea (West) and mountain ranges - Western Ghats (East).

As part of the Government's vision to provide housing for all, a project titled "Livelihood Inclusion and Financial Empowerment (LIFE) mission" is being implemented in Kerala. Under this project, the Government of Kerala plans to build more than 750,000 houses (Issac, 2018). The beneficiaries (i.e. the people of the State) are free to choose among 12 proposed designs which will be used for the construction of the building irrespective of the location or climate.

The existing climate zone classification methods classify Kerala under a single climate zone. The NBC of India classifies Kerala as a Warm-Humid climate zone (BIS, 2016) while the ASHRAE climate zone classification identifies Kerala as belonging to Extremely Hot Humid climate zone (Standard 169, 2013).

A previous study examined climate data across the 14 main cities in Kerala and identified the existence of locations with different climate characteristics (Jaya-palan Nair et al., 2018). The results of the study resonated in the Government's Post Disaster Needs Assessment report (GoK, 2018) which highlighted the urgent need for amendments in Kerala's building codes to account for the local climatic variations in building designs.

The present study forms part of a larger project that aims to develop a methodology to assist early building design stages in terms of energy and environmental performance, and that is specifically tailored, in the first instance, for the State of Kerala.

Methods

The aim of the present study is to define the grid resolution needed for the classification and delineation of climatic zones. The first part of this section describes the methods adopted to define the climate zones. Subsequent parts of the section describe the methods carried out to examine the appropriateness of different grid resolutions in delineating climate zones.

Climate zone definition

The NBC 2016 (BIS, 2016) adopted the adaptive thermal comfort model based on the "Indian Model for Adaptive Comfort (IMAC)" developed by Manu et al. (2016) for the design of natural and mixed-mode ventilated buildings. The present study used a method based on the IMAC model related to mixed-mode ventilated buildings (Equation 1) to analyse the climate data for locations across Kerala and define the climate zones. The comfort acceptability limits were calculated using the equation developed by Manu et al. (2016):

$$T_c = 0.28T_o + 17.9 \quad (1)$$

where T_c is the neutral or comfort temperature in degree Celsius, T_o is the 30-day outdoor running mean air temperature ranging from 13°C to 38.5°C. The limits of 90% acceptability are $\pm 3.5^\circ\text{C}$.

All the hours in a year were classified into Hours Requiring Heating (HRH) and Hours Requiring Cooling (HRC). HRH is defined as the hours at which the value of hourly outdoor dry bulb temperature goes below the IMAC lower acceptability limit ($T_c - 3.5^\circ\text{C}$) and HRC is defined as the hours at which the value of hourly outdoor dry bulb temperature goes above the IMAC upper acceptability limit ($T_c + 3.5^\circ\text{C}$). The limits were calculated using Equation 1.

HRH and HRC values are calculated based on the value of hourly outdoor dry bulb temperatures with respect to the IMAC acceptability limits. This is an idealised case where no thermal envelope is considered. The actual HRH and HRC values for a building will depend on the thermal envelope characteristics.

Standardised typical meteorological years were available only for a limited number of places in Kerala. Thus, the study had to resort to weather files derived from the Meteonorm software (Remund et al., 2014).

Percentages of HRH and HRC were calculated for locations spaced at 25 km grid across Kerala based on Indian Model of Adaptive Comfort (IMAC). With altitude being a major factor influencing HRH and HRC, the inflection point for HRH-Altitude curve (B1) and HRC-Altitude curve (B2) were calculated using piecewise regression analysis (Marsh and Cormier, 2001). These points (B1 and B2) were then used to define the regions into three different adaptive climate zones:

1. *Adaptively Hot Zone (AHZ)*: regions with altitude lower than B1 where the building thermal performance is characterised by cooling demand.
2. *Adaptively Mixed Zone (AMZ)*: regions with altitude between B1 and B2 where the building thermal performance is characterised by heating and cooling demand.
3. *Adaptively Cold Zone (ACZ)*: regions with altitude greater than B2 where the building thermal performance is characterised by heating demand.

