BUILDING DESIGN REPORT

FOR CONSTRUCTION OF RESIDENTIAL BUILDINGS IN KERALA (INDIA)

A guide to assist architects and building designers in the early stage design of buildings that exhibit high thermal and daylight performance in Kerala.

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List of Acronyms

BEE Bureau of Energy Efficiency.

BPS Building Performance Simulation.

CBDM Climate-Based Daylight Modelling.

ECBC Energy Conservation Building Code.

EMS Energy Management System.

GRIHA Green Rating Integrated Habitat Assessment.

IMAC Indian Model of Adaptive Comfort.

NBC National Building Code of India.

SA Sensitivity Analysis.

UA Uncertainty Analysis.

UDI Useful Daylight Illuminance.

UDI-e Useful Daylight Illuminance - exceeded.

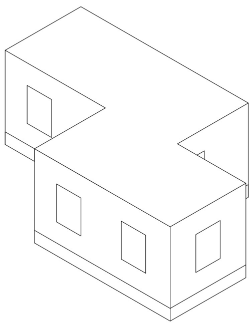
UDI-n Useful Daylight Illuminance - not achieved.

UDI-c Useful Daylight Illuminance - combined.

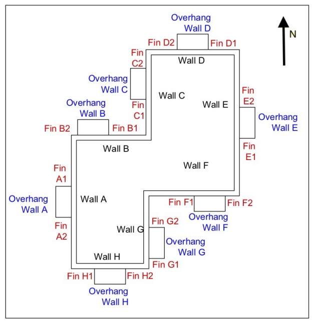
Executive summary

This report forms a part of the residential building design guide developed to assist architects and designers, during the early-stages, to design buildings that exhibit high thermal and daylight performance. The design guide is presented via an interactive web-based platform. This design report was produced from the website, based on the user's design considerations and priorities. The design consideration consists of details regarding the location, building type, building context and building orientation. These details are presented in the table below under location and building details tab. The design priority is for a building that exhibit high thermal and daylight performance. The building's thermal and daylight performance were assessed based on the annual total energy demand and Useful Daylight Illuminance (UDI) values respectively. The annual total energy demand for heating and cooling for the building design is 2 kWh/m^2. This is below the lower threshold value (1 kWh/m^2). Thus the design exhibits better thermal performance. The UDI-c value of the building design is 93%. This is higher than the upper threshold value (92%).Thus the design exhibits better daylight performance.

Building base form: Type 3

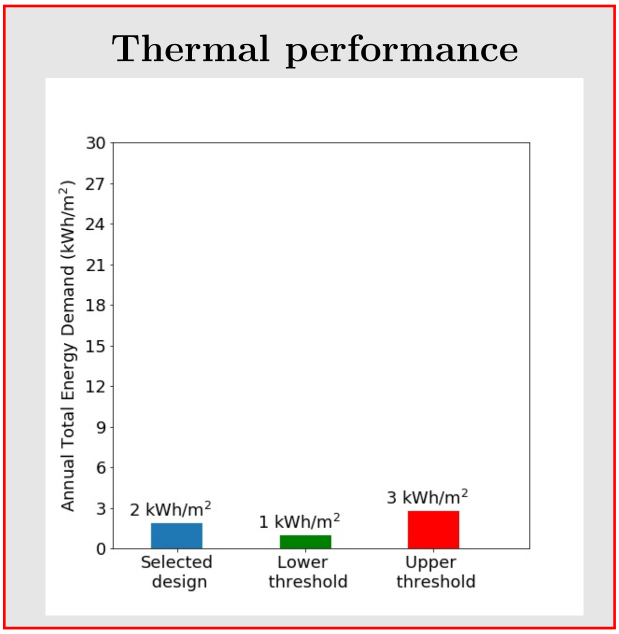


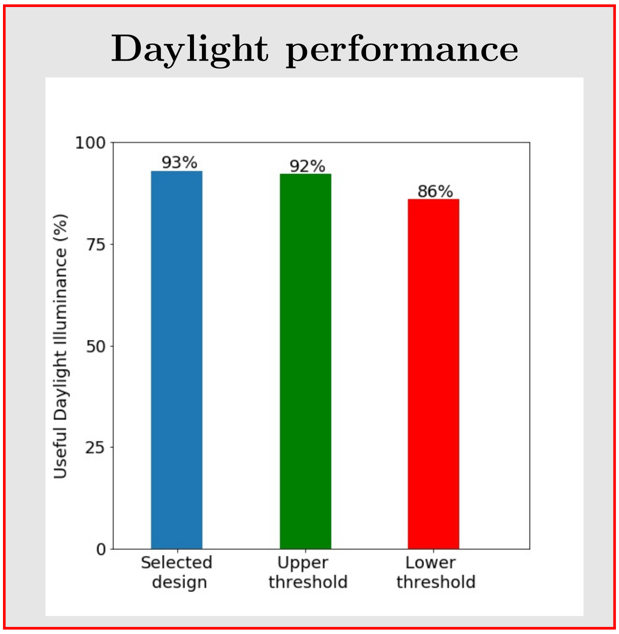
Building plan: Type 3



Design context	
State	Kerala
District	Idukki
Location	-
Climate zone	Adaptively Cold Zone
Building type	3
Building context	Open low rise
Orientation	South
Design number	5
Design ID	21

Building design parameters		
Parameters	**Units**	**Values**
Wall A U-value	W/m^{2}K	1.55
-	-	-
Floor U-value	W/m^{2}K	0.45
Roof U-value	W/m^{2}K	3.38
WWR Wall A	%	66.00
WWR Wall B	%	28.00
WWR Wall C	%	62.00
WWR Wall D	%	60.00
Ground reflectance	-	0.17
-	-	-
-	-	-
-	-	-





The bar charts above show the thermal and daylight performance of the selected design against the lower and upper threshold values. The threshold values are used to identify whether the design exhibits better, medium or worse thermal/daylight performance. The designs that have an annual total energy demand below the lower threshold is considered to exhibit better thermal performance. Those designs that have an annual total energy demand higher than the upper threshold is considered to exhibit worse thermal performance. All other designs that have an annual energy demand in between the lower and upper threshold are considered to exhibit medium performance. To assess the daylight performance of designs, the case is vice-versa to thermal performance.

