

Research Article

# Passive House Design: A Possible Energy Efficient Option in the Building Sector of Nepal

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## Abstract

The diversified geography of Nepal creates huge variations in the country's climatic zones; however, the building industry has so far used standardized methods that tend to neglect local climate conditions. Most of these standards then rely on energy-intensive mechanical systems to maintain indoor thermal comfort, without considering more viable and climate-responsive design methods. In this light, the development of a climate classification related to building design will help develop and encourage energy- and climate-effective building architecture in Nepal. The existing energy-saving practice in the building sector of the country is reviewed in this paper, and it outlines ways to improve the adaptation of energy-efficient methodology. It shows that passive houses are performing much better in comparison with modern constructions that are behind in terms of energy efficiency when compared with traditional homes. The study outlines the climate-specific design criteria and methodologies for various regions and sets the path for exploration of the passive house design process challenges and opportunities that might exist for wider diffusion. Also discussed are strategies to overcome the barriers and promote passive house construction, offering a pathway toward sustainable building practices in Nepal.

## Keywords

Buildings, Diverse Geography, Climate, Passive

## 1. Introduction

The energy industry confronts big problems, which are getting worse every day. The "three Es," as described by the International Energy Agency (IEA), are the environment, energy security, and economic prosperity. The present energy trends raise serious worries about these three aspects. The building industry is one of the biggest energy consumers, consuming a lot of energy and producing a lot of CO<sub>2</sub> [1]. Globally, there is an increasing concern about energy efficiency. Approximately 32% of the world's final energy consumption is currently accounted for by energy use in buildings. Buildings account for about 40% of primary energy con-

sumption in the majority of nations and 65% of total electric usage [2].

Nepal's total energy consumption in FY 2022 AD was 640 PJ, indicating a small increase from the year before. The residential sector dominates the national market with 60.59% of the overall consumption [3]. According to the most recent data from CBS, there are 6,666,937 individual households in Nepal, with a population growth rate of 2.3 per year and an average household size of 4.37 (which has decreased by 0.51 since 2011). These figures suggest that the building sector will see an increase in energy consumption in the future [4].

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One major contributor to the overall end-use energy is the usage of energy-efficient buildings. This includes the energy required for maintaining the structures' internal climate and for appliances, lighting, and other installed equipment. The relative energy efficiency of new construction will have an impact on energy usage for many years because most structures have extended lifespans. Energy-efficient modifications can reduce the demand and expenses for heating and cooling systems. To achieve sustainability in buildings and organizations, the first step is to create energy efficiency. In addition to lowering environmental impact and raising building value and competitiveness, energy efficiency helps manage growing energy costs. The core idea of sustainability is making efficient use of the resources available to us while still meeting our own needs and preserving the ability of future generations to fulfill their own needs.

The residential sector, which accounts for 60.59% of total consumption, dominates the national market. Due to conventional and less energy-intensive methods, the agriculture sector only accounts for 0.94% of overall consumption, even though over 60% of the population works in agriculture [3].

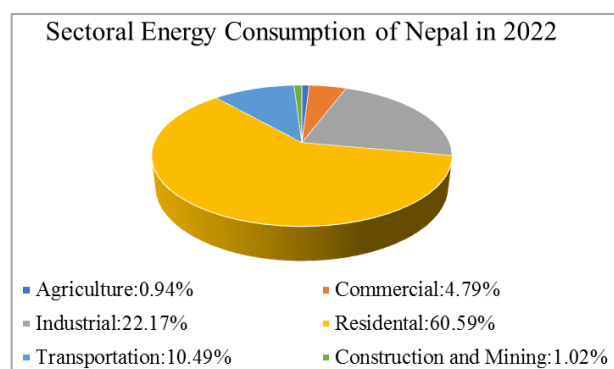


Figure 1. Sectoral Energy Consumption of Nepal in 2022 [3].

## 1.1. Objectives

- 1) To find out what energy-saving methods are currently being used in Nepal's building construction sector.
- 2) Identify the challenges that the building construction sector faces in implementing energy-efficient techniques.
- 3) To Suggest solutions to overcome these challenges.
- 4) Identify potential energy-efficient methods for buildings that are suitable for Nepal.
- 5) Develop strategies to promote these energy-efficient methods.