Climate zone delineation

To determine the appropriate grid resolution required for delineating climate zones, grids of 10, 15, 20 and 25 km spacings were considered. The highest grid resolution used was 10 km. This was because, in Meteonorm, weather files are derived based on the distance of the location from the nearest ground station in Meteonorm's database. The Meteonorm database contains a total of 8275 weather stations and 5 geostationary satellites (Remund et al., 2014). Satellite data is used to derive the weather files when measured radiation data is not available from stations within 200 km from the location of interest. The satellite images (at resolutions of 2 to 3 km for Europe and 8 km for rest of the world) are processed for daily means of global radiation and then summed up to get monthly

values.

The altitude values for each of the grid points for the 10, 15, 20 and 25 km spacings were collected and climate zones of Kerala were delineated over these grids separately.

Since the climate zones were defined and delineated for building design and performance assessment purposes, a building representative of building typology of Kerala was modelled and its thermal performance across the State at the highest grid resolution considered (i.e. 10 km) was used to determine the spacing requirement. The building geometry and specifications used in the study are identical to the one used by Jayapalan Nair et al. (2018).

The building modelled has gross floor dimensions of 5.45 m x 6.90 m and a floor to ceiling height of 2.9 m. The building has windows (single glazed with a window to wall ratio of 20%) on all four facades. The floor of the building lies at an elevation of 0.45 m above ground level and is made of dense concrete. The walls are constructed of brick with plastering on both sides. The roof construction is reinforced cement concrete.

Figure 2: Window and ceiling fan operation.

The building was modelled to have mixed mode ventilation with windows and ceiling fans being operated as shown in Figure 2. The introduction of ceiling fans is the only change made with respect to the model used by Jayapalan Nair et al. (2018). The use of ceiling fans is considered as one of the main mechanisms in Warm-Humid climates to improve the indoor thermal comfort (Manu et al., 2014; Nicol, 1974; Cheng and Ng, 2006). The heating and cooling set points were based on the IMAC adaptive thermal comfort model. When ceiling fans were in operation the cooling set point (i.e. IMAC 90% acceptability upper limit) was offset by 2.2°C (Standard 55, 2013).

The total energy demand for heating and cooling for the building at 10 km grid locations across Kerala was assessed by carrying out dynamic thermal simulations in EnergyPlus. Jayapalan Nair et al. (2018) identified three cities in Kerala that had different climatic characteristics. Consequently, in this study, regions around these cities were investigated in detail, with respect to the building's thermal performance variation, to assess the appropriateness of zone delineation for the different grid resolutions considered.

Results

Climate zone definition

To define the climate zones in Kerala, HRH and HRC values for the locations spaced at 25 km grids were calculated. The points of inflection were identified using piecewise regression analysis. Figure 3 shows the variation of HRH and HRC against altitude. The point of inflection for HRC-Altitude curve is 574.6 m (B1) and that for HRH-Altitude curve is 1338 m (B2). The points of inflection for the HRC-Altitude and HRH-Altitude curves for locations spaced at 10 km grid were also identified. The values found with 10 and 25 km grids were similar, with a variation of less than 1%.

Figure 3: HRH and HRC at 25 km grid.

Thus, based on the inflection points B1 and B2, three adaptive climate zones were defined, namely:

1. *Adaptively Hot Zone (AHZ)*: places/regions with altitudes lower than 574.6 m (B1).
2. *Adaptively Mixed Zone (AMZ)*: places/regions with altitudes between 574.6 m (B1) and 1338 m (B2).
3. *Adaptively Cold Zone (ACZ)*: places/regions with altitudes greater than 1338 m (B2).

Figure 4: Climate zones of Kerala delineated with respect to different grid spacings. For each climate zone, the location of a representative city with significant population is also marked.

Climate zone delineation

To examine the grid resolution appropriateness, the climate zones in Kerala were delineated with respect to four grid spacings: 10, 15, 20 and 25 km. Figure 4 shows the climate zones in Kerala delineated with respect to different grid spacings.

Regions in Kerala are classified predominantly un-

der climate zone AHZ. AMZ are spread towards the western side of the State. To study the appropriateness of different grid resolutions in delineating climate zones, regions surrounding three cities - Thiruvananthapuram (altitude 0 m), Munnar (altitude 1532 m) and Kalpetta (altitude 780 m), classified under zones AHZ, ACZ and AMZ respectively, were considered. The location of these cities are marked in Figure 4.

