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Climate Responsive Residential Architecture in Dhading

by

Jyoti Dhamala

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ABSTRACT

Climate responsive design is considered to be one of the major requirements to drive the building sector towards sustainable development. Climate-responsive design in a particular region is influenced by factors such as air temperature, relative humidity, wind, irradiation, and rainfall. Due to Nepal's very variable geography, there are many different climatic conditions within a short distance. The country's building industry has adopted standard design and construction methods as a result of the introduction of modern construction technologies, ignoring the local climate and relying instead on energy-intensive mechanical measures to offer comfort inside the building. For the study primary quantitative and qualitative field data and secondary quantitative climate data was collected from Department of Hydrology and Meteorology and developed bioclimatic chart and Mahoney table which gives the different design strategies for Dhading. The study reviews examples of traditional and modern residential architecture and its building features in Dhading and analyses in a qualitative and qualitative manner. Climatic data from Dhading shows that most of the month in a year are hot. From bioclimatic chart it was found that the summer temperature is high in day time hence passive cooling strategies are recommended. From Mahoney table also heavy walls and roof with permanent provision of air movement is recommended. From the study it was found that traditional buildings have less indoor air temperature but have high indoor humidity level. However traditional building materials and design features applied in Dhading are climate responsive than contemporary buildings.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATION

CGI	Corrugated Galvanized Iron
DHM	Department of Hydrology and Meteorology
H.max.	Maximum Humidity
H.min.	Minimum Humidity
M.Avg.H.	Modern Building Average Humidity
M.Avg.T.	Modern Building Average Temperature
R.H.	Relative Humidity
T.Avg.H.	Traditional Building Average Humidity
T.Avg.T.	Traditional Building Average Temperature
T.max.	Maximum Temperature
T.min.	Minimum Temperature

CHAPTER 1. INTRODUCTION

1.1 Background

Climate-responsive architecture is described as architecture that effectively incorporates components of the local climate to enhance occupant thermal and visual comfort with little to no recourse to non-renewable energy sources (Yannas, 2003). One of the essential requirements for guiding the construction sector toward sustainable development is climate-responsive design (Szokolay, 2012). Climate responsive design uses climatic elements in formulating design approaches. The greatest use of climate elements like air temperature, relative humidity, wind, irradiation and rainfall can reduce the heating and cooling energy within buildings. Buildings are designed to achieve and produce an environment that is comfortable for people (Lamsal et al., 2021). As a result, this refers to architecture that preserves the ecosystem of which it is a part while minimizing its adverse effects on the environment.

Buildings are now the world's biggest energy consumer and are crucial to attempts to combat climate change. Buildings consume an unexpectedly large 40% of the world's energy, and the accompanying carbon footprint is much more than that of all forms of transportation combined (WBCSD, 2009). This percentage will rise to more than 50% if the energy used in the production of building materials like glass, cement, aluminum, and steel is taken into account. Energy demand in the building sector has increased by 2% annually due to urbanization and wealth growth in developing nations and suburbanization in industrialized nations (Houser, 2009). The residential sector in Nepal accounts for 89% of all energy use, which is a significant factor (Lamsal et al., 2021).

It is not a recent innovation to use micro and macro climate variables in housing. Historically, in Greece, where it first appeared, climate-responsive architecture was created in the fourth century BC, and most likely even earlier (Oktay, 2002). Ancient builders discovered to design and construct homes that would benefit from solar energy during the seasonally mild winters and stay away from its heat and radiation throughout the summer. As a result, solar housing was developed by designing buildings that respond to the sun's moving position throughout the year to maximize its usage of energy. The Greeks constructed openings that could capture much-needed heat because they understood that the sun's route in the southern sky in winter was in a low arc. The roof overhang shaded the surface of the building during the summer when the sun's path was significantly higher overhead. Additionally, the fact that the majority of the earliest structures were constructed from stone and mud allowed for the storing of solar energy. Additionally, early evidence demonstrates that solar principles and other regional climate characteristics were applied not just to solitary, isolated residences or villas but also to clusters of houses on an urban scale (Oktay, 2002).