## 1.2. Scope

- 1) Assess the feasibility and effectiveness of adopting innovative technologies for energy efficiency.
- 2) Participate in creating a long-term plan for Nepal's sus-

tainable energy usage

## 1.3. Research Gaps

The current state of energy-efficient building techniques, the obstacles they face, and the efficacy of workable remedies are not well documented in Nepal. The effectiveness of these measures is not well-illustrated in the literature currently in publication. It is critical to comprehend the unique challenges that Nepalese buildings confront, to determine the best strategies for improving energy efficiency, and to detect any potential problems with laws and regulations. Filling in these knowledge gaps can help the government and building industry professionals in Nepal implement greener, more sustainable energy methods.

## 2. Methodology

- 1) Evaluation Phase: During the evaluation phase, the assessment of the current state of the building sector in Nepal was performed, including the energy demand, building materials, and design practices.
- 2) Planning Phase: In the planning phase, developed strategies and measures to promote energy-efficient building practices in Nepal.
- 3) Recommendation Phase: During the recommendations phase, recommend suggestions for standards for the building industry in Nepal, to introduce and use energy efficiency in the building sector.

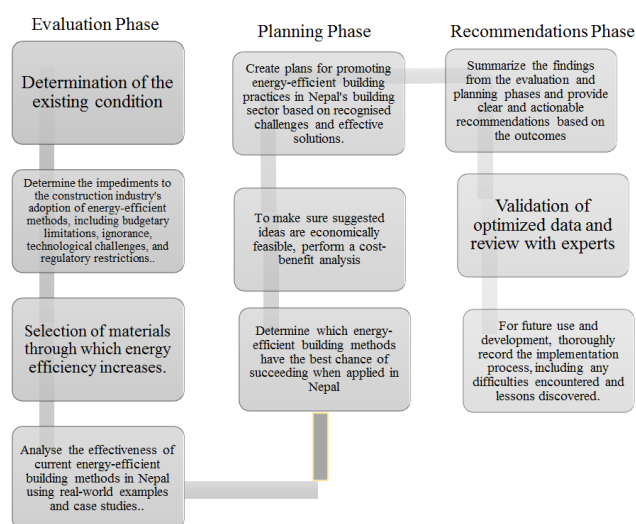


Figure 2. Methodology Chart.

### Existing buildings /Types of Buildings in Nepal

#### 1) Traditional Buildings

Traditional buildings were created with labor, technology, and materials readily available a long time ago [5]. The Nepalese Terai Region offers an abundance of wood, thatch, rich, fertile alluvial soil, and biogenic resources for building

homes. Stones, sand, and gravel are used in the hilly region to make bricks. Although there are plenty of stones, boulders, and mud resources in the Himalayan Mountain Region, there is a shortage of wood and organic materials because of the region's poor fertility and severe temperature [6]. Traditional Nepalese structures have unique architectural characteristics, especially those in the terai and highland regions. These are mostly load-bearing structures that are mostly built with dry bricks. The beams are made of solid wood and are necessary for the structure's integrity. Bricks that have been burned or sun-dried and are kept together by cement or clay mortar are used for the walls. These walls typically measure 505 mm in thickness and have a low U value of about 1.014 W/m<sup>2</sup>°C. The utilization of sun-dried bricks makes interior spaces cozier. When it comes to absorbing moisture, these bricks are exceptionally better than kiln-dried bricks, which are typically found in contemporary homes. These historic buildings are more generally livable because of their innate ability to regulate moisture [7].

### 2) Modern Houses

In Nepal, most residential structures are made with Reinforced Concrete (RCC) for the structural components—beams, columns, and slabs—by the National Building Code (NBC). Concrete and galvanized steel are the two most common materials used to make roofs. Particularly in the country's mountainous and terai regions, bricks and cement are frequently employed for wall construction. Nevertheless, many homes still have issues with thermal comfort despite these construction methods. This problem is exacerbated by the lack of clear design specifications, including those about appropriate air filtration, sufficient insulation for walls and roofs, and ventilation requirements. As a result, these houses experience extremes in temperature—colder winters and warmer summers. Unfortunately, attaining thermal comfort frequently requires spending a substantial amount of energy. For indoor uses such as cooking, lighting, heating, and cooling, electricity is mostly dependent. It is imperative to solve these design flaws and investigate energy-efficient solutions to improve living conditions sustainably [8].

