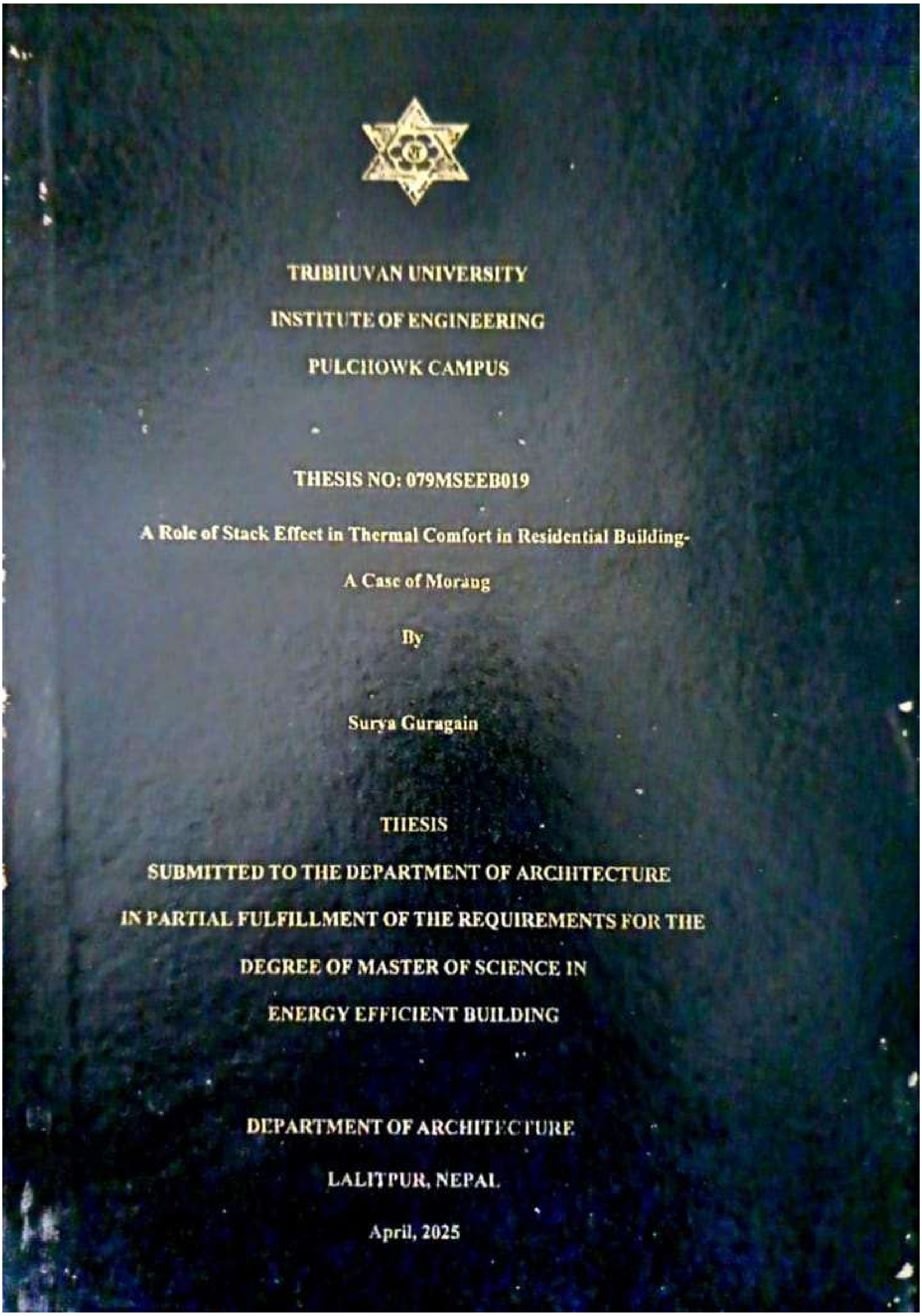

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INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: 079MSEEB019

A Role of Stack Effect in Thermal Comfort in Residential Building-

A Case of Morang

By

Surya Guragain

THESIS

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN

ENERGY EFFICIENT BUILDING

DEPARTMENT OF ARCHITECTURE

LALITPUR, NEPAL

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DECLARATION

I hereby declare that the thesis entitled "A Role of Stack Effect in Thermal Comfort in Residential Building- A Case of Morang" submitted to the Department of Architecture in partial fulfilment of the requirement for the degree of Master of Science in Engineering in Energy Efficient Building, is a record of an original work done under the guidance of Dr. Sanjaya Uprety, Institure of Engineering, Pulchowk Campus. This thesis contains work completed by me except for the referenced material which has been duly cited and acknowledged.

Surya

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"A Role of Stack Effect in Thermal Comfort in Residential Building- A Case of Morang"** submitted by Surya Guragain in partial fulfillment of the requirements for the degree of Master of Science in Energy Efficient Building.

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IV

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ABSTRACT

A key natural ventilation mechanism that greatly improves thermal comfort in residential structures, especially in hot and muggy regions, is the stack effect. It draws colder air in through lower inlets and uses the buoyancy of warm air to rise and depart through higher outlets. By promoting passive cooling, this method reduces the requirement for artificial systems. In the Budhiganga Rural Municipality of the Morang area, this study examines the function of the stack effect—known locally as *Murgar* - a traditional Tharu name for stack projection—in vernacular residential constructions. The significance of climate-responsive architectural methods is highlighted by the region's tropical climate, which is marked by high humidity and high temperatures.

Field measurements were carried out in attic, outdoor and interior spaces with an emphasis on discomfort hours and temperature fluctuations throughout the day. Furthermore, airflow dynamics affected by stack projections were investigated using simulation models. The findings show that well-positioned *Murgar* structures greatly enhance indoor thermal performance and air circulation. The study emphasises how conventional architectural features can lessen reliance on mechanical cooling systems when well optimised. These results support the importance of using traditional knowledge to solve contemporary environmental and comfort issues and aid in the creation of energy-efficient building designs for the Terai region.

Keywords

Stack effect, *Murgar*, natural ventilation, thermal comfort, passive cooling

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CHAPTER 1: INTRODUCTION

1.1 Introduction

A vital component of both energy efficiency and occupant well-being in residential structures is thermal comfort. In areas with notable climatic variances, the stack effect—also referred to as the chimney effect—plays a crucial part in passive cooling and natural ventilation. Knowing how the stack effect works is crucial for creating sustainable and cosy living areas in Morang, Nepal, where the subtropical environment poses problems with humidity and heat accumulation.

The temperature differential between indoor and outdoor spaces is what drives the stack effect, which causes air to rise through vertical apertures and initiate a natural ventilation cycle. Using the stack effect in residential structures can assist lessen reliance on mechanical cooling systems in Nepal, where urbanisation and climate change are driving up energy usage for cooling (Gautam, 2019). High ceilings, courtyards, and ventilated roofs are examples of passive design features that have long been used in traditional Nepalese architecture to maximize airflow and preserve interior comfort (Shrestha, 2017).

Particularly in the summer, Morang, a region in Nepal's Koshi province, endures high temperatures and humidity. Passive design techniques are frequently overlooked in modern dwelling buildings, which increases indoor heat retention and discomfort. The importance of natural ventilation in enhancing thermal comfort and lowering energy consumption is highlighted by studies on passive cooling methods conducted in Nepal (Karki & Adhikari, 2020). Examining how the stack effect affects indoor thermal comfort in residential structures in Morang and investigating methods to increase its efficacy through architectural changes are the goals of this study.

This study will add to the larger conversation in Nepal on climate-responsive design and sustainable architecture by examining Morang's vernacular buildings. The results will support the promotion of energy-efficient housing options that are suited to Nepal's climate by architects, engineers, and legislators.

1.2 Importance of the research

In hot, humid climates like Morang, where excessive heat buildup in buildings can lower indoor comfort and increase dependency on mechanical cooling systems, natural ventilation plays a critical role in attaining thermal comfort. An energy-efficient way to improve indoor airflow and cooling is through the stack effect, a passive ventilation mechanism powered by temperature-induced air pressure variations (Shrestha & Bajracharya, 2019). Knowing how the stack effect affects thermal comfort can help designers create sustainable homes that use less energy while yet providing a cosy living space.

Passive cooling methods, such as ventilation shafts, courtyard openings, and high ceilings, have traditionally been used in Nepali traditional architecture. These features naturally encourage air circulation through the stack effect (Sharma & Shrestha, 2020). However, the efficiency of these natural cooling systems has decreased as enclosed structures with little ventilation are prioritised in contemporary design patterns. According to research by Adhikari et al. (2021), modern residential buildings with insufficient ventilation have worse indoor air quality and higher interior temperatures, especially in the Terai region. As a result, including the stack effect into contemporary building designs might lessen these difficulties and the need for artificial cooling devices like air conditioners and fans.

Since it offers insights into sustainable and reasonably priced building solutions that are appropriate for Morang's climate, this study is especially important for Nepal's urban and rural development sectors. The research can help architects, engineers, and policymakers understand passive design solutions that promote thermal comfort by analysing temperature variations in residential buildings and determining how to improve the stack effect. Furthermore, as stated in national building regulations and environmental laws, Nepal is committed to energy efficiency and climate-responsive architecture, which is consistent with encouraging natural ventilation (Ministry of Urban Development, 2022).

The results of this study will advance the area of sustainable design in Nepal and aid in the development of resilient housing options that are both cost-effective for homeowners and environmentally beneficial. This study intends to impact future construction practices by showcasing the useful applications of the stack effect in Morang's residential buildings, promoting thermally comfortable and energy-efficient living environments.

1.3 Problem statement

A vital component of sustainable living is thermal comfort in residential buildings, especially in areas like Morang where residents are uncomfortable due to high temperatures and humidity. Passive cooling methods, such as natural ventilation via the stack effect, have always been essential to preserving indoor comfort in Nepali vernacular building (Shrestha & Bajracharya, 2019). The Terai region's traditional homes were built with high ceilings, ventilated roofs, and well-placed windows to allow for ventilation. However, natural ventilation systems are frequently disregarded due to the rise of contemporary construction methods that prioritise concrete structures and sealed surroundings, which increases dependency on mechanical cooling systems like fans and air conditioners (Sharma & Shrestha, 2020).

The stack effect is clearly beneficial for increasing indoor air circulation, but its function in Morang's vernacular residential buildings has not been thoroughly studied. Current research on Nepalese residential design pays little attention to the particular climate constraints of the Terai and instead concentrates on thermal comfort in the hilly and mountainous areas (Adhikari et al., 2021). Because thorough study has been lacking, there is a knowledge gap about how effective traditional ventilation techniques are in modern dwellings, which makes it difficult to incorporate them into contemporary designs.

In addition, Morang's fast urbanisation and shifting building styles have prompted the use of designs that put space efficiency ahead of ventilation, which exacerbates internal heat buildup and discomfort. Additionally, the move away from passive cooling methods has led to an increase in energy consumption, which has increased household financial burdens and the environmental effects of excessive power use. Without a thorough grasp of how the stack effect functions in vernacular design, Nepal runs the risk of losing important indigenous knowledge that could help create climate-responsive and sustainable housing solutions.

The purpose of this study is to close this gap by examining the impact of the stack effect on thermal comfort in Morang's traditional residential structures. Insights into optimising passive cooling solutions for both traditional and modern homes will be provided by the study's analysis of temperature differences, architectural features, and environmental conditions. The results will support the development of energy-efficient housing models that are appropriate for the Terai climate while maintaining Nepal's rich architectural legacy by architects, engineers, and policymakers.

1.4 Research gaps

This study aims to bridge this gap by investigating how the stack effect affects thermal comfort in traditional residential buildings in Morang. The study's examination of temperature variations, architectural elements, and environmental factors will offer insights into how to best use passive cooling solutions for both historic and contemporary dwellings. The findings will help architects, engineers, and politicians preserve Nepal's unique architectural heritage while advancing the creation of energy-efficient housing types suitable for the Terai climate.

1.4.1 Limited Focus on Terai Region

The majority of studies on ventilation and thermal comfort in Nepal concentrate on the hilly and mountainous areas, where the climate and building styles are very different from those in the Terai. Although Adhikari et al. (2021) offer insightful information on urban living, they don't go into great detail about how the stack effect functions in the Terai's particular climate. Although Sharma and Shrestha (2020) talk about traditional courtyards, they don't go into detail on the stack effect or how it's used in contemporary Terai homes. Studies that examine how conventional ventilation techniques, such as the stack effect, can be best suited to Morang's hot and muggy climate are scarce.

1.4.2 Absence of Quantitative Data on Stack Effect

Studies that have already been done mostly provide qualitative information about natural ventilation; nevertheless, there is a dearth of empirical information regarding the precise impact of the stack effect on indoor thermal comfort in residential structures. In their 2019 study, Shrestha and Bajracharya, for example, discuss natural ventilation in Nepalese homes but do not measure how much the stack effect lowers temperatures. Practical suggestions for incorporating the stack effect into both conventional and contemporary home designs are challenging to produce in the absence of such data.

1.5 Objectives

The main objective of this research is To assess the impact of the stack effect on thermal comfort in residential buildings by analyzing, indoor temperature variations, and openings efficiency and the secondary objectives are:

- To measure day and night variations in indoor temperature, humidity due to the stack effect,
- To assess the impact of the stack effect on energy consumption for heating and cooling in residential buildings

1.6 Research Questions

How does the stack effect contribute to thermal comfort in vernacular residential buildings?

1.6.1 Sub-questions:

- What architectural features of vernacular residential buildings in Morang facilitate the stack effect?
- How do these features influence indoor thermal comfort?

1.7 Topic validity

It is crucial and relevant to conduct study on how the stack effect improves thermal comfort in traditional residential buildings, especially in light of Nepal's varied climate zones. The study fills a significant vacuum in the literature on natural ventilation systems in the Terai region's hot and muggy climate by concentrating on the district of Morang. Passive cooling strategies, such as the stack effect, have long been used in vernacular design to maximise ventilation and minimise inside heat buildup. Nevertheless, as contemporary urbanisation occurs, the incorporation of these ancient architectural elements has diminished in favour of energy-intensive, sealed structures. This study intends to revive sustainable design principles and offer insightful information for enhancing thermal comfort and lowering energy usage by concentrating on the stack effect in vernacular buildings.

1.7.1 Supporting Literature

- According to Shrestha and Bajracharya (2019), traditional Nepalese homes are designed with natural ventilation—including the stack effect—to preserve thermal comfort without the need for mechanical cooling. In light of Nepal's varied climate, their research highlights the importance of passive cooling, which makes the stack effect a highly pertinent topic in Morang.

- During the study, Adhikari et al (2021) examined passive cooling techniques in urban homes and emphasised the significance stack ventilation plays in lowering indoor temperatures, particularly in urban and peri-urban locations like the Terai region.

- The stack effect was a key component of passive cooling strategies, according to Sharma and Shrestha (2020), who also highlighted the function of courtyard homes and traditional Nepalese architecture in establishing cosy interior environments. This emphasises how important it is to research historic design features in contemporary Morang houses.

- According to Koirala (2018) analysis of traditional construction techniques in the Terai region, vernacular architecture was created with a thorough grasp of the local climate, and the stack effect greatly enhanced the thermal comfort of interior spaces.

- The possibility for improving passive cooling techniques like the stack effect in modern residential buildings was covered by Bhandari (2022), who also talked about energy efficiency and thermal comfort in Nepalese homes.

- A thorough investigation on the thermal performance of Terai buildings was conducted by Thapa and Gautam (2019), who came to the conclusion that natural ventilation techniques, such as the stack effect, can lessen the need for mechanical cooling systems, promoting sustainability.

- Incorporating natural ventilation systems, such the stack effect, greatly enhances thermal comfort and energy efficiency in hot and humid areas like Morang, according to a study on building energy performance by Joshi and Paudel (2020).

- In their study on passive home design in the Terai region, Regmi et al. (2021) stressed the use of conventional ventilation techniques, such as stack ventilation, for enhancing the interior climate of Morang's residential buildings.

- Vernacular design principles, which include characteristics that assist the stack effect, may help maximise the thermal comfort of contemporary structures in the Terai region, according to Nepal et al. (2017), who studied energy-efficient building designs for the area.

- According to Nepal et al. (2017), who researched energy-efficient building designs for the Terai region, vernacular design principles, which include features that aid the stack effect, may help maximise the thermal comfort of modern structures in the area.

This topic adds to the expanding body of knowledge on sustainable architecture in Nepal, especially in the Terai region, making it extremely pertinent. Knowing how the stack effect improves thermal comfort in historic residential buildings allows for the optimisation of these elements in contemporary housing while also preserving traditional design knowledge. Given the increasing demand for climate-responsive architecture and the fast urbanisation of areas like Morang, this research offers crucial information for energy-efficient housing solutions that may be applied to other similar areas in Nepal and abroad.

1.8 Expected output

The architectural elements in Morang's vernacular residential buildings that contribute to the stack effect will be identified and described by the study. High ceilings, ventilated roofs, apertures, cross ventilation, and window placement that naturally promote air circulation and temperature regulation may all play a part in this. The anticipated result will offer a thorough comprehension of conventional design components that support natural cooling and enhanced indoor air quality.

The quantitative examination of the stack effect's contribution to thermal comfort is one of the main anticipated results. The study will examine how the stack effect contributes to the maintenance of a comfortable indoor climate without the need for mechanical cooling systems by gathering empirical data, such as temperature readings and humidity levels. The results will show the efficiency of the stack effect in terms of energy savings and thermal comfort by clearly contrasting interior spaces that are mechanically cooled and those that are naturally ventilated.

The final product will include practical suggestions for enhancing thermal comfort in residential structures, assisting designers, builders, and legislators in producing environmentally friendly and culturally appropriate homes.

1.9 Limitations

There are certain limitations of this study which might affect the accuracy and results of this study:

- The case study and field data collecting took place between the end of January and the start of February 2025, while the simulation makes use of Energy Plus meteorological data from 2009 to 2023. The outcomes could be impacted if the latest weather file is unavailable.
- The analysis is based on single case study building which can limit the ability to generalize the result to other traditional buildings relevant in that areas.

- The chosen case study includes slightly modified traditional Tharu buildings because fully traditional structures are not readily available, although the literature review takes into account traditional Tharu buildings (Toffin, 1991). Over time, many ancient Tharu buildings have been altered to accommodate human needs. For example, the thatch roof has been replaced with CGI sheets, and these structures are now used for storage or cooking purposes, among other purposes.

CHAPTER 2: LITERATURE REVIEW

2.1 Stack Effect:

A natural ventilation phenomena known as the stack effect happens when warm air rises within a building as a result of temperature differences between the interior and exterior. The difference in density between warm (lighter and less dense) and cool (denser) air is what causes this vertical air movement. A low-pressure area is formed at the base of the building as the warm air rises, attracting colder air from the outside. Unwanted ventilation may result from this, especially in high-rise structures or areas with inadequate ventilation.

2.2 Thermal Comfort:

The state in which a person feels neither too hot nor too chilly is known as thermal comfort. Numerous variables, such as air temperature, humidity, air velocity, and radiant temperature, affect it. A comfortable indoor environment is guaranteed by good thermal comfort, yet uncomfortable conditions might result from inadequate ventilation, especially in hot or humid settings.

A key factor in improving thermal comfort in buildings, especially in vernacular residential architecture, is the stack effect, a natural ventilation phenomenon in which warm air rises and exits through openings at higher points in a building, creating a pressure difference that draws cooler air in from lower openings. With its hot and muggy climate, the stack effect can greatly lower indoor temperatures in Morang, a district in Nepal's Terai region. This will improve indoor air quality and lessen the demand for mechanical cooling systems. In order to comprehend the function of the stack effect in enhancing thermal comfort in traditional residential buildings, this literature study examines numerous works written by Nepali and foreign writers, with an emphasis on how well it applies to the climate of Morang.

2.3 Traditional Architecture and Passive Cooling in Nepalese Vernacular Buildings

Natural ventilation systems are a common element of vernacular residential buildings in Nepal, where passive cooling techniques have long been used in traditional construction (Shrestha & Bajracharya, 2019). The natural flow of air, which is fuelled by temperature variations between interior and outdoor spaces, has proved crucial in preserving thermal comfort, especially through the stack effect. According to Shrestha and Bajracharya (2019), high ceilings, open courtyards, and roof ventilation in Nepalese courtyard homes enable the stack effect by allowing warm air to rise and exit the structure, resulting in a steady flow of cooler air from lower-level apertures.

The significance of the stack effect in the Terai region is further highlighted by Adhikari et al. (2021), who point out that traditional homes in the area were built with the purpose of utilising natural ventilation systems. However, many of these historic elements are being neglected as contemporary, airtight construction becomes more popular. According to Sharma and Shrestha (2020), the Kathmandu Valley's contemporary residential constructions have abandoned these conventional cooling techniques as a result of a move towards more energy-intensive and air-conditioned dwellings.

2.4 Role of Stack Effect in Thermal Comfort

In hot and muggy climates, the stack effect works especially well to lower indoor temperatures without the need for mechanical air conditioning. The stack effect draws cooler air into lower regions of structures by allowing hot air to escape from the upper parts, according to Koirala (2018). This natural flow contributes to thermal comfort, which is crucial in the Terai region, including Morang, particularly during hot daytime hours.

The beneficial effects of the stack effect on thermal comfort in residential structures are also supported by international research. According to Emmerich (2017), the stack effect can improve indoor comfort and energy efficiency by lowering the demand for mechanical cooling. In a similar vein, Park et al. (2020) show that the stack effect can dramatically reduce interior temperatures in buildings situated in subtropical regions when paired with other passive cooling techniques like cross ventilation and shade.

2.5 Stack Effect and Vernacular Architecture in the Terai Region

With its extreme heat and humidity, Nepal's Terai area offers both special potential and challenges for the use of passive cooling systems. This area's traditional vernacular architecture frequently makes use of roof vents, high ceilings, and huge windows, all of which intensify the stack effect by generating temperature differentials that encourage airflow. Using natural cooling techniques like the stack effect, Terai vernacular homes were traditionally built to adapt to the temperature, according to Bhandari (2022). But more and more contemporary structures in Morang are using air-conditioned, sealed designs, ignoring the passive cooling potential of older residences.

According to Regmi et al. (2021), urbanisation in the Terai is causing more contemporary yet energy-inefficient dwellings to replace traditional building designs. According to the study, incorporating traditional cooling techniques—like the stack effect—into modern designs may improve energy efficiency and thermal comfort. This is especially important in Morang because summer temperatures there can get very high.

2.6 Quantification and Impact of Stack Effect on Indoor Thermal Comfort

Temperature gradients and air velocity inside buildings can be measured to determine how much the stack effect contributes to thermal comfort. Shrestha et al. (2020) shed light on how these elements affect indoor thermal comfort in Nepali homes, pointing out that the stack effect-driven natural ventilation can reduce interior temperatures by several degrees Celsius, greatly enhancing comfort without consuming more energy.

The measurement of the stack effect in building designs has been studied internationally by Riffat and Zhu (2017), who found that in some climates, a well-designed stack effect can lower cooling loads by up to 30%. According to their findings, natural ventilation techniques like the stack effect should be revived in Nepalese residential buildings, especially those in the Terai.

2.7 Integration of Vernacular Design in Modern Housing

Modern home designs in the Terai, particularly Morang, frequently ignore passive cooling principles, despite the obvious advantages of the stack effect in traditional Nepalese building. According to Joshi and Paudel (2020), contemporary structures in the Terai region frequently put aesthetics and space efficiency ahead of climatic adaptability. As a result, mechanical cooling systems are used more frequently, which raises expenses and energy consumption.

Bhandari (2022) promotes design approaches that combine conventional passive cooling techniques with contemporary construction methods. In this regard, the stack effect can be viewed as a link between conventional and contemporary architecture, supporting climate-responsive housing and sustainable building techniques.

2.8 Contemporary Studies on the Stack Effect

The stack effect has been extensively researched globally as a component of natural ventilation systems to increase energy efficiency and indoor comfort. The stack effect can be a very successful method for cooling buildings in hot regions, lowering the need for air conditioning, and enhancing interior air quality, according to Lomas and Fiala's (2004) analysis of natural ventilation in residential structures. According to their research, the stack effect is especially significant in areas like Nepal's Terai where there are significant temperature fluctuations between indoor and outdoor spaces.

Similarly, the stack effect, when paired with other passive cooling strategies, can successfully lower indoor temperatures and raise comfort levels in tropical regions, as shown by Abel and Givoni (2010) using computer simulations. Their research highlights how modern architectural design may improve thermal comfort and sustainability by incorporating classic design features like high ceilings, vented roofs, and well-placed openings.

Additionally, research by Rijal et al. (2013) highlights how crucial it is to incorporate traditional Nepalese architectural concepts—such as the stack effect—into contemporary structures in order to enhance thermal performance while preserving energy efficiency. Given the growing demand for passive cooling technologies, this has important ramifications for urban growth in the Terai region.

2.9 Challenges and Opportunities for Applying the Stack Effect

The increased popularity of sealed structures that impede airflow presents the biggest obstacle to using the stack effect in contemporary Morang buildings. But according to Rai and Shrestha (2022), by making sure that the ventilation pathways and vent hole placements are appropriate, passive cooling features can still be incorporated into contemporary buildings—even in crowded urban settings. They stress that Morang may have affordable, climate-friendly housing options by fusing the stack effect with contemporary energy-efficient architecture.

2.10 Calculating the Stack Effect

By affecting the temperature and circulation of the air inside a building, the stack effect can affect thermal comfort. In terms of temperature gradients and air movement (velocity), the stack effect and thermal comfort can be simplified. Thermal comfort may suffer as a result of an uneven temperature distribution brought on by the stack effect's impact on ventilation. A condensed formula representation of the stack effect is provided here:

$$V_{\text{stack}} = C \cdot A \cdot \sqrt{h \cdot (T_{\text{in}} - T_{\text{out}})}$$

Where:

- Vstack = air velocity due to stack effect (m/s)
- C = constant that depends on building geometry and air properties
- A = cross-sectional area of the building opening (m^2)
- h = height of the building (m)
- Tin = indoor temperature (°C)

- Tout = outdoor temperature (°C)

The stack effect, which can result in increased air movement and greater air velocities that could affect thermal comfort, increases as Tin increases.

2.11 Bioclimatic chart

A graphical tool for examining the connection between climate and human thermal comfort is a bioclimatic chart. Based on local climatic data, it assists engineers, architects, and urban planners in choosing the best passive design techniques for buildings. In order to provide appropriate design interventions like natural ventilation, shading, evaporative cooling, or thermal mass utilisation, the chart takes into account variables like temperature, humidity, wind speed, and sun radiation.The stack effect, which can result in increased air movement and greater air velocities that could affect thermal comfort, increases as Tin increases.

2.11.1 Types of Bioclimatic Charts

I. Olgyay's Bioclimatic Chart

This chart, which was created by Victor Olgyay in the 1950s, defines the comfortable range for human habitation by examining the relationship between temperature and relative humidity. Based on seasonal differences, it recommends passive design solutions like heating, evaporative cooling, or shade (Olgyay, 1963).

II. Givoni's Bioclimatic Chart

Building on Olgyay's work, Baruch Givoni presented a bioclimatic chart based on psychrometry that incorporates other climatic elements as wind speed, solar radiation, and building envelope characteristics. Givoni's chart is frequently used to evaluate thermal comfort and choose the best passive heating or cooling techniques for buildings (Givoni, 1992).

III. ASHRAE Psychrometric Chart

Thermal comfort models based on temperature, humidity, and air movement are incorporated into the ASHRAE psychrometric chart. Engineers can examine energy-efficient heating and cooling techniques when it comes to HVAC design (ASHRAE, 2017).

2.12 Thermal analysis using software

Architects, engineers, and urban planners employed Autodesk Ecotect Analysis, a potent building performance simulation program, to assess environmental conditions and maximise sustainable building designs. In order to improve energy efficiency and occupant comfort, it offered comprehensive insights into solar exposure, thermal performance, daylighting, acoustics, and ventilation. Before being discontinued in 2015 and largely included into Autodesk's Green Building Studio and Revit, Ecotect was widely used for bioclimatic design (Attia, 2011).

2.12.1 Key Features of Ecotect Analysis

I. Solar and Thermal Analysis

Ecotect helped customers optimise passive solar design techniques by enabling them to examine the impacts of shade and solar radiation on building facades. In order to ascertain the most effective positioning of windows, shading devices, and photovoltaic panels, it offered sun access analysis (Marsh, 2006).

II. Daylighting Simulation

In order to help designers lessen their need on artificial lighting, the software assessed the amount of natural light that entered indoor rooms. It facilitated interaction with Radiance, a potent daylight analysis engine, and climate-based daylight modelling (Mahdavi et al., 2007).

III. Wind and Ventilation Studies

In order to improve thermal comfort, Ecotect replicates natural ventilation and airflow. According to Hensen and Lamberts (2011), it was coupled with CFD (Computational Fluid Dynamics) tools such as ANSYS and OpenFOAM to provide a complete analysis of airflow.

IV. Energy Consumption Estimation

Based on information about the building's orientation, materials, and climate, Ecotect offered preliminary estimates of energy use. In order to help with compliance with international energy codes, it connected with EnergyPlus for comprehensive energy modelling (De Kay & Brown, 2014).

2.13 Ashrae standards for thermal comfort

In order to ensure the productivity and well-being of building occupants, thermal comfort is a crucial design consideration. Standards for defining and evaluating thermal comfort in buildings have been developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). ASHRAE Standard 55, which sets requirements for indoor environments based on variables such air temperature, humidity, airspeed, and metabolic rate, is the main standard controlling thermal comfort (ASHRAE, 2021).

The indoor thermal comfort temperature range is influenced by a number of variables, including clothing insulation, humidity, and air circulation, according to ASHRAE 55 (2020). The following temperature ranges are advised for residential buildings:

Season	Conditioned Buildings (°C)	Naturally Ventilated Buildings (°C)
Winter	20 - 24°C (68 - 75°F)	16 - 26°C (61 - 79°F)
Summer	23 - 27°C (73 - 80°F)	18 - 30°C (64 - 86°F)

Table 1: Temperature ranges of residential building

- Conditioned Buildings: To maintain a consistent comfort zone, buildings with active HVAC systems follow more stringent temperature limits.

- Naturally Ventilated Buildings: A greater temperature range is permitted by the adaptive thermal comfort model since residents naturally adjust to seasonal changes (De Dear & Brager, 1998)

The adaptive model included in ASHRAE 55 is especially helpful for vernacular architecture that uses passive cooling techniques (such as natural ventilation, high thermal mass, and shade).Because residents naturally adjust to seasonal changes, the adaptive thermal comfort model permits a greater temperature range (De Dear & Brager, 1998).

2.13.1 Thermal Acceptability Limits:

I. For indoor operative temperature:

- The mean temperature outside affects the comfort band (De Dear & Brager, 2002).
- In hot climates, if airflow and shade are optimised, the upper limit can surpass 30°C.

II. For relative humidity:

Recommended range: 30% - 60% (ASHRAE, 2020).

Higher airspeed (0.8 m/s) increases comfort in hot-humid areas.

2.14 Key Theories Supporting the Study

2.14.1 Stack Effect Theory (Buoyancy-driven ventilation):

I. Introduction

A natural ventilation phenomena called the stack effect, or buoyancy-driven ventilation, is brought on by variations in air density between interior and outdoor spaces. Usually, temperature changes result in pressure differences that propel air flow within buildings or other structures, which in turn causes this difference in density. In passive ventilation systems, the stack effect is particularly important in high-rise buildings and structures such as lift shafts, stairwells and chimneys.
Architects, engineers, and energy auditors must comprehend stack effect since it has a big impact on thermal comfort, indoor air quality (IAQ), and building energy performance.

II. Principle of Stack Effect

Buoyancy forces, which result from variations in air temperature and, thus, air density, between the interior and exterior of a building, are the basis of the stack effect. The air within a building tends to rise and become less dense when the temperature inside is higher than the temperature outside. A negative pressure is created at the bottom of the building when the warm air rises and departs through openings at higher levels, bringing in colder outdoor air through openings at lower levels. The stack effect is the term for this vertical air movement from bottom to top caused by temperature-induced buoyancy (Awbi, 2003).

$$\Delta P = C \cdot g \cdot h \cdot \left(\frac{1}{T_{\text{out}}} - \frac{1}{T_{\text{in}}}\right)$$

Where:

ΔP\Delta PΔP = pressure difference (Pa)

C = constant (typically related to the density of air)

g = acceleration due to gravity (9.81 m/s^2)

h = height difference (m)

Tin, Tout = absolute indoor and outdoor temperatures (K)

The stack effect causes the pressure differential and airflow rate to increase with height and temperature differential. The Neutral Pressure Level (NPL), or the altitude at which the indoor and exterior pressures are equal, is a key idea in stack effect.

Above the NPL: indoor pressure exceeds outdoor pressure; air tends to flow out.

Below the NPL: indoor pressure is lower than outdoor pressure; air tends to flow in.

The stack effect influences the distribution and direction of airflows, and the location of the NPL can change based on temperature gradients and building design.

III. Types of Stack Effect

a) Winter Stack Effect

Warmer interior air rises and escapes from the top of buildings in colder locations throughout the winter. The bottom draws in cold external air. The most common and potent type of stack effect is this one.

b) Summer Reverse Stack Effect

A reverse stack effect can happen in some situations, especially when the outside air is warmer while the interior of the building is cooler (as in air-conditioned buildings). In this case, cooler internal air tends to sink while warmer exterior air tends to rise through the structure.

IV. Applications of Stack Effect

a. Natural Ventilation

A common technique for passive ventilation in buildings is the stack effect. Buildings can reduce energy consumption by facilitating natural airflow without the need for mechanical systems by strategically arranging operable apertures and developing vertical shafts or atriums (Heiselberg, 2002).

b. Smoke Management in Fires

Smoke movement in tall structures is greatly influenced by the stack effect. Because of its buoyancy, hot smoke rises quickly during fires, which could result in vertical smoke dispersion. Designing smoke control systems requires an understanding of stack effect (Klote & Milke, 2002).

c. Chimneys and Flues

Conventional chimneys pull combustion gases upward and outward via the stack effect. The driving force is the temperature differential between flue gases and ambient air.

d. Solar Chimneys

These architectural elements are intended to increase buoyancy-driven airflow by enhancing the stack effect by heating air in a vertical shaft using solar radiation (Bansal et al., 1993).

V. Design Considerations

A number of things should be taken into account in order to properly harness or reduce the stack effect:

a. Building Height

As the vertical distance between the inlet and the outflow rises, so does the stack effect's amplitude. As a result, it matters more in tall buildings.

b. Temperature Difference

Stronger airflow and larger pressure differentials are the results of greater indoor-outdoor temperature variations.

c. Openings and Leakage Paths

The airflow pattern is significantly influenced by the number, size, and position of openings, whether deliberate or not. Unwanted infiltration or inefficient use of energy might result from uncontrolled leakage.

d. Internal Resistance

Friction and flow resistance in shafts, stairwells, and corridors are examples of airflow pathways. These may impair the efficient airflow caused by stacks.

VI. Advantages of Stack Effect Ventilation

a) **Energy Efficiency**: Airflow paths include things like friction and flow resistance in shafts, stairwells, and hallways. These could hinder the effective airflow that stacks provide.

b) **Sustainability**: supports LEED certification and the design of green buildings.

c) **Improved IAQ**: lowers indoor pollutants and encourages the exchange of fresh air.

d) **Low Operational Cost**: Maintenance is decreased when there are fewer mechanical parts.

2.14.2 Thermal Comfort Theory (ASHRAE Standard 55 & Adaptive Thermal Comfort Model):

I. Introduction

Thermal comfort has a major impact on occupant contentment, productivity, and health, making it a crucial component of indoor environmental quality. "That condition of mind which expresses satisfaction with the thermal environment" is what is meant by thermal comfort (ASHRAE, 2021). It is subjective and influenced by a number of individual and environmental factors. Thermal comfort theory is dominated by two main approaches: the adaptive thermal comfort model, which takes contextual and behavioural adaptability into account, and the heat balancing model, as defined in ASHRAE Standard 55. The application of these two models, as well as its implications for building design and operation, are thoroughly examined in this work.

II. ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers created ASHRAE Standard 55, which offers recommendations for creating livable thermal environments in buildings. The heat balancing theory, on which the standard is predicated, holds that thermal comfort is attained when heat lost to the environment balances the heat generated by human metabolism.

III. Environmental and Personal Factors

According to ASHRAE 55, there are six main elements that affect thermal comfort (ASHRAE, 2021):

Air Temperature: The air around the body's dry bulb temperature.

Radiant Temperature:The average radiative temperature of the surfaces around it.

Air Speed:The speed of airflow close to the body.

Humidity: The air's moisture content, which influences heat loss through evaporation.

Metabolic Rate (Met): The pace at which heat is produced inside, which is influenced by physical activity.

Clothing Insulation (Clo): Heat exchange is impacted by clothing's insulating qualities.

IV. The Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD)

Fanger's PMV model, which forecasts the mean thermal sensation vote of a sizable population on a seven-point scale from -3 (cold) to +3 (hot), is used by ASHRAE 55 to quantitatively assess thermal comfort (Fanger, 1970). The proportion of people who are likely to be unhappy with a particular thermal environment is estimated by the PPD index. A PMV of -0.5 to +0.5 and a matching PPD of less than 10% are deemed acceptable by ASHRAE 55 (ASHRAE, 2021).

V. Design Implications

To ensure thermal comfort, ASHRAE 55 establishes precise guidelines for the design and operation of HVAC systems. These consist of: Providing movable windows or personal environmental control devices; reducing radiant asymmetry and vertical air temperature variations. It helps in preserving suitable humidity levels, which are normally in the range of 30% to 60%.

VI. Limitations of the PMV Model

The PMV model has limitations even though it is widely used. Individual preferences, psychological considerations, and cultural variances are not fully taken into account, and it assumes an unchanging metabolic rate and amount of clothing. Additionally, it functions less consistently in areas with significant seasonal fluctuations or in buildings with natural ventilation.

