Universe International Journal of Interdisciplinary Research
(Peer Reviewed Refereed Journal)

© UIJIR | ISSN (O) – 2582-6417
JAN. 2022 | Vol. 2 Issue 8
www.uijir.com

GREEN ENGINEERING AND BUILDING ENERGY ANALYSIS FOR BHUTANESE RESIDENTIAL DWELLINGS

Author's Name: [1.4]Nimesh Chettri, [2]Jigme Thinley, [3]Namgay Tenzin

Affiliation: [1]*Civil Engineering and Architecture Department College of Science and Technology, Royal University of Bhutan*

[2] *Architecture Department College of Science and Technology, Royal University of Bhutan*

[3] *Electrical engineering Department College of Science and Technology, Royal University of Bhutan*

[4] *Centre of Disaster Risk Reduction and Community Development Studies, College of Science and Technology, Royal University of Bhutan*

Email: nimeshchhetri.cst@rub.edu.bt

DOI No. – 08.2020-25662434

Abstract

The explicit studies are done to assess the energy consumption in the Bhutanese residential dwellings. The preliminary investigation depicts gaps in terms of the green concept which calls for immediate action to sort it out. The results of the initial survey are thus vetted thoroughly to give the green look to the poorly green concept implemented building. The simple green building principle such as "bird nesting philosophy", is incorporated to consider the benefit of the natural resources and energies available around to accomplish the requirements, with negligible impact to the environment. The study also incorporates various sustainable practices of planning, designing, building and maintenance of residential houses to rectify the deficiencies of the existing building. The building energy analysis results of buildings with and without the green concept are presented in the paper.

Keywords*: Sustainability, Green Building, Bhutan, Passive energy, , Dialux*

INTRODUCTION

It is a well-known that the world's major environmental issues are a result of mankind's attempt to shift towards modern technology and globalization. The United Nation Environment Program (UNEP) depicts that the construction sector alone uses 40% of the worldwide energy, 25% of worldwide water, 40% of worldwide resources, and releases around 30% of the greenhouse gases [1][2][3]. The construction industry accounts for a significant pressure on the environment and induces a tremendous threat to the vision of sustainable development. In particular, building construction and operation contribute to a large portion of the emission of greenhouse gases.

Bhutan is a mountainous country and is susceptible to the Glacier Lake Outburst and Flood (GLOF) and other impacts of climate change[4]. A green construction (known by different synonyms such as green engineering, green building, sustainable house, etc.), is a building designed, constructed, repaired, operated, or recycled in a resource-efficient method. Green construction is all about realizing and showing a sense of compassion and responsibility towards the environment. The approach of green construction can be traced to the bird's nesting philosophy, where birds build their nests in the very playfield of nature. The basic idea of keeping nature the way it was before and is preserved exclusively. Due to rising energy costs over the years, it is even more crucial to look for ways to reduce energy consumption in buildings [5]. Very often, climatic factors are given very little importance in the design development of modern buildings owing to the minimal immediate interest of the people involved in the construction sector. The current research reflects the key findings which aim to study and develop the significant climatic data in the southern belt of Bhutan for sustainable building design. Sustainable construction and building amenities systems require cautious contemplation of local climatic settings and features. It is impossible to achieve sustainable building design with an efficient building functioning system without good knowledge about the local climatic conditions [6]. Bhutan presently has shifted towards modern reinforced concrete building system from the sustainable housing typology preserved through the centuries such as rammed earth, stone masonry, timber and wattle and daub. These age-old housing typologies are slowly diminishing due to several factors. Some of the commonly found housing types are projected in figure 1. The Royal Government of Bhutan has taken an indispensable step during the sixth engineering conference, whereby the Bhutan Building Rule (BBR)will be converted to the Bhutan Green Building code[7]. This current paper aims to optimise the use of natural energy and minimize the use of conventional energy, reducing the operating cost of the building, improving occupant health and productivity and reducing the overall impact to the environment. The research is limited to those green building techniques and methodologies which are relevant in the context of Bhutan, considering the level of advancement in modern technology in the construction industry. Long term weather data are analysed to vet the real-world matters of structure design, valuable climatic data and patterns to be incorporated into giving best option for future structures in study area. The data collected and the analysis performed are applicable to site conditions and climatic zones which are similar to the Phuentsholing district of Bhutan.

a. Vernacular Rammed earth residential house

b. Composite stone masonry (ground floor) and wattle and daub dwellings

c. Wattle and daub house (southern Bhutan)

d. Bakal (outer cover of tree) House

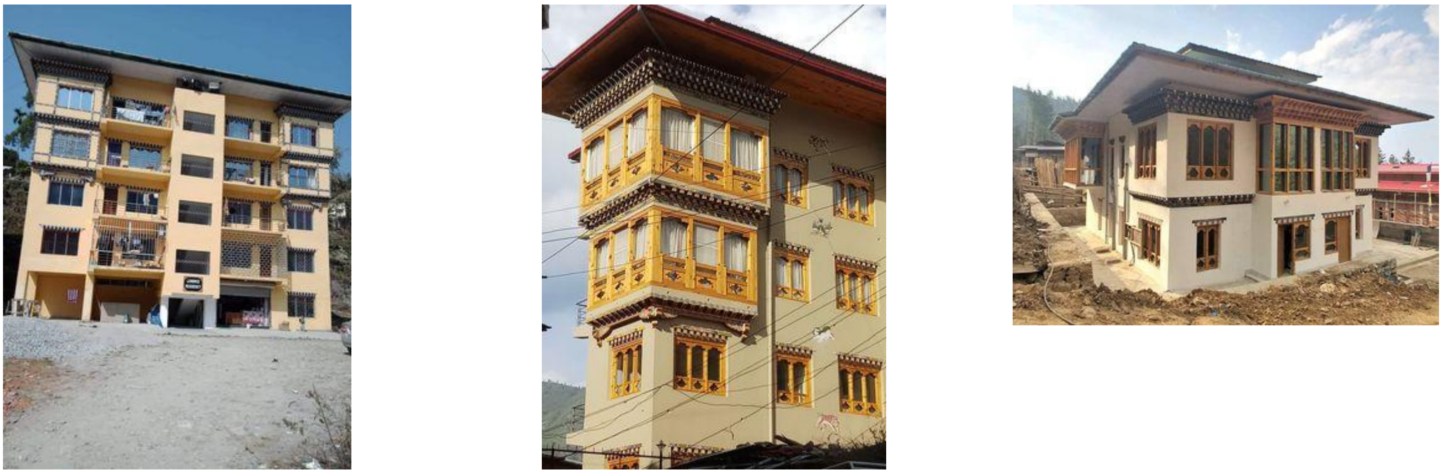
e. Timber as wall elements

f. Composite stone masonry and timber panel

g. Composite rammed earth (ground floor) and wattle and daub (first

h. Stone masonry structures

Floor) house in Haa Dzongkhag (district)



i. Conventional reinforced concrete structures in Bhutan

Figure 1: Highlights on Housing typology in Bhutan

CLIMATOLOGY IN BHUTAN

Climatic data of a particular site is of paramount importance to achieve comprehensive sustainable building design which will consume less energy from its inception to maintenance during its life cycle [6][8]. Climatology scenarios in Bhutan vary parametrically to periodic monsoon winds and the topographical settings i.e. from hot and humid tropical in the South to alpine in the North separating Bhutan into the six main zones (alpine, cool temperature, subtropical, tropical, tundra and warm temperate). Monsoon in Bhutan falls within May to September where 90% of yearly rainfall has been noted by local meteorological centres. The mean yearly precipitation extensively diverges as low as 250 mm in the north to a maximum of 6000 mm in the south with an average of 2000 mm in most of the country. Data (also presented in figure 2) display that uneven day-to-day rainfall exists during the wet season whereby about 10% of the total yearly precipitation happens in one day while 50% of the total yearly precipitation was noted in 10 days during summer. The current study zone lies in the sub-tropical climate zone with warm to hot summer and pleasant to cold winter. There is a radical variation in yearly precipitation.

The maximum precipitation was noted 6699 mm during the year 1998 and the minimum was in 2006 where the total precipitation noted was 1996 mm[9].