### 3) Passive Houses

Passive houses are environmentally friendly, cost-effective, cozy, and highly energy-efficient building standards. Beyond being a low-energy building, Passive House is more. When compared to conventional building stock, passive house buildings can achieve energy savings related to heating and cooling of up to 90%, and when compared to average new builds, these savings can reach over 75%. When buildings need more energy for cooling than for heating, similar energy savings have been shown in warm areas. Additionally commended for their exceptional comfort level are Passive House structures. They make heating simpler by utilizing internal energy sources like resident body heat or solar heat that enters the structure [9].

## 3. Design of Passive House System

Among the existing buildings, Passive houses are better because Modern homes may rely significantly on mechanical systems, while older homes frequently lack insulation and efficient design. In contrast, passive houses prioritize energy efficiency by minimizing energy usage for lighting, heating, and cooling. While traditional and modern homes may have inadequate ventilation and fluctuating indoor temperatures, passive houses maintain constant internal temperatures, guaranteeing comfort all year round. While traditional homes may need more regular maintenance and repairs, modern homes may have cheaper upfront costs but higher operating expenses. Passive houses, on the other hand, greatly reduce long-term energy costs [10].

### 3.1. Based on Climate

Generally, Nepal is divided into three main regions based on its geographical features. They are the Himalayan Region, the Mountain Region, and the Terai Region. Nepal's climate is significantly influenced by its altitudinal features. Table 1 illustrates how Nepal's climate is divided into five climatic zones because of the country's extreme height variations, which span from 70 meters above sea level to 8848 meters. They are in the sub-tropical climate zone, which is found below 1200 meters. the area between 1200 and 2100 meters with a temperate and moderate climate the cold temperate zone 4, situated at an elevation of 2100-3300 meters the alpine climatic zone, which is situated between 3300 and 5000 meters, and the tundra climate zone, which is situated above 5000 meters [11].

**Table 1.** Climatic Zones of Nepal [12].

Climatic Zones	Altitude (meters)	Mean Temperature (Celsius)	
Sub-tropical	0-1200	15	>30
Warm temperate	1200-2100	10	24-30
Cold temperate	2100-3300	<5	20
Alpine	3300-5000	<0	Loka.15
Tundra	Above 5000	<0	<0

### 3.2. Meteorism Software

Meteorism is a special blend of dependable data sources and advanced computation technologies. Access to historical time series and average years are made available. A useful instrument for solar energy applications, building design, heating and cooling systems, education, agriculture, forestry, and many other fields, Meteorism is a global standard [10].

The figure below is the data shown for Nepal as an average. The below data are generated from the software named Met-

ronome from which we have generated the temperature, radiations, etc. of Nepal:

In Nepal, the sunshine radiation produced by Meteonorm is an important consideration in the building of passive dwellings. It is important for maximizing energy efficiency and establishing cozy interior spaces. To maximize solar heat gain, architects and builders take thermal mass, shading devices, and window orientation into account. To maximize energy efficiency and occupant comfort, passive house design can benefit greatly from solar radiation. Maximizing solar heat gain is the goal of passive buildings to reduce dependency on outside energy sources [13].

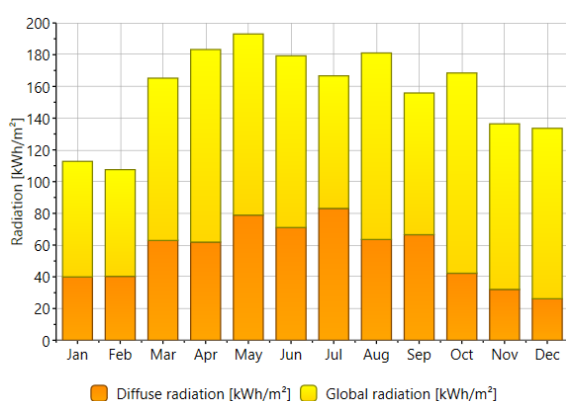


Figure 3. Sunshine radiation generated from Metronorm.

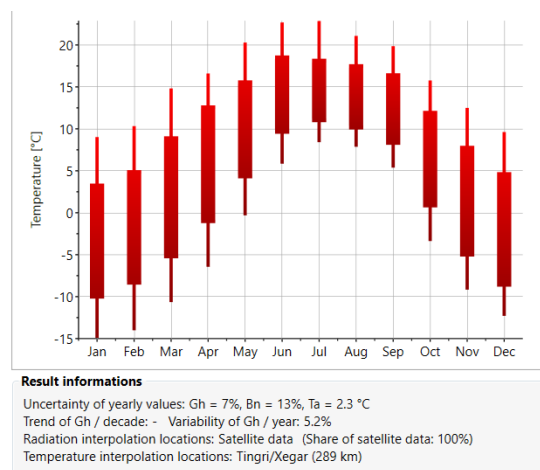


Figure 4. Temperature of Nepal from Metronorm.

