Influence of Climate on the Daylight and Thermal Performance of Buildings in Kerala (India)

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Abstract

Knowledge of location specific climate parameters plays an important role in the design conceptualisation phase if a balance between visual comfort, thermal comfort and energy performance is to be achieved. In this study, the climate diversity of Kerala (India) was assessed using synoptic meteorological tools and three locations with significant population centres and different prevailing climate were identified. A case study building, based on the design proposed in a Government project that aims to built 759,523 houses across Kerala, was simulated under different conditions to understand the sensitivity of daylight and thermal performance to the climate in Kerala.

Introduction

India is one of the fastest growing economies in the world with an average growth rate of 6.5% a year since 1990 (IEA, 2015). Energy plays a vital role as the country has to achieve the committed emission targets while meeting the demands of the growing population. In India, of the total electricity consumed, the building sector consumes around 33%, with the residential sector accounting for 25% and the commercial sector 8% (BEE, 2009). Around 79.9% of the housing stock in India is comprised of residential buildings (Chandramouli, 2014). 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 in 2050 (van Ruijven et al., 2011). Thus performance evaluation of proposed designs becomes an increasingly important consideration.

The energy consumption in a building may vary due to a wide range of factors such as building design, occupant comfort criteria, behaviour etc. Buildings provide shelter to the occupants from adverse climatic conditions while providing healthy and comfortable indoor conditions. The indoor comfort is greatly influenced by the outdoor weather conditions. The responsiveness of the building to the prevailing local climate plays an important role if the dual aspects of occupant comfort and low energy demand/consumption are to be met. A thorough knowledge of the local climatic parameters that influence the buildings performance in terms of providing comfortable indoor conditions would help architects and building designers to design buildings that are sensitive to the local climate thereby helping to reduce the energy consumption. Thus classification of the climate into zones for building energy applications plays a crucial part in aiding the architects and building designers to achieve energy efficiency (Walsh et al., 2017).

The Köppen-Geiger classification system (first introduced around 1900) classifies India under a tropical rainy climate. This classification was introduced to understand the distribution of global vegetation cover (Köppen et al., 2011). The National Building Code (NBC) (BIS, 2016) of India classifies the country into five major climatic zones (Table 1). This classification is based on the work done by Ali et al. (1993), in which mean monthly maximum temperature and humidity data from 225 stations were analysed and locations were classified into zones depending on the prevalence of a defined climatic condition for six or more months in a year. A number of studies (Bansal and Minke, 1995; Singh et al., 2007; Pawar et al., 2015) have analysed the climate data in different magnitudes to classify and delineate the climate in India into different zones. These studies have highlighted the need for location-specific climate assessments for climate responsive building design purposes.

As a 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 (one of the 29 States in India). Under this project, the Government of Kerala plans to build 759,523 houses (Issac, 2018). The beneficiaries (people of the State) are free to chose from among the 12 proposed designs which will be used for construction of the building irrespective of the location or climate.

The aim of the present study is to determine the influence of key climate parameters on the daylight

Table 1: Specifications of existing climate zone classification in India as specified in NBC (BIS, 2016)

Sl No:	Climatic zone	Mean Monthly Max. Temperature (°C)	Mean Monthly Relative Humidity (%)
1	Hot-dry	Above 30	Below 55
2	Warm-Humid*	Above 30	Above 55
		Above 25	Above 75
3	Temperate	25-30	Below 75
4	Cold	Below 25	All values
5	Composite	Zone without any season for more than 6 months	

* The State of Kerala is classified as Warm-Humid zone

and thermal performance of buildings in the State of Kerala (India) (Figure 1). The climate data for different locations were collected and analysed to identify meso-climatic locations in Kerala with significant population centres and different prevailing climatic conditions. The present study forms part of a larger project aimed to develop a methodology to assess building designs in terms of energy and environmental performance and which is specifically tailored, in the first instance, for the State of Kerala. Thus the different climate regions were analysed to identify and understand the key parameters that characterise the prevailing conditions (i.e. amount of solar radiation, temperature, wind, precipitation and relative humidity) and a case study building based on the design proposed in LIFE mission project was simulated under different conditions to understand the sensitivity of daylight and thermal performance to the climates in Kerala.

Methodology

To reach the aim of the study, two objectives were identified: (i) identification of meso-climatic locations and (ii) assessment of daylight and thermal performance of the case study building in the selected locations. This section describes the methodology applied for each of the two objectives.