1 Problem definition

1.1 Problem Scope

The purpose of this report is to provide a set of design features to assist the design of a building in Adaptively Cold Zone that would exhibit high thermal and daylight performance. This report was produced based on the design considerations specified by the user while using the residential building design guide via its web-based platform. The residential building design guide was developed to assist during the early stages, to design high performance buildings, for the first instance, in the State of Kerala.

1.2 Background

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 existing building stock in India accounts for around 33% of the total electricity consumption, of which residential and commercial uses represent 25% and 8% respectively (BEE, 2009). With an additional 315 million people expected to move to urban India by 2040 (IEA, 2015), the final energy demand in buildings is expected to undergo a drastic change with an anticipated rise of about 65% to 75% of 2005 levels by 2050 (van Ruijven et al., 2011). 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, the construction of buildings are governed by building codes and regulations enacted by concerned government departments at national and state levels. At the national level, the National Building Code of India (NBC) is the model code for regulating the construction activities of the construction industry. NBC 2015 is divided into 12 parts which covers basic guidelines and provides a basic framework for developing regulations at local levels (Chandel et al., 2016). The provisions provided in the parts and subparts of NBC does not directly cover the aspect of energy efficiency even though its adoption may result in some energy efficiency improvements. The Bureau of Energy Efficiency (BEE), whose function is to initiate energy efficiency measures and regulations in India, formulated the Energy Conservation Building Code (ECBC) in 2006 which outlays energy efficiency initiatives for buildings having an occupied space of more than $1000\,\mathrm{m}^2$ or having an energy consumption of 500 kW or more (BEE, 2006). The average floor area of dwellings in India are $40.03\,\mathrm{m}^2$ and $39.20\,\mathrm{m}^2$ respectively for rural and urban areas (NSS, 2012). Thus the ECBC speculation limits its use to mainly commercial buildings. A code for residential building envelope "Eco-Niwas Samhita" was launched by BEE in 2018 (BEE, 2018). This code defines a Residential Envelope Transmittance Value (RETV) to evaluate and compare different design alternatives and material options. A maximum RETV value is defined for each climate which needs to be achieved for code compliance. For all the regions having Composite, Hot-dry, Warm-humid and Temperate climate, the maximum RETV is 15 $\mathrm{W/m^2}$ (BEE, 2018). The energy demand corresponding to an RETV of 15 $\mathrm{W/m^2}$ is around 125 $\mathrm{kWh/m^2}$ (Bhanware et al., 2019). The study by Bhatt et al. (2005) found that the annual energy consumption in residential buildings ranges between 12 – 36 $\mathrm{kWh/m^2}$. Thus complying with the RETV value may not result in the building being energy efficient. Moreover, considering that the national level building codes and rating systems like NBC, ECBC, GRIHA etc. are non-mandatory and ineffective at state and local levels (Chandel et al., 2016) and with the power to legislate rules and regulations in all matters regarding land and its development lying only with the State Government (GoI, 2015), any action to be taken regarding reforming the building and energy efficiency rules and regulations, either in the form of amendments or formulation of new ones, should focus from the state level meeting the intrinsic needs of the locality (Kumar and Pushplata, 2013; Kumar, 2016). Thus, a study was conducted, focusing on the needs at the State level, to develop a residential building design method to assist during the early stages, to design buildings that exhibit high thermal and daylight performance. The study in the first instance focused on the State of Kerala. Kerala is located at the South Western part of the country between the Arabian Sea and the mountain ranges Western Ghats. Currently the design and construction aspects of buildings in Kerala are regulated by local building rules – Kerala municipality building code (LSGD, 1999) and Kerala panchayat building code (LSGD, 2011). The provisions provided in the these codes does not directly cover the aspect of energy efficiency and also does not differentiate between the different climatic zones across the State. The need for amendments in Kerala's building codes to account for energy efficiency measures tailored for each of the climatic zones of Kerala was also corroborated in the governments Post Disaster Needs Assessment report (GoK, 2018). The developed method is presented via an interactive web-based platform. This report is the final product from the website and produced based on the design priorities provided by the user. The report outlines the projected thermal and daylight performance of the building. The report also presents a list of design parameters and their corresponding values that need to be considered to design the building in the specified location in Kerala.

2 Design description

The design considerations specified for developing the design specifications are:

1. State – Kerala
2. Climate – Adaptively Cold Zone
3. Building type/base form – Type 3
4. Building context – Open low rise
5. Orientation – South
6. Performance priority – High Daylight

2.1 Climate zone

The regions in Kerala are divided into three climate zones namely – Adaptively Hot Zone, Adaptively Mixed Zone and Adaptively Cold Zone. The location chosen is in Adaptively Cold Zone Figure 2 presents the adaptive climate zones of Kerala. Figure 3 shows the variation of daily maximum and minimum outdoor dry bulb temperatures for locations in the Adaptively Cold Zone. The daily maximum outdoor dry bulb temperature varies between 19.6°C and 30.8°C. The daily minimum outdoor dry bulb temperature varies between 13.0°C and 21.8°C. Figure 3 shows the variation of heating and cooling set point temperatures across the year. The heating and cooling set point temperatures were calculated based on the Indian Model of Adaptive Thermal Comfort (IMAC)[1]. From the figure it can be observed that the daily minimum temperature is below the heating set point temperature for most of the year and that the daily maximum temperature goes above the cooling set point temperature only on a few occasions. Thus, the buildings

[1]For further details about the IMAC please refer to Section 3.