VII. Adaptive Thermal Comfort Model

i. Concept and Rationale

An alternative to the heat balance model, especially for structures without mechanical HVAC systems, is the Adaptive Thermal Comfort Model. It is predicated on the

notion that humans use behavioural, physiological, and psychological processes to adjust to their temperature environment (de Dear & Brager, 1998).
Field studies demonstrating that humans in naturally ventilated rooms can withstand greater temperature ranges than those in air-conditioned areas lend credence to this approach (Nicol & Humphreys, 2002). This strategy revolves around occupants' expectations, window operations, clothing modifications, and other adaptive behaviours.

ii. ASHRAE 55 Adaptive Model

ASHRAE 55 incorporates an adaptable model that can be used in naturally conditioned areas in acknowledgement of its validity. The adaptive approach uses the current mean outdoor temperature to determine permissible indoor operating temperatures. For instance, the following formula is used to determine the allowable indoor temperature range for 80% occupant acceptability:

T_{comfort} = 0.31 × T_{out} + 17.8

Where:

T_{comfort} is the optimal indoor temperature (°C),

T_{out} is the mean outdoor temperature (°C) over the previous 7 to 30 days.

For 80% and 90% acceptability ranges, ASHRAE specifies comfort zones that are normally ±2.5°C and ±2.0°C from the comfort temperature, respectively (ASHRAE, 2021).

iii. Application and Benefits

The adaptable model supports passive cooling, natural ventilation, and user engagement while promoting climate-responsive design. There are several advantages to it:

- lessens dependency on HVAC systems that are mechanical.

Improves sustainability and energy efficiency.

- Conforms to the expectations and behaviour of the occupants.

iv. Limitations and Criticism

Only buildings with moveable windows or other features that give residents influence over their surroundings can use the adaptive model. Additionally, it presumes a certain degree of environmental stability and could not be appropriate for structures housing vulnerable populations, such as hospitals or senior living centres.

v.Thermal Comfort in Sustainable Design

In green building certification programs like LEED, WELL, and BREEAM, thermal comfort theory is essential. These standards frequently call for adherence to ASHRAE 55 or comparable standards. In order to achieve sustainable results, the adaptive model promotes passive methods, low-energy building design, and occupant satisfaction.

Engineers and designers are urged to:

- Optimise insulation and building orientation.
- Make use of shade devices and movable windows.
- Include personal comfort equipment (such as fans and localised heating)
- Involve residents in controlling their level of comfort.

2.15 Theoretical Framework

A conceptual framework is an organised method that outlines the main variables, connections, and theoretical underpinnings of a study. It acts as a road map, assisting researchers in comprehending the interactions between various study components. The conceptual framework shows the cause-and-effect links between independent variables, mediating factors, and dependent variables in the context of thermal comfort, energy efficiency, and occupant satisfaction. A conceptual framework, according to Miles and Huberman (1994), offers a structure for gathering and analysing data as well as aids in the clarification of the study subject.

2.15.1 Independent Variables:

Independent variables are the elements that affect a study's conclusion. Environmental factors and design characteristics make up the independent variables in the given figure. These factors affect a building's occupant happiness, energy efficiency, and thermal comfort. Building design, window placement, roof ventilation, and thermal mass are a few examples of independent variables.

2.15.2 Mediating Variables:

While moderating variables change the direction or degree of the association, mediating variables describe the process by which independent variables influence dependent variables.

Passive Design Strategies (Mediating Variable)

- serves as a link between environmental and design factors and results.
- consists of sun shading, insulation, and natural ventilation.
- minimises energy use without sacrificing comfort.
- The impression of thermal comfort is influenced by cultural factors, which are a moderating variable.
- Temperature tolerance varies among occupants in different climates.

2.15.3 Dependent Variable:

The results impacted by independent variables and mediating factors are known as dependent variables in a research paradigm. They stand for the things the researcher hopes to quantify, examine, and forecast in response to shifts in independent variables. The primary dependent variables in the given conceptual framework are:

- Thermal Comfort
- Energy Efficiency
- Occupant Satisfaction

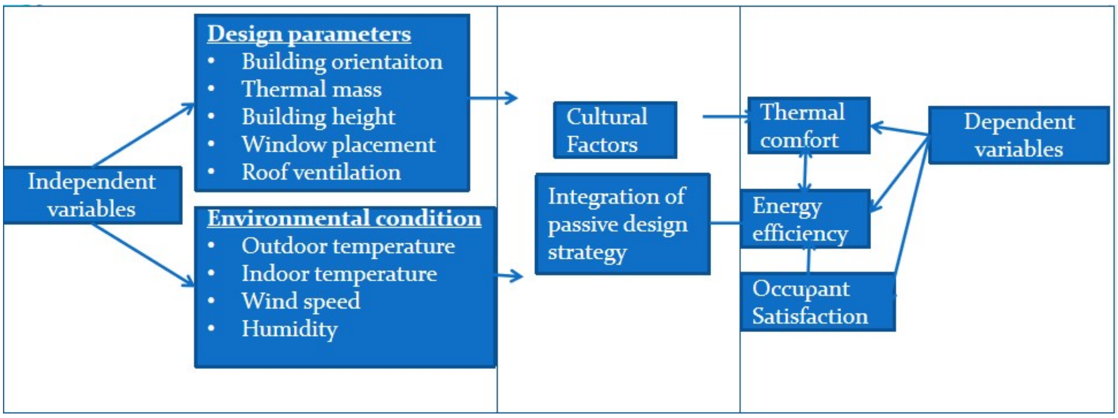


Figure 1: Theoretical framework of the study

In the context of passive design strategies, the given figure serves as a conceptual framework for comprehending the relationship between independent variables (environmental conditions and design parameters) and dependent variables (occupant satisfaction, energy efficiency, and thermal comfort). This approach emphasises how environmental variables and building design affect people's comfort and well-being while highlighting how cultural factors influence how people perceive heat.

Each element of the picture will be examined in this talk, along with the ways in which independent factors affect passive design techniques and, ultimately, thermal comfort, occupant satisfaction, and energy efficiency. Scientific concepts, practical applications, and citations to previous research will be prioritized.

2.15.4 Independent Variables

Design parameters and environmental factors are the two main categories into which the figure divides independent variables. Through their effects on ventilation, heat transmission, and indoor environmental quality, these elements affect thermal comfort and building performance.

i. Design Parameters

Indoor comfort levels are greatly influenced by building design. When establishing how buildings interact with their surroundings, the five design parameters listed in the picture are essential.

ii. Building Orientation

Daylight access, wind exposure, and solar heat uptake are all impacted by building orientation. Olgyay (1963) asserts that environment affects the best orientation:

Hot climates: Buildings can have their cooling loads decreased by being orientated to minimise direct sunshine exposure (e.g., north-south orientation).
In colder climates: passive heating can be enhanced by maximising solar exposure (e.g., east-west orientation).
Temperate climate: A balanced orientation contributes to year-round comfort in temperate areas.

Energy efficiency and occupant happiness are increased in well-designed buildings because they require less mechanical heating and cooling.

iii. Thermal Mass

The term "thermal mass" describes the capacity of construction materials, such as stone, brick, and concrete, to retain and release heat. High thermal mass buildings absorb extra heat during the day and release it at night, hence reducing internal temperature swings (Givoni, 1998). This passive approach uses less energy while increasing thermal comfort.

iv. Building Height

Building height influences:

Stack effect: In warm areas, taller buildings encourage natural ventilation.
Wind exposure: Stronger winds have an impact on thermal comfort in high-rise buildings.
Heat stratification: Higher temperatures are frequently experienced on upper levels of tall buildings.

In high-rise buildings, passive cooling techniques like ventilated atriums and double-skin facades can improve comfort (GhaffarianHoseini et al., 2018).

v. Window Placement

Heat gain, ventilation, and natural illumination are all impacted by window design. Thermal comfort is maximised by strategically placing windows and using shading mechanisms (such as louvres and overhangs):

- Cross-ventilation: By promoting airflow, windows positioned on opposing sides lower interior temperatures.
- Daylighting: In colder climates, windows facing south maximise exposure to sunshine.
- Techniques for shading: In hotter climes, using blinds or reflecting glass reduces warming (Fanger, 1970).

Vi. Roof Ventilation

Heat gain is greatly impacted by roofs. Indoor temperatures can be lowered by passive cooling using reflecting materials, green roofs, or ventilated roof spaces (Santamouris, 2012). By lowering the urban heat island (UHI) impact, roof ventilation encourages energy efficiency.

Vii. Environmental Conditions

The way that structures interact with their surrounds is determined by environmental conditions. Four important environmental factors that affect thermal comfort are listed below:

Viii. Outdoor Temperature

The temperature outside has a direct impact on heat transfer through windows, roofs, and walls. Buildings in cold regions need insulation and passive heating, whereas those in hot climates need ventilation and shade (Nicol & Humphreys, 2002).

Ix. Indoor Temperature

Insulation, HVAC systems, and tenant behaviour all affect indoor temperature. For the best thermal comfort, indoor temperatures should be between 20°C to 26°C, according to ASHRAE Standard 55 (ASHRAE, 2021).

X. Wind Speed

Air quality, cooling, and ventilation are all impacted by wind speed. While air penetration may be uncomfortable in cold areas, high wind speeds improve passive cooling in warm climes. Energy efficiency and thermal comfort are enhanced by wind-driven ventilation techniques (e.g., wind towers, movable windows) (Allard, 2002).

Xi. Humidity

Comfort levels and perceived temperature are affected by humidity. High humidity makes it uncomfortable in warm climates since it decreases perspiration evaporation. To balance thermal comfort and stop mould growth, the optimal indoor humidity range is 30% to 60% (Hens, 2012).

2.15.5 Integration of Passive Design Strategy

The link between independent and dependent variables is created by using passive design techniques. By using natural energy sources, passive design reduces the need for mechanical systems.

The building's inherent capacity to control sunshine, circulation, and temperature is maximised through passive design. Important tactics consist of:

- To minimise heat loss, use thermal insulation.
- To improve airflow, use natural ventilation.
- To reduce overheating, use solar shade.

- Utilising thermal mass to store heat.

A well-executed passive design can drastically increase energy efficiency and occupant satisfaction by reducing energy use by 40% to 60%, claims Baird (2001).

2.15.6 Cultural Factors and Thermal Comfort

The figure recognizes that perceptions of thermal comfort are influenced by cultural influences. Research indicates that regional differences exist in thermal comfort expectations:

- acclimatisation allows people in warmer climates to tolerate higher temperatures.
- Passive cooling techniques appropriate for regional conditions are incorporated into traditional building.
- Comfort preferences are influenced by behavioural adjustments, such as attire and activity levels (de Dear & Brager, 1998)

People adjust to their thermal surroundings according to their expectations and experiences, according to the Adaptive Thermal Comfort Model (Nicol & Humphreys, 2002). This explains why buildings with natural ventilation can have a larger range of comfortable temperatures.

2.15.7 Dependent Variables

The results of well-designed buildings are the three dependent variables: occupant satisfaction, energy efficiency, and thermal comfort.

i. Thermal Comfort

The subjective sense of warmth or coolness is known as thermal comfort. According to ASHRAE 55, comfort is influenced by six factors (ASHRAE, 2021): Air temperature, radiant temperature, air speed, humidity, metabolic rate, and insulation of clothing.

Passive design optimization increases comfort without requiring excessive HVAC consumption.

ii. Energy Efficiency

Energy-efficient buildings include insulation, natural ventilation, and less artificial heating and cooling. It also Cut down on carbon emissions (Santamouris, 2012). According to research, passive buildings can save up to 90% on energy consumption compared to traditional structures (Feist, 2016).

iii. Occupant Satisfaction

Health, productivity, and occupant well-being are all directly impacted by thermal comfort. "Sick Building Syndrome" (SBS), which causes weariness and pain, is brought on by unfavourable indoor conditions (Seppänen et al., 2006). In well-designed workplaces, satisfied occupants report improved health outcomes and increased productivity.

The figure's conceptual framework illustrates how environmental factors, human comfort, and architectural design are all interrelated. Buildings can lessen their dependency on mechanical systems while increasing thermal comfort, energy efficiency, and occupant satisfaction by incorporating passive design techniques. Perceptions of comfort are further influenced by cultural influences, which emphasises the significance of context-sensitive design strategies.

Table 2: Summary of the literature review

Research Articles	Authors	Year	Key Findings
1. Natural Ventilation Potential in Kathmandu's Residential Buildings	Sharma & Adhikari	2010	Stack effect is significant in enhancing airflow in low-rise buildings.
2. Thermal Performance of Traditional vs. Modern Houses in Nepal	Bhattarai & Shrestha	2011	Traditional buildings with higher ceilings and openings promote better stack ventilation.
3. Influence of Stack Ventilation in Passive Cooling of Homes	Ghimire & Karki	2012	Properly designed stack ventilation reduces cooling energy demand by up to 40%.
4. Comparative Study of Natural and Mechanical Ventilation	Acharya & Manandhar	2013	Stack effect performs well in naturally ventilated buildings but is affected by window placement.
5. Thermal Comfort Analysis of Mid-Hill Residences	Paudel & Rijal	2014	Stack effect improves air circulation in mid-hill homes, but is less effective in winter.
6. Effect of Stack Height on Indoor Ventilation in Nepalese Homes	Shakya & Lama	2015	Greater stack height enhances vertical air movement, improving cooling.
7. Passive Ventilation Strategies for Apartment Buildings	Basnet & Joshi	2017	Stack effect is more effective in narrow, tall structures than in low-rise wide buildings.
8. Thermal Comfort Standards in Kathmandu Valley's Homes	Dahal & Thapa	2018	Stack effect ventilation helps in achieving comfort levels but is dependent on outdoor temperature differences.
9. Role of Stack Effect in Hybrid Ventilation Systems	Maharjan & Adhikari	2019	Combining stack ventilation with mechanical systems optimizes comfort and energy efficiency.
10. Natural Ventilation Design Guidelines for Nepalese Homes	Sapkota & Shrestha	2021	Stack effect should be integrated with window openings for optimized ventilation.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This research will employ a quantitative methodology. With an emphasis on the Morang region of Nepal, this method guarantees an examination of the stack effect's contribution to thermal comfort in residential buildings.

3.1.1 Paradigm

The positivist paradigm, which emphasises quantitative research, will be used in this study. Its foundation is positivism, an ideology that prioritises measurement, statistical analysis, and objective reality.It makes it possible to investigate numerical data (thermal loads, temperature variations).

3.1.2 Ontology (Nature of Reality):

Buildings contain measurable physical attributes (materials, insulation), as well as patterns of energy use. By collecting information on building performance, design elements, and energy use, the study will concentrate on revealing these truths.

3.1.3 Epistemology (Nature of Knowledge):

Knowledge is obtained by combining subjective user experiences with objective, measurable data to provide a thorough grasp of the research problem.

3.1.4 Methodology (Approach to Inquiry):

In order to provide useful, solution-focused results, a mixed-methods approach is used, combining data-driven analysis with user-focused insights.

3.1.5 Research Design

The research will use a case study methodology and concentrate on Morang's residential structures.

3.2 Data Collection Methods

3.2.1 Literature Review

A comprehensive analysis of the body of research on the stack effect's impact on thermal comfort in Nepali residential buildings and energy-saving measures will be carried out. The theoretical framework will be established, and important variables for measuring energy efficiency will be identified.

3.2.2 Primary Data Collection

a. Field Surveys

The real data on the case study building's measurements, temperature variations, residents' opinions about the stack technology of their buildings, etc., is gathered through a systematic survey.

b. Interviews

Residents and the owner will be interviewed as usual to learn more about the building methods and materials.

c. Observational Studies

Direct examinations of a few chosen buildings, focussing on elements such as natural ventilation, window arrangement, insulation, etc.

3.2.3 Secondry data collection

The field findings will be supported by information gathered from government records, prior research, and local utility energy use figures.

3.2.4 Data Analysis Techniques

i. Thermal Performance Analysis

Sensors located throughout the structures will be used to gather data on temperature and humidity. The effectiveness of natural ventilation, insulation, and passive cooling will be evaluated through the analysis of this data.

ii. Energy Simulation Models

Data on humidity and temperature will be gathered using sensors located throughout the structures. To evaluate the efficacy of natural ventilation, insulation, and passive cooling, this data will be examined.

3.2.5 Material properties used in simulation model

Table 3: Material properties used in simulation

SN	Name of Material	Thermal Conductivity (W/mK)	Reference Article
1	Mud	0.6	Gupta et. al
2	Window Glass	0.815	Gupta et. al
3	GI Sheet	60.47	Gupta et. al
4	300mm thickness long straw	0.069	Energy Efficiency and Historic Buildings Insulating Thatched Roofs

The simulation model correctly analyses the structure's thermal performance by using a range of building materials with different thermal conductivity values. Watts per meter-kelvin (W/m·K), a measure of thermal conductivity, indicates how well a substance transfers heat. While a greater value implies faster heat conduction, a lower value denotes better insulation. With a thermal conductivity of 0.6 W/mK, mud is utilised in the model to simulate a conventional building material that provides modest insulation and aids in controlling indoor temperatures in both hot and cold climates. Window glass permits more heat transfer than dirt because it has a comparatively higher thermal conductivity (0.815 W/m·K).

In order to reduce undesired heat gain or loss, it is imperative that window orientation, shading, and glazing processes be taken into account in the model. With a remarkable thermal conductivity of 60.47 W/m·K, galvanised iron (GI) sheet is notable for its quick heat transfer. GI sheets can cause severe overheating or heat loss in the absence of supplementary insulation, especially when used for roofing. Last but not least, the 300mm long straw is a great insulator due to its extremely low thermal conductivity of 0.069 W/m·K. It greatly lowers heat transmission and improves thermal comfort, particularly when applied to wall or roof insulation.

These material characteristics are essential for modelling actual thermal behaviour and directing successful passive design solutions. They are taken from reliable sources like Gupta et al. and energy efficiency guidelines for thatched buildings.

3.2.6 Methodological Framework

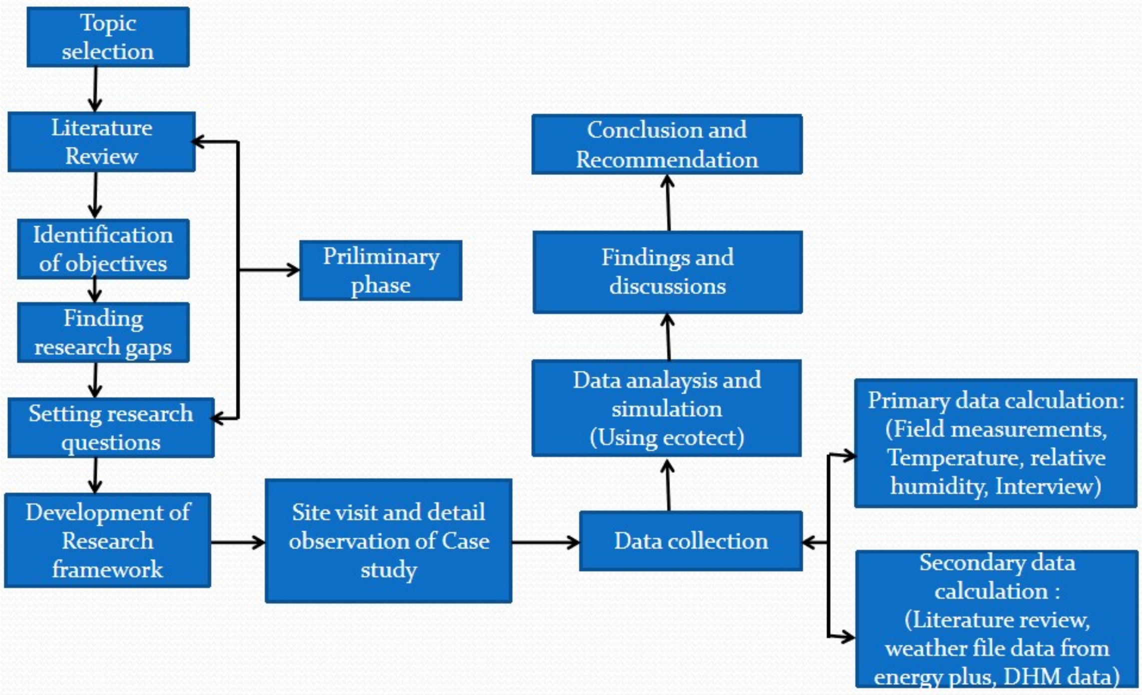


Figure 2: Methodological Framework

The inquiry of the stack effect's contribution to Morang's thermal comfort was successfully led by the methodological approach. Robust results were ensured by combining simulation analysis, empirical data, and theoretical foundation. This study supports sustainable construction practices by highlighting passive ventilation techniques to improve the thermal comfort of homes in Nepal. The approach used to look at the stack effect's impact on thermal comfort is shown in the provided points:

I. Topic Selection

The first step in any study is choosing a research topic. In this case, the study focusses on the impact of the stack effect on thermal comfort in Morang residential buildings. This topic was chosen because of the following factors: the paucity of research on

passive design and stack effect in Nepal, as well as the rising concerns regarding residential building energy efficiency.
the need to improve indoor air quality and thermal comfort through sustainable methods (Givoni, 1994).

II. Literature Review

A comprehensive literature review was conducted in order to compile up-to-date information and pinpoint research gaps. Reviewing studies on thermal comfort models, including ASHRAE Standard 55 and the Adaptive Thermal Comfort Model (de Dear & Brager, 1998), was part of this step. Researchers are looking into how Morang's climate affects residential structures (Shrestha et al., 2016). reviewing previous research on the effectiveness of natural ventilation methods in warm climates (Olesen, 2012).

III. Identification of Objectives

Understanding how the stack effect affects air movement and thermal comfort was determined to be one of the study's main goals. Other goals are:

- Evaluating the natural ventilation effectiveness of Morang's existing residential buildings.

- Making design suggestions to improve passive cooling

IV. Finding Research Gaps

There aren't many studies on stack effect applications in residential buildings in Nepal, according to the literature study.

- In order to validate thermal comfort models in Morang, real-time data collection is required.

- The principles of stack ventilation and passive design solutions are not well integrated.

V. Setting Research Questions

The following research questions were developed in light of the gaps that were found:

- What impact does the stack effect have on thermal comfort in Morang's residential buildings?
- What elements affect how well natural ventilation works through the stack effect?
- How may passive strategies be used to optimise building design to maximise thermal comfort?

VI. Development of Research Framework

The research framework was developed to structure the investigation systematically. This framework included:

- Identification of key variables (e.g., indoor/outdoor temperature, air movement, humidity).
- Selection of case study buildings in Morang.
- Integration of quantitative methods for data collection and analysis.

VII. Preliminary Phase

A preliminary phase includes the literature review, identifications of objectives, finding research gaps and setting out research questions. This phase started after the topic selection. Literature review related to the topic are studied properly for the identification of the objectives i.e. primary objective and the secondary objective. After preparing the objectives, research gaps were identified and the appropriate research questions are prepared for the overall project.

VIII. Site Visit and Detailed Observation of Case Study

A case study approach was employed to analyze real-world conditions (Yin, 2014). The selected residential buildings in Morang were examined for:

- Building orientation and design influencing stack ventilation.

- Temperature and humidity variations across different floors.
- Ventilation openings (windows, vents, skylights) facilitating air movement.

IX. Data Collection

Data collection involved primary and secondary data sources to ensure comprehensive analysis.

i. Primary Data Collection

Field measurements and surveys were conducted to obtain real-time data:Temperature and relative humidity measurements using data loggers. Interviews with residents regarding thermal comfort experiences.

ii. Secondary Data Collection

Secondary data was gathered from: Weather files from EnergyPlus to analyze climatic conditions. DHM (Department of Hydrology and Meteorology) data on historical temperature trends. Previous studies on natural ventilation and stack effect applications in warm climates (Givoni, 1994).

X. Data Analysis and Simulation (Using Ecotect)

Ecotect software was utilised for simulations in order to assess building performance. The efficacy of stack ventilation in various climates was the main focus of the analysis. effects of building design on temperature control and air flow. Validation is done by comparing simulated and measured data.

XI. Findings and Discussions

The data analysis led to key findings, including:

- **Effectiveness of stack effect in Morang's climate:** Buildings with taller ceiling heights and well-placed ventilation openings showed better thermal comfort levels.
- **Influence of design parameters:** Courtyards, roof vents, and strategic window placement significantly enhanced natural ventilation.
- **Limitations of current residential designs:** Many houses lacked adequate ventilation openings, leading to heat buildup and poor air circulation.

XII.Conclusion and Recommendations

Based on findings, the study proposed:

- Architectural modifications such as skylights, higher ceilings, and vented roofs.
- Improved material selection for thermal mass to regulate indoor temperatures.
- Awareness programs for builders and homeowners on passive cooling benefits.

CHAPTER 4: CASE STUDIES

4.1 Introduction

The stack effect, a natural ventilation phenomenon, is crucial for managing indoor thermal comfort, particularly in hotter regions like Morang, a district in the Terai region of Nepal. The centuries-old traditional architecture of Morang incorporates passive cooling strategies to fight the region's extreme summer heat and severe humidity. These traditional architectural features, such as high ceilings, strategically positioned windows, and ventilated courtyards, use the stack effect to create cozy interior spaces without the need for mechanical cooling equipment.

The purpose of this case study is to look at how thermal comfort in typical residential buildings in Morang is impacted by the stack effect. By looking at a sample of homes in the area, the study hopes to understand how the stack effect is used in building design and how it contributes to lowering indoor temperatures, enhancing air quality, and raising overall thermal comfort.

The Terai region's Morang district is home to Budhiganga Rural Municipality, which symbolises Nepal's hot and muggy environment. The average temperature outside is between 14 and 28 degrees Celsius in the winter, and between 26 and 41 degrees Celsius in the summer. According to the Department of Meteorology, the winter months are the shortest in comparison to the summer, and the temperature does not drop significantly. Budhiganga Rural Municipality, located in the Morang district of the Terai region, represents Nepal's hot and humid climate. Winter temperatures range from 14 to 28 degrees Celsius, while summer temperatures range from 26 to 41 degrees Celsius. The winter months are the shortest compared to the summer, and the temperature does not drop much, according to the Department of Meteorology.Budhiganga Rural Municipality, located in the Morang district of the Terai region, represents Nepal's hot and humid climate. Winter temperatures range from 14 to 28 degrees Celsius, while summer temperatures range from 26 to 41 degrees Celsius. The winter months are the shortest compared to the summer, and the temperature does not drop much, according to the Department of Meteorology.

The majority of the residents in the case study area are Morangiya tharu, who build their homes using their traditional building techniques. Similar roofing technology characteristics, such as a heap roof with projections from both sides of the ridge, are typically visible when we visit the case study area. According to the residents' interview with Mr. Parshuram Chaudhary, they constructed this kind of projection (*Murgar*, a typical Tharu term) to stop smoke from emanating from Tuki lamps in the past because of electrical outages in the area. However, the same construction technology is still in use today because of innate craftsmanship knowledge and the fact that everyone in the area, regardless of caste, uses it.

Three distinct temperatures—outside, indoor, and attic—are calculated using data loggers in this investigation of the stack effect's impact on thermal comfort in residential buildings.

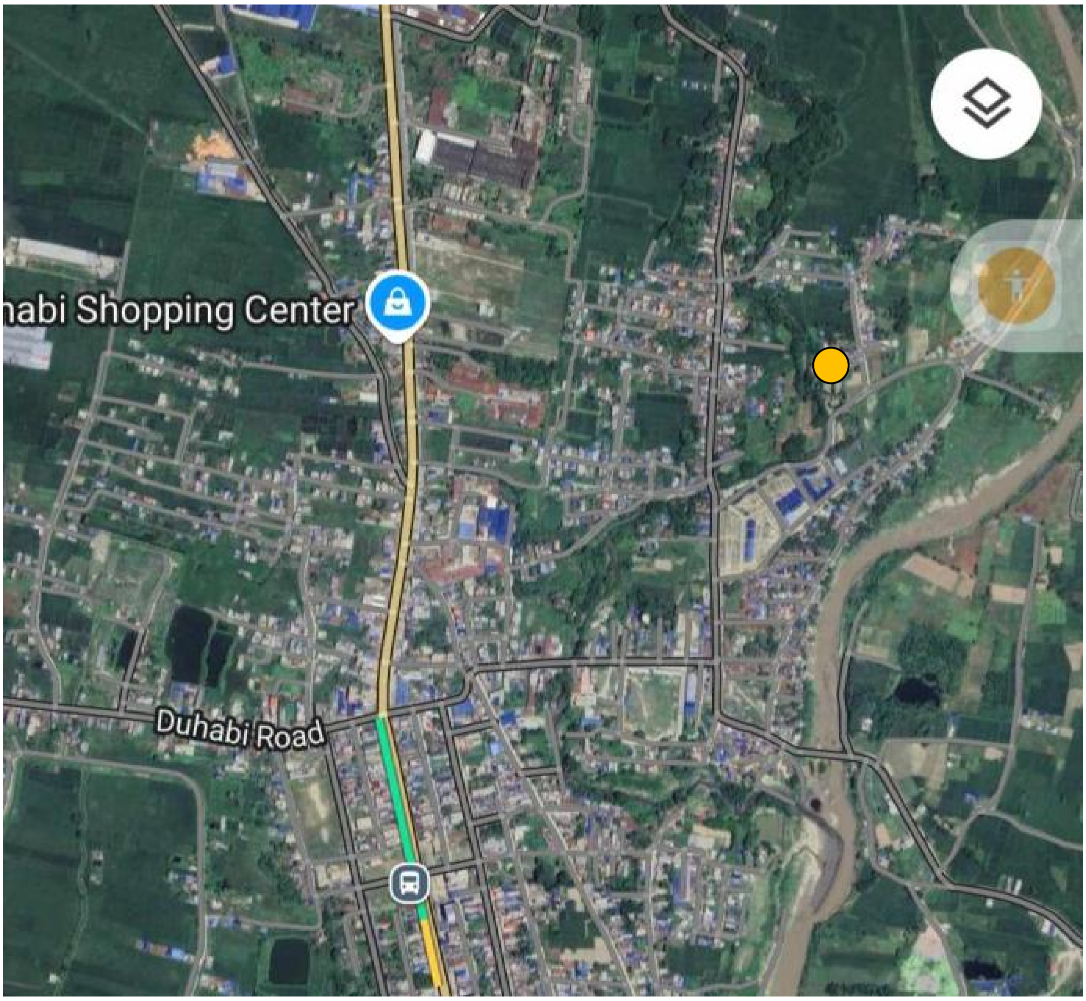


Figure 3: Location map of the site

4.2 Geographical Context

One of the most populous and lively districts in eastern Nepal is Morang, which is situated in Koshi province. Known for its diversity in terrain, culture, language, and economy, Morang has a significant impact on the nation's socioeconomic development. Biratnagar is not only the district headquarters but also the province capital and a major industrial hub of Nepal. Morang occupies an area of approximately 1,855 square kilometres and is situated between latitudes 26°23′ and 26°53′ North and longitudes 87°16′ and 87°47′ East.

i. **Location:** Koshi province, Nepal's Budhiganga rural municipality, Morang District

ii. **Climate:** The Terai region, where Morang is located, has a subtropical climate.

➢ The average temperature during the hot and muggy summer months is between 25°C and 35°C.

➢ Temperatures in the winter range from 10°C to 20°C.

➢ From June to September, there is a lot of monsoon rainfall in the area.

Because of its varied climate, Morang is a great place to research energy-efficient building design and construction that meets the needs of both heating and cooling.

4.3 Demographic and Urban Context

According to the 2021 Census, Morang has a population of approximately 1.15 million, making it Nepal's second most populated district after Kathmandu. The population density is great, especially in places like Biratnagar. Morang's ethnic composition is varied. The following are significant groups: Muslims; Madhesi (Yadav, Tharu, Rajbanshi, Musahar, etc.); Dalit (Kami, Damai, Sarki, etc.); and Hill (Bahun, Chhetri, Rai, Limbu, Tamang, Magar, etc.) communities.

i. **Population:** 1.1 million persons, according to the census taken in 2021. *Morangiya tharu* make up the majority of the site's population.

ii. **Urbanization:** The major city in Morang, Biratnagar, is a fast-growing metropolitan hub with a variety of residential construction types.

- Single-family residences, apartment buildings, and conventional brick and mortar dwellings dominate the residential sector.
- Traditional building techniques, which lack energy-efficient elements, are used in the construction of many homes.
- Urbanisation has led to an increase in demand for contemporary residential units.

iii. Building Typologies for Study

Traditional Houses: Usually built with little insulation and wattle and daub walls.

iv. Energy Usage Patterns

Primary Energy Consumption: Because of the high temperatures and humidity throughout the summer, cooling and ventilation take centre stage. Particularly in cities, the use of appliances and lighting greatly increases energy demand. Renewable energy solutions such as solar photovoltaics are not widely adopted.

4.4 Description of Selected Buildings

Figure 4: Case study building

A typical rural home serves as the case study building surrounding the property. The building is a reflection of the region's vernacular architecture, which was created to accommodate the local climate, resources, and customs.

i. Architectural Features and Materials

The house's primary building materials are thatch, bamboo and mud, all of which are easily accessible and reasonably priced in the area. In the local dialect, "tokra" or "taana" refers to the woven bamboo matting technique used to make the walls. The matting is often covered with mud or cow dung for insulation and lifespan, but in this case, it seems to have retained its natural bamboo appearance. Corrugated metal sheets, a more modern addition to traditional dwellings, have taken the place of earlier thatch roofs. This metal roofing is more resilient and offers better rain protection than organic materials.

ii. Design and Structure

The home features a two-story attic, which is typical for storage in rural locations. Especially after harvest, grain—such as rice, maize, and wheat—is usually kept on the bottom floor. The lowest storey houses the living quarters or livestock shelter.
The broad roofs and overhanging eaves of the Terai are practical architectural features that provide shade and protect the walls from heavy rain. The tiny, elevated ventilation opening at the top (Murgar) helps with air circulation and maintains a lower interior temperature, especially during the hot and muggy summer months.
The same bamboo is used to make the window shutters, which are operated by hand. These shutters provide privacy and security while letting in light and air.

iii. Cultural and Functional Relevance

The sociocultural fabric of the area is deeply embedded with this kind of structure. It represents a way of life that is closely tied to agriculture and customs. The utilisation of renewable resources and a design that naturally controls temperature and ventilation make these dwellings environmentally friendly.

The structure's simplicity also reflects the culture of community-based construction, where homes are built with traditional knowledge and group labour rather than modern architectural engineering. The bamboo structure's adaptability and resilience to mild seismic activity are essential in earthquake-prone regions like Nepal.

iv. Surrounding Environment

The abundance of palm, coconut, nut, and other subtropical plants suggests a humid environment. The layout and spacing of the house imply that it may be a part of a larger hamlet or village cluster, where homes are placed together for social interaction and protection. The house is a perfect example of traditional rural Nepali architecture. It is a well-adapted, culturally significant, and resource-efficient building that serves practical purposes while capturing the rural customs and way of life of the Terai region.

The features of the building are:

Floor height: 6’8”

Builing materials used: Bamboo strips, mud, cow dung, timber & CGI sheet

No. of storey: 2 storey with attic spaces

4.5 Data Collections

Figure 5: Field tools

4.5.1 Primary data collection

For the study and documentation of vernacular architecture, it is crucial to use accurate, simple, and contextually relevant techniques, especially in rural or traditional environments like the Terai region of Nepal. Along with the building's structural soundness, the process considers the building's sociocultural relevance and environmental performance. The three primary tools utilised in this documentation procedure were voice recorders, data loggers based on Arduino Nano, and measurement tapes. Each made a distinct contribution to depicting various aspects of the vernacular houses under investigation.

1. Use of Tape for Physical Measurements

One of the most basic yet crucial instruments utilised in the fieldwork was the measuring tape. The tape was used to determine the actual dimensions of the building, such as its height, breadth, length, door and window sizes, ceiling height, and wall thickness. Certain precise measurements are required in order to produce scaled drawings, such as sections, floor plans, and elevations. They also facilitate understanding of the building's proportions, construction logic, and spatial arrangement.

With the use of measurement tapes, researchers can create accurate manual or digital models of vernacular buildings—especially those constructed without formal blueprints—that faithfully capture the structure as it is. Since measurements allow for cross-regional comparisons of building types and offer insight into the cultural and functional uses of space, this stage forms the basis of architectural documentation.

2. Arduino Nano Dataloggers for Temperature and Humidity Monitoring

The environmental performance of the vernacular homes was assessed using data loggers built on Arduino Nanos. These tiny, programmable devices were set up to monitor three different areas both inside and outside the house and came with temperature and humidity sensors. The living room, kitchen, storage loft, and outdoor space may all be used to observe how the temperature varies during the day and in different parts of the house.

The sensors were deemed adequate for outdoor environmental monitoring due to their precision of 2°C and 5% relative humidity (RH). Researchers can better grasp how conventional building practices and materials affect indoor comfort by reading these texts. Mud-plastered bamboo walls, for instance, might stay cold during the day and warm up at night, but thatched or corrugated roofs might have a distinct effect on temperature and ventilation.

Patterns in the following areas can be seen by continually gathering this data over a ten-day period:

- Heat retention on sunny days
- Effective cooling at night
- Controlling humidity in living areas
- The significance of window placement and ventilation openings

Vernacular buildings' sustainability and climate responsiveness can be confirmed with the help of this data, which frequently shows that these homes are inherently energy-efficient even without the use of contemporary HVAC systems.

3. Voice Recorder for Inhabitant Interviews

It is impossible to ignore the human element of vernacular architecture, even though environmental and physical data offer insightful technical information. The residents of the residences were interviewed briefly using voice recorders in order to chronicle this. Personal experiences, cultural customs, construction knowledge, and everyday routines related to house use were all recorded in these interviews.Residents discussed the following topics:

- the convenience and comfort of conventional homes;
- maintenance procedures; the rationale behind design decisions;
- seasonal modifications and adjustments;
- cultural attitudes related to home materials or layouts.

Voice recorders contributed to the validity of these oral narratives by preserving their language and emotional tones. The technical details are improved by these qualitative insights, which also offer a deeper understanding of how these structures uphold the traditions and lifestyle of their people. The combination of voice recorders, Arduino Nano data loggers, and measuring tapes allowed for a thorough approach to recording vernacular constructions. The tape supplied accurate spatial data, the Arduino system introduced scientific environmental analysis, and the voice recordings contributed the invaluable cultural element.This thorough procedure ensures that, rather than merely being recorded as a tangible artefact, vernacular architecture is viewed as a dynamic, living part of community life that is based on cultural identity, climate-responsive, and demand-adaptive.

