Government of Nepal
Ministry of Urban Development
National Research Center for Building Technology (NRCBT)
Babarmahal, Kathmandu

DESIGNING ENERGY-EFFICIENT BUILDINGS BASED ON DUDBC'S ARCHETYPE MODELS APPLICABLE TO THREE ECOLOGICAL REGIONS IN NEPAL

Introduction

Modern society faces significant environmental challenges, including climate change, dependence on fossil fuels, and increasing energy demands in urban areas. Buildings account for a significant 40% of the world's energy consumption and more than half of the greenhouse gas emissions. Because of this, sustainable energy regulations that prioritize energy efficiency and conservation are now essential to modern building design. Energy efficiency in buildings means using less energy while maintaining comfort, which requires proper design, material selection, construction, and operation. Passive design strategies include building orientation, insulation, shading, and natural ventilation, tailored to local climates. In Nepal, with its diverse ecological regions, these strategies are vital for reducing energy consumption. However, Nepal lacks specific standards for energy-efficient building design, which is why the National Urban Development Strategy (NUDS) 2017 emphasizes promoting passive design and energy-efficient materials. The National Urban Development Strategy (NUDS) of 2017 (S48) focuses on the promotion of passive design and the use of energy-efficient building materials as a key strategy in the energy sector. This strategic approach aims to address the energy crisis and counteract the adverse effects of climate change and associated health problems. The strategy's indicator is to formulate models, guidelines, and disseminate designs for energy-efficient construction across all ecological regions specified in the NUDS 2017. To fulfill this objective, the National Research Center for Building Technology (NRCBT), Ministry of Urban Development (MoUD), has proposed a typical model for constructing energy-efficient buildings that can serve as a benchmark or reference for future researches and exploration in this sector.

Objective

It aims to develop architectural designs aligned with energy-efficient and passive design principles, addressing the requirements of three distinct ecological regions in Nepal and prepare the passive design strategies aimed at reducing energy consumption within the buildings, emphasizing environment friendly solutions and analyze the economic aspects of proposed energy efficient buildings.

Methodology

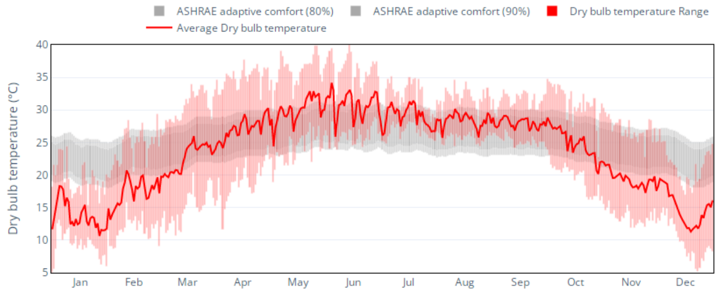
For designing energy-efficient buildings based on DUDBC's archetype models for Nepal's three ecological regions involved a comprehensive approach. It began with a literature review and case study analysis to expand knowledge on energy-efficient and passive building design, including a thermal comfort analysis of building across different regions. Expert consultations and meetings were conducted, particularly with the MinErgy team and energy experts, to discuss energy simulation results and refine strategies. A 15-bedded hospital proposed by DUDBC was selected as the archetype model, where passive strategies and energy-efficient designs were applied. Data collection and site analysis were performed using secondary sources, including meteorological data and bioclimatic charts, to in cooperate in design. Energy simulations were then carried out using Ecotect to analyze the building envelope and compare findings with case study data. Based on the analysis and expert feedback, passive design guidelines and sustainable material recommendations were developed, tailored to enhance thermal performance and energy efficiency in government buildings.

Site introduction

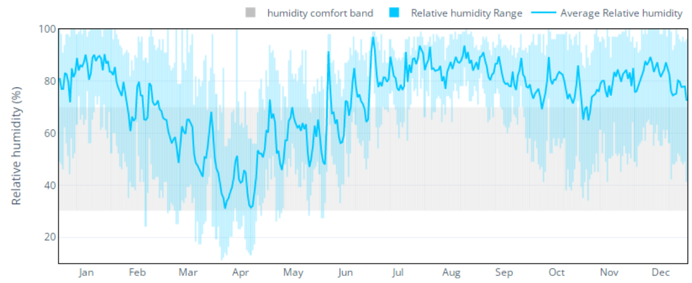
A comprehensive climate analysis was conducted across three ecological regions of Nepal: Terai, Hilly, and Himalayan. To represent these regions, Nepalgunj, Gokarna, and Jomsom were selected, respectively. The study focused on key climatic parameters including site orientation, temperature, relative humidity, wind flow, and solar radiation. The CBE Clima Tool, a web-based platform designed for architects and engineers, was utilized to analyze and visualize the data contained within EnergyPlus Weather (EPW) files. This tool also enabled the calculation of additional climate-related metrics such as solar angles and thermal comfort indices.

Terai Region (Nepalgunj, Banke)

The site coordination's is 28°03'40.6"N 81°37'54.0"E and Elevation above sea level is 165.0 m. Nepalgunj Sub-mertopolitain city has a sub-tropical climate. Temperatures sometimes exceed 44 °C from April to June. During the rainy season in June and lasting into September is less hot but sometimes very humid. Winter is usually pleasant while the sun is out. It sometimes is foggy and overcast; then it can be chilly with temperatures below 10 °C but no frost. Annual cumulative horizontal solar radiation is 1823.45 kWh/m2. The land is flat Gangetic plains.