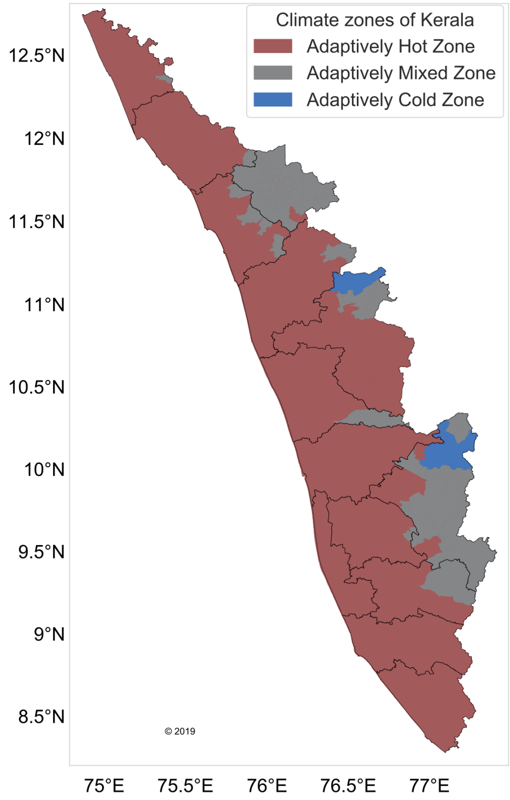


Figure 2: Climate zone map of Kerala.

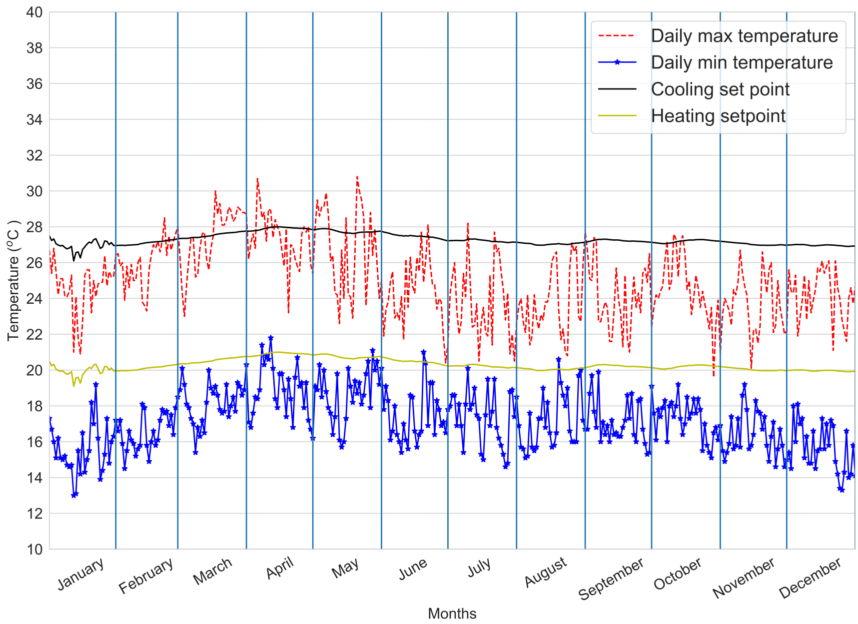
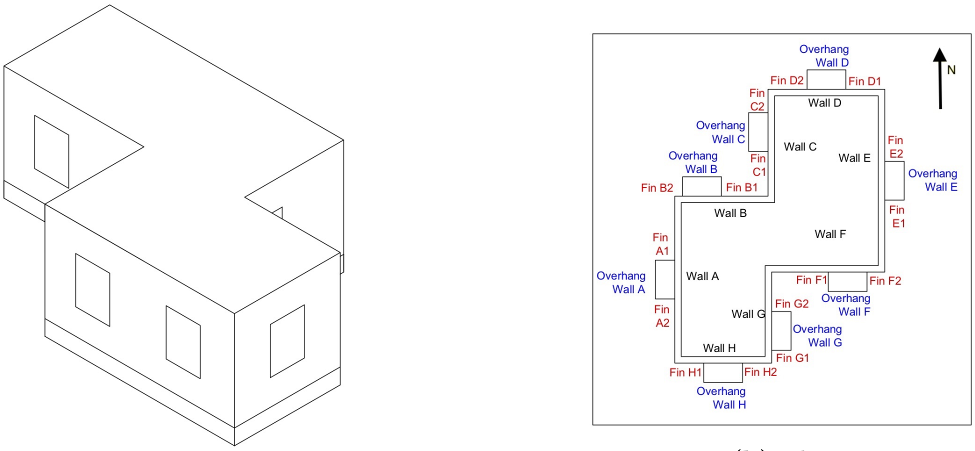


Figure 3: Variation of dry bulb temperature in Adaptively Cold Zone

constructed in Adaptively Cold Zonemay exhibit heating demand to meet the thermal comfort requirements of its occupants.

2.2 Building details

The building type selected was Type 3 which has a base form as shown in Figure 4a. Figure 4b shows the plan view of the selected design. The values of sensitive design parameters[2] that needs to be considered while designing the building are presented in Table 1.



