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Energy Performance of Traditional Tharu Building: A Case of Dang Deukhuri

by

Sumit Chaudhary

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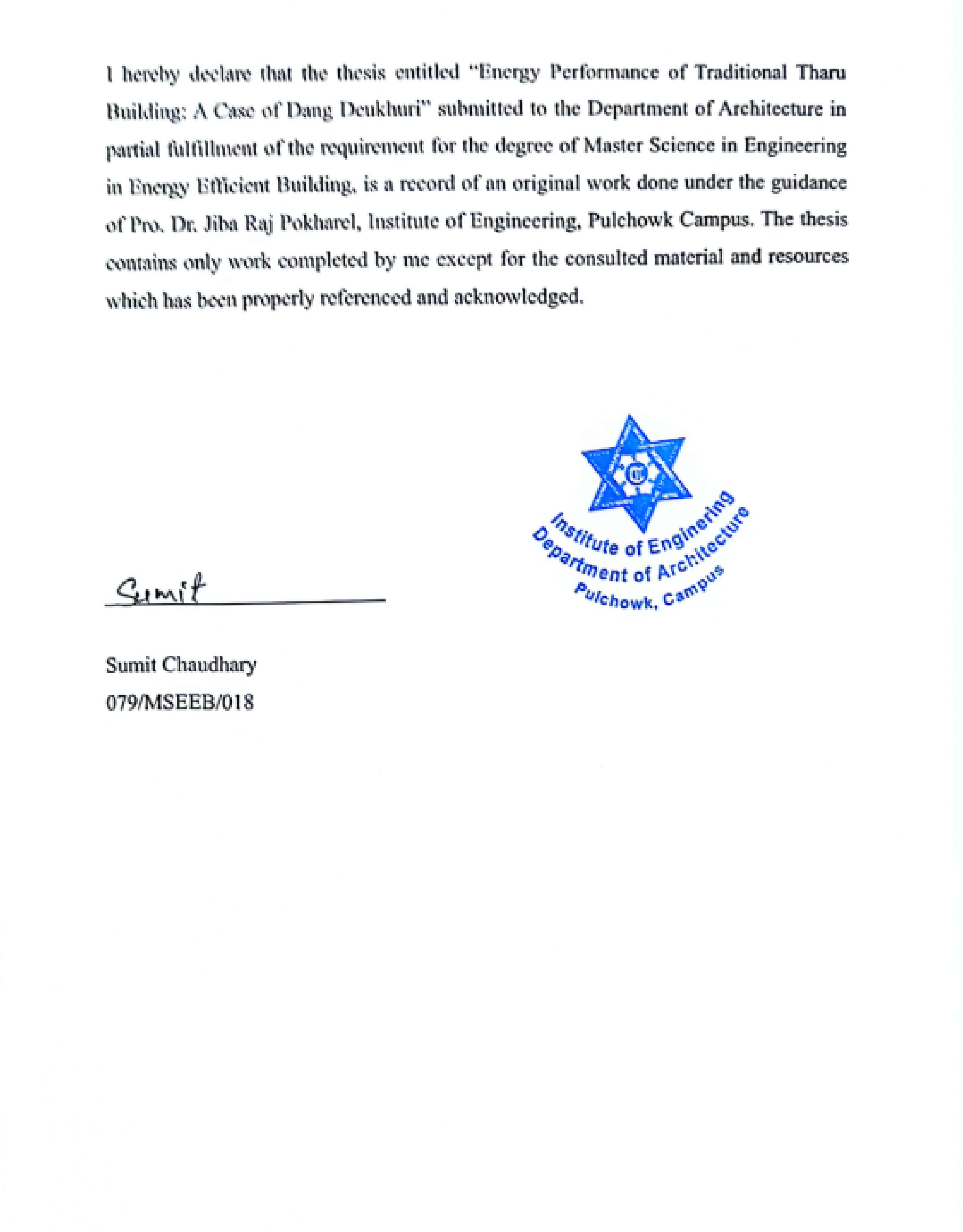

I hereby declare that the thesis entitled "Energy Performance of Traditional Tharu Building: A Case of Dang Deukhuri" submitted to the Department of Architecture in partial fulfillment of the requirement for the degree of Master Science in Engineering in Energy Efficient Building, is a record of an original work done under the guidance of Pro. Dr. Jiba Raj Pokharel, Institute of Engineering, Pulchowk Campus. The thesis contains only work completed by me except for the consulted material and resources which has been properly referenced and acknowledged.

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Energy Performance of Traditional Tharu Building: A Case of Dang Deukhuri"** submitted by Sumit Chaudhary in partial fulfilment of the requirements for the degree of Master of Energy Efficient Buildings.

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Abstract

The world is experiencing rapid change in climate and environment, thus raising concerns for sustainable and energy efficient practices. A study by Oliver shows that around 90% of building worldwide are constructed by people who use them where energy efficiency standards may be inadequate which leaves large potential to reduce energy use. Energy Efficiency in buildings can be achieved via active and passive means. Vernacular architecture has been getting attraction regarding their energy efficient and sustainable design approach since they are built using locally sourced construction materials. These buildings are strongly influenced by the climate and often holds useful ideas for optimizing energy use with simple methods. This report tries to study the energy performance of modified Traditional Tharu building using computer simulation as well as field data collection of temperature and humidity to quantify the actual heat gain and heat lost inside these traditional buildings.

Keywords: Simulation, Energy Performance, Discomfort Hour, Heat Gain and Loss

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CHAPTER 1: INTRODUCTION

1.1 Background

In today’s world, the environment and climate are changing rapidly, raising concerns about sustainable and energy-efficient building practices. Buildings account for about 45% of energy usage world wide and 80% of fresh water use (Zhiqiang (john) Zhai, 2010). The energy used by buildings is a major contributor to greenhouse gas emissions, global warming, and environmental issues like acid rain. To address these challenges, there is an urgent need to adopt sustainable practices in the construction industry, especially in developing countries like Nepal.

In developed countries, most buildings are designed by engineers and architects, and energy efficiency is taken seriously. However, a study by Oliver shows that around 90% of buildings worldwide are constructed by the people who use them. This means many buildings are built without considering energy efficiency, which leaves a large potential to reduce energy use. Energy-efficient buildings achieve this by reducing energy consumption while maintaining comfort (Constantin Ionescu, 2015). A building is considered energy-efficient if it uses less energy throughout its life. Energy-efficient practices not only lower energy demand but also help protect the environment, supporting sustainable development.

Energy efficiency in buildings can be achieved in two ways: passive strategies and active systems. Passive strategies use natural features like insulation, solar heat, ventilation, and shading, while active systems use energy-powered technologies like heating and cooling systems. Learning from traditional buildings, which were built with limited technology but relied on nature for comfort, can provide valuable insights for designing modern energy-efficient buildings. Without studying how traditional buildings worked, it is difficult to create new ideas for reducing energy use in modern construction.

Vernacular building architecture resembles those types of buildings which are designed using local materials, traditional techniques, and knowledge that are transferred from generations to generations. These buildings are strongly influenced by the climate, culture, and resources of the area. Vernacular architecture often holds useful ideas for optimizing energy use with simple methods. Since ancient builders lacked modern heating and cooling systems, they made designs that depended on the sun and wind for natural comfort (Olgyay, 1963; B. Givoni, 1969; Koenigsberger, 1974). Studies have also shown that these buildings can achieve better thermal performance by following passive design strategies (R. Shanthi Priya, 2012).

Article by Susanne Bodach et al. (Susanne Bodach, 2014) examined vernacular architecture in various climate zones and identified four main climate zones: Sub-Tropical (Terai), Warm Temperate (Hills), Cool Temperate, and Alpine. Out of these zones, Tharu buildings in the Sub-Tropical climate have distinct features and stands out since these buildings are built using locally available materials like mud, straw, and bamboo and have passive design elements incorporated in them such as light thermal mass, small openings, raised floor, openings below roof and many more. These buildings are recognized for being thermally comfortable and energy-efficient. However, many traditional Tharu buildings are being replaced by modern reinforced concrete buildings, and the techniques and knowledge used to build them are at risk of being lost.

This study tries to uncover how the traditional Tharu building in Sub-Tropical climate zone behaves by analyzing the energy performance in terms of heat gain and heat loss occurring in the building by considering the literatures mentioned by Susanne Bodach's article. By examining these buildings, the goal is to find out how the construction materials, passive design features and traditional practices have contribution to the energy efficiency. This valuable information not only will help to conserve these traditional buildings but will also serve as a basis for developing more sustainable and energy efficient buildings in the coming future.

1.2 Need & Importance

Global CO2 emissions are increasing, and it is expected they will keep rising in the future. Without strong international policies, greenhouse gas (GHG) emissions could go up by 52% from 2005 to 2050, while energy-related CO2 emissions might rise by 78% (OECD, 2008). The population of the world is growing rapidly and have consequently created pressure on the Earth's climate change ultimately increasing the Earth's temperature. Large number of people means greater demand in economic activity, housing demand and higher energy consumption. Building sectors alone consumes 30-40% of the world's energy and among this 40-50% is consumed alone on building heating, cooling, ventilation and overall HVAC systems (Mubashir Wani, 2019).

In developed countries, there are building codes which regulates energy usage in buildings. But in Nepal, which does not have its own energy efficiency codes, it is important to focus on energy efficiency in buildings through research and studies. These studies can guide policymakers to create strategies that support sustainable development. After the end of the civil war in Nepal, infrastructure and buildings are being developed rapidly, especially reinforced cement concrete (RCC) buildings. Sadly, this has caused traditional buildings and their construction techniques to disappear. Preserving traditional buildings is important not only for protecting our culture and history but also for learning from their natural ability to save energy. For example, traditional Tharu buildings which are built by sourcing locally available materials and construction techniques that are properly suited to the surrounding climate which makes these building structures energy efficient and comfortable to live inside them. By investigating these types of buildings, we can gain valuable insights regarding their design philosophy, building materials, which can be used to build modern structures leading to energy efficient buildings. This will be creating a valuable lesson which can be beneficial for country like Nepal as it is largely affected by climate change which will help to reduce energy use, protect the environment and create a sustainable building practice.

These studies can connect old knowledge with new ideas, helping us adapt traditional methods to modern needs. By doing this, we can save energy, cut greenhouse gas emissions, and support a sustainable building industry in Nepal. Learning from the past and using it in today’s construction can address global environmental issues while also helping Nepal grow in a sustainable and environmentally friendly way.

1.3 Problem Statement

Traditional buildings which are built by utilizing locally sourced materials and utilizes local craftsmanship and building technology which are very much adapted to the local climate and socio-economic conditions. Over the years, these buildings have evolved in design, reflecting the culture and lifestyle of the people, and varying based on climate, topography, and material availability. The Tharu people, who reside in the southern plains of Nepal, traditionally built homes using light thermal mass materials such as mud, straw, and bamboo, with thatched roofs. These buildings are energy-efficient and thermally comfortable due to their natural ventilation and insulating properties, as highlighted by Susanne Bodach.

However, with the easy reach and availability of modern construction materials such as cement, brick, steel etc. the construction of traditional buildings has been slowed, and it has shifted toward modern more energy consuming modern building materials. Similarly, there has also been the lack of availability of local building materials such as timber, reed, roofing grass, mud tiles as well as increase in labor charge and unavailability of construction workers experienced in traditional building technology have also contributed to the downfall of traditional buildings. Consequently, there is a need to assess the energy performance of traditional Tharu buildings, including their thermal efficiency and comfort, before they are entirely replaced by modern construction practices. The future of building design lies in learning from the past and adapting these sustainable practices to modern construction methods.

This study tries to fill this gap by examining the energy performance of traditional Tharu buildings and tries to uncover what passive design features are present in these buildings and how these features are playing role on the thermal comfort, energy efficiency and sustainability.

1.4 Research Gap

Traditional Tharu buildings are built using locally available construction materials which are known for being thermally comfortable and energy efficient. These buildings have built in passive design features which helps them maintain the comfortable indoor living conditions. However, there has been few numbers of study which have explored how these buildings actually maintain the comfort and lower energy usage overall relating to efficiency. In recent years the number of studies being conducted on vernacular architecture have increased, they are focused on thermal comfort, energy performance but have not been carried on Tharu buildings.

Most of the climate-responsive design strategies for vernacular buildings, such as those based on Olgyay’s Bioclimatic Chart, Mahoney Table, and Giovani’s Psychrometric Chart (Susanne Bodach, 2014), are typically used in the early design phase. These tools help inform passive design but lack the capability to accurately predict energy performance and thermal comfort in real-life conditions. They also don’t fully address the complexities of modern energy use, such as daily change in energy consumption and the impact of different microclimate factors.

Additionally, existing studies, such as the thermal comfort study of Tharu buildings in Dang Deukhuri by Binay Raj Singh Tharu et al. (Binay Raj Singh Tharu, 2019 Summer), have primarily relied on room temperature to evaluate comfort. While this provides some insight, it misses other crucial parameters like relative humidity, air flow, and surface temperature, which have an important role in the overall comfort and energy performance of a building. Furthermore, these studies have not incorporated modern computer simulation tools that can predict the energy performance more accurately.

The study by H.B Rijal on the seasonal and regional difference for estimating neutral temperatures in traditional houses of Nepal which has been obtained from thermal comfort survey where researcher have carried out extensive field survey, collected field data like ambient air temperature, moisture present in air, radiation received from sunlight, air velocity and wind direction to investigate how the resident achieves thermal comfort and estimated neutral temperatures in indoor and semi-opened spaces. However, it has considered more on the occupant behavior side and lacks how the building elements affect the energy performance.

Thus, this study seeks to resolve these unexplored areas by providing an analysis of the energy performance of traditional Tharu buildings. By considering field data, such as temperature, humidity inside building, this study will offer a picture of how these buildings perform. Furthermore, it will use advanced computer simulations, such as Energy Plus & Design Builder, to predict energy performance and better understand the long-term sustainability and energy efficiency of Tharu homes.

1.5 Objectives

The primary objective is to evaluate the energy performance of modified traditional Tharu buildings by analyzing their heat gain and heat loss.

- To study the passive design features in modified traditional Tharu buildings.
- To assess how these features are impacting the performance and comfort.

1.6 Research Question

- How do modified traditional Tharu buildings perform in terms of energy efficiency particularly heat gain and heat loss?
- What role do the passive design features play in energy performance of these buildings?

1.7 Hypothesis

- Traditional Tharu buildings are energy efficient due to the use of passive design features like natural ventilation, thatch roof, mud walls and these elements helps to reduce heating and cooling loads.

CHAPTER 2: LITERATURE REVIEW

2.1 Tharu and their Origin

Tharu are the native ethnic settlers who lives in the low flat land of terai which has its border shared with India. A minority of the Tharu people also settles in India, primarily in the Champaran district of Bihar, in Uttarakhand at Udham Singh Nagar and several other places of Uttar Pradesh including Kheri, Pilibhit, Gonda, Balrampur, Gorakhpur and Bahraich (Verma, 2010). Tharu people comprise many different sub-groups, some sharing a very close life style within which there are different sub-cultures (Krauskopff, 1989). Tharu themselves claim that they certainly are the “real Nepalese” and the native ethnic settlers of Nepal, but the traditions about Tharu origins that Tharu recite and remember are not uniform (Majumdar, 1944). There are three theories about their origin. Considering the Tharu facial features, one theory is that Tharu people originated from mongoloid stock (Ibid). As stated by D.N. Majumdar, Tharu people are of mongoloid origin and have successfully inherited certain mongoloid characteristics (Majumdar, 1944). They are believed to have originated in Mongolia and travelled through upper Himalayas in seventh century and over time settled in Terai. The second theory of Rajput origins claim that Tharu people have their origin belonging to Rajasthan area of India as part of Rajput (Majumdar, 1944). The Tharu community living in western Nepal known as Rana Tharu claim they are Rajput descendants. They believe that after the Muslims attacked and killed the Rajput kings, their surviving wives came to Nepal with their servants and eventually married with them. In order to prove this claim, they point to their tradition of matrilineal supremacy in a household (Ibid). The third theory of Tharu origins holds that Tharu originated from the holy city of Banaras in Northern part of India and Tharu people are the descendants of Lord Gautama Buddha (Dahit, 2009; Guneratne, 2002; Singh, 2006). Nepali scholar and former Attorney-General of Nepal, Mr. Ramananda Prasad Singh, and his son, Nepali author Subodha Kumar Singh, argues that Tharu are the descendants of Emperor Asoka the Great and Lord Buddha (Singh, 2006)

Two main and culturally contrasted Tharu groups, Danguara, and Rana, live in Western and far western Terai. Another Tharu sub-group, Kathariya, mostly live in India and in Kailali district (Krauskopff, 2005). Danguara Tharu live in Dang, Banke and Bardiya districts. Tharu also live in Bengal, Bihar, Uttar Pradesh and Orissa states in India (Majumdar, 1944). Nepal has a total population of 29,164,578 out of which

Tharu population is 1,807,124 which is about 6.2% of total population (Nepal Population & Housing Census 2021). Similarly, Tharu people are the second largest ethnic group after Magar.

2.2 Socio-Economic

The Tharu community are the oldest known inhabitants of southern part of Nepal. Their origin is not well defined. The Tharu's belong to the Rana, Raghatiya, Solariya, Danguara and Kathariya groups which are sub-divided into clans and lineages (Toffin, 1991). The Tharu community in Dang valley settles in several villages and the inhabitant's number are in somewhere in between 50 to 200. Each village of Tharu community has a village chief chosen by the villagers called "Mahatua" whose duty is to maintain law and order in the village (Toffin, 1991). The "Mahatua" holds an important position in village both socially and religiously and his service is required when new house is being built. Similarly, the other important person of Tharu village is, "Zamindar", he maintains the relations of village and local government officials at the district level. The Tharu's of Dang don't rely on Brahmin priest for performing their religious functions and ceremonies, instead they have their own priest called, "guruvas". The Tharu people have their own language, and their Tharu language is a mixture of Nepali words (40%), Hindi words (40%) and 20% of words taken from North India (A.W. Macdonald, 1969). The religion of Tharu is composite in nature and have their own deities which are basically forest, mountain. Among them 'Cabahwa' and 'Daharcand' watch over the crops, protect men their livestock and their effigies are built at the festival ground (Toffin, 1991). The village also has a common deity temple where the community performs their ritual during child birth, festival, marriage, death. Every Tharu house has a worship room called 'Dehurar' which is placed on North-East side. The greatest festival of Tharu community 'Maghi', which is the new year for the community. In this festival, new village chief is appointed, farming contract renewed etc. In past the Tharu community preferred to stay on joint families but now slowly they are shifting towards single family. The role of women is important in the Tharu community and are responsible for looking after children, running the house, food and grain reserves (Toffin, 1991).

The Tharu economy is based on agriculture animal husbandry and the sale of certain crops for cash (MCDONAUGH). The Tharu people produces majority of their food requirement through agriculture and some items such as salt, tobacco, soap, cloth, metals are fetched from the local markets. Tharu people earn cash by trading their animals and also selling their surplus grains and oil-seeds. Similarly, these people are making money by selling their local items such as ropes, mats 'Gundri', and baskets. Cash earning also come from local seasonal work in house building, fencing and recently from road construction on a main road project financed jointly by Asian Development Bank and World Bank (MCDONAUGH). The main crop is rice which is planted once a year and is irrigated through monsoon rain. Similarly other crops are wheat, maize, mustard (lahi), potato, onion, radish, cabbages etc. Tharu people keep buffalo and cattle for ploughing field and milk, similarly chicken, goat, sheep, pig, pigeon also. Pig meat is the most favorite meat of these people and pigs are slaughtered on main festivals such as Maghi, marriage etc. Besides farming Tharu people also practice fishing which is very popular among them, hunting in forest and foraging medicine and herbs etc. In Dang everyone knows how to fish and fishing methods vary depending on season and the fish are eaten fresh, dried or sold for cash (Toffin, 1991). The Table below list the economic activity of Tharu community.

Table 1: Socio-Economic Activities of Tharu People

Month	**Agriculture**	**Handicraft, Fishing and Gathering**	**Village Ritual**	**Building and Maintenance, Trade and Social**
Magh	Irrigation of winter wheat. Transplanting reeds to stream beds. Rice threshing finished. Start of Slack Season	Collecting firewood and building materials and grasses. Fishing	Maghi Festival	Village meeting to discuss business of coming year. Renewal of contract and settling accounts. Visits of potters and basket sellers. Buffalo transporting
Phagun	Mustard cutting and threshing. Vegetable cultivation. Slack season.	Making ropes, soap, pots and women's mats. Fishing with traps and barrages	Holi or Dhureri	House building, Marriage
Cait	Harvest of wheat, lentil, barley.	Making baskets, ropes, mats. Jungle		House building, Buffalo transporting.

	Manuring and digging of bari for maize.	trip to collect roofing thatch.		
Baisakh	Linseed harvarest, Ploughing and sowing maize. Planting chilly seedlings.	Rope making. Fishing and preparing bamboo for making rain sheilds.	Dhuriya Gurai Bathanna Auli Lena (for wheat).	House reroofing.
Jeth	Maize weeding, planting minor crops: Beans, turmeric etc.	Collecting firewood and dung cakes for the monsoon.	Haroth Lena	Fence building around maize field. Making new hearths and silos. Cleaning houses.
Asar	Tending maize, planting rice seedlings. Cutting reeds, Start rice cultivation.	Making rain shields. Repairing plough & tools etc. for rice crop, fishing.	Gaiya Berhna	Blacksmiths visit to make and repair tools. Canal repair.
Saun	Rice planting	Cutting cattle fodder. Fishing with traps in canals & streams gathering crabs and snails.	Astimki	Canal repair and maintenance
Bhadaun	Weeding rice, Maize harvest, chilly harvest, Vegetable cultivation	Making ropes,baskets and fish traps.	Hardhwar, Hariya-Gurai, Atwari, Gandi Hakna	Canal work continues
Kuwar	Bari field ploughed and mustard seed sown. Reed seedling planted	Mat making by men	Dasya	Canal work continues, repairing fences, Buffalo transporting
Kartik	Planting onion seedlings, Harvest of squash plants.		Auli Lena	

Aggahan	Rice harvest, sowing linseed into rice fields, planting wheat, lentils, beans and tobacco.		Auli Udharna, Kennwa Badhna, Gauri Badhna, Dhariwan	Basket traders and potters begin to visit
Pus	Rice harvest	Collecting grasses for ropes and thatch, Collecting firewood and fishing		Repair of path and bridges, preparing for maghi festival, beer making, oil pressing etc.

(Sources: (MCDONAUGH))

2.3 Traditional Architecture of Tharu of Western Nepal

2.3.1 Traditional Building Materials

The geology of Terai region is mainly composed of coarse gravel and finer sediments. The soil is rich and fertile which is suitable for agriculture and dense Saal Forest. Thus, the materials for building traditional houses are wood, thatch, mud and sand which are abundant and locally available (Susanne Bodach, 2014). Stone is the scare material which is used for raising the building to plinth level.

2.3.2 Settlement Pattern

The village layout in Nepal’s sub-tropical climate zone is loosely spaced rather than closely spaced. The house in Tharu community village is loosely spaced and placed in linear form close to the road or they are placed in groups forming semi-closed compounds (Skar, 1999; Toffin, 1991). In the village of Danguara Tharu, the houses which are longer in size are placed in single row adjacent to the street with each house having an open spacious yard in the front location (A. Gansach, 2004). This helps in easy movement of air through the houses. The villages are located at a distance of about 20 minutes by foot from each other and connected by mud roads (Toffin, 1991). The villages are generally covered by bamboo and green hedges around them.

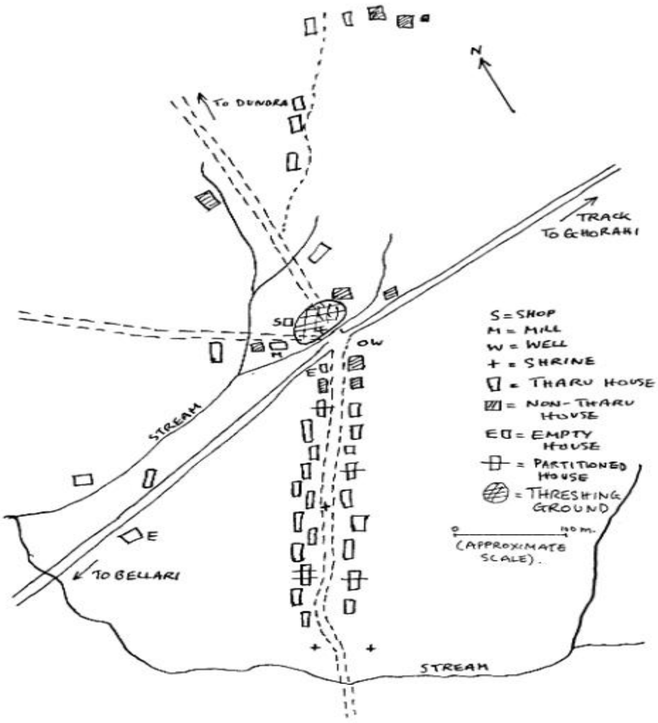


Figure 1: Sukhrwar Village: Main Settlement (Source: (MCDONAUGH))

2.3.3 Building Form and Orientation

The building structure features a rectangular layout and is surrounded with short periphery walls and which in some cases are not higher than 75cm (A. Gansach, 2004). Danguara and the Tharu community of Eastern Nepal knows as Kochila Tharu generally build the houses which are longer in span. In Danguara Tharu house the longer length is two times the shorter length and the longer side is aligned along north-south direction which decreases the solar heat gain from the sun (Susanne Bodach, 2014).

2.3.4 Building Story and internal space arrangement

Most of the traditional house in Terai consists of only one floor level whereas in Rana Tharu community the houses have a ground floor with mezzanine that serves as a storage space (Skar, 1999). These houses have high ceiling which enhances permanent ventilation which is essential in tropical and moist climate. The house is single story so the space arrangement for room is spread laterally instead of vertical. The inner zone is not divided into several parts and this creates a continuous flow which helps in the movement of air which comes from area which is shaded below the upper portion of roof (Skar, 1999). The house of Danguara Tharu have walls or divisions that do not reach the roof which provides free air circulations. In all Tharu house semi-open space in the form of verandah utilizes a considerable amount of floor space and these are shaded by roof overhang which provides an additional space of daily activities (Susanne Bodach, 2014).

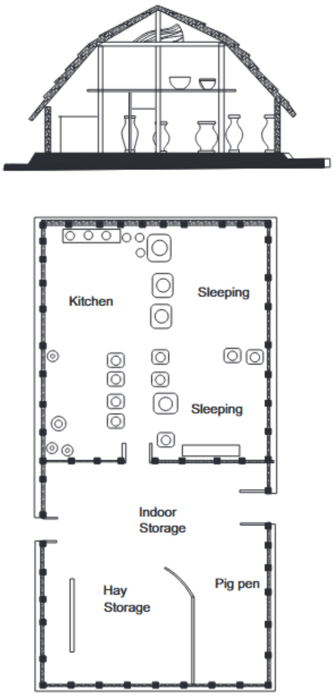


Figure 2: Floor plan and section of Danguara Tharu House
(Source: H.O. Skar)

2.3.5 Walls

The outer walls of traditional houses in terai are generally composed of thinner wall sections which are constructed based on wattle and daub construction technology (J.M. Boch-Isaacson, 1987). The exterior walls located at upper section are often made of bamboo strips which are loosely arranged in a loosely woven net which facilitates natural daylighting and continuous ventilation. Un-plastered wooden or reed walls features voids in them. In some cases, the outer walls are also made from narrow, handwoven mats of cane which are tied together to a timber structure which are plastered with mud and white wash (A. Gansach, 2004).

2.3.6 Roof

Majority of traditional houses in Nepal's sub-tropical climate have roof made of thatch in the form of pitched roof (A. Gansach, 2004 ; Skar, 1999; Toffin, 1991). The triangular opening at both ends, along with low set of windows allow a constant flow of air from the shaded areas below the eaves, which results in inside temperature that are typically cooler than those outside (A. Gansach, 2004). Danguara and Kochila Tharu house features thatch roofs that provides insulation to the building structure. The extended roof overhang prevents wall from receiving direct heat gain from sunlight. Verandah are made by extending the roof which provides comfortable space to work and even rest during night time (J.M. Boch-Isaacson, 1987).

Figure 3: Gable opening for air circulation in Tharu House, Chitwan
(Source: Bodach et. al.)

2.3.7 Foundation Floor and Ceiling

Typical Tharu house are found on plinth usually constructed using rocks or earth to prevent the inside of buildings from water during rainy season (A. Gansach, 2004). Some Tharu buildings are constructed by stacking 90 to 300 cm of wooden pieces to raise its level for preventing against water (J.M. Boch-Isaacson, 1987). The house is raised along with high ceiling enhances air circulation inside the house. Ground slab is built using mud which are compressed, tiles produced from local clay or rocks which are available nearby which are also covered with cement sand mix if allowed (Susanne Bodach, 2014).

2.3.8 Openings

Tharu houses have small number of windows which are placed near to the ground level as well as voids created below the thatch which fosters air movement thus making the interior living zone comfortable during moist and hot months of summer (A. Gansach, 2004). Shading of windows is provided by roof overhangs and placing the vegetation surrounding the building (J.M. Boch-Isaacson, 1987).

2.4 Tharu Buildings

The construction of primary structure starts with a void area demarcated partially on all sides by a bush made from thorny cactus. This space, ’garik-angna’ spans across a land of 3.2 m2 and a rectilinear corridor which moves along it and connects the road with the buildings. Straw and dung are stocked in the ‘garik-angna’.

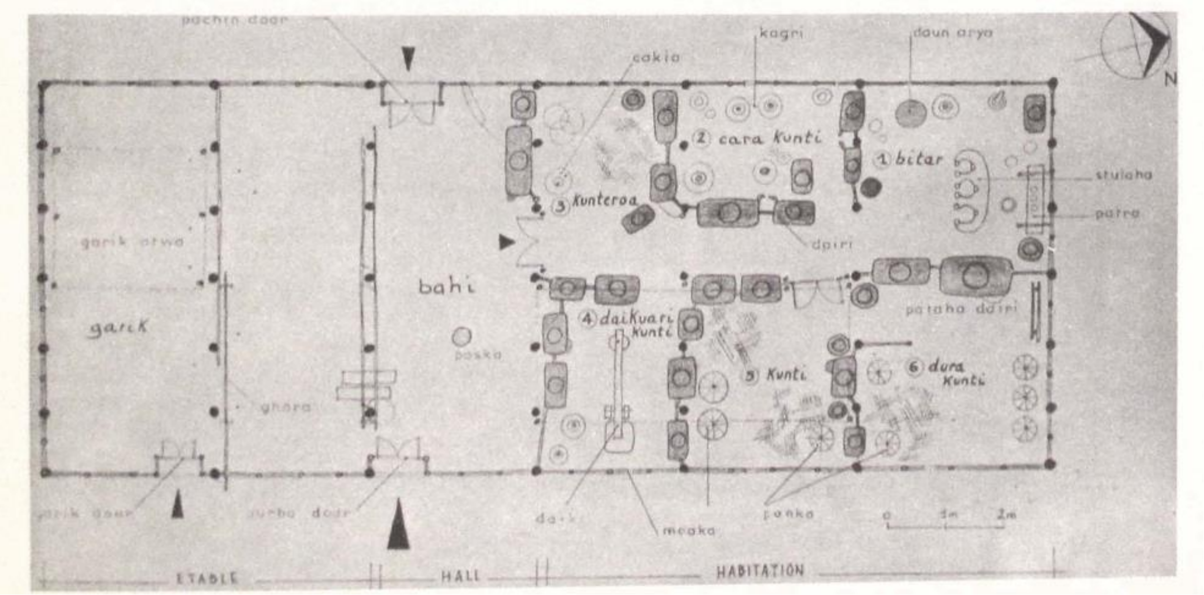


Figure 4: Three Distinct zones of Danguara Tharu House (Source: (Toffin, 1991))

The shape of the building is rectangular and which is built on a slightly raised platform and has height of 5.2m. The roof has slope of 35º which almost touches the ground and leaves very little height for walls. The main facades of Tharu buildings are oriented in east direction and the belief says that it brings prosperity to the family. The main façade has doors and small openings for windows. The Tharu house is typically divided into three distinct zones, cattle shed, entrance hall and the residential space. The house described here is of 6 bays, where two bays is for cattle, one bay which is situated between cattle shed and living space is called bahri or entrance hall. This entrance or bahri has two doors on eastern and western façade. The bahri functions as guestroom as well as meeting and relaxing area. The three bays serve as the living space where it is divided axially into 6 rooms. The entrance hall and living space is partitioned by wall

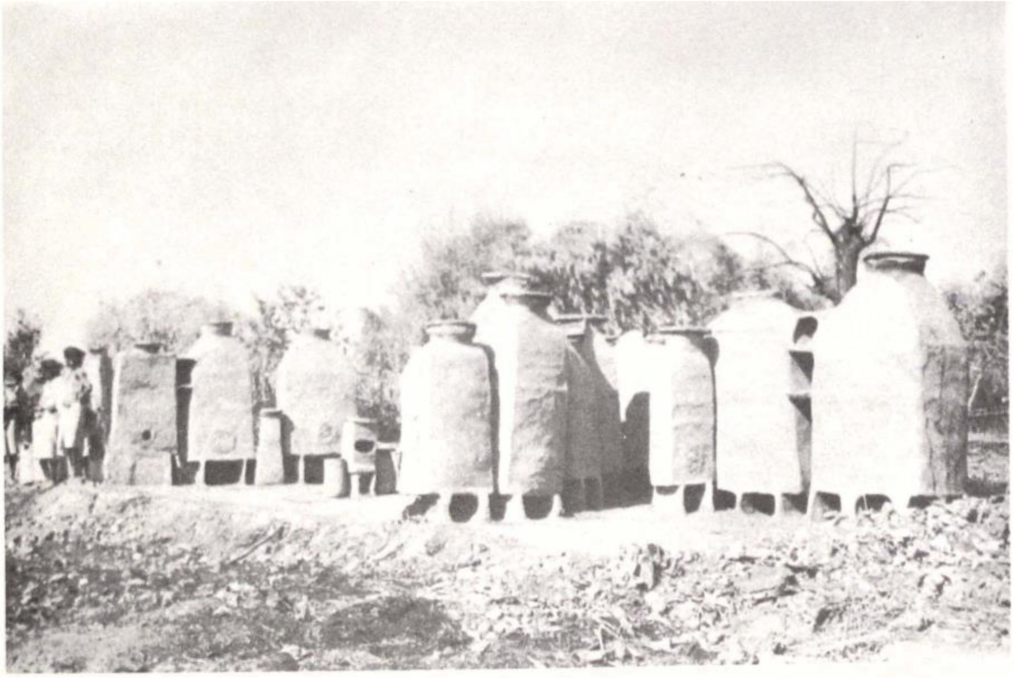


Figure 5: Grain Silos of Danguara Tharu House (Source: (Toffin, 1991))

not exceeding 2m height leaving space below the roof which allows ventilation and keeps the house cool in the summer day. The inner three bay is primarily used for cooking meals, sleeping ang pooja room 'Dehurar'. The rooms are created or partitioned by placing mud grain silos called 'Dehri' (Toffin, 1991).