The broadest definition of climate is the meteorological conditions to a particular region(Hyde, 2000). Nepal is a diverse country in terms of both geography and culture. The latitude and longitude of Nepal are 26°22' to 30°27'N and 80°04' to 88°12'E, respectively. The width from north to south is between 130 and 260 km, while the length from east to west is roughly 885 km. There are many different climatic conditions in Nepal due to the rapid changes in height and aspect throughout the latitude (DHM, 2015). The Himalayas to the north, a hilly region made up of the Mahabharata range and Chure hills, and Tarai to the south, can be separated into on the basis of geographical diversity and climate. Neelakantha Municipality is located between the longitudes of 84°58'49.98" and 84°56'41.37" east and the latitudes of 27°50'45.442" and 27°58'1.27" north. In general, Neelakantha municipality experiences a mild, moderate climate. Though throughout the summer, some southern basins and valleys experience a subtropical climate (Municipality, 2019).

Buildings with high levels of energy efficiency improve the living conditions for occupants while minimizing their negative effects on the environment. On the other hand, the fundamental principle of climate responsive design is the assessment of climatic influence and the enhancement of building environmental performance (Hyde, 2000). In other words, trying to cooperate with the external climate to reduce resource consumption and negative environmental impact. So, without sacrificing contemporary living standards, climate responsive architecture can significantly contribute to lowering building energy use (Hyde, 2000). Truly, a building's ability to respond to climatic elements like wind and sun affects how comfortable its occupants feel within. Consequently, there is a relation between sustainability and climate responsive design, as both aim to reduce on active energy use while providing residents of the building with comfort (Motealleh et al., 2018). Additionally, the application of climate sensitive design would also be able to advance sustainability and reduce energy consumption, which is a current issue.

1.2 Statement of the problem

People had to adapt to the environment and with available natural energy sources in the past because there were not enough abundant energy sources. During the post-World War II construction boom, active energy were mostly used in industrialized nations as a simple and rapid way to address comfort concerns in buildings. Architecture lost its relationship to location during the process. With the advancement of technology, completely controlled constructed environments that were isolated from their surroundings became a reality. This can be the reason why the actual costs of this kind of progress were not given enough consideration (Koch-Nielsen, 2013). According to ideas developed over many generations, vernacular architecture is more able to adapt to the environment than contemporary structures. In many developing nations, passive measures are linked with traditional, even if these practices may not necessarily fit the definition of modernity. This account for the general lack of acceptance, which is understandable, as a similar belief drove the development of the industrial world (Koch-Nielsen, 2013).

Several vernacular practices of Nepal's traditional architecture are sustainable and energy-efficient, though none of them are utilized in today's modern building design. Regrettably, many traditional architectural principles of climate design have slowly disappeared in modern architecture (Rijal, 2018). After the Gorkha earthquake, rural areas quickly adopt contemporary building. Modern architectural forms, materials, and technology are becoming more dominant in rural areas than traditional architecture. Due to advancements in construction forms, technologies, and materials, rural life's cultural aspects are also changing. People are dismissing vernacular architecture as an antiquated, worthless structure that is unfit for use in contemporary society. However, preliminary research indicates that vernacular architecture is climate responsive, energy efficient, extremely sustainable, and environmentally friendly (Rijal, 2018).

According to the current study, the household sector in Neelakantha Municipality consumes 292 TJ of total energy annually, with cooking accounting for the majority of this consumption at 55.20%. According to the study's "business as usual" scenario, home energy demand will increase to 958 TJ in 2050, with 220 TJ of that energy going toward burning firewood. According to the sustainable development scenario, household energy demand would reach 532 TJ in 2050. Of this amount, electricity is expected to account for over 89% of household energy use. (Paudyal & Nakarmi, 2019).

1.3 Rationale of the research

The climate of a particular location has a significant impact on a building's design. All environmental factors that have an impact on both the internal and external environments should be taken into account when designing a building that responds to the environment (Lavaf Pour & Surat, 2012). Although many traditional methods are sustainable and environmentally friendly, some of them are no longer effective due to modern lifestyle changes and ecological conditions. The difficult task in this context is to identify the fundamental vernacular architectural principles and observe how to incorporate those ideas into the design and building process.

The architectural field has been significantly impacted by the growing global concerns about energy-related issues. The traditional Vitruvius triangle model for architecture now incorporates a fourth pillar, called "Energy." According to statistics, a significant amount of energy utilized in buildings is used to create carefully controlled, comfortable indoor conditions, independent of the external climatic conditions (N Charkas, 2019). The bioclimatic approach to building design has simply been concretized through the use of climate sensitive design solutions (Nguyen, 2013). Today, achieving more sustainable buildings requires a foundation built on climate responsive design. Therefore, as a foundation for architectural concepts that take the environment into consideration, climate responsive design ideas must be applied in the practice of building design.