(a) Base form

(b) Plan

Figure 4: Building Type 3

Parameters	Units	Values
Wall A U-value	W/m^2K	1.55
Floor U-value	W/m^2K	0.45
Roof U-value	W/m^2K	3.38
WWR Wall A	%	66.00
WWR Wall B	%	28.00
WWR Wall C	%	62.00
WWR Wall D	%	60.00
Ground reflectance	-	0.17

Table 1: Building design parameters

2.3 Building performance

The thermal performance of the building was assessed by carrying out Building Performance Simulation (BPS)[3] using EnergyPlus v8.9 software (Documentation, 2010). The design has an annual total energy demand of 1.85 kWh/m^2.This value is above thermal performance threshold[4] of 0.99 kWh/m^2 for buildings in the Adaptively Cold Zone. Figure 6 shows the frequency distribution of thermal performance of building designs when located in Adaptively Cold Zone. The category (bar) into which the selected design falls into is marked in red. The plot presented (Figure 6) includes all the three representative building types. Each of the building types was assessed for all the different practical design combinations[5]. Figure 5 shows the frequency distribution of thermal performance of Type 3 building designs when located in Adaptively Cold Zone. For assessing the day-

[2]The method used to identify the sensitive parameters is described in Section 3.

[3]Details about the simulation method used and assumptions made for assessing the thermal performance are provided in Section 3.

[4]The method used to identify the threshold value is described in Section 3.

[5]The design parameters and their practical values are presented in section 3

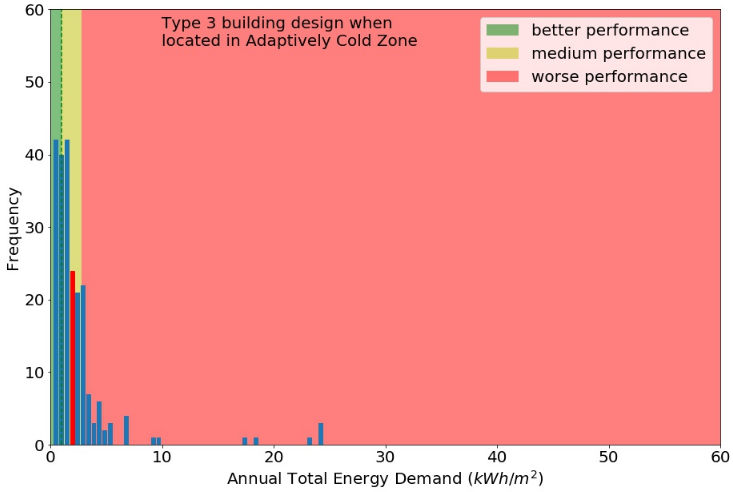


Figure 5: Frequency distribution plot of thermal performance of Type 3 building designs (250 designs) when located in Adaptively Cold Zone. The bar corresponding to the selected design is marked in red.

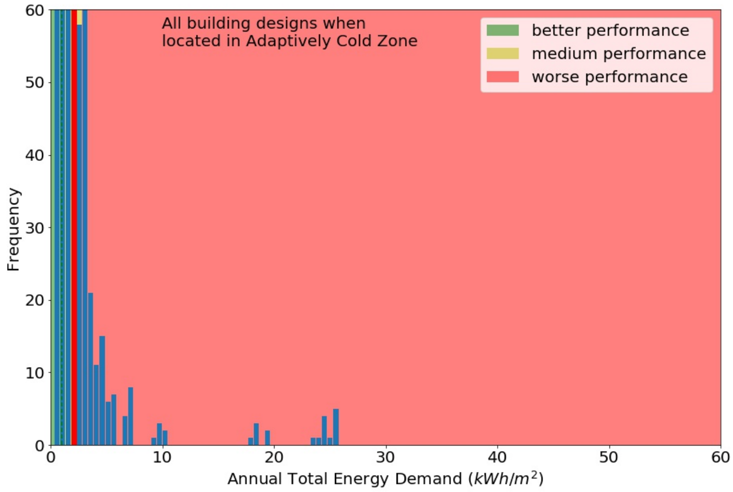


Figure 6: Frequency distribution plot of thermal performance of all building designs (750 designs) when located in Adaptively Cold Zone.The bar corresponding to the selected design is marked in red.

light performance of the buildings, the climate-based metric Useful Daylight Illuminance (UDI) was used. The simulations were run with the 2-Phase method. UDI was calculated in terms of UDI not achieved (UDI-n), UDI combined (UDI-c) and UDI exceeded (UDI-e) (Mardaljevic, 2015). The design provided in this report has a UDI-c of 93.00 %.UDI-c was calculated as the percentage of annual occupied hours for which the illuminance values fall between 100 lux and 3000 lux. This value is well above the daylight performance threshold[6] of 92.25 %for buildings in the Adaptively Cold Zone. Figure 8 shows the frequency distribution of daylight performance of building designs when located in Adaptively Cold Zone. The category (bar) into which the selected design falls is marked in red. The de-

[6]The method used to identify the threshold value is described in Section 3.

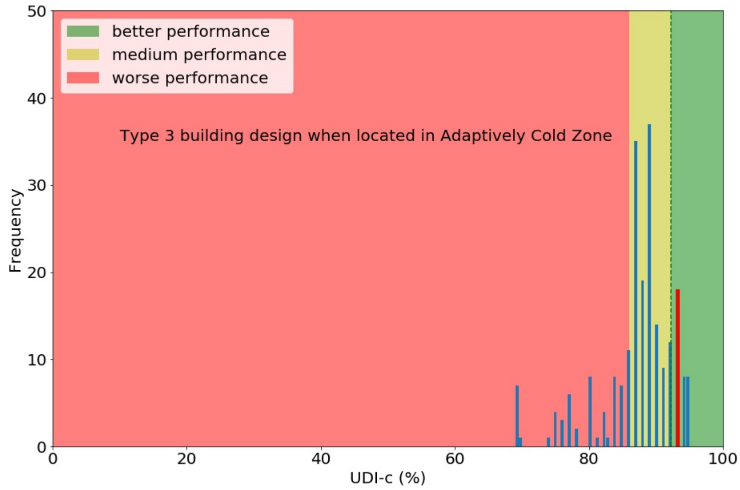


Figure 7: Frequency distribution plot of daylight performance of Type 3 building designs (250 designs) when located in Adaptively Cold Zone.The bar corresponding to the selected design is marked in red.

sign presented in Figure 8 covers all the three representative building types. Each of the building types were assessed for all the different practical design combinations[7]. Figure 7 shows the frequency distribution of daylight performance of Type 3 building design when located in Adaptively Cold Zone.