The temperature graph in the figure shows the range of temperatures for each month in red bars. The temperature range within each month is shown by red bars. It is clear that the temperature varies, indicating seasonal variations. Understanding monthly temperature swings is crucial for developing energy-efficient building designs and comprehending climate trends. This graph offers insights into these fluctuations.

The graph below most likely displays Nepal's average monthly precipitation totals (in millimeters). Because every month is represented, seasonal fluctuations can be seen. Nepal receives a lot of rainfall from June to September, which is the monsoon season. There could be a noticeable increase in precipitation at this time on the graph. Precipitation levels are often lower during the dry season, which runs from October to May. There might be less rain during these months, according to the graph.

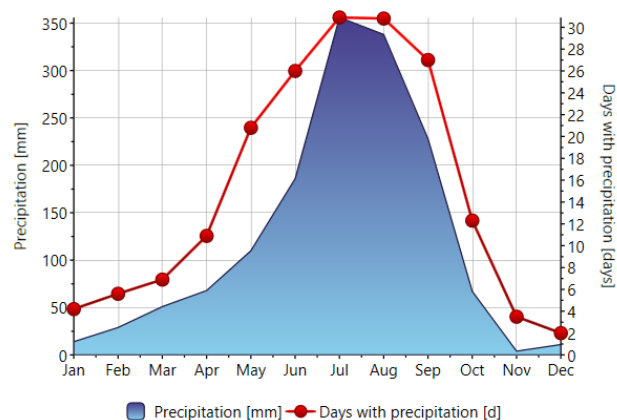


Figure 5. Monthly precipitation of Nepal. Figure created in Metronorm.

The table below shows the mean monthly and yearly data of Nepal which is generated from Meteonorm software.

Table 2. Mean monthly and yearly data for Nepal from Metronorm Month.

Month	Gh (kWh/m <sup>2</sup> )	Dh (kWh/m <sup>2</sup> )	Bn (kWh/m <sup>2</sup> )	Ta (°C)	Td (°C)	FF (m/s)
January	113	40	147	-3.9	-5.7	1.2
February	108	40	122	-2	-3.8	1.7
March	165	63	165	1.5	-0.3	1.9
April	183	62	184	5.7	3.9	2.0

Month	Gh (kWh/m <sup>2</sup> )	Dh (kWh/m <sup>2</sup> )	Bn (kWh/m <sup>2</sup> )	Ta (°C)	Td (°C)	FF (m/s)
May	193	79	162	9.9	8.1	1.9
June	179	71	151	14.3	12.3	1.7
July	167	83	121	14.6	12.6	1.4
August	181	64	172	13.8	11.7	1.4
September	156	67	142	12.4	10.3	1.4
October	168	42	214	6.2	4.5	1.4
November	136	32	210	1	-0.7	1.2
December	134	26	235	-2.5	-4.1	1.1
Year	1880	669	2026	5.9	4.1	1.5

In new housing, 40% of the energy used for heating and cooling to achieve thermal comfort could be reduced to almost zero through sound climate-responsive design. Reducing or eliminating the need for heating and cooling in existing homes is a significant challenge, especially those that were planned and constructed before building energy efficiency standards were introduced when appliances were effective but inefficient. Our current housing stock will still be in use to some extent in 30 years based on annual renewal rates of 1.5 percent [14].

### 3.3. Orientation

The fundamental concept of a passive house design is orientation. The amount of heat or cold that enters a structure depends on its direction. The total efficiency of the building is affected by the site's position, which is determined by the direction of the sun and wind. To avoid spending more than required on heating or cooling, the layout of the rooms in the house should be carefully considered. As everyone knows, the sun rises in the east and sets in the west. The most sun radiation will reach the structure that faces south. As a result, the wall's southernmost section needs to receive the maximum sunlight [15].

In addition to the building's walls, the windows must also be considered for the passive design. It is always advisable to have windows facing south since the thermal mass in the southern half of the building has the greatest potential to collect sunlight and heat, which it then distributes to the other rooms. Since the opening and the windows allow light to enter the space [8].