Building has a big impact on the environment and natural resources. Building design philosophies, tactics, technologies, and construction techniques need to undertake a significant revolution in order to meet the world's emerging energy and environmental concerns. Vernacular architecture refers to the buildings created by individuals under the influence of cultural traditions. Vernacular architecture changes in accordance with the wide range of temperature, geography, and cultural conditions around the world. Vernacular architecture already has the knowledge necessary to improve buildings' energy efficiency utilizing inexpensive local resources (Zhai & Previtali, 2010). Over many years, vernacular architecture has evolved without significantly harming the environment or human health. The buildings are precisely fitted to the climates and cultures by utilizing native building materials and techniques (Rijal, 2018). But during the past two to three decades, building construction techniques have altered significantly, and contemporary designers frequently choose to neglect important factors like the environment.

Specific energy-efficient technologies can potentially save energy, but careful planning of urban environments and individual buildings can save energy even more: all naturally available resources should be incorporated into planning and building in a way that their location, form, and structure encourage energy savings (Koch-Nielsen, 2013).

1.4 Research objectives

The purpose of this study is to discover fundamental principles and ideas from traditional architecture and determine how to apply such ideas to modern design. Therefore, the following are the study's key goals:

- To study climate responsive features of residential architecture in Dhading.
- Analyzing climate responsive design strategies adopted in residential architecture in Dhading.
- Recommend passive design strategies for Dhading.

1.5 Scope and limitations

Only residential buildings, especially low-rise traditional buildings, are the focus of this study. Other building types (e.g. commercial buildings, office buildings, industrial buildings, educational buildings etc.) are not included in this work. All the climatic parameters related to climate responsive design study had not been possible due to availability of data from Department of Hydrology and Meteorology. Hence air temperature, rainfall and humidity data are only analyzed. Also due to limited time frame collection of data of all season were not possible. Field data of summer season was only collected in this study. Because there is not metrological station in Dhading, data of Dhunibesi was taken for the climate analysis.

CHAPTER 2. LITERATURE REVIEW

2.1 Climate analysis

According to Köppen's classification of climates, there are five major world climatic groupings that are meant to coincide with five major vegetation groups. Tropical, desert, temperate, cold, and polar climates are divided into these five groups. Each of these climates is further subdivided into groups based on variations in how temperature and precipitation are distributed throughout the year (Karki et al., 2016).

Nepal's geography is diverse due to the fact that it spans an altitude range of 60 to 8848 meters. A variety of climatic and vegetation zones resulted from this. Despite the fact that Nepal clearly has a very wide diversity of climates within a small latitudinal span. Latitude, altitude, slope orientation, prevailing wind as well as local wind and vegetation are geographical elements that affect the nation climate (Bodach et al., 2014). The geography of the country determines the spatial distribution of maximum and minimum air temperatures, with the highest temperatures occurring in the Tarai and Siwalik regions and the lowest in the High Himalaya regions (DHM, 2015). The presence of the monsoon circulation and its interaction with the topography dominate the precipitation pattern. While most precipitation occurs during the monsoon season (June, July, August and September), the winter (December, January and February) season is the driest time of year. With an average annual precipitation of more than 5400 mm on the southern side of the Annapurna range in the Central Middle Mountain areas, Nepal is the wettest country in the world, while the lee side of the same mountain range is the driest, with an annual precipitation of less than 200 mm. Low winter precipitation is experienced in southern portions of the central and eastern development regions, whereas it is high in the far western development regions (DHM, 2015).