4.5.2 Case study building measurement

A comprehensive study of vernacular architecture must not only document the scale of a building but also include its orientation, surrounding environment, and response to the weather. The internal and external components of the case study building shown in the site plan were precisely measured using a measuring tape. This traditional recording method remains one of the most reliable and straightforward approaches, especially in rural or semi-urban areas where advanced surveying equipment may not be readily available.

Room arrangements, wall thicknesses, door and window sizes, floor-to-ceiling heights, and the amount of roof overhang (referred to as murgar locally) are all included in the physical measurement. These dimensions are essential for creating precise drawings that form the basis for additional analysis and architectural interpretation, such as floor plans, sections, and elevations.

i. Site Analysis and Environmental Observations

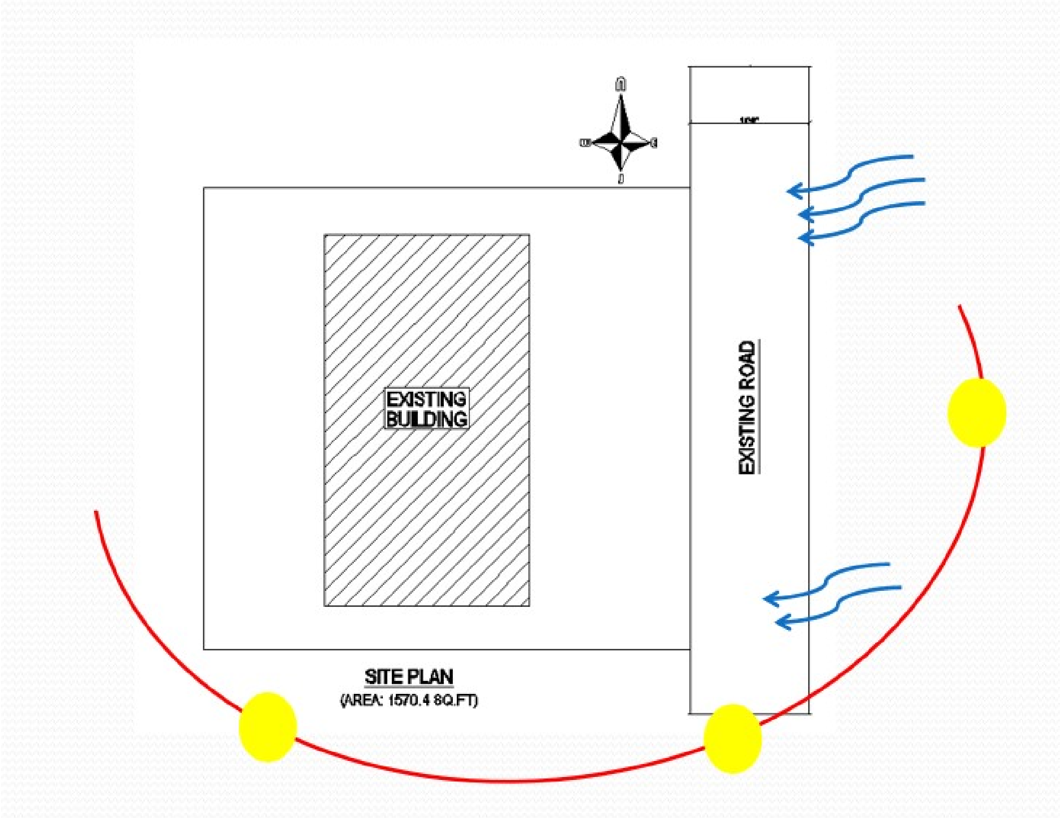


Figure 6: Site plan showing wind and solar path

The site study is equally as significant as the internal measures of the structure. According to the site plan in the picture, the current building is located in the middle of the plot, with a road paralleling its eastern side. The site is a medium-sized plot that permits freedom in moving around the construction, with a total area of roughly 1570.4 square feet.

The site study revealed an important finding: the major wind direction is primarily east to west. Particularly in the hot and humid Terai region, this natural airflow is a significant environmental component that influences the building's thermal comfort, ventilation, and liveability.

One significant discovery from the site assessment was that the predominant wind direction is mainly east to west. This natural airflow is an important environmental factor that affects the building's thermal comfort, ventilation, and liveability, especially in the hot and muggy Terai region.

The wind is coming from the east side of the road and heading west, which indicates a decent opportunity for passive cooling. In order to lower interior temperatures, lessen dependency on artificial cooling, and promote indoor air quality, traditional homes usually take advantage of the prevailing breezes. The benefits of these natural winds are, however, significantly impacted by the ventilation and direction of the building.

ii. **Roof Orientation and Projection (*Murgar*)**

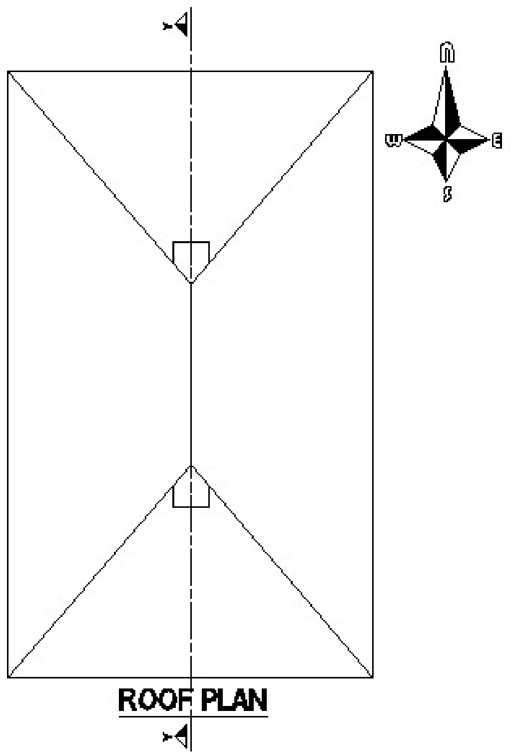


Figure 7: Roof plan

Another significant element that was brought up in the study is the orientation of the *murgar*, or roof protrusion. From north to south, the *murgar* in the case study building runs perpendicular to the wind's direction. In addition to serving as a structural roof extension, the *murgar* in conventional architecture serves a number of practical and environmental purposes, including shielding walls from rain and sunlight, diverting rainwater away from the foundation and walls, and shading openings, especially windows and doors. The thermal buffer zones are also provided.

The roof projection's north-south orientation may have been primarily intended for solar protection because the sun's path travels from east to west and is at a larger angle in the south during the summer. By tilting the murgar from north to south, the structure may reduce direct solar exposure on the east and west sides, which are longer and more susceptible to heat gain in the early morning and late afternoon.
This orientation, however, also raises the possibility that the building's design may not completely take advantage of the predominant east-west wind flow. To get the most out of passive ventilation, the building's long axis or its primary apertures (such as windows and doors) should preferably be parallel to the wind's direction.In this case, if the north and south sides have longer walls or extensive fenestrations, the east-west air may not be entering the structure efficiently unless there are strategically positioned apertures or ventilation paths.

It's possible that the murgar's north-south orientation suggests that solar protection took precedence over wind collecting. This design reasoning is common in the Terai region, where managing intense sunlight might be more crucial than catching wind, especially during the hottest summer months when hyperthermia can be severe. This roof orientation is complemented by the sturdy mud walls and covered verandas that are characteristic of vernacular buildings, creating comfortable interior temperatures.

Additionally, the site's closeness to a road on the east side might have affected the house's positioning and openings. Because roads often bring noise, dust, and unwanted visibility, homeowners choose to limit windows or principal openings on that side of the house, even at the penalty of reduced ventilation. Thus, social and cultural factors like privacy, security, and urban planning boundaries often impact the use of traditional construction elements.

iii. Ground floor

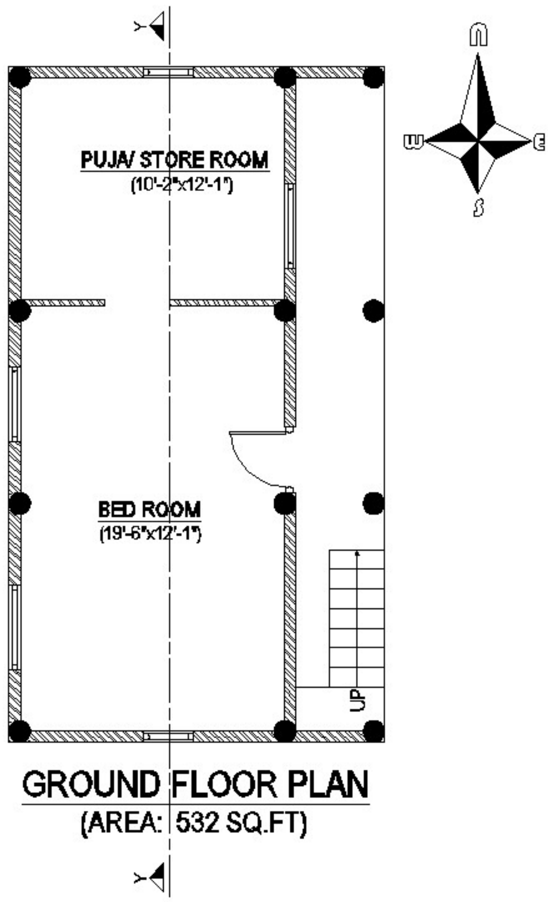


Figure 8: Ground Floor plan

The ground floor design in the submitted architectural sketch provides a compact yet well-organised arrangement with a total space of 532 square feet. A bedroom and a puja/store room are the two main spaces in the arrangement, with an adjoining stairway leading to the upper levels. The design emphasises simplicity and functionality while using key architectural elements to create a cosy home setting.

a) Overall Layout and Orientation

North is shown at the top of the drawing to highlight the orientation of the plan. The house's southeast corner serves as the entrance, and a tiny platform that leads to the interior suggests that Vaastu compliance—a prevalent practice in Indian architecture—is a priority. The interior spaces flow sequentially from public to more private regions since they are structured linearly from south to north.

b) Bedroom (19'-6" x 12'-1")

The largest of the two rooms, the bedroom takes up the southern part of the ground floor. Its approximate measurements are 19.5 by 12.1 feet, providing a roomy space of about 236 square feet. This room is probably intended to be the primary living and sleeping space, and it may include multipurpose pieces of furniture such a bed, wardrobe and chairs.

Key features:

- Natural Lighting and Ventilation: Three windows, one on the western wall and two on the southern wall, provide good sunshine and cross-ventilation, especially in the afternoon and early evening.
- Privacy: The room is perfect for leisure and relaxation because it is farther away from the entrance stairway and partially enclosed, which gives it some distance from more functional or transitional areas.

- Versatility: If the house has few upper stories, this room's size could be used as a living room or a place for family get-togethers.

Easy access to the holy area or stored necessities is indicated by the room's direct opening into the neighbouring Puja/Store room.

c) Puja/Store Room (10'-6" x 12'-1")

The Puja/Store Room is located directly north of the bedroom and is 10.5 by 12.1 feet, or around 127 square feet. As is common in Indian homes where religious rites are integrated into daily life, it is a multipurpose space meant to serve both religious and storage needs.

Key aspects:

- Positioning: The room's orientation towards the north is in line with ancient Vaastu principles, which suggest that in order to harness positive energy, Puja rooms should be placed on the northeast or northern side of the house.

- Functionality: The remaining space can be utilised to store seasonal goods, papers, or household tools, while a section of the room may be devoted to a shrine or prayer place. The space might also serve as a tiny reading or study area.
- Lighting & Airflow: The north-facing wall has two windows that let in natural light and fresh air, which is particularly crucial in a puja room to preserve spiritual purity and ventilation when burning candles or incense

The seamless transition between private and spiritual places is made possible by the seamless connection between this room and the bedroom.

d) Staircase Area

In the southeast corner of the design is a stairway that most likely goes to the terrace or first storey. The location of the stairs allows inhabitants to easily access upper floors without obstructing the flow of the main rooms. Without taking up space in the middle of the house, this corner configuration allows for vertical growth and saves space.

Important Information:

- **Accessibility:** Since the staircase is close to the entrance, it is convenient for guests or residents to get upstairs without having to go through private spaces.
- **Privacy Control:** If the bottom level is utilised as a guest or parent suite, the door that divides the bedroom from the stairs provides an extra degree of seclusion.

Design Considerations

The general design encourages comfort and efficiency:

- Linear Flow: The arrangement of the rooms makes sense from the entryway to the private areas

- Cross ventilation improves thermal comfort and lessens the need for artificial cooling by allowing air to circulate naturally via numerous apertures on all sides of the structure.

- The spacious proportions of both rooms in relation to the entire floor area prevent crowding and provide interior design flexibility.

- Compact Footprint: The ground floor's two major rooms and stairs keep it small, which makes it appropriate for tight lots or urban plots

iv. **First Floor plan**

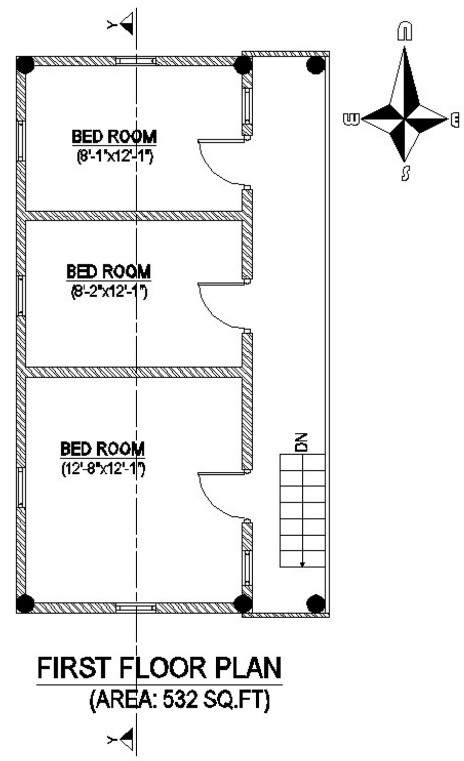


Figure 9: First Floor Plan

The first floor plan of the structure, which is 532 square feet in size and has a compact, linear layout, is shown in the architectural drawing. The residential architecture of the level is specifically designed to accommodate private sleeping chambers. The three bedrooms are arranged along the western edge of the floor plan in a single vertical row and are accessible from a common entrance or hallway on the east side. The design is economical, symmetrical, and structurally balanced, and it makes good use of the available space.

a) General Layout and Orientation

In the layout's upper-right corner, a compass rose indicates the direction of north. Access to this floor is provided via an internal staircase that leads from the ground level, which is located in the layout's bottom-right corner. A corridor or open space extends from the stairs to each of the three bedrooms, which are located along the left (west) side of the floor.

The ground floor plan and the section view complement the structural design, which incorporates load-bearing walls. A strong, framed construction system is suggested by the columns or piers that run the length of the walls and at the corners.

b) Rooms on the First Floor

1. Bedroom 1 (Southwest)

- **Dimensions**: 12’-8” x 12’-1”
- Location: Situated at the southern end of the floor plan, this room is the largest of the three.
- Functionality: Because of its larger size, it works well as the household's main sleeping room or master bedroom.
- Natural Light: There is plenty of daylight and cross-ventilation thanks to the two huge windows on the south and west-facing walls.

2. Bedroom 2 (Center)

- **Dimensions**: 8’-2” x 12’-1”

- **Location**: This room is situated just above the ground floor's centre.

Functionality: Due to its moderate size, it can be used as a guest room, children's room, or even a small home office.

Lighting: Light and ventilation are provided by a single window on the west wall.

3. Bedroom 3 (Northwest)

- **Dimensions**: 8’-1” x 12’-1”

Location: The floor's northernmost bedroom.

Functionality: Almost the same size as Bedroom 2, this room can be used as a guest room or as a bedroom for a second child.

Natural Light: Daylight and ventilation are guaranteed by the single window on the west wall.

Privacy: It might offer a little more seclusion than Bedroom 2 because of its location at the end of the hallway.

v. Sectional details of the building

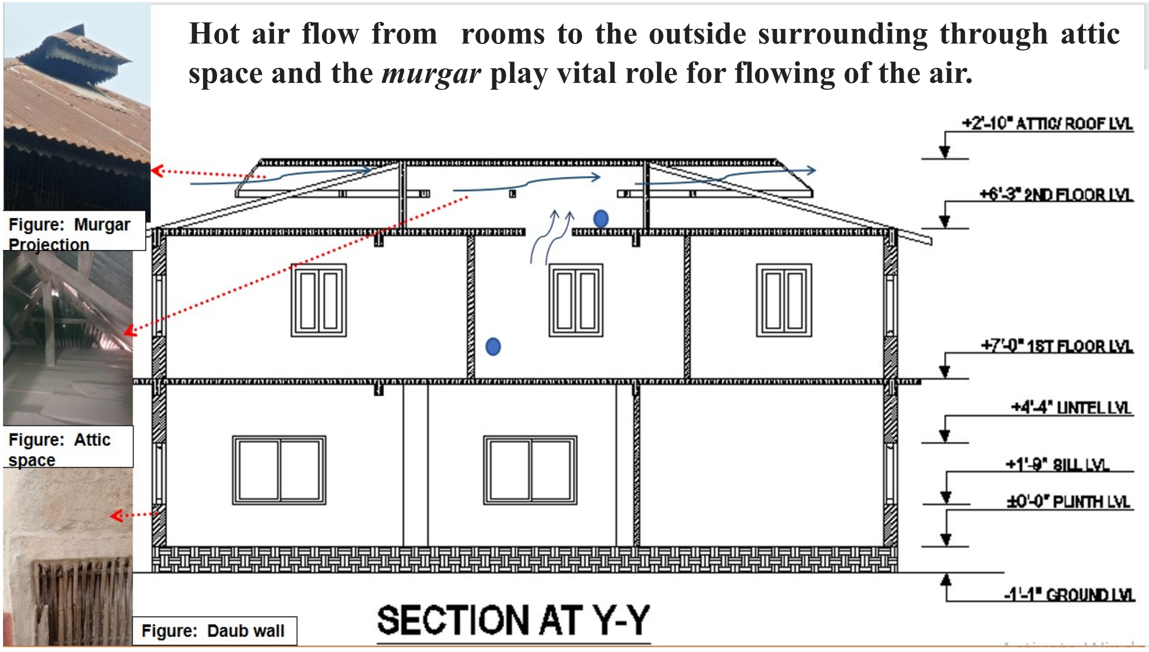


Figure 10: Sectional details of the case study building

A comprehensive vertical cut-through of a typical residential building with wattle and daub walls, timber board floors and CGI sheet roofing is shown in the "SECTION AT Y-Y" sectional drawing. This building approach represents cost-effective, ecologically friendly, and locally created architectural approaches, and it has significant roots in local and cultural contexts. While carefully examining the different levels, components, and materials used in the section, this comprehensive explanation aims to explore the construction systems and their relationship to climate, culture, and sustainability.

1. Ground Level and Foundation

The building's ground level is marked as -1'-1", directly beneath the plinth. In order to compensate for uneven terrain or to protect against moisture, a shallow excavation level was likely developed. This is characteristic of vernacular buildings, where natural slope and drainage are meticulously managed.

The plinth level is located at ±0'-0" and serves as the structural base for the walls. It has a traditional herringbone or checkered pattern and appears to be made of brick or stone. This plinth provides essential termite and ground moisture protection for buildings using organic wall materials like wattle and daub.

2. Wattle and Daub Wall System

From the plinth level above, the primary structural walls are composed of wattle and daub, a traditional building technique frequently used in tropical and subtropical countries. This method involves applying a mixture of clay, straw, soil, and occasionally animal manure (daub) to a lattice of woven wooden strips (wattle).

Principal Benefits:

a. Excellent for hot regions, thermal insulation keeps interiors cool.

b. Breathability: By facilitating the exchange of moisture, walls lessen humidity.

c. Low embodied energy: Biodegradable and locally sourced materials are used.

d. Repairability: Without sophisticated tools, patching or re-coating is simple.

In keeping with wattle and daub construction, which necessitates significant thickness for stability, the portion has thick vertical walls on both floors. The smooth finish of the walls indicates that both the interior and exterior have been plastered with mud or lime.

3. Openings – Sill, Lintel, and Window Placement

The section includes details such as:

Sill level at +1’-9”

Lintel level at +4’-4”

4. First Floor Level and Timber Plank Flooring

These levels are typical for window installations and provide suitable viewing and ventilation heights. Both ground and first story views may show the double-shutter casement windows, which are probably framed in wood. They offer:

- Cross-ventilation, which is crucial in hot or muggy conditions.

- Reducing reliance on artificial lighting with daylighting and preserving the classic visual appeal

The lintels are most likely constructed of wood, which is consistent with vernacular customs. The wood would be hardwood that is readily available in the area and is impervious to rot and insects.

The first-floor level is defined at +7'-0". Timber planks supported by timber beams make up the flooring system between the ground and ground floors, which is a traditional building technique.

Details of Timber Plank Flooring:

- Joists or beams span between load-bearing walls.
- Planks are laid perpendicular over these beams.
- Nailed or pegged connections ensure stability.

This system offers:

- **Flexibility** in construction without the need for heavy machinery.
- **Thermal buffering**, preventing heat conduction between levels.
- **Ease of maintenance**, as damaged planks can be replaced.

The ceiling of the ground floor is often left exposed, revealing the timber planks, which also enhances the aesthetic quality.

5. First Floor Layout

The related floor plans show that the first level has three bedrooms arranged in a linear fashion. This section has three identical window openings that balance light and ventilation. The walls are still composed of wattle and daub to preserve continuity in breathability and insulation.

The transition from ground level to the first floor is supported by vertical supports inserted into the walls or plinth, which efficiently transfers weight. The timber construction is often secured with traditional joinery, including mortise and tenon, wooden pegs, and lap joints.

6. Second Floor Attic Space

A secondary floor slab at +6'-3" is located directly below the roof pitch, above the first-level ceiling. This level, which is supported by intermediate rafters, probably contains a ventilated loft or an attic storage area. Although the attic level (+2'-10") is uninhabitable, it has vital purposes:

- The living area below is shielded from radiant heat by the heat buffer zone.
- Through tiny openings beneath the roof eaves, ventilation enables heated air to escape.
- Storage: A place to store non-perishable household goods.

The attic space is enclosed partially with vertical supports and horizontal trusses connecting the rafters.

7. Roof System – CGI Sheet Roofing

Covered in sheets of Corrugated Galvanized Iron (CGI), the roof structure is a pitched gable roof that slopes in two directions. This roofing material is frequently used in vernacular improvements and provides an excellent defence against rain and strong sunlight.

CGI Roofing Features:

- Durability: Resistant to corrosion, lasts for decades with minimal upkeep.
- Lightweight: Reduces the structural load on timber frames.
- Ease of installation: Requires basic tools and limited labor.
- Rainwater harvesting: Smooth surface is ideal for collection systems.

The CGI sheets are supported by a timber roof truss system, composed of:

- Rafters: Diagonal wooden members.
- Purlins: Horizontal elements that hold the CGI sheets.
- King post or tie beam: Central structural member ensuring rigidity.

Ventilation and Thermal Strategy:

- Roof overhangs provide shading to walls and windows, reducing solar gain.
- Vents beneath the ridge allow heat to escape.

Aesthetic and Cultural Significance

The building mixes in well with the surroundings thanks to the use of natural materials like wood, mud and thatch. Regional character and workmanship are reflected in the material palette, roof form, and fenestration rhythm.

This type of sectional layout is typical of:

- Tropical and subtropical rural housing
- Eco-resorts and sustainable homesteads
- Restoration projects of heritage buildings

The sectional viewpoint of this vernacular construction at Y-Y offers a helpful illustration of the coexistence of traditional building systems and functional residential architecture. The structure is a shining example of how ecological practices, local knowledge, and architectural integrity can come together to produce welcoming, eco-friendly, and culturally significant environments. It has CGI sheet roofing, timber board floors, and wattle and daub walls.

With a well-coordinated material approach and a clear hierarchy of levels from the ground and plinth to the roof attic, this building is a sturdy, economical and environmentally friendly example of rural architecture. It illustrates the enduring worth of conventional techniques in a more modern society, especially as we search for more ecologically friendly and climate-adaptive construction techniques.

4.5.3 Temperature measurement (Datalogger)

To assess the ventilation behaviour and thermal performance of the case study building, data loggers were placed in three distinct locations: the verandah, the inside of the room and the attic space. This setup enabled a detailed analysis of the temperature and humidity variations in the different vertical zones of the structure over a ten-day period. Typical indoor and semi-outdoor spaces that are affected differently by ventilation, stack-driven air movement, and solar exposure are reflected in the monitoring sites selected.

Due to its semi-exposed and frequent exposure to ambient external conditions, the verandah acts as a buffer between the inside and exterior temperatures. It is feasible to record external climate elements, including temperature and humidity fluctuations, that directly impact the interior space by placing a data logger here. It also makes it easier to understand the fundamental conditions that lead to the stack effect, especially when daytime temperatures are high.

The second data logger was installed in the room, which is the main living space in the house. Monitoring this region provides direct information on thermal retention, occupant comfort, and the effectiveness of passive design measures in reducing heat buildup. By comparing the thermal profiles of the room and the verandah, one can ascertain how well the building envelope and ventilation systems mitigate the effects of outside heat.

The third gadget was placed in the attic, a crucial location for studying the stack effect. Because hot air naturally rises, a building's attic typically has the highest temperatures. Keeping an eye on the attic's temperature and humidity levels can provide crucial information regarding heat accumulation and how well vertical ventilation works. It also indicates if the warm air is being efficiently expelled or kept, which may lead to discomfort and inefficient energy use.

The data collected over a 10-day period includes differences within the three zones, variations in humidity, and patterns of temperature increase and fall during the day. These metrics help determine the effectiveness of vernacular ventilation design elements like roof projections or vertical vents, measure discomfort hours, and analyse the heat gradient that results in the stack effect. As seen in the graphic below, this monitoring strategy directs future design improvements appropriate for hot, humid environments like Morang, Nepal, and permits an evidence-based assessment of the building's passive cooling effectiveness.

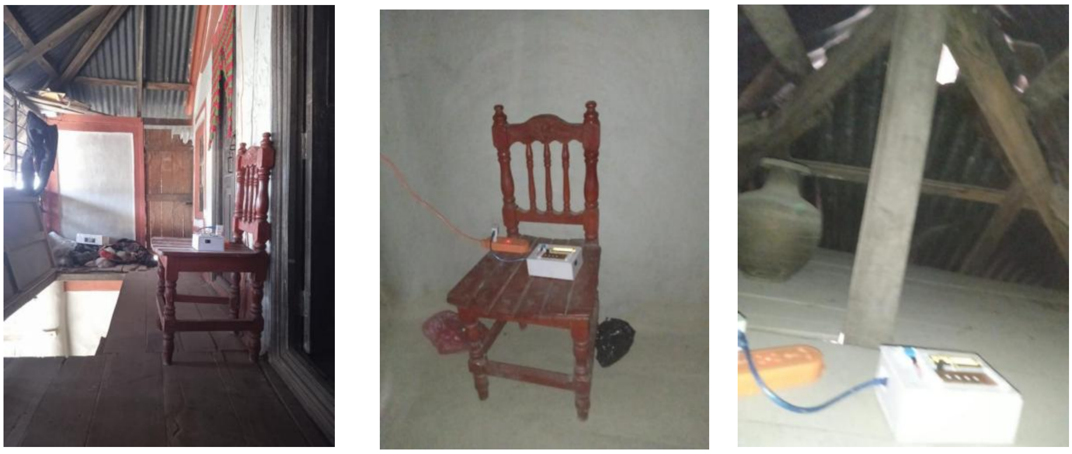


Figure 11: Datalogger placed at (a) verandaha (b) inside room (c) at attic space

After the continuous measurement of the data for 10 days, obtained datas are segregated in the basis of day time data and night time data in the excel.

i. Day time temperature data

The above graphic displays temperature and humidity data collected during the day, from 5:00 am to 5:00 pm, in January and February of 2025. The data points include temperature readings from three different zones: the attic, the interior (indoor), and the outside (outdoor), together with the corresponding humidity percentages in each zone. This dataset provides crucial insights into how temperature changes throughout the day in different parts of the building by highlighting the dynamics of heat uptake and air movement within a residential property located in a hot and humid climate.

ii. Temperature variation : External vs Internal vs Attic

The temperature outside fluctuates a lot throughout the day due to the direct effects of sun radiation. The temperature increases from 11.8°C at 5:46 am to 26.8°C by 2:42 pm on January 29 in accordance with the typical cycle of sun heating. The patterns over the next two days are similar. On January 30, for example, the temperature starts at 11.8°C at 5:46 am and peaks at 25.9°C at 2:48 pm. On February 3, the temperature starts off lower at 14.8°C at 5:03 am but quickly rises to a maximum of 27.1°C by 2:05 pm.

The temperature rises steadily throughout the day due to the intensity of solar radiation, with the highest temperatures often occurring between 1:00 and 3:00 pm.

Although slightly tempered, the interior room temperature curve is similar. For instance, the temperature on January 29 starts at 12.9°C (5:46 am) and rises to 24.1°C by 2:42 pm. On January 30, the temperature rose from 12.9°C (5:46 am) to 23.9°C (2:48 pm). On February 3, the temperature will range from 15.3°C (5:03 am) to 24.1°C (2:05 pm). These observations show how the thermal buffering capacity of the interior environment delays and slightly lessens the heat maxima outside.

		Temperature during day (5:00 am - 5 pm)						
S.N	Date	Time	Temperature (c)			Humidity (%)		
		(Day)	External	Internal	Attic space	External	Internal	Attic space
1	1/29/2025	14:42:48	26.8	24.1	31.2		67.6	
2	1/29/2025	15:43:04	26.3	23.8	30.8		64.9	
3	1/29/2025	16:43:20	24.6	22.8	28.4		67.6	
4	1/29/2025	17:43:35	23.2	21.2	27.8		73.4	
16	1/30/2025	5:46:38	11.8	12.9	14.2		83.3	
17	1/30/2025	6:46:53	12.2	12.5	14.6		83.7	
18	1/30/2025	7:47:07	12.4	12.6	14.9		84	
19	1/30/2025	8:47:22	14	13.5	16.1		82.7	
20	1/30/2025	9:47:37	15.3	14.6	16.9		79	
21	1/30/2025	10:47:52	17.6	16.6	18.8		78.1	
22	1/30/2025	11:48:07	21.3	19.5	23.6		78.7	
23	1/30/2025	12:48:23	24.3	21.8	27.9		72.7	
24	1/30/2025	13:48:38	25.6	23.3	29.8		68.5	
25	1/30/2025	14:48:54	25.9	23.9	30.4		66.6	
37	2/3/2025	5:03:09	14.8	15.3	17.4		79.1	
38	2/3/2025	6:03:25	15.1	15.6	18.3		83	
39	2/3/2025	7:03:40	16.2	15.5	19.4		82	
40	2/3/2025	8:03:55	16.8	15.9	19.8		82.2	
41	2/3/2025	9:04:11	17.9	16.6	21.2		79	
42	2/3/2025	10:04:26	20.1	18	23.4		79	
43	2/3/2025	11:04:42	22.3	19.8	25.6		76.7	
44	2/3/2025	12:04:57	24.1	21.5	27.3		73.4	
45	2/3/2025	13:05:13	25.8	23.1	28.6		70.4	
46	2/3/2025	14:05:29	27.1	24.1	31.4		66.4	

Table 4: Temperature during day

The attic area consistently records the highest temperatures of the three zones, demonstrating the concept of heat accumulation caused by the stack effect. On

January 29, the attic temperature increases from 14.2°C in the morning to 31.2°C at 2:42 pm. Similar peaks are seen on other days, such as January 30 at 30.4°C and February 3 at 31.4°C. Due to the substantial heat accumulation that supports the function of vertical air movement—in which warm air naturally rises and accumulates in upper regions—the attic is an essential space for thermal management.

iii. Comparison and Thermal Gradient

Throughout the course of the three days, the attic consistently remains 5–7°C warmer than the indoor room temperature, especially in the mid-afternoon. As an example, at 2:05 pm on February 3, the attic reaches 31.4°C, 7.3°C warmer than the interior, despite the interior and exterior temperatures being 24.1°C and 27.1°C, respectively. This vertical temperature differential fuels the stack effect, which promotes upward air movement and facilitates passive ventilation when appropriately designed.

This phenomenon is particularly important in traditional homes with ventilated attics, where cooler air is pulled via lower openings and warmer air is released to maintain thermal comfort inside the living spaces.

iv. Night time temperature data

The temperature and humidity readings from January to February 2025, obtained from a traditional residential building in Morang, Nepal, between 6:00 p.m. and 4:00 a.m., are displayed in the following table. In addition to the corresponding humidity levels in each of the three spatial zones—the attic, the interior (indoor), and the exterior (outdoor)—this information contains temperature readings for each of these zones. This data must be examined in order to understand the building's thermal behaviour at night, particularly with regard to natural cooling, passive ventilation, and occupant comfort.

v. General Nighttime Temperature Trend

In contrast to daytime settings, nighttime temperatures in all three zones exhibit a declining tendency due to the absence of solar light and the natural radiative cooling process. The temperature outside on January 29, for instance, starts at 21.2°C at 6:43 p.m. and progressively drops to 15.9°C by 11:45 p.m. and then to 12.6°C at 4:46 a.m.

the next day. A similar pattern is observed on January 30, when the temperature drops from 15.3°C at 12:45 am to 12.6°C at 4:46 am. The coolest outside readings are taken early in the morning (about 4:00 am), reflecting the cumulative cooling influence of the overnight atmosphere.Passive design night cooling strategies, which allow the interior environment to dissipate collected heat, are especially important during this time.

vi. Indoor Temperature Behaviors

The inside temperature curve is less erratic and more constant than the external temperature curve. The thermal bulk of the building materials, their limited exposure to the outside world, and their daytime heat retention all contribute to this. On January 29, the internal temperature drops by 6.6°C, from 19.8°C at 6:43 pm to 13.2°C at 4:46 am. On the other hand, the outside temperature drops by nearly 8.6°C in the same period of time. This reduced rate of internal heat loss highlights the insulating properties of the building envelope, which slow down temperature variations and increase thermal comfort.

vii. Attic Space Thermal Pattern

The thermal behaviour of the attic space is moderate. Because of the heat from the day, attic temperatures are a little higher than the interior zone in the early hours of the night. The attic space has moderate thermal behaviour. Attic temperatures are slightly higher than the interior zone in the early hours of the night due to the heat from the day. However, as the night goes on, attic temperatures begin to converge with or even sharply decline below indoor measurements due to increased exposure to roof cooling. For instance, the attic temperature is 17.1°C at 8:46 p.m. on January 29, which is marginally colder than the inside temperature of 17.8°C. At 4:46 am, the attic space drops to 13.4°C, only 0.2°C warmer than the interior.

		Temperature during night (6:00 pm - 4 pm)						
S.N	Date	Time	Temperature (c)			Humidity (%)		
		(Night)	External	Internal	Attic space	External	Internal	Attic space
5	1/29/2025	18:43:51	21.2	19.8	19.1		75.8	
6	1/29/2025	19:44:06	19.4	18.8	18.2		77.8	
7	1/29/2025	20:44:22	18.6	17.8	17.1		78.7	
8	1/29/2025	21:44:37	17.8	17	16.6		79.6	
9	1/29/2025	22:44:52	16.8	16.2	16.4		80.1	
10	1/29/2025	23:45:08	15.9	15.6	16.1		80.3	
11	1/30/2025	0:45:23	15.3	15	15.8		80.6	
12	1/30/2025	1:45:38	14.1	14.5	14.9		81.4	
13	1/30/2025	2:45:53	13.2	13.9	14.2		81.4	
14	1/30/2025	3:46:08	12.9	13.4	13.6		82.6	
15	1/30/2025	4:46:23	12.6	13.2	13.4		82.8	
26	2/2/2025	18:00:18	23.6	22.4	21.8		72.8	
27	2/2/2025	19:00:34	22.4	21.3	20.8		74.5	
28	2/2/2025	20:00:49	21.8	20.4	20.1		74.6	
29	2/2/2025	21:01:05	20.4	19.6	19.4		75.2	
30	2/2/2025	22:01:21	19.5	18.6	18.8		75.8	
31	2/2/2025	23:01:37	18.8	18.1	18.3		77.7	
32	2/3/2025	0:01:52	17.8	17.6	17.9		76.9	
33	2/3/2025	1:02:08	16.8	17	17.2		77.6	
34	2/3/2025	2:02:23	16.2	16.6	16.8		77.9	
35	2/3/2025	3:02:39	15.6	16.1	16.3		78.1	
36	2/3/2025	4:02:54	15.0	15.7	15.9		78	
50	2/3/2025	18:06:33	23.6	22.1	21.8		74	
51	2/3/2025	19:06:49	22.5	21.2	21	80.9	76.6	

Table 5: Night time temperature data of the building

This strong association shows that attics cool quickly at night and heat up significantly during the day, highlighting the significance of ventilated attic designs for efficiently controlling thermal gain and loss. Attic spaces can act as thermal buffers, helping to pull in cooler night air and expel warmer air, if they are configured with the right vents or ridge openings. This improves stack ventilation even in colder weather.

4.6 Secondary data collection

The secondary data on the site, including daily temperature, humidity, sunshine, wind flow, etc., comes from the Department of Meteorology in Dharan, Sunsari. The closest station, Biratnagar Airport, which is 12 kilometres distant, is used to collect data because Budhiganga Rural Municipality, the original site, does not have a meterological station. Excel is used to assess the temperature data collected between 2014 and 2025, as shown below. The remaining data is supplied in the annexe.