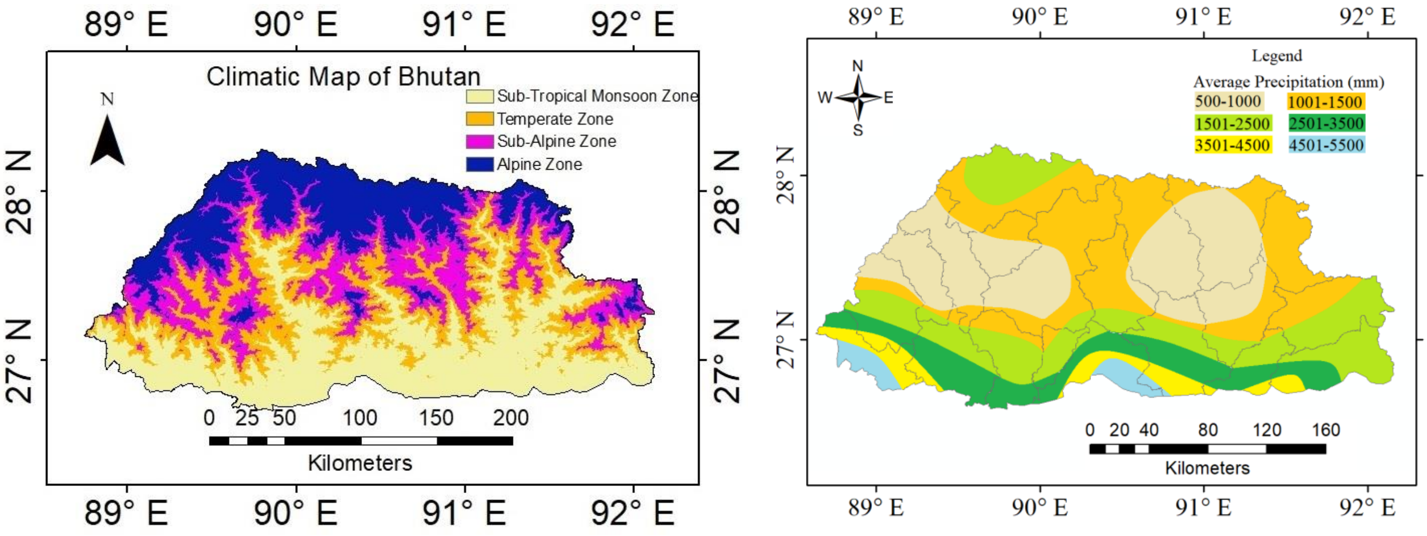


Figure 2: Climatic zonation and rainfall distribution map of Bhutan

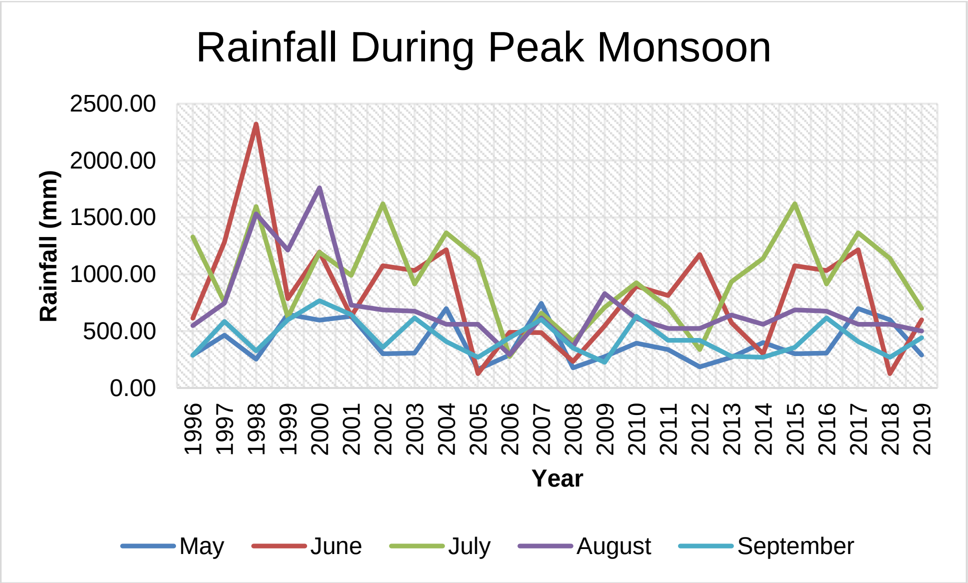


Figure 3: Variation of rainfall during peak monsoon in the study area

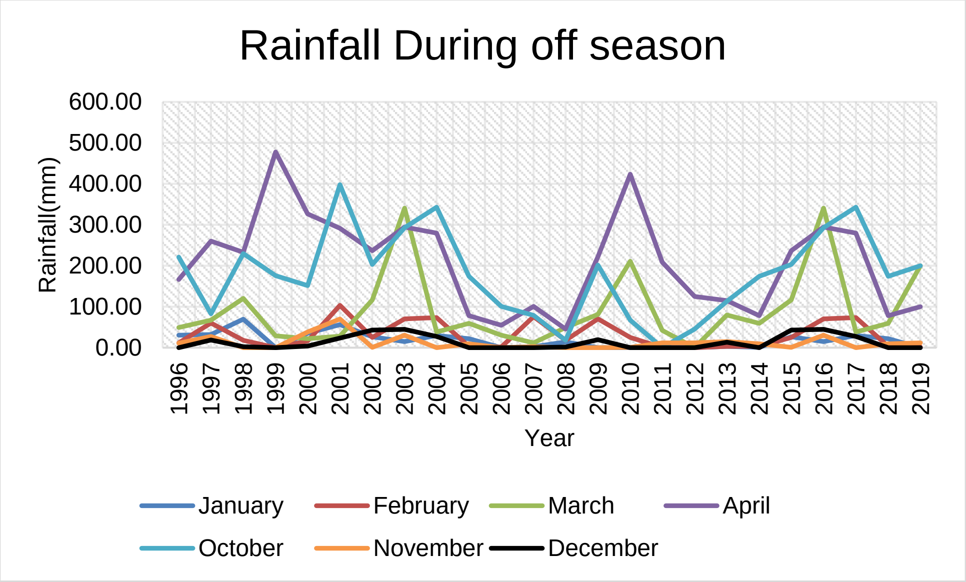


Figure 4: Variation of rainfall during the off-season in the study area

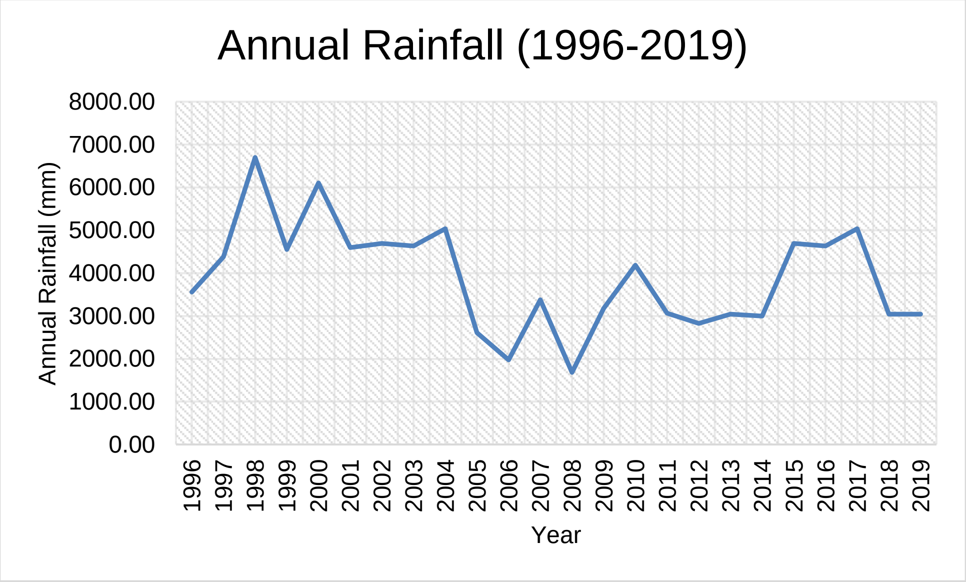


Figure 5: Variation of annual rainfall (1996-2019)