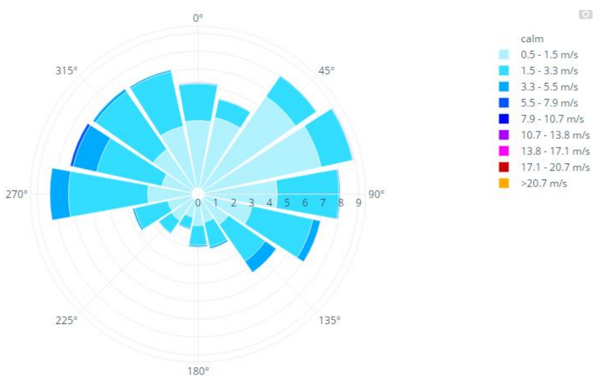
Temperature



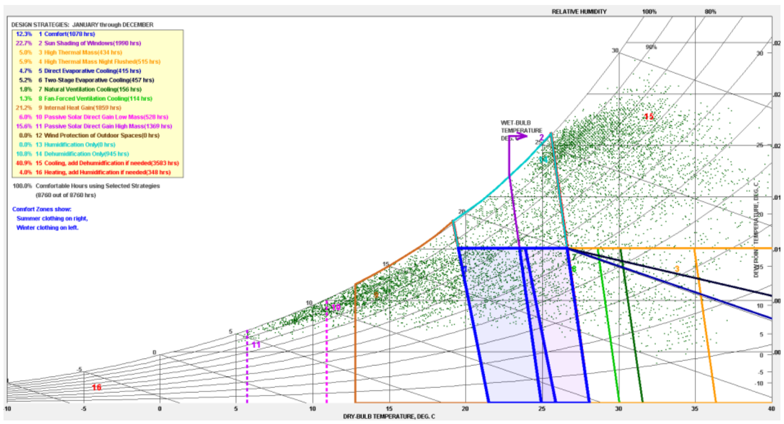
Relative humidity

Taking, the data from Department of Hydrology & Meteorology (2013 to 2023), the monthly mean maximum temperature reaches up to 40.6°C while in winter the monthly mean minimum temperature reaches up to 11.3°C

The humidity also fluctuates daily and seasonally. The average monthly maximum humidity in the morning is 95.16% whereas during daytime, the average monthly minimum reaches down to 52.04 %.



Annual wind rose chart

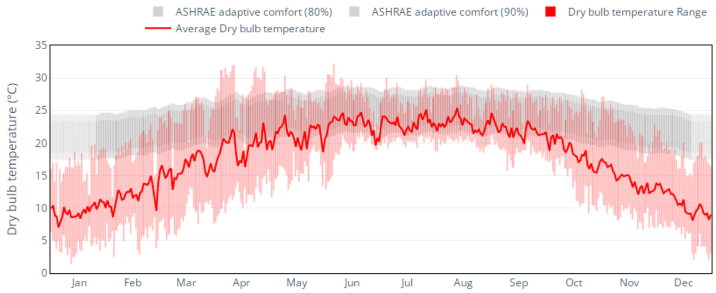


Psychometric Chart of Nepalgunj

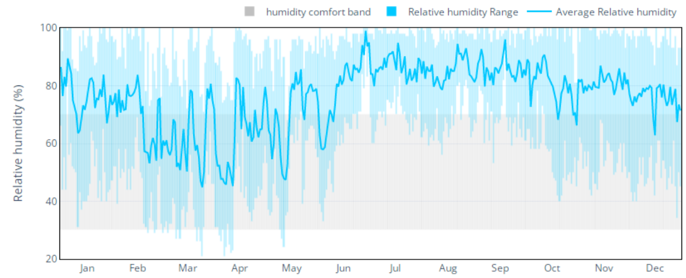
A suitable construction technique for the exterior walls could be the reverse brick veneer wall. High thermal mass of the northern outside wall without solar exposure is also possible. In any case shading of the openings and the construction elements of high thermal mass has to be provided in summer to avoid overheating. Furthermore, building design should enhance air movements within the building through cross or stack ventilation.

Hilly Region (Gokarna municipality, Kathmandu)

The site is situated at Gokarneshowr municipality near Gokarneshowr Mahadev. Its GPS coordinates is 27°44'20.2"N 85°23'11.5"E and elevation above sea level: 1338.1 m

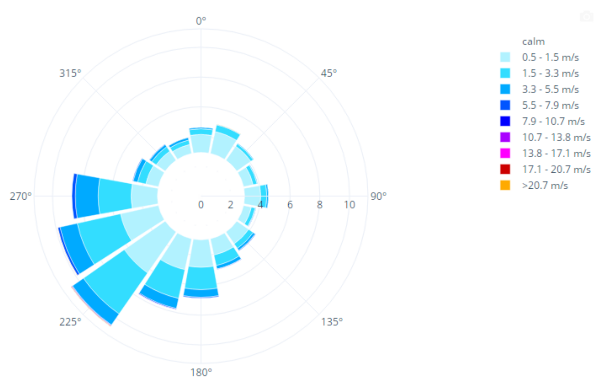


Temperature

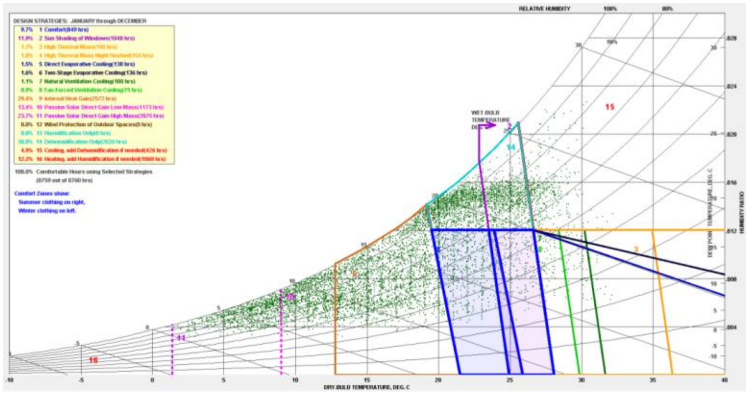


Relative humidity

Taking, the data from Department of Hydrology & Meteorology (2013 to 2023), the monthly mean maximum temperature reaches up to 32.2°C while in winter the monthly mean minimum temperature reaches up to 2.39°C.



Annual wind rose chart

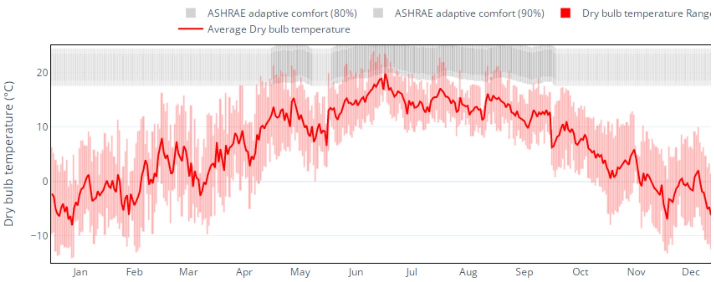


Psychometric Chart of Kathmandu

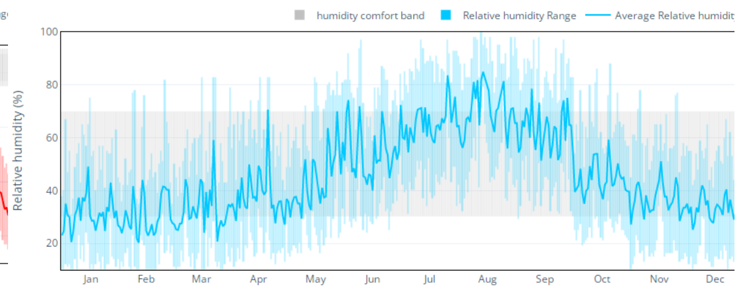
The temperate climate zone is the most comfortable bio-climatic zone of Nepal. Passive solar heating combined with the minimization of air filtration and good insulation of the building envelope can fulfill most of the heating demand in winter. High thermal building mass is desirable for passive heating as well as passive cooling due to the high daily temperature swing. Enhancing natural air movement through cross or stack ventilation is required during the warm and humid monsoon season.