2.4.1 Construction techniques of Tharu Buildings

The materials required for constructing Tharu house are collected from local area and the materials include wood, bamboo, grass, soil, materials from agriculture, cow dung, rice husk and straw. The small plants provide necessary wood which have size varying from 12 to 14 cm is used for making post and beams and for framework of ceiling local wood are used as pole called 'argol' (Toffin, 1991).

(a)

(b)

(c)

Figure 6: Construction Materials (a) Bamboo (b) Reed (c) Mud
(Source: Internet)

Bamboo is collected from the existing building and it is used for constructing wall and roof structure. The bamboo is made into latches where small branches are inserted and the mud plaster is applied on both sides. The mud plaster consists of mud, cow dung and rice husk. The yellow clayey ochre soil ‘mato’ is obtained from village and when mixed with rice husk forms a cohesive cement paste. A layer of soil with clay material and cattle poo which is in dried state is sprayed on the surface of walls made from branches twigs called cob walls, ground slab and the house hold equipment: grain storage, fire pits etc. The walls of the house below roof on eastern and western façade is called ‘oreyanti’ in tharu language and the wall below the gable on north and south side is called ‘badka vita’. The construction of these two walls is distinct. The eastern and western façade walls are 3 cubits (1.4m) and 10cm thick and are sprayed on exterior and interior sides with mud and cow dung. The walls below gable extend to full height where small branches are placed in between the vertical poles and tied with bamboo strip placed horizontally and plastered with mud and cattle poo plaster, but the upper portion is un-plastered to facilitate air flow for natural ventilation (Toffin, 1991)

The house frame consists of wood structure which is placed along the length of the house. The wooden post is driven two cubits inside the group form support and stability. The 7-wood post of distance 1m are placed along the length of the house with each bay 3.15m wide. The height from roof ridge keeps decreasing to the extreme ends. The 7 purlins sit on the u shaped wooden duri and the purlins are made of 2 or more woods

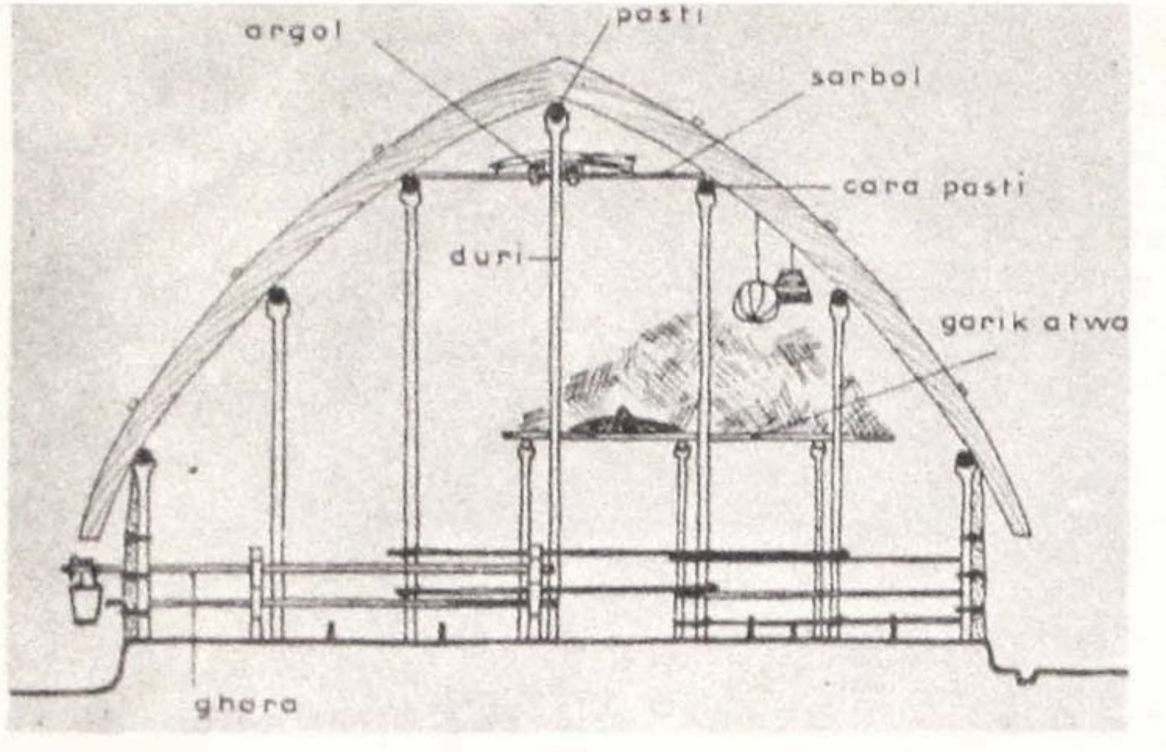


Figure 7: Framing System of Danguara Tharu House (Source: (Toffin, 1991))

joined to span over the entire length of house. The two upper purlins are called ‘cara pasti’ and the wood connecting them horizontally is called ‘sarbol’ (Toffin, 1991).

The thatch roof is made of structural members called rafter ‘keri’ and these rafters rest on vertical wooden poles which extend from ridge to roof. Above these rafter purlins are placed which are 30cm parallel from ridge. The rafters are placing 60 to 80 cm distance along the length of the house over poles. These are tied by bati, a plant collected from forest which is dipped in river water before peeling its bark for using it as ropes. Together with rafters, purlins it forms a light structure on which straw or reed are placed in successive layers. The thickness of the roofing is 30 cm and the straw or reeds are placed in such a way that it is water proof. The grass inserted in the thatch belongs to the Gramineae. It has hollow stem,’cano’ a long rhizome and grows in the alluvium. The straw is trimmed to a span of 1m and tied into bundles (Toffin, 1991).

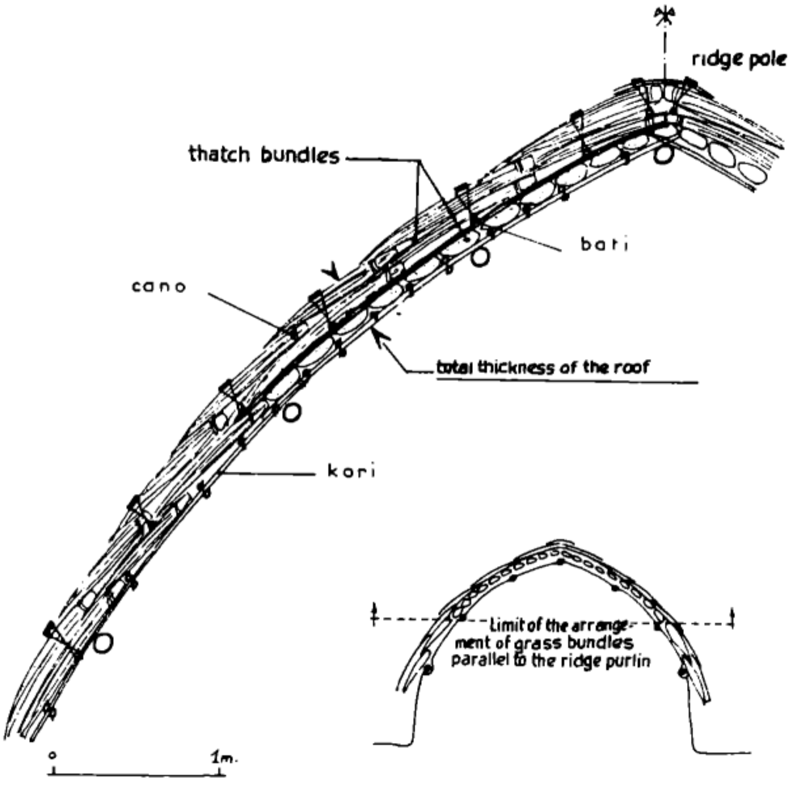


Fig. 10 — The roofing.

Figure 8: Roof Section of Danguara Tharu House (Source: (Toffin, 1991))

Doors and windows are provided on eastern and western façade only. The side of door is 63cm wide and 150cm height. The openings called ‘moaka’ may be rectangular or circular in size with 15cm diameter which provides daylighting and natural ventilation.

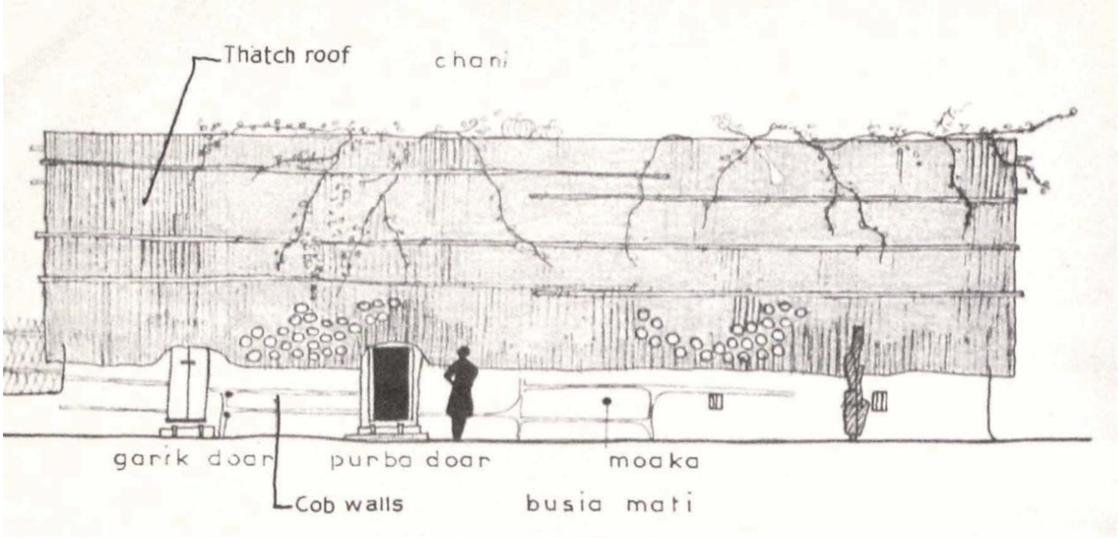
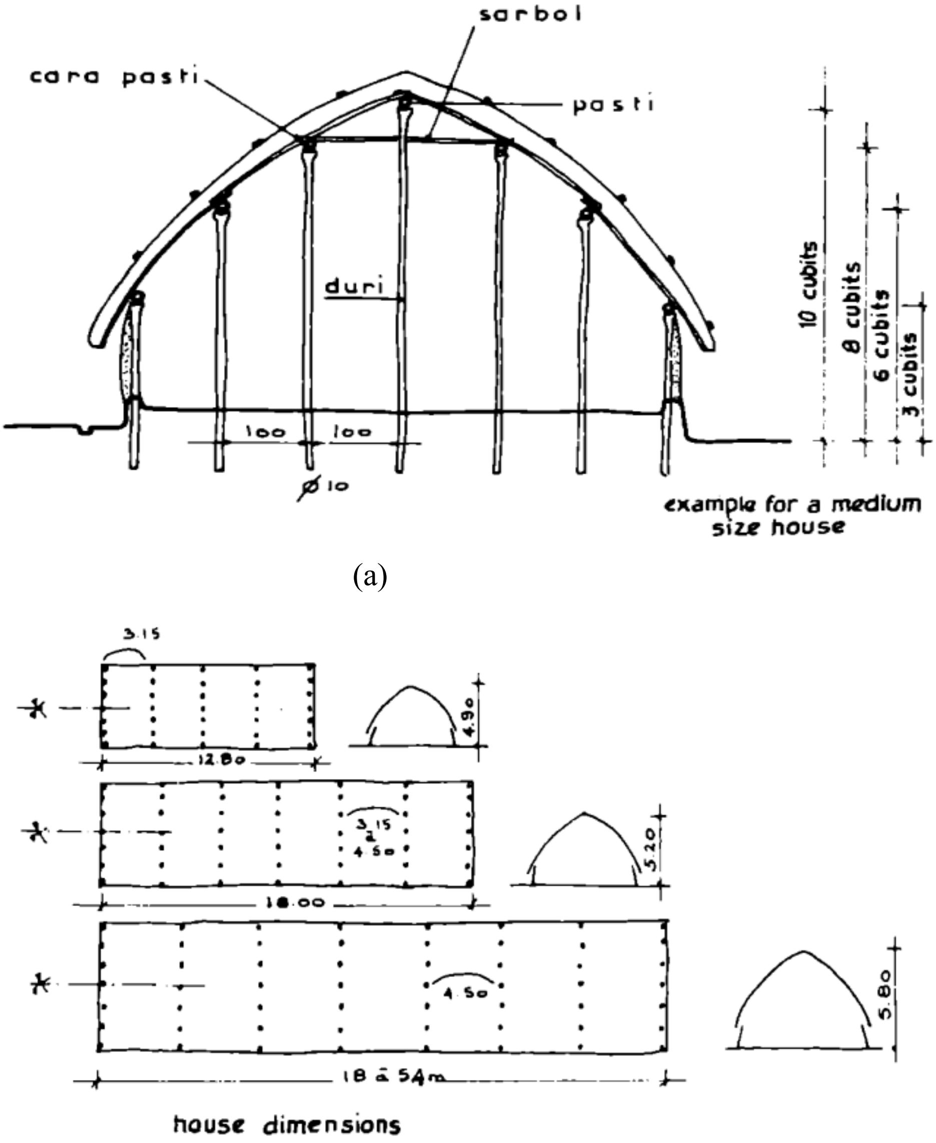


Figure 9: Front Façade of Danguara Tharu House (Source: (Toffin, 1991))

The Tharu house size depends on the quantity of people residing. The medium sized house height is 10 cubits high 4.42 m and the height of small house is 9 cubits high 5.35m which is the maximum height. Similarly, the width depends on the number of poles which and the spacing between these poles is 2 to 3 cubits. In general, the breadth can span from 5.4 m to 7.8m. Similarly, the length of house also varies. The length of bay between two row is almost constant which is 3.15m. The tinniest house smallest has 4 bays, largest house has 12 bays. The overall length of the house thus extends from 12.8m to 54m (Toffin, 1991).



(a)

(b)

Figure 10: a) Frame and b) House Dimensions (Source: (Toffin, 1991))

It is found from observation that, 4 bay house is occupied by inhabited by 4 to 6 people, 6 bay by 6 to 10 people and the biggest house in exceptional case can house more than 32 people. The time required for constructing Tharu house is 37 days: 16 days for preparation of materials 10 days to build the framework and 14 days for clay masonry and coating. Compared to other Nepali house Tharu house are not built to last longer which means they need periodic repair such replacing roof, mud plastering of wall, floors every year (Toffin, 1991). But the major highlight of these houses is light thermal mass, permeable walls, high ceiling fostering natural ventilation which makes them well adapted to warm and damp environment.

2.5 Thermal Performance of Buildings

2.5.1 Thermal Comfort

Hensen defines Thermal comfort as conditions where individuals feel no need to adjust their surroundings through behavior (JLM, 1991). The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defined it as ‘‘the condition of the mind in which satisfaction is expressed with the thermal environment’’ (55-2004). There is variation from person to person regarding physiologically and psychologically so everyone in the space cannot be satisfied and the comfort condition for one might not be comfortable for another person. There are six primary factors that must be addressed when defining conditions for thermal comfort (55-2004) which are listed below:

- Metabolic Rate
- Clothing Insulation
- Air Temperature
- Radiant Temperature
- Air Speed
- Humidity

2.5.1.1 Air temperature

It refers to the average temperature of air which a person is surrounded which considers both the space and time where the person is sited. At minimum the average of air temperature is taken by considering the numerical value which is mean temperature of air which is measured at three different height levels: the ankle, waist and head. For person who is sitting these levels are 0.1m, 0.6m and 1.1m which corresponds to 4, 24 and 43 inches while for people who are standing the heights are taken at 0.1m, 1.1m and 1.7m which in inches are 4, 43 and 67 inches (55-2004).

2.5.1.2 Mean radiant temperature

This can be defined as the temperature of a surrounding object which includes wall, floor, roof through which heat is emitted or absorbed by the person living in the surrounding space. It has significant importance for finding out how the person actually feels in an environment (55-2004).

2.5.1.3 Operative temperature

It is calculated by taking the average of air temperature and mean radiant temperature where the weighted value is taken which is based on heat transfer via convection and radiation which varies linearly from the person. For individuals who are involved in doing light activities whose metabolic value varies from 1.0 to 1.3 and who are also not in the open area under direct sun light and also not exposed to wind whose speed does is not greater than 0.2 m/s (40 feet per minute), this relationship can be reasonably calculated by using the flowing equation (55-2004).

$$t_o = (ta + tr) / 2$$

where,

t_o = operative temperature,

t_a = temperature of ambient air,

t_r = temperature of black or radiant body.

2.5.1.4 Mean monthly outdoor temperature

This temperature is calculated by taking arithmetic average of the month’s average daily minimum and average daily maximum outdoor temperature (55-2004).

2.5.1.5 Air speed

Air speed can be referred as the average velocity of air or wind which hits a person’s body and this is taken average over space and time. The method for finding out average over space and time are very much similar to those used for ambient temperature of air. The things to consider is that the averaging time span is limited to a maximum of three minutes. If the air speed changes over longer time frame greater than three minutes, each change should be considered as different air speed condition (55-2004).

2.5.1.6 Humidity

Humidity or relative humidity basically refers to the amount of water or water vapor which is present in the surrounding air. It has significant importance in how favorable the air feels in the built environment. If there is high humidity then sweating can be less effective and if low humidity then body can feel dry. It can be expressed many variables like dew point, vapor pressure, humidity ratio etc. (55-2004).

2.5.2 Thermophysical Properties of Material

The heat exchange process that takes place in the building is complex phenomenon and occurs through direct physical contact, heat exchange from air flow and radiating body. The heat coming in and going out inside the building depends on several parameters such as heat energy received from sun, temperature of air, outside surrounding temperature of air, properties which governs materials thermal behavior and surface area of buildings or object which are directly in contact with heat source (Nusrat Jannat, 15 June 2020). The thermophysical properties which affect the heat transfer rate are density, thermal conductivity, heat capacity, thermal transmittance, thermal resistance and surface characteristics (B. Givoni, 1969).

2.5.2.1 Thermal conductivity

It is the attribute of material which enables it to conduct heat through it. It is denoted by K and measured in watts per meter kelvin (W/mK). In building materials or objects which have small voids or pores in them (most building materials), the method through which heat transfer takes place is primarily through direct contact called conduction, radiation and convective heat transfer (Harmathy).

2.5.2.2 Specific heat

It is the characteristic that describes the quantity of heat energy which is required to increase the change in a one-unit mass of the material at unit temperature. Its unit is Joule per kg per Kelvin J/kg*K (Harmathy).

2.5.2.3 Thermal transmittance (U-Value)

The rate at which heat is exchanged through a building structure which may be composed of single or several building materials and which also have different temperatures at various surface. It is denoted by letter U. The U-value of a building structure or materials is influenced by thermal resistance called R-value of several layers or single depending on the construction type. The U-value varies in inverse proportion with R-value and it can be easily calculated by taking R-value of materials and also taking resistance which occurs at inside and outside surface. The value of thermal resistance can be computed by using heat flow rate of materials with the depth or thickness also included. If U-value is high that means more heat flow will occur and if small then small heat change takes place. So small value of U is accepted than larger value (Evangelisti, Guattari, Gori, & Vollaro, 2015; Zheng, Cho, Wang, & Li, 2016)

2.5.2.4 Thermal diffusivity

Defined as the ratio of thermal conductivity to the volumetric specific heat of the material. It measures the rate of heat transfer from an exposed surface of a material to the inside. The larger the diffusivity, the faster the temperature rise at a certain depth in the material. Similar to thermal conductivity and specific heat, thermal diffusivity varies with temperature rise in the material (Harmathy).

2.5.3 Adaptive Model

Both Humphreys and Auliciems found significant correlation between the comfort temperature observed and the average interior and exterior temperatures during the field studies (A., 1981; Bouden C, 2005). Adaptive model makes use of mean monthly outdoor temperature to estimate the comfort temperature for the purpose of practical prediction. This input data can be obtained from the nearest weather station or can be measured at the location. The adaptive model is based on extensive field measurements. The relationship between expected clothing and outdoor climate is already in-built into the empirical relation (Feriadi H, 2004; Olesen BW, 2002).

Drawing from global database of over 30 years of comfort surveys, Humphreys created a model and introduced a set of straight forward correlations for predicting the thermal comfort. The comfort temperature (T_{co}) can be calculated from mean monthly exterior temperature (Tm) in C, using the following equation for naturally ventilated buildings (Bouden C, 2005).

$T_{CO} = 0{:}53 * T_m + 11{:}9$ (r=0.97) (1)

The prediction claims to have a standard error of 1 ºC and applies to temperature range of 10 ºC < Tm < 34 ºC (Bouden C, 2005).

Auliciems tried to reanalyze the Humphreys data by removing some incompatible information. These results are based on more recent field studies and combines data for both types of buildings with active and passive climate control (Bouden C, 2005). The absence of thermal discomfort is predicted by simple equation in terms of mean indoor (Ti) and outdoor temperature (Tm) in C (Bouden C, 2005).

$T_{CO} = 0{:}48 * T_i + 0.14 * T_m\ 9.22$ (r=0.95) (2)

Both Eqs. (1) and (2) are utilized to assess how well adaptive models can predict comfort temperatures within the interior space of three traditional buildings in the region.

2.6 Recent Studies from several Researchers

- **Climate responsive building design strategies of vernacular architecture in Nepal** (Susanne Bodach, 2014)

Susanne Bodach et al. (Susanne Bodach, 2014) conductive extensive study on the building design strategies of vernacular architecture in Nepal in 4 climate zones. The methodology used for study is extensive literature review, studying the climatic condition of Nepal from data collected 4 weather stations representing 4 different climatic zones and analyzing several traditional buildings located in 4 climatic zones in terms of their village layout, building shape and size with their alignment, height of buildings, space arrangement and design and construction of building envelope elements. For climate analysis Olgyay’s bioclimatic Chart, Giovani’s Psychrometric Chart and Mahoney Table is used. Among 4 different climate zone the observed strategies adopted in Sub-tropical are settlements are loose in pattern to allow air movement, buildings are rectangular in shape, wall and roofs are made of light material and permeable to allow air flow for cooling. It was found that solar passive heating bioclimatic strategies missing in the vernacular buildings of sub-tropical climate. Moreover, it was found buildings were very climate responsive and relied heavily on natural ventilation.

- **A study on Addressing climate change through the use of bamboo and laterite soil** (Jiba Raj Pokharel, 2024)

Pokharel et. al. carried out the study to find out whether the sustainable building materials like bamboo and laterite soil could be used for temporary as well as permanent construction. The paper says that even the carbon emission of Nepal is nil 0.23 % but it will obviously rise up as the buildings are being constructed using energy intensive materials like cement and steel. It is also known that bamboo and mud are widely used in post disaster relief shelter. The study found that the temporary shelter constructed with bamboo and mud and silpauline sheet with 2-inch air gap on wall and roof was found to comfortable compared to galvanized sheet shelter. Moreover, it is also evident that in terai region there are permanent houses constructed with mud and bamboo reinforcement. The paper examined the load test of the walls and found that the test was 207 Kn/m^2 for laterite soil only and as the bamboo content increased the compressive strength increased 3019 kn/m^2 for 17.25% bamboo content. Also, the bamboo grid floor load test was also conducted which showed it was able to withstand the dead and live load. The paper highlights that for commercial and multi-story buildings energy intensive materials can be used but for low rise buildings bamboo and laterite soil can be used for permanent as well as temporary shelters contributing sustainability and promoting local architecture.

- **Effect of building shape on a residential building's construction, energy and life cycle costs** (E., 2010)

A study conducted by Bostancioglu et al. (E., 2010) showed the relation between cost, heating energy cost, proper shape and building orientation of the same are for different shapes: square, rectangular, star, T & H shape. By changing different building material, insulation for building envelope analysis was performed and analyzed to reduce the energy cost for heating cooling, operation cost. The most appropriate shape which gave best results are square and rectangular than T & H shape.

- **MS. Embodied energy analysis of adobe house** (Shukla A, 2009)

Shukla et al. (Shukla A, 2009)studied the building process of a prototype sample with low energy materials such as cattle dung, mud and sand. The demo house was checked for the embodied energy related to the construction of main structure, foundation, flooring, finishes, furniture, maintenance and electric work. It was observed during the study that the building built using local materials was able to conserve a lot of energy usage and this was also able to decrease the quantity of Co2 released into the atmosphere when a comparison was made with commonly built buildings.

- **Building microclimate and summer thermal comfort in free-running buildings with diverse spaces: a Chinese vernacular house case** (Du X, 2014)

Du et al. (Du X, 2014) examined building climatic data which includes presence of vapor in air, variation of surrounding air, heat energy received from sun and air velocity which have potential to change or alter the comfort condition and to understand energy efficiency as well as role of vernacular elements in bioclimatic designs for achieving energy efficiency. The study was focused on relation of building microclimate and thermal comfort for a typical vernacular house located in Chongqing in hot and humid climate of China. Field measurement, dynamic thermal and CFD (Computational Fluid Dynamics) simulation model was performed for studying the relations. The validation of simulation was done through the field measurement. It was found that during the day time the average of surrounding air and black body temperature was greater than the favorable temperature range for almost 1/3 of hotter season, air flowing in the semi-exterior and exterior parts of buildings uplifted the comfort requirements. The study showed the effectiveness of vernacular design planning element like courtyard, placing living room and other important room around the courtyard etc. which regulated the building microclimate and creates thermally comfortable interiors both at day and night time in summer.

- **Energy saving in the conventional design of a Spanish house using thermal simulation** (Ruiz MC, 2011)

Ruiz and Romero (Ruiz MC, 2011) considered that changing the buildings features by adding methods to cool the building which includes adding exposed obstacles which provides shading. They studied the effect of providing lintels to transparent window surface on the thermal energy use. According to their result, it is required to make proper decision about how much is the energy required for making building warm and cooler when it is required to provide shading. Variables which can change the energy usage when shading is used are climate and latitude.

- **Analysis on building energy performance of Tibetan Traditional dwelling in cold rural area of Gannan** (Hejiang Sun, 2015)

A study by Hejiang Sun et al (Hejiang Sun, 2015) showed that the summer cooling load is smaller than winter heating load so the Tibetan dwellings should focus on heating load in winter. The heat loss in winter can be improved by increasing rammed wall of thickness from 300 mm to 1000 mm. It was also found out that adding 25mm thick opening board as insulation is considerable. Similarly, the Tibetan dwellings have a central opening in 1st floor ceiling which is notable architectural features of Traditional Tibetan residential building in farming community. The opening of 0.6mx0.6m significantly reduced heating load from 123.41 to 96.19 Kwh/m2.

- **A study on Seasonal and Regional differences in neutral temperatures in Nepalese traditional vernacular houses** (Rijal, 2010)

Rijal et al. (Rijal, 2010) carried out study by conducting temperature profile of surrounding and thermal sensation surveys during summer and winter season for 5 different locations like Banke, Bhaktapur, Dhading, Kaski and Solu-Khumbu. The survey carried out for 4 days with 103 people participating with 7116 responses. The parameters that were collected are temperature of surrounding air, water vapor presence in air, heat received from sunlight, speed of air and the direction from where it is coming. It was observed that Banke (Sub-tropical) has the highest mean outdoor temperature of 32.4˚C and 32˚C indoor while Solu Khumbu had the lowest during summer and winter. It is observed that firewood consumption is highest in cool climate (2kg), lower in sub-tropical (1.9kg) and least in temperate climate (0.6kg) per day. The thermal adjustment survey reveals that people responds to their environment by adjusting clothing, ventilation apertures, firewood and beverages during summer and winter months.

- **Energy Performance of Traditional Bath Buildings** (Kristina Orehounig, 2011)

Kristina Orehounig et al. (Kristina Orehounig, 2011) conducted the study on the how the traditional public bathing buildings performs in terms of energy usage. The paper studied five different traditional bath houses called as hammams located in Egypt, Morocco, Turkey, Algeria and Syria. The data related to energy use and thermal conditions were collected for 1 year. The computer simulation model for 3 location named BAB (Bab el Bahr), SEN(Sengul) & SAG (Suq al Ghazal) including 5 different scenarios was conducted. S1(exiting condition), S2(air level changed), S3(thermal insulation of roof), S4(thermal insulation of external wall) & S5(use of double glazing). It was found from study that air change rate was not sufficient in the existing condition so increasing air change rate would certainly increase the heating load. The improvement of glazing material did not significantly reduce the heating load due to low percentage of glazing in the building envelope. The simulation study suggests that improvement in the thermal insulation of roof could result in the reduction of heating load by approximately by 20%.

- **A study on Passive Cooling strategy for Buildings in Hot and Humid Region of Nepal** (Manandhar Rashmi, 2015)

Manandhar Rashmi et al. (Manandhar Rashmi, 2015)conducted a study on design or process which makes the building cooler without requiring energy for buildings which were located in warm and moist climate of Nepal. The energy consumed for making the building warmer and cooler was calculated using Energy Plus v6.0 software. It was observed that heating energy requirement was very small in comparison to energy required for making the buildings cooler. The study suggest that cooling energy can be reduced by 12% by changing the length, breadth of the windows. Also due to existence of objects which helps to reduce the heat energy reaching inside the energy used for making building cooler decreases by 1.3% on average. It was also found that by improving the construction technology to control the unwanted infiltration the energy bill for making building cooler decreases by 10%. Moreover, it was observed from the study that the thermal conductivity (U-value) of the building envelope has more significant impact on the cooling energy than any other design strategies.

The review of literature avoids redundant efforts and builds upon existing studies by evaluating research findings from parts of the world with focus on different approaches and methodologies. For example, Sussane Bodach have used Bioclimatic chart, Mahoney Table Giovani Psychrometric chart to suggest design passive design strategy whereas Md Jahangir Alam have used computer simulation to predict the energy consumption and so thus the others articles differ in various aspect.

2.6.1 Findings from Articles

Table 2: Summary of Findings from Literatures

SN	Title	Author/Published Date	Key Findings
1	Climate responsive building design strategies of vernacular architecture in Nepal	Bodach et al. (2014)	Studied vernacular architecture in 4 bio-climatic zones of Nepal. Among 4 zones, in subtropical climate the buildings are highly permeable, rectangular shape, light thermal mass and solar passive heating strategy not found.
2	A study on Addressing climate change through the use of bamboo and laterite soil	Pokharel et. al. (2024)	Study suggests that bamboo and mud temporary shelter with 2-inch air gap showed greater comfort compared to galvanized sheet. The compressive strength of bamboo and laterite soil increases as the content of bamboo increases which is equal to brick work strength and for floor it can take dead and live load easily becoming a viable option for low rise buildings enhancing sustainability.
3	Effect of building shape on a residential building’s construction, energy and life cycle costs	Bostancioglu (2010)	Found that square and rectangular shape of building most suitable for reducing energy cost compared to T & H shape.
4	MS. Embodied energy analysis of adobe house	Shukla et al. (2009)	Vernacular house not only saves energy but also led to reduced amount of co2 compared to conventional house.

5	Building microclimate and summer thermal comfort in free-running buildings with diverse spaces: a Chinese vernacular house case	Du X et al. (2014)	The study showed the effectiveness of vernacular design planning element like courtyard, placing living room and other important room around the courtyard etc. which regulated the building microclimate and creates thermally comfortable interiors both at day and night time in summer.
6	Energy saving in the conventional design of a Spanish house using thermal simulation	Ruiz et al. (2011)	Studied the effect of adding lintels to glazing on thermal energy use and found that it depends on climate and latitude.
7	Analysis on building energy performance of Tibetan Traditional dwelling in cold rural area of Gannan	Sun et al. (2015)	Found that heat loss in winter can be improved by increasing wall thickness as well as reducing central opening size can also lower heating load requirement.
8	A study on Seasonal and Regional differences in neutral temperatures in Nepalese traditional vernacular houses	Rijal et al. (2010)	Residents find their houses comfortable because of thermal adjustment behaviors such as clothing, firewood use and changing spaces to meet the comfort. In sub-tropical people used adaptive behaviors like taking nap in semi-open spaces, taking multiple showers and drinking large quantity of cold water.
9	Energy Performance of Traditional Bath Buildings	Orehounig et al. (2011)	The simulation study suggests that improvement in the thermal insulation of roof could result in the reduction of heating load by approximately by 20%.

10	A study on Passive Cooling strategy for Buildings in Hot and Humid Region of Nepal	Manandhar et al. (2015)	The study suggest that cooling energy can be reduced by 12% by changing the size of the windows. it was observed from the study that the thermal conductivity (U-value) of the building envelope has more significant impact on the cooling energy than any other design strategies

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research Design

The main objective of this research is to quantify the energy performance of modified traditional Tharu buildings in Dang Deukhuri during summer and winter and to identify which passive design elements influence their energy efficiency as well as incorporating it to modern buildings. To achieve this, field measurements will be conducted to collect data on measurable variables such as temperature, relative humidity. These parameters are crucial in understanding the building's interaction with the surrounding environment. The thermal comfort will also be assessed in the case study buildings. For evaluating the thermal performance, the thermophysical properties such as density, thermal conductivity and specific heat capacity of material are required (Vincelas & Ghislain Robert, 2017). Additional data, such as weather files, will be gathered from secondary sources, including articles, literature, online resources, and archives, to complement the field data.