		Yearly maximum and minimum temperature of Biratnagar (2014-2024)											
Year		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2014	Tmax (oc)	28.5	27	37.5	39.6	39	37.8	36.1	36	35.5	35.4	34	29
	Tmin (oc)	16	19	26.2	30.5	26	29	30.2	27.8	27	26.3	26.2	19
2015	Tmax (oc)	28.5	31.6	35	36.5	36.6	37	37.6	35.6	36	34.5	31.5	28.5
	Tmin (oc)	17.5	24	25.8	26.6	31	28.6	30.3	27.4	28.4	29.2	27.5	18.7
2016	Tmax (oc)	26.8	31.7	35	40.5	36.8	36.4	35	38.8	33.5	35.2	32	30.2
	Tmin (oc)	14	24.5	28.5	28	28.8	26.3	27.8	30.7	26.1	26.8	28	19.3
2017	Tmax (oc)	28.2	30.8	32.8	38.4	36.8	36.9	38.5	37.5	37.3	35.9	32.2	30
	Tmin (oc)	16.9	22	26.6	25.9	29.3	28	29.2	27.7	30.3	27.6	25.8	21
2018	Tmax (oc)	24.4	29	34.8	35.5	35	37.8	38	37.4	35.3	34.9	32.8	30.7
	Tmin (oc)	13.9	22	26.6	27.7	29.4	29	27.4	30.3	29.2	27.8	24	18.5
2019	Tmax (oc)	28.1	29.7	33.9	36.1	36.8	38	38.5	38.5	36.4	35.9	33.8	29.6
	Tmin (oc)	18.3	19.1	24.9	27	27.2	28.2	28.5	29.2	26.1	27.8	25.4	18.3
2020	Tmax (oc)	26	29.7	34.5	35.8	37	36.6	36	38.5	36.5	35.4	32.8	27.9
	Tmin (oc)	14.1	18.6	22.5	26.5	26.7	26.3	28.3	28.3	27.4	27.3	25.5	18.5
2021	Tmax (oc)	27.4	30	35.8	38.2	36.7	35.5	34.8	35.6	35.5	35.2	32.2	29.4
	Tmin (oc)	12.8	22.7	27.2	27.1	25.7	26.7	26.8	28.2	28.5	23.8	20.6	16.2
2022	Tmax (oc)	27.4	31.7	35	39.9	40.5	39.3	38.5	38	37.3	36	33.6	30.7
	Tmin (oc)	14.3	17	21.5	25.9	27.8	28.6	28.5	28	26.7	24.5	21.2	17.6
2023	Tmax (oc)	28.3	29.6	33.9	38.6	40.3	41.5	36.1	36.5	35.9	32.5	32.4	28.4
	Tmin (oc)	12.9	22.2	22.7	28.8	27.8	28.2	28	28.4	25.3	28.2	26.5	20
2024	Tmax (oc)	25.7	28.2	35.2	40.2	38.7	35.8	37.4	36.1	37.2	33.4	32.1	28.6
	Tmin (oc)	12.7	21	20.7	32.5	26.9	26.4	26.4	29.8	23.8	29.5	26.1	19.6
Mean	Tmax (oc)	27.2	29.9	38.1	38.1	37.5	37.5	37.0	37.1	36.0	34.9	32.7	29.4
	Tmin (oc)	14.9	21.1	24.8	24.8	27.9	27.8	28.3	28.7	27.2	27.2	25.2	18.8
Taverage		21.0	25.5	31.5	31.5	32.7	32.6	32.6	32.9	31.6	31.1	28.9	24.1

Table 6: DHM data, Dharan

A comprehensive dataset displaying the monthly temperature extremes—both Tmax (maximum temperature) and Tmin (minimum temperature)—for Biratnagar, Nepal, spanning an 11-year period from 2014 to 2024 is presented in the provided image, "Yearly Maximum and Minimum Temperature of Biratnagar (2014–2024)". A Taverage row, which appears to represent long-term monthly averages across the dataset, and the mean Tmax and Tmin for each month are also included at the bottom of the table.

Understanding Biratnagar's environmental and human comfort conditions requires knowledge of its long-term temperature trends, patterns, seasonal variability, and possible anomalies, all of which are shown by this thorough temperature record.

i. Contextual Background: Climate of Biratnagar

Biratnagar is situated in the humid subtropical Terai area of southeast Nepal. It has warm winters, scorching summers, and a heavy monsoon season. Effective urban planning, agricultural, health, and thermal comfort strategies all depend on an understanding of the temperature extremes in these areas.

ii. Overview of the Dataset

The table is divided into:

- Yearly Tmax (maximum temperature) and Tmin (minimum temperature) for each month from January to December, across 2014 to 2024.
- Mean values of Tmax and Tmin at the bottom represent the monthly averages over 11 years.
- Taverage row likely represents the overall long-term climatological averages for each month.

Monthly Temperature Trends

January to March – Winter to Early Spring

- January is the coldest month on average, with mean Tmin of 14.9°C and mean Tmax of 27.2°C.
- Tmin values show notable variation, dropping as low as 12.7°C in 2023, and 13.2°C in 2022, signaling cold spells.
- From February to March, there's a consistent rise in both Tmin and Tmax, transitioning the climate toward spring conditions.

April to June – Pre-Monsoon (Hottest Season)

These months represent the hottest period of the year.

- April and May are particularly warm, with mean Tmax values of 38.1°C and 38.1°C, respectively.
- May 2016 recorded one of the highest temperatures at 39.9°C.
- Tmin also rises sharply, reaching close to 30°C in June, contributing to heat stress and thermal discomfort, especially during the night.

July to September – Monsoon Season

Despite high humidity and rainfall, temperatures remain elevated.

- Tmax values drop slightly due to cloud cover: mean values of 37.5°C (July), 32.6°C (August), and 32.9°C (September).

- Tmin values remain very high: above 27°C, contributing to hot and humid nights that affect sleep and overall comfort.
- The diurnal range (difference between Tmax and Tmin) is narrowest during these months, indicating less daytime cooling, typical of monsoon conditions.

October to December – Post-Monsoon to Winter Transition

A noticeable cooling trend begins in October.

- Tmax drops from 35.5°C in September to 29.9°C in December, while Tmin declines steadily to about 18.1°C in December.
- November and December are relatively pleasant but can bring chilly mornings.

Inter-Annual Variability and Anomalies

Extreme Heat Events

- 2016 and 2015 show particularly high Tmax values in April and May, exceeding 39°C, suggesting heatwaves.
- 2018 and 2019 had consistently high pre-monsoon Tmax values, possibly indicating gradual warming trends.

Colder Winters

- In contrast, 2022 and 2023 saw particularly cold Januarys, with Tmin values of 13.2°C and 12.7°C, respectively.
- 2020 had the lowest December Tmin at 16.2°C, pointing to an unusually cold end to the year.

Moderation in Recent Years

- The years 2023 and 2024 show a slight reduction in Tmax, particularly in April and May.
- This could either indicate year-to-year variability or the effects of local climate moderation possibly from increased greenery, changes in land use, or weather anomalies.

Mean Monthly Temperatures (2014–2024 Averages)

- **Tmax Mean Values:**

Peak in April and May (38.1°C).

Lowest in January (27.2°C).

Remain relatively stable around 32–36°C through the monsoon and post-monsoon months.

- **Tmin Mean Values:**

Highest in July and August (28.4°C and 28.3°C).

Lowest in January (14.9°C) and December (18.1°C).

Show a smooth gradient aligning well with seasonal transitions.

- **Taverage Row:**

Reinforces the same trends with average values such as:

January (21.0°C),

May (32.7°C) – the hottest average month,

December (21.4°C) – cool but not extremely cold.

4.7 Bioclimatic charts

Bioclimatic chart is prepared from the obtained data in the following procedure in order to find out the comfort band of the site for winter and summer season.

1. Find the neutrality temperature for both, $T_n = 17.8 + 0.31 \times T_{av}$°c

January

Tn=17.8 + 0.31 x 21

Tn = 17.8 + 6.51

Tn = 24.3oc

Then limits of comfort,

TL= 24.3-2.5 = 21.8oc

TU= 24.3 + 2.5 = 26.8oc

Mark these on the 50% RH curve.

August

Tn=17.8 + 0.31 x 32.6

Tn = 17.8 + 10.106

Tn = 28oc

Then limits of comfort,

TL= 28-2.5 = 25.5oc

TU= 28+ 2.5 = 30.5oc

2. Construct the corresponding sloping SET(Standard Effective Temperature) lines by determining the X axis intercept from

T = TL +0.023 * (TL 14) * AH50 By marking these limits on 50% RH curve

January

AHL= 6.8g/kg

AHU= 9.2g/kg

T1= TL + 0.23 x (TL-14) X AH50

T1= 21.8 + 0.023 x (21.8-14) x 6.8

T1= 21.8 + 1.21992

T1= 23oc

T2=TU + 0.023 X (TU-14) X AH50

T2= 26.8 + 0.023 X (26.8-14) X 9.2

T2= 29.5^{o}c

August

T1= TL + 0.23 x (TL-14) X AH50

T1= 25.5 + 0.023 x (25.5-14) x 6.8

T1= 25.5 + 1.7986

T1=27.3^{o}c

T2=TU + 0.023 X (TU-14) X AH50

T2= 30.5 + 0.023 X (30.5-14) X 9.2

T2= 34^{o}c

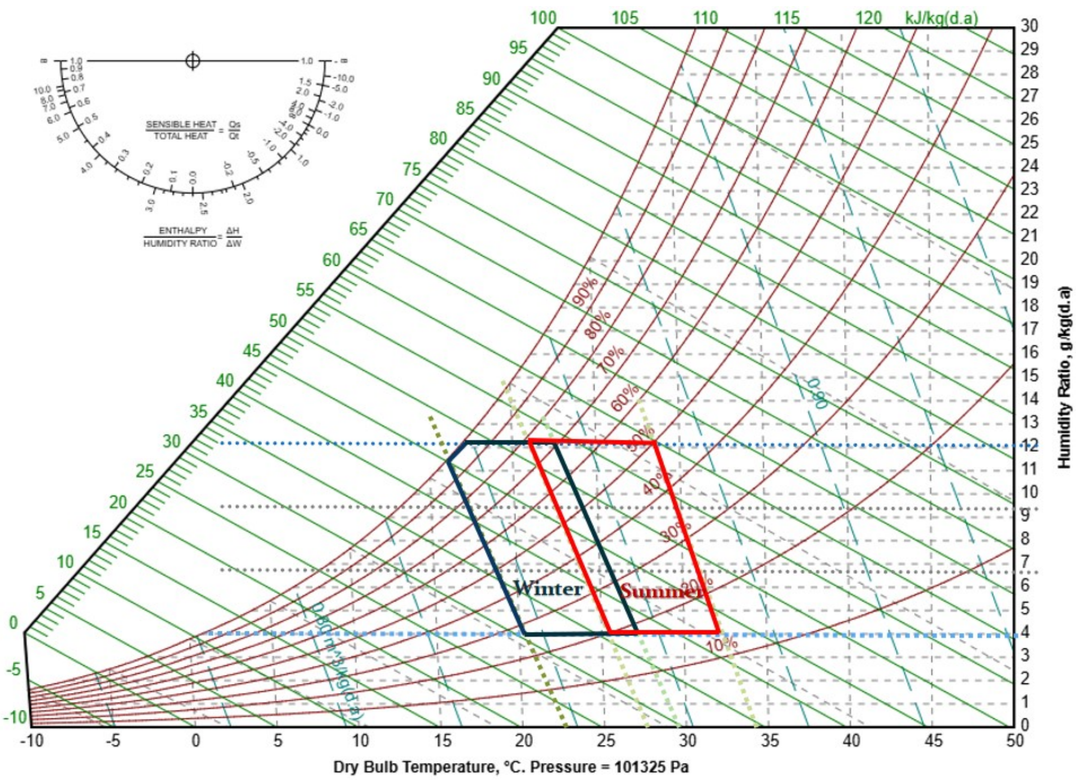


Figure 12: Psychometric chart of Biratnagar

Now the values are plotted in the psychrometry chart as shown in the below:

Thus, the comfort band for the case study site is obtained as:

Winter comfort band: (23-29.5)^{o}c

Summer comfort band: (27.3-34)°c

4.8 Temperature Validation

The data and graph presented here compare daily outdoor temperatures over a 10-day period from two different sources: the Department of Hydrology and Meteorology (DHM) and site-specific observations. As shown below, the data is verified by contrasting secondary data from the Department of Meteorology, Dharan, Sunsari, with the primary temperature data gathered at the location. These are the data for the same month, February 2025, from both the site and the DHM. This temperature validation effort is critical to the quality and reliability of localised climate data, which can significantly influence design decisions, especially in bioclimatic architecture and urban planning.

The dataset includes three key columns:

- **Date**: From January 30, 2025, to February 9, 2025.
- **DHM Temperature (°C)**: Official recorded temperature values.
- **Site Temperature (°C)**: Localized temperature measurements taken directly at the specific study site.
- **Temperature Difference (°C)**: The difference between the site measurement and the DHM data (Site temp - DHM temp).

Graphical Analysis

The line graph titled "Outdoor daily temperature comparison, February" plots both DHM and site temperatures across the same date range. The two curves indicate:

- **Blue Line (DHM temp)**: Official temperature data.
- **Orange Line (Site temp)**: Actual measurements at the specific site.

Key Observations from the Graph

General Trend:

- Both temperature lines follow a broadly similar trend over time, suggesting that both data sources are generally consistent with each other.

● However, the orange line (Site temp) is noticeably higher and plotted against a higher range (40–55°C) — likely due to a graphing scale error (more on that below).

Scale Inconsistency:

● The site temperatures in the graph appear exaggerated due to the y-axis maxing out at 60°C, even though actual site temps are only between 22.8°C and 26.3°C.

● This scale mismatch visually misrepresents the data and should be corrected for accurate interpretation.

Most Aligned Date:

● On 2/7/2025, both DHM and site temperatures are identical (23.1°C), validating the calibration of instruments or data alignment for that day.

Largest Temperature Difference:

● Occurs on **2/4/2025**, where DHM recorded 25.5°C and the site recorded only 23.9°C — a **1.6°C difference**. This may be due to microclimatic influences, sensor placement, or local obstructions.

After analysing the temperature difference between the provided data and the graph, we can conclude that the temperature obtained from the nano dataloggr is roughly the same, with an error of about 6%. The small variations are caused by the microclimatic variables that are present there.

Table 7: Temperature comaparision

OUTDOOR DAILY TEMPERATURE COMPARISON (^{O}C)				
DATE	**DHM temp.**	**Site temp.**	**Temp. difference**	
1/30/2025	24.2	24.3	-0.1	
1/31/2025	22.6	23.1	-0.5	

2/1/2025	24.3	25.6	-1.3	
2/2/2025	24.5	24.9	-0.4	
2/3/2025	24.6	24.1	0.5	
2/4/2025	25.5	23.9	1.6	
2/5/2025	26.5	26.3	0.2	
2/6/2025	25.2	26.1	-0.9	
2/7/2025	23.1	23.1	0	
2/8/2025	24	22.8	1.2	
2/9/2025	25.5	24.6	0.9	

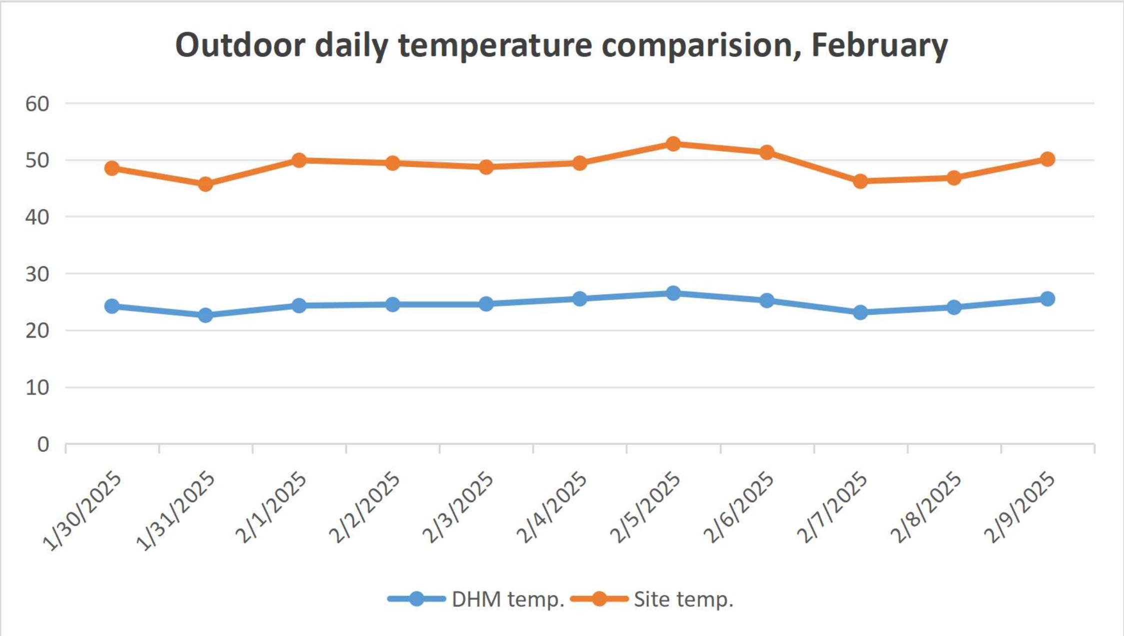


Figure 13: Graph showing temperature comparisions

CHAPTER 5: FINDING AND DISCUSSION

5.1 Temperature analysis

The survey's temperature data is compared across indoor, outdoor, and attic temperatures and examined using the bar graph below.

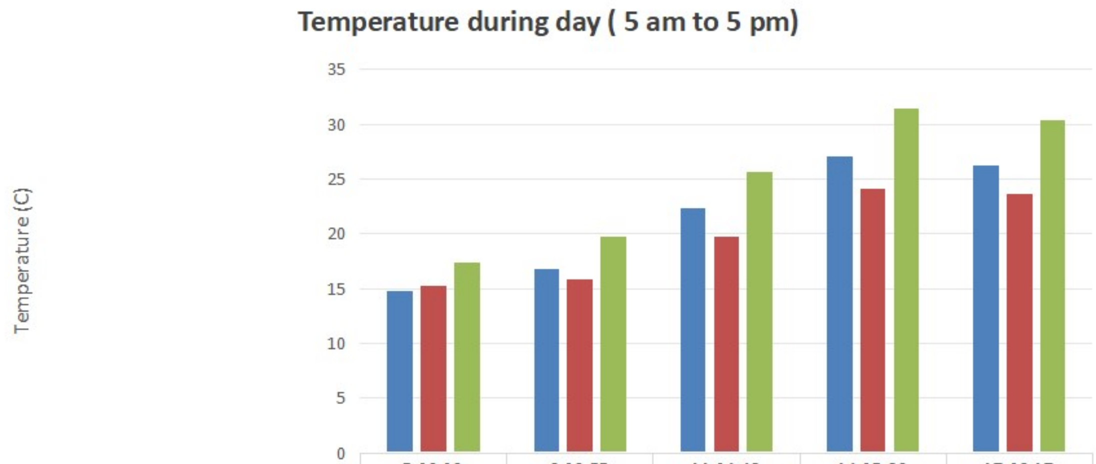
5.1.1 Day time temperature analysis

		Temperature during day (5:00 am - 5 pm)			
S.N	Date	Time	Temperature (c)		
		(Day)	External	Internal	Attic space
37	2/3/2025	5:03:09	14.8	15.3	17.4
40	2/3/2025	8:03:55	16.8	15.9	19.8
43	2/3/2025	11:04:42	22.3	19.8	25.6
46	2/3/2025	14:05:29	27.1	24.1	31.4
49	2/3/2025	17:06:17	26.3	23.7	30.4

Table 8: Temperature during day

The data in the table and bar chart clearly illustrate the temperature variation in three different zones of a residential building—exterior (outside), interior (indoor), and attic space—during the course of the day (from 5:00 AM to 5:00 PM) on February 3, 2025. In the context of passive approaches and building design in climates similar to Morang's, this research is essential for understanding the dynamics of thermal behaviour within the structure, particularly for occupant comfort and energy efficiency.

At 5:03 AM, the outside temperature is recorded at 14.8°C, which is relatively low and indicative of heat loss over the night. The temperature inside is currently 15.3°C, which is somewhat warmer than the outdoor temperature. The building envelope is still partially heated from the previous day, according to this. Of the three, the attic region has the highest temperature (17.4°C). This is significant because it suggests that, maybe as a result of less ventilation and heat gain from the previous day, the attic space—the uppermost and enclosed part of the building—effectively holds heat during the night.



	5:03:09	8:03:55	11:04:42	14:05:29	17:06:17
Temperature (c) External	14.8	16.8	22.3	27.1	26.3
Temperature (c) Internal	15.3	15.9	19.8	24.1	23.7
Temperature (c) Attic space	17.4	19.8	25.6	31.4	30.4

Figure 14: Bargraph showing temperature comparison

By 8:03 AM, the outside temperature has slightly increased to 16.8°C, while the internal temperature has reached 15.9°C and the attic space has reached 19.8°C. In this time window, the early warming part of the day is represented. The slower rise in inside temperatures when compared to outdoor settings is evidence of the building materials' good thermal inertia, which aids in controlling internal temperatures. At around 20°C, the attic remains the warmest space, which could mean that there is insufficient ventilation there, which is allowing heat to build up, or that early in the day, sunlight is beginning to penetrate the roof.

By 11:04 AM, the increase becomes more apparent. The temperature inside climbs to 19.8°C, the outside temperature reaches 22.3°C, and the attic temperature dramatically jumps to 25.6°C. Because of the high levels of solar radiation at this time of day and the heat acquisition from the sun, the attic's temperature is currently more than 6°C higher than the interior area. This implies that the attic may be acting as a heat trap by absorbing solar radiation through the roof surface. The building structure continues to moderate the internal temperature, even if it is beginning to reflect the upward thermal trend.

The outdoor temperature reaches the day high of 27.1°C at 2:05 PM. The inside chamber warms to 24.1°C, while the attic reaches 31.4°C. This discovery is crucial since the attic is now 7.3°C warmer than the inside and 4.3°C hotter than the exterior. This glaring discrepancy shows that the attic has poor thermal control and excessive amounts of solar heat gain. The building's thermal mass and insulation properties have caused a lag effect, which has caused the interior temperature to rise considerably as well, getting closer to the outside temperature while staying somewhat lower. The gradual accumulation of heat in the attic, however, may begin to impact interior comfort by radiating heat downward into living spaces if it is not sufficiently ventilated.

The outdoor temperature begins to slightly decrease to 26.3°C at 5:06 PM, while the inside temperature peaks at 23.7°C, which is marginally lower than the 2:00 PM reading. Interestingly, the attic temperature has hardly dropped from its peak at 30.4°C. This demonstrates that the attic retains heat much longer than the outside environment, which starts to cool, due to thermal lag and continuous solar exposure in the late afternoon. The interior temperature has also somewhat decreased, which could be due to internal ventilation or shading strategies, as well as less sunshine.

Therefore, we can state that the room's interior temperature is in the comfort band, which is 24.1 °C (the ASHRAE-recommended comfort range for vernacular buildings is 16 °C to 30 °C). Heat is entering the room from the outside and exiting to the attic space through cross ventilation.

5.1.2 Night time temperature analysis

The nighttime temperature analysis, which was taken on February 3rd and 4th, 2025, from 6:00 pm to 5:00 am, provides crucial details about the thermal behaviour of several spatial zones, such as the attic, interior, and external spaces. Understanding the thermal retention characteristics of a residential property and its surrounding environment requires an understanding of how buildings cool down after sunset and how heat drains over time.

		Temperature during night (6:00 pm - 5 ar			
S.N	Date	Time	Temperature (c)		
		(Night)	External	Internal	Attic spac
50	2/3/2025	18:06:33	23.6	22.1	21.8
53	2/3/2025	21:07:20	20.8	19.8	20
56	2/4/2025	0:08:07	18.3	18.9	19.3
59	2/4/2025	3:08:54	15.8	16.9	17.2
60	2/4/2025	4:09:10	15.1	16.3	16.6

Table 9: Night time temperature analysis

The accompanying table and bar graph show a consistent trend of cooling throughout the night in all three zones: the attic, interior spaces, and the outside environment. At the beginning of the observation window on February 3rd at 18:06:33, the outside temperature was recorded at 23.6°C. It is not unexpected that this temperature is the highest of the midnight observations because it occurs immediately after the daily heat accumulation. During this time, the inside temperature was 22.1°C and the attic area was 21.8°C. Heat from the outside has already started to diffuse into both areas, though not enough to create sharp contrasts, as evidenced by the little temperature difference between the interior and attic at this hour.

Around 21:07:20, the temperature began to drop more sharply. The temperature inside decreased to 19.8°C after falling to 20.8°C outside, while the attic space reached 20°C. This mild inversion, where the attic temperature was slightly higher than the interior space, is caused by the attic being exposed to leftover heat that was trapped during the day and takes longer to cool down due to the enclosed upper parts' sometimes insufficient insulation or ventilation.

At 00:08:07 on February 4th, after midnight, the cooling trend continues as the temperatures start to align. The temperature decreased to 18.3°C outside, 18.9°C indoors, and 19.3°C in the attic. It's interesting to note that the attic and interior temperatures now somewhat exceed the outside temperature. This suggests that there is a thermal lag within the house, where some midday heat is retained by the building exterior and released later. As the building's uppermost layer, the attic also holds heat for a little while longer than the outside, especially if insulation traps heat or ventilation is inadequate.

By 3:08:54 am, the temperature had dropped to 15.8°C outside, 16.9°C indoors, and 17.2°C in the attic. The attic and interior temperatures generally decrease more slowly than the outside temperature, according to these observations, which confirm earlier findings. The attic is still a little warmer than the inside, most likely due to heat accumulation from the previous day and slower dissipation at night due to structural and material constraints.

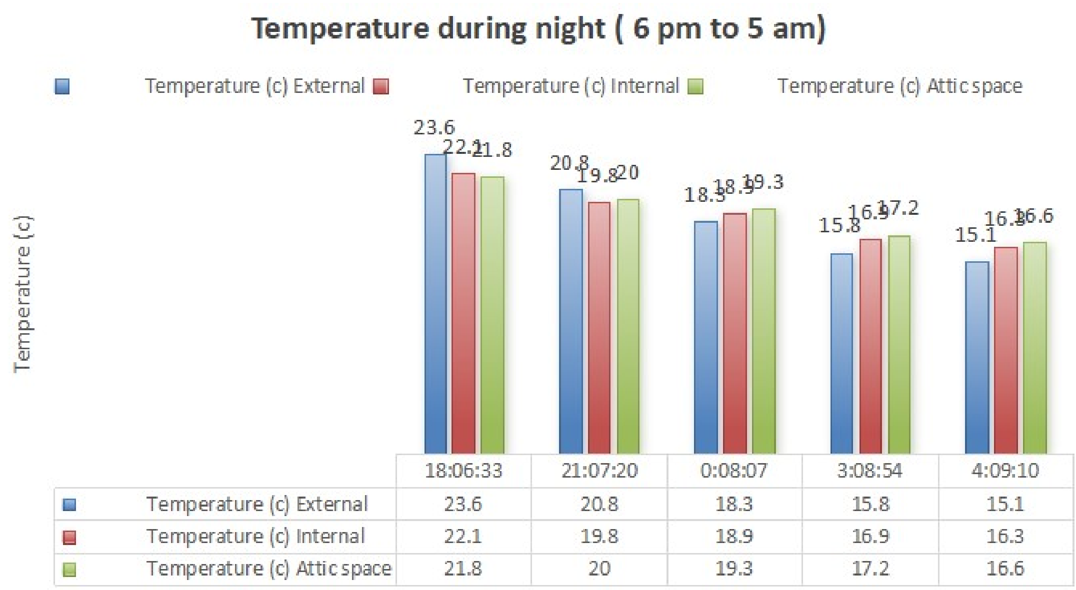


Figure 15: Night time temperature comparison

Finally, just before sunrise at 4:09:10 am, the outdoor temperature hit its lowest recorded value of 15.1°C. The attic and interior areas had respective temperature values of 16.3°C and 16.6°C. This final fact highlights the fact that the air inside the house and attic is significantly warmer than the air outside. During the coldest parts of the night, the interior and attic temperatures are continuously higher than the outside temperature, suggesting that the building is effectively retaining heat. Because it would reduce the need for additional heating, this could be helpful in the cold.

The night temperature study provides a good picture of the thermal behaviour of structures and their subspaces after sunset. The rate of heat escape and retention of a structure have a significant impact on thermal comfort at night. Attic spaces in particular become essential for understanding thermal inertia. The fact that they remain slightly warmer than the outside and even the interior spaces for the most of the night illustrates their role as a temperature buffer.

We can conclude from the analysis of the provided nighttime temperature data that the temperature within the room is greater than the temperature outside and that heat is continuously lost to the attic space through cross ventilation since the attic is hotter than the inside. Despite losing heat to the attic, the temperature inside is still within the 16.9 ^{o}C comfort zone.

5.2 Thermal analysis using software

To analyse the numerous scenarios of the different cases, Ecotect software is utilised. Before the simulation begins, zone and material management are completed first. Below are the simulation findings for three distinct situations, each with its own zone management and material management:

5.2.1 Base case

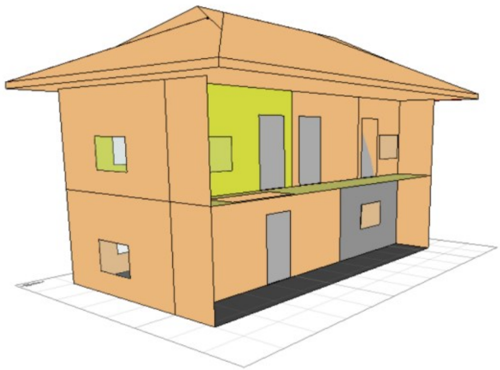


Figure 16: Base case model

In this instance, the thermal comfort band that was derived from the bioclimatic chart is used to represent the case study building in real life. The primary data is then utilized for zone and material management, as illustrated below:

- Floor height: 7’
- Stack hole size (Murgar): 6”x 6” both sides
- Roof: Heap with attic space
- Windows size: 3’10” x 2’6” (Total: 7.12 m^2)
- No. of voids between rooms and attic space: 1 in the middle room

i. Zone management

Ground floor, first floor, and roof zones are the three basic categories into which zones are separated. The specific zones' details are provided below:

a) Ground Floor Zone

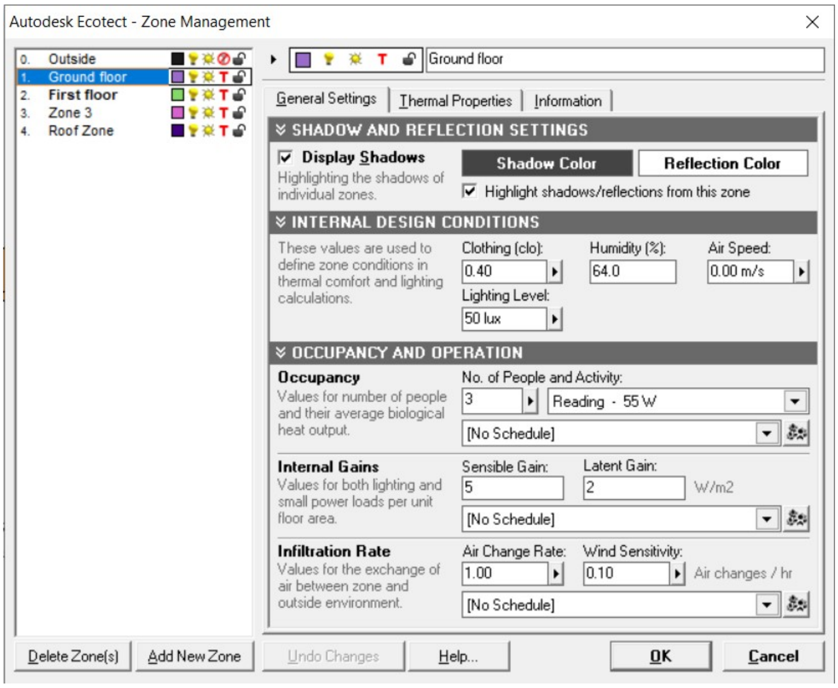


Figure 17: Zone management ground floor

Lightweight clothing suitable for temperate conditions is recommended, with a garment insulation level of 0.40 in the ground floor zone. The reported relative humidity of 64% is moderately high and could be a factor in the damp interior atmosphere. The lack of active airflow, indicated by the airspeed of 0.00 m/s, could result in temperature stagnation unless movement is aided by natural ventilation or an outside wind. This region has a small density of three persons, which could increase internal heat gain and humidity. The air change rate of one indicates that the air in the room is replaced once every hour. Even though this is a basic ventilation rate, it could not be enough when heat load is at its highest.

With a low wind sensitivity of 0.10, the zone is not very sensitive to changes in the outside wind. The appropriate temperature range in which occupants will feel thermally comfortable is indicated by the comfort band, which is 23°C to 34°C. However, there is a chance of thermal discomfort, particularly during hotter times, when there is little air movement and several inhabitants.

b) First Floor Zone

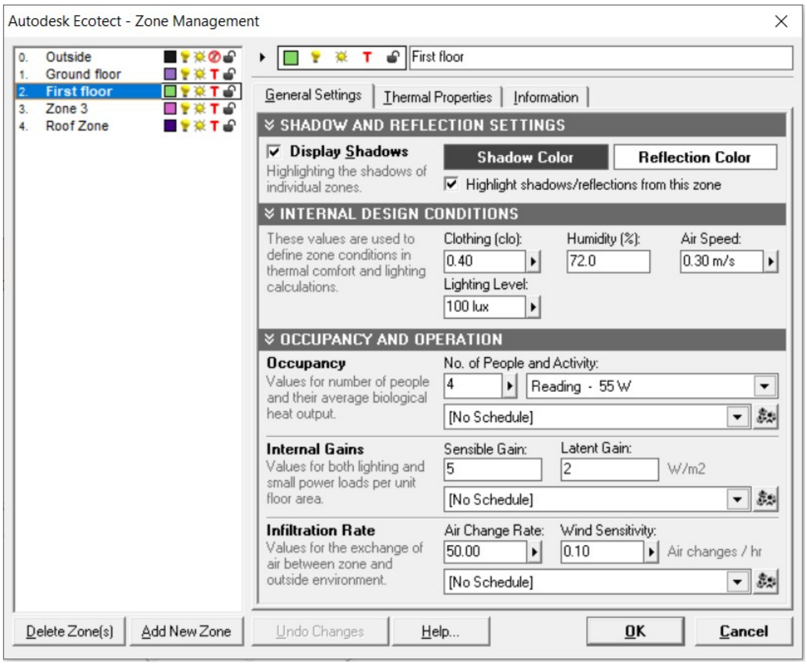


Figure 18: Zone management First floor

The first floor zone has a different microclimate than the bottom floor. Light clothing is appropriate for warm weather because the garment insulation is constant at 0.40. Because of its higher elevation and proximity to heat-retaining structures like the roof or attic, this zone has a higher humidity (72%). Heat might feel more intense when there is more humidity present. In contrast to the ground floor, this area has an airspeed of 0.30 m/s, which is beneficial for promoting air circulation and dissipating interior heat. The passenger density is slightly higher when there are four people, which may lead to increased thermal needs. Curiously, the air change rate is 50, which is significantly higher than the amount on the lower floor. Either a well ventilated design or mechanical intervention is indicated by the fact that the air in this zone is replenished fifty times each hour. Temperature management, humidity reduction, and air quality maintenance are all successfully achieved with such a high ventilation rate. The wind sensitivity is minimal at 0.10 once more, indicating that even with substantial air exchange, there is little passive reaction to outside air movements. The 23°C to 34°C comfort zone may be the most advantageous for active or passive ventilation systems because of its high air change rate and enhanced air speed.

c) Roof Zone

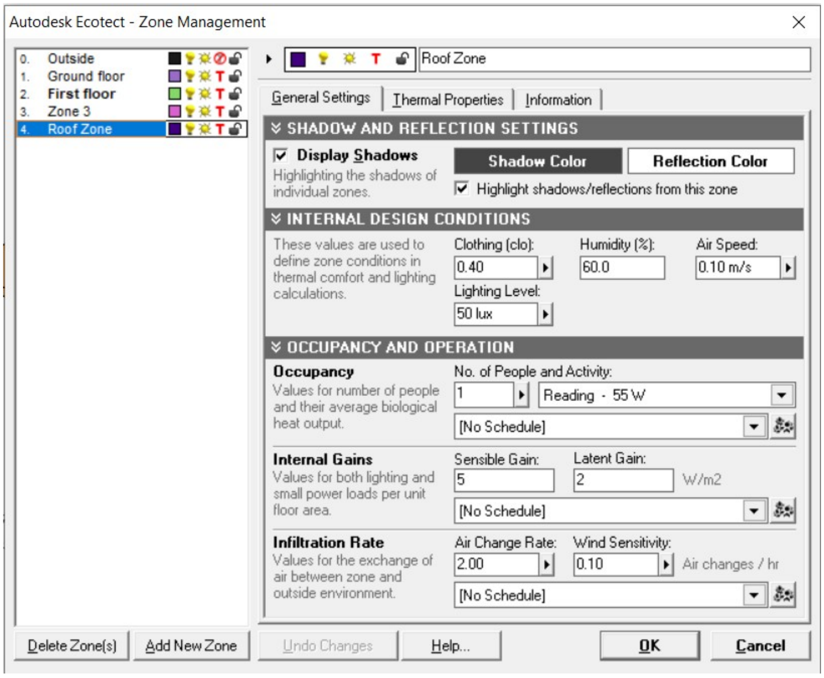


Figure 19: Zone management of Roof zone

Being the highest area of the building, the roof zone has its own micro environment. At 0.40, the garment insulation doesn't change. Due to its exposure to outside air and more direct temperature interaction with outdoor circumstances, this zone has the lowest humidity of the three at 60%. With an airspeed of 0.10 m/s, this space has a modest air movement that could have a limited cooling impact. It is higher than the ground floor but lower than the first story. Since there is only one passenger, the interior heat gain is automatically reduced. The air change rate is still a good two, however not as high as the bottom floor.Heat buildup in the attic area may be somewhat mitigated even with this limited ventilation, especially when combined with passive ventilation methods like ridge vents or stack effect mechanisms. The zone's wind sensitivity of 0.10 indicates that it is not very sensitive to natural wind flow. Like the other zones, the comfort band remains between 23°C and 34°C. However, because of its direct exposure to sunlight, the roof zone often acts as a thermal buffer and can significantly affect the indoor conditions of the floors below if there is insufficient ventilation.

ii. Material management

The properties of different materials used in the base model are described and shown in the figure below:

a) Wall

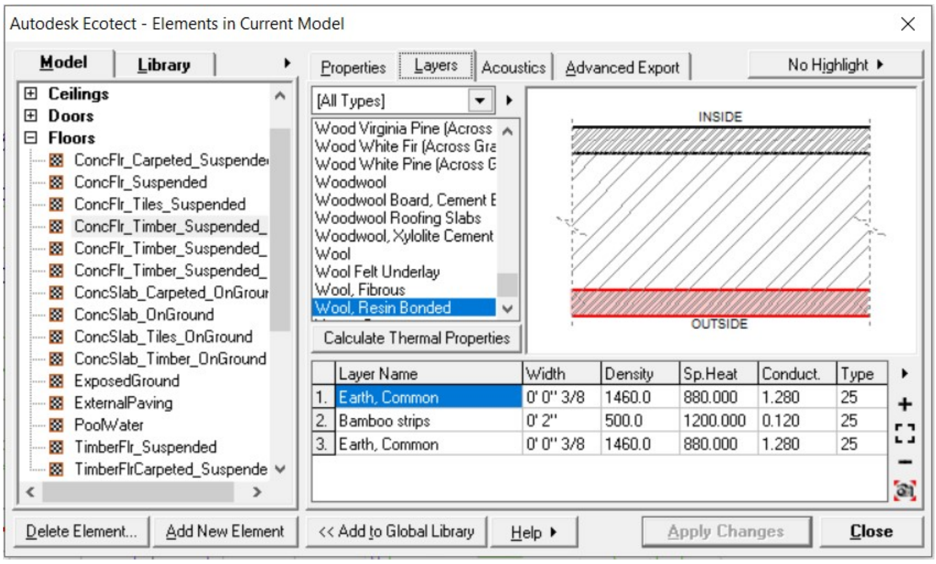


Figure 20: Material management of wall

The wall construction includes the following layers:

Earth, Common

This layer, which is 0'3/8" (around 10 mm) thick and has a density of 1460 kg/m³, appears three times in the structure. It has an 880 J/kg·K specific heat capacity and a thermal conductivity of 1.280 W/m·K. This layer's recurrence suggests that it adds thermal mass to the wall, which helps to stabilise interior temperatures by absorbing and releasing heat gradually.