Mountain Region (Jomsom, Mustang)

The site is situated at Gharpajhong Rural Municipality near Jomsom airport. Its GPS coordinates is 28°46'08.2"N 83°43'36.0"E and elevation above sea level: 2743 m.



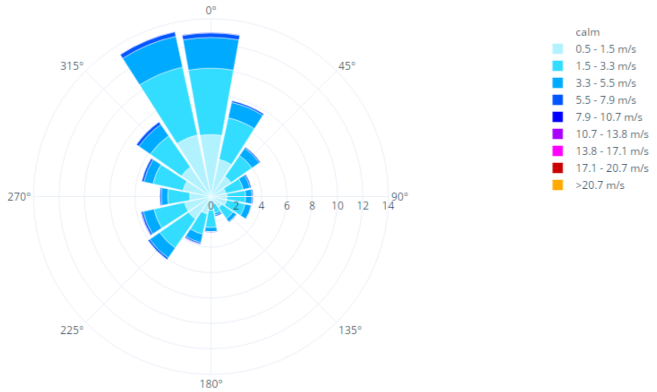
. Temperature



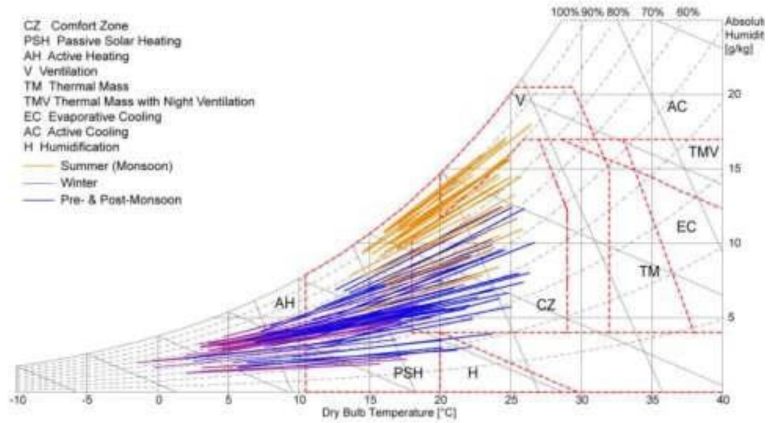
Relative humidity

Taking, the data from Department of Hydrology & Meteorology (2013 to 2023), the monthly mean maximum temperature reaches up to 21.1°C while in winter the monthly mean minimum temperature reaches up to -4.8°C., dry winter, cool summer.

The average monthly maximum humidity in the morning is 80.46% whereas during daytime, the average monthly minimum reaches down to 30.54%



Annual wind rose chart

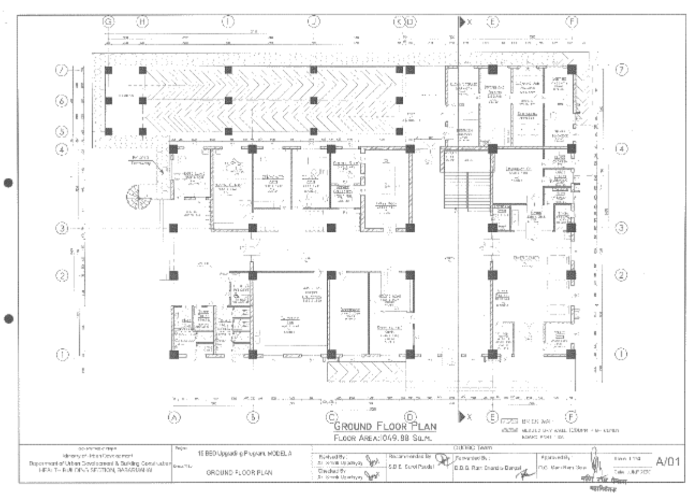


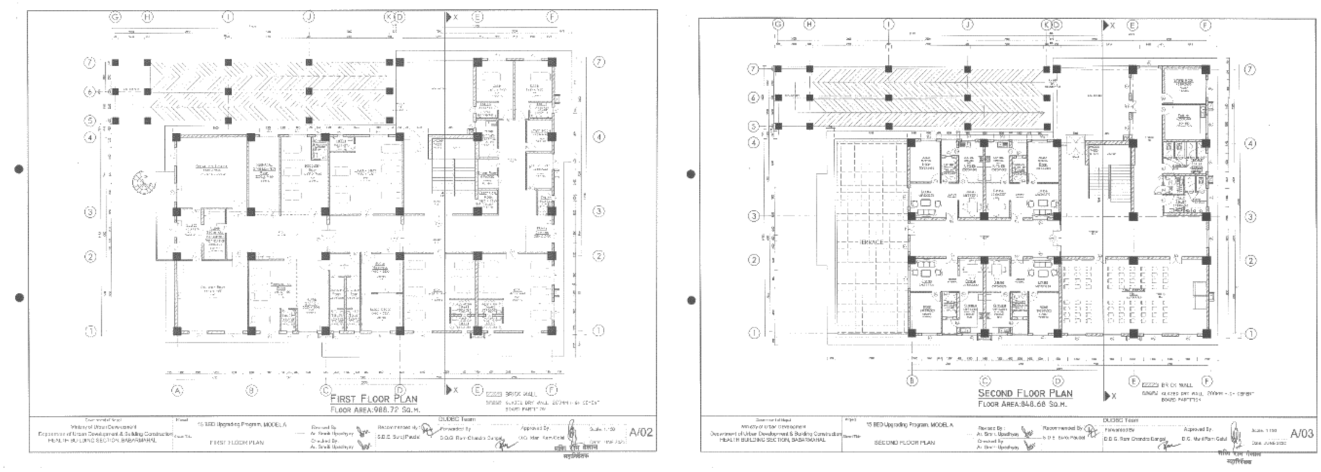
Psychometric Chart of Jomsom

In the cold climate temperature hardly reach the comfort zone (Figure 4). During summer, day time temperature rarely rises above 18°C. During winter average temperature are around the freezing point. In the cold climate of Nepal passive solar heating is the only design strategy that can be applied. It will reduce the heating demand during the summer month. However, mechanical heating is required all over the year. Compact building layout, reduction of air infiltration and good insulation of roof, walls and windows are the imperative to protect from the cold in this harsh mountain climate. The application of active solar heating to support a conventional heating system is recommended due to vast availability of solar irradiation