This study adopts a quantitative research approach, focusing on numerical data and computer simulations. The research follows a post-positivist approach because it seeks to understand how Tharu buildings performs in terms of energy using measurable data and objective methods but it also assumes that this energy performance depends on other factors also. The ontological claim of this study is: "The energy performance of traditional Tharu buildings is influenced by their passive design features, which interact with the surrounding environment to make the buildings energy-efficient and sustainable." The epistemological claim of this study is that it will focus on collecting real word data to understand energy performance. Similarly, studies by other researchers, findings, valid sources like journals, research papers will be followed which will help to validate the ontological claim. This study will primarily follow deductive approach where it will find out the energy performance of Tharu buildings using measurable variable and simulation and will finally recommend what can be learnt from them and incorporated to modern buildings. The simulations will compute essential factors such as heating and cooling loads, energy use, and discomfort hours. These analyses will help evaluate the building's thermal performance in different seasons. The simulations will be performed using Design Builder software which is a widely recognized tool for energy modeling in buildings. By studying the passive design elements of Tharu buildings, such as material choices, spatial organization, and natural ventilation strategies, this research aims to provide insights into how these features contribute to energy efficiency and occupant comfort. The findings will also help explore how traditional design strategies can inspire modern, energy-efficient building practices.

3.2 Conceptual Framework

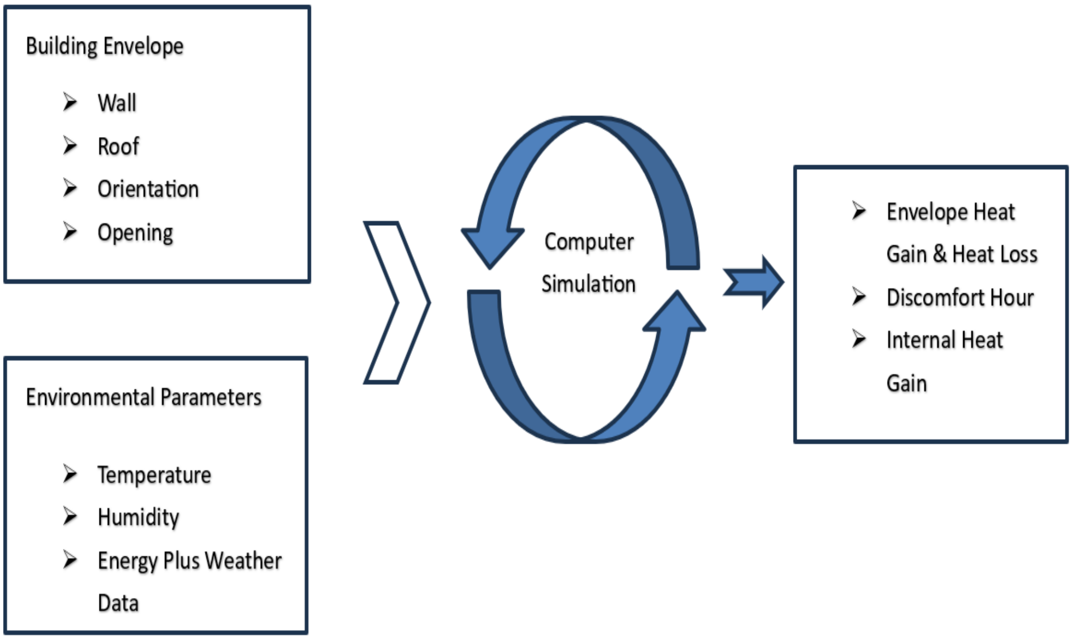


Figure 11: Conceptual Framework of Research

3.3 Case Study Selection

To carry out the study and fulfill the objectives the case study is chosen in the Dang district of Lumbini Province. It is evident that Tharu people resides on the southern lowland of Nepal and are scattered from east to west. The selected area for study is predominantly Tharu village where majority are Tharu people. Single building is selected at Mahadewa village for indoor data collection.

To better understand the characteristics of the Traditional Tharu Buildings the literature from *Man and His House in Himalayas* by Gerard Toffin is consulted (Toffin, 1991). However, over time people have slightly modified the old Tharu buildings to match their requirements, where the spatial arrangements have changed but the construction methodology and practices remains similar to the old Tharu Buildings mentioned in the literature by Toffin. The current practices of buildings being built in the case study site are displayed below.

(a) (b)

Figure 12: (a) Case Study Buildings and (b) House of Ramautar Chaudhary

Additionally, recent news article reports also suggest that the traditional Tharu buildings are gradually being disappeared due to various challenges. The difficulty in sourcing the natural building materials, the rising wage of the construction workers and also due to ease and cheap availability of modern construction materials such as brick, cement, steel (Setopati, 2019-03-04). The buildings located in central regions of Iran have bulky wall which are thick have open spaces in inner middle part with water bodies near them and also have shaft structure which draws winds to cool the buildings. Even though presence of these passive strategy is present but people don’t use them or rely on mechanical devices. The reason for decline is in case of wind channeling structure the people are aware of its positive advantages like it cools the indoor environment creates air movement, lower cost for paying electricity bills, add beauty to the buildings but despite these there are some disadvantages which the residents mention such as it is expensive to build, brings dust and impure air, occupies more space and not very efficient , all these factors are responsible for the decline of these noteworthy traditional building features (Foruzanmehr, 2011). Despite all these challenges, many Tharu people still builds the traditional buildings retaining the old construction techniques even though their usage is different than old times.

3.4 Selection of Research Parameters

For finding out the energy performance and thermal comfort in buildings various parameters need to be examined which is evident from various literature reviewed. The parameters include examining environmental factors, human factors, building envelope and thermophysical properties. The environmental factors include temperature, humidity, air speed, solar radiation, rainfall human factors include occupancy behavior, clothing factor, metabolic rate, building envelope includes wall, roof, floor, windows & openings and thermophysical properties includes density, thermal conductivity, thermal transmittance etc. The mass per unit volume, ability to pass heat through it, heat energy needed to increase temperature by 1° C are the three necessary thermophysical characteristics required for the thermal behavior analysis of the building materials (Vincelas & Ghislain Robert, 2017; Wonorahardjo, et al., Eng. 2020). But all of these parameters cannot be looked upon due to time limitation, lack of equipment etc. and only those considered are briefly described below:

3.4.1 Measurement of Air Temperature and Humidity

The indoor air temperature and humidity are measured with the help of digital instrument which can be compared with other building case and also with the simulation data. The temperature will be collected in winter season for 14 to 21 days.

3.4.2 Building Orientation

This is the next parameter which will also be considered. It is observed from literature that the Tharu buildings longer sides oriented along north-south and doors and openings facing east and west side. Using this parameter the simulation will be run to see are there any changes in energy performance.

3.4.3 Opening Size

Typically, in Tharu buildings the size of openings is small even though they foster natural ventilation so this will also be looked upon to see how they affect the thermal and energy performance to see if they can in adapted in modern buildings. Similarly, Tharu houses have opening below gable roof also so this will also be simulated.

3.4.4 Wall

The Tharu buildings have walls made up of bamboo and mud plaster which are permeable and which helps to regulate the thermal comfort inside the buildings. So, this will also be looked upon by replacing brick wall with bamboo and mud plaster and the thermal performance will be looked upon using computer simulations.

3.5 Data Collection

Data collection refers to gathering of raw information on particular area before they are processed into useful form. The data are basically collected from two sources: primary data and secondary data.

3.5.1 Primary Data

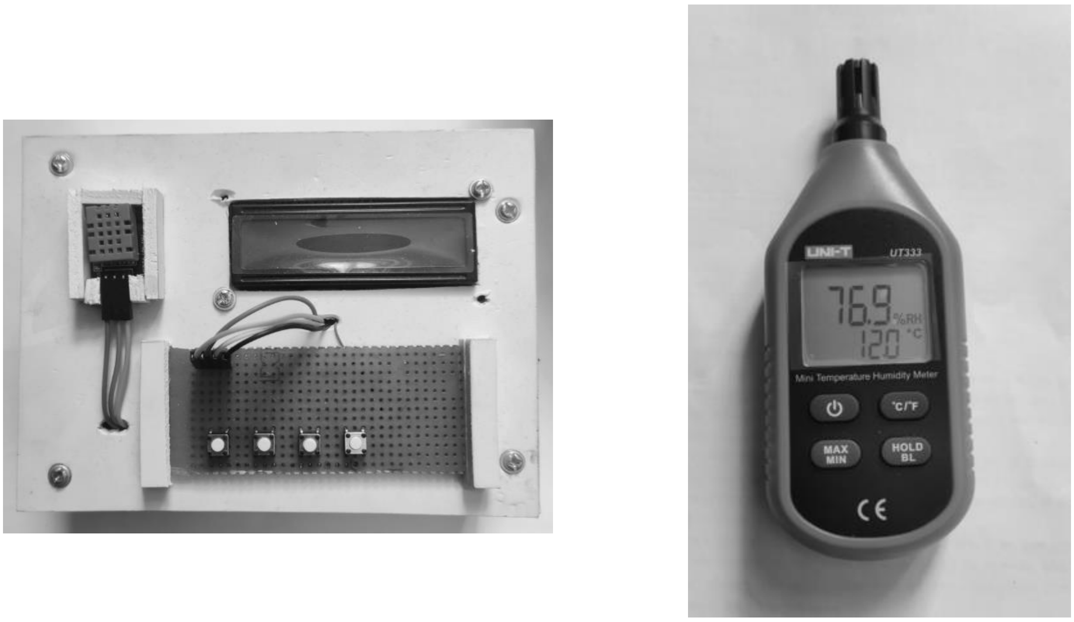
This primary data is the information collected from actual field with the help of instrument. In this study temperature and humidity is collected from single house at situated at Gadhawa Rural Municipality Ward number 2 Mahadewa village using digital instruments. The primary data include essential microclimate parameters such as temperature, relative humidity which will be obtained through precise field measurements using the digital equipment mentioned above. The temperature is recorded inside the house and for outdoor temperature it is relied on secondary data source. These primary data are critical as they represent the real-time conditions of the site and provide a foundation for accurate analysis. Additionally, measurements of the traditional buildings located at the respective site will be conducted. These measurements will aid in developing detailed building drawings, which will subsequently be utilized for simulations using the Design Builder software which uses Energy Plus.

3.5.2 Secondary Data

This includes data which are collected from various literature, research paper, books. Since the study is focused around energy performance which also requires climatic data and these data can be fetched from the nearest Department of Hydrology and Metrology station which is another crucial component of this study, will be collected from a nearby meteorological station to ensure it reflects the local climate conditions accurately. Other secondary data, such as the Energy Plus weather file, will be obtained from reliable sources like the Energy Plus website or the Metronome website. This data is necessary for simulating the energy performance of buildings under realistic weather scenarios. Similarly other required data such as material thermophysical properties like thermal conductivity, density, thermal transmittance is taken from literature, internet source, books and other media which will provide additional context and validation for the study. By combining these primary and secondary data sources, the study aims to create a robust dataset that ensures the findings are both accurate and reliable.

3.6 Equipment Required

For conducting the study data collection is required which is collected with the help of digital instrument. The instruments used are UT333 mini temperature and humidity meter and Arduino Nano Datalogger. Due to unavailability of data loggers, in this study a custom data logger was built. The data logger was built by assembling various electronics components such as Arduino nano microcontroller, I2C module, DHT 11 temperature humidity sensor, 16x2 LCD Display, jumper wires, lithium-ion battery, real time clock module, SD card module for storing data on board. The data stored in the device was easily accessed via computer using the free open-source data communication software named Putty. The accuracy of UT333 is ±5% RH & ±1ºC. Similarly, the accuracy for DHT11 is ±5% RH & ±2ºC. Using UT333 the data will be collected at three different time and using Arduino Nano Datalogger it will record the temperature and humidity of the single case study buildings for 24 hour for 21 days.



(a) (b)

Figure 13: Instrument Used a) Arduino Nano Datalogger b) UT333 Mini Temperature and Humidity Meter

3.7 Computer Simulation

For performing the analysis, computer simulations will be employed. Software tools, like Climate Consultant, Design Builder & Energy Plus, will be used for this purpose. Climate Consultant will assist in understanding the local climate by processing raw climate data into meaningful charts, such as temperature ranges, psychrometric charts, and design guidelines. These insights can be particularly helpful during the first stage of design, as they highlight suitable design strategies based on the local climate. By analyzing these outputs, the study will identify how passive strategies can optimize building performance.

Energy Plus, developed by the U.S. Department of Energy (DOE), is a widely recognized and extensively used building energy simulation program. It can simulate energy consumption for heating, cooling, lighting, ventilation, and water use in buildings. Using field measurement data, microclimate parameters, and architectural drawings, the building geometry will be created in Energy Plus to conduct simulations. The software will provide detailed energy performance results, helping to evaluate the impact of passive design strategies on energy use. Similarly, Design Builder is also a high quality easy to use simulation software for performing energy performance, daylighting, HVAC design, CFD and many more. It provides graphical user interface to the users but uses Energy Plus API for performing all these simulations.

3.8 Simulation Architecture

The simulation architecture basically describes the methodology which have been adopted for carrying out the study to fulfill the objectives using Design Builder software. The methodology is presented in block diagram and described in detail

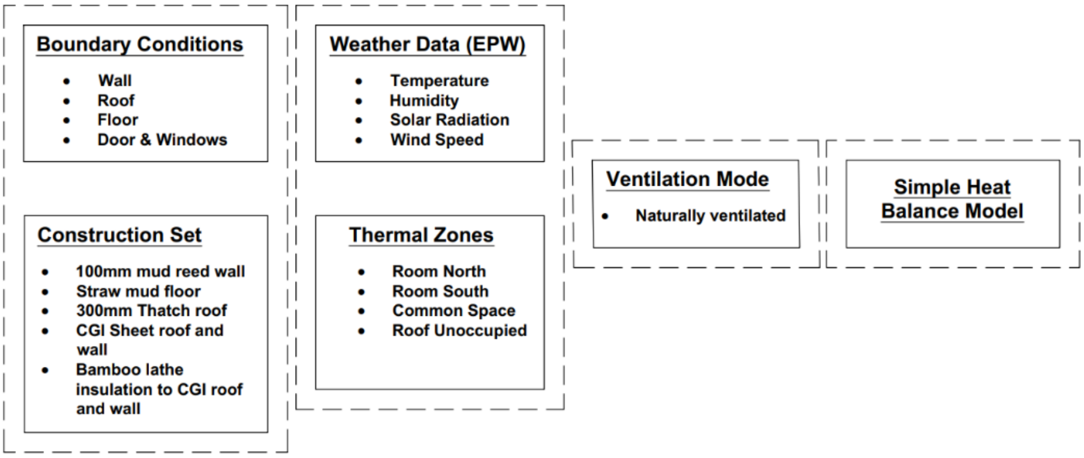


Figure 14: Simulation Methodology Framework

Boundary Condition and Construction Set

The boundary condition in the simulation represents the whole building which is composed of several walls, roof, floor, door and windows is considered as a zone or single block which will respond to its outer environment. The actual building which will be measured from site and drawn inside the software in general represents the boundary conditions because it creates a space indoor and outdoor through which the heat transfer can take place. The boundary conditions depend on the construction sets which we can define to match the model properly with the selected case study building. In our study for Base Case existing building the set of construction materials are 100mm mud reed wall, straw mud floor, thatch roof, wooden doors and windows. While creating these set of construction materials we also need thermal properties which is discussed in the report. For comparison we have other set of materials such as CGI sheet wall, roof, concrete floor and CGI sheet with bamboo lathe with 2-inch air gap.

Energy Plus Weather Data

This energy data is very important because without supplying energy plus weather data the simulation cannot be started. This file basically contains information such as dry bulb temperature, dew point temperature, global solar radiation, ground temperature, relative humidity, wind speed at various height and ground temperature for several years which are presented in Typical Meteorological Year form. This file can be easily obtained from energy plus website and on several online media.

Thermal Zone

The thermal zones basically create space or rooms to which we can assign various data such as zone template, clothing factor, number of occupancies, metabolic rate, equipment and plug load energy usage in watts per meter square. These can be easily assigned since Design Builder have several pre-built zone templates. In our case study we have defined domestic bedroom for room north and room south whereas for common space we have assigned common circulation area.

HVAC or Ventilation Type

The case study building which we have taken is traditional Tharu building which relies on natural ventilation for running the building. In the simulation software we have defined window schedule to be open for 24 hours for June and in January opened during day but closed at night time. The ventilation type considered is natural mode and it is calculated based on window openings and actual wind speed. The outside air change rate is defined as 5 air change per hour. The infiltration in simulation is taken to be 6 air change per hour because the building is not air tight since it is a traditional building and the value of infiltration is taken from article (Fuller, 2009). Inside the simulation software the ventilation rate which is driven by wind is calculated based on following formula given below:

$P_w = 0.5 * \text{rho} * C_p * V^2_z$ (Ltd, n.d.)

The notation used in above equations are P_w = surface pressure because of wind, rho is density of air, C_P is wind pressure coefficient on the surface and V_z is the mean velocity of wind at a respective height z.

Simple Heat Balance Model

The model which the energy plus uses is simple heat balance model to calculate all the heat that are incoming and outgoing inside the building. The heat balance model is displayed in mathematical form.

Heat Gain – Heat Loss = 0

Heat Gain = Heat Loss

$Q_i + Q_s \pm Q_c \pm Q_v \pm Q_m - Q_e = 0$ (Bowen, 1979)

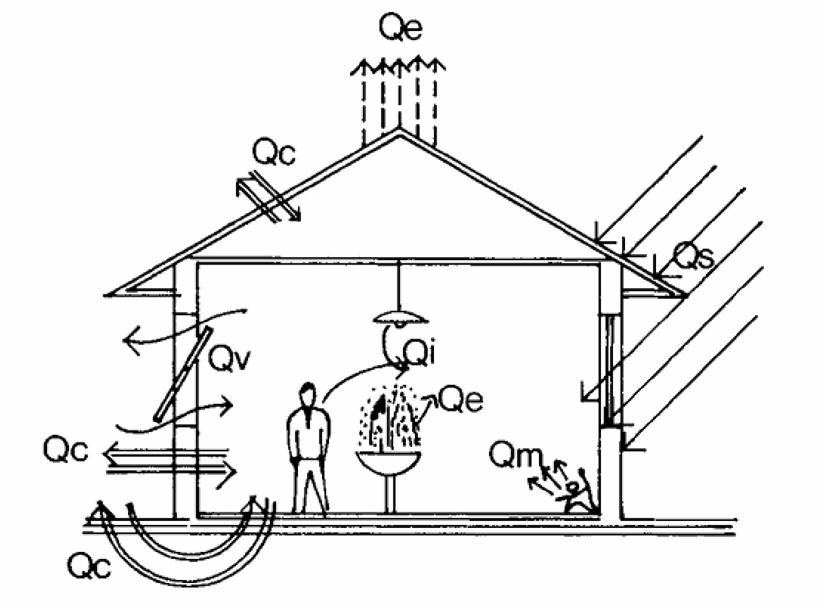


Figure 15: Heat Transfer Inside Building *(Bowen, 1979)*

Q_c is the heat transfer that takes place via conduction through building envelope such as wall, floor, roof, doors and windows. Q_s is the heat that enters the building through window openings and other transparent surfaces. Q_v is the heat transfer that takes place when air flows in and out. Q_i is the heat added internally due to human activities, lighting systems, electrical appliances etc. Q_m is the heat addition or heat reduction due to HVAC system. Q_e represents evaporative cooling on the exterior surface of building or within the building. The simulation software uses heat balance model to calculate heat coming and going and based on this and other simulation algorithms which are built inside the software required outputs such as discomfort hour, fabric heat gain, internal heat gain and air temperature are calculated based on which we can fulfill the objectives of this study.

CHAPTER 4: CASE STUDY & DATA COLLECTION

4.1 Introduction

The study will be conducted in the Dang Deukhuri valley of Lumbini Province, Dang District. This region, home to the Danguara and Deukhariya Tharu communities, is known for its rich cultural diversity and unique environmental settings. It provides an excellent opportunity to examine the energy performance of traditional Tharu buildings. Single building will be selected for study and data collection, located in the villages of Mahadewa. The Mahadewa village represents a distinct geographical and environmental setting, offering diverse contexts to explore how local traditions and environmental factors influence the energy performance of traditional types of buildings. This study focuses on evaluating the energy efficiency of these traditional structures, aiming to uncover the relationship between cultural practices, environmental conditions, and building performance.

4.1.1 Case Study Area

The case study will be conducted at Mahadewa village which is situated in Gadhawa Rural Municipality ward no 2. The latitude is 27º48’40’’ and longitude is 82º38’53’’ and elevation 291m taken from google map. It is approximately 10 Km south from the East West highway. The nearest market to this village is Sisahaniya & Gadhawa bazar. The climate of the case study area is sub-tropical climate. The topography of the case study building is flat terrain.

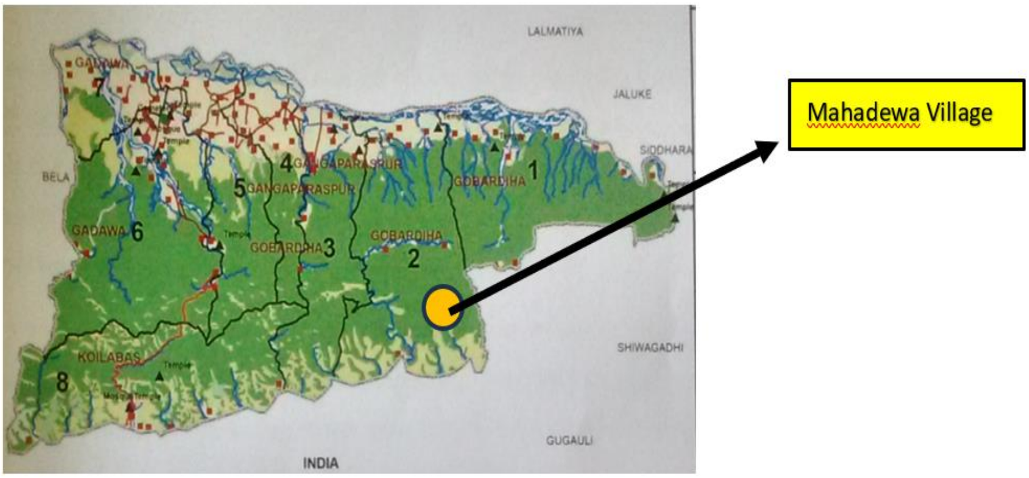


Figure 16: Case Study building location Site (Gadhawa Ga. Pa)

The population of this ward is 5596 out of which 2754 are male and remaining 2842 are female with the sex ratio of 96.9. as per Nepal Population and Housing Census 2021. Similarly, the number of households in this ward is 1169. In this ward 62.3% people lives in joint family and remaining 37.7% lives in small family. In this rural municipality, the Tharu ethnic group constitutes the largest portion of the population at 42.4%, followed by the Nepali group at 37.9%. In this ward majority of people are employed in non-agriculture sector and remaining in agriculture. The percentage of people dependent on agriculture are 33.8% and non-agriculture are 66.1%. All these data are obtained from Nepal Population and Housing Census 2021. This village is near to the second longest bridge in Nepal. This village is close to the Rapti river and another river flows near the village. It is situated close to the forest also on the south side and near to Indian border. It is also close to the Tharu religious temple of Baghnath Baba located in the forest called “Jangalwa Kuti”. The Jangalwa Kuti has significant importance to Tharu community since in this sacred place people performs rituals, religious offerings known as bhandaras. The Jangalwa Kuti is also popular spot for picnic and public gatherings. Similarly other important landmark close to this case study area are Lal Durbar at Gobardiha built by Tharu Satgauwa family as well as Shiv Mandir. The case study area is also located very close to Nepal’s second longest bridge and this bridge is also very popular since many people visit this bridge.

4.1.2 Building by Material

In this ward 544 number of buildings have walls made from brick or stone masonry with cement mortar followed by 287 bamboo walls. The number of buildings having walls made from Corrugated Galvanized Sheet are 10. These data are displayed in the chart below. From the chart we can clearly say that the buildings are following modern trends of construction.

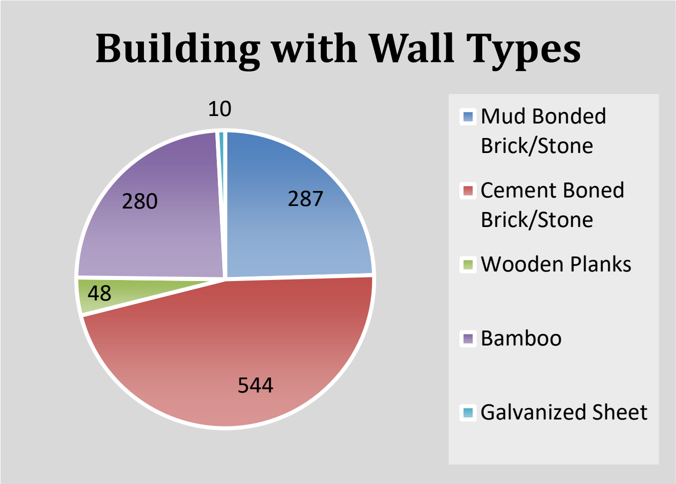


Figure 17: Building by wall types (Nepal Population & Housing Census 2021)

While categorizing buildings based on the material used at foundation level 327 houses have mud boned brick/stone foundation, 213 houses have bricks or stone laid with cement foundation, 226 number of houses have Reinforced Cement Concrete foundation with columns erected and 403 buildings have foundation made with wooden pillars as data obtained from Nepal Population and Housing Census 2021 report. These data are graphically represented in the pie chart below for better visual appearance.

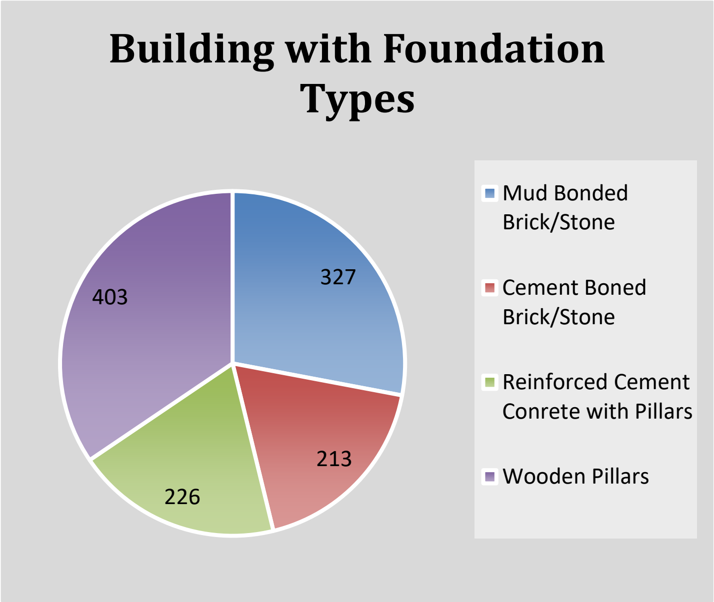


Figure 18: Building by foundation types (Nepal Population & Housing Census 2021)

According to data available from Nepal Population and Housing Census 2021, it is observed that most of the buildings have roof made from reinforced concrete slab accounting 574 number which is highest when compared to other types of roofing CGI sheet, thatch roof and mud tiles.

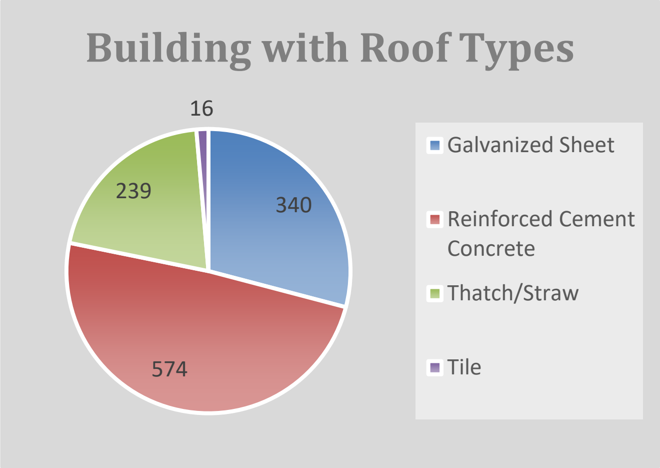


Figure 19: Building by roof types (Nepal Population & Housing Census 2021)

The second most laid roofing material is CGI sheet accounting 340 buildings followed by thatch or straw roofing accounting 239 buildings and

the least number of roofing is made from mud tile. This data clearly shows that modern materials are dominating the construction sector in the case study area.

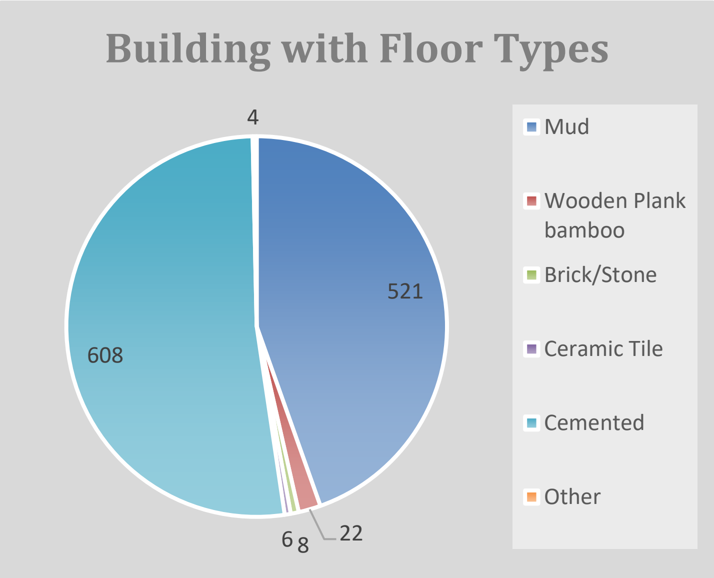


Figure 20: Building by floor types (Nepal Population & Housing Census 2021)

The data from Nepal Population and Housing Census 2021 shows that the most commonly used flooring material in this ward is made from Reinforced Cement Concrete with 608 numbers of buildings followed by 521 numbers of houses with mud flooring. The houses featuring floor made from wood or bamboo plank is 22 and the number of houses having floor made from brick or stone, ceramic tile and other are 8, 6 and 4 numbers respectively. We can clearly see from the data that the most used building material is Reinforced Cement and then mud. Thus, we can say that the traditional buildings are slowly being replaced by the modern building material. But at the same time there are still traditional buildings built followed by modern building which also indicates that these buildings need improvements to withstand the changing lifestyle of people as well as to the changing environment.

4.1.3 Settlement Pattern

The Tharu people have traditionally lived in the southern flatlands of Nepal. They usually settle in areas with dense forests and rivers. Their way of living is closely connected to nature. They depend on forests for resources like wood and plants and on rivers for water. Because of this, their villages are mostly built near forests and rivers. Their religion and beliefs are also connected to nature. They worship natural elements like forests, water, and rivers as their gods. In this study, three Tharu villages were selected for observation. All these villages are close to rivers and forests. Satellite images of these villages were taken from Google Earth and shown below to explain their settlement pattern.

Figure 21: Settlement pattern of Mahadewa village (Google Earth Image)

From the images, it is clear that Tharu villages are built in a linear pattern along the roads. The houses are built on both sides of the road, as described in literatures and other writings about Tharu settlements. One important feature of these settlements is the direction of the houses. The longer sides of the houses are usually built along the North-South direction, and the front of the houses faces East or West. This direction helps to keep the houses cool during the day and allows sunlight inside. The houses are built close to each other, creating a compact settlement. Even though the houses are close, each family has a kitchen garden at the back of their house. These gardens are used to grow vegetables and herbs that the families use daily. The same settlement pattern can be seen in all three case study villages. This shows that the Tharu people have followed a similar way of building their homes and organizing their villages for a long time.

4.2 Climate Data of Dang

4.2.1 Energy Plus Weather File Data Presentation

The weather file portrays climate data taken from year 2011 to 2023 in which Typical Meteorological Year data is taken. The latitude and longitude of data collection site is 28.05º North and 82.5º East at elevation 634m. This data is collected from Ghorahi (Dang) weather station with WMO number 44429. The topography of terrain is plain. The highest temperature is 35.8˚ C in June and similarly the lowest temperature is 4.2˚ C in February. The highest wind speed is in May of 1.81 m/s and lowest average wind speed is 0.9 m/s in December month. The ground cover of station is short grass and exposure as listed below:

East Exposure: Office compound with short grass

West Exposure: Office compound with short grass

North Exposure: Office Building

South: Exposure: Office Quarter

Table 3: Climate Data of Dang Ghorahi (EPW Data)

SN	Month	Tmax	Tmin	Tavg	Rh 9(am)	Rh 3(pm)	Avg Wind Speed (m/s)
1	Jan	21.9	4.7	11.8	74	67	1.06

2	Feb	25.3	4.2	15.1	69	56	1.59
3	Mar	28.1	6.2	18.5	57	42	1.37
4	Apr	33.4	11.1	23.3	45	32	1.68
5	May	34.5	16	25.7	53	47	1.81
6	Jun	35.8	19.9	26.3	74	67	0.99
7	Jul	31.9	21.6	25.8	86	80	0.94
8	Aug	30.6	22.2	25.5	84	80	1.39
9	Sep	30.2	21.6	24.9	85	82	1.21
10	Oct	32.4	14.6	21.4	74	66	0.88
11	Nov	27.4	10.9	16.7	82	71	1.18
12	Dec	23.1	5.7	12.4	75	61	0.9

The comfortable temperature range for 80% acceptability limit obtained from climate consultant software is 17.8˚ C to 29.5˚ C and similarly for 90% acceptability limit the comfortable temperature range is 18.8˚ C to 28.5˚ C. The chart for temperature and humidity is plotted and the preliminary design strategies for each month is briefly described as obtained from climate consultant software by using weather file data.