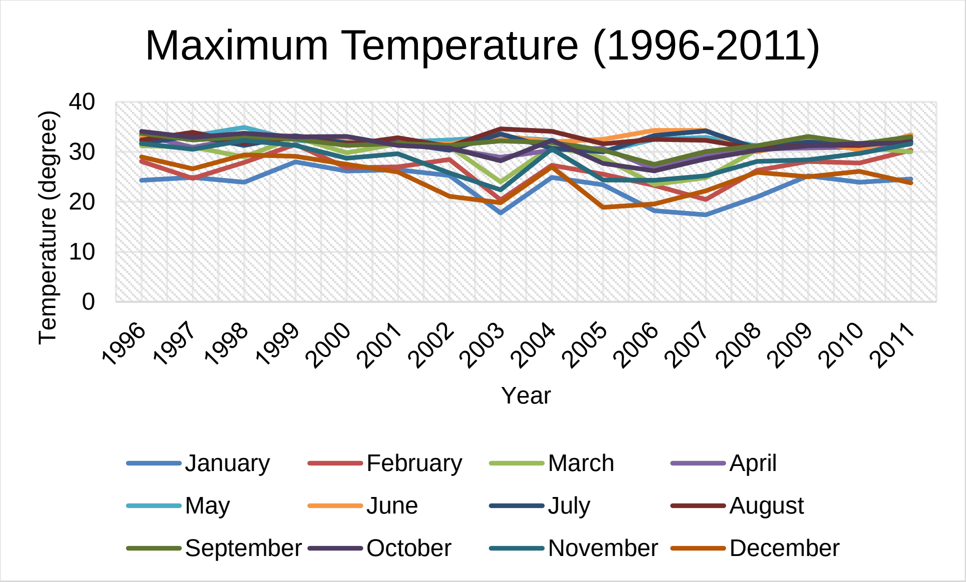


Figure 6: Variation of Annual Maximum Temperature

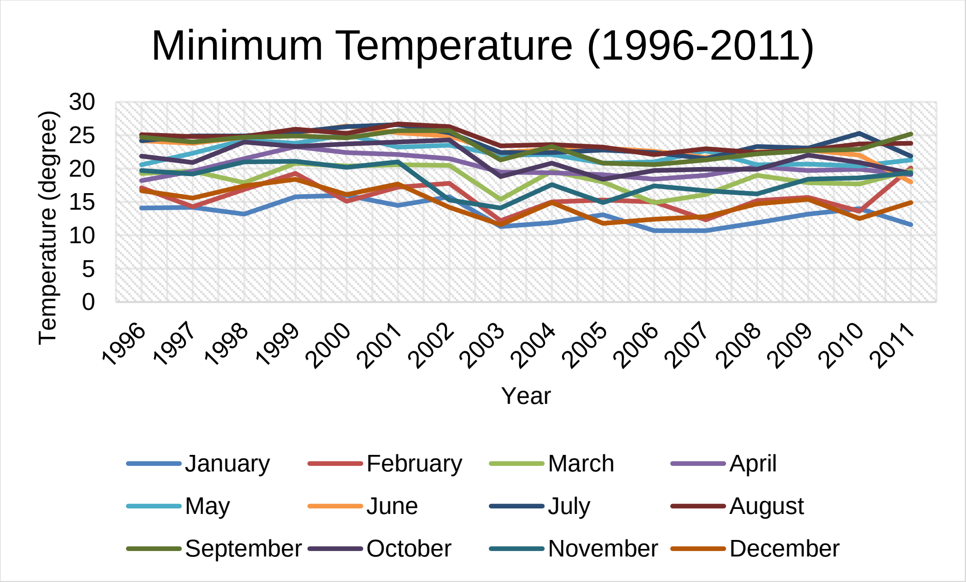


Figure 7: Variation of Annual Minimum Temperature

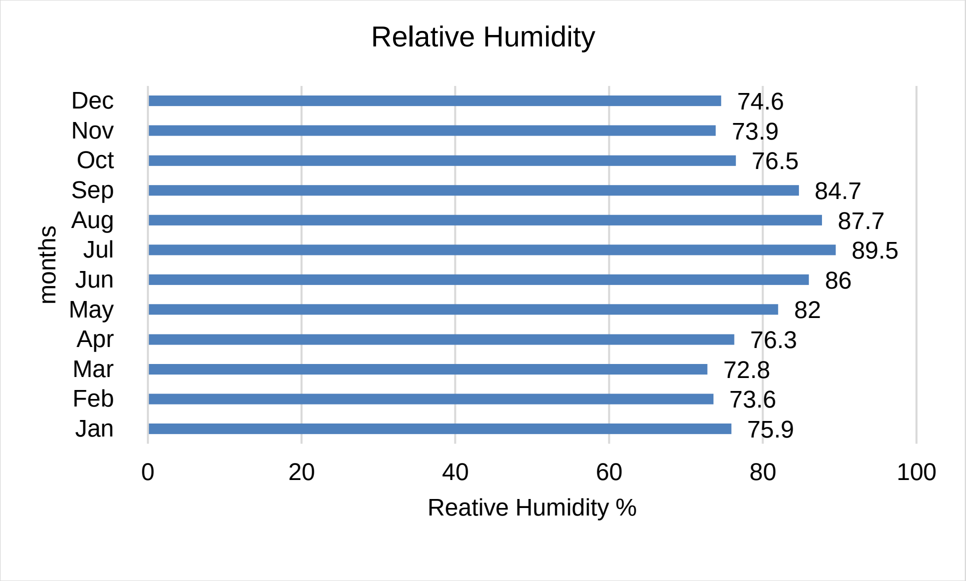


Figure 8: Variation of Relative Humidity

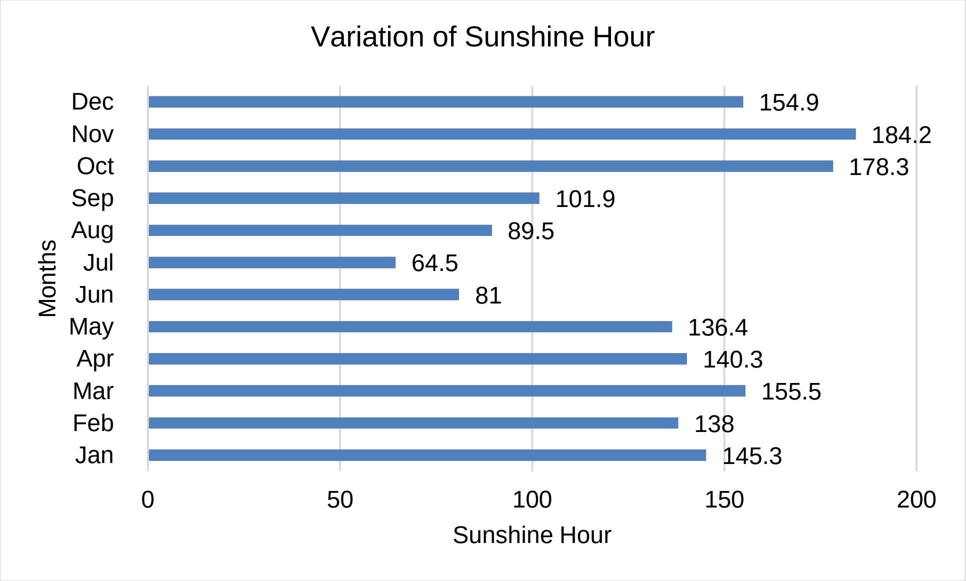


Figure 9: Variation of Sunshine Hour

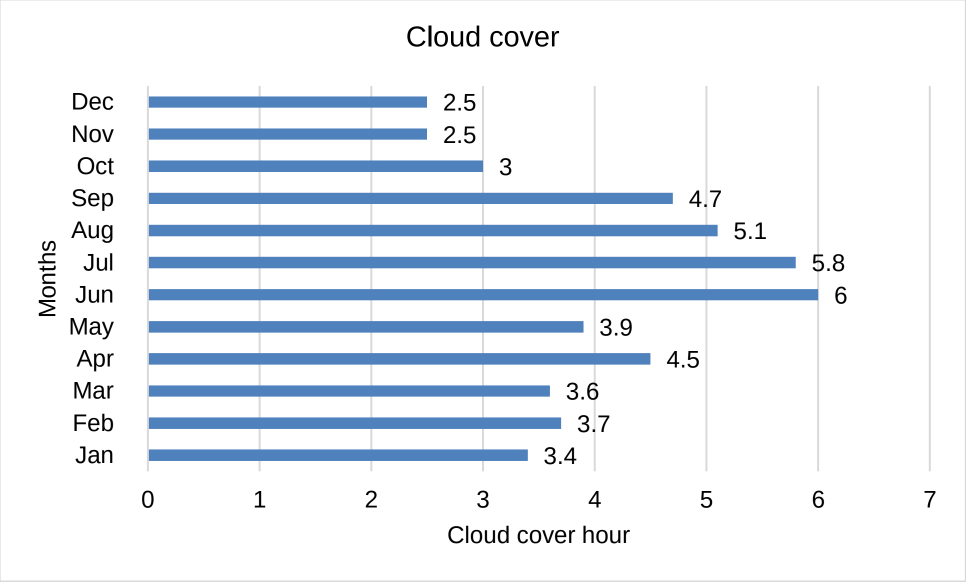


Figure 10: Variation of cloud cover

METHODOLOGY

3.1 Topography Study of the study area

Bhutan is situated in the eastern fringe of the Himalayas between latitudes of 26° 41’52” N to 28° 14’ 52” N and longitudes of 88° 44’ 54” E to 92° 41’ 7” E. The 38,686 sq.km^2 of the landlocked mountainous country has elevations ranging from about 160 m in the southern foothills to more than 7500 m in the greater Himalayas. The case study building lies in Phuentsholing Dzongkhag (district) which is in the southern foothills edging the Indian bordering town Jaigon, West Bengal. The climate of Phuentsholing is sub-tropical, experiencing hot-wet summer and cool-dry summer. The investigation of rainfall statistics in the past depicts that Phuentsholing receives an annual rainfall of around 6000 mm. The maximum mean temperature recorded annually and as projected in conjunction with figures 6 and 7 projects that the months within June to September with the highest temperature. Due to the complex geological terrain of Phuentsholing and the slopy curvature of the plot size, the construction activities have been challenging. The site exploration however gave imperative prospects to enable the benefits of exclusive good sunshine, cloud cover and humidity as indicated in Figures 8, 9 and 10.

3.2 Reviews on Bhutanese Building rules and Housing Typology

As per the population and housing survey by the Royal Government of Bhutan in 2017, Bhutanese structures can be characterized into 13 types. Buildings in each district as per the 2017 record is mapped in Figure 11 while figure 12 signifies different wall material. Three groups are demarcated as per the number of houses: districts having more than 10,000 houses; districts having 5,000-10,000 houses, and districts having less than 5,000 houses which are denoted in Figure. The RCC building alone covers 33.37% of housing stock, whereas, the masonry covers 42.81 %. The rest are classified as “other buildings”. This category includes wooden (7.76%), wattle and daub (7.11%), plywood (3.26%), cane/palm/trunk/bamboo (2.88%), other (2.48%), and cardboard (0.33%)[10][11][12][13].

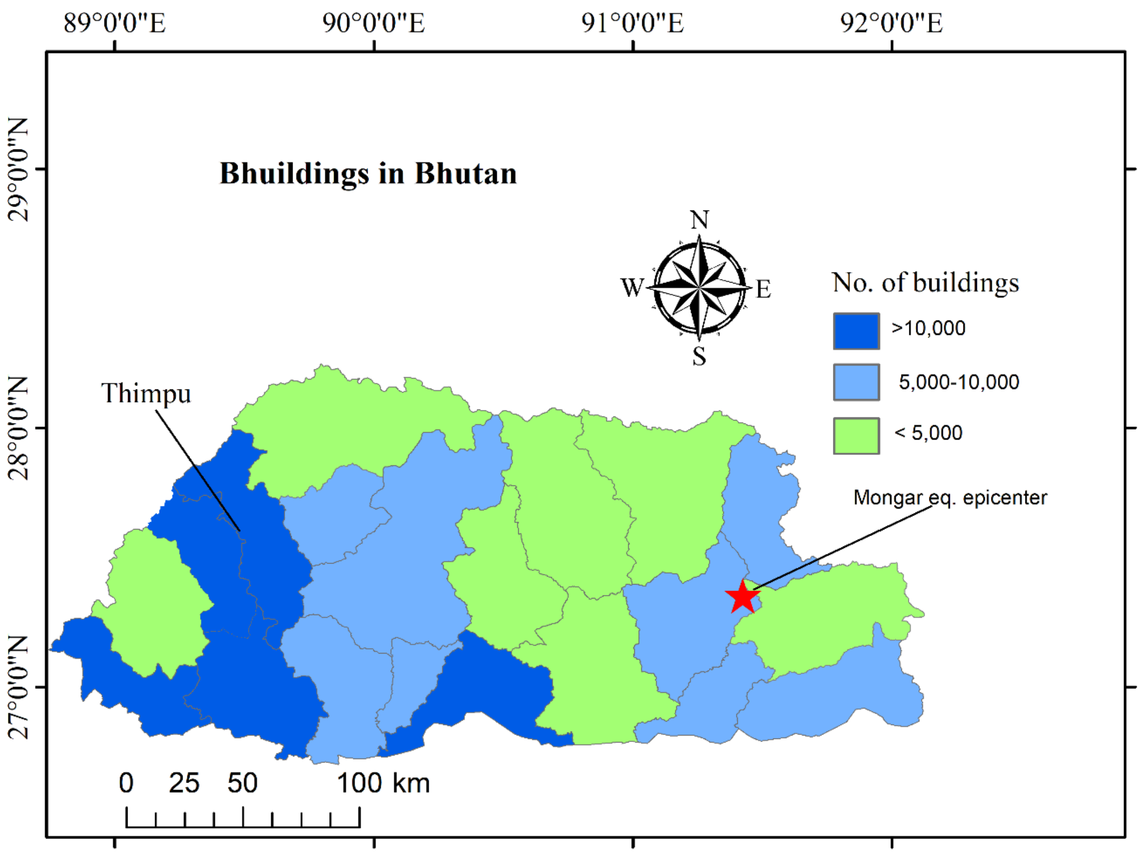


Figure 11: Building distribution in Bhutan[12]

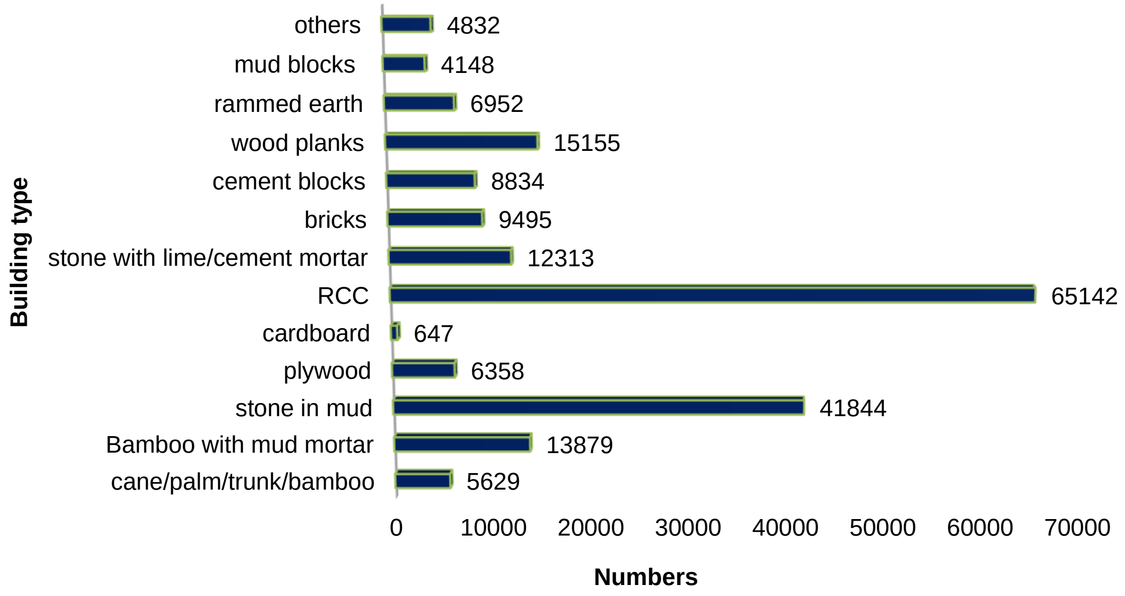


Figure 12: Typological distribution of Bhutanese buildings[14]

The Thromde (city) agencies in the dzongkhag oversee the matters of confirming the procedural drawings in Bhutan. Drawings need to fulfil the mandate of "Bhutan Building regulation 2018" and "Guidelines on Traditional Architecture". "Bhutan Building Rules 2002" was reframed and termed as "Bhutan Building regulation 2018" to simplify and control safe house construction and to promote healthy living [7]. BBR stipulates room height, room dimension, parking places, offset reserve, paintings, and other artistic features. It also stresses fire care necessities, aeration, water supply, and provision to differently-abled individuals. The structure height in rural zones should be a maximum of three stories. As Per Table 3.0.2 of Thimphu Municipal Development Control Regulations (2004), a maximum of five stories are allowed in urban communities [15][16][17]. Due to the limited standards to cover masonry structures in Bhutan, old-style information and mason/carpenter experience-based constructions are prevalent. Buildings are typically owner-built and mostly the dimensions, size and shapes and details are governed by the requirements of the landlords. RCC building was made compulsory to stick to the Indian standard code of practice in 1997. The royal government of Bhutan has lately developed green building guidelines to counter the rising ignorance to harness the advantage of free energy from nature.