Bamboo Strips

This layer provides an environmentally friendly and sustainable building choice because it is situated between the ground layers. Bamboo is noted for its strength, light weight, and thermal efficiency. It is 800 kg/m³ in density, 1320 J/kg·K in specific heat, 0.160 W/m·K in relatively poor thermal conductivity, and 0'3/8" thick. As a result, bamboo is a good insulator and a helpful element in lowering heat transmission through walls.

Wool, Resin Bonded

This insulating substance is used closer to the internal wall surface, inside the wall cavity, as the diagram illustrates. Superior thermal and acoustic insulation is provided by wool, while resin bonding strengthens the material's structural integrity. Because it reduces heat gain or loss through the wall, it helps the building be more energy efficient.

b) Floor

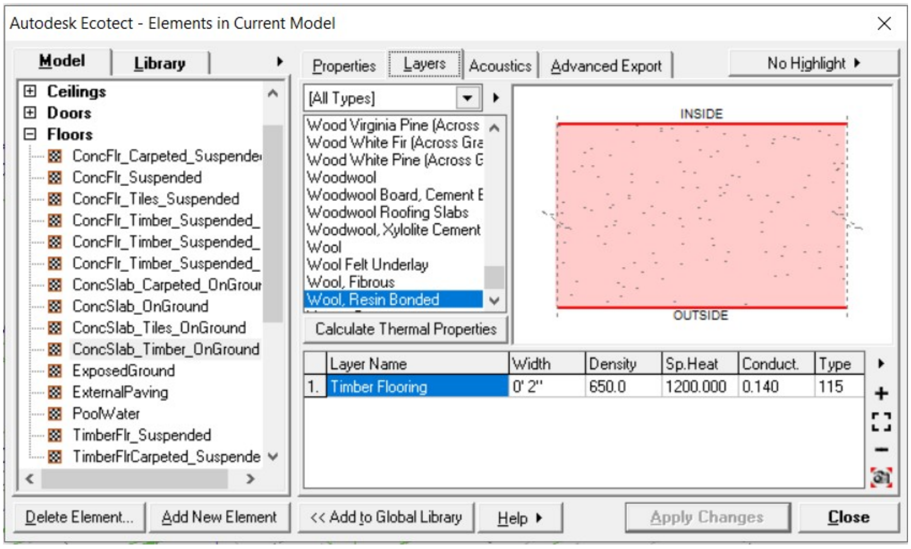


Figure 21: Material management of Floor

The interface states that a single layer of timber, 0.7 inches (about 18 mm) thick, makes up the entire floor structure. It is affordable, quick to install, and suitable for a variety of indoor environments where durability and moderate insulation are required due to its straightforward design.

A density of 650 kg/m³, a specific heat capacity of 1200 J/kg·K, and a thermal conductivity of 0.140 W/m·K are the thermal characteristics of the wood utilised in this floor design. Timber performs reasonably well as an insulating material, according to these figures.It can store a large quantity of thermal energy because to its high specific heat and moderate density, which helps control indoor temperatures by gradually absorbing and releasing heat. This helps avoid abrupt temperature changes, which is especially helpful for preserving thermal comfort in interior settings.

The timber layer's thermal conductivity of 0.140 W/m·K indicates that heat conduction is relatively slow. In multi-story structures in particular, this reduces the upward or downward transfer of heat between floors. It contributes to increased energy efficiency by lowering excessive heat gain in hot seasons and undesirable heat loss in colder ones.

c) Attic space

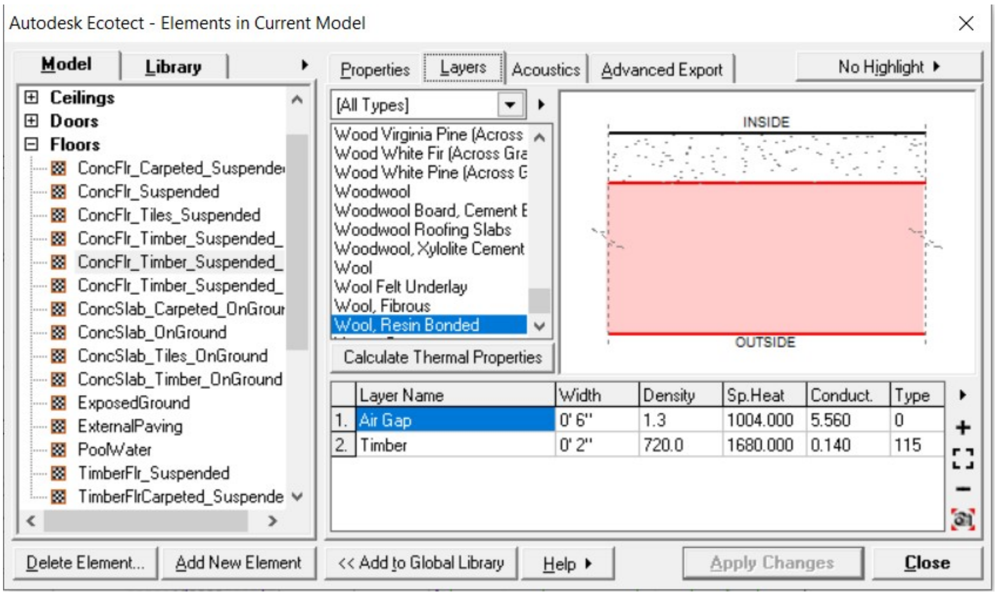


Figure 22: Material management of Attic space

The two primary parts of attic space construction are timber and an air gap, which are placed from the interior of the attic envelope to the outside. Every layer has a unique role in reducing heat transmission and enhancing the building's overall energy efficiency.

The first layer inside is called an Air Gap, and it is 0'6" (approximately 150 mm) thick. This air cavity is a crucial part of thermal insulation. Because of its extremely low thermal conductivity of 0.050 W/m·K, specific heat of 1004 J/kg·K, and density of 1.3 kg/m³, the air gap functions as a passive insulating barrier. Due to its high specific heat and low density, air can effectively delay the transfer of heat between the inner and exterior surfaces. This produces a buffer that reduces thermal gain in hotter weather and minimises heat loss in cooler weather. Building envelopes are frequently designed with an air gap, especially in attic or roof spaces where solar radiation can cause substantial heating. The second layer, which is situated on the outside, is made of timber and is 0.7" (about 18 mm) thick. Timber's specific heat is 1660 J/kg·K, its density is 720 kg/m³, and its thermal conductivity is 0.140 W/m·K. Timber is a naturally occurring insulator that offers structural strength and resistance to heat. Its high specific heat enables it to collect and retain heat energy, releasing it gradually, but its moderate conductivity prevents it from quickly transferring heat from the outside inward.This thermal lag contributes to the stability of interior temperatures.

d) Roof

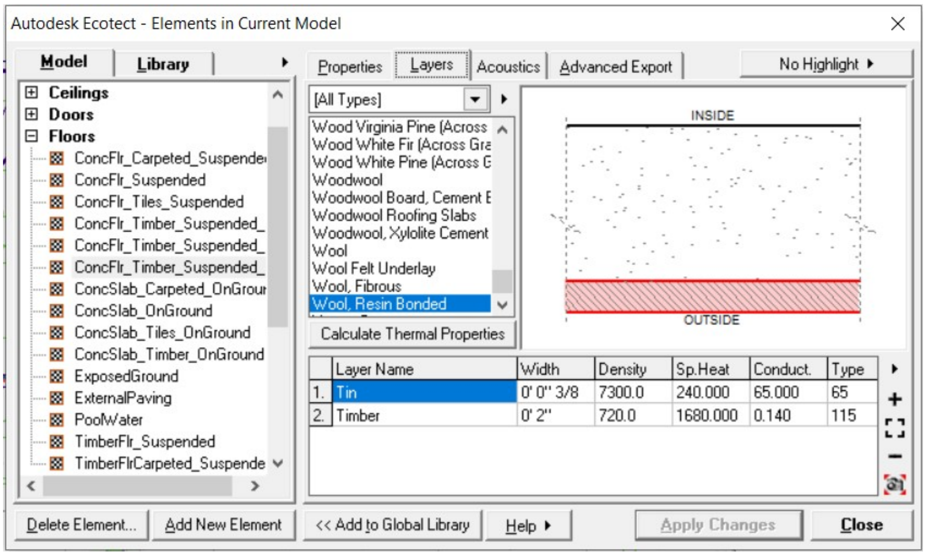


Figure 23: Material management of Roof

Tin and timber are the two main materials used to construct the roof; each was chosen for its own thermal and physical characteristics. Strength, insulation, and resistance to heat transfer are all balanced by the thoughtful arrangement of these layers.Tin, a highly conductive metal with a reputation for being lightweight and weatherproof, makes up the first layer (external side). With a high density of 7300 kg/m³, a very low specific heat capacity of 240 J/kg·K, and an exceptionally high thermal conductivity of 65 W/m·K, the tin layer in this configuration is rather thin at 0' 3/8" (about 10 mm). According to these characteristics, tin will transfer heat into the roof structure very quickly, which could result in temperature spikes inside if improperly insulated. Tin's thermal behaviour must therefore be carefully controlled even if it offers durability and resistance to climatic factors including rain, wind, and sunlight. The counterweight is made of timber, which is much thicker (0.7"; around 18 mm), with a density of 720 kg/m³, a specific heat of 1660 J/kg·K, and a thermal conductivity of 0.140 W/m·K. Timber is far more effective as an insulator than tin. Due to its poor conductivity and high specific heat, it slows down the transmission of heat from the outer surface to the interior, hence preserving indoor thermal comfort. In addition to maintaining the roof's structural integrity, timber improves its natural appearance.

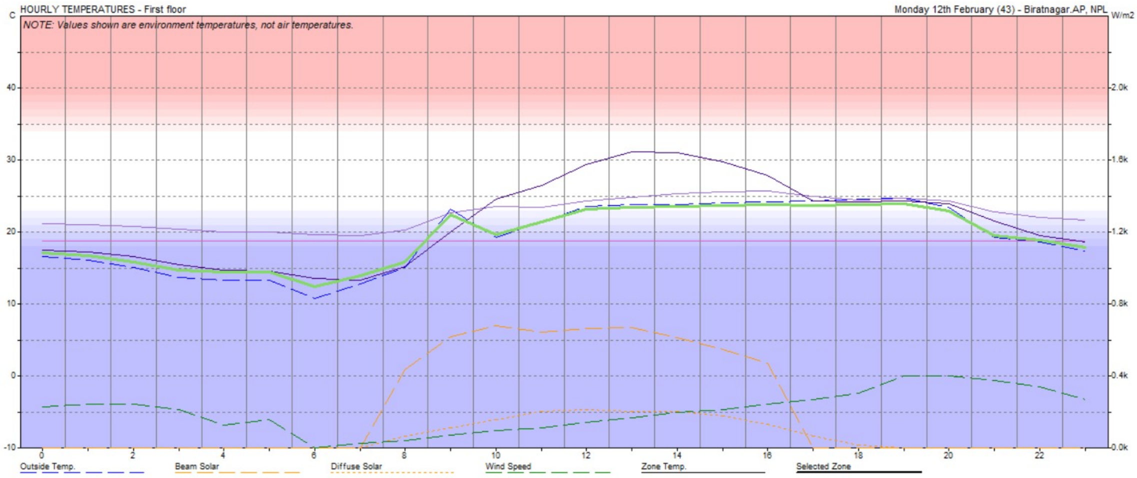


Figure 24: Hourly temperature of February

iii. Hourly temperature profile (February)

The hourly temperature profile for the first floor zone, which was taken on Monday, February 12 in Biratnagar, Nepal, may provide a comprehensive knowledge of how temperatures fluctuate within and outside the building during the day. This analysis is necessary to comprehend the thermal behaviour of the building and occupant comfort, especially in light of energy efficiency and climatic adaptability.

The graph and data table make it evident that the temperature varies significantly every day. The outside temperature is represented by the dark blue solid line, which starts at around 16.6°C at midnight and gradually decreases to its lowest point of roughly 10.8°C at 6:00 AM. The coldest time of day is right before sunrise.The first-floor interior temperature, shown in the graph by a green dashed line, also shows a decreasing trend but remains somewhat higher than the external temperature due to thermal mass and insulation. The internal temperature reaches its lowest point at 12.5°C around 6:00 AM. With an indoor-outdoor temperature differential of 1.7°C, this time of day has the biggest temperature difference (TEMP.DIF), indicating that the building envelope has a moderate insulating effect in the early morning.

As the sun rises and solar radiation increases, temperatures begin to rise both indoors and outside. The effects of beam and diffuse sun radiation become apparent at around 7:00 AM, when the outdoor temperature starts to rise more quickly. By 9:00 AM, the outside temperature increases to 23.2°C, slightly higher than the indoor temperature of 22.4°C, resulting in a negative temperature differential of -0.8°C. This trend implies that external heat gains begin to dominate the thermal dynamics of the region.

Base case			
HOURLY TEMPERATURES - Monday 12th February (4			
Zone: First floor			
Total Surface Area: 279.025 m2 (159.0% flr area).			
Total Exposed Area: 92.907 m2 (52.9% flr area).			
Total South Window: 0.890 m2 (0.5% flr area).			
Total Window Area: 4.452 m2 (2.5% flr area).			
HOUR	INSIDE	OUTSIDE	TEMP.DIF
	(C)	(C)	(C)
-----	-------	--------	---------
00	17.2	16.6	0.6
01	16.8	16.1	0.7
02	15.9	15.1	0.8
03	14.8	13.7	1.1
04	14.4	13.3	1.1
05	14.5	13.4	1.1
06	12.5	10.8	1.7
07	14	12.9	1.1
08	15.9	15.1	0.8
09	22.4	23.2	-0.8
10	19.7	19.3	0.4
11	21.4	21.5	-0.1
12	23.2	23.6	-0.4
13	23.5	23.8	-0.3
14	23.6	23.9	-0.3
15	23.8	24.1	-0.3
16	23.8	24.3	-0.5
17	23.8	24.4	-0.6
18	23.8	24.6	-0.8
19	24	24.8	-0.8
20	22.9	23.5	-0.6
21	19.5	19.3	0.2
22	18.9	18.7	0.2
23	17.9	17.4	0.5

Table 10: Hourly temperature profile, February

Between 10:00 AM and 3:00 PM, a distinct heating phase is present. Around 3:00 PM, the internal temperature peaks at 23.8°C, closely followed by the outdoor temperature peaking at about 24.6°C. The temperature differential stays somewhat negative during this period, indicating that inside temperatures are somewhat lower than exterior temperatures, maybe as a result of controlled ventilation and thermal inertia. This implies that the structure can moderate heat gains to a certain degree, postponing and reducing the indoor temperature increase.

A major contributor to this warming process is solar radiation, which is shown by the light orange and dotted lines (beam and diffuse solar, respectively). Around 8:00 AM, beam solar radiation starts to become active. It peaks at midday and then progressively decreases. The noon thermal peak is largely caused by this solar effect, which is essential for the zone's passive solar heating.

Temperatures gradually start to drop after 4:00 PM. By 6:00 PM, the inside temperature also starts to decline, and the outside temperature starts to drop back down to about 22°C. The temperatures return to those of the early morning during this cooling period, which lasts throughout the night. Notably, at 8:00 PM, the temperature differences turn positive once more, showing that the interior is warmer than the exterior because of heat retention and reduced heat loss, both of which are indicative of effective insulation.

The table also provides useful details on surface characteristics. 52.9% of the zone's 279.025 m² total surface area is exposed, and 2.5% is window space. This small glazing ratio (window-to-wall area) helps to provide a more stable indoor atmosphere by lowering extremes of heat loss and solar gain. The window's 0.89 m² total south-facing window area is a design choice that may reduce the chance of overheating during hotter months but somewhat limits solar heat gain during winter days.

The information shows a fairly ventilated, well-insulated interior space that reacts gradually to changes outside. The internal temperature is mostly within or near the comfort band (23–34°C) during the day, despite some heat gain that is noticeable owing to solar radiation. The temperature drops below the comfort level in the early morning hours (5:00 AM to 8:00 AM), nevertheless, indicating the possibility of thermal discomfort in the absence of passive heating or improved insulation.
Based on this data, we can conclude that the average temperature difference between indoor and outdoor temperatures is within the comfort range, at around 1 °C.

iv. Hourly temperature profile (June)

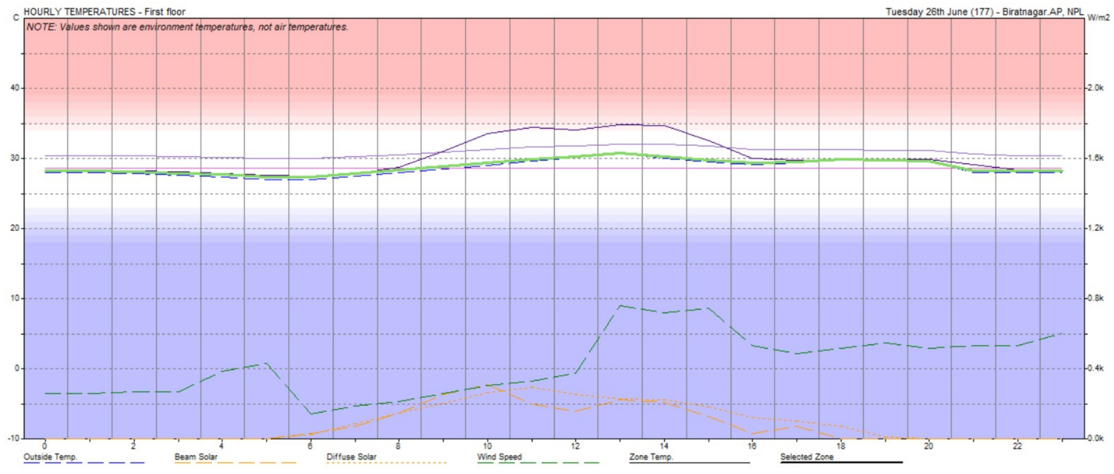


Figure 25: Hourly temperature of June

A thorough summary of the thermal conditions within and outside the building over the day is provided by the hourly temperature profile for the first floor on Tuesday, June 26. Hourly temperature readings, sun radiation, and wind speed indicators are among the data, which provide information on indoor thermal stability and diurnal heat changes. While the external temperature exhibits a little diurnal change caused by solar radiation and wind patterns, the inside temperature stays generally constant over the course of a 24-hour period.

Early in the day, from midnight until about nine in the morning, there is a little decrease trend in both indoor and outdoor temperatures. At 00:00, the internal temperature is 28.3°C, and by 09:00, it is 28.9°C. This tiny increase is indicative of the warming influence of the early morning, even if the interior environment is mostly protected from significant outdoor temperature variations. It is noteworthy that during this period, the temperature difference (TEMP.DIF) remains very low, ranging between 0.3°C and 0.5°C, suggesting that the interior space is efficiently thermally buffered.

	Base case			
HOURLY TEMPERATURES - Tuesday 26th June (177)				
Zone: First floor				
Total Surface Area: 279.025 m2 (159.0% flr area).				
Total Exposed Area: 92.907 m2 (52.9% flr area).				
Total South Window: 0.890 m2 (0.5% flr area).				
Total Window Area: 4.452 m2 (2.5% flr area).				
HOUR	INSIDE	OUTSIDE	TEMP.DIF	
	(C)	(C)	(C)	
-----	-------	--------	---------	
00	28.3	28	0.3	
01	28.3	28	0.3	
02	28.2	27.9	0.3	
03	27.9	27.6	0.3	
04	27.8	27.4	0.4	
05	27.4	27	0.4	
06	27.5	27	0.5	
07	27.9	27.5	0.4	
08	28.4	28.1	0.3	
09	28.9	28.6	0.3	
10	29.4	29.1	0.3	
11	29.9	29.7	0.2	
12	30.3	30.2	0.1	
13	30.8	30.8	0	
14	30.3	30.1	0.2	
15	29.8	29.6	0.2	
16	29.4	29.2	0.2	
17	29.5	29.4	0.1	
18	29.9	29.9	0	
19	29.8	29.8	0	
20	29.7	29.7	0	
21	28.3	28	0.3	
22	28.4	28.1	0.3	
23	28.3	28.1	0.2	

Table 11: Hourly temperature profiel, June

Solar radiation increases in intensity as the day goes on into the late morning and afternoon (10:00–15:00), and this influence may be seen in both internal and external temperature data. Between 13:00 and 14:00, the inside temperature slightly surpasses 30°C, while the outdoor temperature peaks at about 30.8°C. During these hours, the graph's zone temperature (green dashed line) likewise peaks, illustrating how the indoor environment is impacted by increasing beam and diffuse solar radiation (seen by the orange and yellow dotted lines). The temperature difference is still quite small, though, at only 0.1°C to 0.3°C, indicating that the building envelope is successfully reducing rapid heat transfer.

In the late afternoon and nighttime hours (16:00–23:00), the outside temperature gradually decreases from 29.4°C to 28.1°C, while the internal temperature rises from 29.4°C to 28.3°C in a similar but more gradual manner. Even when the outside temperature drops, thermal comfort can be maintained indoors because to excellent insulation and thermal inertia. Usually, the temperature differential is about 0.2°C or less. Wind speed, indicated by the green dashed line, increases significantly throughout the day due to the building's regulated air exchange elements, but it doesn't seem to have a significant effect on interior temperatures.

The temperature differential between indoors and outdoors is consistently very small, not increasing by more than 0.5°C during a 24-hour period. This suggests a highly efficient building envelope with superior thermal resistance and minimal conductive heat absorption or loss. As previously stated, the comfort band for this zone is 23°C to 34°C, and internal temperatures can readily remain within this range all day. This demonstrates how passive design features or insulating materials have been effectively employed to maintain comfortable indoor temperatures even during the hottest summer months. It is possible to draw the conclusion that, at 12 pm, the temperature is within the ASHRAE- recommended adjustable comfort band at 30.3 ^{o}C indoors and 30.2 ^{o}C outside.

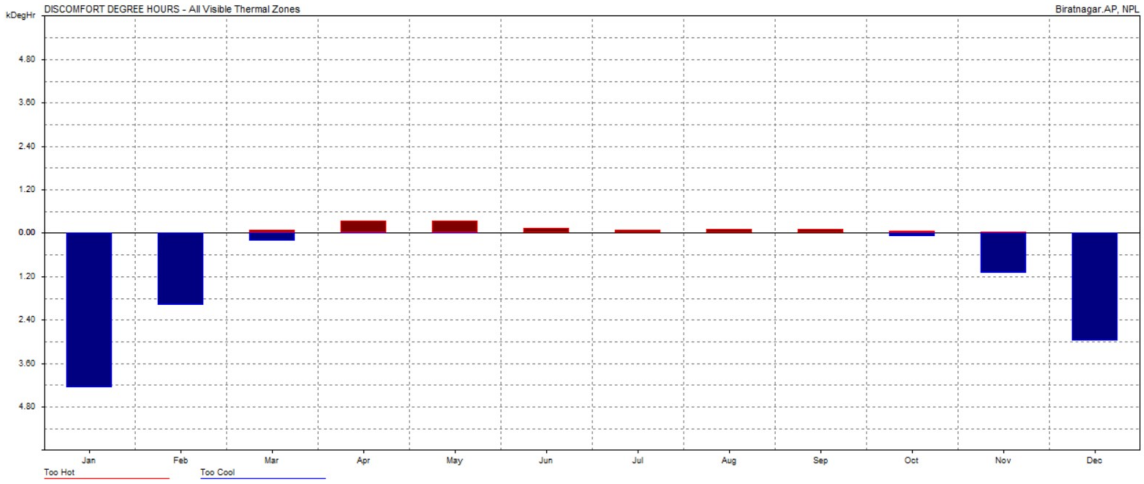


Figure 26: Discomfort degree hours of base case

v. Discomfort degree hours

Biratnagar, Nepal's year-round thermal comfort conditions across all visible thermal zones are thoroughly and in-depthly understood thanks to the Discomfort Degree Hours (DDH) chart and data table that go with it. Discomfort Degree Hours are a crucial statistic in assessing the performance of buildings since they quantify the number of hours that indoor temperatures deviate from a specified comfort range. This range typically corresponds to temperatures that are generally considered suitable for occupants, often falling between 20°C and 27°C, depending on the building's environment and the type of occupancy. When temperatures go outside of this comfortable range, residents may feel too hot or too cold, which is known as thermal discomfort.These uncomfortable hours fall into two main categories: "Too Cool" and "Too Hot." A higher DDH score denotes a higher level of discomfort and, consequently, a more urgent requirement for ventilation, insulation, HVAC, or building design interventions.

A clear pattern emerges from the data, highlighting the fact that the pain of cold is far more than that of heat. Throughout the year, the building experiences 10,629.4 degree-hours of cold-related pain, compared to merely 1,317.2 degree-hours of hot discomfort. This obvious discrepancy implies that the building is generally more vulnerable to cold weather than to hot weather. It also suggests that for a significant amount of the year, indoor temperatures frequently fall below the lower limit of the thermal comfort band, highlighting the need for effective heating systems, improved insulation, or interior heat-preserving design modifications.

DISCOMFORT DEGREE HOURS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
	TOO HO	TOO COC	TOTAL
MONTH	(DegHrs)	(DegHrs)	(DegHrs)
------	---------	---------	---------
Jan	0	4256	4256
Feb	7	1986	1993
Mar	86	222	308
Apr	341	17	358
May	333	0	333
Jun	128	0	128
Jul	80	0	80
Aug	120	0	120
Sep	125	0	125
Oct	68	81	149
Nov	29	1092	1121
Dec	1	2975	2976
------	---------	---------	---------
TOTAL	1317.2	10629.4	11946.6

Table 12: Discomfort degree hours of Base case

Because of the low indoor temperatures, January and December had the highest degrees of pain, both surpassing 2,900 degree-hours. With an incredible 5,155 degree-hours of cold-related misery, January leads the list. December comes in second with 3,747 degree-hours. These numbers highlight the building's inadequate thermal performance during the coldest winter months. They most frequently result from a lack of mechanical heating systems altogether, high air leakage, inadequate passive solar heating, or inadequate insulation. These results underline the urgent need for energy-efficient design techniques centred on heat retention in areas like Biratnagar, where winters can still be rather cold. Sealing gaps, upgrading window glazing, and insulating walls and roofs are examples of retrofitting solutions that would significantly improve thermal comfort and lessen the need for additional heating systems.

The primary issue is discomfort from the cold, but heat-related discomfort also becomes a significant issue during the warmer months, particularly in April and May. April had the highest "Too Hot" pain with 341 degree-hours, closely followed by May with 333 degree-hours. This spike in overheated pain occurs during the cyclical transition from spring to summer, when ambient temperatures and solar intensity rise dramatically. It appears that during these months, the building's ability to reject excess heat or maintain thermal equilibrium is compromised. The figures suggest that a lack of shade, high thermal mass without enough cooling, poor ventilation, and solar gain through windows may all play a significant role in this situation. This emphasises the necessity of passive cooling techniques in the summer and pre-monsoon seasons.

Overheating can be prevented and the need for mechanical air conditioning can be decreased by employing strategies including cross-ventilation, evaporative cooling, strategic shadowing, and the application of reflective or insulating materials on the building envelope.

It's interesting to see that during the mid-year months of June through September, pain levels are frequently moderate and balanced. Interior temperatures are at their most comfortable during these months, as seen by the much reduced total number of hours of pain. For instance, July is the most thermally tolerable month, with only 80 degree hours of total agony. This relative comfort may be caused by a combination of the monsoon season's moderate climate, more clouds obstructing the sun, and possibly improved ventilation through open windows or other tenant practices. These months offer an opportunity to optimise natural ventilation and passive cooling without relying too much on mechanical systems, which might significantly lower energy use and advance sustainability.

Transitional months with mild discomfort are March and October. March is characterised by a mix of hot and cold temperatures, with 421 degree-hours of chilly weather. Although less extreme, October's 161 degree-hours of frigid misery nevertheless follows a similar pattern. These months see a lot of temperature fluctuations, thus flexible and adaptive comfort solutions are required. Adjustable HVAC systems, movable shade devices, and dynamic thermal zoning could all be helpful during these periods to handle brief weather variations.

November, when temperatures begin to drop significantly at the end of the year and show a return of cold-related misery with 1,541 degree-hours, is another notable aspect. This rise in discomfort indicates that winter preparations should begin well before December and emphasises the need for a proactive thermal comfort approach.

The total annual discomfort degree hours (DDH) show how well the building performs overall in maintaining indoor comfort throughout the seasons. The building's year-round thermal problems are evident from its total DDH of 11,946.6, which comprises 1,317.2 "Too Hot" hours and 10,629.4 "Too Cool" hours. The disparity in pain between hot and cold temperatures highlights how critical it is to prioritise improving performance throughout the winter. However, this does not mean that summertime challenges should be ignored. Even if heat-related discomfort is not as bad, it is still significant, especially when considering the health, well-being, and productivity of residents during hot and muggy months.

It's also important to recognise that the degree of discomfort shown by this data might have broader implications. Tenant satisfaction, health, and productivity can all be impacted by prolonged exposure to hot, uncomfortable conditions. Cold interior environments can cause physical discomfort, lower productivity, and a higher risk of illness, while overheating can lead to fatigue, thirst, and difficulty concentrating. Therefore, in addition to reducing energy costs, improving interior thermal comfort is crucial for occupant productivity and well-being.

Additionally, this data can be used to inform future construction designs in the area. Planners, engineers, and architects can use these insights to design year-round, optimally performing thermally sensitive structures. Climate-responsive design concepts, such as window placement, orientation optimisation, thermal mass balancing, and integrated passive systems, can significantly reduce heat and cold discomfort in new construction. Even the most difficult periods in older buildings might be manageable with a comprehensive refit strategy that emphasises window adjustments, insulation, and natural ventilation systems.

The Discomfort Degree Hours data from Biratnagar, Nepal, offers a useful perspective on how thermal comfort varies across a building throughout the year. The prevalence of cold-related discomfort, particularly in January and December, suggests a severe lack of heat retention and winter readiness. However, overheating pain rises in April and May, indicating that cooling measures are required during specific seasons. The monsoon months of June through September, when discomfort is relatively low, allow for energy-efficient comfort measures. Overall, with 10,629.4 hours of "Too Cool" discomfort and 1,317.2 hours of "Too Hot" discomfort annually, the data shows a critical need for both winter and summer thermal performance improvements.Thermal comfort may be greatly enhanced all year long with focused enhancements to the building envelope, passive design, and adaptive systems.

5.2.2 Case I

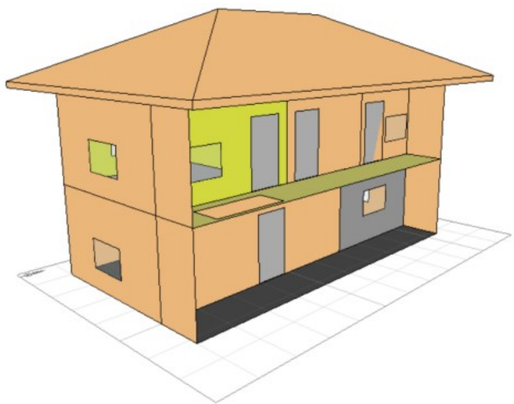


Figure 27: Case I model

In this case there is no attic space and *Murgar* for the stack effect in comapare to base model and uses the obtained thermal comfort band from the bio climatic chart. The primary data are used for the material management and zone management as shown below:

- Floor height: 7’
- No Murgar, no stack effects
- Roof: Hip but not possesses attic space
- Windows size: 3’10” x 2’6” (Total: 7.12 m^2)

i. Zone management

To ensure a typical indoor climate, all three zones—ground floor, first floor, and roof zone—maintain a constant comfort band of 23–34°C, with controlled humidity at 60% and airspeed at 0.10 m/s. As is common in warmer climes, the clothing insulation level is maintained at 0.40 for all zones.

The ground floor zone offers moderate ventilation with three people and an air change rate of 1. The ground floor zone can accommodate the most people (4) and is similar to the ground floor in terms of air change rate and environmental conditions, possibly due to its centre location within the building.However, because it is more exposed to the outside world and only has two occupants, the roof zone has a reduced air change rate of 0.50, most likely to prevent undesired heat gain or loss. The constant wind sensitivity of 0.10 throughout all zones indicates that interior temperatures are unaffected by outside wind. This well-planned zoning ensures that each level effectively satisfies its functional and environmental requirements while maintaining occupant comfort.

ii. Material management

The properties of different materials used in the case I are similar to the base case model.

iii. Hourly temperature profile (February)

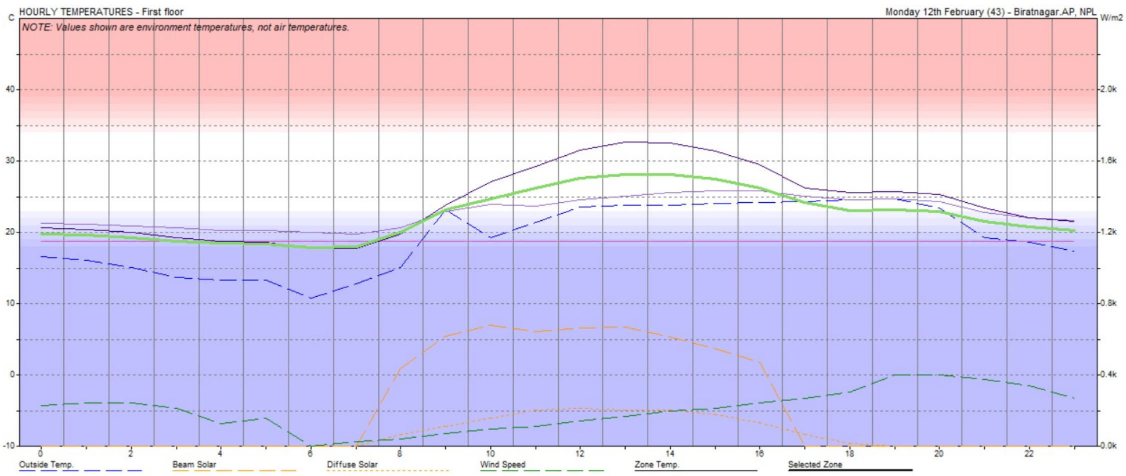


Figure 28: Hourly temperature of case I

HOURLY TEMPERATURES - Monday 12th February (43

Zone: First floor

Total Surface Area: 279.025 m2 (201.7% flr area).

Total Exposed Area: 92.907 m2 (67.2% flr area).

Total South Window: 0.890 m2 (0.6% flr area).

Total Window Area: 4.452 m2 (3.2% flr area).

HOUR	INSIDE (C)	OUTSIDE (C)	TEMP.DIF (C)
-----	-------	--------	---------
00	19.8	16.6	3.2
01	19.7	16.1	3.6
02	19.3	15.1	4.2
03	18.8	13.7	5.1
04	18.5	13.3	5.2
05	18.5	13.4	5.1
06	17.9	10.8	7.1
07	18	12.9	5.1
08	20	15.1	4.9
09	23.2	23.2	0
10	24.8	19.3	5.5
11	26.3	21.5	4.8
12	27.6	23.6	4
13	28.2	23.8	4.4
14	28.1	23.9	4.2
15	27.5	24.1	3.4
16	26.3	24.3	2
17	24.3	24.4	-0.1
18	23.1	24.6	-1.5
19	23.2	24.8	-1.6
20	22.9	23.5	-0.6
21	21.5	19.3	2.2
22	20.8	18.7	2.1
23	20.3	17.4	2.9

Table 13: Hourly temperature profile, February

The hourly temperature profile for the first level on Monday, February 12 demonstrates dynamic thermal behaviour throughout the day. The temperature inside begins at 19.8°C at midnight, which keeps it marginally warmer than the 16.6°C outside. As the early morning hours progress, the largest indoor-outdoor temperature disparity is 7.1°C, with the outer temperature falling to a low of 10.8°C and the interior temperature gradually decreasing to a minimum of 17.9°C at 06:00. This suggests that amid cold overnight conditions, the building has a significant potential to retain heat.