[7]The design parameters and their practical values are presented in section 3

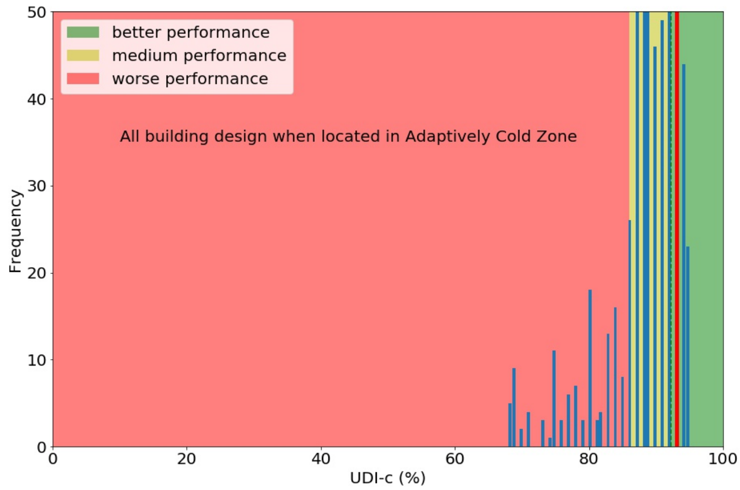


Figure 8: Frequency distribution plot of daylight performance of all building designs (750 designs) when located in Adaptively Cold Zone.The bar corresponding to the selected design is marked in red.

3 Technical reference

3.1 Simulation method

3.1.1 Thermal simulation

The thermal performance of the buildings was assessed by carrying out Building Performance Simulation (BPS) using EnergyPlus v8.9 software (Documentation, 2010). In this study, the whole building was assumed as a single thermal zone. The HVAC template in the model was defined using Packaged Terminal Air Conditioner (PTAC) whereas ventilation was defined using airflow network. The thermostat set point temperatures for heating and cooling were defined based on adaptive thermal comfort model, as the latest version of the NBC of India (BIS, 2016) adopted the IMAC. According to the IMAC model, for mixed-mode ventilated buildings the neutral/comfort temperatures are calculated using the equation:

$$T_c = 0.28T_o + 17.9 \tag{1}$$

where T_c is the neutral/comfort temperature in degree Celsius and 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. 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 for cooling and heating respectively. The building was modelled to have

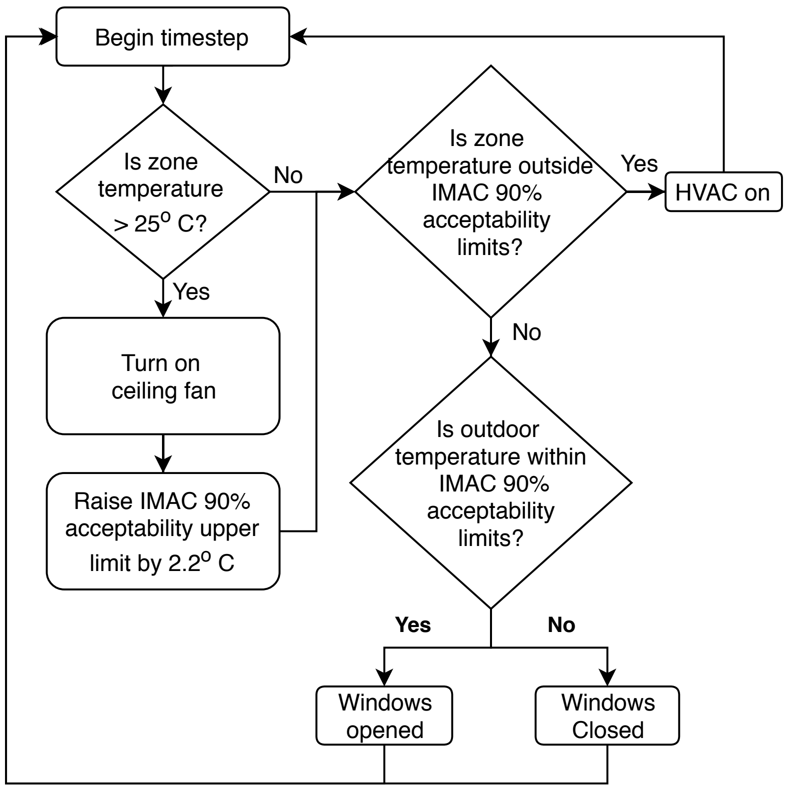


Figure 9: Window and ceiling fan operation.

mixed mode ventilation and the ventilation was controlled by opening the windows (at an angle of 90^o) when both mean zone and outside air temperature were within the IMAC acceptability comfort limits (90%). The buildings were also modelled to have ceiling fans which were functional when the indoor zone temperature was above 25^oC and when the

HVAC was not ON. 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). When ceiling fans were in operation the cooling set point (i.e. IMAC 90% acceptability upper limit) were offset by 2.2^oC (Standard 55, 2013). Energy Management System (EMS) programs were written to define the ventilation and ceiling operation schedules and their operations were controlled as shown in Figure 9. To assess the building performances, only annual heating and cooling energy demands were considered.