3.3 Energy Matrix in Bhutan and Highlights on Green Engineering

During the lecture series by the Bhutan Ecological Society (BES), it was brought to notice that **the** paucity of green concept in Bhutanese dwellings leads to high energy consumption during winter particularly residential houses being highest (48.7% of the total energy consumption). It was felt the need to construct energy-efficient buildings to help reduce greenhouse gas emissions[1].

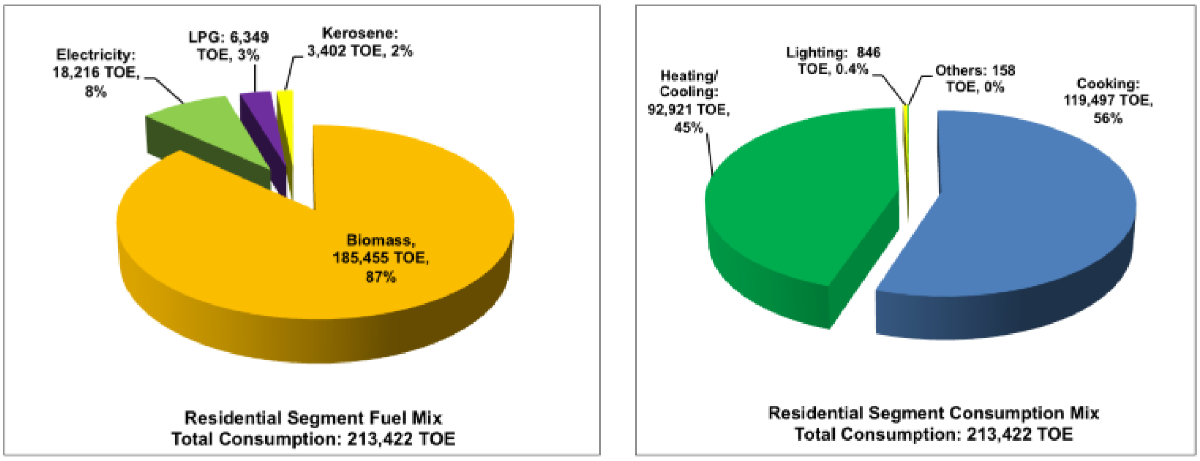


Figure 13: Residential Energy Consumption Split and Fuel Mix for 2014[18]

The energy use in Bhutan is dominated still by the traditional biomass, followed by electricity. The use of electricity has grown with electricity coverage of 99.8% to all parts of the country and it has one of the cheapest tariffs in the region which makes it one of the preferred energy sources. Bhutan is still an agriculture-based economy with about 70% of the population still surviving in the rural parts who depend upon subsistence farming and forestry for their livelihood. Due to this, the use of traditional biomass for heating and cooking are mostly met by the use of biomass. The heating demand of the rural households is mostly met by burning biomass or fuelwood.

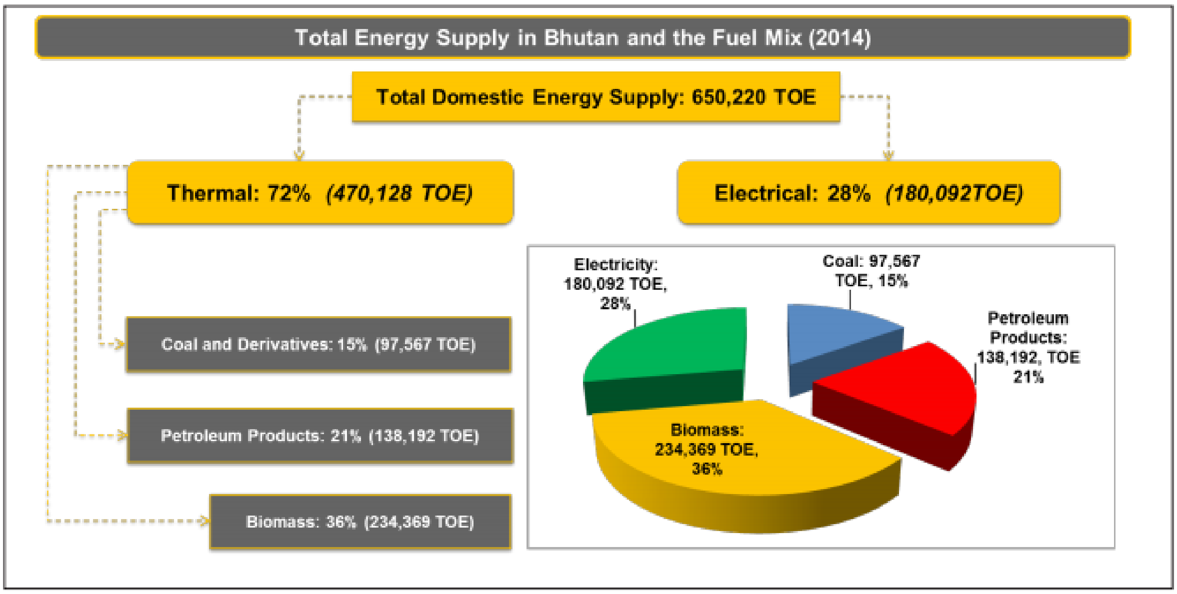


Figure 14: Energy matrix in Bhutan[19]

A survey is done to know whether, common Green Building traits like daylighting, cross ventilation and solar shading were incorporated in conventional buildings. Along with the survey few practising engineers were interviewed as to why those traits are not incorporated in the Bhutanese construction industry. Having done with the survey and the interview, it was found that the concept is rarely practised. With most leading reasons being:

- Lack of awareness of the concept
- Lack of skilled manpower and expertise
- Absence of green building codes
- Inaccessibility of relevant detailed data

This is carried out to find the availability of energy-efficient lighting appliances like CFL and LED lamps in the market and their prizes. Availability of water conservative faucets and water closet cisterns was also assessed. However, this paper presents only the aspects of passive energy.

3.4 Energy Analysis of Bhutanese Residential Building

The appliance survey mainly focused on finding out the number of lighting fixtures and the type of appliances used and their energy rating. It also includes those home appliances which use water, like measuring the discharge of the facets used in the kitchen and washrooms and the flushing cisterns of the water closet. Based on the context of usage of phase, buildings rank top for resource consumers, particularly water, energy and nutrients. The association between these resources is firm, and the link energy–water–food (or energy–water–nutrients) is presently known as the vital link for the sustainable growth of mankind[20].

It's indispensable to act on the ways to deal with excessive usage of non-renewable sources of energy. Although Bhutan is mostly dependent on electricity as a major energy source, however, the studies prognoses that the threat to limited available energy in Bhutan is inevitable in future.

LIGHTING EFFICIENCY

Lighting efficiently and effectively has always been challenging to the designers. The balance between artificial and natural lighting should be maintained to make the occupants living environment comfortable and the building to be energy efficient [21]. The lighting energy of the building depends on many parameters such as the orientation of the building, colour of the building walls, surrounding vegetation and geographic location. Many buildings today are either illuminated beyond the required limit and some are underlit. While designing and deciding on the building orientation the daylighting and artificial lightning requirement should be considered to reduce lighting energy demand by using daylight.

The built-up environment should be adequately lit and the illumination required depends upon the purpose of the built-up environment, the living room would require far less illumination compared to the operating theatre in a hospital. A general required illumination in general rooms vary from 150 to 200 lux for general rooms or built-up environment [22]. To have visual comfort the illumination should be distributed uniformly throughout the room.