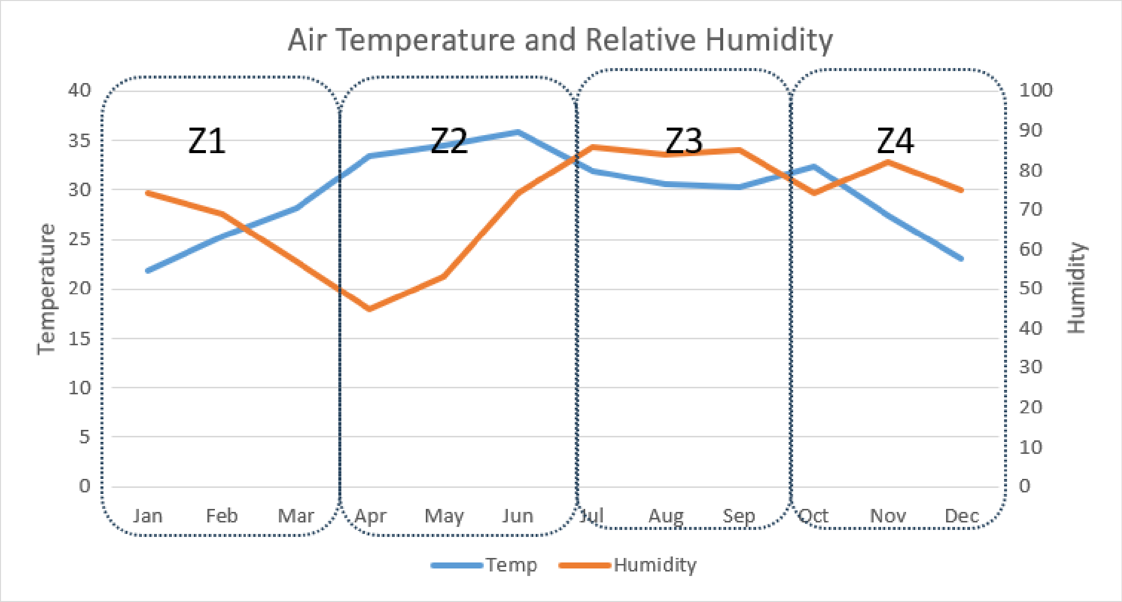


Figure 22: Climate Analysis using Air Temperature and Humidity

In the above figure we have plotted the air temperature and relative humidity obtained from energy plus weather file for case study area and we have divided the 12 months into 4 block each with 3 months for proper climate analysis. There are 4 separate zones created with 3 months in each zone named as Z1, Z2, Z3 and Z4. In block Z1, we have taken January to March, in zone Z2 we have taken April to June, in zone Z3 we have taken July to September and in zone Z4 we have taken October to December.

For zone Z1 the temperature is low in January and can be seen rising as it reaches March. If we look at humidity it can be seen in decreasing order but in overall it is greater than 60%. Thus, the discomfort in this zone is due to low ambient temperature and humidity.

For zone Z2 the temperature is high and highest for June month and the humidity level can be seen rising as it approaches June months. Thus, in zone Z2 the discomfort is caused by high air temperature.

For zone Z3 the air temperature and humidity levels are both high in the range of about 80% which indicates that discomfort is caused due to high observed air temperature and higher water vapor presence in air.

Similarly, for zone Z4 we can clearly see that the temperature starts decreasing from October month and further decreases as it approaches December month but humidity is still high greater than 60%. Thus, we can clearly say that the discomfort in zone Z4 is caused due to low surrounding air temperature followed by high humidity level.

The climate analysis software also recommends design strategy for each month which is essential for early design phase. These design strategy for each month is briefly described below considering 80% acceptability limit where comfortable temperature range is between 17.8˚ C to 29.5˚ C. For January month the natural ventilation mode maintains only 10% comfortable of about 75 hours and the comfort level can be increased to 45% with internal heat gain direct heat gain from sun light. For February month the natural ventilation mode maintains only 26% comfortable approximately 175 hours but the comfort level increases to 60% when the design strategy like internal heat gain and passive solar radiation gain. For March month natural ventilation mode only maintains 29% comfort approximately 204 hours and the comfort level can be further increased to 69% when heat is added from internal sources. For April month the natural ventilation mode maintains a comfort level of about 42% which is 210 hours and it can be increases to 74% when heat is added from internal sources. Here passive solar heat gain via envelope does not show much improvements compared to internal gain. For May month natural ventilation maintains a comfort level of 59% and when internal heat gain is applied comfort increases to 67% but when internal heat gain is removed and direct evaporative cooling is used then comfort increase to 72%. This shows that for May month natural ventilation with direct evaporative cooling shows better result. For June month natural ventilation alone maintains a comfort level of 61% and other design strategy such as internal heat gain, evaporative cooling does not show much improvements compared to dehumidification which increases comfort level to 75%. For July month the natural ventilation maintains a comfort level of 81% which accounts for about 602 hours. For August month the natural ventilation mode maintains highest comfort level of 95% accounting 710 hours which is highest comfort level maintained alone by natural ventilation mode only. Thus, in August natural ventilation can be very effective. Similarly for September also the natural ventilation can be see working very effectively which maintains the comfort level of 92% nearly accounting for 662 hours. If we consider designer strategy for October month natural ventilation only maintains 39% comfort level but when heat addition from internal source is applied the comfort level increases to 78%. For November month the natural ventilation mode can be see maintaining the comfort level of only 27% accounting 186 hours and when heat is added from occupancy, lighting and heat gain from sunlight comfort level increases to 78%. For December month the natural ventilation mode maintains comfort level of only 14% which shows it is struggling and even with addition of heat from internal source the comfort level is around 45% which clearly shows that in December passive design strategy are not sufficient to maintain the indoor comfort.

Thus, we can make preliminary conclusion that a building which works on natural ventilation mode is able to maintain comfort using natural mode pretty well in summer months but in winter season even with passive design strategies, the comfort level is still low requiring active means of heating.

4.2.2 DHM Weather Data

The data collection was carried out for 11 days from January 17 to January 30. Indoor temperature and humidity were measured inside the Traditional Tharu building and for outdoor temperature and humidity it was collected from Department of Hydrology and Meteorology (source: www.dhm.gov.np). The weather station which is close to the case study site is Ghorahi (Dang) which is approximately 46 km away. The collected data is presented below

Table 4: Outdoor Temperature Data for Measured Period (DHM Ghorahi)

Day	Date	Tmax	Tmin	Tavg	Rhmax	Rhmin	Rhavg
1	1/16/2025	21.4	8.1	13.55	100	44.6	86.35
2	1/17/2025	23.1	8.2	14.42	100	36.3	82.83
3	1/18/2025	22.4	7.6	13.74	100	31.6	83.39
4	1/19/2025	22.6	8.4	13.68	100	39.1	84.32
5	1/20/2025	23	8	14.72	100	39.6	81.66
6	1/21/2025	25.6	9.1	16	100	27	79.18
7	1/22/2025	23.3	8.7	15.42	100	40.6	83.18
8	1/23/2025	23.4	7.9	14.78	100	33.6	85.92
9	1/24/2025	22.4	9.4	14.78	100	26.9	74.45
10	1/25/2025	20.7	7.5	13.88	100	51.4	85.74
11	1/26/2025	19.8	9.8	14.6	100	58.2	88.48
12	1/27/2025	21.5	9.5	13.95	100	50.9	89.42
13	1/28/2025	21.8	7.5	14.07	100	45.7	88.96
14	1/29/2025	21.4	8.9	14.53	100	55.5	90.03

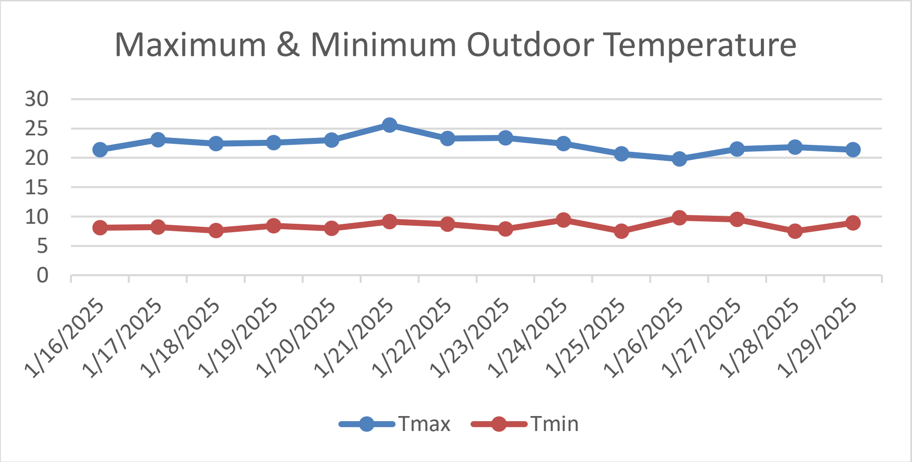


Figure 23: Chart Displaying Outdoor Maximum & Minimum Temperature Data

4.2.3 Case Study Building Indoor Temperature

The case study building is Traditional Tharu building of dimension 5.95m x 10.15m. For recording the indoor temperature, the datalogger was placed inside the building and data was logged from Friday 04 Magh to16 Magh approximately for 12 days. The data logged using custom made Arduino Nano Datalogger. The measured temperature inside the building is presented in the table.

Table 5: Daily Indoor Temperature Data for Measured Period (Case Study Building)

Date	Day	Max Temp	Max Rh	Min Temp	Min Rh	Avg Temp	Avg Rh
1/17/2025	1	21.4	73	16.6	61	19.83	66.42
1/18/2025	2	20.6	70	15.7	59	17.87	64.08
1/19/2025	3	20.2	70	17	61	18.33	65.76
1/20/2025	4	20.2	71	15.2	60	17.42	65.81
1/21/2025	5	21	73	14.4	63	17.35	66.17
1/22/2025	6	21.4	71	15.2	62	17.90	65.43
1/23/2025	7	21.4	71	17.8	65	19.24	67.96
1/24/2025	8	21	69	17.3	48	18.64	60.90
1/25/2025	9	20.1	65	14.4	55	17.30	59.50
1/26/2025	10	20.2	71	16.6	62	18.21	65.13
1/27/2025	11	20.6	70	16.1	62	18.03	65.78
1/28/2025	12	21	70	17.4	64	18.69	66.74
1/29/2025	13	21	70	15.7	62	17.22	64.69

(a) (b)

Figure 24: (a) Location of Datalogger Placed (b)Datalogger showing Temperature & Humidity

The air temperature inside and outside the Tharu building was measured from January 17 to January 29 which is used as a variable to evaluate the performance of the building and also to find out how effective it is at maintaining the comfortable indoor setting. The recorded temperature shows that the temperature inside the building ranges from 17.22˚ C to 19.83˚ C with daily fluctuation in temperature in smaller value which clearly shows that the building is stable at retaining the indoor temperature. The outside air temperature was also recorded for same period which were normally lower than the inside temperature which were in the range of 13.55˚ C to 15.42˚ C.

Table 6: Measured Indoor and Outdoor Average Temperature Comparision

Date	Day	Avg Temp Indoor	Avg Temp Outdoor	Temp Difference
1/17/2025	1	19.83	13.55	6.28
1/18/2025	2	17.87	14.42	3.45
1/19/2025	3	18.33	13.74	4.59
1/20/2025	4	17.42	13.68	3.74

1/21/2025	5	17.35	14.72	2.63
1/22/2025	6	17.9	16	1.9
1/23/2025	7	19.24	15.42	3.82
1/24/2025	8	18.64	14.78	3.86
1/25/2025	9	17.3	14.78	2.52
1/26/2025	10	18.21	13.88	4.33
1/27/2025	11	18.03	14.6	3.43
1/28/2025	12	18.69	13.95	4.74
1/29/2025	13	17.22	14.07	3.15

The difference between indoor and outdoor temperature for 12 days duration shows that the lowest difference is 1.9˚ C and highest difference is 6.28˚ C. For example, the highest temperature difference is on January 17 when the outside temperature was 13.55˚ C the inside temperature was 19.83˚ C which clearly shows that the passive building elements available inside the building has active role in maintaining this temperature. The recorded temperature was also compared with the comfortable temperature interval obtained from climate consultant software. The comfortable temperature for 80% acceptability limit is 17.8˚ C to 29.5˚ C and the measured temperature is above the comfort temperature range which clearly says that the building is performing effectively without relying on active heating and cooling system. Even though other environmental variables may affect the comfort but the early temperature analysis shows this type of result.

4.3 Building Site Details

As displayed in the site plan above, there are three different buildings present within the case study area. Among these two buildings the case study and kitchen are modified traditional Tharu buildings while the third building is made from Reinforced Cement Concrete. For the intent of this study, only the case study building is considered and its detail measurement is also taken which is essential for carrying out computer simulation.

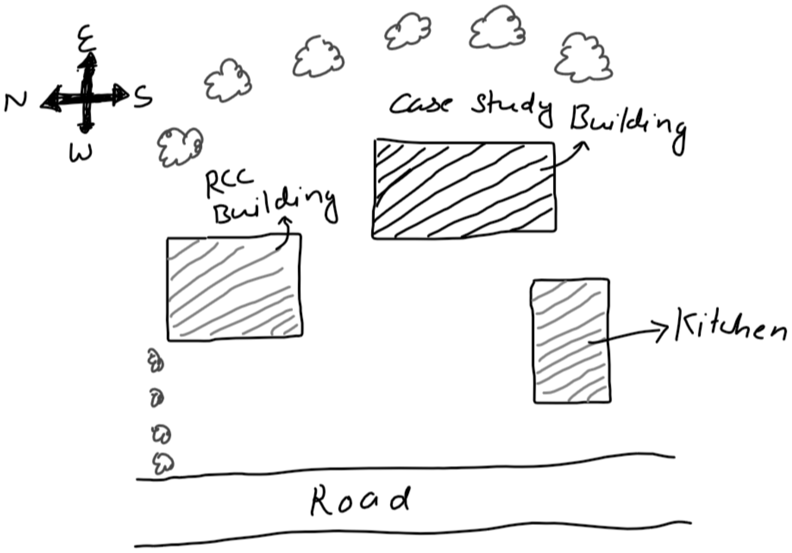


Figure 25: Site Plan of Case Study Building

This case study building is used for sleeping and storage whereas kitchen is used primarily for cooking and eating foods. In RCC building 10 people lives whereas in 4 people lives in case study building. The RCC buildings have 4 rooms. The road is 6m wide gravel road and it lies on west side of the buildings. We can also see the kitchen garden located on the back side of the buildings. On south side there is small fields where various crops are planted. The kitchen building’s longer length is aligned along East and West direction whereas the case study building’s longer length is aligned along North-South direction which is clearly visible in the above site plan drawing.

4.4 Building Plan Details

The building selected for case study is located at Mahadewa village. It is traditional Tharu building. The plan dimension of the house is 5.95m x 10.15m. The building is rectangular in plan. The house is oriented along N-S direction and shorter side facing E-W direction. The typical plan of the house is shown in the figure below:

The Tharu building have 5 different zones like two-bedroom, storage, common space, pooja (Dehurar). The zones are separated by 100 mm thick reed and mud plaster wall as well as grain silos of size 0.9m long, 0.6m wide and 1.7m height. The house has 1 bay along shorter side and 3 bay along longer sides. The pooja room is located on the North-East side where the prayers and rituals are conducted during festivals. The pooja room is restricted room since the entry of outsider is restricted. The total number of family members are 14 but in case study house only 4 people lives only for sleeping in bedroom and in common space during daytime.

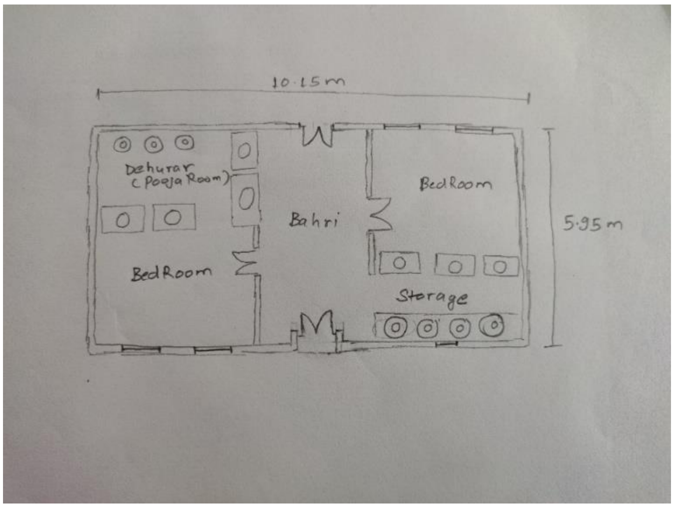
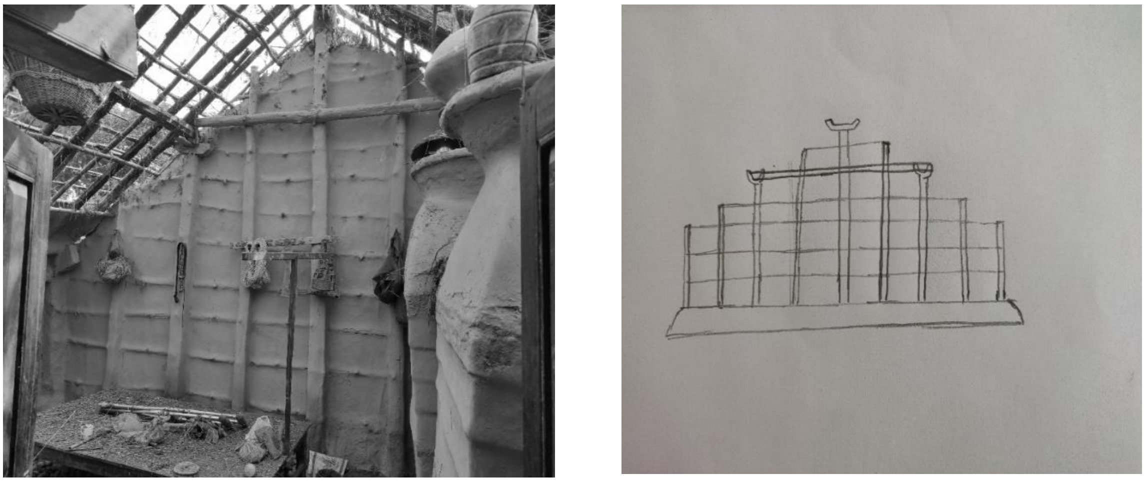


Figure 26: Floor Plan Details of Case Study Building

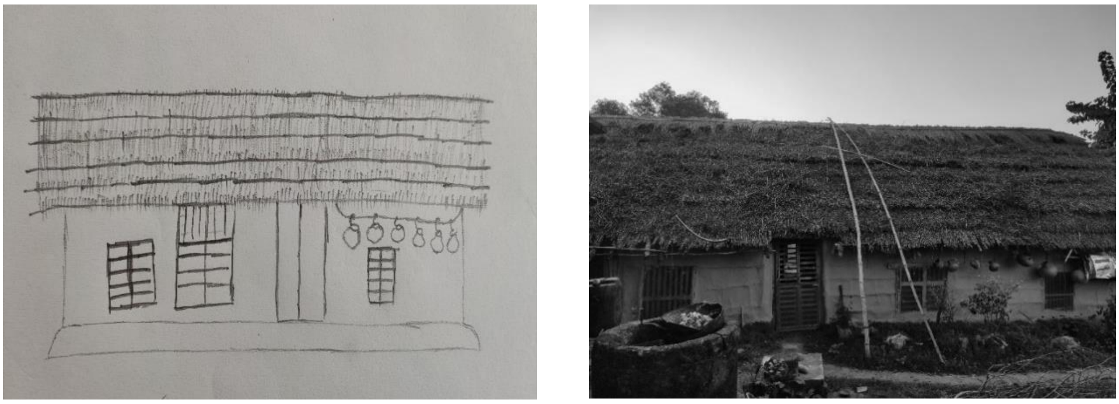
The rest of the time the building is unoccupied. The building is completely made from local materials. The materials required are reed, clayey soil, dried bamboo, ropes, rice or wheat paddy straw, small crushed straw, cow dung. The building is raised 300 mm from the ground level as per site measurement. The floor is made by laying straw then applying the mixture of mud, cow dung, crushed straw. The plastered mud applied on floor gradually settles after 3 to 4 days and the thickness of the floor is approximately 100mm. Similarly, local hardwood is used for forming the structural support members. The post is placed 750mm center to center and along width 9 numbers of vertical post is placed and similarly along the length side placed at 4 locations. The figure below shows the structural support member.



(a) (b)

Figure 27: (a) Structural Framing of Tharu Building (b)Section Details of Tharu Building

The building has total of 7 wooden casement windows. The 2 wooden doors placed on eastern and western side. The east and west side wall height is 1.45m and it is made air tight by plastering mud to the lower part of thatch also shown in the figure below.



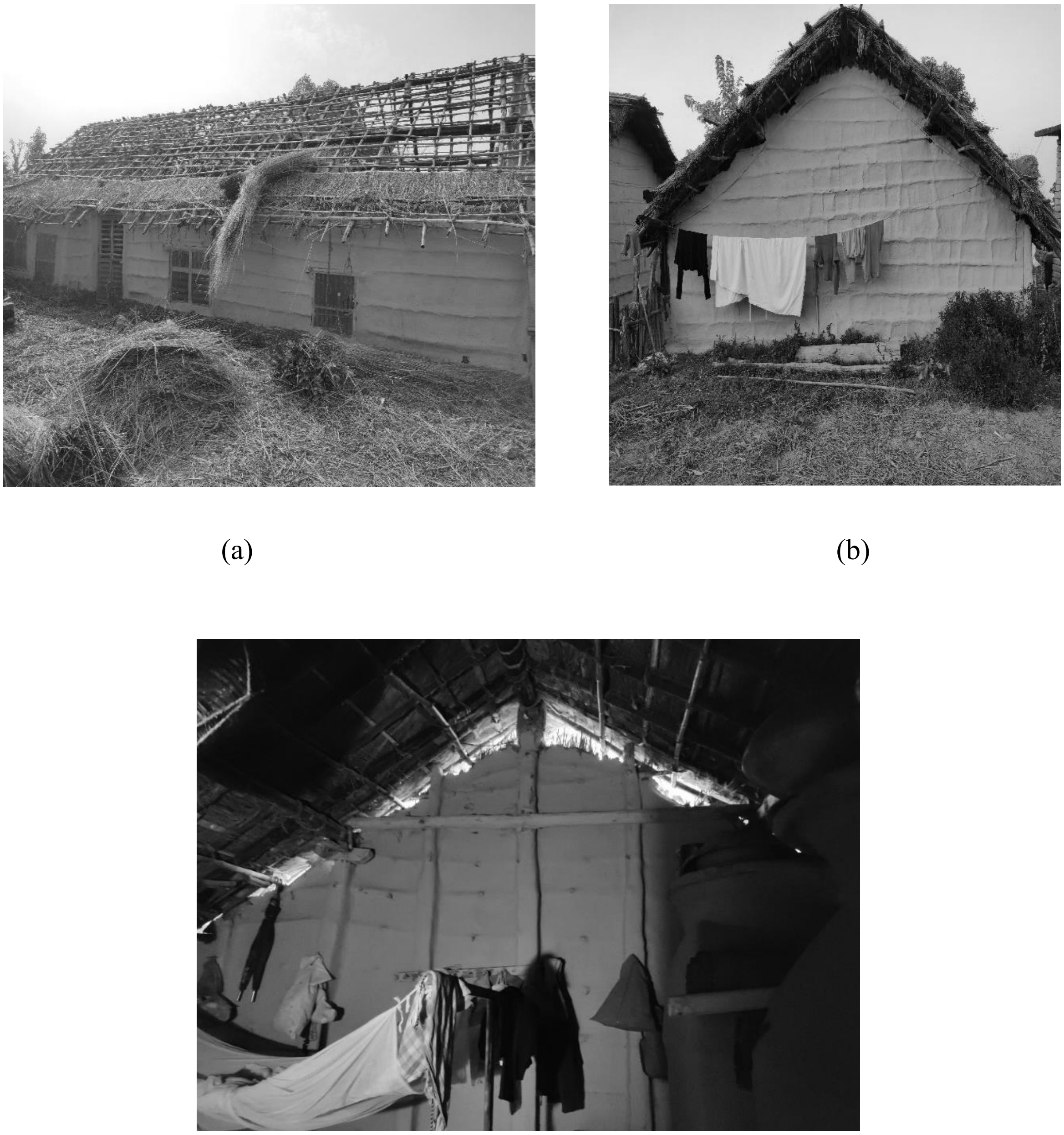
(a) (b)

Figure 28: Tharu Building Front View Image & Hand Drawn

The Tharu buildings have openings below the roof along the North-South direction which foster air movement but in East & West façade the gaps are sealed by plastering mud to the lower end of the roof which is visible in the image provided below.

Figure 29: Wall Plaster Applied to the roof lower end to seal gaps

The roof is made of reed thatch of thickness 300mm. The reed is supported on the bamboo rafter and purlins. The reed bundles are placed on these support and ties with ropes made from twigs collected from forest. The total of the building along N-S façade is 3.35m also there is openings left on N-S side below the gable roof to allow natural ventilation as well as air circulation.



(a) (b)

(c)

Figure 30: (a) Roof Framing Members (b)South Side View and (c)Opening Locations below the roof level

The figure above shows the structural members of roof where we can see bamboo rafter and sliced bamboo purlins placed which are tied with ropes made from material collected from forest called “Bankas” in Tharu language. Similarly, as shown in figure above the openings visible is also considered for computer simulation. There is gap left between the roof and upper part of wall these allows air movements which helps to regulate the air temperature of indoor environment.

4.5 Material Properties

The case study building is measured on site and the model needs to be prepared for performing energy simulation. The energy simulations require appropriately modelling all the building envelopes like wall, thatch rood, floor slab, windows etc. These materials also should resemble thermophysical properties in order to predict the behavior of the building in the simulated environment. Thus, the thermal conductivity of the materials used is collected from various articles for this study which is presented in the table below. These material properties are very important because the simulation program uses these properties to calculate the heat transfer taking place inside the buildings and based on this heat transfer the energy performance can be measured.

Table 7: Thermal Conductivity of material used for simulation

SN	Name of Material	Thermal Conductivity (W/mK)	Reference Article
1	Mud	0.6	(Gupta, 2020)
2	Window Glass	0.815	
3	GI Sheet	60.47	
4	Thatch	0.35	
5	Mat from reed 180x155mm	0.056	(Tsapko, 2020, August)
6	Bamboo Plywood	0.17	(Shan, 2020)
7	300 mm thickness water reed	0.087	(England., England, H. (2016))
8	300mm thickness long straw	0.069	

4.6 Simulation Setting

4.6.1 Software Input

For accurately modelling the building inside the simulation software some inputs need to be provided to the software. The inputs are listed down.

Clothing Factor for Summer = 0.5 & Winter 1

Infiltration rate = 6 ach (Fuller, 2009)

Outside Air Ventilation Rate = 5 ach

Window Opening Schedule opened 24 hours in summer and in winter opened from 8 AM to 5 PM by 20% and closed at night (Hom Bahadur Rijal, 2005)

Door Opening schedule is based on occupancy and opened 50% for 5% of occupancy time

Zones created: Bedroom North, Bedroom South and Common Space

4.6.2 Simulation Cases

The number of simulation cases that will be performed are 4. These are given in the table below along with the construction material detail.

Base Case Existing Building

External & Internal Wall: 100mm Mud Reed Wall

Ground Floor: 100mm Straw and mud

Roof: 300mm Reed Thatch

Door & Window: Wooden

Case 1 Building

External & Internal Wall: 100mm Mud Reed Wall

Ground Floor: 100mm Straw and mud

Roof: CGI Sheet

Door & Window: Wooden

Case 2 Building

External & Internal Wall: CGI Sheet

Ground Floor: 75mm concrete

Roof: CGI Sheet

Door & Window: Wooden

Case 3 Building

External & Internal Wall: CGI Sheet with bamboo lathe insulation

Ground Floor: 75mm concrete

Roof: CGI Sheet with bamboo lathe insulation

Door & Window: Wooden

CHAPTER 5: SIMULATION & DATA ANALYSIS

5.1 Base Case Existing Building

In the Base Case the existing building was simulated for winter and summer season for January and June month and the data that are considered for examining how the building would actually work are comfort temperature, internal heat gain, discomfort hour and fabric heat gain. In Base case for January the windows are opened from 8 am to 5 pm by 20% and closed after that which is taken from literature conducted by Hom Bahadur Rijal and in June the windows are opened and simulated.

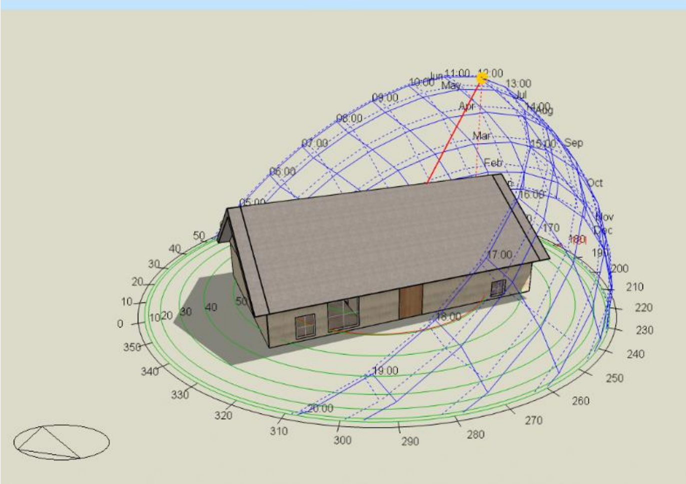


Figure 31: Rendered View of Base Case Existing Tharu Building with Solar Path Diagram

The Details of the construction materials used in Base Case Existing building is given in image below.

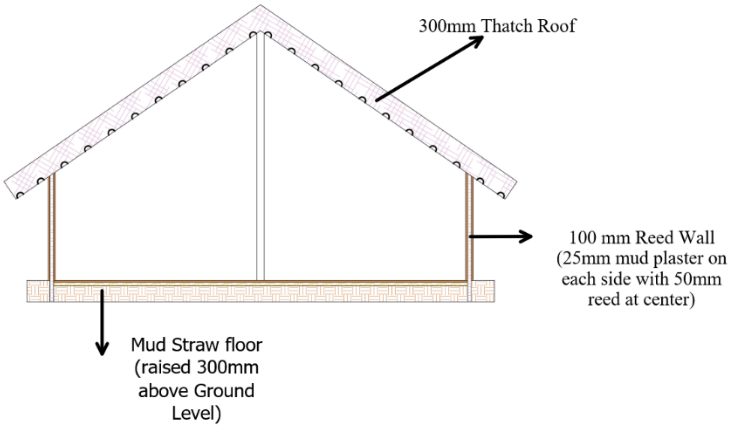


Figure 32: Material Details of Base Case Existing Building

The roof is made of 300mm reed and these roofing materials are easily found near the river area. The roofs are supported on the sliced bamboo which are tied together with ropes made from plants collected from forest. The wall is made from 100mm mud reed wall where reed is sandwiched between mud plaster on both sides. The mud for plastering can be obtained from nearby field or forest by digging pits. The floor level is raised by 300 mm and it is made from straw collected after harvesting from rice field which is applied with a mixture of cow dung, mud and straw.

5.2 Case 1: CGI Roof

In Case 1 the building is virtually emulated by shifting the roof material from thatch to corrugated roof to see how it performs. The wall, floor was same and the windows size was made similar in all zones. The simulated was done for January and June month similar to existing case and the data that are considered for examining the performance of the building is comfort temperature, internal heat gain, discomfort hour and fabric heat gain. In January window opening schedule is kept similar to Base Case Existing building and in June window is opened for 24 hours and simulated.

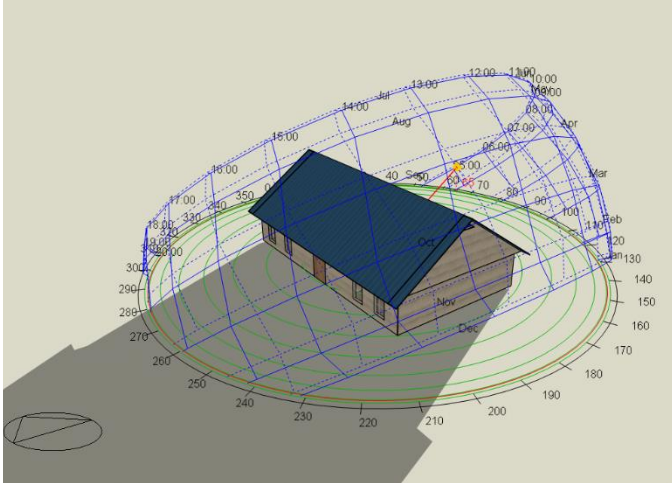


Figure 33: Rendered View of Case 1 with Solar Path Diagram

The Details of the construction materials used in Case 1 building is given in image below. In Case 1 Building the thatch, roof is replaced to CGI sheet only and other building materials remains similar to Base Case Existing building.

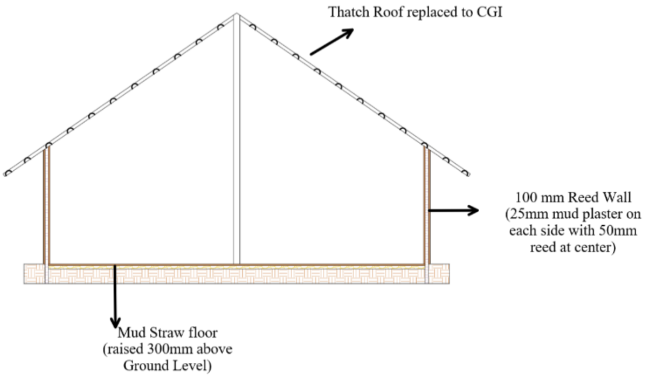


Figure 34: Material Details of Base Case 1 Building

5.3 Case 2: CGI Roof & CGI Wall

In Case 2 the building is simulated by changing roof, wall and ground floor slab to CGI sheet and concrete to see how it performs. The simulation was done for January and June month similar to other case and the data that are considered for examining the performance of the building is comfort temperature, internal heat gain, discomfort hour and fabric heat gain. In January window schedule is kept similar to Base Case Existing Building and June window is opened for 24 hours and simulated.