As per the Koeppen-Geiger climate classification, Nepal features four distinct climatic zones: warm climate with dry winters and hot summers (Cwa), warm climate with dry winters and hot summers (Cwb), snow climate with dry and cold winters and cool summers (Dwc), and tundra climate (Bodach et al., 2014). All five different types of climate (including tropical) that were seen in Nepal could not be distinguished by the original Köppen-Geiger classification (Karki et al., 2016). In order to define the accurate climatic situation of Nepal, the original scheme was significantly adjusted by shifting the boundary of the coldest month's mean air temperature value from 18 °C to

14.5 °C. With this adjustment, the sub-tropical, warm temperate, cool temperate, alpine, and tundra climates (including tropical) that divide Nepal into five climatic areas were determined. Temperate, with dry winters and hot summers, is Nepal's most prevalent

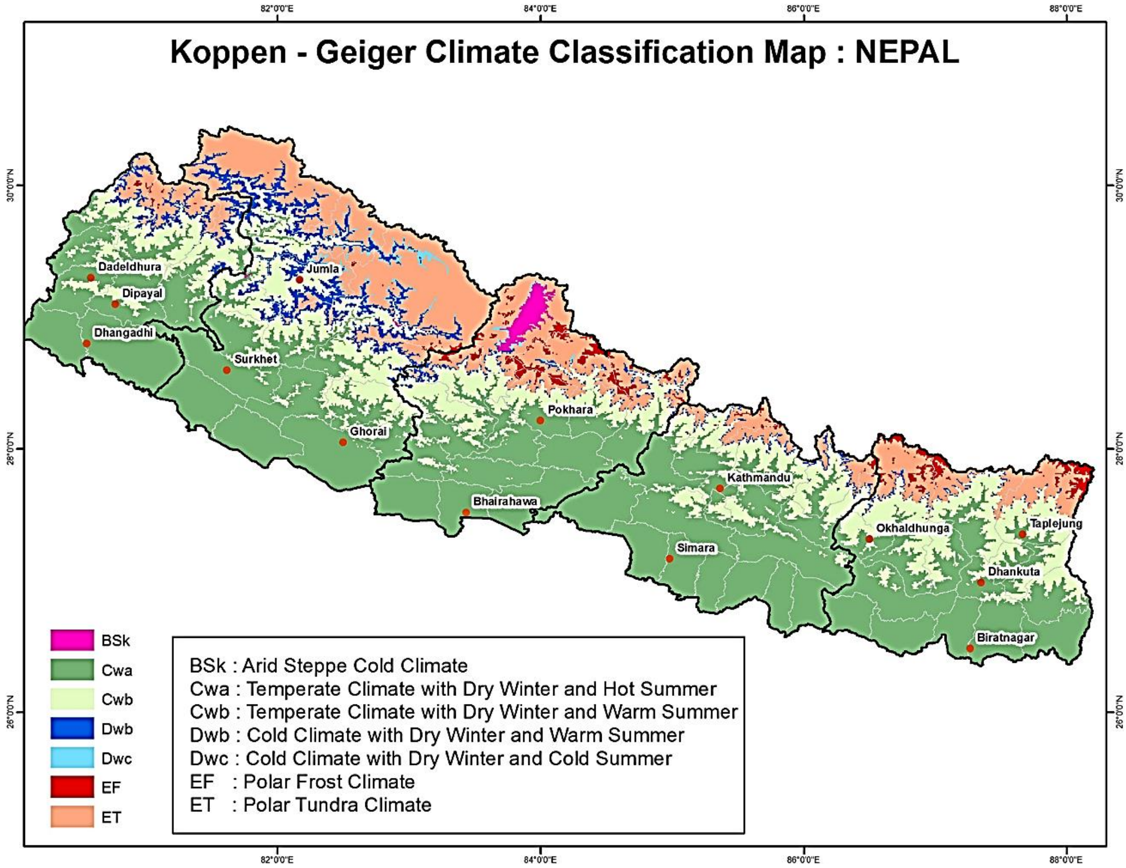


Figure 2.1: The climatic map of Nepal based on Köppen–Geiger classification

Source: (Karki et al., 2016)

predominant climate type (Cwa) (Karki et al., 2016).

According to DHM (2015) The five primary physiographic zones of Nepal are the Tarai plain, Siwalik hills, middle hills, high hills, and high mountains (composed of the main Himalayas and inner Himalayan valleys), as illustrated in Fig. 2.1 below.

Tarai: The Indo Gangetic plain, which stretches roughly 800 km from east to west and 30 to 40 km north to south with elevations varying from 60 to 200 masl, reaches its northern limit in Nepal's Tarai. With some slight relief brought on by river channel changes and basin downwarping, it is essentially flat.