3.1.2 Daylight simulation

A number of Radiance-based methods are available to perform climate-based daylight modelling (CBDM). The simulations were run with the 2-Phase method. Since the study does not involve complex glazing systems, the 2-Phase method (with higher sky resolution) was used to assess the daylight performance of buildings. 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 for which the illuminance values are less than 100 lux.
- UDI-c was calculated as the percentage of annual occupied hours for which the illuminance values fall between 100 lux and 3000 lux and
- UDI-e was calculated as the percentage of annual occupied hours for which the illuminance values are greater than 3000 lux.

The time schedule 08:00-17:00 (without considering daylight saving time) was used as occupancy period. The sensor grid points were placed on a horizontal working plane height of 0.8 m above the floor level and 0.25 m from the surrounding walls. Results from each UDI range were obtained for all sensor points on the working plane, and then averaged.

3.2 Performance thresholds identification

The thermal and daylight performance of the selected building design was assessed based on threshold values of annual total energy demand and UDI-c respectively for buildings in the Adaptively Cold Zone. The performance thresholds to assess the thermal and daylight performance of buildings were determined by carrying out an Uncertainty Analysis (UA).UA helps to identify the uncertainty in the output due to uncertainties in the input and the results of this analysis were used to identify the threshold values for assessing the thermal and daylight performance of buildings. Table 2 presents the different parameters and their corresponding lower and upper limit values considered for carrying out the uncertainty analysis. To carry out UA the Window Wall Ratio (WWR), the U-values of walls and windows, the depth of overhang and the length of fins were varied separately for each wall. This was done to cover all possible design scenarios. The UA was carried out for each of the different representative building types. For UA, all the parameters were sampled 250 times with Latin hypercube sampling. Under Latin hypercube sampling method all the input parameter are varied simultaneously for each sample. The samples were created using SALib library in Python (Herman and Usher, 2017). SALib is an open

Parameters	Lower limit	Upper limit
Rural Context		
Window Wall ratio (WWR)	10%	70%
Roof U-value ($W/m^2.K$)	0.10	3.60
Floor U-value ($W/m^2.K$)	0.10	2.94
Wall U-value ($W/m^2.K$)	0.10	3.50
Window U-value ($W/m^2.K$)	0.70	7.10
Overhang depth (m)	0.01	0.60
Fins length (m)	0.01	0.60
Ground reflectance	0.05	0.30
Floor reflectance	0.05	0.40
Wall reflectance	0.20	0.85
Ceiling reflectance	0.50	0.95
Window transmittance	0.40	0.90

Table 2: Input parameters for UA/SA

source library for performing sensitivity analysis and the sample generation function was used to create the input parameter values. To identify the uncertainty in thermal performance, the simulations were carried out in EnergyPlus with the help of JEPlus software. JEPlus is an EnergyPlus simulation manager for parametric simulations (Zhang and Korolija, 2010). The UA for daylight performance was carried out by running the simulation for each of the cases in Radiance using the 2-Phase method. The results were then post-processed in Python. From the results of UA, the lower inter-quartile value was chosen as the lower threshold and the upper inter-quartile value was chosen as the upper threshold value for assessing the thermal/daylight performance of buildings. The designs that have an annual total energy demand below the lower threshold is considered to exhibit better thermal performance. Those designs that have an annual total energy demand higher than the upper threshold is considered to exhibit worse thermal performance. All other designs that have an annual energy demand in between the lower and upper threshold are considered to exhibit medium performance. To assess the daylight performance of designs, the case is vice-versa to thermal performance.

Figure 10 and 11 presents the results of UA for thermal and daylight performance, respectively, for the different building types in Adaptively Cold Zone.The threshold values for thermal and daylight performance are 0.99 kWh/m^2 and 92.25 % respectively.

3.3 Sensitive parameters identification

The list of sensitive design parameters presented in this report (Table 1) is based on results of Sensitivity Analysis (SA). SA helps to identify the design input parameters that affect the building's performance the most. SA was carried out to identify the sensitive building elements that needs to be considered while designing high performance buildings in Adaptively Cold Zone.Table 2 presents the different design parameters considered for carrying out SA. The methods involved in carrying out SA is similar to UA. The difference between the methods was with respect to the sampling method and results post-processing. For SA, the sampling was done using Morris method with 8 trajectories. In Morris method only one parameter is changed at a time i.e. only one parameter value is changed for subsequent simulations. Thus Morris method is one-step-at-a-time method. For carrying out SA, the Window Wall Ratio (WWR), the U-values of walls

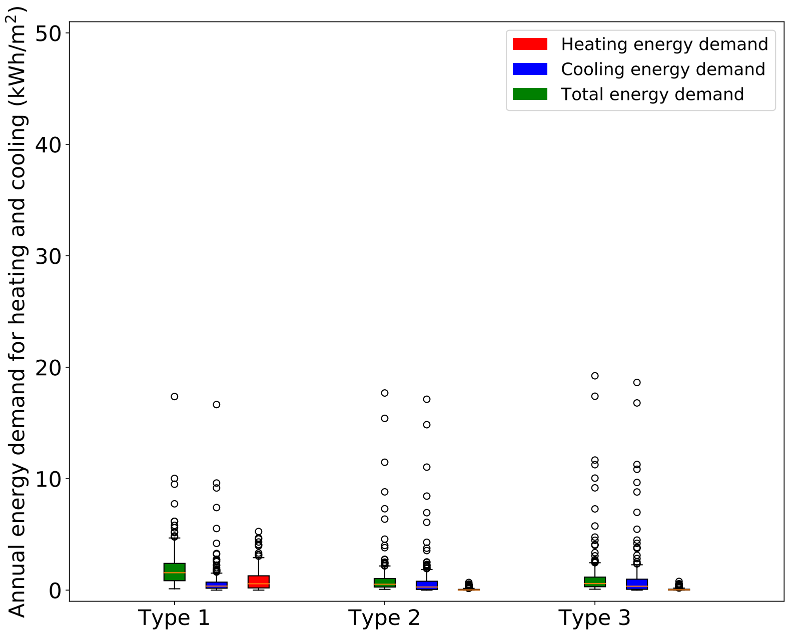


Figure 10: Results of Uncertainty Analysis for thermal performance of buildings in Adaptively Cold Zone