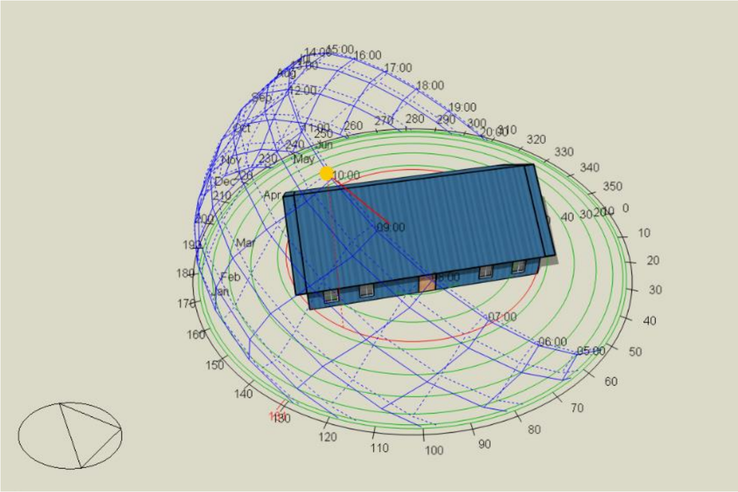


Figure 35: Rendered View of Case 2 with Solar Path Diagram

The Details of the construction materials used in Case 2 building is given in image below. Similarly in Case 2 building the roof is made from CGI sheet, mud reed wall replaced to CGI sheet wall and the mud flooring is also replaced to 75mm concrete floor

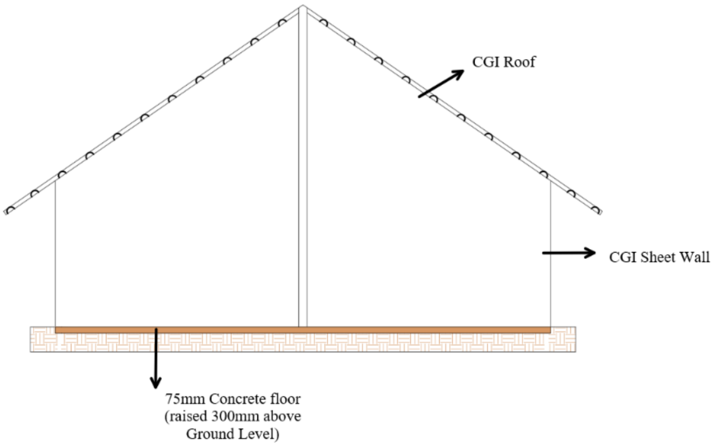


Figure 36: Material Details of Base Case 2 Building

5.4 Case 3: CGI Roof & CGI Wall with Bamboo Lathe Insulation

In Case 3 the bamboo insulation was provided to roof, wall to see how it performs. The simulation was done for January and June month similar to other case and the data that are considered for examining how the building would actually work are comfort temperature, internal heat gain, discomfort hour and fabric heat gain. In January window schedule is kept similar to Base Case Existing Building and in June window is opened for 24 hours and simulated.

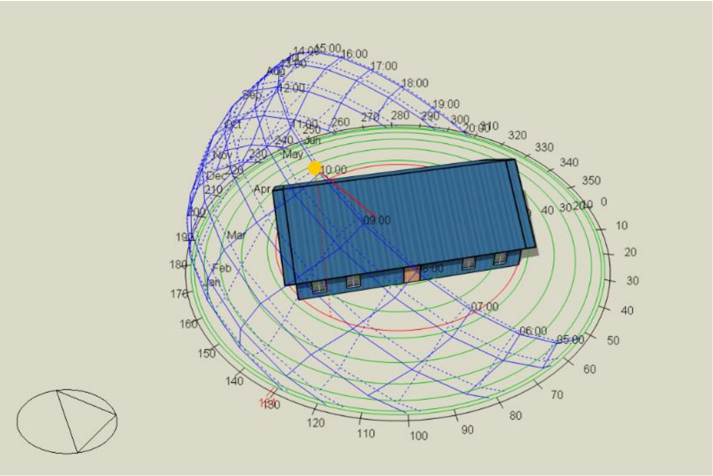


Figure 37: Rendered View of Case 3 with Solar Path Diagram

The Details of the construction materials used in Case 3 building is given in image below. In Case 3 the roof, floor and wall remain similar to Case 2, here only insulation is provided to roof and wall. The insulation provided is made from bamboo lathe whose total thickness is 100mm where there is 2-inch air gap provided between the bamboo lathe.

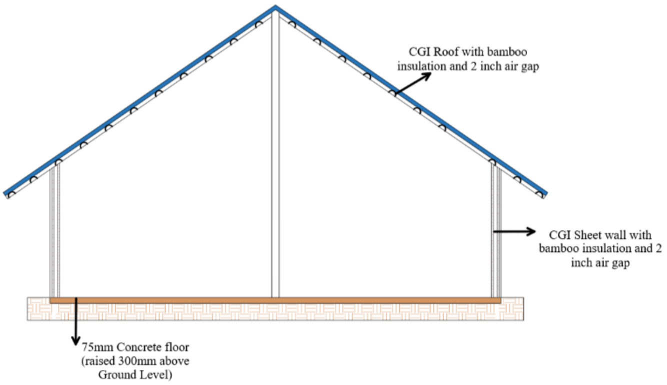


Figure 38: Material Details of Base Case 3 Building

5.5 Summer Air Temperature

The internal temperature inside the building obtained from simulation is presented in table for all 4 cases considered. In simulation three zones are created named Room North, Room South and common space but the air temperature presented in the table below is taken from Room South zone. The computer virtual modelling was carried out for 1 month but we have displayed the air temperature of 1 day only for 24 hours. The simulation for summer season was conducted for June months and the temperature are presented on three time at 7 AM morning, at 3 PM after noon and at 7 Pm evening as well as the outside dry bulb temperature.

Table 8: Simulated Indoor Air Temperature June month

		Outside Temperature			**Inside Temperature**		
SN	**Case**	**7:00 AM**	**3:00 PM**	**7:00 PM**	**7:00 AM**	**3:00 PM**	**7:00 PM**
1	Base Case	24.77	28.24	28.34	25.53	29	29.14
2	Case 1				25.23	30.19	29.8
3	Case 2				26.61	29.57	28.97
4	Case 3				25.28	28.32	28.64

For Base case at morning when outdoor temperature was 24.77˚C the indoor temperature was 25.53˚C which is slightly higher than outside indicating that the reed mud wall allows heat transfer. Similarly, Case 2 (CGI roof & wall) is warmest among all three in morning. The time during which the building is occupied is from 6:00 PM evening to 7:00 AM morning and if we inspect closely the temperature of air value from 7:00 PM to 7:00 AM it ranges from 29.14˚ C to 25.53˚ C and it lies in the range of comfortable temperature of 80% tolerable coverage which is from 17.8˚ C to 29.5˚ C. At 3:00 PM the temperature is highest.

In afternoon at 3 PM the Base case shows temperature of 29˚C which is cooler than Case 1, Case 2 showing that the Thatch roof, reed wall slows the heat gain. If we consider Case 3 its temperature is 28.32˚C indicating that bamboo insulation helps prevent overheating. If we see the temperature variation for Case 1, we can see it varies from evening to morning with 29.8˚ C to 25.23˚ C it obviously lies within comfortable range but the time of discomfort increases almost twice compared to base case which is discussed below.

In evening at 7 PM Base case maintains a stable temperature of 29.14˚C which slows heat loss. Case 2 (CGI roof & wall) as it heats and cools faster shows similar temperature to Base Case. The lowest temperature if for Case 3 of 28.64˚C showing that bamboo insulation prevents heat loss and gain.

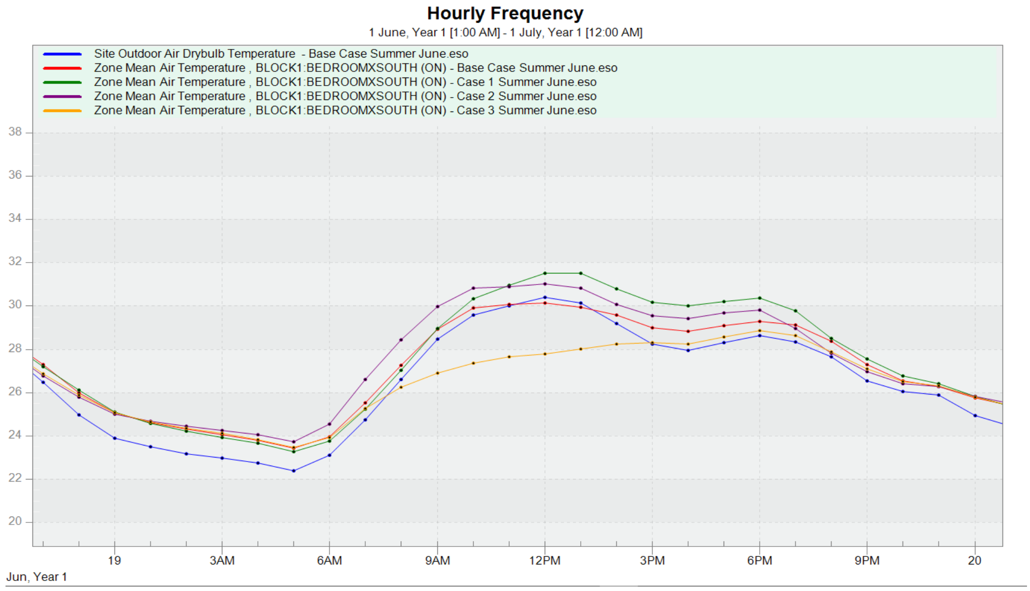


Figure 39: Hourly Temperature Variation of Buildings June

If we see the temperature variation for Case 2, we can see it varies from evening to morning with 28.97˚ C to 26.61˚ C it obviously lies within comfortable range but the time of discomfort also increases almost twice compared to base case. For Case 3 if we compare the temperature change from evening to morning it ranges from 28.64˚ C to 25.28˚ C it is of course in the band of favorable temperature and in contrast to Base Case Existing building it shows 13 hours less discomfort.

5.6 Winter Air Temperature

The internal temperature inside the building obtained from simulation is also presented in table for all 4 cases considered. In simulation three zones are created named Room North, Room South and common space but the air temperature presented in the table below is taken from Room South zone. The computer emulation was carried out for 1 month but we have displayed the air temperature of 1 day only for 24 hours. The simulation for winter season was conducted for January months and the temperature are presented on three time at 7 AM morning, at 3 PM after noon and at 7 Pm evening as well as the outside dry bulb temperature.

Table 9: Simulated Indoor Air Temperature January month

		Outside Temperature			**Inside Temperature**		
SN	**Case**	**7:00 AM**	**3:00 PM**	**7:00 PM**	**7:00 AM**	**3:00 PM**	**7:00 PM**
1	Base Case	8.09	18.95	16.58	14.25	21.03	20.79
2	Case 1				11.16	21.67	21.6
3	Case 2				12.87	23.28	18.74
4	Case 3				14.71	19.91	20.77

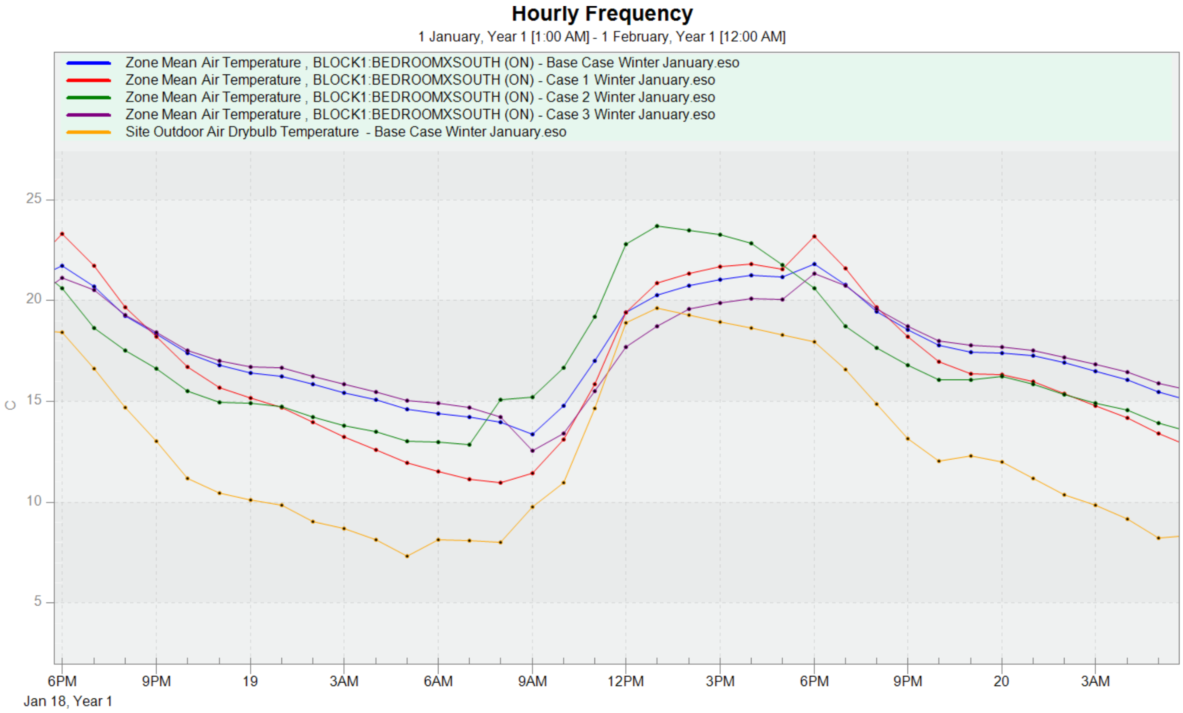


Figure 40: Hourly Temperature Variation of Buildings January

For Base Case we can observe that at morning when outside temperature was 8.09˚C inside temperature is 14.25˚C showing the heat insulation effect. But when we compare the temperature at afternoon it is lower than Case 3. At evening time when we compare the temperature drop from afternoon to evening it is 0.24˚C only but when we compare with Case 3 the temperature drop is 4.54˚C when the outside temperature was 16.58˚C. This indicates that the Thatch roof gains and loses heat slowly whereas the CGI sheet heats and cools faster.

5.7 Roof Air Temperature

In simulation we have considered roof as unoccupied zone and the discomfort level for roof is not calculated inside the simulation software. The interzonal heat transfer takes place between roof and the occupied zone. The air temperature of roof zone for June and January month is presented and briefly described.

Table 10: Simulated Indoor Air Temperature for Roof Level June month

		Outside Temperature			**Inside Temperature**		
SN	**Case**	**7:00 AM**	**3:00 PM**	**7:00 PM**	**7:00 AM**	**3:00 PM**	**7:00 PM**
1	Base Case	24.77	28.24	28.34	26.12	29.58	29.68
2	Case 1				26.84	36.74	32.86
3	Case 2				27.74	36.03	31.96
4	Case 3				25.62	30.80	30.55

For Base case building which is modified traditional Tharu building with mud reed wall, thatch roof and straw mud flooring and obviously they are traditional materials. It is also known fact that mud is not completely seal proof and thus have voids in them which are known for its insulating and breathable nature. At 7:00 AM, the inside temperature was measured 26.12˚ C which has increased by 1.35˚ C compared to outdoor temperature and this is due to heat preserved from the previous day. At noon 3:00 PM the inside air temperature increased to 29.58˚ C with 1.34˚ C increment and maintained a stable temperature of 29.68˚ C at evening 7:00 PM. If we look at the temperature measured at During this time interval, we can clearly see that the change in temperature is small which shows that the traditional building materials are effective at maintaining the temperature stable during the June month.

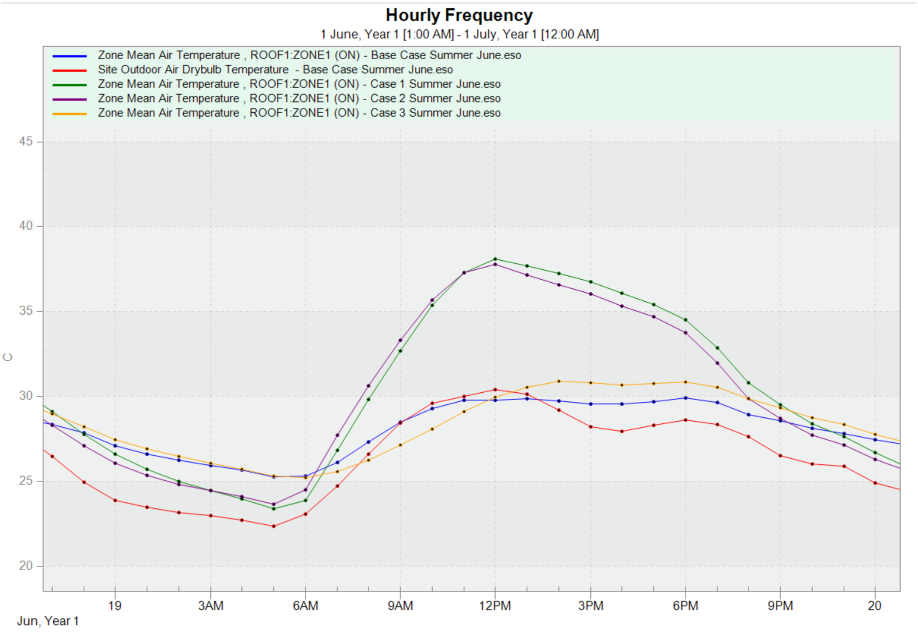


Figure 41: Hourly Temperature Variation of Roof Level June

In Case 1 where thatch roof is replaced by CGI roof, the inside air temperature at 7:00 AM was measured to be 26.84˚ C which is 2.07˚ C more than outside temperature. At 3:00 PM it increased to 36.74˚ C with 8.5˚ C increase compared to outside temperature which indicates high heat absorption. Also, at 7:00 PM the inside temperature is at 32.86˚ C which is 4.52˚ C more than outside. This temperature data reveals the downside of using CGI sheets in hot climate zones.

For Case 2 where the wall, roof are made from CGI sheet and concrete floor the inside air temperature at 7:00 AM is 27.74˚ C which is 2.97˚ C higher than outside. At 3:00 PM the inside temperature is at 36.03˚ C with 7.79˚ C higher than outside. At 7:00 PM it cools down to 31.96˚ C 4.07˚ C less compared to 3:00 PM.

For Case 3 with bamboo lathe which features passive design elements. At 7:00 AM the indoor temperature is 25.62˚ C which is 0.85˚ C higher than outside. At 3:00 PM indoor temperature was 30.8˚ C slightly increased by 2.56˚ C and at 7:00 PM it remained at a stable temperature of 30.55˚. If we compare this case to Case 1 and Case 2 it shows improved performance highlighting the importance of cost-effective local insulation materials. The comparison of these temperature data shows that Thatch roof and CGI sheet with bamboo lathe performs much better when compared to Case 1 and Case 2.

Table 11: Simulated Indoor Air Temperature for Roof Level January month

		Outside Temperature			**Inside Temperature**		
SN	**Case**	**7:00 AM**	**3:00 PM**	**7:00 PM**	**7:00 AM**	**3:00 PM**	**7:00 PM**
1	Base Case	8.09	18.95	16.58	14.16	19.99	20.05
2	Case 1				7.65	25.58	18.83
3	Case 2				8.42	26.58	18.21
4	Case 3				13.25	19.45	19.89

The air temperature below roof for Base Case building at early morning 7:00 AM maintains comparatively warm temperature of 14.16˚ C when outdoor temperature was 8.09˚ C which indicates that the heat from previous day is retained. At same time Case 1 and Case 2 records 7.65˚ C and 8.42˚ C which is lower temperature which suggest that they have higher heat loss at night time. Case 3 with bamboo lathe records temperature of 13.25˚ C which shows similar performance to Base Case building in preventing heat loss.

At mid-afternoon 3:00 PM Case 1 and Case 2 shows 25.58˚ C and 26.58˚ C. Here the temperature has significantly risen and this is because of higher thermal transmittance value of roof and wall materials. The Base Case and Case 3 records air temperature of 19.99˚ C and 19.45˚ C which is due to lower thermal transmittance value.

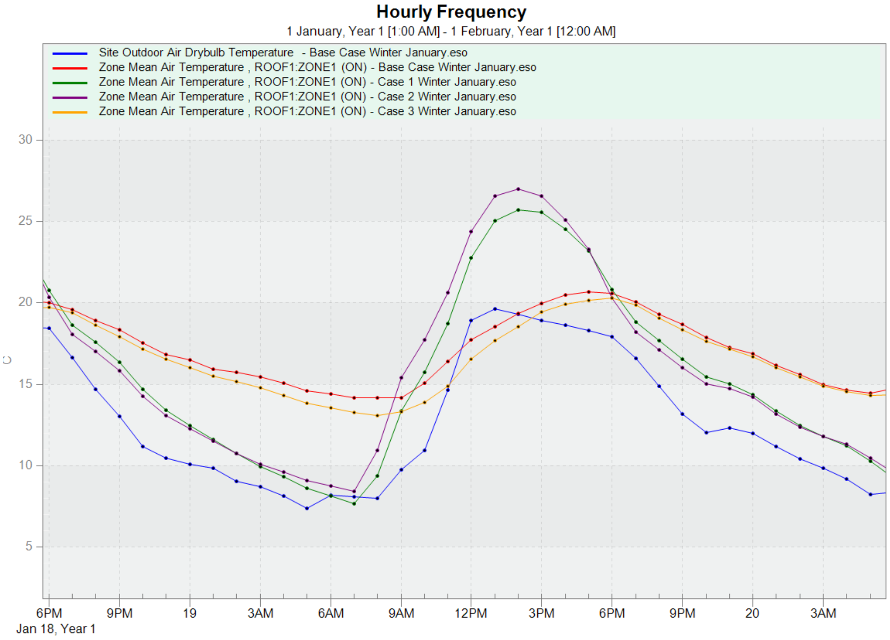


Figure 42: Hourly Temperature Variation of Roof Level January

In the evening at 7:00 PM, Base Case and Case 3 shows temperature of 20.05˚ C and 19.89˚ C which shows higher value compared to Case 1 and Case 2 with temperature value of 18.83˚ C and 18.21˚. If we observe the temperature range for Base Case from morning to evening the temperature varies from 14.16˚ C to 20.05˚ C with difference of 5.89˚ C. The temperature range for Case 3 is between 13.25˚ C to 19.89˚ C with difference of 6.64˚. This all indicates that the Thatch roof and CGI with bamboo insulation heats slowly and loses slowly maintain the indoor temperature fairly stable. If we observe this trend for Case 1 it fluctuates from 7.65˚ C to 18.83˚ C with difference of 11.18˚ C and for Case 2 it changes from 8.42˚ C to 18.21˚ C with difference of 9.79˚. The variation in temperature is high where the roof heats and loses faster which does not maintain stable temperature.

5.8 Air Change Rate

The simulation is carried out with two window opening schedule one for June during which the windows are opened for 24 hours and the next one is for January where the windows are opened from 8 AM to 5 PM by 20% and closed at night time obtained from Literature (Hom Bahadur Rijal, 2005). The air exchange that takes place inside the building when the windows are opened and closed are presented in the table below for all 4 cases simulated during June and January months. Air coming in and out also changes the temperature as it can bring hot air and cold air. The air change rate is can be calculated using formula, a = Q*3600/V where Q is volumetric air flow and V is the volume of the zone or room (Nazaroff, 2021).

During June month, all zones have shown significantly higher value of ach and this is due to window schedule where windows remained open for 24 hours. The Base Case record 17.27 air change per hour for room north and 10.66 air change per hour for room south. This higher range of air change indicates the presence of strong natural ventilation ability of traditional Tharu buildings which supports the idea of passive cooling of buildings. Case 1 and Case 2 show an even higher value of air change in room north and south. However, if we observe the air change at roof level it has remained relatively low and this is because the roof level lacks windows or openings. If we consider air change value for Case 3 it shows 11.23 and 10.78 for room north and south but have high air change of about 0.93 compared to other cases. The roof air change for Base case and Case 3 is 0.66 and 0.93 which suggest that there is air flow in vertical direction also.

Table 12: Air change at various zones of simulated cases

		Room North (ach)	Room South (ach)	Common Space (ach)	Roof (ach)
Base Case Building	Summer	17.27	10.66	0.55	0.66
	Winter	3.73	3.17	2.2	1.03
Case 1 Building	Summer	18.16	17.51	1.48	0.33
	Winter	4.77	5.53	2.85	1.26
Case 2 Building	Summer	18.67	17.73	1.53	0.22
	Winter	5.25	6.93	3	1.17
Case 3 Building	Summer	11.23	10.78	1.29	0.93
	Winter	2.9	3.8	3.38	1.49

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5.9 Heat Gain & Heat Loss

The heat incoming and heat outgoing inside the building are from various elements. In this simulation, the heat transfer inside the building for simulated cases are from two elements: a) Internal Heat Gain b) Fabric Heat Gain. The internal heat gain includes heat generated from people, equipment load. Lighting system and solar heat gain from windows. The building considered here has general purpose lighting only and generally used during night time for short duration only. The Fabric heat gain includes heat transfer from glazing, wall, ceiling, ground floor, partition, internal natural ventilation, external air, external ventilation and roof. There are three zones inside the building name Room North, Room South and Common Space but we have summed all the heat gains for all zones including unoccupied roof also and it also includes results all 4 simulation cases.

Table 13: Building Heat Gain and Loss June month

Case	Heat Gain (kwh)	Heat Loss (kwh)	Heat Balance (kwh)	Overall Discomfort 90% Acceptability	Overall Discomfort 80% Acceptability
Base Case	718.61	-603.35	115.26	89.30	37.74
Case 1	1686.77	-1572.53	114.24	145.79	89.12
Case 2	1934.93	-1986.75	-51.82	120.97	71.77
Case 3	1149.53	-1044.42	105.11	65.75	24.37

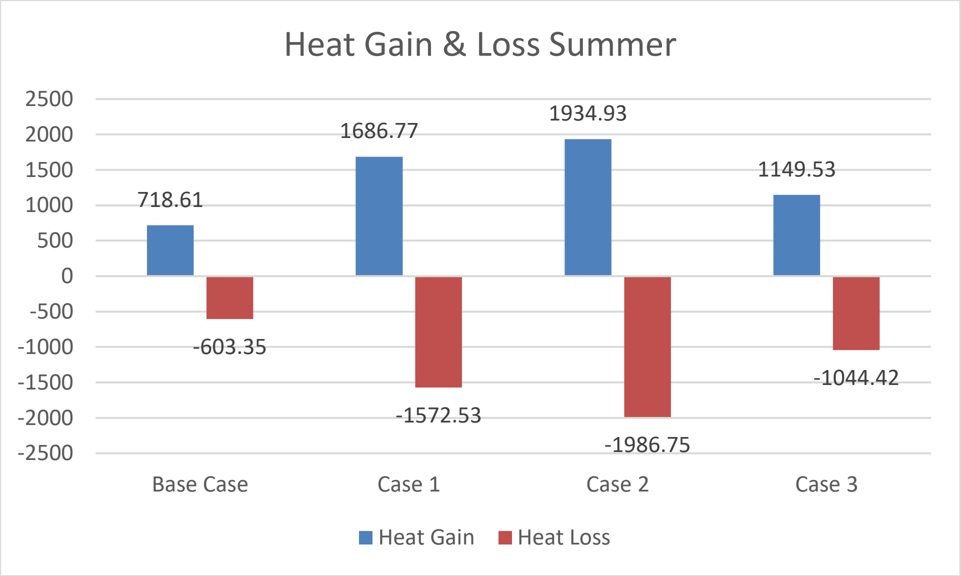

Figure 43: Building Envelope Total Heat Gain June

For Base Case building with mud plastered reed wall, thatch roof the total heat balance is 115.26 Kwh whereas the discomfort hour for 80% acceptability is 37.74 hours. It is seen that it is gaining more heat than loosing but also the discomfort hour is low this is because of mud plastered wall and thatch roof which heats and cools slowly.

For Case 1 building with CGI roof when compared with base case the heat gain is increased by 968.16 Kwh and heat loss also increased by 969.18 Kwh. The heat gain and loss are almost more than double even though the heat balance of Base Case and Case 1 are similar but the discomfort hour is also increased to 89.12 hours. Since the thermal transmittance of CGI is more than thatch roof it heats and cools slowly thereby increasing the indoor temperature and making condition uncomfortable.

For Case 2 the heat balance is -51.82 kwh which indicates that the building is losing heat but despite this the discomfort hour is 71.37 hours higher than Base Case building. In this case when the reed walls are also replaced by CGI sheet wall the heat incoming and outgoing has increased tremendously.

Similarly, for Case 4 the heat incoming and outgoing are lower than Case 1 & 2 but still higher than Base Case by almost 430 kwh and also the discomfort hour is lowest among all cases considered. We can clearly see bamboo insulation preventing heat incoming and heat outgoing.

Table 14: Building Heat Gain and Loss January month

Case	Heat Gain (kwh)	Heat Loss (kwh)	Heat Balance (kwh)	Overall Discomfort 90% Acceptability	Overall Discomfort 80% Acceptability
Base Case	608.22	-551.07	57.15	301.21	280.66
Case 1	712.23	-662.9	49.33	305.15	292.64
Case 2	967.82	-1142.87	-175.05	308.82	291.40
Case 3	692.48	-642.66	49.82	319.84	297.43

For Base Case building in winter the heat balance 57.15 kwh which is positive suggesting that the building is retaining heat. But with this amount of heat retained the discomfort hour for 80% acceptability limit is 280.66 hours. Even though this discomfort hour is lowest among 4 cases but still it is not enough for winter. This suggests that the Base Case building is unable to retain sufficient heat to make the indoor comfortable.

For Case 1 the heat gain has increased but at the same time the heat lost is also higher compared to Base Case. The total heat balance is 49.33 kwh and with this much amount of heat retained the discomfort hour is 292.64 hours greater than Base Case showing the buildings inefficiency.

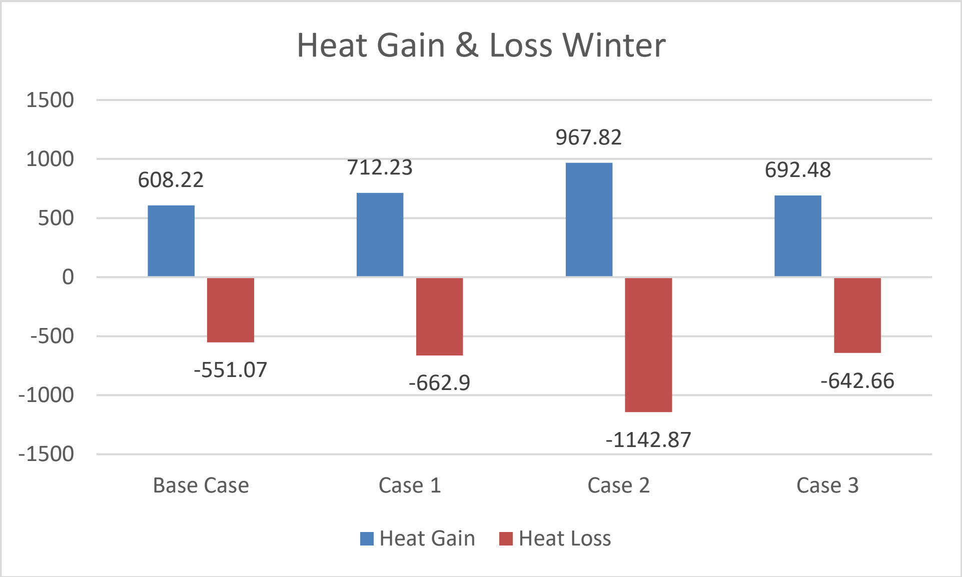

Figure 44: Building Envelope Total Heat Gain January

For Case 2 the heat balance is -175.05 Kwh which is highest and the discomfort hour is 291.40 hours which means it is losing more heat than it has gained indicating that it is performing worse than Base Case, Case 1 & Case 3.

For Case 3 also even though it has bamboo insulation provided it is also not able to retain the heat even though it gains more heat than Base Case but also loses more heat. The heat balance is similar to Case 1 but despite all this it has highest discomfort hour of 294.43 hours compared to all cases.

5.10 Internal Heat Gain

The internal heat gain includes heat generated from people, equipment load, lighting system and solar heat gain from window. In the simulated Existing Tharu building the heat gain internally is similar to other three cases. The building has general purpose lighting only and is based on occupancy schedule defined. The data for June and January is presented in the table below for various zones.

Table 15: Internal Heat Gain Inside the Building June Month

SN	Zone	Lighting (Kwh)	Occupancy (Kwh)	Solar Gain from Windows (Kwh)
1	Room North	1.2	28.19	151.18
2	Room South	1.2	28.19	96.27

3	Common Space	1.2	45.78	0

Table 16: Internal Heat Gain Inside the Building January Month

SN	Zone	Lighting (Kwh)	Occupancy (Kwh)	Solar Gain from Windows (Kwh)
1	Room North	1.2	29.3	134.57
2	Room South	1.2	29.3	85.86
3	Common Space	1.2	104.79	0

In June month if we see the heat gain data, we can see that heat energy dissipated from 10-watt light bulb for room north, room south and common space is 1.2 kwh which is very small and same because in the case study building light bulb was used and for short time duration from 6 pm to 9 pm. If we observe the heat which is generated due to people inside the building, we can clearly see that for room north and south which is primarily used as bed room and is occupied at night time only and the state of people inside those room are resting mode which generates less heat which uses value specified in software. The heat generated in room north and south is 29.3 kwh but in common space is 45.78. It can be figured out that heat due to people if more compared to room north and room south and it happens due to 4 people during occupied time compared to 2 people in room north and south. Similarly, the heat energy which enters inside the building from transparent window is different in room north and room south, this happens due to different size of windows. In common space the heat which the building gains from windows is zero since there are no windows in common space. Similar, nature of data can also be obtained for the simulation during January month. The huge surge in data we observe is for heat added due to people in common space and it’s because of 4 number of people with clothing providing insulation level 2 times compared to 0.5 insulation value provided in summer.

5.11 Model Validation

For validating the result, we have compared the hourly temperature data collected from the Arduino Nano Data logger with the simulated temperature data for existing Base Building because the data collection was done in winter season. The data was logged from January 17 to January 29 so the hourly temperature data of one particular day was compared with simulated air temperature. The graph is shown below, where we have presented hourly temperature data for January 20.