Meso-climatic location identification

India is a federation composed of 29 States and 7 union territories. Each State is further divided into administrative districts. The State of Kerala, one among the 29 States of India, is uniquely located at the South Western part of India between the Arabian Sea (West) and mountain ranges - Western Ghats (East). The climate of entire State of Kerala is classified under Warm-Humid zone as per the existing National Building Code of India (2016) (BIS, 2016). To analyse the variation in climate across Kerala, the climate data for the main cities in the 14 districts of

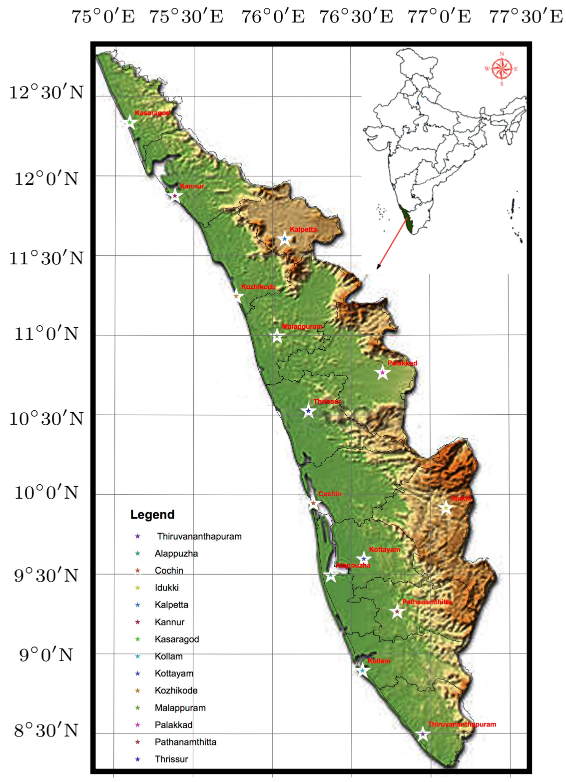


Figure 1: Location of Kerala and its 14 districts with respect to the other 29 States of India. The location of the weather stations in the 14 districts is also marked.

the State were generated using Meteonorm Software (Remund et al., 2014). Figure 1 shows the location of the 14 weather stations in the 14 different districts of Kerala.

For the identification of meso-climatic locations, analysis based on adaptive thermal comfort was adopted. Thermal comfort plays a vital role in the design of buildings. The NBC 2016 (BIS, 2016) have adopted the adaptive thermal comfort model based on the "Indian Model for Adaptive Comfort (IMAC)" developed by Manu et al. (2016) for design of natural and mixed-mode ventilated buildings. Until a decade ago, naturally ventilated buildings dominated the housing stock in India, but the sale of air conditioning (AC) units have grown at a compounded annual growth of 18-20% in the last decade (ISHRAE, 2018). This may be due to the rising indoor comfort expectations of people coupled with an increase in disposable income. Thus the present study has used the IMAC model related to mixed-mode ventilated buildings (Equation 1) to analyse the climate data for the different locations and thereby identify the locations with different climatic conditions. The 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 ±3.5°C.

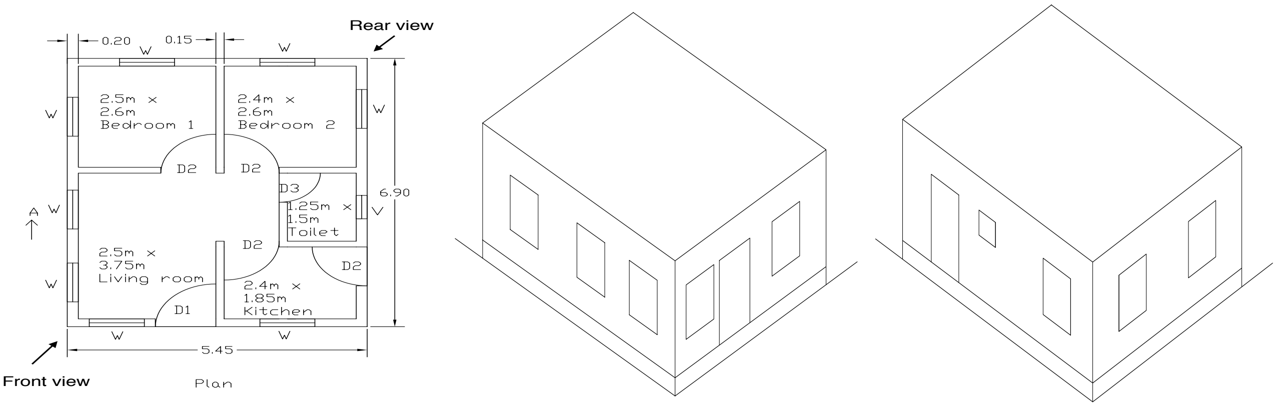
Days in a year were classified into days requiring heating (DRH) and days requiring cooling (DRC) based on the value of daily maximum and minimum temperatures with respect to the comfort acceptability limits. Days requiring heating (DRH) are defined as the days where the value of daily minimum temperature goes below the IMAC lower acceptability limit (90%) and days requiring cooling (DRC) are defined as the days where the value of daily maximum temperature goes above the IMAC upper acceptability limit (90%). The limits were calculated by using Equation 1. The characteristics shown by each location with respect to DRH and DRC were studied to identify the meso-climatic locations.