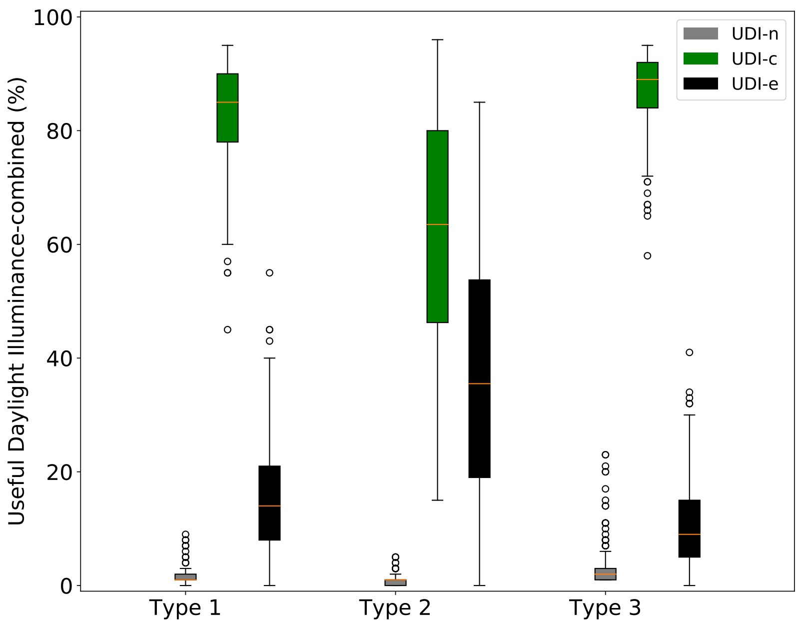


Figure 11: Results of Uncertainty Analysis for daylight performance of buildings in Adaptively Cold Zone

and windows, the depth of overhang and the length of fins were varied separately for each wall. This was done to cover all possible design scenarios. The sampling was done using SALib library in Python. The number of samples depends upon the trajectories and the number of parameters. The number of samples is calculated as:

$$N = k(P + 1) \tag{2}$$

where N is the number of samples, k is the number of trajectories and P is the number of parameters. Similar to UA, to identify the sensitive input parameters influencing the thermal performance, the simulations were carried out in EnergyPlus with the help of

JEPlus software. The UA for daylight performance was carried out by running the simulation for each of the cases in Radiance using the 2-Phase method. The results were then post-processed in Python using Morris analysis method to determine the sensitive parameters. Figures 12 and 13 present the results of SA for thermal and daylight performance of building Type - 1. The sensitive design parameters are ranked according to the order of significance. Only the values corresponding to the parameters that showed (comparatively) higher sensitivity towards thermal and daylight performance were selected and presented with the design specification.