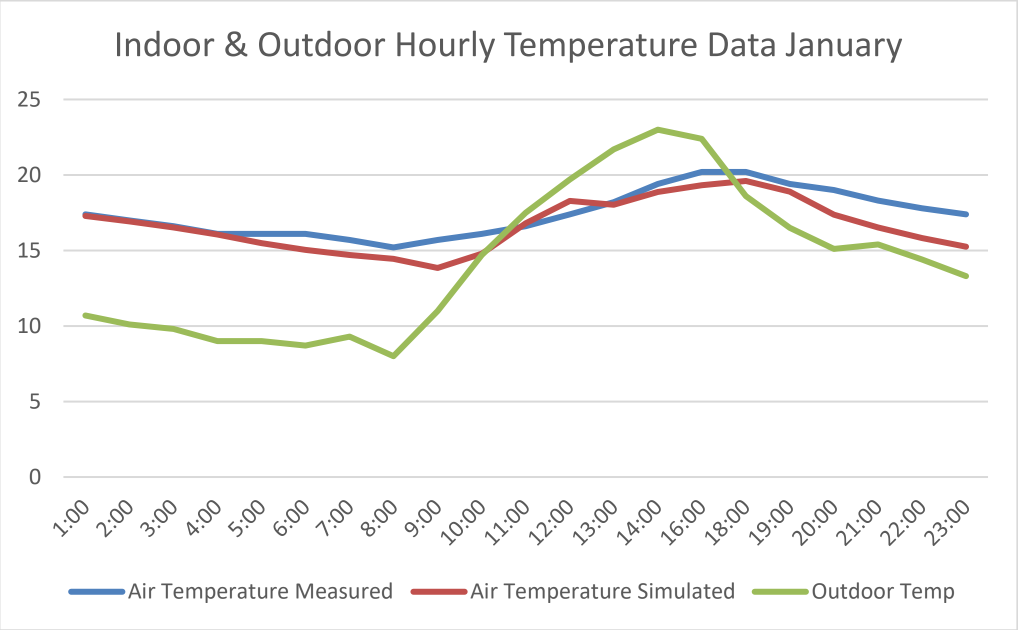

Figure 45: Simulated and Measured Indoor Temperature of Base Case Building

In the graph we can clearly see measured, simulated and outdoor temperature following the similar pattern as seen from graph. At night 1 AM when outdoor temperature is 10.7˚C the measured and simulated temperature are 17.4˚ C and 17.28˚ C. At 7 PM when outdoor temperature was 9.3˚ C then the simulated and measured temperature are 15.7˚ C and 14.7˚ C. At 2 PM when the outdoor temperature was 23˚ C the measured and simulated indoor temperature are 19.4˚ C and 18.88˚ C. Similarly, at 7 PM when the outdoor temperature was 16.5˚ C then the measured and simulated temperature are 19.4˚ C and 18.91˚ C. This helps to validate out simulated model in the Design Builder Software because the difference between the simulated and measured air temperature is less than 2.16˚ C which is maximum and others even less which can be clearly observed in the table below.

Table 17: Simulated and Measured Indoor Temperature for Validation (January)

Time	Air Temperature Measured	Air Temperature Simulated	Outdoor Temp	Difference
1:00	17.4	17.28	10.7	0.12
2:00	17	16.92	10.1	0.08
3:00	16.6	16.52	9.8	0.08
4:00	16.1	16.07	9	0.03
5:00	16.1	15.48	9	0.62
6:00	16.1	15.05	8.7	1.05
7:00	15.7	14.70	9.3	1.00
8:00	15.2	14.44	8	0.76
9:00	15.7	13.84	11	1.86
10:00	16.1	14.78	14.7	1.32
11:00	16.6	16.79	17.5	-0.19
12:00	17.4	18.28	19.7	-0.88
13:00	18.2	18.03	21.7	0.17
14:00	19.4	18.88	23	0.52
16:00	20.2	19.32	22.4	0.88
18:00	20.2	19.60	18.6	0.60
19:00	19.4	18.91	16.5	0.49
20:00	19	17.36	15.1	1.64
21:00	18.3	16.53	15.4	1.77
22:00	17.8	15.82	14.4	1.98
23:00	17.4	15.24	13.3	2.16

CHAPTER 6: RESULT AND DISCUSSION

6.1 Discomfort Hour

The time not meeting the adaptive comfort limit based on for the simulated building during the time of occupancy for June and January for 4 cases are presented and discussed.

The Base Case building in summer has discomfort hour of 26.52 hours (Room North), 23.93 hours (Room South) and 62.78 hours (Common Space). In summer the hottest zone is common space. In winter the same building experiences high discomfort with 337.45 hours (Room North), 333.82 hours (Room South) and 170.72 hours (Common Space) which gives insight that the building is unable to retain heat. In winter the zone common space shows lowest discomfort hour, this is higher heat gain from 4 amount of occupancy. The room south shows 3.63 hours less discomfort than room north which is very small but also shows variation since the south side room is more preferred for winter due to exposure to sun light.

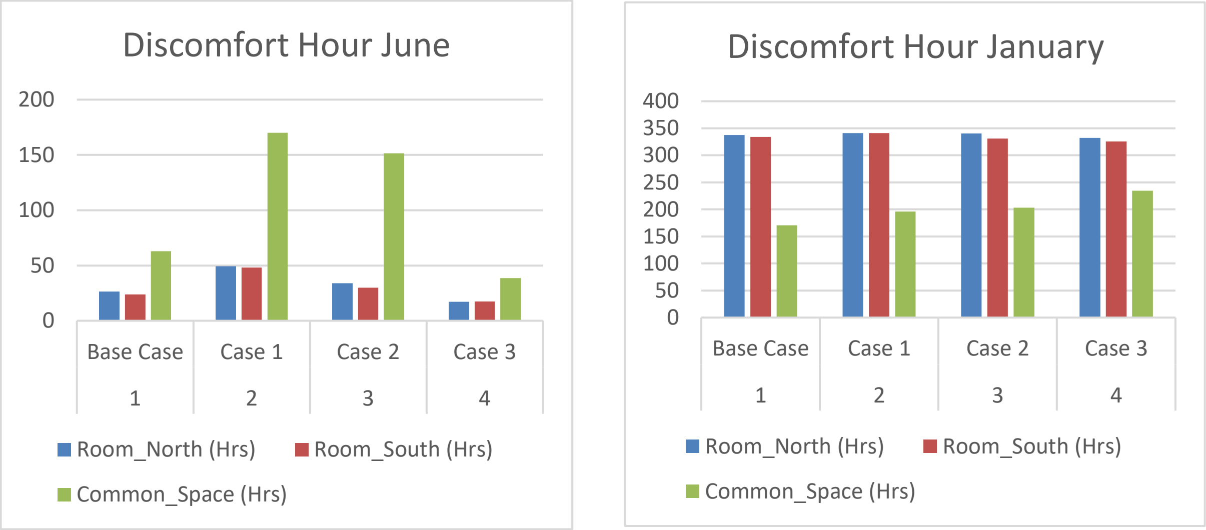

Figure 46: Discomfort Hour of all the cases considered during June and January month

In case 1 with CGI roof the discomfort, hour have increased in summer to 49.17 hours (Room North), 48.13 hours (Room South) and 170.07 hours (Common Space). The common space shows higher discomfort in summer due to high heat gain from occupancy. In winter the same building experiences high discomfort with 341 hours (Room North & South) and 196.1 hours (Common Space). Again, in winter the same heat from occupancy which caused discomfort in summer can be seen effective in winter for lowering discomfort hour.

In case 2 the discomfort hour in summer is 33.98 hours (Room North), 29.78 hours (Room South) and 151.55 hours (Common Space). It is higher than Base Case because of conductivity of CGI which leads to faster heat transfer and overheating in summer. In winter the performance remains even poor, with discomfort hour of 340.22 hours (Room North), 330.87 discomfort hours (Room South) and 203.1 hours (Common Space). We can see that the room in south side shows 9.35 hours less discomfort.

In case 3 adding bamboo lathe insulation with air gap significantly reduces the discomfort hour of common space to 38.58 hours and the discomfort hour for Room North and Room South are 17.13 hours and 17.4 hours during June which is lower than Base Case. Similarly, in January the discomfort hour can be seen decreasing with 332.07 hours (Room North), 325.67 hour (Room South) and 234.55 hours (Common Space) compared to CGI houses without bamboo insulations as well as Base Case. For common space we can see that the discomfort hour is highest for Case 3 with bamboo lathe insulation.

6.2 Wall Heat Transfer

The Base Case building has walls made from reed and mud plaster with 100mm thickness, in case 1 it is also same material wall but with CGI sheet, in case 2 reed mud wall is replaced by CGI sheet wall and in case 3 also it is replaced with CGI sheet wall but with bamboo lathe insulation applied for both roof and wall. The heat transfer taking place for room south is discussed along with its thermal transmittance value.

Table 18: Wall Heat Transfer Rate

Case	**Wall Type**	**Thermal Transmittance U (W/m2K)**	**June Heat Transfer (Kwh)**	**January Heat Transfer (Kwh)**
Base Case Existing Building	Reed Mud Wall	0.279	16.55	26.44
Case 1	Reed Mud Wall	0.279	-2.43	41.79
Case 2	CGI Sheet Wall	7.142	41.03	215.48

Case 3	CGI Sheet with bamboo lathe insulation	1.2	30.26	42.07

In Base Case the u-value of reed wall is 0.279 W/m2K and it is gaining heat of 16.55 Kwh in June and in January it is gaining 26.44 Kwh. In Case 1 the u-value is also 0.279 W/m2K and it is losing -2.43 Kwh heat in June and gaining 41.79 Kwh in January. In Case 3 the u-value of CGI sheet wall is 7.142 which is very high and the heat gain in June increased to 41.03 Kwh and heat gain also increased to 215.48 Kwh in January. In Case 3 the addition of bamboo lathe insulation reduced the u-value to 1.2 W/m2k thus the heat gain in June decreased from 41.03 Kwh to 30.26 Kwh and also in January the heat gain inside dropped to 42.07 Kwh from 215.48 Kwh from Case 2. We can clearly see that as the thickness of wall increases the thermal transmittance value also decreases which also changes the heat transfer rate. From the table above we can figure out that Case 3 has highest heat gained in summer and at the same time highest heat absorbed in winter. Case 3 will obviously gain more heat and lose more since it has high value of thermal transmittance and we are aware of the fact that higher transmittance leads to more ingoing and outgoing heat and smaller transmittance value just work opposite of higher value.

6.3 Roof Heat Transfer

Table 19: Heat Transfer through Roof during June and January

Case	Roof Type	Thermal Transmittance U (W/m2K)	June Heat Gain (Kwh)	January Heat Gain (Kwh)
Base Case Existing Building	Thatch Roof	0.279	101.73	-11.68
Case 1	CGI Sheet	7.142	901.19	90.7
Case 2	CGI Sheet	7.142	964.46	-84.6
Case 3	CGI Sheet roof with bamboo lathe insulation	1.2	336.87	-54.6

In Base Case Existing Building during summer the 300 mm thatch roof gains 101.73 kwh indicating good insulation and low heat absorption and in winter it loses only -11.68 kwh suggesting moderate heat retention. The lower thermal transmittance of thatch roof also says that it loses and gains heat at slower rate.

In case 1 replacing the thatch roof with CGI increases the heat gain from 101.73 kwh to 901.19 kwh which indicates that CGI absorbs more heat making the building hotter. In winter the heat gain increased compared to Base Case to 90.7 kwh. We can clearly see that the heat gain and loss have both increased by almost 9 times compared to Base Case Building. The reason behind this is the higher thermal transmittance of the CGI sheet which makes CGI sheet to gain and loose heat at faster rate compared to thatch roof which has smaller U-value.

In case 2 the heat gain further increases to 964.46 kwh the highest recorded which indicates extreme overheating. While in winter the heat loss is -84.6 kwh making it the coldest case which indicates that CGI and concrete floor does not provide good insulation. Again, if we compare this heat gain with Base Case it has increased by 9 times and heat loss increased by 8 times.

In case 3 with bamboo lathe insulation the heat gain in summer is reduced to 336.87 significantly lower than case 2 & 3 showing that bamboo lathe insulation improves thermal performance. Winter loss is -54.6 kwh much lower than case 2 meaning that bamboo lathe insulation helps retain heat better. If the heat gain is compared with Base Case, then heat gain in June is increased by 3 times and in January it has increased by 5 times. But compared to Case 2 and Case 3 heat gain is decreased by approximately 600 kwh and heat loss also decreases. The U-value also decreases from 7.142 W/m^{2}K to 1.2 W/m^{2}K. Since lower value is more desirable than higher value.

6.4 Role of Passive Design Elements

Table 20: Role of Openings Below Roof Before

Case	Summer Window Open(kwh)	Winter window Open (kwh)	Discomfort Hour Open Summer	Discomfort Hour Open Winter
Base Case Building	5.42	-53.4	37.74	280.66
Case 1	-1.47	-26.88	89.12	292.64
Case 2	-1.1	-31.16	71.77	291.40
Case 3	2.79	-76.51	24.37	297.43

Table 21: Role of Openings Below Roof After

Case	Summer Window closed(kwh)	Winter window closed (kwh)	Discomfort Hour Closed Summer	Discomfort Hour Closed Winter
Base Case Building	0.12	-0.17	35.54	243.93
Case 1	-2.79	-0.39	93.17	277.44
Case 2	-2.06	-0.06	80.91	259.04
Case 3	-0.22	-0.03	21.63	246.43

In Base Case building during June when opening below the roof is kept open, it allows air flow which brings adds up 5.42 kwh head at the indoor space and with his heat buildup discomfort hour is measured to be 37.74 hours but when we compare it with scenario where that opening is closed we can see the quantity of heat incoming decreases from 5.42 kwh to 0.12 kwh and with 5.3 kwh less heat incoming the discomfort hour is at 35.54 hours. The discomfort hour decreases by 2.2 hours which is not very large but shows that strategy of opening and closing door can obviously change the performance of building which in this case is traditional Tharu Buildings. If we compare the similar types of trends in January month for Base Case Building where at first scenario windows are opened through which -53.24 kwh of heat is lost and discomfort hour is at 280.66 hours. When we close the openings below roof the heat outgoing also decreases to -0.17 kwh and discomfort hour is 243.93 hours which is 36.73 hour less. Here, the discomfort hour decreased in winter is more compared to summer case, thus closing openings below roof is more preferrable in winter month.

If we compare for Case 1 during June for windows opened, we can see that -1.47-kwh heat is outgoing which shows discomfort hour of 89.12 hours. The heat lost is higher when windows is closed accounting -2.79 kwh and discomfort hour is 93.17 hours. Here, even though heat lost is more compared to openings opened but we get 4.05 hour of discomfort hour in openings closed. When we compare openings open during January month for Case 1, we can see that heat that is losing is -26.88 kwh and discomfort hour is 292.64. In openings below roof closed scenario heat lost is decreased from -26.68 kwh to -0.39 and in doing so the discomfort hour lowers to 277.44 hours. This suggest that for building with CGI roof opening below roof should be opened during summer and closing the opening in winter is preferred.

For Case 2 during June month for openings below roof opened accounts for heat loss of -1.1 kwh with discomfort hour at 71.77. But when openings are closed then the heat being lost increase to -2.06 kwh which accounts for 80.91 discomfort hour, here discomfort hour is increased by 9.14 hour. We have obtained two cases where discomfort hour increases when openings below roof is closed indicates that opening below roof should be opened. If we observe same trend but in January month where opening is opened then heat outgoing is -31.16 kwh with discomfort hour at 291.40 and when opening is closed then heat that was being lost becomes almost zero which also decreases discomfort hour to 259.04 by 32.36 hours. This also suggest that opening below roof to be closed during winter.

For Case 3 which is equipped with bamboo lathe with 2-inch air gap during June month with openings opened heat incoming is 2.79 kwh and discomfort hour accounts 24.37. If openings are closed then heat travels from inside to outside by -0.22 kwh and discomfort hour accounts 21.63. The discomfort hour has decreased by 2.74 hours which is very similar to Base Case Existing Building June month. Thus, we can say that decrease in discomfort hour is very small, so its better to leave the openings opened. If we observe this phenomenon during January month where at first openings are opened then heat that is leaving the building is -76.51 kwh which is high so should be prevented from leaving and discomfort hour is at 297.43 hours. When openings are closed then heat leaving the building also decreases and almost becomes zero with discomfort hour being at 246.43. The difference in discomfort hour before and after closing openings is 51 hours which is quite high and highest among all the cases considered. Thus, we can fairly say that for Case 3 building openings below roof to be closed for increasing the efficiency of the building.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The building selected for case study is modified traditional Tharu building which has been altered by the Tharu people who uses them to match according to their needs. The building has very minimal energy usage only for lighting purpose only and so the energy performance of the building is carried out by considering heat incoming and heat outgoing which is taking place inside the building. In total 4 simulation cases were performed for better understanding the performance of modified traditional Tharu building by comparing with other simulation cases.

- The main objective of this study was to evaluate the energy performance of modified Tharu Traditional building. From the simulation result we can see that the total incoming heat and outgoing heat for Building in June is 718.61 kwh & -603.35 kwh. Here, the total heat balance is equal to 115.26 Kwh. In June which is hotter days heat loss is preferred so we can see that Base Case building is gaining heat but despite this the overall discomfort hour is 37.74 hours. Similarly, in January during winter season the heat incoming is 608.22 kwh and heat outgoing is -551.07 kwh and the heat balance is 57.15 kwh. In winter heat retention is required inside the building to make the indoor comfortable whereas with 57.15 surplus heat which is not enough to make the indoor comfortable leading to high discomfort hour of 280.66. This suggest that the Tharu Building struggles to retain heat in winter whereas performs very well in winter.
- The passive design elements that are available in the case study buildings are light thermal mass wall with reed & mud plaster, 300mm thick reed thatch roof, openings below the gable roof for enhancing the air flow inside the building to enable passive air cooling.
- In Base Case the 100 mm mud reed wall which has lower thermal transmittance of 0.279 W/m2k compared to Case 2 which has CGI sheet wall the heat transfer via the wall is 16.5 kwh whereas in Case 2 is 41.03 kwh and this overall have impact on discomfort hour. Also, the thatch roof which has lower thermal transmittance than other cases slow the rate of heat gain and loss. Also, the openings provided below the roof is open 24 hours and during winter through which the heat loss of -53.40 is taking place and if that heat loss is controlled then the heat loss decrease to -0.17 kwh. This decrease in heat loss also

decreases the discomfort hour from 280.66 hours to 243.93 hours and the indoor air temperature also rises from 16.63˚ C to 17.68º C by almost 1.05º C.

The study by Hom Bahadur Rijal in sub-tropical climate region at Banke also suggests that people beat the environment by taking behavior-oriented changes such as drink large amount of water, stays in shade, takes short rest during hot time of days, opens and closes the windows as their requirements (Hom Bahadur Rijal, 2005). In this study also in computer simulation methods such as opening and closing of door and window is implemented to see if they make any changes to the indoor living space. The simulation result also provides fact that the openings which was placed below the roof when was left open and closed in summer so very little difference in discomfort hour but when it was opened and closed it showed improved performance in winter thus this opening below roof which people have been building plays an important role in overall building performance. In Case 3 with bamboo insulation the difference in discomfort hour was also very small close to Base Case but it winters opening and closing the openings significantly improves the performance in terms of comfort hour. In Case 1 and Case 3 closing of openings below roof in summer further increased the discomfort level and in winter closing improves the discomfort level. The study was executed by Jiba Raj Pokharel where a temporary shelter was built in Jajarkot without bamboo lathe and with bamboo lathe to CGI sheet, it was observed that the temperature at interior space was comfortable in shelter with bamboo lathe compared to CGI sheet only (Jiba Raj Pokharel, 2024) and the similar results are seen in Base Case building where it outperforms Case 1 and Case 2 buildings.

7.2 Recommendations

The simulation results have shown that the modified traditional Tharu buildings performs better than CGI roof and CGI buildings in both summer and winter season. It was also observed that results from Case 3 building built with bamboo lathe with 2-inch air gap to CGI sheet wall and CGI roof also enhances performance in summer but it performs poorly in winter. The study recommends that whenever it is feasible and possible the modified traditional Tharu buildings should be prioritized and constructed. Corrugated Galvanized sheet usage should be avoided where possible due to poor performance and if it is necessary, it should only be used with some level of insulations such as bamboo lathe with 2-inch air gap as used in the simulation in Case 3 during this study.

7.3 Limitations

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

1. The simulation uses Energy Plus weather data from 2009 to 2023, while the field data collection and case study were carried out in January 2025. The unavailability of the updated weather file may affect the results. The simulated models air temperature was compared with temperature of January only and the air temperature obtained for June from simulation software was not compared since no field temperature data of June was collected. The equipment used for collecting data was also not easily available thus a custom-made device was built during this thesis time frame called Arduino Nano Data Logger at a very low cost of about Nepalese Rupees 3500.
2. The analysis is based on single case study buildings which can limit the ability to generalize the result to other traditional buildings relevant in that areas. The buildings features such as its length, breadth, height was measured, along with windows dimensions, building materials used, its orientation but they were used in Base Case only and not many cases were conducted. The simulation was done by changing building materials only so the results obtained might differ if its direction, shape and size were changed. This limitation thus provides future scope for carrying out more detailed study.
3. The literature review is done by considering traditional Tharu buildings (Toffin, 1991), while the selected case study involves slightly changed traditional Tharu buildings due to unavailability of completely traditional structures. Many original Tharu buildings have been modified over time to meet the needs of people such as thatch roof being replaced by CGI sheet or using these buildings for kitchen or storage etc.

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APPENDIX-I: Outdoor Temperature from DHM

Date	Time	Temperature	Humidity		Date	Time	Temperature	Humidity
1/16/2025	0:45	10.3	100		1/17/2025	0:45	11	99.6
1/16/2025	1:45	9.7	100		1/17/2025	1:45	10.5	97.6
1/16/2025	2:45	9.3	100		1/17/2025	2:45	10.1	97.8
1/16/2025	3:45	9.2	100		1/17/2025	3:45	9.7	97.7
1/16/2025	4:45	8.9	100		1/17/2025	4:45	9.2	93.6
1/16/2025	5:45	8.6	99.6		1/17/2025	5:45	9.3	95.9
1/16/2025	6:45	8.2	95.8		1/17/2025	6:45	8.8	95
1/16/2025	7:45	8.1	96		1/17/2025	7:45	8.2	95.5
1/16/2025	8:45	9	99.3		1/17/2025	8:45	9.5	95.5
1/16/2025	9:45	11.7	100		1/17/2025	9:45	12.4	100
1/16/2025	10:45	13.2	99.7		1/17/2025	10:45	15.2	98.5
1/16/2025	11:45	16.7	81.5		1/17/2025	11:45	17.7	85.9
1/16/2025	12:45	19.2	63.9		1/17/2025	12:45	20.4	62.5
1/16/2025	13:45	20.9	51.7		1/17/2025	13:45	22.4	43.1
1/16/2025	14:45	21.4	44.6		1/17/2025	14:45	22.9	37.4
1/16/2025	15:45	21.3	45.8		1/17/2025	15:45	23.1	36.3
1/16/2025	16:45	20	50.1		1/17/2025	16:45	22.5	38.1
1/16/2025	17:45	18.2	58.4		1/17/2025	17:45	19.6	51.9
1/16/2025	18:45	16.3	86.1		1/17/2025	18:45	16.9	75.6
1/16/2025	19:45	14.5	100		1/17/2025	19:45	14.8	90.4
1/16/2025	20:45	13.6	100		1/17/2025	20:45	13.8	100
1/16/2025	21:45	13	100		1/17/2025	21:45	13.1	100
1/16/2025	22:45	12.2	100		1/17/2025	22:45	12.7	100
1/16/2025	23:45	11.6	100		1/17/2025	23:45	12.3	100
1/18/2025	0:45	11.8	100		1/19/2025	0:45	10.8	100
1/18/2025	1:45	10.5	100		1/19/2025	1:45	10.6	100
1/18/2025	2:45	9.7	100		1/19/2025	2:45	10.4	100
1/18/2025	3:45	9.3	100		1/19/2025	3:45	9.1	99.6
1/18/2025	4:45	8.8			1/19/2025	4:45	8.6	95.8

1/18/2025	5:45	8.3	100		1/19/2025	5:45	8.9	95.4
1/18/2025	6:45	8.1	100		1/19/2025	6:45	8.4	94.4
1/18/2025	7:45	7.6	99.6		1/19/2025	7:45	8.6	95.7
1/18/2025	8:45	9	100		1/19/2025	8:45	9.1	95.4
1/18/2025	9:45	13.4	98.3		1/19/2025	9:45	10	94.7
1/18/2025	10:45	15.5	89.8		1/19/2025	10:45	11.1	98
1/18/2025	11:45		59.5		1/19/2025	11:45	14.9	89.9
1/18/2025	12:45	19	57.6		1/19/2025	12:45	18.5	58.7
1/18/2025	13:45	21.2	39.9		1/19/2025	13:45	20.7	39.1
1/18/2025	14:45	22.4	31.6		1/19/2025	14:45	21.4	40.4
1/18/2025	15:45	22.2	42.1		1/19/2025	15:45	22.2	42.5
1/18/2025	16:45	21.4	50		1/19/2025	16:45	22.6	44.4
1/18/2025	17:45	18.1	65.7		1/19/2025	17:45	20	58.7
1/18/2025	18:45	15.9	83.8		1/19/2025	18:45	16.3	91
1/18/2025	19:45	14.5	100		1/19/2025	19:45	15	95.9
1/18/2025	20:45	13.3	100		1/19/2025	20:45	14.4	94.1
1/18/2025	21:45	12.5	100		1/19/2025	21:45	13.3	100
1/18/2025	22:45	12.1	100		1/19/2025	22:45	12.1	100
1/18/2025	23:45	11.5	100		1/19/2025	23:45	11.3	100
1/20/2025	0:45	10.7	100		1/21/2025	0:45	12.8	98.6
1/20/2025	1:45	10.1	100		1/21/2025	1:45	12.2	97.9
1/20/2025	2:45	9.8	100		1/21/2025	2:45	10.8	100
1/20/2025	3:45	9	100		1/21/2025	3:45	10	100
1/20/2025	4:45	9	100		1/21/2025	4:45	9.7	100
1/20/2025	5:45	8.7	100		1/21/2025	5:45	9.4	100
1/20/2025	6:45	8.3	100		1/21/2025	6:45	9.1	100
1/20/2025	7:45	8	100		1/21/2025	7:45	9.5	100
1/20/2025	8:45	11	99.4		1/21/2025	8:45	12.1	95.9
1/20/2025	9:45	14.7	79.3		1/21/2025	9:45	16.3	68
1/20/2025	10:45	17.5	53.1		1/21/2025	10:45	19.4	51.8
1/20/2025	11:45	19.7	43.4		1/21/2025	11:45	21.7	43.7

1/20/2025	12:45	21.7	39.6		1/21/2025	12:45	23.8	34
1/20/2025	13:45	23	39.6		1/21/2025	13:45	25.6	27
1/20/2025	14:45	22.2	49.3		1/21/2025	14:45	25.4	34.7
1/20/2025	15:45	22.4	47.9		1/21/2025	15:45	24.2	44.7
1/20/2025	16:45	21	58		1/21/2025	16:45	22.7	48.5
1/20/2025	17:45	18.6	74.7		1/21/2025	17:45	20	66.8
1/20/2025	18:45	16.5	94.2		1/21/2025	18:45	17.9	88.9
1/20/2025	19:45	15.1	100		1/21/2025	19:45	16.3	99.8
1/20/2025	20:45	15.4	94.5		1/21/2025	20:45	14.8	100
1/20/2025	21:45	14.4	90		1/21/2025	21:45	13.9	100
1/20/2025	22:45	13.3	99		1/21/2025	22:45	13.4	100
1/20/2025	23:45	13.2	97.8		1/21/2025	23:45	13.1	100
1/22/2025	0:45	12.4	100		1/23/2025	0:45	12.6	100
1/22/2025	1:45	11.9	100		1/23/2025	1:45	11.7	100
1/22/2025	2:45	10.8	100		1/23/2025	2:45	11	100
1/22/2025	3:45	10.1	100		1/23/2025	3:45	10.2	100
1/22/2025	4:45	9.8	100		1/23/2025	4:45	9.1	100
1/22/2025	5:45	9.1	100		1/23/2025	5:45	9	96.5
1/22/2025	6:45	8.7	100		1/23/2025	6:45	8.2	98
1/22/2025	7:45	8.8	100		1/23/2025	7:45	7.9	96.4
1/22/2025	8:45	11.8	94.9		1/23/2025	8:45	9.8	99.4
1/22/2025	9:45	16.1	68.2		1/23/2025	9:45	13.2	100
1/22/2025	10:45	18.5	66.2		1/23/2025	10:45	15.3	98.1
1/22/2025	11:45	20.3	61.1		1/23/2025	11:45	18.5	83.8
1/22/2025	12:45	22.3	47.5		1/23/2025	12:45	20.7	56.7
1/22/2025	13:45	23.3	40.6		1/23/2025	13:45	22.4	45.8
1/22/2025	14:45	23.1	46.9		1/23/2025	14:45	23.3	33.6
1/22/2025	15:45	22.5	49.8		1/23/2025	15:45	23.4	40.6
1/22/2025	16:45	21.9	54.9		1/23/2025	16:45	22.1	56.3

1/22/2025	17:45	19.7	71.1		1/23/2025	17:45	19.2	67.4
1/22/2025	18:45	17.3	95.2		1/23/2025	18:45	16.7	93.7
1/22/2025	19:45	15.6	100		1/23/2025	19:45	15.8	100
1/22/2025	20:45	14.8	100		1/23/2025	20:45	15.1	97.2
1/22/2025	21:45	14.3	100		1/23/2025	21:45	14.1	98.6
1/22/2025	22:45	13.8	100		1/23/2025	22:45	13.1	100
1/22/2025	23:45	13.2	100		1/23/2025	23:45	12.4	100
1/24/2025	0:45	11.8	100		1/25/2025	0:45	11.2	93.4
1/24/2025	1:45	11.9	100		1/25/2025	1:45	10.6	97.2
1/24/2025	2:45	11	100		1/25/2025	2:45	9.9	100
1/24/2025	3:45	10.8	100		1/25/2025	3:45	9.8	100
1/24/2025	4:45	10.4	100		1/25/2025	4:45	8.9	100
1/24/2025	5:45	9.9	100		1/25/2025	5:45	8.1	100
1/24/2025	6:45	9.9	100		1/25/2025	6:45	7.5	100
1/24/2025	7:45	9.4	100		1/25/2025	7:45	8	100
1/24/2025	8:45	11.5	100		1/25/2025	8:45	10.4	100
1/24/2025	9:45	14.7	93		1/25/2025	9:45	13.7	87.3
1/24/2025	10:45	17.4	68.3		1/25/2025	10:45	16.2	73.1
1/24/2025	11:45	20.4	42		1/25/2025	11:45	18	61.1
1/24/2025	12:45	21.6	37.4		1/25/2025	12:45	19.2	54.7
1/24/2025	13:45	22.3	37.6		1/25/2025	13:45	20.2	51.9
1/24/2025	14:45	22.4	31		1/25/2025	14:45	20.6	52.3
1/24/2025	15:45	22.1	26.9		1/25/2025	15:45	20.7	51.4
1/24/2025	16:45	20.7	30.7		1/25/2025	16:45	19.8	60.1
1/24/2025	17:45	18.4	35.5		1/25/2025	17:45	17.6	82.1
1/24/2025	18:45	15.9	50.7		1/25/2025	18:45	15.6	93.1
1/24/2025	19:45	13.7	66.7		1/25/2025	19:45	13.9	100
1/24/2025	20:45	13	78.7		1/25/2025	20:45	13.4	100
1/24/2025	21:45	12.3	93.3		1/25/2025	21:45	13.7	100

1/24/2025	22:45	11.7	99.5		1/25/2025	22:45	13.6	100
1/24/2025	23:45	11.5	95.5		1/25/2025	23:45	12.6	100
1/26/2025	0:45	12.5	100		1/27/2025	0:45	11.4	100
1/26/2025	1:45	12.8	100		1/27/2025	1:45	10.9	100
1/26/2025	2:45	12.9	100		1/27/2025	2:45	10.5	100
1/26/2025	3:45	12.9	100		1/27/2025	3:45	10.5	98.5
1/26/2025	4:45	11.8	100		1/27/2025	4:45	10.7	96.1
1/26/2025	5:45	10.7	100		1/27/2025	5:45	10	96.9
1/26/2025	6:45	10.2	100		1/27/2025	6:45	9.7	96.9
1/26/2025	7:45	9.8	100		1/27/2025	7:45	9.5	96.3
1/26/2025	8:45				1/27/2025	8:45	9.5	96.3
1/26/2025	9:45	14.5	95.8		1/27/2025	9:45	9.8	96.1
1/26/2025	10:45	16.3	89		1/27/2025	10:45	12.5	99.6
1/26/2025	11:45	18.1	72.1		1/27/2025	11:45	16	98.9
1/26/2025	12:45	19.5	63.6		1/27/2025	12:45	19.1	73
1/26/2025	13:45	19.8	58.2		1/27/2025	13:45	20.5	55.7
1/26/2025	14:45	19.1	60.1		1/27/2025	14:45	21.2	52.3
1/26/2025	15:45	18.9	63.4		1/27/2025	15:45	21.5	50.9
1/26/2025	16:45	18	67.7		1/27/2025	16:45	20.7	57.1
1/26/2025	17:45	17.1	77.3		1/27/2025	17:45	18.3	81.4
1/26/2025	18:45	16.2	89		1/27/2025	18:45	15.9	100
1/26/2025	19:45	14.9	98.9		1/27/2025	19:45	14.4	100
1/26/2025	20:45	13	100		1/27/2025	20:45	14	100
1/26/2025	21:45	12.6	100		1/27/2025	21:45	13.1	100
1/26/2025	22:45	12.1	100		1/27/2025	22:45	12.8	100
1/26/2025	23:45	12	100		1/27/2025	23:45	12.4	100
1/28/2025	0:45	12.10	100		1/29/2025	0:45	12.1	100
1/28/2025	1:45	11.30	100		1/29/2025	1:45	11.7	100
1/28/2025	2:45	10.90	100		1/29/2025	2:45	11.1	100
1/28/2025	3:45	10.00	100		1/29/2025	3:45	10.7	100
1/28/2025	4:45	9.30	99.2		1/29/2025	4:45	10	100