### 3.4. Thermal Mass

Thermal mass is a material's ability to absorb, store, and release heat as needed. A thermal mass absorbs, stores, and releases heat during the day in response to variations in the ambient temperature. In conjunction with passive solar design

principles, thermal mass must be used appropriately to achieve any kind of outcome. There is a clear correlation between the thermal mass and the density of the material.

**Table 3.** Thermal capacity of different materials [8].

Building Material	Density (kg/m <sup>3</sup> )	Specific heat capacity (J/kg.K)
Water	1000	4190
Air	1.0035	1204
Brick	888	840
Concrete	2240	2240
Stone, Granite	2640	820
Stone, Marble	2600	800

### 3.5. Insulation

Insulation is essential in passive houses. The house's floors, roof, and walls can all let heat escape. It is feasible to keep the surroundings cool and minimize heat loss in the winter by adding insulation to the buildings. EPS, glass wool, cotton, cellulose, mineral wool, fiberglass, and sheep's wool are a few of the several insulation materials utilized in passive buildings. By acting as a barrier between the interior and exterior walls, insulation materials help to keep the interior space warm in the winter and cool in the summer [16].

The thermal heat loss coefficient, or U-value, determines how successful certain insulation is. The rate of heat transfer through a structure divided by the temperature differential within the structure is known as the U value. The unit of U-value is W/ (m<sup>2</sup> °C) which means the amount of heat loss in watts per m<sup>2</sup> at a standard temperature of 1- degree Kelvin. The material is better the lower the u value [17].



## 4. Passive House Requirements

- 1) The building must meet the following characteristics, according to the Passive House Institute.
- 2) The wall, ceiling, and floor must be adequately insulated, with a maximum U- value of 0.15 W/m<sup>2</sup>.
- 3) Windows with a U-value of 0.80 W/m<sup>2</sup> °C or less are well insulated and fitted.
- 4) During a pressure test at 50 Pascal, leakage from holes shall not exceed 0.6 of the total volume of the home per hour.
- 5) To prevent thermal bridges, every edge, corner, connection, and penetration must be airtight to the greatest

extent possible. If thermal bridges cannot be avoided, they must be reduced as much as feasible.

An effective heat recovery system needs to be constructed to allow the circulation of good-quality air and recover enough heat for use with a traditional central heating system [16, 18].

## 5. Overall Design

An overview of the principal design goals and solutions for building thermally suitable dwellings in each major climate zone is given in this section.