Case study building description

In order to understand the sensitivity of daylight and thermal performance to the climate of the selected locations, a case study building based on local building typology was modelled and simulated. The design specifications of the building were collected from an ongoing housing project, Livelihood Inclusion and Financial Empowerment (LIFE) Mission, under which the Government of Kerala plans to build 759,523 houses for people in the State (Issac, 2018).
The floor plan and isometric view of the building is shown in Figure 2. The case study building has gross floor dimensions of 5.45 m x 6.90 m and a floor to ceiling height of 2.9 m with internal partitions. The building has 5 rooms comprising of 1 living room, 2 numbers of bedrooms, 1 kitchen and 1 common toilet. A lintel band runs along the entire length of the wall (exterior and interior) at a height of 2.1 m from the floor level. The provision of the lintel will help the building walls to maintain integrity during earthquake shaking (Murty, 2005). Except for the entrance door and toilet door (marked D1 and D3 respectively in Figure 2a) all other doors (D2) are of dimension 1.00 m x 2.10 m. The doors D1 and D3 are of dimension 1.1 m x 2.1 m and 0.75 m x 2.1 m respectively. All the windows are of size 1.00 m x 1.35 m (marked W in Figure 2a) except the window in the toilet which is of size 0.60 m x 0.60 m (marked V in Figure 2a). The floor of the building lies at an elevation of 0.45 m above ground level. The specifications of the case study building used for daylight and thermal simulations are described in Table A1.

Analysis/performance measures

The performance of the case study building at different locations was analysed by carrying out daylight and thermal simulations. The climate-based metric 'Useful Daylight Illuminance' (UDI) was used to assess daylighting performance. UDI was calculated in terms of UDI not achieved (UDI-n), UDI combined (UDI-c) and UDI exceeded (UDI-e) (Mardaljevic, 2015). UDI-n was calculated as the percentage of annual occupied hours, averaged over the working plane, for which the illuminance values are less than 100 lux. UDI-c was calculated as the percentage of annual occupied hours, averaged over the working plane, in which the illuminance values falls between 100 lux and 3000 lux and UDI-e was calculated as the percentage of annual hours, averaged over the working plane, for which the illuminance values are greater than 3000 lux. The working plane was set at a height of 0.8 m above floor level and 0.25 m away from the surface of the interior walls. The grid spacing was set as 0.25 m. The time schedule 08:00-17:00 (without daylight savings) was used as the occupancy period. Daylight simulations were carried out using DIVA for Rhino and Grasshopper.
To evaluate the thermal performance of the case study building at different locations, the heating and cooling demand was calculated using EnergyPlus. For the purpose of thermal simulation the whole building was considered as a single zone and the nat-



(a) Floor plan

(b) Isometric (front) view

(c) Isometric (rear) view

Figure 2: Floor plan and isometric view of LIFE Mission building Type-1 (adapted from GoK (2018))