Figure 5: Climate zones delineated around Thiruvananthapuram using data from grid spacings (a) 10 km, (b) 15 km, (c) 20 km and (d) 25 km. The energy demand (kWh/m^2) at 10 km grid spacings are also marked and labelled.

Climate zone delineation: region around Thiruvananthapuram

Figure 5 shows the climate zones around Thiruvananthapuram delineated with data from different grid spacings. The total energy demand for the building located at 10 km grid locations are also marked.

The places around Thiruvananthapuram are classified under AHZ for all the different grid resolutions considered. The thermal performance at these locations also show similar characteristics. Thus, for places with altitudes less than 574.6 m, a grid spac-

ing of 25 km is appropriate.

With 25 km grid resolution, a relatively small region is delineated into AMZ (North East of Thiruvananthapuram in Figure 5d). This is because at 25 km grid, a location near the concerned zone has an altitude which is slightly above the inflection point value for the HRH-Altitude curve (i.e. 574.6 m). This variability reduces at higher resolutions as seen from Figures 5a, 5b & 5c. The following sections examine the grid spacing appropriateness at altitudes above 574.6 m.

Figure 6: Climate zones delineated around Kalpetta using data from grid spacings (a) 10 km, (b) 15 km, (c) 20 km and (d) 25 km. The energy demand (kWh/m^2) at 10 km grid spacings are also marked and labelled.

Climate zone delineation: region around Kalpetta

Figure 6 shows climate zones around Kalpetta delineated with data from different grid resolutions. The region immediately around Kalpetta has an altitude between 574.6 m and 1338 m. The predominant zone around the region is AMZ.

From Figures 6b, 6c and 6d places with similar thermal characteristics (Energy demands of 2.24, 2.34 and 2.19 kWh/m^2 - located to the North/ North East of Kalpetta) are classified into different zones. Thus, for places with altitudes between 574.6 m and 1338 m,

higher resolution grid spacing of no more than 10 km is required.

In Figure 6b a location with a cooling demand of 1.68 kWh/m^2 is classified under ACZ. This is because the altitude of the concerned location is 1380 m, which is slightly above the point of inflection for HRC-Altitude curve (i.e. 1338 m). This variability, as seen earlier, is reduced at higher resolutions.

Climate zone delineation: region around Munnar

Figure 7 shows the climate zones around Munnar delineated with data from different grid resolutions.

Figure 7: Climate zones delineated around Munnar using data from grid spacings (a) 10 km, (b) 15 km, (c) 20 km and (d) 25 km. The energy demand (kWh/m^2) at 10 km grid spacings are also marked and labelled.

The regions around Munnar show different climatic characteristics. Except under 25 km grid spacing (Figure 7d) all the locations under AHZ show energy demand characteristics which are predominantly due to heating demand.

Under 20 km grid resolution, locations with similar energy demand characteristics ($3.16 kWh/m^2$ and $3.17 kWh/m^2$ - East of Munnar in Figure 7c) are classified under two different zones. A similar observation is also made with regard to 15 km grid resolution. Locations with similar energy demand characteristics ($0.93 kWh/m^2$ and $0.77 kWh/m^2$ - North

East of Munnar in Figure 7b) are classified under two different zones.

Thus, for places with altitudes greater than 1338 m, a grid resolution of not more than 10 km is required.

Conclusion

The study presented in this paper investigated the grid resolution required for the classification and delineation of climate zones for energy efficient building design and performance assessment purposes. For the purpose of the investigation, climate zones in Kerala (India) were classified and delineated at grid resolu-

tions of 10, 15, 20 and 25 km. For the classification of climate zones, a method based on adaptive thermal comfort model was used. The appropriateness of the grid resolution for delineation was examined by comparing the variation of thermal performance of a building across different identified climatic zones.

This study identified the presence of three climate zones in Kerala which is in contrast to the observations in NBC of India and ASHRAE climate classification which delineate Kerala to be predominantly under a single climatic zone. From the findings, it was observed that for regions with altitudes lower than 574.6 m above sea level a grid spacing of 25 km is appropriate while for regions at higher altitudes, a grid resolution of not more than 10 km is required. Thus, the findings highlight the importance of the choice of grid resolution for classification and delineation of climate zones.

The study only considered grid resolution for climate zone classification and delineation. It is expected that at lower resolutions the point from which grids are placed may also play an important role in delineating climate zones. This will be investigated in further studies.

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