Archetype model

A 15-bed hospital, proposed as an archetype by the DUDBC, served as the study model. This three-story building includes emergency services, a minor operation theater, and outpatient facilities on the ground floor. The first floor houses an operation theater, labor room, recovery room, ward, and cabin, while the second floor accommodates a multipurpose hall and dormitory. Due to its anticipated high public flow and energy consumption, this archetype was selected for the study. Energy simulation was conducted on this model to provide a sample design for energy-efficient building practices. While basic design principles can be applied universally, but for achieving optimal energy efficiency and cost-effectiveness for a specific building it is recommended to do the energy simulation and design of the particular building.





Archetype model

Energy Simulation Analysis

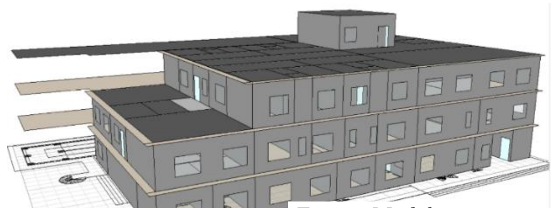
The energy modeling of the hospital was conducted using Ecotect 2011, and energy simulations were performed for three ecological regions, utilizing local climatic data specific to each area. Four scenarios were considered, based on varying materials used in the building envelope (wall, roof, and window). The thermal analysis of different hospital zones was conducted by calculating the heating and cooling loads for each zone across different months, using Ecotect 2011 for each scenario.

Table: Building envelope composition in different U-value for simulation

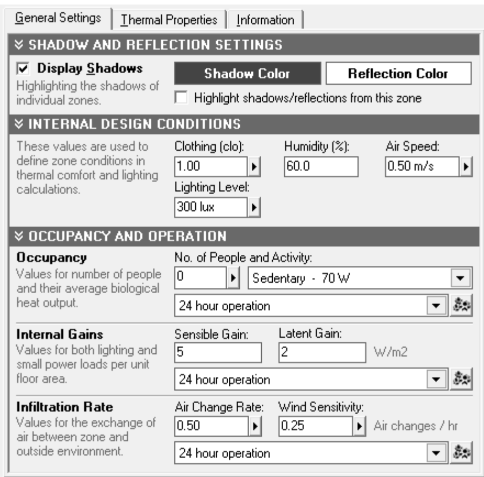
	EXTERNAL WALL		ROOF		GLAZING		FLOOR		INTERNAL WALL		DOOR	
	COMPOSITION	U-VALUE (w/m2k)	COMPOSITION	U-VALUE (w/m2k)	COMPOSITION	U-VALUE (w/m2k)	COMPOSITION	U-VALUE (w/m2k)	COMPOSITION	U-VALUE (w/m2k)	COMPOSITION	U-VALUE (w/m2k)
BASE CASE	12.5mm thick plaster+230mm thick brickwork+12.5mm thick external plaster	1.86	12mm thick tile+38mm thick screed+125mm thick concrete slab+10mm thick plaster at ceiling	1.12	6mm thick glazing with aluminum frame	5.44	10mm thick tile+50mm thick screed+125 mm thick slab+10mm thick plaster	2.51	12.5mm thick plaster+110mm thick brickwall+12.5mm thick plaster	2.59	6mm thick glazing with aluminum frame	5.44
SCENARIO 01	12.5mm thick plaster+110mm brickwork+50mm air cavity+100 mm concrete block+12.5mm thick plaster	1.16	12mm thick tile+50mm thick k insulation+50mm thick screed+125mm thick concrete slab+10mm thick plaster at ceiling	0.91	6mm thick double glazing with aluminum frame	2.710	10mm thick tile+50mm thick screed+125 mm thick slab+10mm thick plaster	2.51	12.5mm thick plaster+110mm thick brickwall+12.5mm thick plaster	2.59	6mm thick glazing with aluminum frame	5.44
SCENARIO 02	12.5mm thick plaster+110mm brickwork+50mm insulation+110 mm concrete block+12.5mm thick plaster	1.04	12mm thick tile+50mm thick screed+50mm thick insulation+125mm thick concrete slab+10mm thick plaster at ceiling + 150 mm air gap + 10mm gypsum board	0.77	6mm thick double glazing with aluminum frame	2.710	10mm thick tile+50mm thick screed+125 mm thick slab+10mm thick plaster	2.51	12.5mm thick plaster+110mm thick brickwall+12.5mm thick plaster	2.59	6mm thick glazing with aluminum frame	5.44
SCENARIO 03	12.5mm thick plaster+230mm hollow concrete block+12.5mm thick plaster	1.95	12mm thick tile+25mm thick screed+125mm thick concrete slab+10mm thick plaster at ceiling	1.2	6mm thick double glazing with aluminum frame	2.710	10mm thick tile+50mm thick screed+125 mm thick slab+10mm thick plaster	2.51	12.5mm thick plaster+110mm thick brickwall+12.5mm thick plaster	2.59	6mm thick glazing with aluminum frame	5.44
SCENARIO 04	100 mm thick mud plaster outside+ 600mm stone wall+ 20mm thick plaster inside	2.23	12mm thick tile+25mm thick screed+125mm thick concrete slab+10mm thick plaster at ceiling	1.2	6mm thick double glazing with aluminum frame	2.710	10mm thick tile+50mm thick screed+125 mm thick slab+10mm thick plaster	2.51	12.5mm thick plaster+110mm thick brickwall+12.5mm thick plaster	2.59	6mm thick glazing with aluminum frame	5.44

Ecotect Setting for Simulation of the 15-bed hospital Building

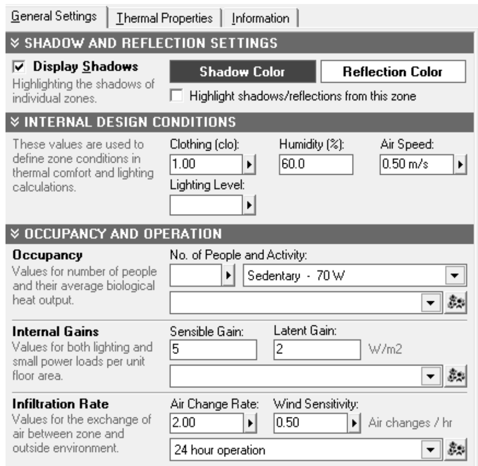
In general, for the internal design considerations, values used for the clothing of occupancy were taken as 1 as light business suit, humidity of 60 % and normal air speed of 0.50m/s, number of people, schedules and lighting levels for different zones was also considered. The comfort range was taken as 18°C to 22°C.