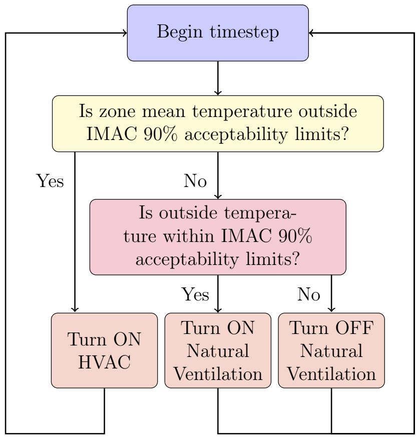


Figure 3: Natural Ventilation operation control flow chart

ural ventilation is operated as shown in Figure 3. The venting is controlled by opening the windows (at an angle of 90^o) when both mean zone and outside air temperature are within the IMAC acceptability comfort limits (90%). The upper and lower limits of 90% acceptability comfort/neutral temperature were calculated using IMAC model (Equation 1) and were used as set point temperatures of cooling and heating respectively. For both daylight and thermal performance evaluations the case study building was simulated in eight different orientations. The building was said to be oriented towards South if the entrance door of the building faces due South and likewise for other directions.

Results

Meso-climatic location identification and analysis

Three places, namely Thiruvananthapuram, Kalpetta and Idukki, were chosen based on the DRH and DRC values (Table 2). Thiruvananthapuram, the capital city with a population of 3,307,284, is located at the southern end of the State and requires cooling nearly 86% of the days in the year.

Idukki, located at an altitude of 1900 m above sea level, has a climate quite different from Thiruvananthapuram. Idukki could be identified to have a cold climate requiring only heating throughout the year.

Compared to Thiruvananthapuram and Idukki, Kalpetta has a unique climate requiring cooling as well as heating. Kalpetta, located at an altitude of 780 m above sea level, is one of the main cities in the

Table 2: Location, population and details of no: of days requiring cooling and heating (based on IMAC 90% acceptability) for the selected locations

Location	**Latitude**	**Longitude**	**Altitude (m)**	**Population**	**DRC**	**DRH**
					IMAC 90% acceptability	
Thiruvananthapuram	$8°30'0''$	$76°57'0''$	0.00	2,810,892	316	27
Kalpetta	$11°36'36''$	$76°4'48''$	780.00	3,307,284	251*	151*
Idukki	$9°55'12''$	$77°5'60''$	1900.00	1,107,453	3*	365*

* DRH & DRC values add upto more than 365 days because there are days in a year where the daily max. and min. temperatures go beyond the IMAC 90% acceptability upper and lower limits on the same day.

Table 3: Specification of climate parameters for the selected locations of Kerala

Parameter	**Thiruvananthapuram**		**Kalpetta**		**Idukki**	
Temperature range (°C)						
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Monthly mean	26.47	28.73	23.52	28.20	17.42	19.82
Monthly Mean of daily max.	30.00	33.10	28.10	32.39	20.64	24.34
Monthly Mean of daily min.	22.76	25.07	19.21	24.18	13.26	15.70
Relative humidity (%)						
Monthly mean	72.18	86.15	54.61	75.95	67.36	83.42
Monthly Mean of daily max.	91.54	97.73	71.58	92.58	88.16	95.84
Monthly Mean of daily min.	51.82	72.03	37.71	59.33	47.32	70.40
Wind speed (m/s)						
Monthly mean	0.59	2.10	1.40	3.70	1.19	3.00
Mean of daily max.	1.57	5.84	4.34	6.36	2.80	6.06
Wind Direction	Predominantly from West		Predominantly from West		Predominantly from West	
Sky condition(Based on diffuse fraction (k))	Around 70% of days partly cloudy (0.15<k<0.7)		Around 62% of days partly cloudy (0.15<k<0.7)		Around 60% of days partly cloudy (0.15<k<0.7)	

district of Wayanad.

The specifications of climate parameters for the selected three locations are described in Table 3. From the present study it could be observed that Thiruvananthapuram could be classified as a location with Hot-Humid climate, Kalpetta as Cool-Humid climate and Idukki under Cold-Humid climate.

Daylight performance of case study building in the three locations

For assessing the daylight performance, plots showing the directional variation in terms of UDI-n, UDI-c and UDI-e were produced. Figure 4 shows the plot of directional variation of UDI-n, UDI-c and UDI-e for case study building located in Thiruvananthapuram, Kalpetta and Idukki. UDI-n is not visible as the value is very low (<1%).

It could be observed from Figure 4 that the trend in directional variation of UDI-n, UDI-c and UDI-e for the building is similar for all three locations. For all three locations, the building performs comparatively better in terms of daylight when it is oriented towards the North-West direction with higher UDI-c values and least when it is oriented towards South, because of higher daylight levels (higher UDI-e).