A residential building at Phuentsholing, Bhutan was studied for visual comfort and lighting efficiency as a case study. It is observed that most of the rooms were either poorly lit or very brightly lit and from Dialux simulations it is observed that the rooms in the building were not distributed uniformly. One of the major observations made is concerning the building orientation and poor illumination design. Even with a good amount of sunshine during the day, some of the rooms in the building were not able to use daylight for illuminating the rooms. The illumination level of most of the rooms was not adequate and not uniformly distributed as evident from the simulation causing visual discomfort.

Table 1. Illumination levels in different rooms were measured at different times.

Sl.No	Floor	Time of Measurement	Room Type	LUX Measured	LUX Required
1	Ground Floor	Evening (6:30 PM)	Living Room	70	200
2			Kitchen	80	150
3			Bedroom	60	150
4			M Bedroom	120	150
5			Toilet	5	100
6	Ground Floor	Noon	Living Room	160	200
7			Kitchen	15	150
8			Bedroom	340	150
9			M Bedroom	280	150
10			Toilet	10	100

From table 1 it is clear that the lighting is not adequate with both natural and artificial lighting. The measurements taken at 6:30 PM shows that the illumination is not adequate and uniformly distributed in all the rooms. This is further proved with Dialux simulations of the existing room causing visual discomfort. From figure 1 and Figure 2 it is clear that the artificial light is not distributed uniformly throughout the rooms. The measurements from noon show that daylight is also poorly used in the building as rooms like kitchen and toilets are not able to use daylighting. These rooms have to be lit with artificial luminaries despite having good outdoor illumination. This may be solved by properly orienting the building during the design stage so that maximum daylighting can be used.

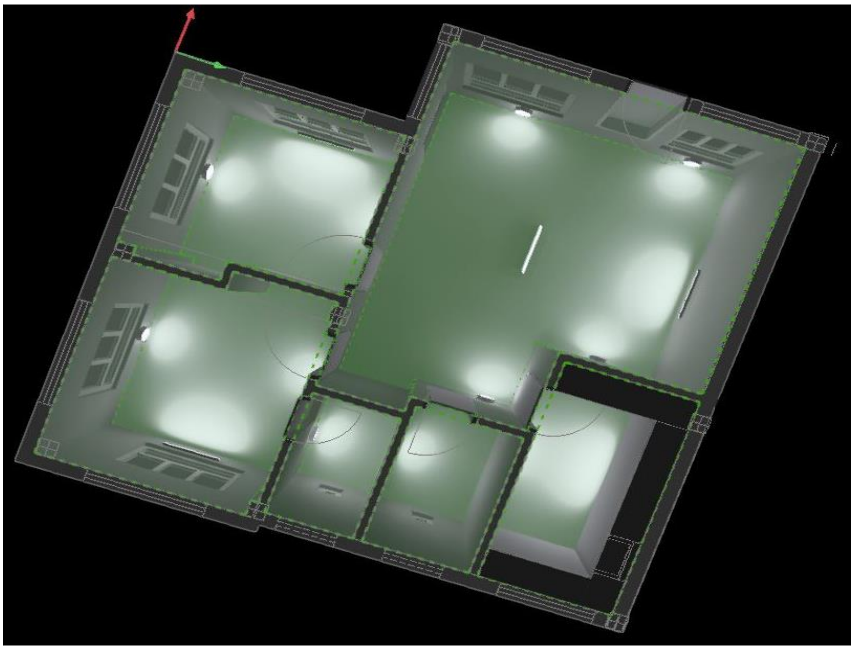


Figure 15: Dialux simulation for artificial light distribution of the unit understudy

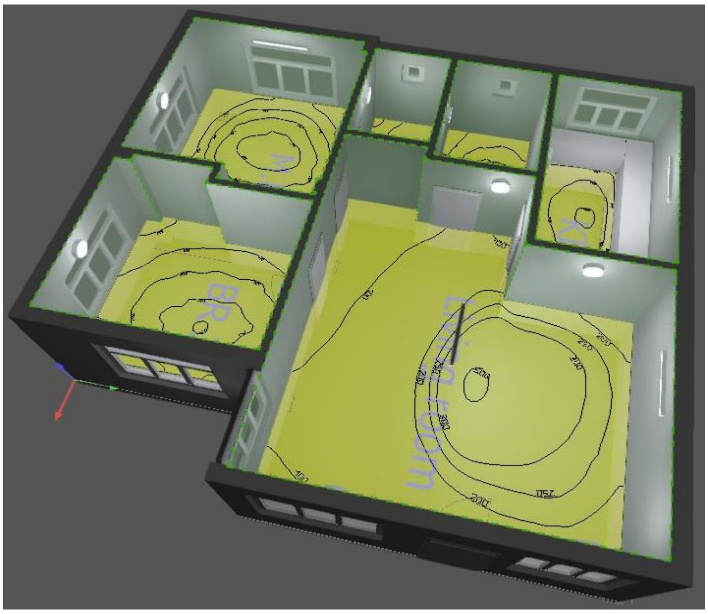


Figure 16: Artificial Light illuminance level at various points in the unit understudy

Electrical energy consumption in most of the buildings was found to be inefficient with most buildings using luminaries which are not efficient according to the wattage. Luminaries such as light emanating diodes (LEDs) and compact fluorescent lamps (CFLs) are efficient compared to incandescent lamps and even for fluorescent lamps, T5 tubes are efficient compared to usual T14 ones. Table 2 shows the lumens per watt output of various general luminaries, as observed LED has the highest lumens per watt ratio with 80 to 90 lumens per watt [23].

Table 2: General Luminaires Lumen Output vs Wattage Comparison.

General Luminaires Lumen Comparison				
Lumens (lm)	**Incandescent (W)**	**HID (W)**	**CFL (W)**	**LED (W)**
250	25	18	6	2-3
560	40	29	10	3-6
800	60	43	13	7-10
1100	75	53	18	10-15
1600	100	72	23	15-20
2600	150	100	42	20-30

The use of energy-efficient appliances can lessen the overall energy usage by changing the existing inefficient luminaires with efficient luminaries like CFLs and LED lamps. Therefore, by changing the existing luminaires with energy-efficient there is a scope for significant energy savings.

IMPROVED DESIGN OF RESIDENTIAL BUILDINGS

Globally, one of the biggest challenges remains to achieve sustainable energy nexus which balances the growing demand for energy along with environmental and liveability standard considerations [3]. Renewable energies are considered in the aforementioned case.

Alternatively, energy efficiency is considered as a reliable solution in response to response to the growing inefficiency of several domestic and industrial applications and the unsustainable behaviors of the people regarding over energy usage. The concept of energy efficiency deals with the production of the same amount of services or goods with a much-reduced energy requirement which would be achieved by the optimization and prioritization of conventional practices.[24]

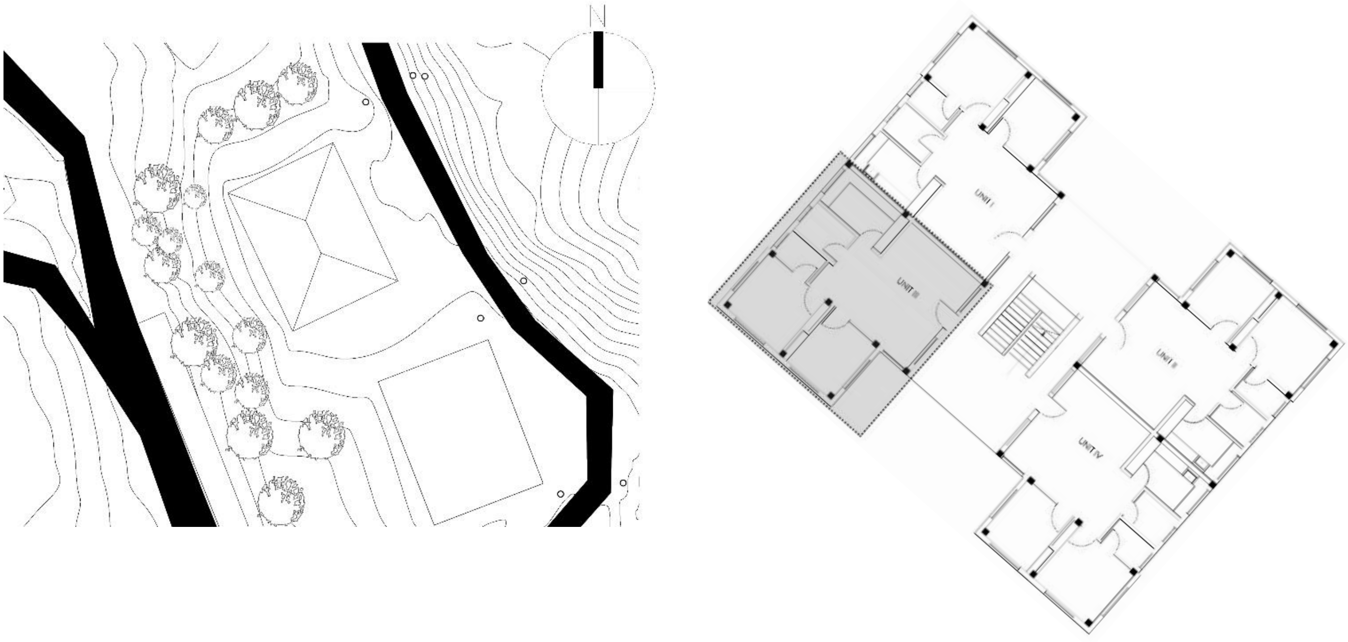
The concept of passive design is exclusively used in the work to improve the case study building. A passive building system is a method of designing a home that makes the best use of natural energy for heating and cooling homes instead of mechanical and other conventional energy.