**Table 4.** Overall Design for Passive heating system [19-24].

Basis	Hot humid summer, warm winter	Warm humid summer, mild winter	Hot dry summer, warm winter	Hot dry summer, cool winter
Windows and shading	<ol style="list-style-type: none"> <li>1) All windows and walls, even those that face south, should be shaded. If possible, provide extended eaves; if not, use vertical shading.</li> <li>2) To prevent heat gain or cooling loss, use window frames with thermal breaks and glazing with a low solar heat gain coefficient (SHGC)</li> <li>3) Planting and shade structures can provide shade for the house, especially for the windows and outdoor areas.</li> </ol>	<ol style="list-style-type: none"> <li>1) Use glazing sparingly.</li> <li>2) In regions with cooler winters or hotter summers, use low SHGC glazing in all situations, and low U value glazing with thermally fractured frames in other regions.</li> <li>3) Utilize windows that can be fully opened, such as louver or casement windows, and cover</li> </ol>	<ol style="list-style-type: none"> <li>1) Use low U- value glazing and try to avoid overusing it.</li> <li>2) In areas with warm summers and moderate winters, use low SHGC glazing; in areas with chillier winters, use double glazing.</li> <li>3) In the summer, shade all windows with an east or west exposure, and in structures located north of the tropic of Capricorn, shade windows with a south exposure.</li> </ol>	<ol style="list-style-type: none"> <li>1) Use double glazing sparingly and think about using it in bedrooms and living spaces to reduce the need for glazing.</li> <li>2) Utilize frameworks that are insulated or thermally enhanced.</li> <li>3) Add passive solar shade to north-facing windows, and in the summer, cover all east- and</li> </ol>
Insulation	<ol style="list-style-type: none"> <li>1) Keep walls and ceilings free of bulk insulation, unless they are in climate-controlled areas.</li> <li>2) Internal wall surfaces should be well-insulated from any external thermal mass.</li> <li>3) To prevent condensation and upward heat movement, insulate elevated floors using reflective, closed-cell bulk insulation.</li> </ol>	<ol style="list-style-type: none"> <li>1) Use several layers of the reflective foil to produce a 1-way valve effect in roof and ceiling spaces in places where no winter heating is needed.</li> <li>2) Discourage any external thermal mass by insulating interior wall surfaces.</li> <li>3) Walls should be lined with highly permeable reflective vapor barriers, and air-conditioned rooms should also have bulk insulation added.</li> </ol>	<ol style="list-style-type: none"> <li>1) Utilize bulk or reflective insulation in the walls and ceilings.</li> <li>2) All thermal mass should have exterior insulation.</li> <li>3) When using in-slab heating and higher floors, insulating concrete slabs should be done</li> </ol>	<ol style="list-style-type: none"> <li>1) All thermal</li> <li>2) mass should have exterior insulation.</li> <li>3) When using in-slab heating and higher floors, insulating concrete slabs should be done.</li> <li>4) Verify that every compartment is airtight.</li> </ol>
Construction systems	<ol style="list-style-type: none"> <li>1) Utilize lightweight (low-mass) building materials.</li> <li>2) Use materials for the external walls and roof that are light-colored and reflective.</li> </ol>	<ol style="list-style-type: none"> <li>1) When day-night temperature differences are small, use lightweight wall construction; when they are greater than 6 °C, add thermal bulk.</li> </ol>	<ol style="list-style-type: none"> <li>1) Build with high thermal mass.</li> <li>2) Use insulated concrete slabs or elevated lightweight floors with high thermal mass walls in</li> </ol>	<ol style="list-style-type: none"> <li>1) Take high thermal mass building as an example.</li> <li>2) Use slabs with earth coupling.</li> <li>3) Select roofing mate-</li> </ol>

Basis	Hot humid summer, warm winter	Warm humid summer, mild winter	Hot dry summer, warm winter	Hot dry summer, cool winter
		2) Use elevated lightweight floors where the ground temperature in the summertime is more than 19 °C at a depth of 3meters.	areas where summer ground temperatures are above 19 °C at a depth of 3 meters.	rials in bright colors.
	Warm temperate	Mild temperate	Cool temperate	Alpine
Windows and shading	1) Do not overdo glazing. 2) For windows that face orth, use passive solar shading, and during the summer, cover any windows that face east and west. 3) To permit varying solar access in the spring and fall, take into account changeable shade.	1) Use high SHGC and low U- value glazing instead of overusing. 2) Use tight-fitting drapes with pelmets or insulating blinds. 3) Reduce and cover all east and west- facing windows during the summer.	1) Don't utilize glazing excessively, and carefully size and align windows. 2) Utilize double glazing with a high SHGC, low U value, and thermally enhanced or insulated frames. 3) Include passive solar-shade for windows with a north orientation.	1) Use thermally improved or insulated frames, double glazing with a high SHGC, and windows with a low U value. 2) Use thick drapes with sealed pelmets or insulating blinds. A couple more options to think about are double curtains or insulating blinds. 3) East-facing windows should be avoided since morning fog reduces winter solar benefits.
Insulation	1) Use bulk or reflective insulation in the walls and ceilings, respectively. 2) When using in- slab heating and higher floors, insulating concrete slabs should be done 3) All thermal mass should have exterior insulation.	1) If employing under-slab heating, insulate concrete slabs. 2) To estimate the proper insulation levels in high thermal mass walls like rammed earth or mud brick, calculate the thermal lag. 3) Include entry airlocks and completely seal the area to prevent drafts.	1) All walls, ceilings, and exposed floors should be bulk-insulated. 2) For walls, utilize bulk insulation with highly permeable sarking or several layers of reflective foil insulation, with careful planning to lower the risk of condensation. 3) If employing under-slab heating, insulate concrete slabs and add airlocks to entrances.	1) All walls, ceilings, and exposed floors should be thickly insulated. 2) To attain a higher rating for the wall insulation, think about utilizing 150mm or 200mm deep studs. 3) Use the highest degrees of bulk insulation in the ceilings and externally insulate to high levels of any thermal mass, especially rammed earth and mud brick.
Construction systems	1) Take earth-coupled slabs and composite thermal mass construction into consideration. 2) Choose finishing, roofs, and walls with low embodied energy.	1) Take thermal mass composite construction as an example. 2) Glass-to-mass ratios that are appropriate can be used with high thermal mass walls.	1) Unless the earth's temperature is below 16 °C at a depth of 3 meters in the winter, use earth-coupled slabs. 2) Increase thermal mass and solar exposed glass as diurnal temperature variations rise above 6 °C, and use lightweight wall construction where they are low.	1) Use highly insulated, lightweight flooring or insulate the ground beneath slabs. 2) In areas that do not receive direct sunshine, use well-insulated, low-thermal mass walls.