1/28/2025	5:45	8.40	98.6		1/29/2025	5:45	9.8	99.8
1/28/2025	6:45	7.90	98.7		1/29/2025	6:45	9.1	99.8
1/28/2025	7:45	7.50	97.2		1/29/2025	7:45	8.9	98.8
1/28/2025	8:45	9.00	98		1/29/2025	8:45	9.4	99.9
1/28/2025	9:45	11.60	100		1/29/2025	9:45	12.5	100
1/28/2025	10:45	14.30	100		1/29/2025	10:45	15.9	99.5
1/28/2025	11:45	16.90	95.4		1/29/2025	11:45	18.3	80.9
1/28/2025	12:45	19.70	66.8		1/29/2025	12:45	19.5	70.7
1/28/2025	13:45	21.30	54.2		1/29/2025	13:45	21	60.8
1/28/2025	14:45	21.80	45.7		1/29/2025	14:45	21.4	55.5
1/28/2025	15:45	21.20	50.9		1/29/2025	15:45	20.8	58.2
1/28/2025	16:45	20.10	58.1		1/29/2025	16:45	20.1	63.8
1/28/2025	17:45	18.60	74.3		1/29/2025	17:45	18.4	76.7
1/28/2025	18:45	16.70	98		1/29/2025	18:45	16.5	96.2
1/28/2025	19:45	14.90	100		1/29/2025	19:45	15.1	100
1/28/2025	20:45	14.10	100		1/29/2025	20:45	14.7	100
1/28/2025	21:45	13.70	100		1/29/2025	21:45	14.5	100
1/28/2025	22:45	13.50	100		1/29/2025	22:45	14	100
1/28/2025	23:45	12.80	100		1/29/2025	23:45	13.1	100

APPENDIX-II: Indoor Temperature Measured Inside Tharu Building

Date	Time	Temperature	Humidity		Date	Time	Temperature	Humidity
2025/1/17	11:03	16.6	72		2025/1/18	0:24	18.2	60
2025/1/17	13:22	18.6	73		2025/1/18	1:24	17.8	60
2025/1/17	14:22	19.8	71		2025/1/18	2:24	17	60
2025/1/17	15:22	21	68		2025/1/18	3:25	16.6	59
2025/1/17	16:22	21.4	68		2025/1/18	4:25	16.1	60
2025/1/17	17:22	21.4	66		2025/1/18	5:25	16.1	61
2025/1/17	18:23	21	64		2025/1/18	6:25	15.7	62
2025/1/17	19:23	20.6	65		2025/1/18	7:25	15.7	63
2025/1/17	20:23	20.2	64		2025/1/18	8:26	15.7	64
2025/1/17	21:23	19.8	63		2025/1/18	9:26	15.7	65
2025/1/17	22:23	19	62		2025/1/18	10:26	15.7	68
2025/1/17	23:24	18.6	61		2025/1/18	11:26	16.6	70
					2025/1/18	12:26	17.8	70
					2025/1/18	13:27	18.6	70
					2025/1/18	14:27	19.4	69
					2025/1/18	15:27	20.2	66
					2025/1/18	16:43	20.6	65
					2025/1/18	17:43	20.2	65
					2025/1/18	18:44	20.2	65
					2025/1/18	19:44	19.8	65
					2025/1/18	20:44	19.4	64
					2025/1/18	21:44	19	63
					2025/1/18	22:44	18.6	62
					2025/1/18	23:45	18.1	62
2025/1/19	0:45	17.4	61		2025/1/20	0:14	17.4	61
2025/1/19	1:45	17.4	62		2025/1/20	1:14	17	60
2025/1/19	2:45	17.4	63		2025/1/20	2:14	16.6	60
2025/1/19	3:45	17.4	64		2025/1/20	3:14	16.1	61
2025/1/19	4:46	17.4	65		2025/1/20	4:14	16.1	62
2025/1/19	5:46	17	65		2025/1/20	5:15	16.1	63
2025/1/19	6:46	17	66		2025/1/20	6:15	15.7	64
2025/1/19	7:46	17	67		2025/1/20	8:01	15.2	65
2025/1/19	8:47	17	68		2025/1/20	9:41	15.7	68
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2025/1/19	11:02	17.4	69		2025/1/20	11:42	16.6	70
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2025/1/19	13:03	18.6	70		2025/1/20	13:42	18.2	71
2025/1/19	14:10	19.4	70		2025/1/20	14:42	19.4	71
2025/1/19	15:10	20.2	68		2025/1/20	16:28	20.2	70
2025/1/19	16:11	20.2	66		2025/1/20	18:12	20.2	70

2025/1/19	17:11	20.2	65		2025/1/20	19:12	19.4	67
2025/1/19	18:11	20.2	64		2025/1/20	20:13	19	67
2025/1/19	19:11	19.8	64		2025/1/20	21:13	18.3	65
2025/1/19	20:11	19.4	63		2025/1/20	22:13	17.8	65
2025/1/19	21:12	19	62		2025/1/20	23:13	17.4	64
2025/1/21	0:13	17	64		2025/1/22	0:46	17	62
2025/1/21	1:14	16.6	63		2025/1/22	1:46	16.6	62
2025/1/21	2:14	16.1	63		2025/1/22	2:46	16.6	62
2025/1/21	3:14	15.7	64		2025/1/22	3:46	16.1	62
2025/1/21	4:37	15.2	64		2025/1/22	4:46	16.1	63
2025/1/21	5:37	15.2	64		2025/1/22	5:47	16.1	64
2025/1/21	6:37	14.8	64		2025/1/22	6:47	15.7	64
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2025/1/21	11:38	16.6	70		2025/1/22	12:33	17.9	71
2025/1/21	12:39	17.8	72		2025/1/22	14:39	20.6	70
2025/1/21	13:39	19.4	73		2025/1/22	15:39	21	67
2025/1/21	14:39	20.6	71		2025/1/22	16:39	21.4	66
2025/1/21	15:39	21	68		2025/1/22	18:26	20.6	67
2025/1/21	16:39	21	67		2025/1/22	19:26	20.5	66
2025/1/21	17:40	20.6	67		2025/1/22	20:26	19.8	65
2025/1/21	19:45	19.4	66		2025/1/22	21:26	19.4	65
2025/1/21	20:45	19	65		2025/1/22	22:27	19	65
2025/1/21	21:45	18.6	64		2025/1/22	23:27	19	65
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2025/1/21	23:45	17.8	63					
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2025/1/23	4:28	19	69		2025/1/24	4:55	18.2	65
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2025/1/23	10:29	17.8	69		2025/1/24	10:56	17.8	66
2025/1/23	11:29	18.2	70		2025/1/24	12:47	19.4	69
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2025/1/23	15:30	21.4	70		2025/1/24	19:34	19.4	52

2025/1/23	16:30	21.4	69		2025/1/24	20:34	19.4	53
2025/1/23	17:31	21	66		2025/1/24	21:34	19	54
2025/1/23	19:53	20.2	66		2025/1/24	22:34	18.6	55
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2025/1/23	22:54	19	65					
2025/1/23	23:54	19	65					
2025/1/25	0:35	17.4	55		2025/1/26	0:12	17.8	63
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2025/1/25	2:35	16.6	55		2025/1/26	2:12	17.8	64
2025/1/25	3:35	16.1	55		2025/1/26	3:13	17.8	64
2025/1/25	4:36	15.7	56		2025/1/26	4:13	17.4	64
2025/1/25	5:36	15.2	56		2025/1/26	5:13	17	64
2025/1/25	6:36	14.8	56		2025/1/26	6:13	17	64
2025/1/25	7:47	14.4	56		2025/1/26	7:13	16.8	64
2025/1/25	8:47	14.4	58		2025/1/26	8:14	16.6	65
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2025/1/25	10:59	15.7	61		2025/1/26	10:14	16.6	69
2025/1/25	13:10	18.6	65		2025/1/26	11:14	17.4	70
2025/1/25	14:10	19.4	65		2025/1/26	12:14	18.2	71
2025/1/25	15:10	19.8	64		2025/1/26	13:15	19	70
2025/1/25	16:10	20.1	63		2025/1/26	14:15	19.8	68
2025/1/25	17:11	19.8	62		2025/1/26	15:15	20.2	67
2025/1/25	18:11	19.4	61		2025/1/26	16:15	20.2	65
2025/1/25	19:11	19	61		2025/1/26	17:16	20.2	64
2025/1/25	20:11	18.6	61		2025/1/26	18:16	19.8	63
2025/1/25	21:11	18.2	61		2025/1/26	19:16	19.4	63
2025/1/25	22:12	17.8	61		2025/1/26	20:21	19	63
2025/1/25	23:12	17.8	62		2025/1/26	21:21	18.6	63
					2025/1/26	22:21	18.2	63
					2025/1/26	23:22	17.8	62
2025/1/27	0:22	17.4	62		2025/1/28	0:25	17.8	64
2025/1/27	1:22	17	62		2025/1/28	1:26	17.4	64
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2025/1/27	3:22	16.9	63		2025/1/28	3:26	17.4	65
2025/1/27	4:23	16.7	63		2025/1/28	4:26	17.4	66
2025/1/27	5:23	16.6	64		2025/1/28	5:26	17.4	67
2025/1/27	6:23	16.6	64		2025/1/28	6:27	17.4	67
2025/1/27	7:23	16.1	64		2025/1/28	7:27	17.4	67
2025/1/27	8:23	16.1	65		2025/1/28	8:27	17.4	67
2025/1/27	9:24	16.1	65		2025/1/28	10:33	17.4	69
2025/1/27	11:23	16.6	68		2025/1/28	11:33	17.8	69
2025/1/27	12:23	17.4	69		2025/1/28	12:34	18.6	70
2025/1/27	13:23	18.6	70		2025/1/28	13:34	19.4	70

2025/1/27	14:23	19.4	70		2025/1/28	14:34	20.2	70
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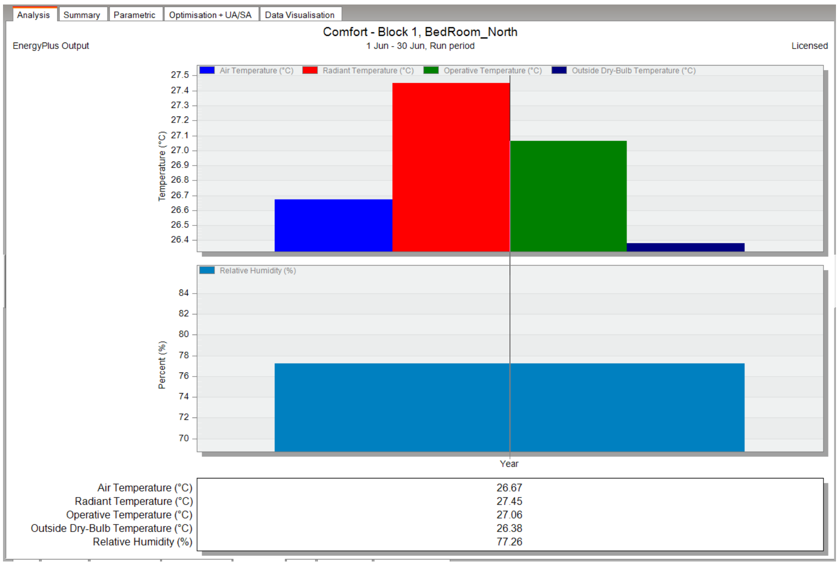
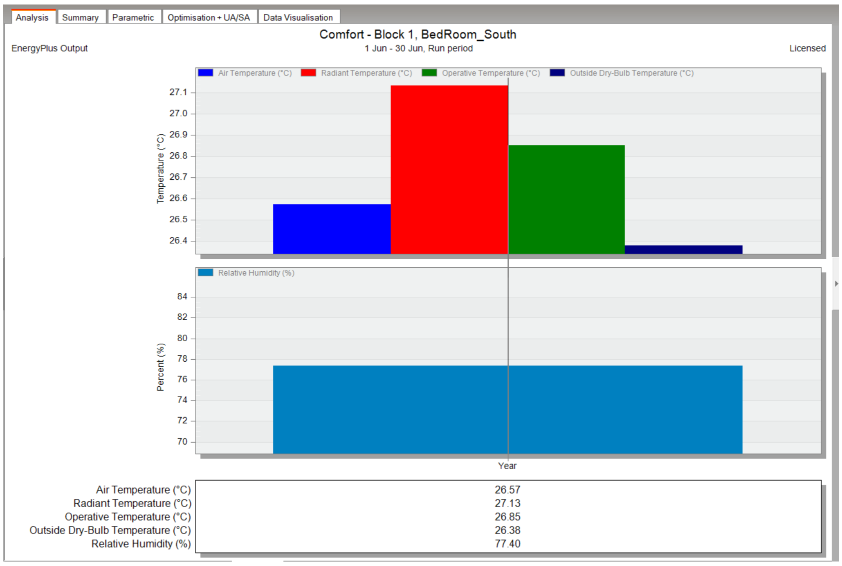
2025/1/27	16:24	20.2	69		2025/1/28	16:34	21	68
2025/1/27	17:24	20.6	69		2025/1/28	17:35	21	67
2025/1/27	18:24	20.2	68		2025/1/28	18:35	20.6	67
2025/1/27	19:24	19.8	67		2025/1/28	19:35	20.2	66
2025/1/27	20:24	19.4	66		2025/1/28	20:35	19.8	65
2025/1/27	21:25	19	65		2025/1/28	21:35	19	65
2025/1/27	22:25	18.6	65		2025/1/28	22:36	18.6	64
2025/1/27	23:25	18.2	64		2025/1/28	23:36	18.2	64
2025/1/29	0:36	17.8	63					
2025/1/29	1:36	17.4	63					
2025/1/29	2:36	17	63					
2025/1/29	3:37	17	63					
2025/1/29	4:37	16.6	63					
2025/1/29	5:37	16.2	63					
2025/1/29	6:37	16.1	62					
2025/1/29	7:37	15.7	64					
2025/1/29	8:38	15.7	66					
2025/1/29	9:38	16.1	66					
2025/1/29	10:38	17.4	69					
2025/1/29	11:38	19.8	70					
2025/1/29	12:39	21	66					

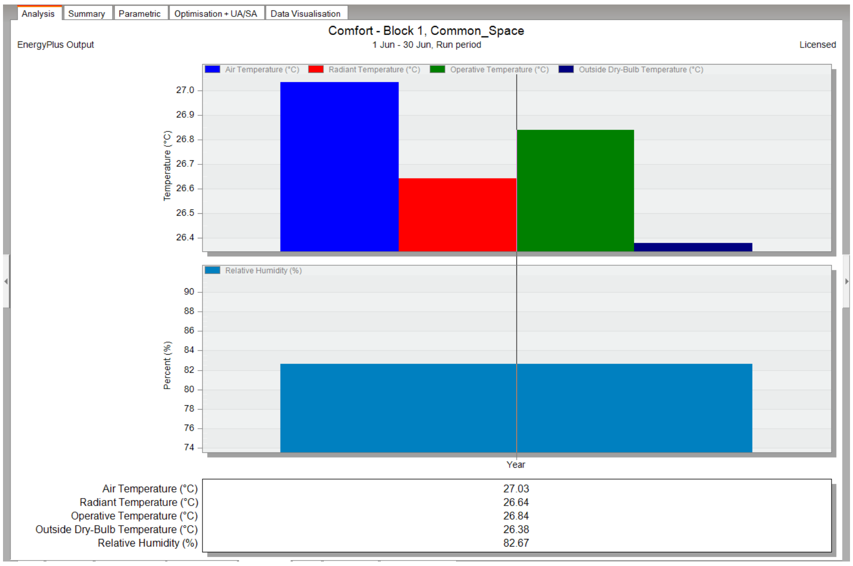
APPENDIX-III: Building Simulation Data for June Base Case Scenario



Air Temperature (°C)	26.67
Radiant Temperature (°C)	27.45
Operative Temperature (°C)	27.06
Outside Dry-Bulb Temperature (°C)	26.38
Relative Humidity (%)	77.26



Air Temperature (°C)	26.57
Radiant Temperature (°C)	27.13
Operative Temperature (°C)	26.85
Outside Dry-Bulb Temperature (°C)	26.38
Relative Humidity (%)	77.40

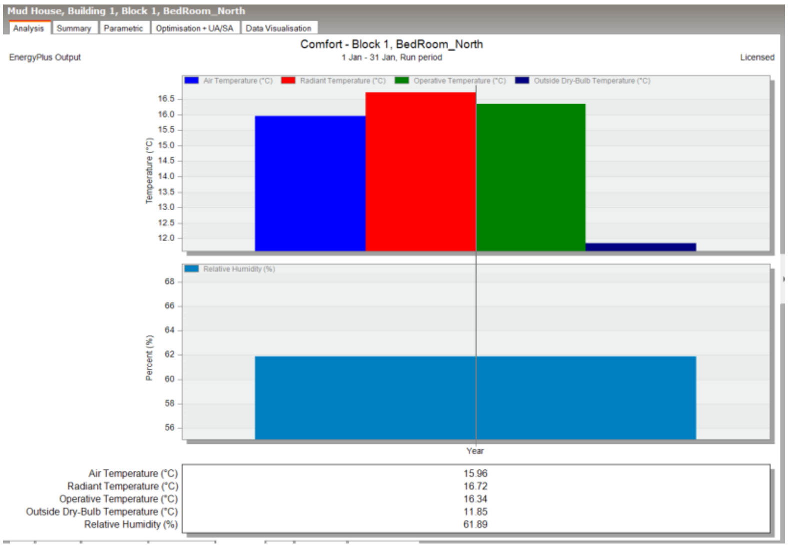


Air Temperature (°C)	27.03
Radiant Temperature (°C)	26.64
Operative Temperature (°C)	26.84
Outside Dry-Bulb Temperature (°C)	26.38
Relative Humidity (%)	82.67

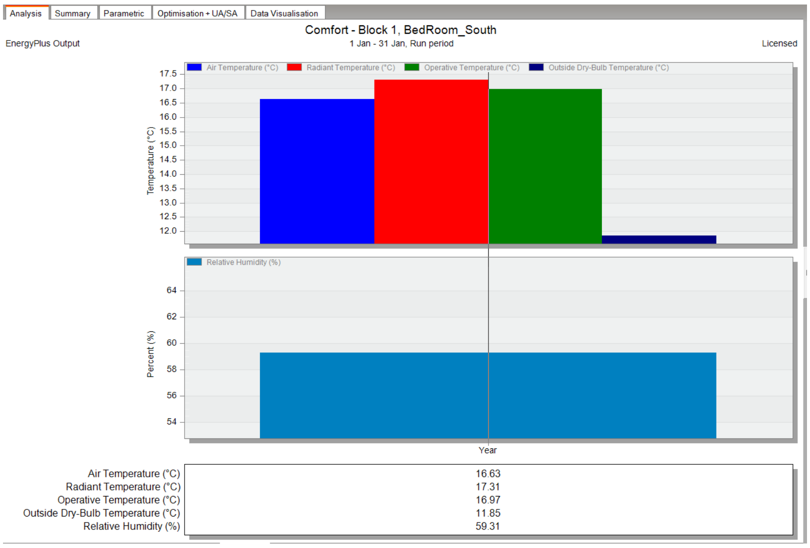
Room North Heat Transfer			Room South Heat Transfer		
Description	**Heat Gain (kwh)**	**Heat Loss (kwh)**	**Description**	**Heat Gain (kwh)**	**Heat Loss (kwh)**
Glazing		-14.69	Glazing		-6.82
Wall	16.15		Wall	16.55	
Ceiling internal		-2.95	Ceiling internal	21.95	
Ground Floor		-115	Ground Floor		-109.47
Partition internal		-6.35	Partition internal		-3.49
Internal Natural Ventilation	8.72		Internal Natural Ventilation	2.81	
External Air		-0.06	External Air		-0.05
External Ventilation		-64.91	External Ventilation		-46.96
General Lighting	1.2		General Lighting	1.2	
Occupancy	28.19		Occupancy	28.19	
Solar gain exterior window	151.18		Solar gain exterior window	96.27	
Latent Load			Latent Load	0.16	
Total	205.44	-203.96	Total	167.13	-166.79

Common Space Heat Transfer			Roof Heat Transfer		
Description	**Heat Gain (kwh)**	**Heat Loss (kwh)**	**Description**	**Heat Gain (kwh)**	**Heat Loss (kwh)**
Glazing		0	Glazing		-0.52
Wall	28.31		Wall		-3.8
Ceiling internal	26.4		Floor internal		-45.17
Ground Floor		-99.22	Roof	101.73	
Partition internal	9.93		Floor external	3.16	
Internal Natural Ventilation		-7.52	Internal Natural Ventilation		-71.38
External Air		-0.2	External Air		-0.05
External Ventilation		-4.74	External Ventilation	5.42	
General Lighting	1.2		General Lighting		
Occupancy	45.78		Occupancy		
Solar gain exterior window	0		Solar gain exterior window	15.02	
Latent Load	109.09		Latent Load	0	0
Total	220.71	-111.68	Total	125.33	-120.92

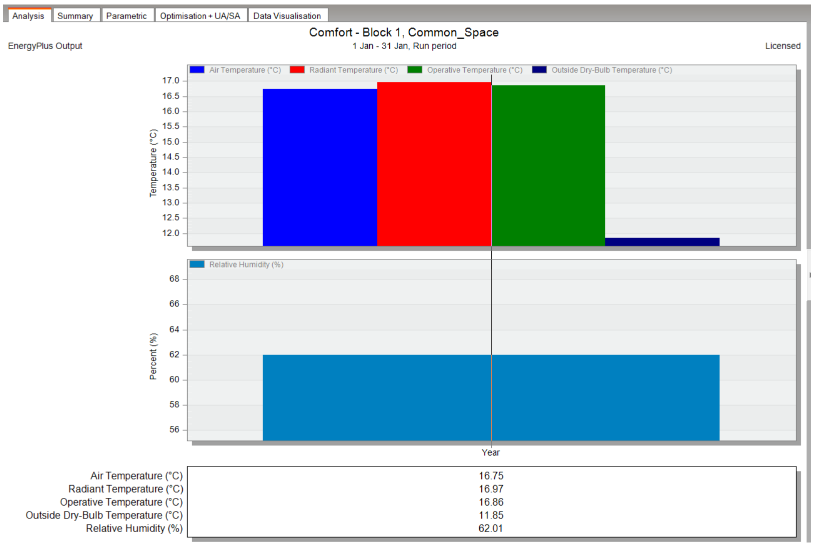
APPENDIX-IV: Building Simulation Data for January Base Case Scenario



Air Temperature (°C)	15.96
Radiant Temperature (°C)	16.72
Operative Temperature (°C)	16.34
Outside Dry-Bulb Temperature (°C)	11.85
Relative Humidity (%)	61.89



Air Temperature (°C)	16.63
Radiant Temperature (°C)	17.31
Operative Temperature (°C)	16.97
Outside Dry-Bulb Temperature (°C)	11.85
Relative Humidity (%)	59.31

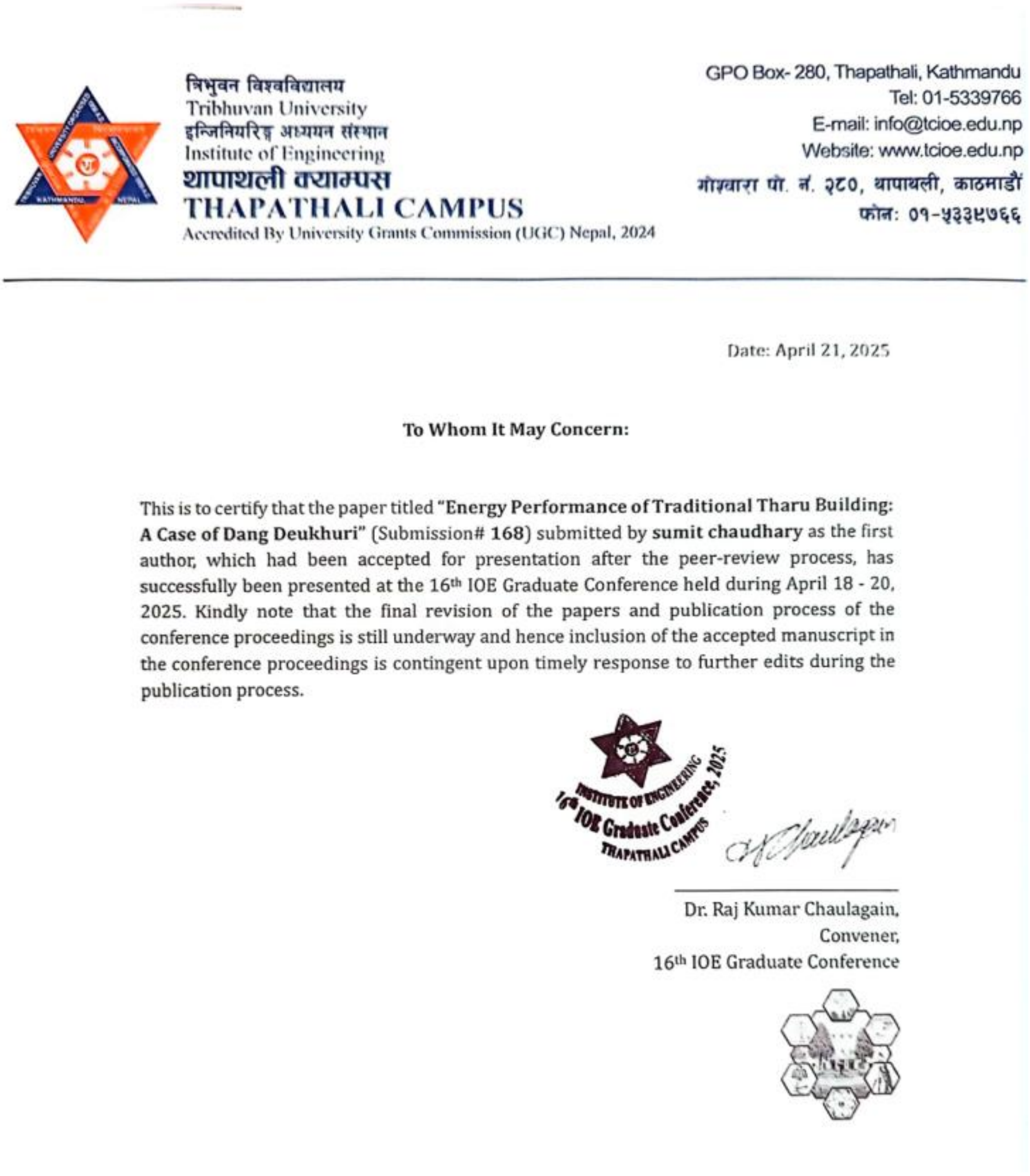


Air Temperature (°C)	16.75
Radiant Temperature (°C)	16.97
Operative Temperature (°C)	16.86
Outside Dry-Bulb Temperature (°C)	11.85
Relative Humidity (%)	62.01

Room North Heat Transfer			**Room South Heat Transfer**		
Description	**Heat Gain (kwh)**	**Heat Loss (kwh)**	**Description**	**Heat Gain (kwh)**	**Heat Loss (kwh)**
Glazing		-42.26	Glazing		-27.07
Wall		-46.46	Wall	26.44	
Ceiling internal		-24.63	Ceiling internal		-46.93
Ground Floor	10.45		Ground Floor	5.53	
Partition internal	1.62		Partition internal		-2.35
Internal Natural Ventilation	5.82		Internal Natural Ventilation		-1.58
External Air		-5.33	External Air		-6.44
External Ventilation		-63.37	External Ventilation		-64.26
General Lighting	1.24		General Lighting	1.24	
Occupancy	29.3		Occupancy	29.3	
Solar gain exterior window	134.57		Solar gain exterior window	86.02	
Latent Load			Latent Load		
Total	183	-182.05		148.53	-148.63

Common Space Heat Transfer			**Roof Heat Transfer**		
Description	**Heat Gain (kwh)**	**Heat Loss (kwh)**	**Description**	**Heat Gain (kwh)**	**Heat Loss (kwh)**
Glazing		0	Glazing		-1.45
Wall		-20.01	Wall		-13.66
Ceiling internal		-12.04	Floor internal	84.5	
Ground Floor	12.12		Roof		-11.68
Partition internal	1.16		Floor external		-2.86
Internal Natural Ventilation		-6	Internal Natural Ventilation		-7.9
External Air		-2.74	External Air		-10.1
External Ventilation		-78.55	External Ventilation		-53.4
General Lighting	1.24		General Lighting		
Occupancy	104.79		Occupancy		
Solar gain exterior window	0		Solar gain exterior window	15.02	
Latent Load	57.86		Latent Load		
Total	177.17	-119.34		99.52	-101.05

APPENDIX-V: IOE GCC Article



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फोन: ०१-५३३९७६६

Date: April 21, 2025

To Whom It May Concern:

This is to certify that the paper titled **"Energy Performance of Traditional Tharu Building: A Case of Dang Deukhuri"** (Submission# **168**) submitted by **sumit chaudhary** as the first author, which had been accepted for presentation after the peer-review process, has successfully been presented at the 16th IOE Graduate Conference held during April 18 - 20, 2025. Kindly note that the final revision of the papers and publication process of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon timely response to further edits during the publication process.

Dr. Raj Kumar Chaulagain,
Convener,
16th IOE Graduate Conference

IOE Graduate Conference

Certificate of Participation

THIS CERTIFICATE IS AWARDED TO

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Energy Performance of Traditional Tharu Building: A Case of Dang Deukhuri

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Abstract

The world is experiencing rapid change in climate and environment, thus raising concerns for sustainable and energy efficient practices. A study by Oliver shows that around 90% of buildings worldwide are constructed by people who use them where energy efficiency standards may be inadequate which leaves large potential to reduce energy use. Energy Efficiency in buildings can be achieved via active and passive means. Vernacular architecture has been getting attraction regarding their energy efficient and sustainable design approach since they are built using locally sourced construction materials. These buildings are strongly influenced by the climate and often holds useful ideas for optimizing energy use with simple methods. This paper tries to study the energy performance of modified Traditional Tharu buildings using computer simulation as well as field data collection of temperature and humidity to quantify the actual heat gain and heat lost inside these traditional buildings.

Keywords

simulation, energy performance, discomfort hour, heat gain and loss

1. Introduction

The world is experiencing rapid change in climate and environment, thus raising concerns for sustainable and energy efficient practices. Building sector accounts for about 45% of global energy consumption and 80% of potable water use [1]. Building uses energy to meet its heating cooling and lighting and cooking demand which requires usage of fossil fuel, electricity etc. which contributes to greenhouse gas emission, global warming and environmental issues. However, a study by Oliver shows that around 90% of buildings worldwide are constructed by the people who use them where the energy efficiency standard may be inadequate which leaves large potential to reduce energy use. Energy efficient buildings achieve this by reducing energy consumption while maintaining comfort[2]. Energy efficiency in buildings can be achieved in two ways: passive strategies and active systems. Passive strategies use natural features like insulation, solar heat, ventilation, and shading, while active systems use energy-powered technologies like heating and cooling systems. Learning from traditional buildings, which were built with limited technology but relied on nature for comfort, can provide valuable insights for designing modern energy-efficient buildings. Without studying how traditional buildings worked, it is difficult to create new ideas for reducing energy use in modern construction.

Vernacular architecture refers to buildings designed using local materials, traditional techniques, and knowledge passed down through generations. These buildings are strongly influenced by the climate, culture and resources of the area. Vernacular architecture often holds useful ideas for optimizing energy use with simple methods. Since ancient builders lacked modern heating and cooling systems, they made designs that depended on sun and wind for natural comfort [3, 4, 5]. Studies have also shown that these buildings can achieve better thermal performance by following passive design strategies [6]. Tharu buildings are made with locally sourced building materials providing thermal comfort and energy efficiency which have incorporated passive design features into them. However, there has been limited study that quantifies how these buildings perform in terms of energy consumption and efficiency. A similar study conducted by Susanne Bodach have identified the passive design features of Tharu buildings using Oglay's Bioclimatic Chart, Mahoney Table and Giovani's Psychrometric Chart [7]. Another study conducted by Binay Raj Singh which have used field temperature data to evaluate the thermal performance of these Tharu buildings [8]. The study by H.B Rijal in Nepalese traditional building to evaluate thermal comfort based on extensive field survey also considered the Tharu buildings and is more occupant behavior oriented. Thus, this study seeks to study the energy performance of modified Traditional Tharu building by using computer simulation as well as field data collection to quantify the actual heat lost and gained inside these buildings in winter season.

2. Objectives

Main Objectives:

- To evaluate the energy performance of modified Traditional Tharu building by analyzing their heat gain and heat loss.

Secondary Objectives:

- To study the passive design features in modified traditional Tharu buildings.
- To assesses how these features are impacting the performance and comfort.

3. Literature Review

The Tharu are the indigenous people living on the Terai plains of Nepal and India. The climate of these region is sub-tropical and the settlements in these regions is loose rather than dense. The houses are scattered along the road in linear pattern. The building longer side is oriented along the North-South whereas shorter side along East-West thus limiting the solar exposure. The house of the Dangaura Tharu is typically single story [7]. The walls of traditional Tharu houses are made from light thermal mass element mostly from wattle and daub [9]. Majority of traditional houses in Nepal's sub-tropical climate have roof made of thatch in the form of pitched roof. Below these gable roofs the openings in the shape of triangle are left which ensures the permanent inflow of air from the shaded area below the eaves that leads to inside temperature that are cooler than the outside temperature. These houses are generally raised from the ground level which are made from stone or earth to protect from flooding during the rainy season. These traditional Tharu houses have very few and low openings which together with the openings below the roof and windows enhances the air circulation to provide comfort during hot and humid summer months [10].

A building primarily composed of various elements such as wall, roof, windows, floors, ceiling. The heat transfer inside the building takes place via conduction, convection and radiation. The rate at which heat gain and heat loss occurs inside the buildings depends on several variable such as solar gain, indoor temperature, outdoor temperature, material thermophysical properties and exposed surface [11].

4. Methodology

For measuring the energy performance of the modified traditional Tharu building we need to study the climate first and for this purpose we can use climate data collected from energy plus. The climate data are in Energy Plus Weather format called epw. This contains environmental parameters such as temperature, humidity, air speed, solar radiation and many more.

Similarly, filed observation of the selected case study building was also conducted. The time duration for collection of temperature and humidity data inside the building was from January 17 to January 29 during the winter season. The building plan was also measured to help build the simulation model. Also details about the construction material, building technique studied from field and other secondary literature sources. The thermophysical properties for building envelopes used during the simulation also collected from various literatures. The simulation will be performed using software named "Design Builder" which uses energy plus to perform the energy simulation which is complex and popular software in building energy simulation field developed by US Department of Energy.