The passive solar design creates a comfortable living environment by responding to microclimatic conditions and by reducing the dependence on mechanical means. In this system, the building envelope such as walls, windows, floors and roofs are efficiently designed to gain heat during winter and adversely reject heat during summer.

Passive design strategies are strongly dependent on the site climate and it is the most economical and effective tool in minimizing the active energy demand in residential buildings [25]. It utilizes the general design recommendations as per the respective site climate to lessen the energy usage and improve the thermal ease of the occupants [26]. Globally, 40 per cent to 60 per cent of national energy usage is dedicated to heating, lighting, ventilating and services [27].

This section presents the current thermal performance using the passive design strategies including, siting and orientation, natural ventilation and internal layout. These parameters are particularly assessed with the help of design recommendations from the Mahoney table. Mahoney tables are used as a device for sustainable progress as their predictions and commendations objects at condensed energy consumptions and effectual usage of resources [28].

The case building, 3 storied residential building with 4 units on each floor, is located at 26°50'59.0" N, 89°23'47.8" E and at an elevation of 434 meters above sea level. The analysis is specific to one of the ground floor dwellings, Unit III only (fig 1), due to the availability of the measured air temperature and humidity data for the study. In a warm and humid climate, where humidity is generally high (more than 70%) throughout the year and air temperature extending from 21ºC to 32ºC, movement of air is the only available method to achieve relief from climatic stress [29].



a

b

Figure 17: Details of case study building in Phuentsholing Bhutan (a) Site plan of the case building (b) Building layout of the case building.

The building is located on the north-east facing slope and has lush green vegetation to the south and south-west. The unit III dwelling is oriented towards the southwest, facing the 20-25-degree descending slope of approximately 7 m. (fig 3). Mahoney Table design recommendations suggest the longer side of the structure to be oriented in east-west axis to decrease solar heat advantages during the summer and take advantage during winter due to reduced altitude angle of sun rays. It recommends openings to be of medium size ranging from 20% to 40% of the outer wall area. Typically, the design layout in this climate should be open and single-banked with the provision of continuous exchange of air through cross ventilation or stack ventilation [30].

Figure 18: Sectional elevation setting the context of the case building.

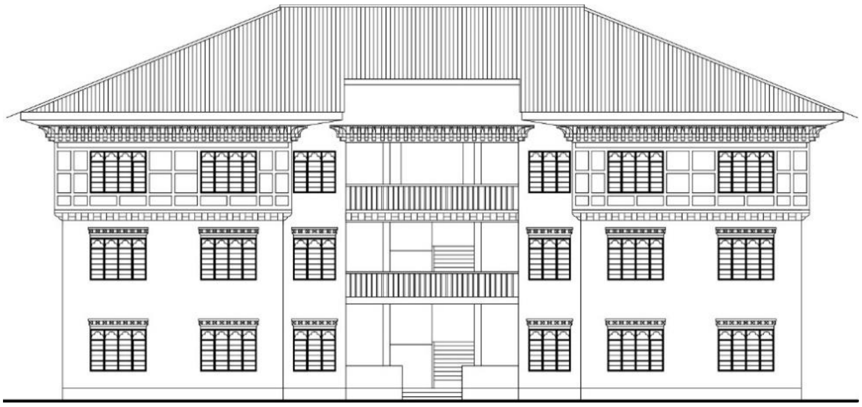


Figure 19: South-west elevation of the case building

The descending slope and the evergreen vegetation to the south and south-west act as a natural barrier against solar radiation. Moreover, Unit III is situated on the ground floor, drastically minimizing the heat gain from the roofs as high as 50% [31].

These features profoundly diminish the solar heat gains; however, it adversely affects the much-required air exchange, leading to thermal distress. In an experimental study, two weeks of data were collected during October month. It has been observed that the air temperature ranges from 29-32 degrees Celsius at the top floor unit and about 27-29 degrees in Unit III. On the contrary, the relative humidity level at the top floor fluctuates only around 62% to 75% whereas in Unit III it ranges from 69% to as high as 82%. The living room of the study area, which is the heart of the family interaction has the highest thermal distress owing to the absence of cross ventilation.

Exclusively, the apartment fares well with the solar radiation which is associated with the climate, but, thermal discomfort is still an issue owing to the minimal exchange of saturated air for evaporative cooling. This case example is a typical representative of most of the contemporary box-like apartment buildings [32], whereby, the individual units are displaced as per the design and cost-saving conveniences with very little focus on the basic design recommendations to attain thermal comfort.

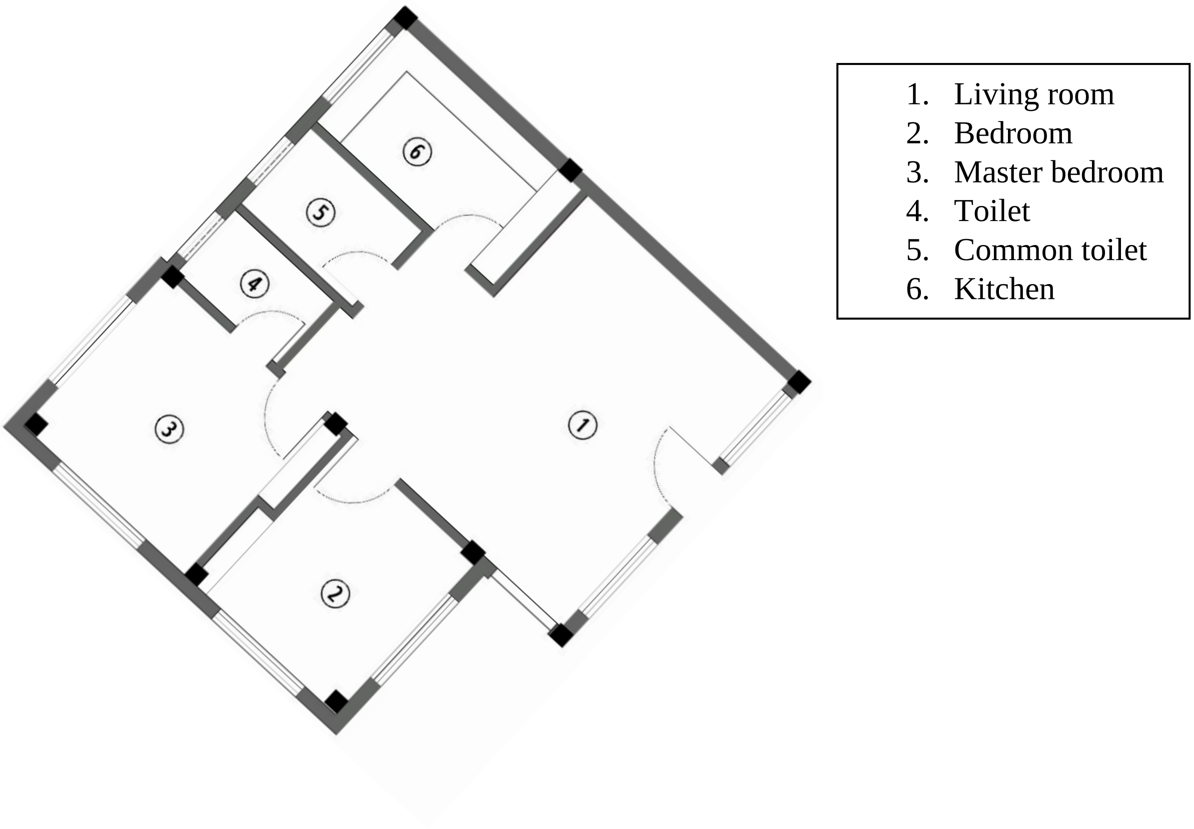


Figure 20: Unit III layout.