Due to light radiation and ambient warming, internal temperatures start to climb from 9:00 and peak at 28.3°C at 13:00, which is quite comparable to the outdoor peak of 24.3°C. In the afternoon, the interior temperature momentarily surpasses the comfortable level as the temperature differential diminishes. With negative values in the difference column at 17:00 and 18:00, indoor temperatures begin to drop after 16:00, suggesting a brief period during which they are slightly warmer than the outside but still fall within a small difference margin. The inside temperature reaches roughly 20.3°C by 23:00, indicating a constant thermal environment that is getting close to nightfall.Based on this data, we may conclude that the temperature inside is higher than the temperature outside, with a difference of roughly 4-5 degrees Celsius.

iv. Hourly temperature profile (June)

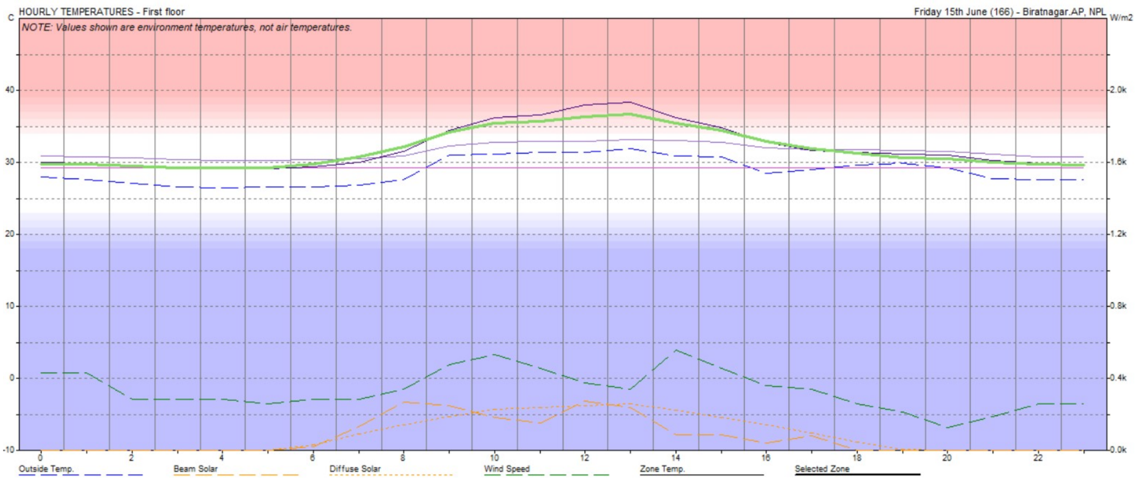


Figure 29: Hourly temperature profile of Case I

HOURLY TEMPERATURES - Friday 15th June (166)
Zone: First floor
Total Surface Area: 279.025 m2 (201.7% flr area).
Total Exposed Area: 92.907 m2 (67.2% flr area).
Total South Window: 0.890 m2 (0.6% flr area).
Total Window Area: 4.452 m2 (3.2% flr area).

HOUR	INSIDE (C)	OUTSIDE (C)	TEMP.DIF (C)
-----	-------	--------	---------
00	29.9	28	1.9
01	29.8	27.7	2.1
02	29.6	27.1	2.5
03	29.4	26.6	2.8
04	29.3	26.5	2.8
05	29.3	26.6	2.7
06	29.8	26.7	3.1
07	30.8	26.9	3.9
08	32.2	27.7	4.5
09	34.2	31.1	3.1
10	35.5	31.2	4.3
11	35.8	31.5	4.3
12	36.4	31.4	5
13	36.8	32	4.8
14	35.5	31	4.5
15	34.5	30.8	3.7
16	32.9	28.6	4.3
17	32	29.1	2.9
18	31.4	29.7	1.7
19	30.7	29.9	0.8
20	30.5	29.3	1.2
21	30	27.8	2.2
22	29.8	27.7	2.1
23	29.7	27.6	2.1

Table 14: Hourly temperature profile, June

The first floor zone's hourly temperature profile for Friday, June 15th shows a steady and regular rise in both interior and outdoor temperatures from early morning until early afternoon, then a slow decline into the evening. Potential thermal discomfort during peak hours is shown by the indoor temperature, which begins at 29.9°C at midnight and peaks at 36.8°C at roughly 13:00. This temperature is much higher than the highest limit of the comfort zone, which is between 23 and 34°C. Similar trends apply to the outdoor temperature, which starts at 28°C and reaches a peak of 31.5°C between 12:00 and 13:00.

From 1.9°C to 5°C, the temperature difference between indoor and outdoor readings varies more throughout the day, when internal gains and solar radiation likely have a greater impact on internal conditions. We may infer from this data that at 12 pm, the temperature outside is 31.4 ^{o}C, but the temperature inside is 36.4 ^{o}C, which is higher than the ASHRAE comfort zone.

v. Discomfort degree hours

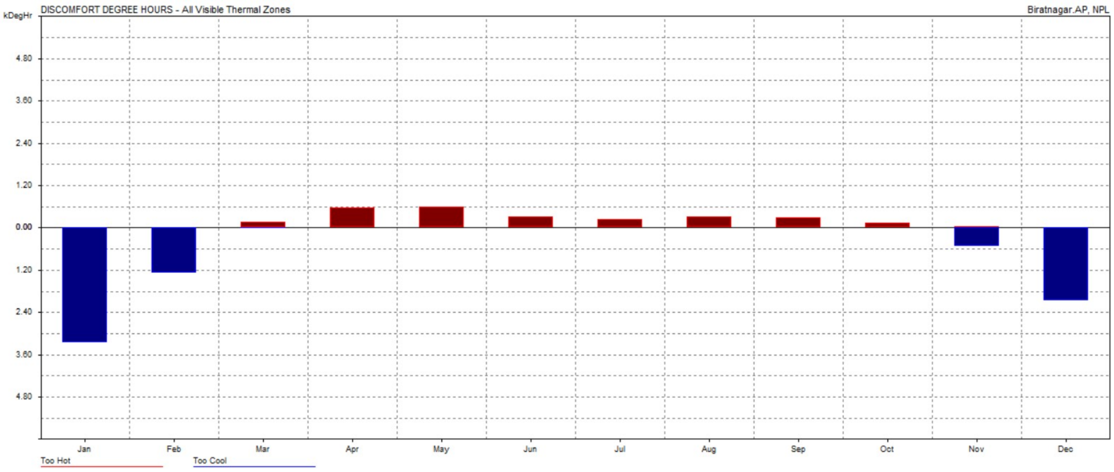


Figure 30: Discomfort degree hours of Case I

An analysis of the discomfort degree hours (DDH) gives a comprehensive understanding of the building's year-round thermal performance. Two extremes—overcooling in the winter and overheating in the summer—cause the most obvious discomfort, revealing significant seasonal variations in indoor thermal comfort. This information serves as a vital diagnostic tool for identifying the locations and times at which the thermal climate of the building deviates from occupant comfort by offering important insights into how architectural and operational changes could improve comfort and energy efficiency.

It is evident from the data that the most important problem influencing the thermal environment is discomfort caused by cold. January and December have the worst cases, with pain degree hours reaching 3,253 and 2,069, respectively. This represents extended intervals during which the internal temperature falls below the comfort threshold, which seems to be between 23°C and 34°C based on previous background. These high DDH readings suggest that residents will likely endure persistent and protracted discomfort during these colder months as a result of inadequate interior heating. The building's absence of effective heating systems or sufficient thermal insulation, which can help preserve heat indoors and lessen dependency on outside sources, is strongly suggested by the data.

DISCOMFORT DEGREE HOURS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
	TOO HO	TOO COC	TOTAL
MONTH	(DegHrs)	(DegHrs)	(DegHrs)
------	---------	---------	---------
Jan	0	3253	3253
Feb	15	1271	1286
Mar	163	4	167
Apr	575	0	575
May	595	0	595
Jun	323	0	323
Jul	242	0	242
Aug	322	0	322
Sep	293	0	293
Oct	141	0	141
Nov	39	521	559
Dec	1	2069	2070
------	---------	---------	---------
TOTAL	2708.3	7116.8	9825

Table 15: Discomfort degree hours of Case I

Heat loss from poorly insulated walls, roofs, floors, or large windows—particularly single-glazed or inadequately sealed windows—can cause cold discomfort. In addition to being uncomfortable, these heat losses raise energy consumption if heating systems are used to compensate.

The data also suggests that the building's envelope might not be set up to maximise passive solar gain in the winter. By absorbing and storing solar radiation during the day, passive solar techniques including solar-absorptive materials, thermal mass for heat retention, and strategically placed windows can greatly increase indoor temperature. The high discomfort levels imply that these tactics are either not being used enough or are not working as they are being used. It may be possible to significantly lessen winter discomfort by retrofitting the structure with stronger glass, insulation and even little fixes like caulking air leaks.

During the warmer months, especially from April to September, overheating becomes the main worry, in sharp contrast to the misery of the winter cold. With 595 degree hours of thermal pain related to extreme heat, May stands out among these. This suggests that interior temperatures regularly rise above the comfort band's upper limit, which probably causes discomfort for occupants, lowers productivity, and may even result in higher cooling energy consumption. A major need for cooling interventions, particularly passive cooling techniques such cross-ventilation, thermal mass cooling, shade, and reflecting roof coatings, is indicated by the cumulative discomfort caused by warming during this time.

Although not as much as in May, the months of April, June, July, August, and September also contribute to the discomfort of overheating. The data indicates a general tendency of rising interior temperatures during this half of the year, which may be caused by a number of things, including inadequate ventilation, solar radiation from big window areas, or a lack of shade on the building envelope. By collecting heat during the day and releasing it gradually at night, the use of high thermal mass materials without proper nighttime flushing may also make overheating worse. These observations highlight the necessity of implementing dynamic cooling techniques, such as automated shading systems, light shelves, operable windows, and overhangs, which may all passively control heat gain and preserve indoor comfort.

There is a change between these extremes throughout the transitional months of March, October, and November. Both heat and cold contribute to mild discomfort episodes, but their discomfort values are comparatively lower. The discomfort values, for instance, are moderate in March and October, suggesting that the internal environment stays within the comfort band for a sizable amount of these months. This mixed pain points to a need for flexible adaptive techniques that can adapt to mild temperature changes. When paired with user-controlled fans or heaters, operable features like windows and blinds can let residents adapt to changes in the temperature in real time, improving comfort without using a lot of energy.

The disparity between the many forms of discomfort encountered during the year is what is most noticeable from the annual report. A total of 2,708.3 degree hours of overheating pain and a significantly larger 7,116.8 degree hours of overcooling discomfort are experienced by the building. An annual total of 9,825.1 discomfort degree hours are caused by this imbalance. The necessity for a more resilient and adaptable thermal management plan throughout the seasons is highlighted by this high cumulative value. The overwhelming majority of overcooling DDH (almost 73%) supports the previous finding that the building is especially susceptible to cold weather, maybe as a result of inadequate heating provisions and weak thermal barriers.

Furthermore, even though the discomfort caused by overheating is very minor, it nevertheless merits consideration, particularly given that it occurs primarily throughout the six-month period from April to October. Solar heat gain probably raises indoor temperatures at this time, and if it isn't controlled, it may result in more people using mechanical cooling, which would increase energy costs and carbon emissions. This also raises the possibility that the building's architecture is not sufficiently suited to Biratnagar's hot summer environment. The requirement for climate-responsive design components is highlighted by the significant level of discomfort experienced during these months, which suggests a mismatch between the building envelope and the outdoor thermal conditions.

It is advised to use an integrated strategy that incorporates both passive and active techniques to manage these pain patterns. Upgrades to insulation, draft-proofing, thermal curtains, and perhaps the installation of energy-efficient heating systems could significantly lessen the misery of cold throughout the winter. In the meanwhile, using reflecting materials, being orientated correctly, having external shading, and having better natural ventilation could help prevent overheating and lessen the need for air conditioning during the summer. The performance of the building may also be better matched with actual human expectations and behaviours by investigating adaptive comfort models, which permit a wider range of comfort based on the season and occupant adaptability.

When analysing pain data, it's also critical to take building utilisation trends and tenant behaviour into account. The impact on tenants may be less severe than the data indicates, for example, if the building is empty during the hours of greatest discomfort. However, there may be significant detrimental consequences on productivity, health, and well-being if occupancy occurs during the times when discomfort is at its peak. Therefore, employing this data successfully in retrofitting or redesigning projects requires an awareness of how areas are used throughout the day and year.

The data on discomfort degree hours provides a comprehensive view of the building's year-round thermal issues. The data unequivocally shows that overheating becomes more problematic from April to September, peaking in May, whereas cold discomfort predominates during the winter, especially in January and December. Moderate conditions are available during transitional months, indicating that the building may achieve near-comfortable conditions for most of the year with the correct actions. The building may greatly increase occupant comfort, lower energy usage, and improve overall sustainability by tackling these problems with conscientious design and operating solutions that are adapted to seasonal needs.

5.2.3 Case II

This case is updated from the base case model. In this case the height of the model is 10' and s there is attic space with more broad *Murgar* for the stack effect in compare to base model and uses the obtained thermal comfort band from the bio climatic chart. The primary data are used for the material management and zone management as shown below:

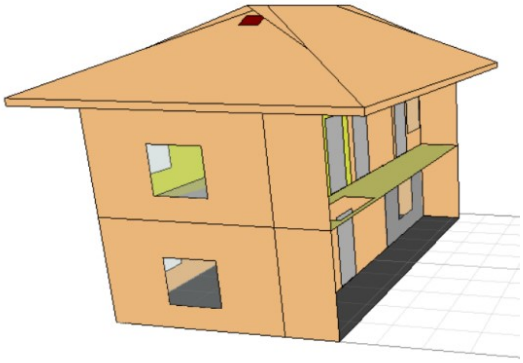


Figure 31: Case II model

- Floor height: 10’
- Murgar void size: 1’6” x 1’6”
- Roof: Heap with attic space
- Windows size: 4’0” x 3’6” (10.41 m^2)
- No. of voids between rooms and attic space : 3 (1 in each room) for cross ventilation

i. Zone management

The ground floor, ground floor and roof zone management choices provide a well-balanced approach to achieving thermal comfort in a structure, particularly in warm and humid areas. Each zone maintains a continuous comfort band of 23–34°C, suitable for naturally ventilated spaces in tropical conditions, and a garment insulation factor of 0.40 clo shows that people are wearing light clothing, which is typical of hot climes. However, variations in humidity, airspeed, occupancy, and air change rates underscore the different climates and ventilation strategies of the zones.

With a moderate velocity of 0.50 m/s, a moderate humidity of 64%, and an air change rate of 50 ACH (air changes per hour), the ground floor zone is inhabited by three persons. This design suggests a well-ventilated space that relies on either natural or mechanical ventilation to sustain airflow and lessen heat accumulation. The wind sensitivity of 0.25 indicates a good degree of reactivity to external breezes, supporting enhanced thermal comfort without the need for mechanical cooling.

The first floor's humidity rises to 87%, most likely as a result of less shade or more exposure to internal heat gains. The slightly higher airspeed here, at 0.70 m/s, helps to lessen the discomfort caused by the air's high moisture content. Since the zone has the highest population (4) and the air change rate is 50, the ventilation system is crucial to preventing overheating and maintaining indoor air quality. The wind sensitivity is kept at 0.25 to maintain cross-ventilation efficiency.

The airspeed in the roof zone is 0.70 m/s, which is similar to the first floor, and the humidity level is 75% when just one person is present. The exceptionally high air change rate of 200 in this zone makes it stand out; it suggests a well-ventilated space that is most likely required to counteract the significant solar heat gains that are characteristic of roof-level zones. The improved ventilation helps to quickly cool the space and avoid overheating because the roof is directly exposed to the sun and the weather. The wind sensitivity, which remains constant at 0.25, ensures reaction to natural ventilation even in this highly exposed area.

ii. Material management

The properties of different materials used in the case I are similar to the base case model.

iii. Hourly temperature profile (February)

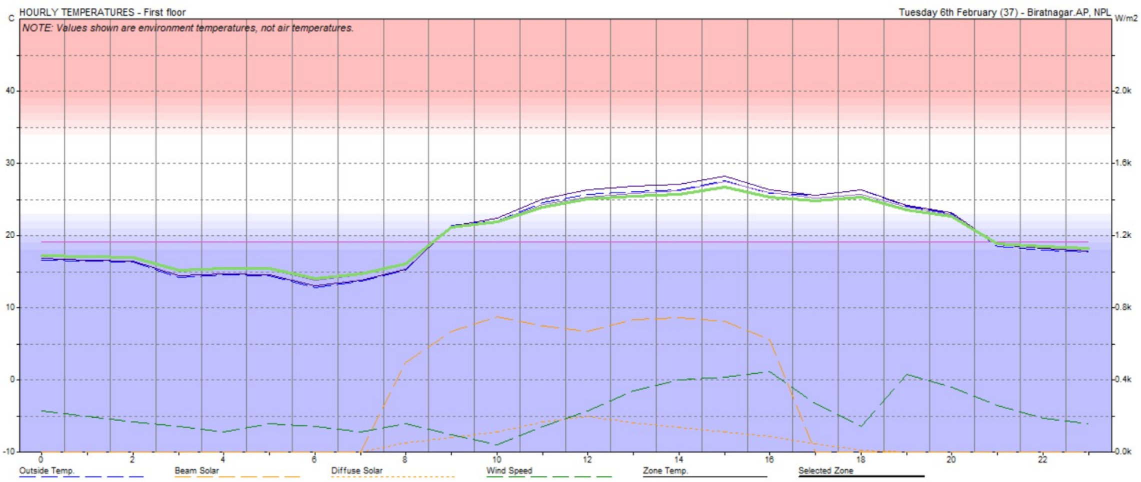


Figure 32: Hourly temperature profile of February

	Case 2			
HOURLY TEMPERATURES - Tuesday 6th February (37)				
Zone: First floor				
Total Surface Area: 280.256 m2 (160.4% flr area).				
Total Exposed Area: 92.907 m2 (53.2% flr area).				
Total South Window: 1.301 m2 (0.7% flr area).				
Total Window Area: 6.503 m2 (3.7% flr area).				
HOUR	INSIDE	OUTSIDE	TEMP.DIF	
	(C)	(C)	(C)	
-----	-------	--------	---------	
00	17.3	16.7	0.6	
01	17.1	16.5	0.6	
02	17	16.4	0.6	
03	15.3	14.2	1.1	
04	15.5	14.6	0.9	
05	15.5	14.5	1	
06	14.1	12.8	1.3	
07	14.8	13.7	1.1	
08	16.2	15.3	0.9	
09	21.2	21.5	-0.3	
10	21.9	22.1	-0.2	
11	24	24.6	-0.6	
12	25.1	25.7	-0.6	
13	25.5	26.1	-0.6	
14	25.8	26.4	-0.6	
15	26.8	27.7	-0.9	
16	25.3	25.9	-0.6	
17	24.9	25.6	-0.7	
18	25.4	26.4	-1	
19	23.6	24.1	-0.5	
20	22.7	23.1	-0.4	
21	19	18.5	0.5	
22	18.5	18.1	0.4	
23	18.3	17.8	0.5	

Table 16: Hourly temperature profile, February

The hourly temperature profile for the first floor on Tuesday, February 6th, demonstrates a gradual change in the inside and outdoor temperatures during the day. Early morning (00:00–06:00) temperatures outside range from 16.7°C to 12.8°C, while indoor temperatures remain mostly consistent between 17.3°C and 14.1°C. The temperature difference (inside being slightly warmer) is minimal, often between 0.6 and 1.3°C, suggesting very good insulation and thermal stability indoors.

After 7:00, both interior and outdoor temperatures begin to climb as solar radiation increases. During peak heat hours, there is a slight cooling effect indoors because the temperature outside hits 27.7°C while the temperature inside peaks at 26.8°C at approximately 15:00. This pattern indicates that excessive heat gain during the day is effectively prevented by the building envelope. After 16:00, the temperature gradually decreases, and by 23:00, the internal readings fall to 18.3°C, which is about the same as the outside temperature of 17.8°C.

The space's thermal behaviour is balanced since, on average, the daytime temperature differential stays within ±1°C. This profile demonstrates how the interior environment may adapt to changes outside while preventing abrupt temperature swings to better maintain indoor comfort throughout the day.

Based on this data, we may conclude that the inside temperature at 8 am is 16.2 °C and the outdoor temperature is 15.3 °C, both of which fall within the ASHRAE comfort zone. In comparison to the outside temperature, the interior is warmer in the morning and evening.

iv. Hourly temperature profile (June)

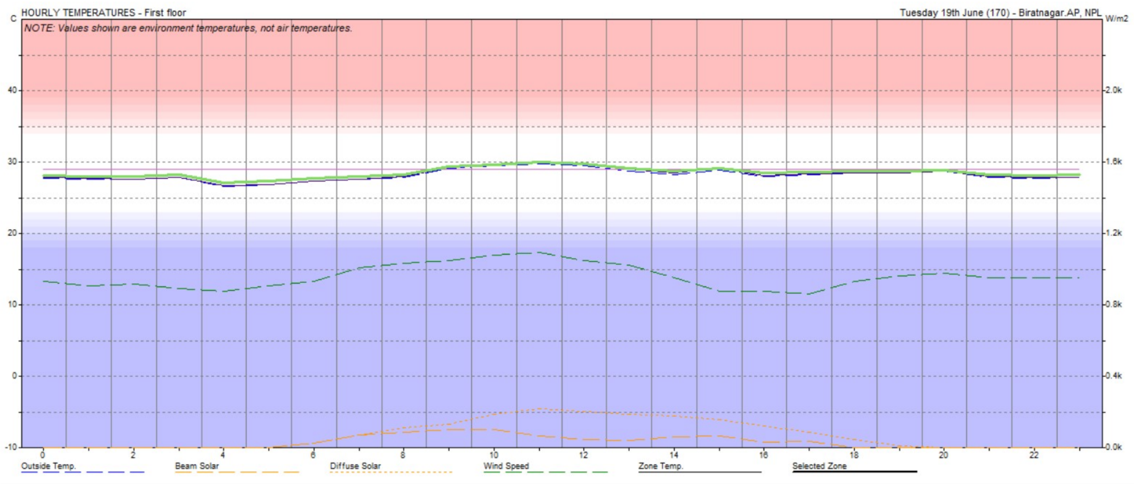


Figure 33: Hourly temperature of June

HOURLY TEMPERATURES - Tuesday 19th June (170)
Zone: First floor
Total Surface Area: 280.256 m2 (160.4% flr area).
Total Exposed Area: 92.907 m2 (53.2% flr area).
Total South Window: 1.301 m2 (0.7% flr area).
Total Window Area: 6.503 m2 (3.7% flr area).

HOUR	INSIDE (C)	OUTSIDE (C)	TEMP.DIF (C)
-----	--------	---------	----------
00	28.2	27.8	0.4
01	28.1	27.7	0.4
02	28	27.6	0.4
03	28.2	27.9	0.3
04	27.2	26.6	0.6
05	27.4	26.9	0.5
06	27.8	27.4	0.4
07	28	27.6	0.4
08	28.3	27.9	0.4
09	29.4	29.2	0.2
10	29.7	29.5	0.2
11	30	29.8	0.2
12	29.8	29.6	0.2
13	29.2	28.8	0.4
14	28.8	28.3	0.5
15	29.2	28.9	0.3
16	28.5	28	0.5
17	28.7	28.3	0.4
18	28.8	28.5	0.3
19	28.7	28.5	0.2
20	29	28.8	0.2
21	28.3	27.9	0.4
22	28.2	27.8	0.4
23	28.2	27.9	0.3

Table 17: Hourly temperature profile, June

The hourly temperature profile for the first floor on Tuesday, June 19, provides crucial details on the thermal performance of the building, particularly in relation to its ability to maintain a consistent and comfortable interior environment. With lows of 27.2°C in the early morning and highs of 30°C in the mid-afternoon, the figures and accompanying graph demonstrate that indoor temperatures remain impressively consistent throughout the day. This slight change of only 2.8°C over a 24-hour period indicates that the daily fluctuations in the external weather have little effect on the indoor environment. Outside, the temperature changes slightly more than indoors, ranging from 26.5°C to 29.5°C.The internal atmosphere is successfully buffered despite these external fluctuations, indicating that the building has significant thermal inertia and thoughtful passive design elements.

The most noticeable feature is the slight temperature difference between the inside and outdoor spaces, which generally remains between 0.2°C and 0.6°C. This suggests that thermal equilibrium is being effectively maintained by the building envelope. An adequately insulated envelope, which includes the walls, roof, windows, and floors, reduces the rate of heat transfer between the inside and exterior of a building. Since there is so little fluctuation in this case, active heating or cooling is not necessary because heat intake or loss is appropriately regulated. This kind of temperature control is essential not only for passenger comfort but also for energy efficiency.Energy is saved and operating expenses are decreased when there is a minor temperature differential because it lessens the strain on mechanical systems, which would otherwise need to work harder to maintain the required thermal conditions.

The graph also demonstrates that, within the designated thermal comfort range of 23°C to 34°C, the zone temperature—that is, the observed internal ambient temperature—remains consistent throughout the day. This suggests that occupants would appreciate a comfortable indoor environment free from extreme heat pain. It indicates that the design and material choices were sound because the building was able to stay well within this comfort zone despite changes in the outside temperature and solar radiation. The effective use of materials with a high thermal mass, appropriate ventilation methods, and perhaps careful window positioning all contributed to this outcome.By reducing solar heat gain during the hottest times of the day and permitting heat dissipation during cooler times, natural ventilation and shade components may be aiding in the regulation of indoor temperatures.

Thermal stability may also be provided by passive solar control systems and design orientation integrated into the building's architecture, in addition to insulation. By strategically positioning openings, overhangs, and shading devices, the building most likely avoids overheating, and the uniformity of the interior temperature profile raises the possibility that direct solar heat gains may be limited. Additionally, the flatness of the indoor temperature curve suggests that either thermal mass or ventilation adequately counteracts any temperature increases, or that the thermal environment is not significantly impacted by internal heat loads from equipment or occupant activity.

All things considered, the building's observed thermal behaviour on June 19 makes a strong case for effective design and passive thermal control. The building's consistent temperature indicates that environmental design techniques that preserve occupant comfort without depending on energy-intensive technologies have been successfully integrated. An extremely desirable quality in sustainable architecture is the building's ability to blend in with its surroundings while reducing the need for active interventions.

v. Discomfort degree hours

Important details on the building's thermal performance and occupant comfort levels in Biratnagar, Nepal, can be found in the statistics on discomfort degree hours for the designated thermal zones throughout the year. Discomfort degree hours, or DDH, are a measure of how much and how long interior environmental conditions deviate from preset comfort limits. In this case, the comfort band is defined by the temperature range of 23°C to 34°C. Any temperature that climbs or falls below this range, expressed in degree hours, exacerbates discomfort. The monthly data summary highlights areas where thermal performance could be enhanced and highlights significant seasonal variations. It is presented both mathematically and graphically.

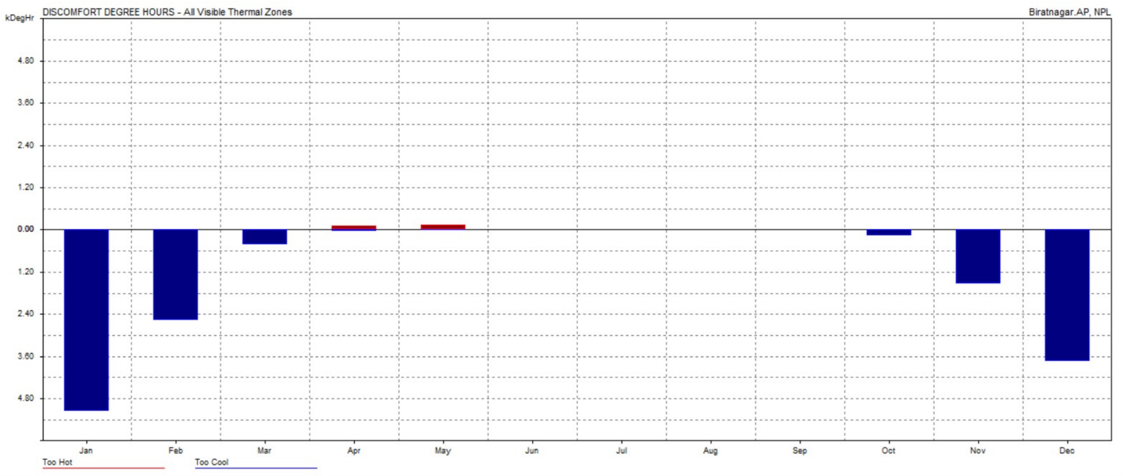


Figure 34: Discomfort degree hours of Case II

DISCOMFORT DEGREE HOURS			
All Visible Thermal Zones			
Comfort: Zonal Bands			
	TOO HO	TOO COC	TOTAL
MONTH	(DegHrs)	(DegHrs)	(DegHrs)
------	---------	---------	---------
Jan	0	5155	5155
Feb	0	2579	2579
Mar	1	421	423
Apr	118	48	166
May	132	1	133
Jun	3	0	3
Jul	1	0	1
Aug	5	0	5
Sep	9	0	9
Oct	0	161	161
Nov	0	1541	1541
Dec	0	3747	3747
------	---------	---------	---------
TOTAL	269.7	13651.9	13921.5

Table 18: Discomfort degree hours of Case II

The data indicates that the cold makes the building extremely uncomfortable, particularly during the winter months of January, February, and December. In January alone, the most degree hours of discomfort from being "too cool" are recorded—5,155—more than in any other month. 3,747 degree hours are added in December, and 2,579 in February. These three months together account for most of the anguish caused by cold, with 11,481 degree hours, or around 84% of the annual unhappiness caused by cold weather. A lack of winter heating, inadequate insulation, or insufficient passive solar gain are all strongly suggested by this level of discomfort.It also suggests that heat may be lost through the building envelope, either through walls, windows, or ventilation systems that aren't designed for cold climates.

On the other hand, heat-related discomfort, while evident, is much less prevalent. According to the research, hot discomfort peaks in April and May and is only experienced throughout the months of March through October. May marginally surpasses April's 118 scorching degree hours with 132. The marginal values for other months, such March, June, July, August, and September, are usually in the single digits. The entire amount of heat-related discomfort that occurs each year is 269.7 degree hours, or under 2% of the 13,921.5 total discomfort degree hours that are documented during the year. This discrepancy highlights that although the building can experience mild warming in the late spring and early summer, this is not a major problem and can be controlled using natural ventilation or passive cooling strategies.

The transitional months of March and October, it is interesting to note, exhibit very moderate levels of pain, with March posting 423 degree hours (mostly due to mild weather) and October contributing 161 (also due to chilly weather). These months, when internal temperatures begin to fluctuate and discomfort is less intense but still noticeable, are symbolic of the swing seasons. This also suggests that the building can benefit from features that allow for seasonal adaptation, such as selective thermal mass consumption, adjustable ventilation openings, or shade devices, which can adjust to changing weather conditions without compromising comfort.

Ideal thermal performance is indicated by exceptionally low discomfort scores in June, July, August, and September, the warmest months of the year. Only 18 degree hours of total discomfort occur during these months due to the mildly intense heat. Biratnagar's hot and muggy summer weather is typical for this time of year, when there is no cold. The low levels of discomfort during these months may be due to effective ventilation, perhaps through cross-ventilation and high air change rates, as well as potential passive cooling from building orientation or landscape shadowing. It's also possible that higher humidity and airspeed during this period helped keep the felt comfort level within the comfort range, even in spite of the higher temperatures.

A comprehensive analysis of the data reveals a stark difference between the discomforts related to heat and cold. It is obvious that addressing cold weather concerns should be the primary focus of any comfort optimisation strategy for this structure, as there are around 13,651.9 cold degree hours and only 269.7 hot degree hours. Improving insulation, especially in windows, roofs, and walls, would significantly reduce heat loss and increase thermal retention. Passive solar heating strategies, such as maximising solar gain, installing windows facing south, and utilising thermal mass for heat storage, may also help raise interior temperatures on chilly days without requiring mechanical heating.

Another important issue to consider is the function of occupant variables and air exchange, as reported in the zone data. For example, the ground floor, first floor, and roof zone differ in terms of population, humidity, wind sensitivity, and air change rates. These variations in thermal comfort have distinct effects on each zone. For instance, higher air change rates—such as the 200 air changes per hour reported on the roof zone—may cause a considerable loss of heat in the winter if they are not appropriately controlled or reduced during cold seasons. Furthermore, all zones have low clothing insulation values (0.4), which may indicate that residents are wearing light clothing for a comfort analysis focused on the summer. Seasonal changes in garment levels may also affect how comfortable a person feels and change how uncomfortable they are at any one time.

To increase comfort, building management systems could also incorporate automated capabilities like fan control, window opening changes, and shading device regulation based on the present indoor and outdoor conditions. In addition to reducing the duration of discomfort, such dynamic responses to temperature changes would increase overall energy efficiency. The building's mechanical heating and cooling systems should also be inspected and enhanced for better performance during periods of extreme discomfort, especially in the winter.

It's also critical to keep in mind that discomfort degree hours, while useful, do not provide a whole picture of comfort. Other factors, including as metabolic rate, humidity, radiant temperature asymmetry, and individual preferences, can affect how comfortable a person feels. DDH is a strong foundational indication that may be used to find trends, rank solutions, and assess the results of design and operation techniques.

The analysis of discomfort degree hours emphasises the necessity of better thermal measures in this structure during the winter. The cold months provide a big problem and account for the vast majority of the year's suffering, whereas the summer months represent a well-managed interior climate with minimal discomfort. During the summer months in this area, which run from June to September, the building is chilly.

5.3 Comparisons of different cases

COMPARISON OF DISCOMFORT DEGREE HOURS						
All Visible Thermal Zones						
Comfort: Zonal Bands						
	Base Case		Case I		Case II	
	TOO HOT	TOO COOL	TOO HOT	TOO COOL	TOO HOT	TOO COOL
MONTH	(DegHrs)	(DegHrs)	(DegHrs)	(DegHrs)	(DegHrs)	(DegHrs)
-------	---------	---------	---------	---------	---------	---------
Jan	0	4256	0	3253	0	5155
Feb	7	1986	15	1271	0	2579
Mar	86	222	163	4	1	421
Apr	341	17	575	0	118	48
May	333	0	595	0	132	1
Jun	128	0	323	0	3	0
Jul	80	0	242	0	1	0
Aug	120	0	322	0	5	0
Sep	125	0	293	0	9	0
Oct	68	81	141	0	0	161
Nov	29	1092	39	521	0	1541
Dec	1	2975	1	2069	0	3747
------	---------	---------	---------	---------	---------	---------
TOTAL	1317.2	10629.4	2708.3	7116.8	269.7	13651.9

Table 19: Comparison of Discomfort degree hours

A comparison of the Base Case, Case I, and Case II's Discomfort Degree Hours (DDH) offers important information about how well various building configurations or design approaches perform in terms of thermal comfort throughout the year. The accompanying bar graph and the tabular data clearly show how these variations affect occupiers' comfort, especially when it comes to times when indoor temperatures are either too hot or too cool.

The main cause of thermal discomfort in the Base Case, which most likely reflects the existing or unaltered building condition, is chilly temperatures. The incredibly high "Too Cool" degree hours (10,629.4 DegHrs yearly) and the far lower "Too Hot" pain (1,317.2 DegHrs) are clear indicators of this. In the winter months of January (4,256 DegHrs), February (1,986 DegHrs), and December (2,091 DegHrs), the discomfort caused by cold is especially severe. This implies that the building has excessive ventilation heat losses, insufficient winter solar gain, or poor insulation. The building maintains pleasant temperatures during hotter times, as seen by the DDH values being minor or negligible during the summer months of June, July and August.

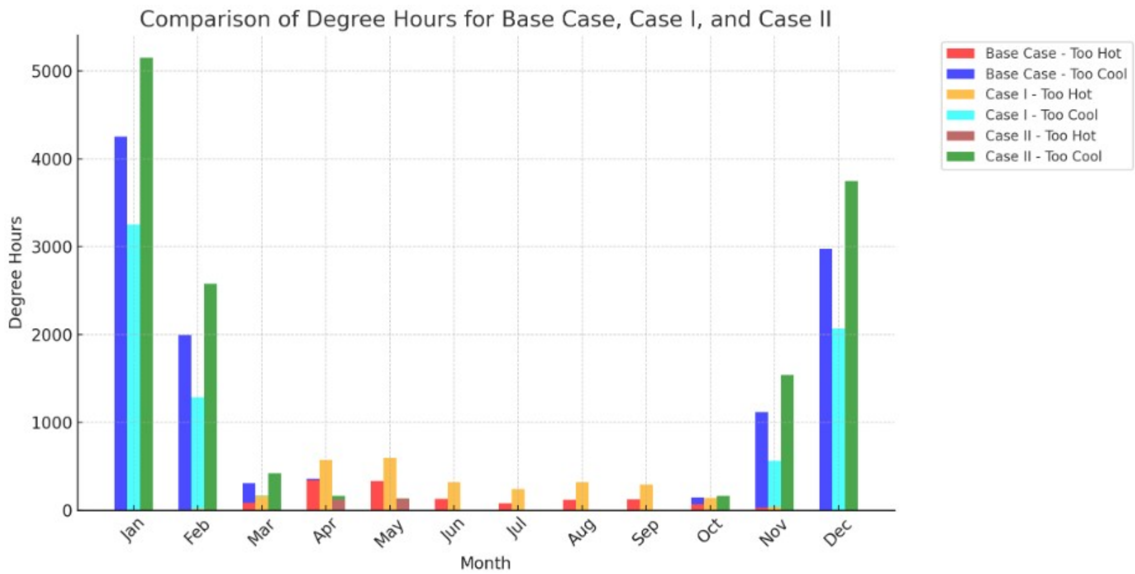


Figure 35: Bar-graph showing comparison of degree hours of different cases

The case It seems to include some design enhancements, most likely passive solar heating, greater insulation, or strategically placed windows. The "Too Cool" discomfort hours are therefore greatly decreased to 7,116.8 DegHrs, which is a 33% improvement over the Base Case. In the winter, when discomfort hours significantly decrease, such as in January (from 4,256 to 3,253) and February (from 1,986 to 1,271), this decrease is particularly noticeable. In contrast to the Base Case, this case adds more "Too Hot" pain, bringing the total to 2,708.3 DegHrs.This increase in overheating is caused by improved thermal retention, which produces surplus heat during the warmer transition seasons like April, May, and October even if it is advantageous in the winter. This suggests that in order to balance thermal gains during these times, tactics like shading or ventilation are required.