The performance in terms of UDI-c increases with increase in altitude. The UDI-c values for the case study building located in Thiruvananthapuram are comparatively lower than for the building located in Kalpetta and Idukki. The building located in Kalpetta and Idukki have nearly similar UDI values for the respective orientations.

Thermal performance of case study building in the three locations

The influence of climate on the thermal performance of the case study building were studied by evaluating the heating and cooling demand for the building located in the three locations and by examining their sensitivity to changes in the building orientation. For accessing the thermal performance, plots showing the directional variation of annual heating and annual cooling demand were produced.

Figures 5 shows the directional variation of annual cooling/heating demand for the locations Thiruvananthapuram, Kalpetta and Idukki. The building at Thiruvananthapuram and Kalpetta shows cooling demand whereas Idukki shows heating demand. The annual cooling demand for the building at Kalpetta is observed to be nearly half of that for Thiruvananthapuram. Thiruvananthapuram has an annual cooling demand of $26.11\,kWh/m^2$ (averaged over all directions) where as the same for Kalpetta is $13.45\,kWh/m^2$. For the building located in Idukki, the highest heating demand is observed when oriented towards the South West direction $(2.21\,(\mathrm{kWh/m^2})$ and the lowest is observed towards due North $(2.09\,(\mathrm{kWh/m^2}))$ (Figure 5c).

Under adaptive thermal comfort conditions, the NBC 2016 specifies design temperatures of $21.8\,^oC$ and $29.5\,^oC$, as lower and upper limits for 90% acceptability, for mixed mode buildings in Thiruvananthapuram (BIS, 2016). Figure 6 shows the heating/cooling demand for the case study building located in the three locations based on the above mentioned design temperatures. It could be observed that the building performs better with low cooling demand when it is located at Kalpetta. High heating demand observed for the building at Idukki and the building at Thiruvananthapuram shows nearly three times as much the cooling demand than that for in Kalpetta. On comparing the thermal performance of the building at the different locations assessed with the respective weather conditions to that assessed with the NBC 2016 specified design temperature conditions, huge variation is observed for the building at Kalpetta and Idukki. The annual energy demand (averaged over all directions) for Kalpetta and Idukki assessed using the respective weather conditions were $13.45\,kWh/m^2$ (cooling) and $2.15\,kWh/m^2$ (heating) respectively. The annual energy demand (averaged over all directions) for Kalpetta and Idukki assessed using the NBC 2016 design temperature conditions were $6.48\,kWh/m^2$ (cooling) and $25.25\,kWh/m^2$ (heating) respectively.

Discussion

This study investigated the influence of climate on the daylight and thermal performance of buildings in Kerala (India). The results identified meso-climatic locations in Kerala with Warm-Humid (Thiruvananthapuram), Cool-Humid (Kalpetta) and Cold-Humid (Idukki) types of climate. The observations of the previous related climate classification studies and also the National Building Code of India 2016 classified the whole of Kerala under one zone (Warm-Humid), thus the results highlight the need for studies at higher spatial resolution for classification of climate zones.

The influence of climate on daylight and thermal performance was assessed by simulating a case study building located in the selected three meso-climatic locations. The case study building used in the study was based on the design proposed by the Government of Kerala for a project, LIFE mission, which aims to build 759,523 houses for people in the State.

The building was observed to perform better in terms of both daylight performance and thermal performance, with higher UDI-c values and lower overall heating and cooling demand respectively, when it was located at higher altitudes (Kalpetta & Idukki) compared to being located at lower altitudes (Thiruvananthapuram). The building performs comparatively better, in terms of daylight, when it is oriented towards the North West with higher UDI-c values and least when oriented towards South with higher UDI-e values, irrespective of location. Even though the