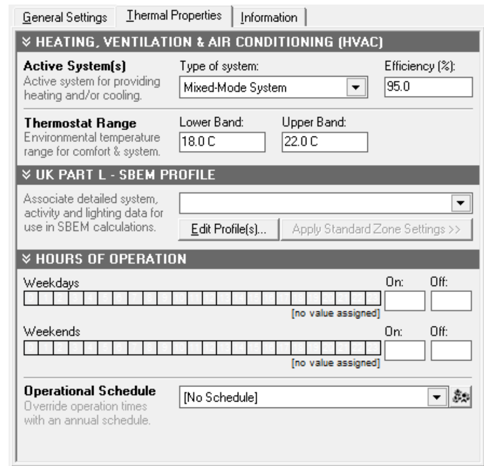
Energy Model



Ecotect general setting for well-sealed condition



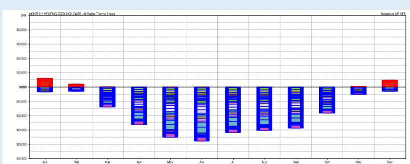
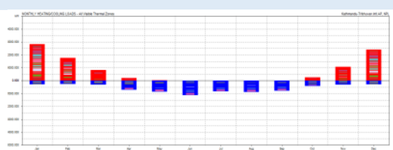
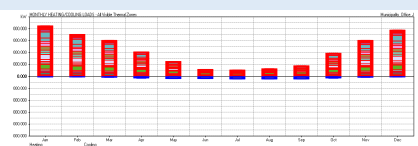
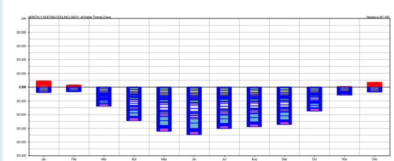
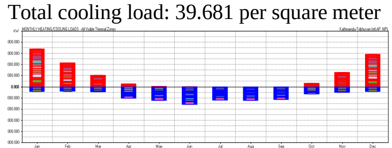
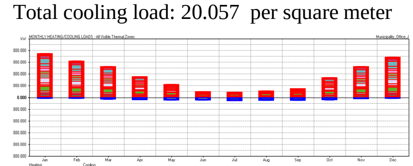
Ecotect general setting for cross ventilated condition

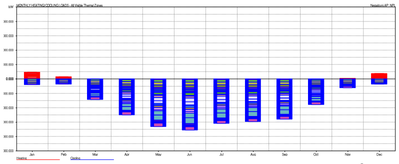
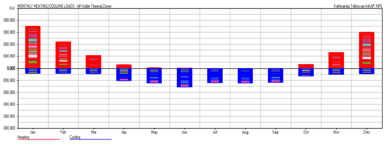
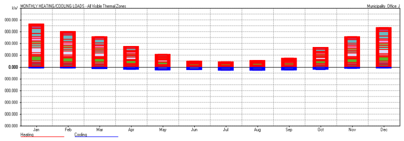
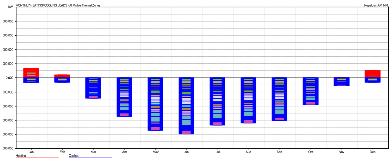
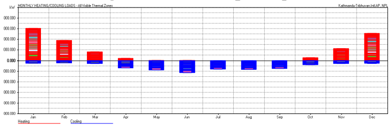
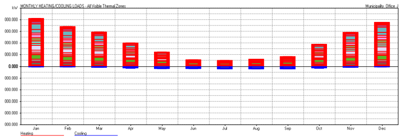


Thermal properties for simulation

Result and Discussion

From the thermal analysis conducted across three different ecological regions, the maximum heating and cooling loads for various months of the year were determined. The total annual load consumption for all scenarios were also calculated, revealing how energy consumption varies depending on the materials used in the building envelope.

	Terai (Nepalgunj)	**Hilly (Kathmandu)**	**Himalayan (Jomsom)**
BASE CASE	 Max heating: 26.823 kW at 07:00 on 22nd December Max cooling: 94.933 kW at 14:00 on 14th June Total annual load consumption: 199822.4 kwh Total heating load: 10.552 per square meter Total cooling load: 180.096 per square meter	 Max heating: 49.979 kW at 07:00 on 21st December Max cooling: 56.167 kW at 14:00 on 6th June Total annual load consumption: 98616.125 kwh Total heating load: 53.176 per square meter Total cooling load: 39.681 per square meter	 Max heating: 104.189 kW at 07:00 on 13th January Max cooling: 20.089 kW at 14:00 on 4th July Total annual load consumption: 277229.188 kwh Total heating load: 240.981 per square meter Total cooling load: 20.057 per square meter
SCENARIO 01	 Max heating: 19.566 kW at 07:00 on 22nd December Max cooling: 88.621 kW at 14:00 on 14th June Total annual load consumption: 190515 kwh Total heating load: 7.665 per square meter Total cooling load: 171.723 per square meter	 Max heating: 41.140 kW at 07:00 on 21st December Max cooling: 54.607 kW at 14:00 on 6th June Total annual load consumption: 88316.445 kwh Total heating load: 42.920 per square meter Total cooling load: 40.238 per square meter	 Max heating: 94.052 kW at 07:00 on 13th January Max cooling: 21.735 kW at 14:00 on 4th July Total annual load consumption: 250561.438 kwh Total heating load: 211.529 per square meter Total cooling load: 24.399 per square meter