4.1 Climate Analysis

The weather file portrays the climate data taken from year 2011 to 2023 where Typical Meteorological Year data is taken. The latitude and longitude of the data collection site is 28.05° North and 82.5 East at elevation of 634m. This data is collected from Ghorahi(Dang) weather station with WMO (World Meteorological Number) 444290.

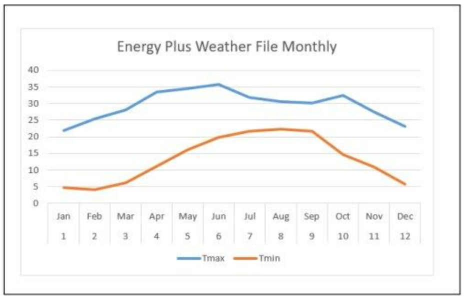


Figure 1: Monthly Max Min Temperature EPW Data

Also, it is required to collect the outdoor and indoor temperature of the site. For collecting outdoor temperature and humidity it was collected from DHM site manually for the same time and duration during which the indoor temperature is collected. The outdoor temperature data is presented in the figure below.

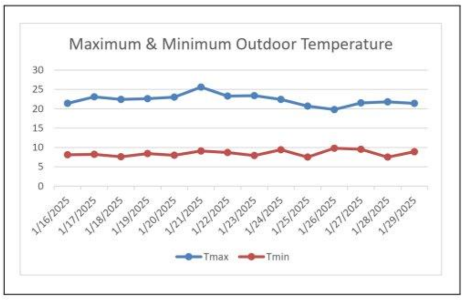


Figure 2: Daily Max Min Outdoor Temperature

Similarly, the indoor temperature inside the case study house collected is also presented here. The temperature is collected on hourly basis. The hourly temperature data is collected for 11 days. It was collected using custom made datalogger named Arduino Nano Data Logger.

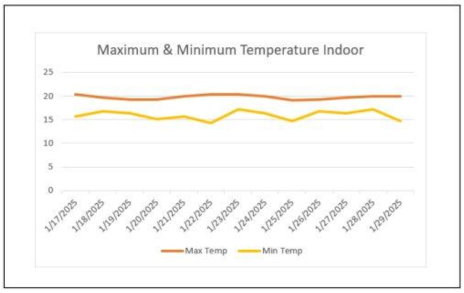


Figure 3: Daily Max Min Indoor Temperature

5. Case Study Area

The building selected for study is located in Lumbini Province Dang district Gadhawa Gaunpalika ward no 2 Mahadewa village. The latitude is 27º48’40” and longitude 8238’53” with elevation 291m (source: google earth). The total population of this ward is 5596 as per Nepal Population Housing Census 2021. In this ward percentage of house made from RCC is 46% whereas made from bamboo materials is 24% data obtained from Nepal Population Housing Census 2021. The case study is inhabited by mostly Tharu community and also the number of RCC houses is more compared to traditional houses. The village is located close to popular landmark like the second longest bridge, Tharu Baghnath Baba temple, Lal Durbar and Shiv temple. Like other Tharu villages this village is situated close to rapti river and forest and the settlement pattern is linear along the road. The house selected is made from local materials like thatch roof made from reed (Khar), wall made from reed sandwiched between mud plaster. The thickness of the wall is 100mm. The floor is raised 300mm above the ground level and is made from mud, straw, cow dung.

Figure 4: Case Study Building

The selected building is occupied mostly during night time because during the data collection time it was observed that they spent most of their time working in the field. Regarding, electricity consumption it was also used only for lighting purpose only generally from evening 6 pm to 9 pm. The family was joint family with more than 12 family members and only 4 people stayed in that traditional house.

6. Computer Simulation Result

6.1 Simulation

The method of simulating a real house inside the computer to find out how the building perform in terms of energy usage, heat gain heat loss is called computer simulation. It is a powerful tool which can be used to make buildings energy efficient and sustainable and recently gaining more momentum because of global concern regarding the climate change. There are wide number of energy simulation and performance measuring software available in the market such as Ecotect, Energy Plus, Design Builder to name some of them. For this study Design Builder software is used to examine the energy performance of modified traditional Tharu building. Design Builder offers powerful user-friendly modelling environment which can be used for wide range of applications such as thermal simulation, HVAC modelling, solar analysis, scripting etc. In order to perfectly simulate the behavior of traditional building we need to draw the building envelope measured from the field data. The floor plan is 5.95m by 10.15m in dimension.

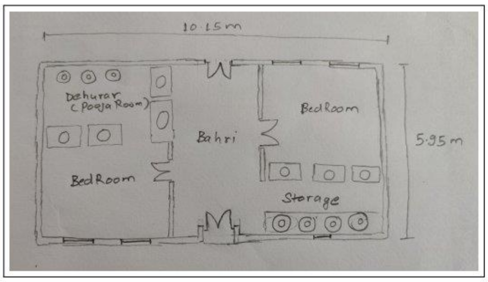
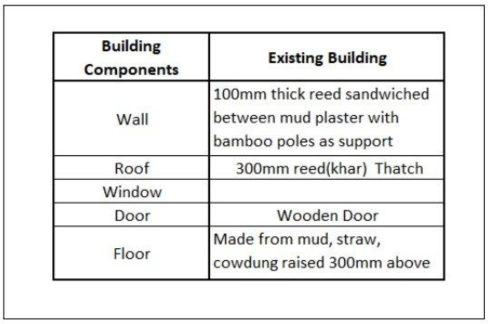


Figure 5: Floor Plan of Case Study Building

6.2 Construction Materials

The material which was used in the actual buildings also needs to be same in the simulation model as construction materials.



Building Components	Existing Building
Wall	100mm thick reed sandwiched between mud plaster with bamboo poles as support
Roof	300mm reed(khar) Thatch
Window	
Door	Wooden Door
Floor	Made from mud, straw, cowdung raised 300mm above

Figure 6: Construction Materials Used

6.3 Software Input

Some variables need to be entered manually on the software collected from the field observation. The whole floor plan has three main zones namely two bed room on North South side and in middle common room. The input data will be according to these zones. The clothing factor taken is 1 for winter and 0.5 for summer.

Table 1: Software Inputs

SN	Description	Room North & South	Common Room
1	Occupancy No	2	4
2	HVAC	Nat Vent	Nat Vent
3	Metabolic Activity	Sleeping	Light Work
4	Comfort Range	Based on Adaptive Comfort	
5	Infiltration Rate	6 ACH	

6.4 Material Properties

The thermophysical properties of the various materials used for the simulation are presented in the table. These properties are obtained from various literatures. These properties are essential to properly predict the heat loss and gain through the building envelope.

Table 2: Material Properties

SN	Material Name	Thermal Conductivity(W/mK)
1	Mud	0.6
2	GI Sheet	60.47
3	Thatch	0.35
4	300mm water reed	0.087
5	300mm Long straw	0.069

6.5 Results

The computer simulation was performed for the selected base case buildings and other 3 cases for making comparison. The simulation was performed for winter January and summer June month and the results generated are presented in this section. The 3 cases are Case 1 (Mud reed wall with CGI roof and mud floor), Case 2 (CGI roof with CGI Sheet wall and concrete floor) and Case 3 (CGI roof and wall with bamboo lathe insulation with concrete floor).

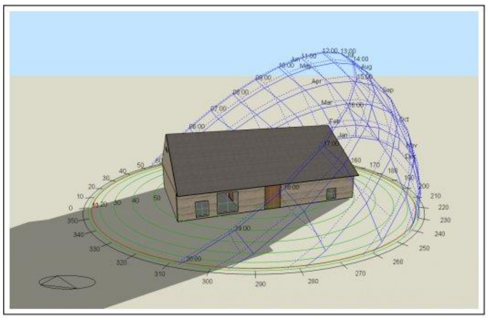


Figure 7: Rendered View of the Existing Building

6.5.1 Indoor Summer Air Temperature Variation

The indoor air temperature during June is simulated for Base Case and other cases and discussed. For Base case existing building when the outdoor air temperature was 24.77^{o} then indoor temperature was 25.53^{o}. Similarly in afternoon at 3 PM the Base case building shows a indoor temperature of 29^{o} which is cooler than Case 1 and 2 indicating that the Thatch roof and reed walls slows the heat transfer rate. In evening at 7 PM the Base case has 29.14^{o} when the outdoor temperature was 28.34^{o}.

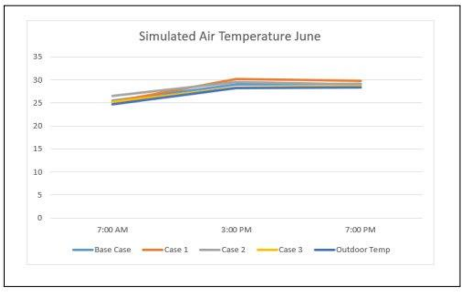


Figure 8: Indoor Simulated Air Temperature June

6.5.2 Indoor Winter Air Temperature Variation

For Base Case we can observe that at morning when outside temperature was 8.09^{o} C inside temperature is 14.25^{o} C showing the heat insulation effect. But when we compare the temperature at afternoon it is lower than Case 2. At evening time when we compare the temperature drop from afternoon to evening for Base case it is 0.24^{o} C only but when we compare with Case 2 the temperature drop is 4.54^{o} C when the outside temperature was 16.58^{o} C. This indicates that the Thatch roof gains and loses heat slowly whereas the CGI sheet heats and cools faster.

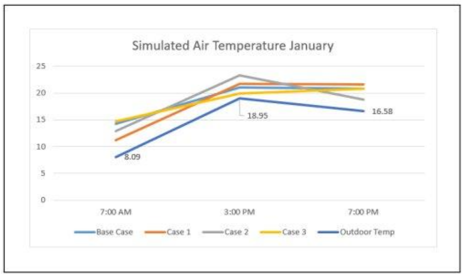


Figure 9: Indoor Simulated Air Temperature January

6.5.3 Heat Gain Heat Loss

The heat gain and heat loss inside the building are from various elements. In this simulation, the heat transfer inside the building for simulated cases are from two elements: a) Internal Heat Gain b) Fabric Heat Gain. The internal heat gain includes heat generated from people, equipment load. Lighting system and solar heat gain from windows. The building considered here has general purpose lighting only and generally used during night time for short duration only. The Fabric heat gain includes heat transfer from glazing, wall, ceiling, ground floor, partition, internal natural ventilation, external air, external ventilation and roof.

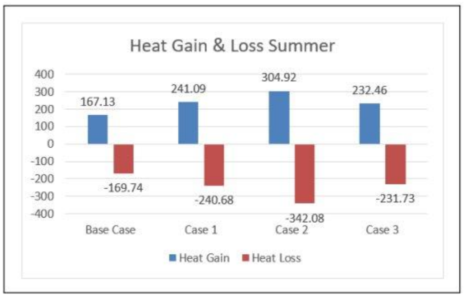


Figure 10: Heat Gain Loss Summer

For Base Case building with mud plastered reed wall,thatch roof the total heat balance is -2.61 Kwh which is nearly balanced,suggesting that the building naturally maintains the temperature within comfortable limit. For Case 1 building with CGI roof, when compared with base case, the heat gain increases by 73.96 Kwh and heat loss also increased by 70.94 Kwh. The heat gain is much higher compared to Base Case due to faster heating and cooling of CGI roof. For Case 2 the heat gain and loss are highest among all cases which indicates overheating due to CGI roof and sheet wall. Similarly, for Case 3 the heat gain and loss is lower than Case 1 and 2 but still higher than Base Case. We can clearly see that bamboo insulation prevents heat gain and heat loss.

For Base Case building in winter the heat balance is nearly zero which suggest that heat incoming is equal to heat outgoing but in winter we need heat build up to make the interior comfortable. Thus, we can see from heat transfer chart that the base case building is not able to retain the heat properly. For Case 1 it is gaining more heat but again losing the same amount of heat which makes the indoor space uncomfortable. For Case 2 the heat balance is -58.97 Kwh which means it is losing more heat than it has gained indicating that it is performing worse than Base Case, Case 1 Case 3. For Case 3 also even though it has bamboo insulation provided it is also not able to retain the heat even though it gains more heat than Base Case but also loses more heat.

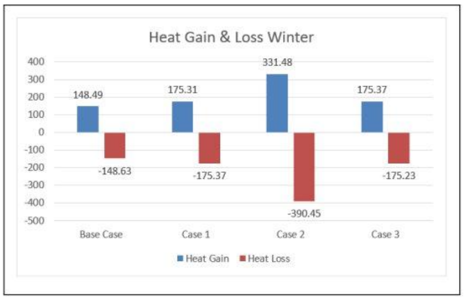


Figure 11: Heat Gain Loss Winter

6.5.4 Discomfort Hour

The time not meeting the adaptive comfort limit based on for the simulated building during the time of occupancy for June and January for 4 cases are presented and discussed.

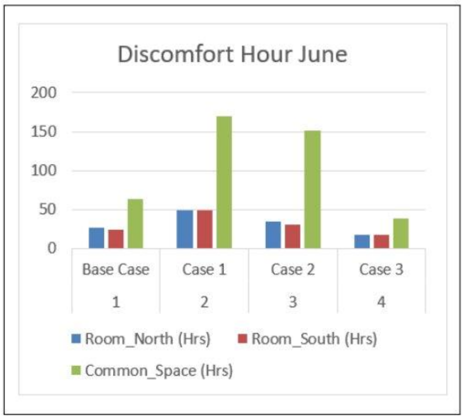


Figure 12: Time Not Comfortable During Ocupied Hours June

The Base Case building in summer has discomfort hour of 26.52 hours (Room North), 23.93 hours (Room South) and 62.78 hours (Common Space). In winter the same building experiences high discomfort with 337.45 hours (Room North), 333.82 hours (Room South) and 170.72 hours (Common Space) which gives insight that the building is unable to retain heat.

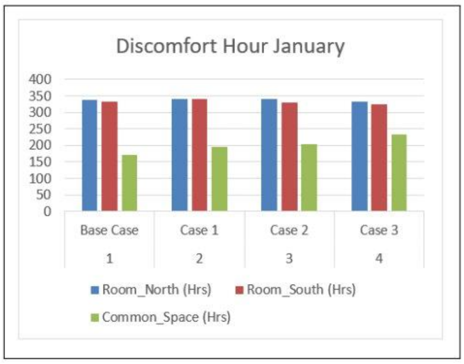


Figure 13: Time Not Comfortable During Ocupied Hours January

From the graph we can clearly see that in January Room North and Room South for all case have huge discomfort hour above 300 hours and the discomfort hour for zone Common space is above 150 hours which is lower than other cases considered even though it is not comfortable.

6.5.5 Internal Heat Gain

The internal heat gain inside the building is due to occupancy, lighting and equipment and also through solar gain coming via window. In the base case building energy used was due to lighting only. The heat gain form lighting in all three zones is 1.2 Kwh, due to occupancy is 29.3 Kwh for Bed Room North Bed Room South and 102.79 Kwh for Common Space during January and in June it is 28.19 kwh for Room North Room South and 45.78 kwh for Common Space. The reason for difference in the heat gains due to occupancy is because of number of occupant and their metabolic activity. In Room North South occupancy number is 2 whereas in common space is 4.

6.5.6 Passive Design Elements Impacts

The passive design elements that are found in the case study building observed from field investigations are: light thermal mass wall made from reed and mud plaster wall, thatch roofs, openigns provided below the gable which foster air circulation helping in passive cooling of buildings. The roof over hang of 450 mm.

In Base Case the u-value of reed wall is 0.279 W/m2K and it is gaining heat of 16.55 Kwh in June and in January it is gaining 26.44 Kwh. In Case 1 the u-value is also 0.279 W/m2K and it is losing -2.43 Kwh heat in June and gaining 41.79 Kwh in January. In Case 3 the u-value of CGI sheet wall is 7.142 which is very high and the heat gain in June increased to 41.03 Kwh and heat gain also increased to 215.48 Kwh in Janauary. In Case 3 the addition of bamboo lathe insulation reduced the u-value to 1.2 W/m2k thus the heat gain in June decreased from 41.03 Kwh to 30.26 Kwh and also in January the heat gain inside dropped to 42.07 Kwh from 215.48 Kwh from Case 2.

In Base Case Existing Building during summer the 300 mm thatch roof gains 101.73 kwh indicating good insulation and low heat absorption and in winter it loses only -11.68 kwh suggesting moderate heat retention. In case 1 replacing the thatch roof with CGI increases the heat gain from 101.73 kwh to 901.19 kwh which indicates that CGI absorbs more heat making the building hotter. In winter the heat gain increased compared to Base Case to 90.7 kwh. In case 2 the heat gain further increases to 964.46 kwh the highest recorded which indicates extreme overheating. While in winter the heat loss is -84.6 kwh making it the coldest case which indicates that CGI and concrete floor does not provide good insulation. In case 3 with bamboo lathe insulation the heat gain in summer is reduced to 336.87 significantly lower than case 2 3 showing that bamboo lathe insulation improves thermal performance. Winter loss is -54.6 kwh much lower than case 2 meaning that bamboo lathe insulation helps retain heat better.

7. Conclusion

The building selected for case study is modified traditional Tharu building which has been modified by the people who uses them to match according to their needs. The building has very minimal energy usage only for lighting purpose only and so the energy performance of the building is carried out by considering heat gain and heat loss taking place inside the building. In total 4 simulation cases were performed for understanding the performance of Tharu building by comparing with other cases.

- The main objective of this study was to evaluate the energy performance of modified Tharu Traditional building. From the simulation result we can see that the total heat gain and heat loss for Building in June is 167.13 kwh and -169.74 kwh. Here, the total heat balance is equal to -2.61 Kwh. In June which is hotter days heat loss is preferred so we can see that heat gain and heat loss nearly balanced. With this balanced heat the time not comfortable during occupied hour during June is 23.93 hrs. Similarly, in January during winter season the heat incoming is 148.49 kwh and heat outgoing is -148.63 kwh which is again balanced. But in winter heat is required inside the building to make the indoor comfortable whereas the time not comfortable is quite high 332.82 hours.

- The passive design elements that are available in the case study buildings are light thermal mass wall with reed mud plaster, 300mm thick reed thatch roof, openings below the gable roof for enhancing the air flow inside the building to enable passive air cooling.

- In Base Case the 100 mm mud reed wall which has lower thermal transmittance of 0.279 W/m2k compared to Case 2 which has CGI sheet wall the heat transfer via the wall is 16.5 kwh whereas in Case 2 is 41.03 kwh and this overall have impact on discomfort hour. Also, the thatch roof which has lower thermal transmittance than other cases slow the rate of heat gain and loss. Also, the openings provided below the roof is open 24 hours and during winter through which the heat loss of -53.40 is taking place and if that heat loss is controlled then the heat loss decrease to -0.17 kwh. This decrease in heat loss also decreases the discomfort hour from 333.82 hours to 308.37 hours and the indoor air temperature also rises from 16.63 C to 17.68^{o} C by almost 1.05^{o} C.

Acknowledgments

The author is greatful to the owner of house for granting permission to place datalogger and carry out field measurements required for the study.

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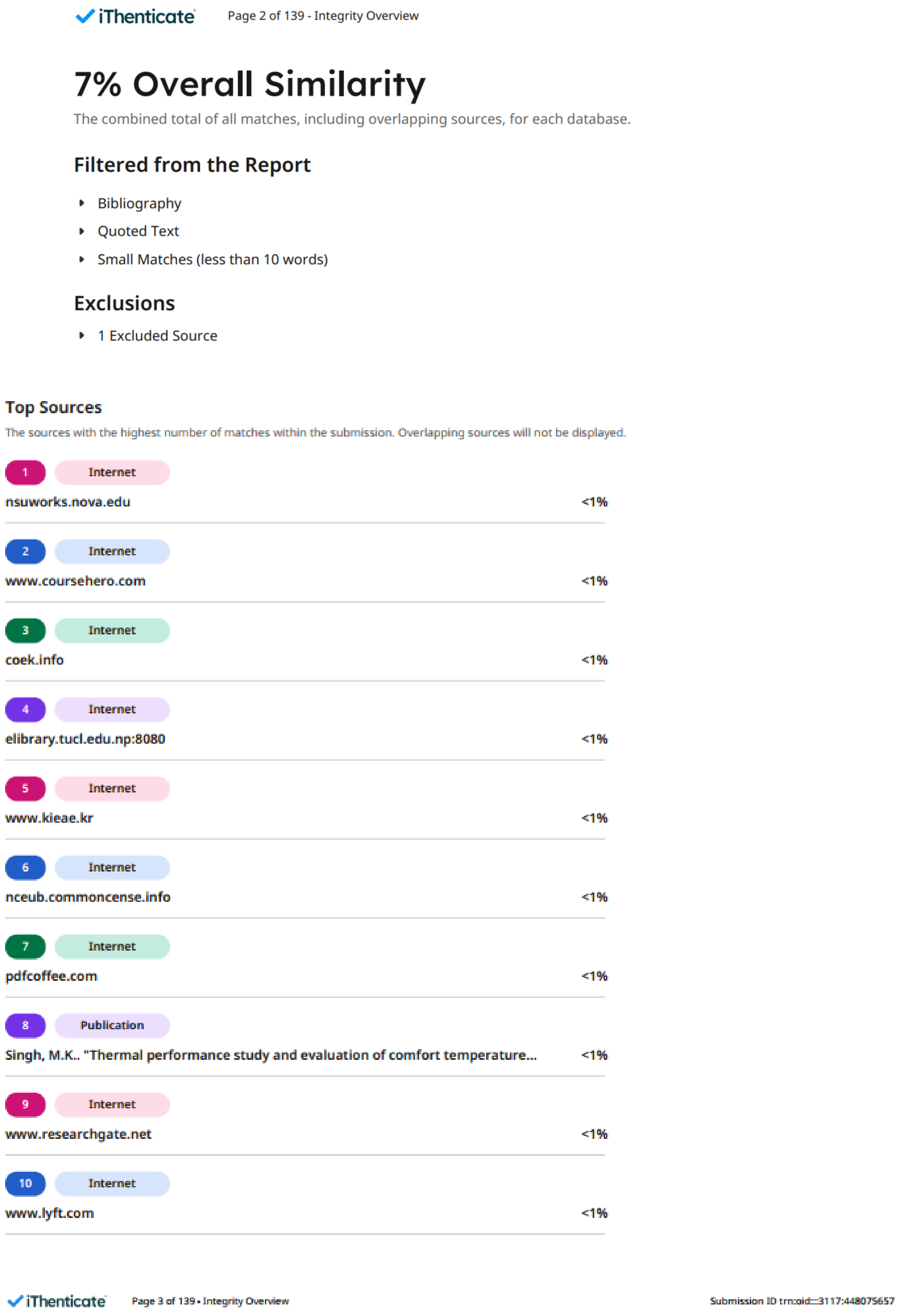
APPENDIX-VI: Plagiarism Check Report



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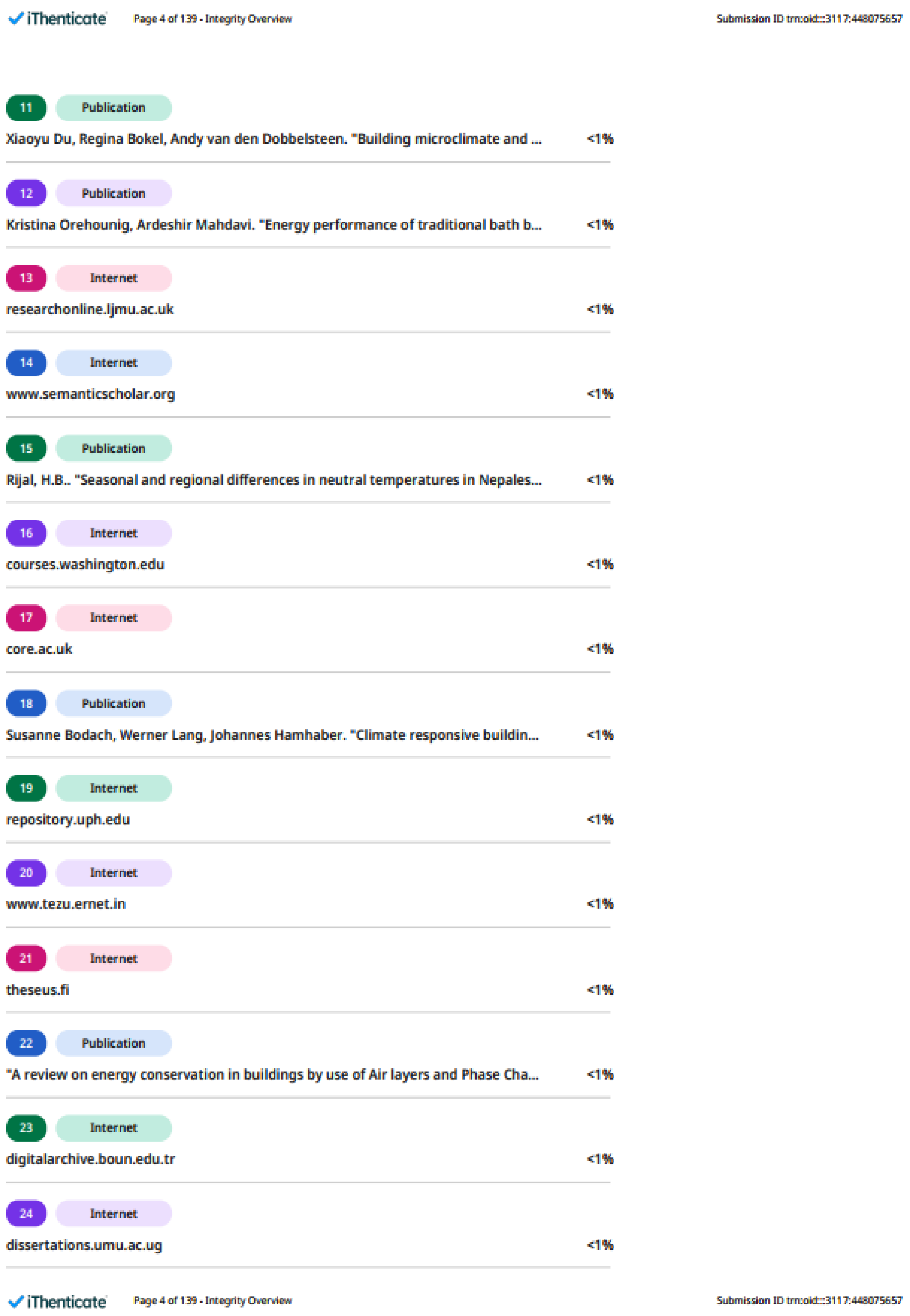

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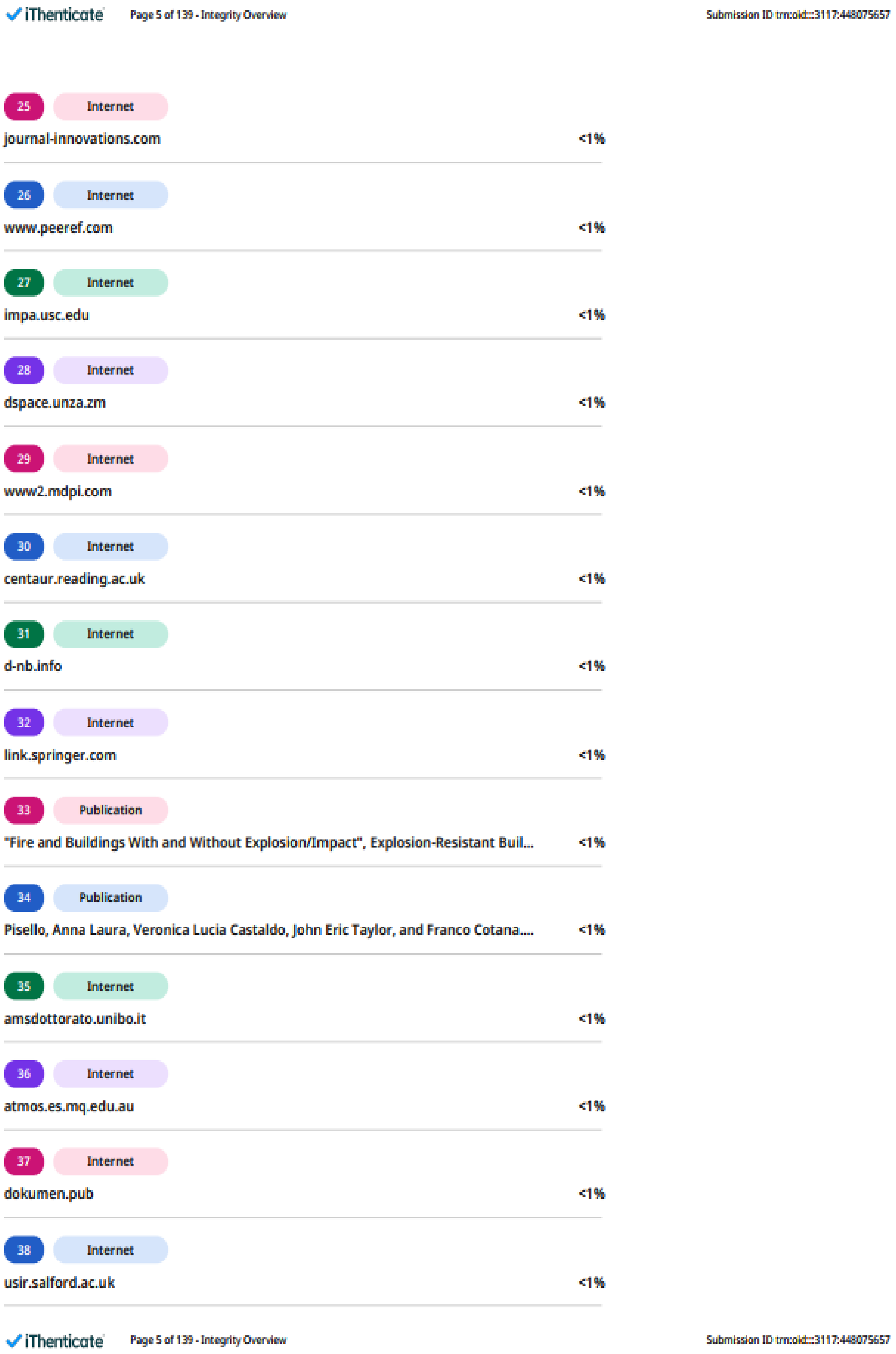

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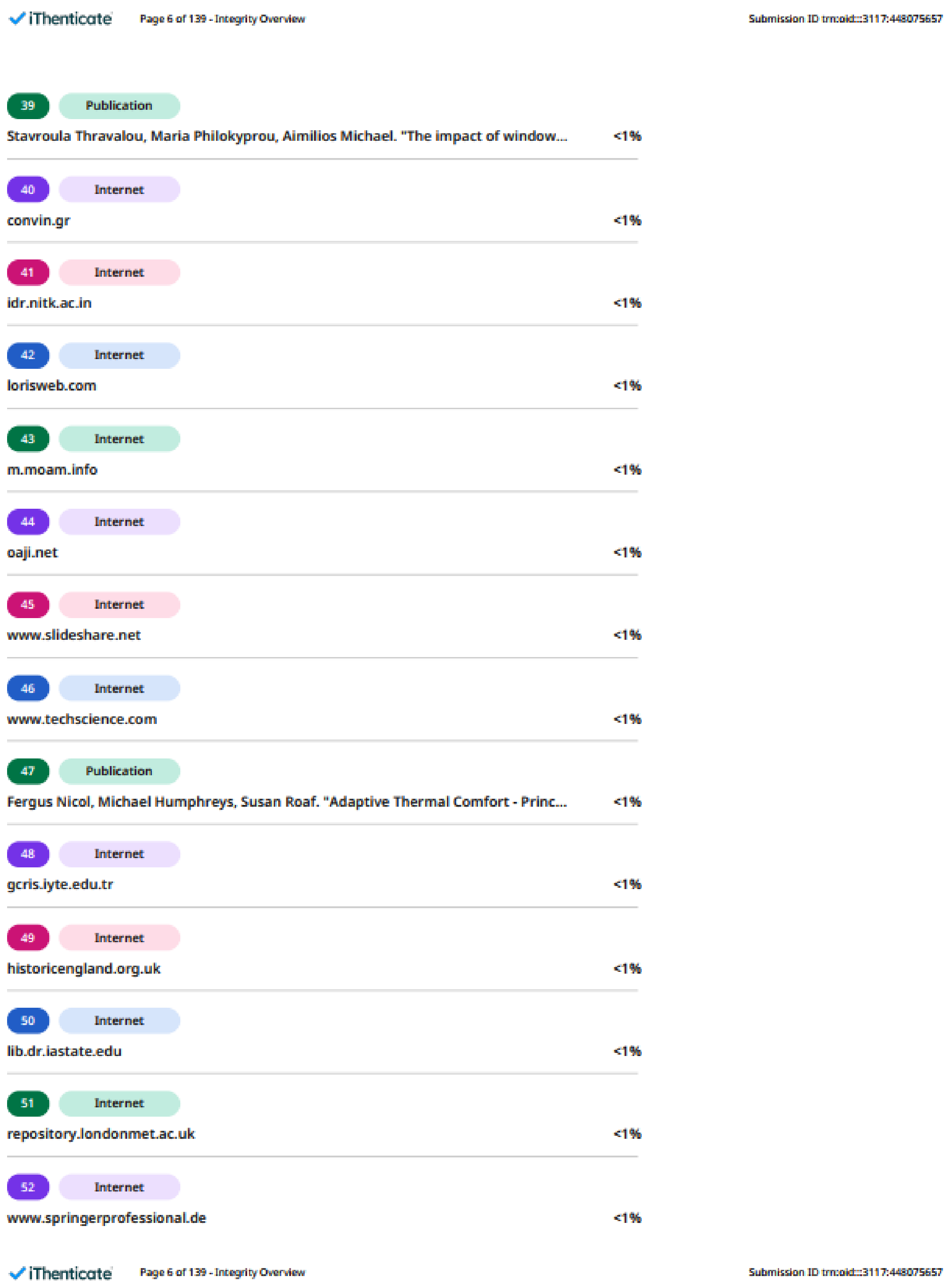

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