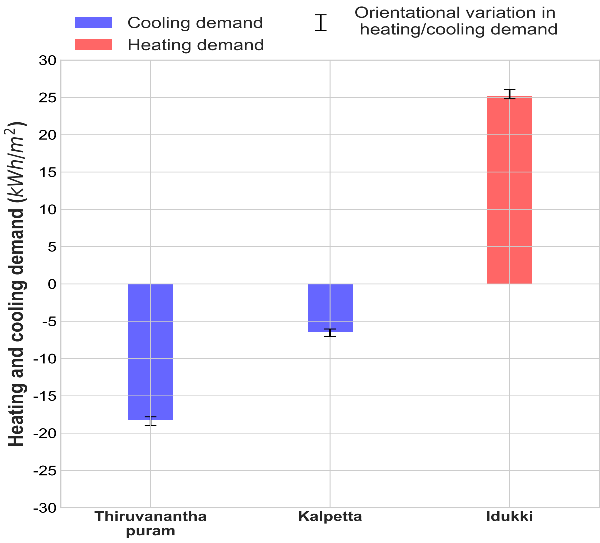
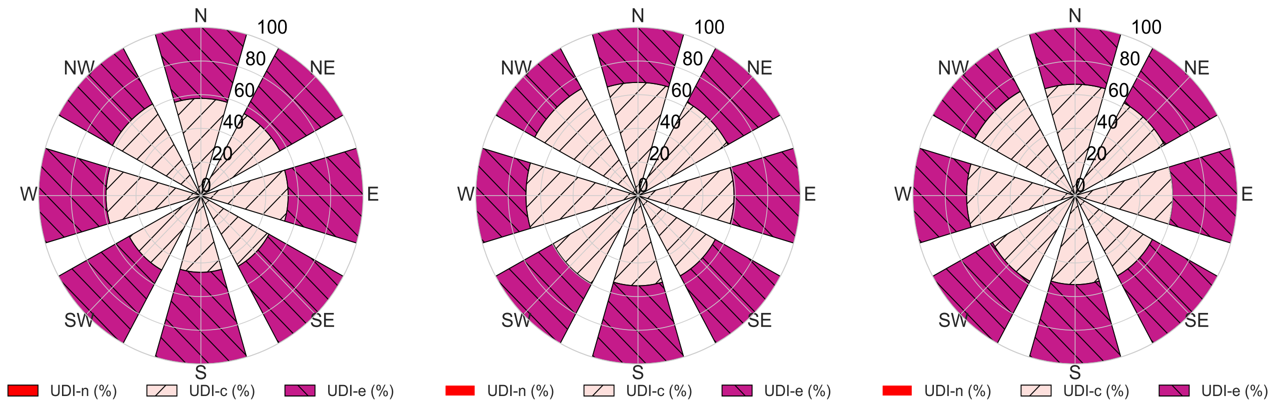


Figure 6: Thermal performance of case study building in the three locations based on NBC 2016 specified design set point temperatures

building has glazing on all four sides, the directional variation observed could be because of the window-wall ratio being different for all the four walls. For the case study building located in all the three locations and for all directions, the UDI-n was less than 1 (%). Thus provision of shading, such as overhangs, could improve the buildings daylight performance by improving the UDI-c and reducing the UDI-e values.

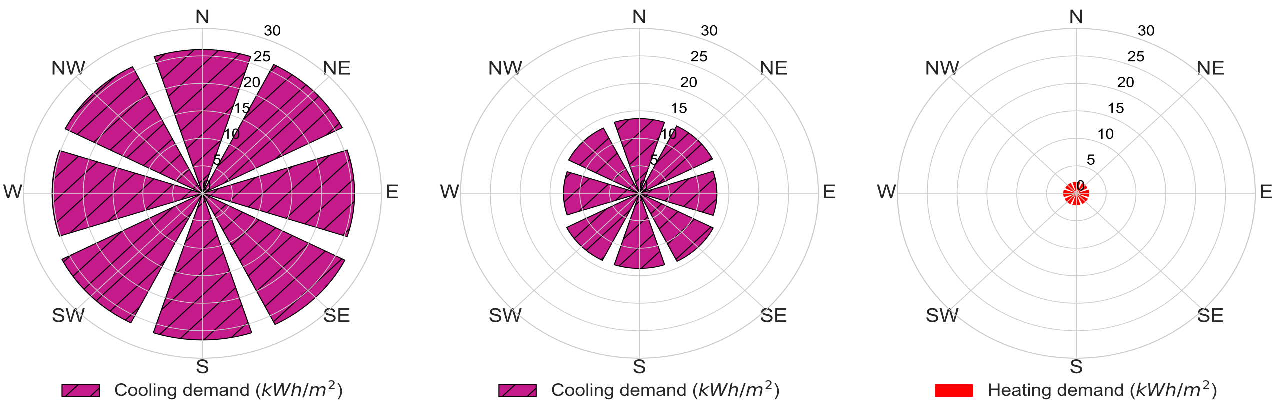
In terms of thermal performance the building performs comparatively better when it is oriented towards the North, with lower heating/cooling demand and least when oriented due South East with higher heating/cooling demand. The thermal performance was assessed based on adaptive thermal comfort model IMAC. Thiruvananthapuram was observed to have an annual cooling demand of 26.11 kWh/m^2 (averaged over all directions) which was nearly twice as that observed for Kalpetta (13.45 kWh/m^2).