## 6. Barriers and Opportunities

Barriers:

- 1) Awareness and Education: Inadequate knowledge of green building techniques and energy efficiency.
- 2) Guidelines and Skilled Manpower: Insufficient rules and qualified experts to implement green buildings.
- 3) Cultural Factors: Cultural traditions have led to limited demand for green building rating systems.
- 4) Embodied Energy: It's still difficult to quantify the embodied energy of building materials [25, 26].

Opportunities:

- 1) Energy Audit and Baseline Data: Conduct energy audits to understand consumption patterns and establish baseline data for energy use in Nepalese residences
- 2) Renewable Energy Sources: Encourage the use of solar energy and other renewable sources to lessen reliance on imported energy.
- 3) Improved Building Design: Blend common sense with sustainable design ideas. Improve thermal comfort and create public open areas.
- 4) Local Materials: Reduce the number of imported commodities to help the country's economy.

## 7. Strategies

Strategies to promote these energy-efficient methods in the construction of buildings in Nepal

Sustainable development requires encouraging the use of energy-efficient building techniques. The following are some tactics that may be used in Nepal:

- 1) Campaigns for Public Awareness and Education: Inform the public, architects, and builders about the advantages of energy-efficient buildings.
- 2) To spread awareness of sustainable practices, hold training sessions, seminars, and workshops.
- 3) Rules and Incentives from the Government: Provide tax breaks to builders who use energy-saving equipment. Put in place laws requiring energy-efficient materials and designs.
- 4) Capacity Building: Educate local experts on energy-efficient building practices, such as designers, architects, and engineers. Urge technical schools and universities to incorporate energy efficiency into their courses.
- 5) Working together and establishing connections: Encourage cooperation amongst all parties involved, such as NGOs, government agencies, and business leaders, and Establish channels for exchanging best practices and knowledge.
- 6) Demonstration Projects: Provide instances of effective, energy-efficient construction and emphasize comfort,

financial savings, and environmental advantages [26].

- 7) Financial Assistance: Set up grants or funds expressly for construction projects that use less energy. Urge banks to provide loans for these kinds of projects in advantageous conditions.
- 8) Local Materials and Techniques: Encourage the use of low-embodied-energy, locally accessible materials. Examine conventional construction methods that are inherently energy-efficient.
- 9) Certification and Labelling: Create a mechanism for Nepal-specific green building certification. Buildings with energy-efficient labels will raise awareness among prospective purchasers.
- 10) Work Together with Foreign Partners: Take note of the energy policies and practices that other nations have found successful. Take part in workshops and conferences held internationally.
- 11) Research and Development: Make research investments in cutting-edge, energy-saving technology [6].

## 8. Conclusion

The construction traditions of Nepal are highly varied, both in terms of the materials utilized and the architectural designs. The most important factors that have contributed to the diversity of the nation's building stock are both local materials and ethnicity and cultural identity. An airtight structure could be achieved with the help of appropriate measures that lower energy demand, which is otherwise employed for the same reason as indoor thermal comfort. Buildings with inadequate airtightness were shown to be responsible for about 30% of the thermal load. By using a comprehensive strategy that incorporates community awareness, legislative backing, and technology developments, Nepal's building industry may attain energy efficiency. We can make our built environment greener and more robust in the future by adopting sustainable practices. Important factors include natural ventilation, insulation, and building orientation. According to the Passive House design standard, thermal comfort can be achieved with less heating and cooling by using insulation, airtightness, suitable window, and door design, ventilation systems with heat recovery, and eliminating thermal bridges. When a building is passively constructed, features like orientation, thermal mass, insulation, and glass combine to reduce unwanted heat gain and loss while harnessing natural sources of heating and cooling, such as the sun and breezes.

## Conflicts of Interest

The authors declare no conflict of interest.



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