In contrast, the performance pattern in Case II is much different. It obviously prioritizes techniques that improve natural cooling, such as stack effect ventilation, higher ceiling heights, or increased cross-ventilation, as evidenced by the remarkable decrease in "Too Hot" discomfort hours to just 269.7 DegHrs. It is therefore perfect for preventing summer heat. A significant increase in cold pain is the trade-off, though, as "Too Cool" hours skyrocket to 13,651.9 DegHrs, the highest of all cases. January (5,155 DegHrs), February (2,579 DegHrs), and December (3,747 DegHrs) are the most miserable months of the year. These numbers imply that although the building stays cool throughout the summer, it is not adequately insulated or equipped with passive heating systems for the winter.

These results are supported by the graphical representation, which displays big blue bars for Base Case's "Too Cool" discomfort in the winter and somewhat smaller red bars for "Too Hot" discomfort. While Case I's "Too Hot" values, which are displayed in orange, somewhat increase in the spring and autumn, its "Too Cool" bars are noticeably lower than those of the Base Case. However, Case II has a distinct profile: its yellow "Too Hot" bars are minimal all year long, while its green "Too Cool" bars are highest during the winter, emphasizing the rise in cold discomfort.

In conclusion, every situation fulfil a distinct design purpose. The Base Case has a significant heating demand and is not well optimized. Though it comes at the expense of some overheating during the shoulder months, Case I offers a well-balanced enhancement by greatly increasing winter comfort. If combined with cooling techniques, it is a good option for year-round thermal comfort. Case II is best suited for regions with long hot seasons or where cooling is the primary issue because it performs well in the summer and is less effective in the winter. The information highlights the value of context-based thermal techniques in building design, particularly in areas with notable seasonal temperature changes like Morang.

CHAPTER 6: CONCLUSIONS

The study uses a case study of the Morang area to illustrate how the stack effect affects thermal comfort in residential buildings. This study was conducted in the vernacular structure in the village area. Although the building's materials and various climatic elements, such as the microclimate and shading devices, are important for the building's thermal comfort, I have assumed that all of these elements are constant for the purposes of this study and have only focused on the conventional roof construction technology used in this region. Additionally, using a single original building as a foundation example, I developed three scenarios based on the literature review and carried out various analyses using Ecotect simulation.

An understanding of the thermal behaviour of the external, interior, and attic space environments may be gained from the temperature data taken from the case study building throughout the day (5:00 AM to 5:00 PM) and at night (6:00 PM to 5:00 AM).

In Daytime Observations:

The outside temperature increases from 14.8°C at 5:03 AM to 27.1°C at 2:05 PM, then slightly drops to 26.3°C at 5:06 PM, according to observations made during the day. A similar pattern can be seen in internal temperatures, which rise from 15.3°C to 24.1°C before levelling off at 23.7°C. Due to solar heat gain from the CGI sheet roof, the attic space has the most rise, reaching 31.4°C at the height of the day (2:05 PM).

In night time observations:

Between 6:06 PM and 4:09 AM, the outside temperature progressively decreases from 23.6°C to 15.1°C. In comparison to the exterior world, internal temperatures remain more stable as they decline, albeit more slowly. Similar trends are seen in the attic area, which cools from 21.8°C to 16.6°C by early morning.

This indicates that the temperature differential between the interior and exterior compartments is more noticeable at night and that internal temperatures stay more constant than external temperatures, indicating efficient cross ventilation from the room to the attic space. The greatest temperature swings are seen in the attic area, which shows considerable heat absorption during the day and heat loss at night. These factors are crucial in lowering the interior room temperature by cross ventilation through *Murgar*.

These results were further supported by the Ecotect simulation, which showed that case I, which had no attic space and *Murgar* as a cross ventilation, had the most uncomfortable hours during the summer compared to other cases. In contrast, case II, which had a higher floor height, larger openings, more voids between rooms and the attic space, and large *Murgar* openings on two sides, had the most comfortable summer months compared to other cases. Since summer lasts for over ten months in Budhiganga rural municipality of Morang, case II, which has an upgraded version of the stack effect, would be able to improve thermal comfort in the residential building's living areas.

This study should be helpful to researchers, designers, and employees because there is a lack of quantitative data about the stack effect in the Morang, Terai region. With higher floor heights, more voids for cross ventilation between rooms and attic spaces, and a large enough Murgar for the proper stack effect, these results indicate the need for better roof construction techniques in terai region vernacular residential buildings, like Morang. Controlling the stack effect effectively can reduce energy consumption, reduce heat loss, and improve indoor comfort—all of which contribute to the construction of more energy-efficient and ecologically friendly buildings. Inadequate attic ventilation can trap heat, which might cause discomfort in lower floors, according to the study (Givoni, 1998). According to research by Santamouris et al. (2006), the stack effect is enhanced by increased ceiling heights, strategically positioned apertures, and roof venting, which encourages natural cooling and lessens the need for artificial ventilation.

CHAPTER 7: RECOMMENDATION

In places like Morang, Nepal, where summer temperatures can rise sharply and using artificial cooling systems is costly and energy-intensive, passive cooling solutions are crucial for sustainable living. One of the best natural ventilation methods in this case is the stack effect, a phenomenon based on basic concepts of air flow and temperature fluctuations. By using the stack effect in architectural design elements like attic ventilation, window and vent placement, and higher ceiling heights, homeowners in Morang can significantly reduce interior warmth, enhance airflow, and reduce their need on electrical cooling equipment. In addition to enhancing thermal comfort, these design changes support international objectives for environmental sustainability and energy efficiency.

Understanding the Stack Effect

The stack effect, often referred to as the chimney effect, is a natural ventilation process that is powered by the temperature differential between inside and outdoor air. Warm air is lighter and tends to ascend, therefore the air in a building travels upward. Cooler air from the outside is taken in by lower openings (like windows, vents or doors) as the warm air leaves through upper openings (like roof ventilators, clerestory windows or attic vents). This creates a continuous cycle of airflow that can be quite helpful in clearing an area of pollutants and heat accumulation.

This effect can be used to keep homes comfortable without the need of mechanical systems in warm places like Morang, where daytime temperatures are high but evening or early morning breezes may still be cooler. Making the most of the stack effect requires careful opening placement and design.

Attic Ventilation for Heat Dissipation

The attic plays a crucial role in regulating indoor temperatures. Attics that aren't properly ventilated can retain heat throughout the day, especially in direct sunshine. This heat radiates downhill into the living rooms below, raising the interior temperature and necessitating cooling. Hot air can more easily escape through the use of turbine ventilators, gable vents, or ridge vents for attic ventilation, preventing an excessive buildup of heat.

For homes in Morang with lots of natural light For Morang homes that get a lot of sunlight in the summer, efficient attic ventilation can greatly increase thermal comfort. Including passive roof ventilation features like soffit vents and vented roof ridges can provide a natural pressure differential that encourages air movement. These solutions are affordable, low maintenance, and can drastically reduce heat gain in the attic and interior. During the summer, effective attic ventilation can have a major impact on thermal comfort. Including passive roof ventilation features like soffit vents and vented roof ridges can provide a natural pressure differential that encourages air movement. These solutions are affordable, low maintenance, and can drastically reduce heat gain in the attic and interior.

Optimizing Window and Vent Placement for Airflow

For efficient natural ventilation, windows and vents must be positioned, sized, and able to be opened. Given the environment of Morang, which is characterized by hot seasons and high humidity, cross-ventilation ought to be a top priority in design. Cross-ventilation is the movement of air from one side of a building to the other, facilitated by wind and pressure differentials.

Windows on neighbouring or opposing walls, particularly those facing the directions of the predominant winds, should be positioned to improve this. The best orientations in Morang should be determined by studying the local wind patterns. The stack effect can be improved by combining high vents on the leeward side with low-set windows on the windward side, which let warmer air escape at higher levels and cooler air enter at lower ones.

Furthermore, louvred vents near the rooftop or movable clerestory windows can be used to offer hot air outflow locations. When these upper apertures are connected to lower inflow vents or windows, a vertical airflow—which is necessary for stack-driven ventilation—is created.

Passive ventilation can also be facilitated while preserving privacy and security by using materials like vent blocks, jaali walls, or perforated bricks. Traditional South Asian architecture already incorporates these architectural aspects, which can be modified for both practical and aesthetic purposes in contemporary homes.

Increasing Ceiling Height

Raising the ceiling height is another efficient way to take use of the stack effect. By allowing hot air to ascend above the inhabited area of a room, taller ceilings can lower the perceived temperature and increase occupant comfort. The lower portions of the room remain cooler because to this design technique, which produces a buffer zone where heat builds up above head level.

In homes with high ceilings, ventilators or high-level apertures are more effective ways to discharge warm air. In Morang, where humidity is a problem and temperatures can climb quickly, this architectural feature can greatly increase passive cooling efficiency. When combined with ceiling fans that gently circulate air, raising the ceiling can assist maintain comfortable interior temperatures while consuming less energy.

Additionally, double-height areas in communal spaces like living rooms or stairwells can serve as thermal chimneys, enhancing air circulation throughout the house and speeding up the stack effect. By drawing air upward from nearby rooms, these zones improve ventilation in general.

Adding the stack effect and other natural ventilation methods to residential buildings is a logical and highly effective strategy to increase thermal comfort in Morang. By properly placing windows and vents to allow airflow, installing attic ventilation to dissipate heat, and raising the ceiling to promote air stratification, homeowners can significantly reduce interior overheating and energy use.

These design strategies enhance a home's affordability, environmental sustainability, and comfort. As climatic patterns become more unpredictable and energy demands continue to rise, employing passive design ideas like the stack effect offers a long-term solution for cities like Morang and other climates with similar conditions worldwide. In addition to raising living standards, these adjustments support larger initiatives in climate change and sustainable development.

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APPENDIX I: Climate data

Time	Manual Daily Maximum Air Temperature			
1/1/2014 12:00	26			
01/02/2014 12:00	23.5			
01/03/2014 12:00	21			
01/04/2014 12:00	25			
01/05/2014 12:00	23			
01/06/2014 12:00	24			
01/07/2014 12:00	19.9			
01/08/2014 12:00	16			
01/09/2014 12:00	22.5			
01/10/2014 12:00	24.5			
01/11/2014 12:00	19.5			
01/12/2014 12:00	26			
01/13/2014 12:00	24.2			
01/14/2014 12:00	18			
01/15/2014 12:00	21.8			
01/16/2014 12:00	20.4			
01/17/2014 12:00	26.2			
01/18/2014 12:00	23.5			
01/19/2014 12:00	28.5			
01/20/2014 12:00	21.5			
01/21/2014 12:00	25.5			
01/22/2014 12:00	27			
01/23/2014 12:00	26			
01/24/2014 12:00	22			
01/25/2014 12:00	21.5			
01/26/2014 12:00	20.5			
01/27/2014 12:00	17.6			
01/28/2014 12:00	20			
01/29/2014 12:00	25			
01/30/2014 12:00	22.5			

APPENDIX II: Manual sunshine duration

Time	Manual Sunshine duration in 1 h		
01/01/201	0		
01/02/201	0		
01/02/201	0		
01/02/201	0		
01/02/201	0		
01/02/201	0		
01/02/201	0		
01/02/201	0		
01/02/201	0		
01/02/201	0.5		
01/02/201	1		
01/02/201	1		
01/02/201	0.35		
01/02/201	0		
01/02/201	0		
01/03/201	0		
01/03/201	0		
01/03/201	0		
01/03/201	0		
01/03/201	0		
01/03/201	0		
01/03/201	0.7		
01/03/201	1		
01/03/201	1		
01/03/201	1		
01/03/201	0.25		

APPENDIX III: Accumulated Precipitation from manual station measured at 03UTC

Time	24h accumulated Precipitation from manual station measured at 03UTC						
01/01/201	0						
01/02/201	0						
01/03/201	0						
01/04/201	0						
01/05/201	0						
01/06/201	0						
01/07/201	0						
01/08/201	0						
01/09/201	0						
01/10/201	0						
01/11/201	0.1						
01/12/201	0						
01/13/201	0						
01/14/201	0						
01/15/201	0						
01/16/201	0						
01/17/201	0						
01/18/201	0						
01/19/201	0.7						
01/20/201	0						
01/21/201	0						
01/22/201	0						
01/23/201	0						
01/24/201	0						
01/25/201	0						
01/26/201	0						

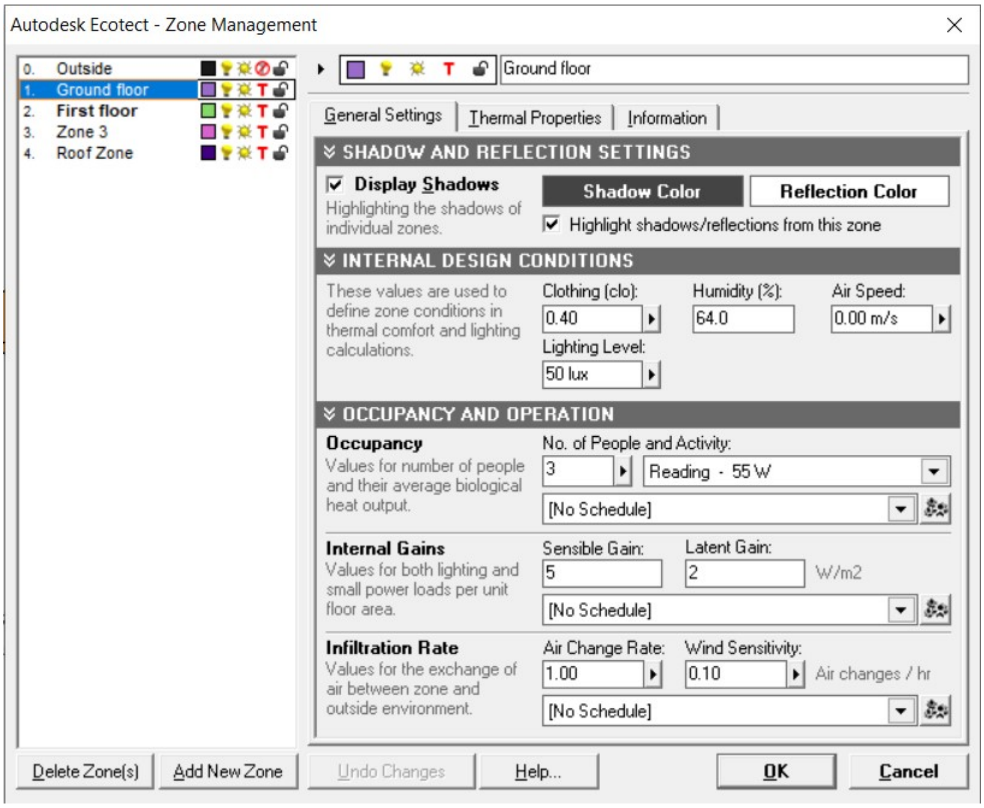
APPENDIX IV: Manual relative humidity

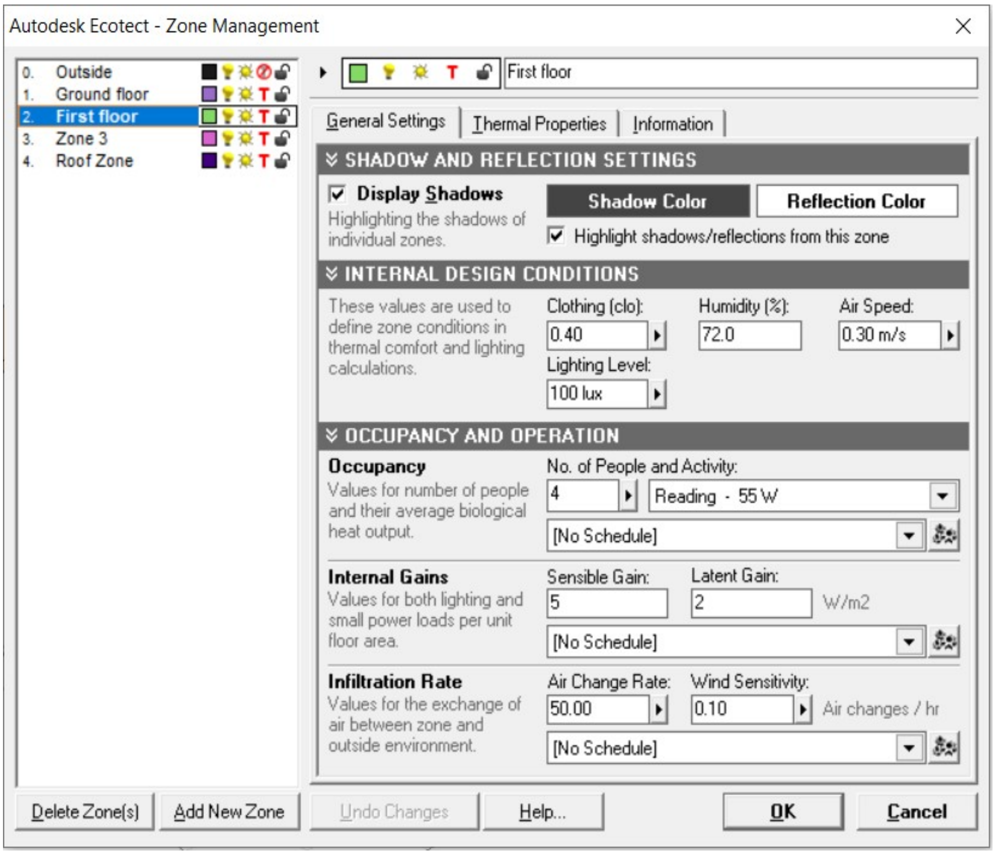
Time	Manual Relative Humidity		
01/01/201	97.5		
01/01/201	71.2		
01/02/201	98.8		
01/02/201	72.9		
01/03/201	100		
01/03/201	79.4		
01/04/201	98.7		
01/04/201	90		
01/05/201	100		
01/05/201	82.4		
01/06/201	100		
01/06/201	81.1		
01/07/201	98.7		
01/07/201	87		
01/08/201	100		
01/08/201	97.7		
01/09/201	95.6		
01/09/201	83.8		
01/10/201	97.1		
01/10/201	79.4		
01/11/201	90.7		
01/11/201	81.7		
01/12/201	92.7		
01/12/201	63		
01/13/201	100		
01/13/201	74.1		

APPENDIX V: Manual daily wind direction

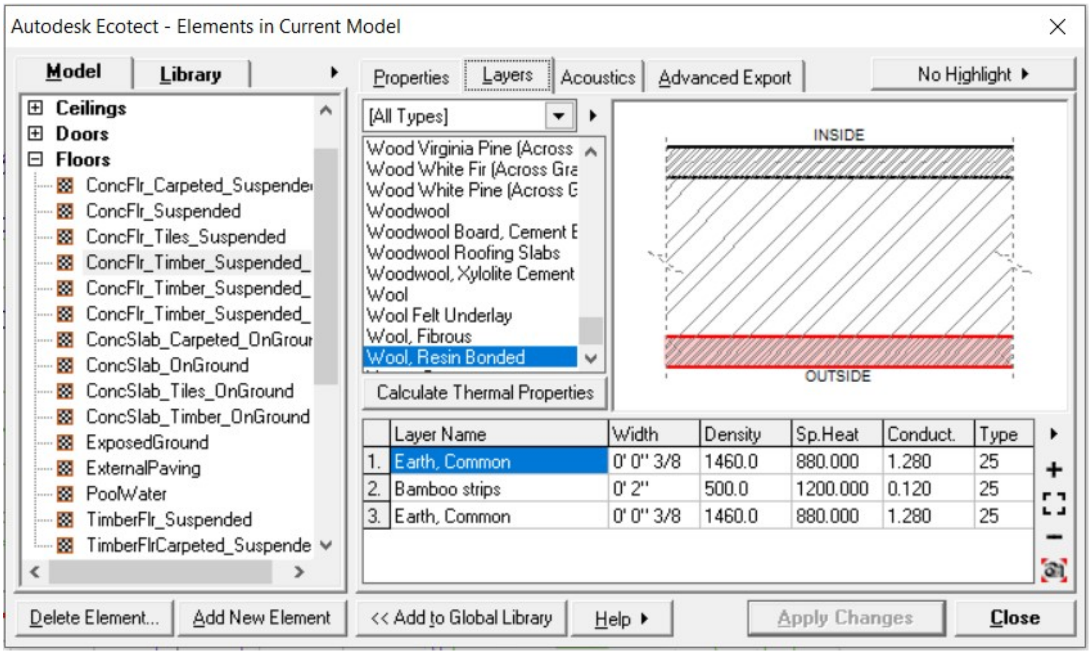
Time	Manual Wind Direction		
01/01/202	0		
01/01/202	0		
01/01/202	300		
01/01/202	90		
01/01/202	0		
01/02/202	0		
01/02/202	0		
01/02/202	90		
01/02/202	90		
01/02/202	0		
01/03/202	0		
01/03/202	0		
01/03/202	90		
01/03/202	60		
01/03/202	50		
01/04/202	0		
01/04/202	0		
01/04/202	90		
01/04/202	180		
01/04/202	0		
01/05/202	270		
01/05/202	270		
01/05/202	260		
01/05/202	270		
01/05/202	0		
01/06/202	260		

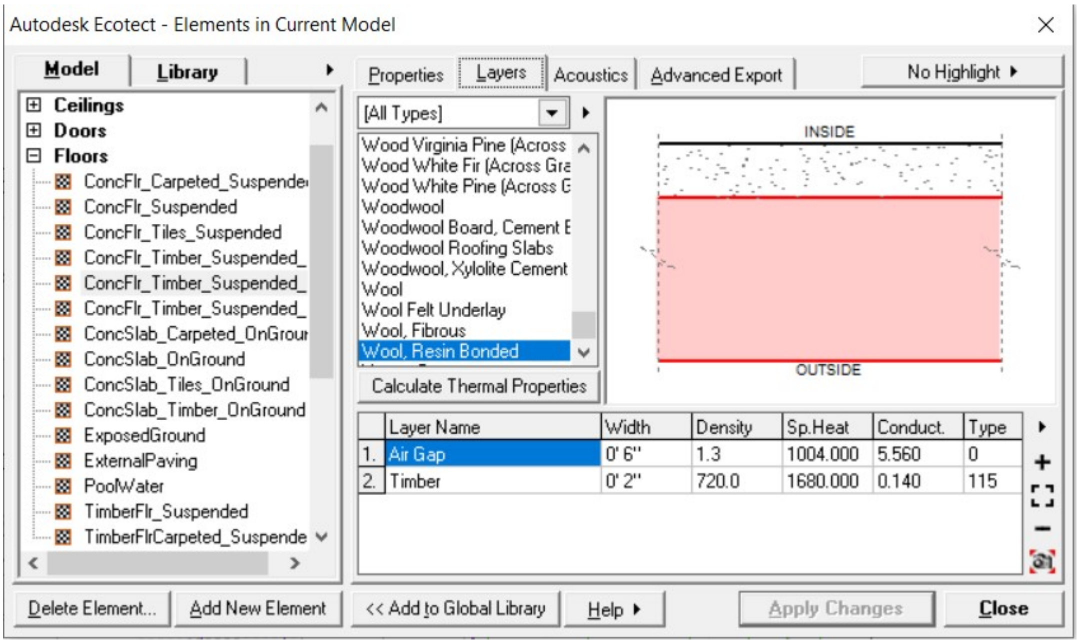
APPENDIX VI: Zone management



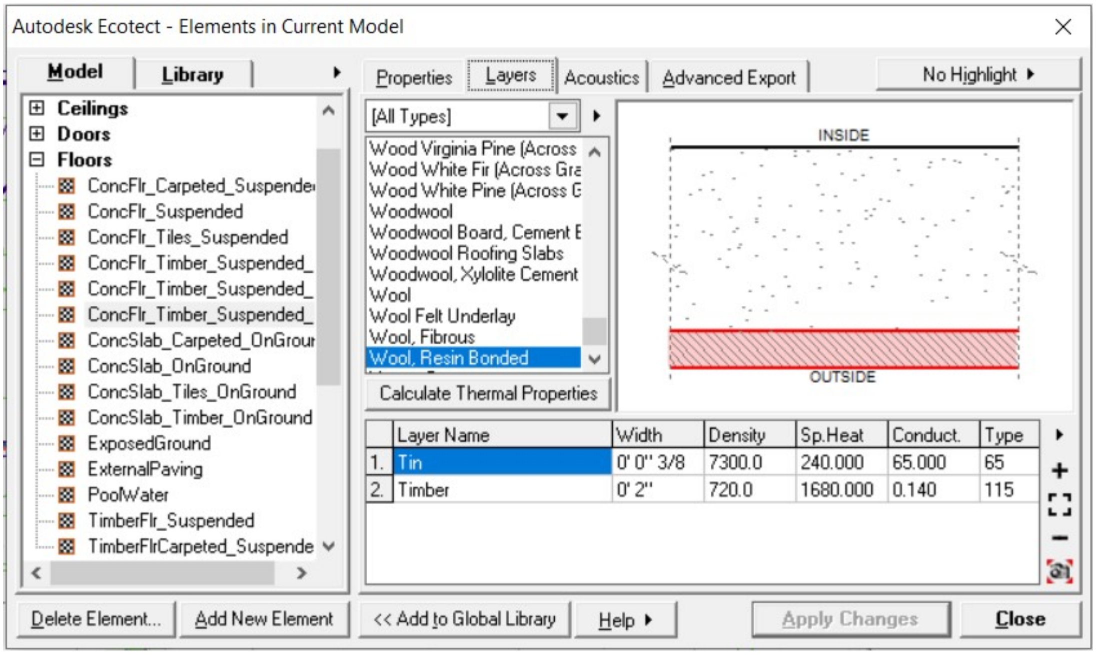


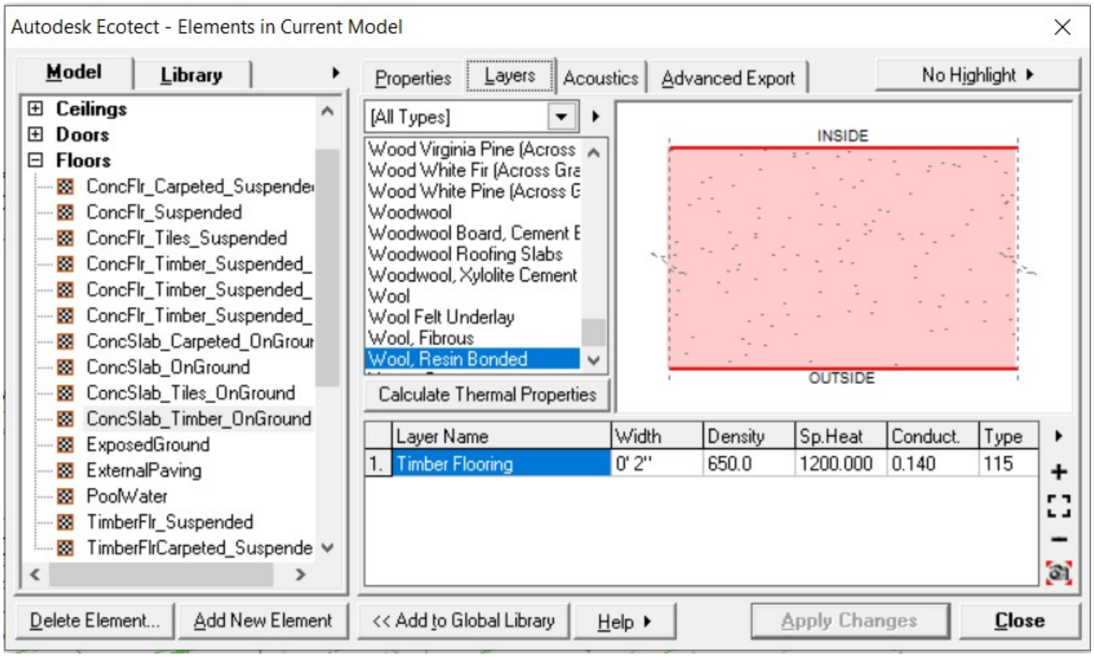
APPENDIX VII: Material management





APPENDIX VIII: Material management





IOEGC Acceptance Letter

4/7/25, 6:02 PM Guragain | A Role of stack effect in thermal comfort in residential building- a case of morang | 16th IOE Graduate Conference

Notifications ×

[IOEGC16] Editor Decision

2025-04-03 09:19 PM

Surya Guragain:

We are pleased to inform you that your manuscript titled "A Role of stack effect in thermal comfort in residential building- a case of morang" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings. Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

With Warm Regards,
IOEGC-16 Editorial Team

IOEGC Graduate Conference Certificate of Participation

IOE Graduate Conference
[Placeholder for Publication Information]

A role of stack effect in thermal comfort in residential building- a case of Morang

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Abstract

The stack effect plays a crucial role in maintaining thermal comfort in residential buildings by facilitating natural ventilation and passive cooling. This study examines the role of stack effect (*Murgar*- typical tharu word for stack projection) in the vernacular residential building in the context of Budhiganga rural municipality of Morang district, where hot and humid climatic conditions influence indoor airflow dynamics. Through field measurements and simulations, we analyze temperature differentials (indoor, outdoor and attic spaces) and degree discomfort hours to assess the effectiveness of stack-driven ventilation. The findings highlight design considerations that optimize thermal comfort by reducing the reliance on mechanical cooling systems. This research provides insights for energy-efficient building design tailored to the local climate in terai region.

Keywords

Stack effect, *Murgar*, natural ventilation, thermal comfort, passive cooling

1. Introduction

Thermal comfort in residential buildings is a critical aspect of energy efficiency and occupant well-being. The stack effect, also known as the chimney effect, plays a significant role in natural ventilation and passive cooling, particularly in regions with distinct climatic variations. In the context of Morang, Nepal, where the subtropical climate presents challenges related to heat buildup and humidity, understanding the role of the stack effect is essential for designing sustainable and comfortable residential spaces.

The stack effect is driven by the temperature difference between indoor and outdoor environments, causing air to rise through vertical openings and creating a natural ventilation cycle. In Nepal, where energy consumption for cooling is increasing due to urbanization and climate change, leveraging the stack effect in residential buildings can help reduce reliance on mechanical cooling systems (Gautam, 2019). Traditional Nepalese architecture has long incorporated passive design elements, such as high ceilings, courtyards, and ventilated roofs, to optimize airflow and maintain indoor comfort (Shrestha, 2017).

Morang, a district in Koshi province of Nepal, experiences high temperatures and humidity, especially during summer. Modern housing structures often neglect passive design strategies, leading to increased indoor heat retention and discomfort. Studies on passive cooling techniques in Nepal emphasize the significance of natural ventilation in improving thermal comfort and reducing energy consumption (Karki & Adhikari, 2020). This study aims to examine how the stack effect influences indoor thermal comfort in site's residential buildings and explore strategies to enhance its effectiveness through architectural modifications.

By analyzing Vernacular structures in site, this research will contribute to the broader discourse on sustainable architecture and climate-responsive design in Nepal. The findings will help architects, engineers, and policymakers in promoting energy-efficient housing solutions tailored to Nepal's climatic conditions.

1.1 Importance of the research

The role of natural ventilation in achieving thermal comfort is crucial, particularly in hot and humid regions like Morang, where excessive heat accumulation in buildings can reduce indoor comfort and increase reliance on mechanical cooling systems. The stack effect, a passive ventilation mechanism driven by temperature-induced air pressure differences, offers an energy-efficient solution for enhancing indoor airflow and cooling (Shrestha & Bajracharya, 2019). Understanding the stack effect's impact on thermal comfort can contribute to sustainable housing designs that minimize energy consumption while maintaining a comfortable living environment.

In Nepal, traditional architecture has long incorporated passive cooling techniques, including ventilation shafts, courtyard openings, and high ceilings, which naturally promote air circulation through the stack effect (Sharma & Shrestha, 2020). However, as modern construction trends prioritize sealed buildings with minimal ventilation, the effectiveness of such natural cooling mechanisms has diminished. Research by (Adhikari et al., 2021) indicates that inadequate ventilation in contemporary residential buildings leads to poor indoor air quality and increased indoor temperatures, particularly in the Terai region. Therefore, integrating the stack effect into modern building designs can help mitigate these challenges, reducing the dependence on artificial cooling systems such as fans and air conditioners.

This study is particularly significant for Nepal's urban and rural development sectors, as it provides insights into cost-effective and sustainable building solutions suitable for site's climatic conditions. By examining temperature differences in residential buildings and identifying strategies to enhance the stack effect, the research can inform architects, engineers, and policymakers about passive design techniques that improve thermal comfort. Additionally, promoting natural ventilation aligns with Nepal's commitment to energy efficiency and climate-responsive architecture, as outlined in national building codes and environmental policies (Ministry of Urban Development, 2022).

The findings of this research will contribute to the broader field of sustainable architecture in Nepal, helping to create resilient housing solutions that are not only environmentally friendly but also economically feasible for homeowners. By demonstrating the practical applications of the stack effect in site's residential buildings, this study aims to influence future construction practices, fostering energy-efficient and thermally comfortable living spaces.

1.2 Problem statement

Thermal comfort in residential buildings is a critical aspect of sustainable living, particularly in regions like Morang, where high temperatures and humidity levels create discomfort for occupants. In Nepal's vernacular architecture, passive cooling techniques, including natural ventilation through the stack effect, have historically played a vital role in maintaining indoor comfort (Shrestha & Bajracharya, 2019). Traditional houses in the Terai region were designed with high ceilings, ventilated roofs, and strategically placed openings to facilitate airflow. However, with the rise of modern construction practices that emphasize concrete structures and sealed environments, natural ventilation mechanisms are often overlooked, leading to increased reliance on mechanical cooling systems such as fans and air conditioners (Sharma & Shrestha, 2020).

Despite the evident benefits of the stack effect in improving indoor air circulation, there is a lack of systematic research on its role in vernacular residential buildings in Morang. Existing studies on Nepalese residential architecture primarily focus on thermal comfort in the hilly and mountainous regions, with limited attention to the unique climatic challenges of the Terai (Adhikari et al., 2021). The absence of comprehensive research has resulted in a knowledge gap regarding the effectiveness of traditional ventilation strategies in contemporary housing, preventing their integration into modern designs.

Furthermore, rapid urbanization and changing construction trends in site have led to the adoption of designs that prioritize space efficiency over ventilation, exacerbating indoor heat accumulation and discomfort. The shift away from passive cooling techniques has also contributed to rising energy consumption, increasing the economic burden on households and the environmental impact of excessive electricity use. Without an in-depth understanding of the stack effect's role in vernacular architecture, Nepal risks losing valuable indigenous knowledge that can contribute to sustainable and climate-responsive housing solutions.

This research aims to address this gap by investigating how the stack effect influences thermal comfort in vernacular residential buildings in Morang. By analyzing temperature differences, architectural elements, and environmental factors, the study will provide insights into optimizing passive cooling strategies for both traditional and modern residences. The findings will help architects, engineers, and policymakers develop energy-efficient housing models suited to the Terai climate while preserving Nepal's rich architectural heritage.

1.3 Research gaps

Despite the growing interest in energy-efficient and climate-responsive building designs, there remain significant gaps in understanding the specific role of the stack effect in thermal comfort within vernacular residential buildings, particularly in regions like Morang, Nepal. These gaps limit the ability to fully integrate passive cooling strategies into modern housing solutions.

a. Limited Focus on Terai Region

Most research on thermal comfort and ventilation in Nepal focuses on the hilly and mountainous regions, where climatic conditions and architectural designs differ significantly from those in the Terai. Adhikari et al. (2021) provide valuable insights into urban residences but fail to delve deeply into how the stack effect operates in the unique climate of the Terai. Sharma and Shrestha (2020) discuss traditional courtyards but do not extend their analysis to the stack effect or its application in modern Terai dwellings. There is a lack of region-specific studies that analyze how traditional ventilation strategies, including the stack effect, can be optimized in Morang's hot and humid climate.

b.Absence of Quantitative Data on Stack Effect

Existing studies primarily offer qualitative insights into natural ventilation but lack empirical data on how the stack effect specifically influences indoor thermal comfort in residential buildings. For instance, Shrestha and Bajracharya (2019) touch on natural ventilation in Nepalese dwellings but do not quantify the impact of the stack effect in terms of temperature reduction. The absence of such data makes it difficult to develop practical recommendations for integrating the stack effect into traditional and modern housing designs.

1.4 Objectives

The main objective of this research is **To assess the impact of the stack effect on thermal comfort in residential buildings by analyzing, indoor temperature variations, and openings efficiency** and the secondary objectives are:

- To measure day and night variations in indoor temperature, humidity due to the stack effect,
- To assess the impact of the stack effect on energy consumption for heating and cooling in residential buildings

1.5 Research questions

How does the stack effect contribute to thermal comfort in vernacular residential buildings?

Sub-questions:

- What architectural features of vernacular residential buildings in Morang facilitate the stack effect, and how do these features influence indoor thermal comfort?

- How does the stack effect compare to other passive cooling strategies (such as cross ventilation and shading) in terms of maintaining thermal comfort in Morang's climate?

2. Literature review

2.0.1 Stack Effect:

The stack effect is a natural ventilation phenomenon that occurs when warm air rises within a building due to differences in temperature between the inside and outside. This vertical movement of air is caused by the density difference between warm air (which is lighter and less dense) and cool air (which is denser). As the warm air rises, it creates a low-pressure zone at the lower part of the building, drawing in cooler air from outside. This can lead to unwanted ventilation, particularly in high-rise buildings or poorly ventilated spaces.

2.0.2 Thermal Comfort:

Thermal comfort refers to the condition in which a person feels neither too hot nor too cold. It is influenced by a number of factors, including air temperature, humidity, air velocity, and radiant temperature. Good thermal comfort ensures a comfortable indoor environment, whereas poor ventilation can lead to discomfort, particularly in the case of hot or humid environments.