Kalpetta was identified as a place having days requiring both heating and cooling, during meso-climatic loaction identification. Thermal analysis shows that the building located at Kalpetta has only cooling demand and not heating. This is because the DRH and



(a) Thiruvananthapuram *(b) Kalpetta* *(c) Idukki*

Figure 4: Directional daylight performance of case study building in the three locations (UDI-n is not visible as the value is really low)



(a) Thiruvananthapuram *(b) Kalpetta* *(c) Idukki*

Figure 5: Directional thermal performance of case study building in the three locations

DRC values were calculated based on an ideal case where a building envelope wasn't considered.

Even though the directional variation trend of annual energy demand is the same for all the three places, only Idukki was observed to have heating demand. Idukki has a cold climate with an annual heating demand of $2.15\,kWh/m^2$ (averaged over all directions). This was expected as the climate data analysis identified Idukki as having a cold climate with mean monthly temperatures ranging between $17.42\,^oC$ and $19.82\,^oC$ (Table 3).

The thermal performance of the building was also assessed based on the NBC 2016 specified adaptive themal conditions. Thiruvananthapuram is the only place from Kerala for which the design temperature values are specified in the NBC 2016. This is understandable as NBC 2016 delineates Kerala under one single climatic zone. The high heating demand observed for the building in Idukki is expected as Idukki has a cold climate (Table 3) and the design temperatures were based on a warmer climate (Thiruvananthapuram).

Thus it is evident that the same design conditions are not compatible for the different locations within Kerala. The case study building performs comparatively better under adaptive comfort conditions, when it is constructed in Idukki, with very low overall heating and cooling demand, than in the other two places. The results highlight the existence of different climatic zones within Kerala and the need for separate building designs tailored for each climatic zone.

Conclusion

With the NBC classifying the whole of Kerala under one single climate zone, the construction of a building across the State based on the same design conditions could result in huge variations in terms of daylight and thermal performance. Considering that the building type used in this study forms one among the 12 designs proposed by the Government of Kerala and assuming that these buildings once constructed will exist for the next 50 years or so, the results from this study highlights the urgent need to revisit the climate zone classification at higher resolutions as well as the need for development of design methodologies tailored for each climate zone.

Due to lack of reliable occupancy schedule data typical to Kerala residential buildings, the thermal performance of the building was assessed assuming that the building was occupied at all times. This forms one of the limitations of the study. Also the locations were selected based on a method that used adaptive thermal comfort model to calculate the number of days requiring cooling and heating. These days were calculated based on the value of minimum and maximum daily outdoor temperature and not the indoor (zone) temperature. This forms an idealised case and the actual number of days requiring cooling and heating may vary depending on the building typology and construction parameters.

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Table A1: Specification of building elements of case study building used for daylight and thermal simulations (BEE, 2017)

Building element	**Material**	**Dimension (m)**	**Density** (kg/m^3)	**Specific heat** (J/kgK)	**Thermal conductivity** ($W/m-K$)	**Reflectance (%)**	**Transmittance**	**Transmissivity**
External Wall	Cement plaster	0.015	1762	849	0.721	50	-	-
	Burnt brick	0.170	1820	880	0.811			
	Cement plaster	0.015	1762	849	0.721			
Partition Wall	Cement plaster	0.015	1762	849	0.721	50	-	-
	Burnt brick	0.120	1820	880	0.811			
	Cement plaster	0.015	1762	849	0.721			
Lintel band	Reinforced Cement Concrete	0.100	2288	880	1.58	50	-	-
Roof	Cement plaster	0.015	1762	849	0.721	70	-	-
	Reinforced Cement Concrete	0.120	2288	880	1.58			
	Cement plaster	0.015	1762	849	0.721			
Floor	Cement plaster	0.015	1762	849	0.721	20	-	-
	Dense Concrete	0.100	2410	880	1.74			
	Cement plaster	0.015	1762	849	0.721			
Window	Glass (single pane)	0.003	2500	750	1.06	8	0.88	0.96