SCENARIO 02	 Max heating: 20.472 kW at 07:00 on 22nd December Max cooling: : 90.309 kW at 14:00 on 14th June Total annual load consumption: 195460.4 kwh Total heating load: 7.954 per square meter Total cooling load: 176.091 per square meter	 Max heating: : 42.064 kW at 07:00 on 21st December Max cooling: 54.114 kW at 14:00 on 6th June Total annual load consumption: 89792.992 kwh Total heating load: 44.188 per square meter Total cooling load: 40.360 per square meter	 Max heating: 92.478 kW at 07:00 on 15th February Max cooling: 21.774 kW at 14:00 on 4th July Total annual load consumption: 246606.266 kwh Total heating load: 207.309 per square meter Total cooling load: 24.894 per square meter
SCENARIO 03	 Max heating: : 29.617 kW at 06:00 on 1st January Max cooling: 96.885 kW at 14:00 on 14th June Total annual load consumption: 212966.047 kwh Total heating load: 11.277 per square meter Total cooling load: 189.251 per square meter	 Max heating: 52.567 kW at 07:00 on 21st December Max cooling: 54.423 kW at 14:00 on 6th June Total annual load consumption: 102611.617 kwh Total heating load: 55.927 per square meter Total cooling load: 40.691 per square meter	 Max heating: 101.624 kW at 07:00 on 13th January Max cooling: : 19.814 kW at 14:00 on 4th July Total annual load consumption: 269287.469 kwh Total heating load: 233.668 per square meter Total cooling load: 19.892 per square meter

Thermal analysis (Monthly)-(Blue representing cooling load and red representing heating load)

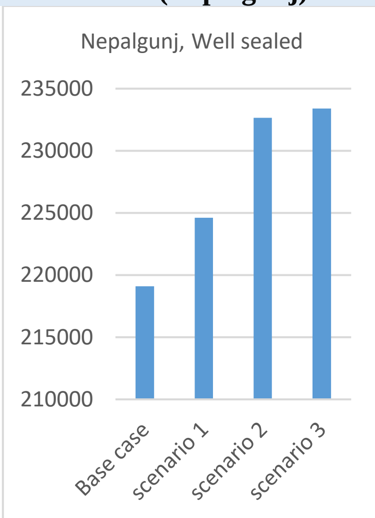
The above chart on "*Thermal analysis (Monthly)*" reveals a clear disparity in energy consumption across the three regions of Nepal. The Himalayan region, characterized by its colder climate, necessitates a higher level of heating to maintain comfortable indoor temperatures. This increased heating demand translates to greater energy consumption. In contrast, the Terai region, known for its warmer climate, requires more cooling to ensure thermal comfort, leading to higher energy usage. The Hilly region, situated between these two extremes, experiences a more balanced energy consumption for both heating and cooling, reflecting its moderate climate. These findings emphasize the crucial role of climatic conditions in determining building energy requirements.

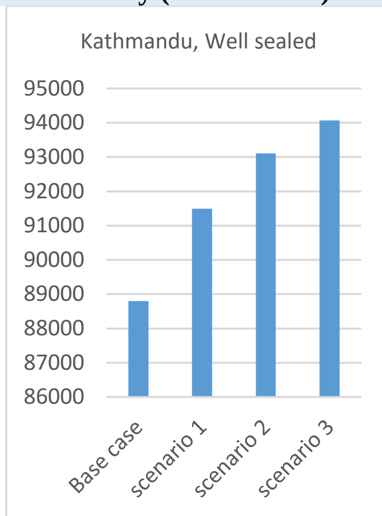
Energy simulation and its analysis comparing well-sealed and cross-ventilated building conditions reveals the contrast between theoretical and practical energy efficiency. Simulations of well-sealed buildings often show lower energy consumption due to reduced air leakage, enabling HVAC systems to maintain indoor comfort efficiently but represents an ideal scenario for energy savings. However, in practice, achieving a completely airtight system is not possible due to construction limitations, material imperfections, and the need for adequate ventilation to ensure good indoor air quality. Even with the best design efforts, some air infiltration is inevitable, making the perfect well-sealed condition difficult to achieve. On the other hand, cross-ventilation, which is less optimal in strictly controlling energy use, is more practical and feasible. Simulations indicate that cross-ventilated designs may result in higher energy consumption because they rely on natural airflow instead of airtight control. However, they offer a more realistic solution that balances energy efficiency with practical construction considerations and occupant comfort. Thus, while well-sealed buildings theoretically provide better energy efficiency, but the practical challenges and the impossibility of achieving a fully airtight system make cross-ventilation a more viable option in real-world scenarios.

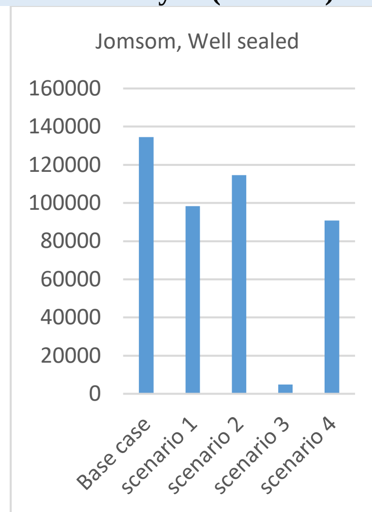
The below chart on "*Total annual load consumption (kwh) for Well-sealed and Cross-ventilated condition"* compares the energy consumption for well-sealed and cross-ventilated condition of building across three regions in Nepal. The data reveals that while well-sealed buildings theoretically offer lower energy consumption due to reduced air leakage, but achieving a perfectly airtight system in practice is challenging. As a result, cross-ventilated buildings, despite their higher energy consumption, often provide a more practical and feasible solution. In Terai and Hilly region, the energy consumption pattern seems quite similar both in well-sealed buildings and cross ventilated condition while, Himalayan region shows notable differences, likely due to its harsh climate and geographic diversity. Additionally, the chart reveals that under cross-ventilated conditions, the energy load is highest in the Himalayan region, followed by the Terai region, and lowest in the Hilly region. This highlights the significant influence of climatic conditions on building energy consumption, particularly in the Himalayan region, which faces more extreme weather.

	Terai (Nepalgunj)	Hilly (Kathmandu)	Himalayan (Jomsom)

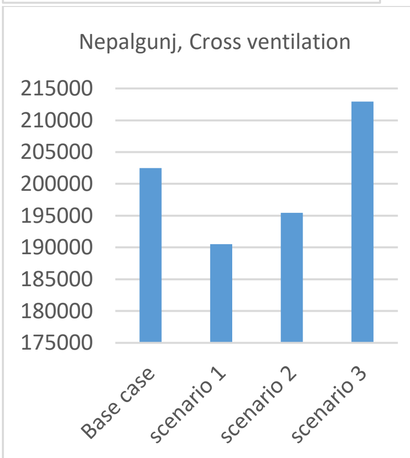
Total annual load consumption (kwh) in well sealed condition