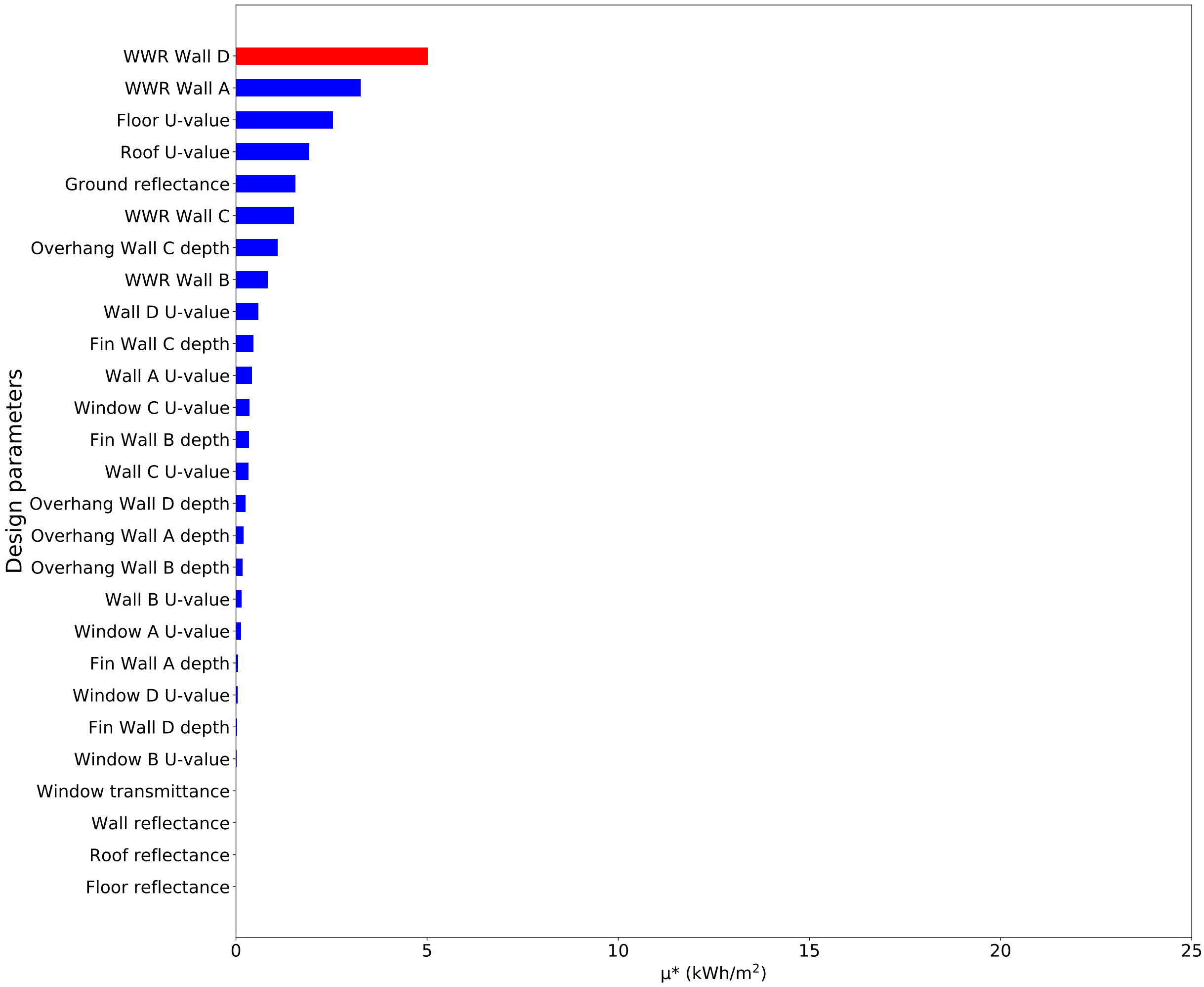


Figure 12: Results of Sensitivity Analysis for thermal performance of buildings in Adaptively Cold Zone(To be read along with Figure 4b).

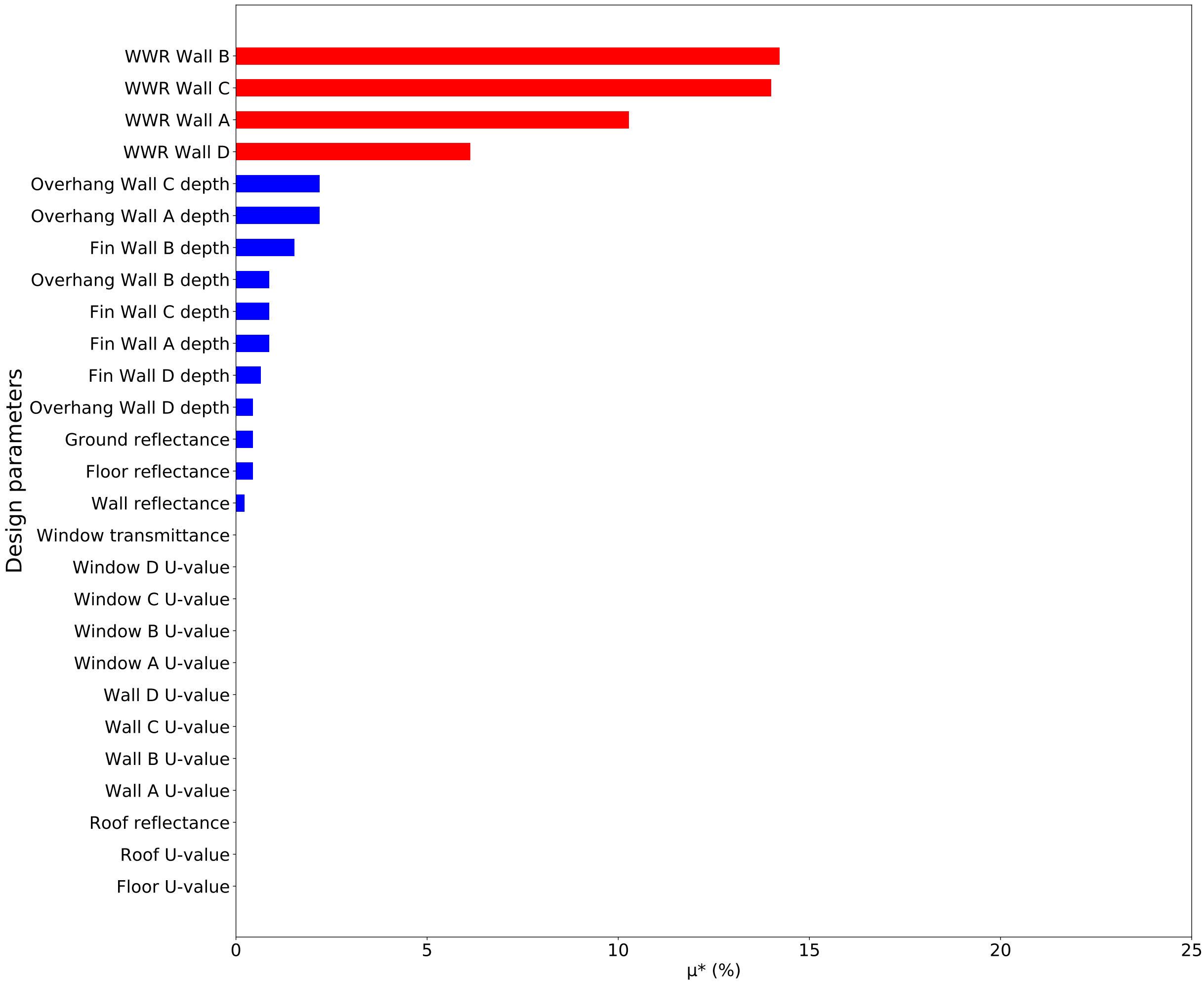


Figure 13: Results of Sensitivity Analysis for daylight performance of buildings in Adaptively Cold Zone(To be read along with Figure 4b).

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