CONCLUSION

Advancement in technology always had its advantages and disadvantages. Realizing the negative impacts and coming up with countermeasures and ingenious solutions to overcome a problem is the overwhelming trait of human inventions. Sustainable Building Technology in the construction industry is a wonderful initiative to overcome the unimaginable adverse effects of buildings on the natural environment.

This paper touches on various green and sustainable building technologies that would lessen the effect of buildings on the natural environment, minimizing the operating cost and induce energy efficiency in buildings while giving top priority to human health and comfort. Energy efficiency and quality of the interior environment of a building depends on how well it is planned, what materials were used and also on the microclimate of the building surrounding. Keeping this in mind, a new plan along with the project site of the building was developed. Various components of the buildings like windows, roof, attic, etc. were designed as per energy efficiency and indoor environment requirements.

Bhutanese people do not feel the pinch of electricity bills, thanks to advance and cheap power from hydropower plants. However, this has resulted in people being ignorant and carefree when it comes to saving energy at home. To sensitize people on energy efficiency, a small-scale research analysis was done comparing the efficiency and payback periods of incandescent, CFL and LED lighting systems. It was concluded that the use of LED lamp is a cost-effective, environment friendly and energy-efficient measure for sustainable buildings. In line with the above, various energy-efficient and environmentally sound building technologies were researched and applied as per the climatic conditions of the site.

REFERENCE

[1] Ministry of Works and Human Settlement Bhutan, “Bhutan Green Building Design Guidelines,” *Bhutan Green Build. Des. Guide.*, p. 126, 2013.

[2] F. Rodrigues, A. Isayeva, H. Rodrigues, and A. Pinto, “Energy efficiency assessment of a public building resourcing a BIM model,” *Innov. Infrastruct. Solut.*, pp. 9–15, 2020, doi: 10.1007/s41062-020-00291-1.

[3] K. Aljundi, F. Rodrigues, A. Pinto, and A. Dias, “LCA integration in the construction industry : A case study of a sustainable building in Aveiro University,” no. i, pp. 1–10.

[4] P. Wangdi, P. M. Lepcha, Preki, and T. Dorji, “ASSESSMENT OF EXISTING BUILDING FOR SUSTAINABLE,” College of Science and Technology Royal University of Bhutan, 2013.

[5] C. Dorji, “Building energy analysis for humboldt state university,” HUMBOLDT STATE UNIVERSITY, 2010.

[6] S. C. M. Hui and M. F. Tsang, “Climatic Data for Sustainable Building Design in Hong Kong,” in *New Challenges in Building Services, 15 November 2005, Hong Kong SAR*, 2005, no. November, p. 5.

[7] Royal Government of Bhutan, “Bhutan Building Regulation,” 2018.

[8] R. Spinelli, A. F. Pitol, P. Henrique, D. Agnol, F. P. Cambeiro, and O. Konrad, “Energy Efficiency Assessment of the Involvement of an Educational Building using the Prescription Method (RTQ-C).,” no. December, 2019, doi: 10.22161/ijaers.611.75.

[9] Department of Geology and Mines, “Technical Report of DGM : proposed landslide mitigations in P / Ling Thromde,” pp. 1–60, 2009.

[10] U. Tshering, N. Tender, G. Koirala, L. Rai, M. Thapa, and N. Chettri, “Structural Assesment of Bhutanese Traditional Buildings,” vol. 4, no. May 2017, 2018.

[11] N. Chettri, J. Thinley, and G. S. Koirala, “The Comparative Study on Vernacular Dwellings in Bhutan,” *United Int. J. Res. Technol.*, vol. 01, no. 02, pp. 42–47, 2019.

[12] N. Chettri, D. Gautam, and R. Rupakhety, “Seismic vulnerability of vernacular residential buildings in Bhutan,” *J. Earthq. Eng.*, vol. 26, no. 1, pp. 1–16, 2021, doi: 10.1080/13632469.2020.1868362.

[13] “From Tship Chim to Pa Chim: Seismic vulnerability and strengthening of Bhutanese vernacular buildings - ScienceDirect.” https://www.sciencedirect.com/science/article/pii/B9780128210871000090 (accessed May 15, 2021).

[14] N. Chettri, D. Gautam, S. Chikermane, V. Prakash, and K. Vaghela, “Sustainability assessment of Bhutanese vernacular wattle and daub houses,” *Innov. Infrastruct. Solut.*, pp. 1–13, 2021, doi: 10.1007/s41062-021-00576-z.

[15] U. Tshering, N. Tender, G. Koirala, L. Rai, M. Thapa, and N. Chettri, “Structural Assesment of Bhutanese Traditional Buildings,” in *zorig melong*, vol. 4, no. May 2017, 2018, pp. 1–7.

[16] N. Chettri, C. Wangmo, and S. Passang, “Quality Control of Concrete in Bhutanese Construction Industry and the Requirements of Indian Standards,” *GNH J. Constr. Technol. Manag.*, vol. 1, no. 1, pp. 23–34, 2020, [Online]. Available: http://www.cdb.gov.bt/uploads/downloads/Construction Journal Final.pdf.

[17] Thimphu Thromde, “Thimphu Municipal Development Control Regulations,” 2004.

[18] Department of Renewable Energy Ministry of Economic Affairs, “Bhutan Energy Directory 2015,” 2016.

[19] Department of Renewable Energy., “Energy Efficiency Roadmap,” no. May, 2018.

[20] C. Pimentel-rodrigues and A. Silva-afonso, “Nearly zero water buildings,” pp. 1–11.

[21] T. W. Kruisselbrink, R. Dangol, and E. J. van Loenen, “A comparative study between two algorithms for luminance-based lighting control,” *Energy Build.*, vol. 228, p. 110429, 2020, doi: 10.1016/j.enbuild.2020.110429.

[22] I. W. B. Institute, “WELL Building Standard V1 Copyright.” International WELL Building Instute, New York, 2019.

[23] “Lumen to Watt Comparison - Energy vs Brightness,” *Energy Efficient Lighting Solutions & Supply*, 2020. .

[24] F. Silvero, F. Rodrigues, and S. Montelpare, “Energy efficiency policies to face buildings’ climate change effects in Paraguay,” *Appl. Sci.*, vol. 10, no. 11, 2020, doi: 10.3390/app10113979.

[25] X. Gong, Y. Akashi, and D. Sumiyoshi, “Optimization of passive design measures for residential buildings in different Chinese areas,” *Build. Environ.*, vol. 58, pp. 46–57, 2012, doi: 10.1016/j.buildenv.2012.06.014.

[26] S. Zahiri and H. Altan, “The effect of passive design strategies on thermal performance of female secondary school buildings during warm season in a hot and dry climate,” *Front. Built Environ.*, vol. 2, no. March, pp. 1–15, 2016, doi: 10.3389/fbuil.2016.00003.

[27] E. Green, T. Hope, and A. Yates, *Sustainable Buildings*. Institution of Civil Engineers, 2013.

[28] U. C. Eusebius, “Use of Mahoney tables in Nigeria,” pp. 1–17, 2011.

[29] O. H. Koenigsberger, T. G. Ingersoll, A. Mayhew, and S. V. Szokolay, *Manual of tropical housing and building*. 1975.

[30] S. Bodach, W. Lang, and J. Hamhaber, “Climate responsive building design strategies of vernacular architecture in Nepal,” *Energy Build.*, 2014, doi: 10.1016/j.enbuild.2014.06.022.

[31] M. Mathi, S. Radhakrishnan, and R. S. Priya, “Sustainable roofs for warm humid climates — A case study in Residential Buildings in Madurai,Tamilnadu, India,” *World Appl. Sci. J.*, no. 32.6, pp. 1167–1180, 2014.

[32] T. Lhendup and T. Powdel, “Analysis of Thermal Performance Improvement of Residential Building: A Case Study in an Urban Bhutan,” *J. Educ. Pract.*, no. September, 2020, doi: 10.7176/jep/11-27-14.