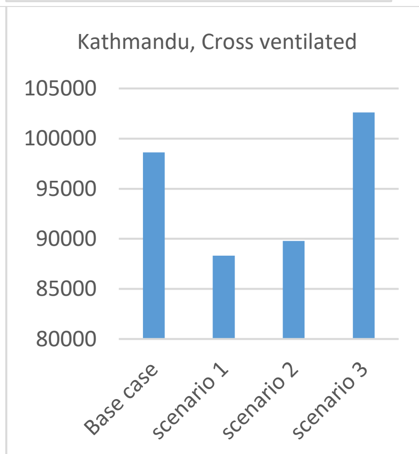


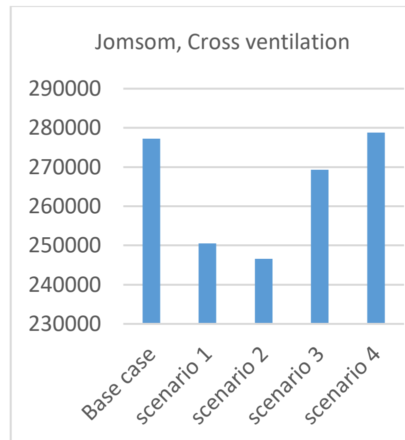




Total annual load consumption (kwh) in cross ventilated condition

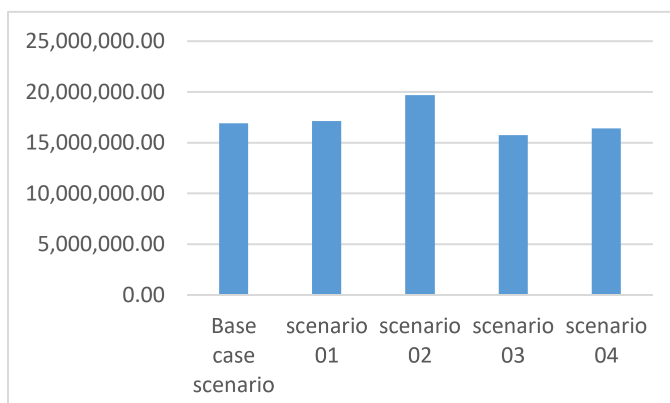






Total annual load consumption (kwh) for Well-sealed and Cross-ventilated condition

For the energy analysis, different materials were selected to form the building envelope across various scenarios, each providing a specific U-value that significantly influences energy and load consumption. A cost analysis was conducted to assess the impact of these material changes from the base case, revealing that Scenario 3 had the lowest cost, while Scenario 2 had the highest. However, this cost comparison alone does not justify the selection of a particular scenario for cost-effectiveness. To determine the most effective energy-efficient model, both cost and energy consumption must be evaluated together, ensuring that the chosen scenario balances financial investment with energy savings.



Cost analysis of materials (wall, roof and glazing) as per different scenario

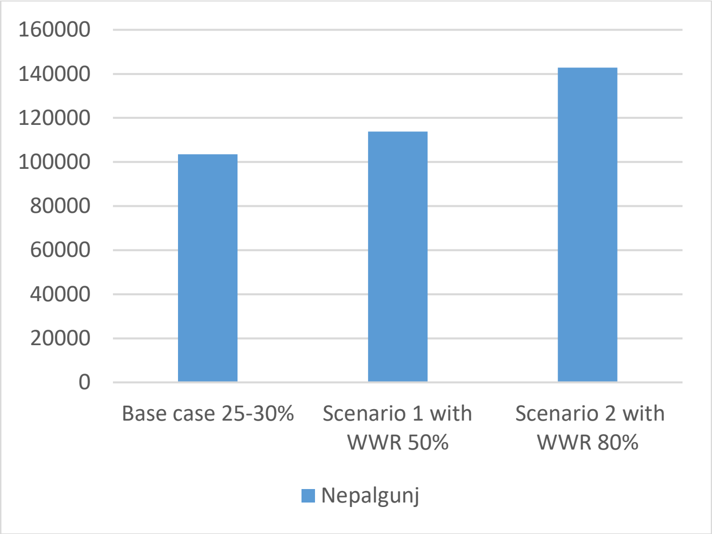
Comparative Analysis of Building Scenarios: Cost, Energy, and Payback

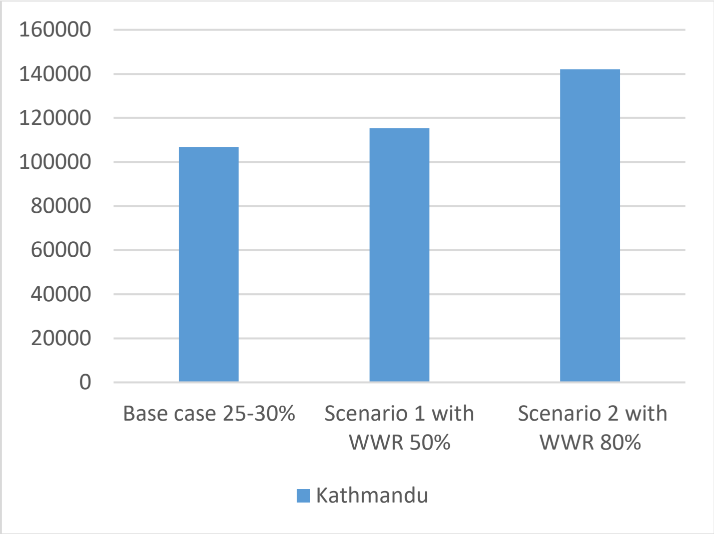
The provided table below compares the energy efficiency and economic viability of different building scenarios across three regions in Nepal. The data reveals that while increasing the cost of construction through improved wall, roof, and glazing materials can lead to higher annual energy savings and the payback period for these investments varies significantly based on the region. For instance, in the Terai region, Scenario 01, which involves a 9% increase in construction cost, offers a relatively quick payback period of 8.60 years. However, in the Hilly region, the same scenario has a payback period of 9.99 years. The Himalayan region demonstrates the most significant energy savings potential, with Scenario 02 achieving a payback period of just 6.06 years. Overall, the chart suggests that while investing in energy-efficient building materials can be economically advantageous in certain regions, a careful evaluation of the payback period is essential to make the economic viable decisions.