The stack effect, a natural ventilation phenomenon where warm air rises and exits through openings at higher points in a building, creating a pressure difference that draws cooler air in from lower openings, plays a crucial role in enhancing thermal comfort in buildings, particularly in vernacular residential architecture. In the case of Morang, a district in Nepal's Terai region with its hot and humid climate, the stack effect can contribute significantly to reducing indoor temperatures, thereby improving indoor air quality and reducing the need for mechanical cooling systems. This literature review explores various studies, both from Nepali and international authors, to understand the role of the stack effect in improving thermal comfort in vernacular residential buildings, focusing on its applicability to site's climate.

2.1 Traditional Architecture and Passive Cooling in Nepalese Vernacular Buildings

In Nepal, traditional architecture has long utilized passive cooling techniques, with natural ventilation mechanisms being a prominent feature of vernacular residential buildings (Shrestha & Bajracharya, 2019). The stack effect, in particular, has been integral in maintaining thermal comfort through the natural movement of air, which is driven by temperature differences between the indoor and outdoor environments. Shrestha and Bajracharya (2019) explain that, in Nepalese courtyard houses, the stack effect is facilitated by high ceilings, open courtyards, and roof ventilation, which allow warm air to rise and exit the building, creating a constant flow of cooler air from openings at lower levels. Adhikari et al. (2021) also emphasize the importance of the stack effect in the Terai region, noting that traditional dwellings in the region were specifically designed to take advantage of natural ventilation systems. However, with the rise of modern, airtight construction, many of these traditional features are being overlooked. Sharma and Shrestha (2020) discuss how modern residential buildings in Kathmandu Valley have lost these traditional cooling strategies due to a shift towards more energy-intensive and air-conditioned homes.

2.2 Role of Stack Effect in Thermal Comfort

The stack effect is particularly effective in hot and humid climates, as it helps to reduce indoor temperatures without the use of mechanical air conditioning. According to Koirala (2018), the stack effect promotes air circulation by allowing hot air to escape from the upper parts of buildings, thus drawing cooler air into lower areas. This natural flow helps maintain thermal comfort, especially during hot daytime hours, which is critical in the Terai region, including Morang.

International studies also support the positive impact of the stack effect on thermal comfort in residential buildings. Emmerich (2017) notes that the stack effect can reduce the need for mechanical cooling, improving energy efficiency and indoor comfort. Similarly, Park et al. (2020) demonstrate that the stack effect, when combined with other passive cooling strategies such as shading and cross ventilation, can significantly lower indoor temperatures in buildings located in subtropical climates.

2.3 Stack Effect and Vernacular Architecture in the Terai Region

The Terai region of Nepal, with its high temperatures and humidity, presents unique challenges and opportunities for applying passive cooling techniques. Traditional vernacular architecture in this region often utilizes large windows, high ceilings, and roof vents, all of which enhance the stack effect by creating temperature differentials that promote airflow. Bhandari (2022) outlines how vernacular homes in the Terai were historically designed to respond to the climate, utilizing natural cooling methods like the stack effect. However, modern buildings in Morang are increasingly adopting sealed, air-conditioned designs, which disregard the passive cooling potential of traditional homes.

Regmi et al. (2021) argue that urbanization in the Terai is contributing to the replacement of traditional building designs with more modern but energy-inefficient housing. The study suggests that integrating vernacular cooling strategies, such as the stack effect, into contemporary designs could enhance both thermal comfort and energy performance. This is particularly crucial in Morang, where temperatures can reach high levels during the summer months.

2.4 Quantification and Impact of Stack Effect on Indoor Thermal Comfort

The stack effect's contribution to thermal comfort can be quantified by measuring temperature gradients and air velocity within buildings. Shrestha et al. (2020) provide insights into how these factors influence indoor thermal comfort in Nepali dwellings, noting that natural ventilation, driven by the stack effect, can lower indoor temperatures by several degrees Celsius, significantly improving comfort without increasing energy demand.

Internationally, Riffat and Zhu (2017) have investigated the quantification of the stack effect in building designs, showing that a well-designed stack effect can reduce cooling loads by up to 30% in certain climates. Their findings support the argument that Nepalese residential buildings, particularly those in the Terai, could benefit from a revival of natural ventilation strategies like the stack effect.

2.5 Contemporary Studies on the Stack Effect

Internationally, the stack effect has been widely studied as part of natural ventilation systems for improving indoor comfort and energy efficiency. In their review of natural ventilation in residential buildings, Lomas and Fiala (2004) highlighted that the stack effect can be a highly effective strategy for cooling buildings in hot climates, reducing reliance on air conditioning and improving indoor air quality. Their research suggests that the stack effect is particularly important in regions with large temperature differences between indoor and outdoor environments, such as the Terai in Nepal.

In a similar vein, Abel and Givoni (2010) demonstrated through computational simulations that the stack effect, combined with other passive cooling techniques, can effectively reduce indoor temperatures and increase comfort levels in tropical climates. Their study underscores the potential for using traditional design elements, such as high ceilings, ventilated roofs, and strategically placed openings, in modern architectural design to enhance thermal comfort and sustainability.

Furthermore, studies by Rijal et al. (2013) emphasize the importance of integrating traditional Nepalese architectural principles, like the stack effect, into modern buildings to improve thermal performance while maintaining energy efficiency. This has significant implications for urban development in the Terai region, where the need for passive cooling solutions is becoming more pressing.

2.6 Challenges and Opportunities for Applying the Stack Effect

The main challenge in applying the stack effect in modern Morang buildings is the growing trend of sealed structures that inhibit airflow. However, Rai and Shrestha (2022) suggest that it is still possible to incorporate passive cooling features into modern buildings, even in dense urban areas, by ensuring proper ventilation pathways and vent opening placements. They emphasize that combining the stack effect with modern energy-efficient designs can lead to cost-effective, climate-friendly housing solutions for Morang.

2.7 Bioclimatic chart

A **bioclimatic chart** is a graphical tool used to analyze the relationship between climatic conditions and human thermal comfort. It helps architects, engineers, and urban planners determine appropriate passive design strategies for buildings based on local climate data. The chart considers factors like temperature, humidity, wind speed, and solar radiation to suggest suitable design interventions such as natural ventilation, shading, evaporative cooling, or thermal mass utilization.

2.8 Ecotect analysis

Autodesk Ecotect Analysis was a powerful building performance simulation software used by architects, engineers, and urban planners to analyze environmental conditions and optimize sustainable building designs. It provided detailed insights into solar exposure, thermal performance, daylighting, acoustics, and ventilation to enhance energy efficiency and occupant comfort. Ecotect was widely utilized for bioclimatic design before being discontinued in 2015 and partially integrated into Autodesk's Green Building Studio and Revit (Attia, 2011).

Ashrae standards for thermal comfort

Thermal comfort is a key factor in building design, ensuring occupant well-being and productivity. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has developed standards to define and assess thermal comfort conditions in buildings. The primary standard governing thermal comfort is ASHRAE Standard 55, which establishes criteria for indoor environments based on factors such as air temperature, humidity, airspeed, and metabolic rate (ASHRAE, 2021).

According to ASHRAE 55 (2020), the indoor thermal comfort temperature range depends on factors such as air movement, humidity, and clothing insulation. The recommended temperature bands for residential buildings are: Winter: 20-24 oc for naturally ventilated buildings Summer: 23-27 oc for naturally ventilated buildings ASHRAE 55 incorporates an adaptive model, which is particularly useful for vernacular architecture relying on passive cooling (e.g., shading, high thermal mass, natural ventilation).

Thermal Acceptability Limits: For indoor operative temperature: Comfort band shifts with outdoor mean temperature (De Dear & Brager, 2002).

Upper limit can exceed 30°C in hot climates if airflow and shading are optimized.

For relative humidity: Recommended range: 30% - 60% (ASHRAE, 2020). In hot-humid climates, higher airspeed (0.8 m/s) improves comfort.

3. Research Methodology

The methodology for this study will be a mixed-methods approach, combining both qualitative and quantitative research techniques. This approach ensures a comprehensive analysis of a role of stack effect in thermal comfort in residential building, focusing on the Morang region of Nepal.

3.1 Paradigm

This research will adopt a pragmatic paradigm, which integrates both qualitative and quantitative approaches. The pragmatic paradigm emphasizes using methods that provide practical insights into the research problem, without being bound by rigid methodological doctrines. It allows for an exploration of both numerical data (temperature differences, thermal loads) and contextual understanding (architectural design, stakeholder perceptions).

3.2 Ontology (Nature of Reality)

Buildings have physical characteristics (insulation, materials) and energy consumption patterns that can be objectively measured. The research will focus on uncovering these realities by gathering data on energy consumption, design features, and building performance.

3.3 Epistemology (Nature of Knowledge)

Knowledge): Knowledge is derived from a combination of objective, quantifiable data and subjective user experiences, providing a comprehensive understanding of the research issue.

3.4 Methodology (Approach to Inquiry)

A mixed-methods approach is employed, blending data-driven analysis with user-focused insights to offer practical, solution-oriented outcomes.

3.5 Research Design

The study will adopt a case study approach, focusing on residential buildings in Morang.

3.6 Data Collection Methods

1. Literature Review

A thorough review of existing literature related to role of stack effect in thermal comfort in residential buildings in Nepal is conducted. This helps to identify research gaps, problem statement, research objectives and research questions. This establish the theoretical framework and help to identify key variables to measure thermal comfort in the residential building.

2. Primary Data Collection

a. Field Surveys

Primary data is collected through the detail surveyed of the case study building. Measuring tape is used for determining the actual dimension the building. Arduino Nano Dataloggers are used for the calculation of the three different temperatures and humidity of the buildings which has the accuracy of ±5% RH & ±2 °C. Voice recorder is used for the short interview of the house inhabitants.

b. Interviews

Surface interviews is conducted with residents and owner, to explore the construction practices and materials used.

c. Observational Studies

Direct observations of selected buildings paying attention to aspects like insulation, window placement, natural ventilation, opening sizes, etc.

3. Secondary data collection

Data from previous studies, government reports, climate datas from department of meterology, weather EPW file, etc are collected to support the field findings.

Data Analysis Techniques

A. Thermal Performance Analysis

Temperature and humidity data thus collected through sensors in different parts of the buildings are analyzed to assess the effectiveness of cross ventilation, attic space, effect of *Murgar size*- typical term of *tharu* for the projection of ridge of roof, passive cooling, and natural ventilation.

B. Energy Simulation Models

Using energy simulation software Ecotect, models of case study building with different cases are created to simulate thermal performance under various conditions (e.g., seasonal variations, indoor comfort levels). The simulation will help to predict the hourly temperature differences, discomfort hours, etc of the buildings. After collecting all the datas and simulations outcomes, the results are analyzed for the conclusion and recommendation.

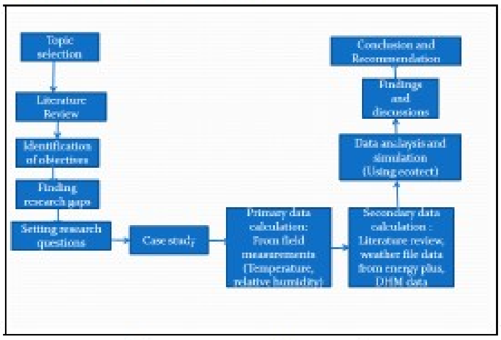

Figure 1: Research framework

4. Case study

1. Introduction The stack effect, a natural ventilation phenomenon, plays a crucial role in regulating indoor thermal comfort, particularly in regions with hot climates like Morang, a district in Nepal's Terai region. The vernacular architecture in site, developed over centuries, has integrated passive cooling strategies to address the region's extreme summer temperatures and high humidity levels. These traditional design features, such as high ceilings, strategically placed windows, and ventilated courtyards, exploit the stack effect to create comfortable indoor environments without the need for mechanical cooling systems.

The purpose of this case study is to explore how the stack effect influences thermal comfort in vernacular residential buildings in Morang. By investigating a selection of homes in this region, the study aims to understand how the stack effect is harnessed in building design and how it contributes to reducing indoor temperatures, improving air quality, and enhancing overall thermal comfort.

Budhiganga rural municipality lies in Morang district of Terai region representing the hot and humid climate of Nepal. In summers the outdoor temperatures range from 26 to 41°C while in the winter the mean temperature ranges from 14 to 28 °C. The temperature during the winter does not drop down drastically and the winter months is minimum compare to summer (Department of meterology).

Figure 2: Typical house of the site area

The case study area is mostly inhabited by *Morangiya tharu* and uses their typical method of construction while constructing their houses. While we visit the case study area, we can usually observe similar roofing technology characters consisting of heap roof with the projection from the two sides of ridge. According to the interview of the inhabitants Mr. Parshuram Chaudhary they built this type of projection (*Murgar*- typical tharu term) for the escape of smokes coming form *Tuki* lamp in the past due to shoratage of electricity in that area but the same construction technology continuous till today due to inherent knowledge of workmanship and the technology is using by all the people of different castes in that region.

For this study of role of stack effect in thermal comfort in residential building, data loggers are used for the calculation of three different temperatures: outdoor, indoor room temperatures and attic space temperatures.

Description of Selected Buildings Vernacular building is selected for the case study the features of the building are:

Floor height: 6'8"

Builing materials used: Bamboo strips, mud, cow dung, timber & CGI sheet

No. of storey: 2 storey with attic spaces

Case study building measurement Case study building is detailly measured using measuring tape and site is analyzed. While analyzing the site it is observed that, wind breeze is flowed from East to west direction of the building and the roof projection (*Murgar*) is made in the north to south direction of the house. From the analysis of the case study building, we can see that hot air flow from the room to the outside surrounding through attic space and the *murgar* play vital role for flowing of the air.

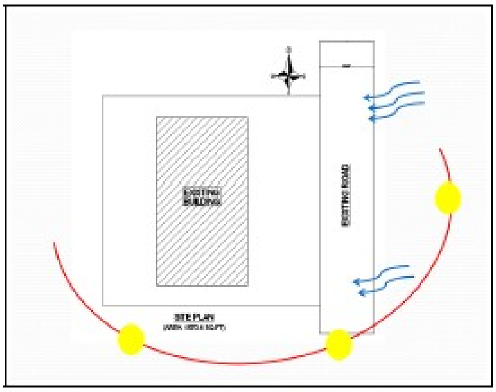

Figure 3: Site plan of the case study building showing solar path and wind direction

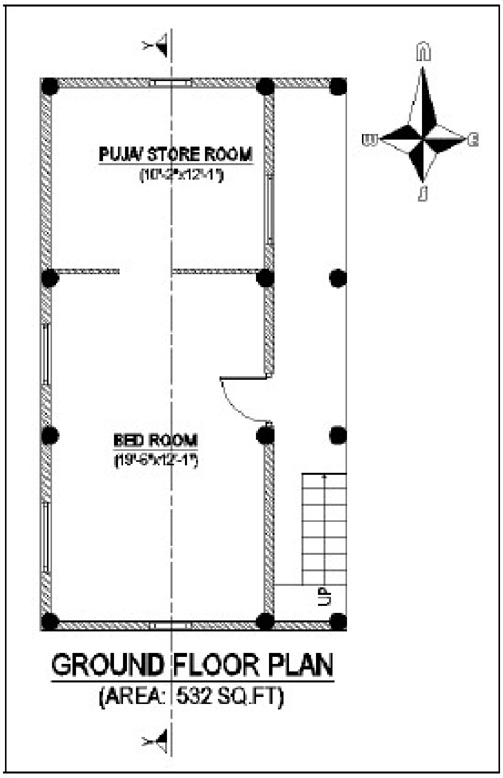

Figure 4: Ground floor plan

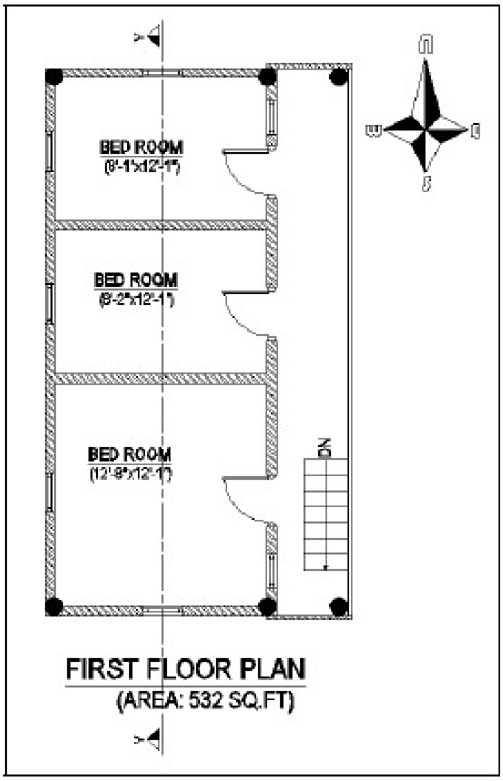

Figure 5: First floor plan

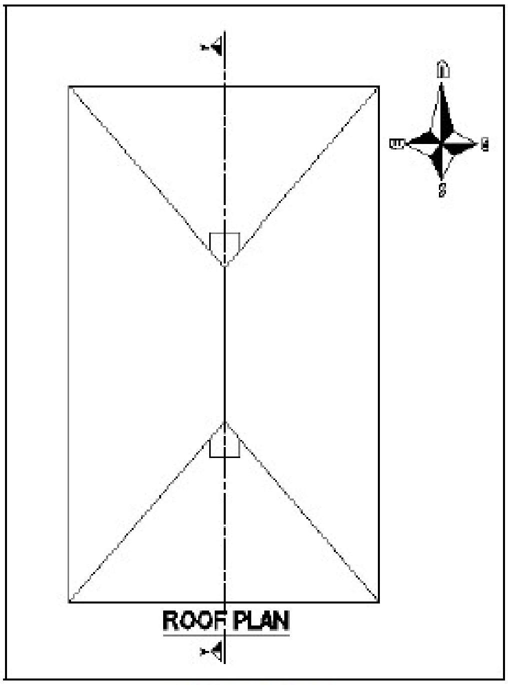

Figure 6: Roof plan

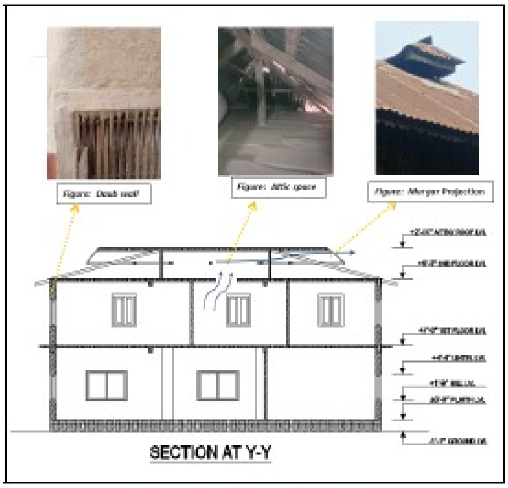

Figure 7: Sectional details

Figure 8: Datalogger placed inside the room for indoor temperature

Temperature measurement (Datalogger)

Datalogger are placed at verandah, inside the room and at the attic space of the case study building for the measurement of temperature and humidity for 10 days as shown in the figure below:

Figure 9: Datalogger placed inside Attic space

After the continuous measurement of the data for 10 days, obtained datas are segregated in the basis of day time data and night time data in the excel as shown below:

Temperature during day (5:00 am - 5 pm)								
S.N	Date	Time	Temperature (c)			Humidity (%)		
		(Day)	External	Internal	Attic spac	External	Internal	Attic space
1	1/29/2025	14:42:48	26.8	24.1	31.2		67.6	
2	1/29/2025	15:43:04	26.3	23.8	30.8		64.9	
3	1/29/2025	16:43:20	24.6	22.8	28.4		67.6	
4	1/29/2025	17:43:35	23.2	21.2	27.8		73.4	
16	1/30/2025	5:46:38	11.8	12.9	14.2		83.3	
17	1/30/2025	6:46:53	12.2	12.5	14.6		83.7	
18	1/30/2025	7:47:07	12.4	12.6	14.9		84	
19	1/30/2025	8:47:22	14	13.5	16.1		82.7	
20	1/30/2025	9:47:37	15.3	14.6	16.9		79	
21	1/30/2025	10:47:52	17.6	16.6	18.8		78.1	
22	1/30/2025	11:48:07	21.3	19.5	23.6		78.7	
23	1/30/2025	12:48:23	24.3	21.8	27.9		72.7	
24	1/30/2025	13:48:38	25.6	23.3	29.8		68.5	
25	1/30/2025	14:48:54	25.9	23.9	30.4		66.6	
37	2/3/2025	5:03:09	14.8	15.3	17.4		79.1	
38	2/3/2025	6:03:25	15.1	15.6	18.3		83	
39	2/3/2025	7:03:40	16.2	15.5	19.4		82	
40	2/3/2025	8:03:55	16.8	15.9	19.8		82.2	
41	2/3/2025	9:04:11	17.9	16.6	21.2		79	
42	2/3/2025	10:04:26	20.1	18	23.4		79	
43	2/3/2025	11:04:42	22.3	19.8	25.6		76.7	
44	2/3/2025	12:04:57	24.1	21.5	27.3		73.4	
45	2/3/2025	13:05:13	25.8	23.1	28.6		70.4	
46	2/3/2025	14:05:29	27.1	24.1	31.4		66.4	

Figure 10: Temperature measured during day

Temperature during night (6:00 pm - 4 pm)								
S.N	Date	Time	Temperature (c)			Humidity (%)		
		(Night)	External	Internal	Attic spac	External	Internal	Attic space
5	1/29/2025	18:43:51	21.2	19.8	19.1		75.8	
6	1/29/2025	19:44:06	19.4	18.8	18.2		77.8	
7	1/29/2025	20:44:22	18.6	17.8	17.1		78.7	
8	1/29/2025	21:44:37	17.8	17	16.6		79.6	
9	1/29/2025	22:44:52	16.8	16.2	16.4		80.1	
10	1/29/2025	23:45:08	15.9	15.6	16.1		80.3	
11	1/30/2025	0:45:23	15.3	15	15.8		80.6	
12	1/30/2025	1:45:38	14.1	14.5	14.9		81.4	
13	1/30/2025	2:45:53	13.2	13.9	14.2		81.4	
14	1/30/2025	3:46:08	12.9	13.4	13.6		82.6	
15	1/30/2025	4:46:23	12.6	13.2	13.4		82.8	
26	2/2/2025	18:00:18	23.6	22.4	21.8		72.8	
27	2/2/2025	19:00:34	22.4	21.3	20.8		74.5	
28	2/2/2025	20:00:49	21.8	20.4	20.1		74.6	
29	2/2/2025	21:01:05	20.4	19.6	19.4		75.2	
30	2/2/2025	22:01:21	19.5	18.6	18.8		75.8	
31	2/2/2025	23:01:37	18.8	18.1	18.3		77.7	
32	2/3/2025	0:01:52	17.8	17.6	17.9		76.9	
33	2/3/2025	1:02:08	16.8	17	17.2		77.6	
34	2/3/2025	2:02:23	16.2	16.6	16.8		77.9	
35	2/3/2025	3:02:39	15.6	16.1	16.3		78.1	
36	2/3/2025	4:02:54	15.0	15.7	15.9		78	
50	2/3/2025	18:06:33	23.6	22.1	21.8		74	
51	2/3/2025	19:06:49	22.5	21.2	21	80.9	76.6	

Figure 11: Temperatue of Night

Preparation of Bioclimatic chart The original site Budhiganga rural municipality do not possess any meterological station so that temperatures datas are obtained from the nearest station i.e. Biratnagar airport, which is 12 km from the site .It is the datas from 2014-2025.

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Figure 12: Temperature data from DHM, Dharan

Bioclimatic chart is prepared from the obtained datas in order to find out the comfort band of the site for winter and summer season and the comfort band of the site are:

Winter comfort band: (23-29.5)$^{\circ}$c

Summer comfort band: (27.3-34)$^{\circ}$c

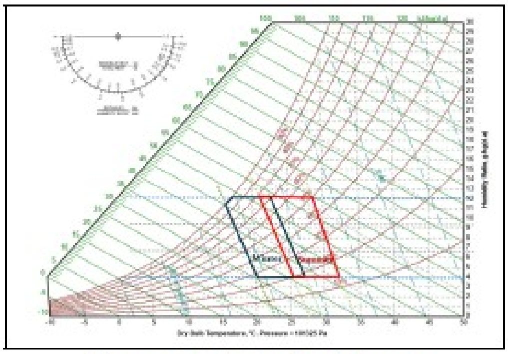

Figure 13: Bioclimatic chart of Morang

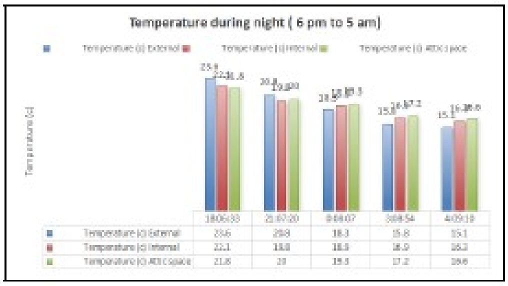

Figure 15: Night time temerature analysis

5. Analysis and Findings

5.1 Temperature Analysis

The obtained temperature datas from the survey are compared between outdoor, indoor and attic space temperature and analyzed using bar graph as shown below. From the analysis of the day time temperature datas and bar graph of February of the case study building, we can easily view that outdoor building temperature is more than the indoor temperature and the attic temperature is more than the indoor temperature. So that, we can say heat is gaining by the room from the outdoor and losing heat to the attic space through cross ventilation of the room we can say that internal temperature is in comfort band i.e. 24.1°c (Adapt comfort band for vernacular building is 16°c-30°c according to ASHRAE standards).

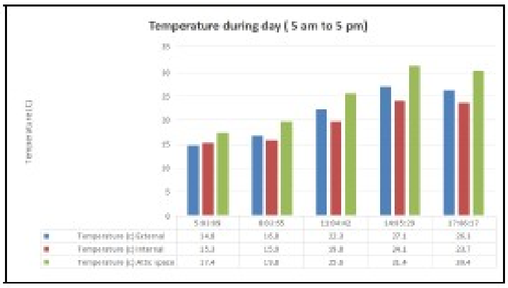

Figure 14: Day time temperature analysis

From the analysis of the given night time temperature data, we can say that internal room temperature is more than the outdoor temperature and constantly losing heat to the attic space through the cross ventilation of room since attic possesses higher temperature than indoor. Although, indoor is losing heat to the attic it is still lying within the comfort band i.e. 16.9°c.

5.2 Ecotect model analysis

Ecotect software is used for the analysis of the different scenario of the various cases. At first zone management and material management are done before starting the simulation. Three different cases with their different zone management and material management and the simulation results are given below:

a) Base case In this case actual modeling of the case study building is done with the obtained thermal comfort band from the bio climatic chart and the primary data are used for the material management and zone management as shown below:

- Floor height: 7'
- Stack hole size (*Murgar):* 6"x 6" both sides
- Roof: Heap with attic space
- Windows size: 3'10" x 2'6"
- No. of voids between rooms and attic space: 1 in the middle room

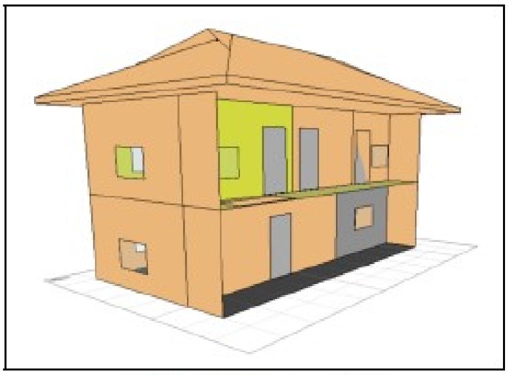

Figure 16: Base case model

Zones are divided under mainly three zones, they are: Ground floor zone, First floor zone and Roof zone. The details of particular zones are given below:

Groud floor zone

Clothing: 0.40

Humidity :64%

Air speed: 0.00 m/s

No. Of people: 3

Air change rate: 1

Wind sensitivity: 0.10

Comfort band: 23-34 °c

First floor zone

Clothing: 0.40

Huidity : 72%

Air speed: 0.30 m/s

No. Of people: 4

Air change rate: 50

Wind sensitivity: 0.10

Comfort band: 23-34 °c

Roof zone

Clothing: 0.40

Huidity : 60 %

Air speed: 0.10 m/s

No. Of people: 1

Air change rate: 2

Wind sensitivity: 0.10

Comfort band: 23-34 °c

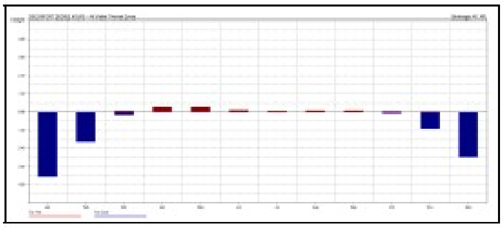

Figure 17: Discomfort degree hours of Base case

The data shown above here is the discomfort degree hours of all visible thermal zones. By observing this data, we can say that total too hot degree hours is 1317.2 and the total too cool degree hours is 10629.4.

b) Case I In this case there is no attic space and *Murgar* for the stack effect in comapare to base model and uses the obtained thermal comfort band from the bio climatic chart. The primary data are used for the material management and zone management as shown below:

- Floor height: 7'
- No ***Murgar***, no stack effects
- Roof: Heap but not possesses attic space
- Windows size: 3'10" x 2'6"

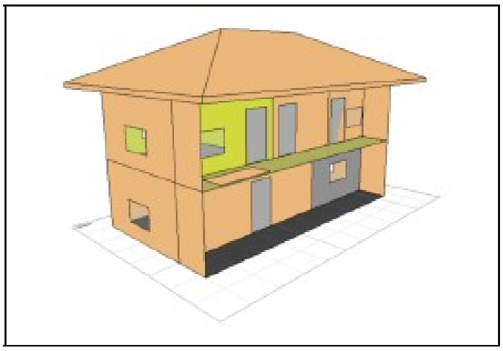

Figure 18: Case I model

Zones are divided under mainly three zones, they are: Ground floor zone, First floor zone and Roof zone. The details of particular zones are given below:

Ground floor zone

Clothing: 0.40

Humidity :60%

Air speed: 0.10 m/s

No. Of people: 3

Air change rate: 1

Wind sensitivity: 0.10

Comfort band: 23-34 °c

First floor zone

Clothing: 0.40

Humidity : 60 %

Air speed: 0.10 m/s

No. Of people: 4

Air change rate: 1

Wind sensitivity: 0.10

Comfort band: 23-34 °c

Roof zone

Clothing: 0.40

Humidity : 60 %

Air speed: 0.10 m/s

No. Of people: 2

Air change rate: 0.50

Wind sensitivity: 0.10

Comfort band: 23-34 °c

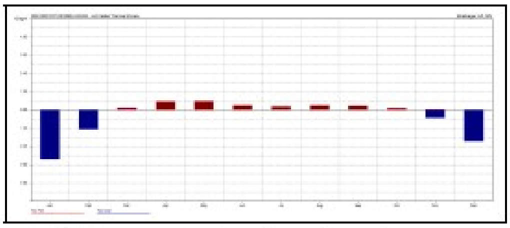

Figure 19: Discomfort degree hours of Case I

The data shown here is the discomfort degree hours of all visible thermal zones. By observing this data, we can say that total too hot degree hours is 2708.3 and the total too cool degree hours is 7116.8. The building is more hot from the month April to October.

c) Case II This case is updated from the base case model. In this case the height of the model is 10' and s there is attic space with more broad *Murgar* for the stack effect in compare to base model and uses the obtained thermal comfort band from the bio climatic chart. The primary data are used for the material management and zone management as shown below:s

l Floor height: 10'

l ***Murgar*** void size: 1'6" x 1'6"

l Roof: Heap with attic space

l Windows size: 4'0" x 3'6"

l No. of voids between rooms and attic space : 3 (1 in each room) for cross ventilation

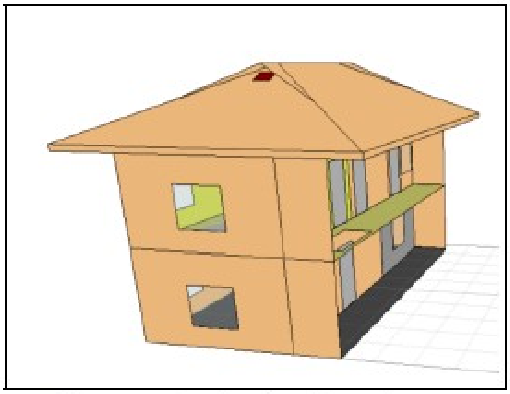

Figure 20: Discomfort degree hours of Case II

Zones are divided under mainly three zones, they are: Ground floor zone, First floor zone and Roof zone. The details of particular zones are given below:

Ground floor zone

Clothing: 0.40

Humidity :64%

Air speed: 0.50 m/s

No. Of people: 3

Air change rate: 50

Wind sensitivity: 0.25

Comfort band: 23-34 °c

First floor zone

Clothing: 0.40

Humidity : 87 %

Air speed: 0.70 m/s

No. Of people: 4

Air change rate: 50

Wind sensitivity: 0.25

Comfort band: 23-34 °c

Roof zone

Clothing: 0.40

Humidity : 75 %

Air speed: 0.70 m/s

No. Of people: 1

Air change rate: 200

Wind sensitivity: 0.25

Comfort band: 23-34 °c

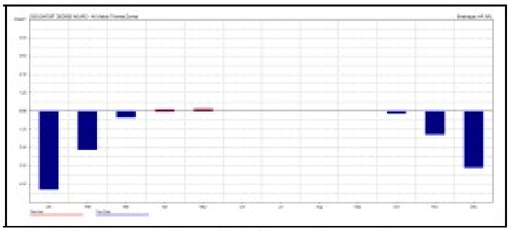

Figure 21: Discomfort degree hours of Case II

The data shown here is the discomfort degree hours of all visible thermal zones. By observing this data, we can say that total too hot degree hours is 269.7 and the total too cool degree hours is 13651.9 The building is cool from the month June to September, which is summer season in this region.

Comparisons of different cases Here is discomfort degree hours of three different cases. These data and bar graph shows that, case II building is too cool in month of January in compare to others with total degree hours 13651.9 and the case I is less cool with the total degree hours 7116.8. Similarly, according to the graph case I building is too hot from the months March to September with the total hot degree hours of 2708.3 and the case II building is lesser hot in most of the summer months in compare to others with the total hot degree hours of 269.7.

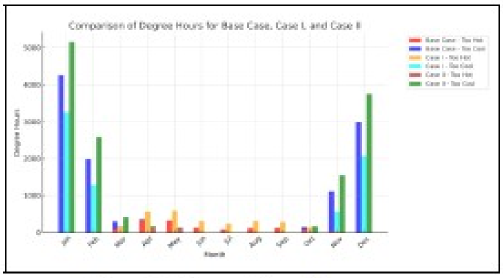

Figure 22: Comparision of three cases

6. Conclusions

The study highlights the role of stack effect in thermal comfort in residential building in a case of Morang district. This research has been carried out in the village area in the vernacular building. Although, building materials, different climatic factors like micro climate, shading devices, etc also play a vital role in thermal comfort of the building but here in this study I have taken all these constituents of the building as constant and only focus on the traditional roof construction technology of this area. Also, I have created three cases on the basis of literature review with one original building as a base case and performed different analysis through simulation using Ecotect.

The temperature data recorded from the case study building during the day (5:00 AM - 5:00 PM) and night (6:00 PM - 5:00 AM) provides insights into the thermal behavior of external, internal, and attic space environments.

In Daytime Observations:

- The external temperature rises from 14.8°C at 5:03 AM to 27.1°C at 2:05 PM, then slightly decreases to 26.3°C at 5:06 PM.
- Internal temperatures follow a similar trend, increasing from 15.3°C to 24.1°C before settling at 23.7°C.
- The attic space experiences the most significant rise, reaching 31.4°C at peak daytime (2:05 PM) due to solar heat gain from CGI sheet roof.

In night time observations:

- External temperature drops gradually from 23.6°C at 6:06 PM to 15.1°C at 4:09 AM.
- Internal temperatures also decrease but at a slower rate, maintaining higher stability compared to the external environment.
- The attic space follows a similar pattern, cooling down from 21.8°C to 16.6°C by early morning.

This shows that, Internal temperatures remain more stable compared to external temperatures as well as the temperature difference between external and internal spaces is more prominent at night suggesting effective cross ventilation from room to attic space. The attic space exhibits the highest temperature fluctuations, indicating significant heat gain during the day and heat loss at night which play vital role in losing the internal room temperature from cross ventilation through *Murgar.*

The Ecotect simulation further validated these findings, the case I which possesses no attic space and *Murgar* as a cross ventilation has maximum discomfort hours in summer months in compare to other cases while the case II which possesses the rise in floor height, increase in the opening sizes, increase in the number of voids between rooms and attic space as well as possesses large size of *Murgar* openings from two sides has the best comfort level during the summer months in compare to other cases. Since, Budhiganga rural municipality of Morang experience summer in most of the months nearly about 10 months, case II which possesses updated form of stack effect will able to create better thermal comfort in the living spaces of the residential building.

Given the lack of quantitative data on stack effect in case of Morang, Terai region, this research hopefully provides valuable insights for designer, workmanhsip and researchers. These findings emphasize the need for improved roof construction technology with more floor height, more number of voids for the cross ventilation between rooms and attic spaces and sufficient size of *Murgar* for the proper stack effect in verncacular residentail bulding of terai region like Morang. Addressing proper stack effect can reduce energy consumption, mitigate heat loss, and improve indoor comfort, contributing to more sustainable and energy-efficient buildings. The study (Givoni, 1998) also highlight that improper attic ventilation can trap heat, leading to discomfort in lower floors. Studies by Santamouris et al. (2006) suggest that higher ceiling heights, well-placed openings, and roof venting enhance the stack effect, promoting natural cooling and reducing reliance on mechanical ventilation.

7. Recommendation

The stack effect is a critical natural ventilation mechanism that can significantly enhance thermal comfort in residential buildings in Morang. By implementing attic Ventilation for better heat dissipation, optimizing window and vent Placement for effective airflow and increasing ceiling height, homeowners can reduce indoor overheating, enhance airflow, and lower energy dependence on artificial cooling systems. These recommendations aim to make homes more energy-efficient, comfortable, and environmentally sustainable in the context of Morang's climate.

+

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