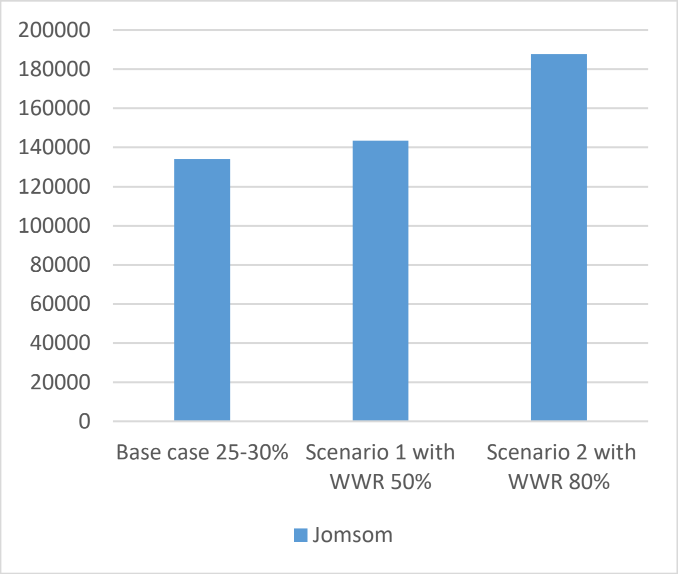
For Terai Region (Nepalgunj)							
Scenarios	**Total cost of wall, roof and glazing**	**% increase**	**Increase in cost for construction**	**Annual load (kwh)**	**Annual load saving**	**Annual amount saving**	**Pay back period in years**
Base case scenario	16,910,358.58			202473.78			
Scenario 01	**18,453,024.42**	**9%**	**1,542,665.84**	**190515.02**	**6%**	**179,381.48**	**8.60**
Scenario 02	19,693,002.49	16%	2,782,643.90	195460.44	3%	105,200.15	26.45
Scenario 03	15,742,217.73	-7%	-1,168,140.86	212966.05	-5%		
For Hilly Region (Kathmandu)							
Scenarios	**Total cost of wall, roof and glazing**	**% increase**	**Increase in cost for construction**	**Annual load(kwh)**	**Annual load saving**	**Annual amount saving**	**Pay back period in years**
Base case scenario	16,910,358.58			98616.13			
Scenario 01	**18,453,024.42**	**9%**	**1,542,665.84**	**88316.45**	**10%**	**154,495.20**	**9.99**
Scenario 02	19,693,002.49	16%	2,782,643.90	89792.99	9%	132,347.00	21.03
Scenario 03	15,742,217.73	-7%	-1,168,140.86	102611.62	-4%		
For Himalayan Region (Jomsom)							
Scenarios	**Total cost of wall, roof and glazing**	**% increase**	**Increase in cost for construction**	**Annual load(kwh)**	**Annual load saving**	**Annual amount saving**	**Pay back period in years**
Base case scenario	16,910,358.58			277229.19			
Scenario 01	18,454,718.94	9.13%	1,544,360.36	250561.44	9.6%	400,016.25	
Scenario 02	**19,693,002.49**	**16.46%**	**2,782,643.90**	**246606.27**	**11.0%**	**459,343.80**	**6.06**
Scenario 03	15,742,217.73	-6.91%	(1,168,140.86)	269287.47	2.9%	(51,307.97)	
Scenario 04	14,585,307.04	-13.75%	(2,325,051.54)	278791.94	-0.6%	60,090.12	

Natural Lighting-WWR

Natural lighting is directly related to amount of solar radiation enter through the window. The total energy consumption also varies with change in window wall ratio along with the amount of heat gain or loss through window area. The influence of the glass thermal conductance in building energy performance is dependent. The three types of data were set in Ecotect (2011) simulation model with WWR varying from 25-30%, 50% to 80%. Its shows that the moderate (50% WWR), and full (80% WWR) opening size consume more energy than base case (25-30%).







Influence of WWR on energy consumption

The chart on "*Influence of WWR on energy consumption*" analyzes the impact of window-wall ratio (WWR) on building energy consumption in Nepal. The data reveals that increasing WWR from 25-30% to 50% or 80% leads to higher energy consumption in all three regions studied. This is primarily due to increased heat gain through larger window openings. However, the specific impact of WWR varies across regions. In Nepalgunj, annual cooling load increases by 10% and 38% for scenarios 1 and 2, respectively. In Kathmandu, the increases are 8% and 33%, while in Jomsom, the annual heating and cooling load increases by 7% and 40%. The chart suggests that while a higher WWR can provide more natural lighting, it may also lead to increased energy consumption, especially in regions with extreme climates. Therefore, a careful balance between natural lighting and energy efficiency is crucial when designing buildings. WWR of 25-30% is generally recommended for optimal daylighting, and also the use of double glazing panel is found to significantly improve thermal performance, helping to offset some of the energy consumption associated with higher WWRs.

Some recommendations for the typical U-value of the buildings similar to this archetype across 3 ecological region:

Terai (Nepalgunj)

- U-value of wall: 1.16 w/m2k
- U-value of roof : 0.91 w/m2k
- U-value of window : 2.710 w/m2k

Hilly (Kathmandu)

- U-value of wall: 1.16 w/m2k
- U-value of roof : 0.91 w/m2k
- U-value of window : 2.710 w/m2k

Himalayan (Jomsom)

- U-value of wall: 1.04 w/m2k
- U-value of roof : 0.77 w/m2k
- U-value of window : 2.710 w/m2k

Conclusion:

Energy consumption occurs at every stage of a building's life cycle, but the usage and maintenance phase is where the majority of energy is consumed. By adopting passive design strategies, such as optimizing building orientation, improving the building envelope, and planning natural ventilation, thermal comfort and indoor air quality can be achieved efficiently. The energy performance analysis conducted using Ecotect Analysis 2011 validates these strategies by comparing energy consumption across different scenarios with varying building envelope materials. The results show that energy consumption can be significantly reduced by altering construction materials, leading to long-term energy conservation and reduced energy costs. The study further emphasizes the importance of building orientation, shading devices, and material selection in minimizing energy consumption, tailored to specific ecological regions.

To optimize energy efficiency in building, it is crucial to consider region-specific design adaptations. For instance, in hilly and mountainous regions, orienting buildings towards the south reduces energy consumption, while in Terai region, a northward orientation is more effective in blocking the summer sun and decreasing cooling loads. The analysis also highlights the importance of material selection, such as using cavity walls, double-glazing windows, and insulation, which contribute to energy savings. This study recommended the specific U-values for walls, roofs, and windows, along with optimized window-to-wall ratios (WWR) and shading device dimensions to ensure energy efficiency as per different ecological region. Moving forward, further energy savings can be achieved by incorporating iterative adjustments during the planning stage and leveraging region-specific archetype models. The integration of traditional Nepali architectural elements with modern energy-efficient designs will promote sustainable construction practices that respect local culture and heritage. Continuous research and performance monitoring will help refine these models and adapt them to evolving climatic conditions and technological advancements, ensuring that buildings remain energy-efficient in the long term.