Siwalik: The region from Tarai that is more commonly referred to as Churia hills rises abruptly and finishes at the start of the middle hills range. The Siwalik is situated between 200 and 1,500 masl above sea level. The Siwalik, which makes up approximately 13% of the country's total size, is typically distinguished by low terraces and an alluvial fan with steep topography. The area is very susceptible to landslides, mass wasting, and debris flow, which adds a substantial amount of sediment load to Nepal's major rivers.

Middle hills: The Mahabharata range also refers to the middle hills. The elevation of middle hills spans from 1,000 to 2,500 masl and stretches throughout the length of the country. The Koshi, the Gandaki, the Karnali, and the Mahakali are only a few examples of the preceding rivers that cut over the range in various locations. These rivers serve as the source of water that comes from this range's north and flows south. Due to orographic effects, it is the first significant barrier to the monsoon winds, which provide heavy precipitation on its southern slope.

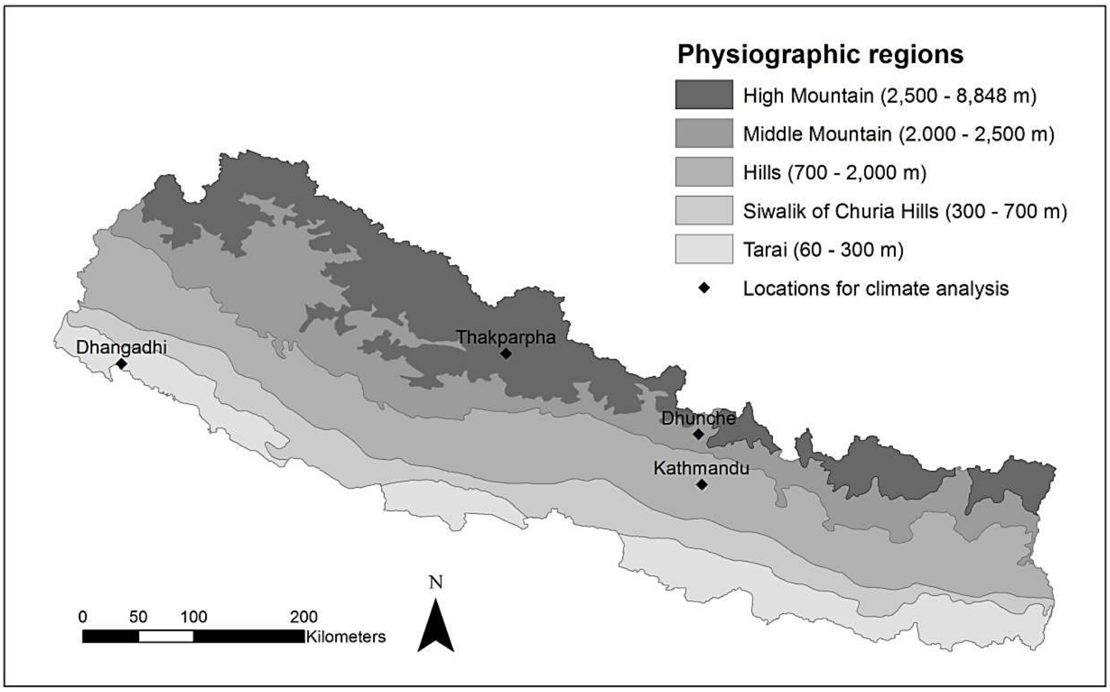


Figure 2.2: Physiographic regions of Nepal

Source: (Bodach et al., 2014)

High hills: This area is located further to the north of the middle hills, which have an elevation range of 2,200 to 4,000 masl. It is a strip-shaped region with an average width of 50 km that runs from east to west. The high hills, which are made up of low hills, river valleys, and tectonic basins, display an established landform. The climate in this area is mild and cool.

Mountains or the Himalayas: The snow-capped high Himalayas are made up of hills of high mountains that steadily ascend to the north. Elevations vary from 4,000 to 8,848 meters above sea level. The primary north-south rivers that originate on the northern side of the Himalaya have carved out some of the world's deepest gorges, including the

5,791 m-deep Kali Gandaki valley gorge. Glaciers, snowy summits, rocky outcroppings, talus, and colluvial deposits are the predominant landforms in the area. Its terrain is very rough, with sharp peaks and narrow valleys.

2.2 Climatic elements

The distribution of different elements and their mixtures in a specific area determines the climate there. Solar radiation, long-wave radiation to the sky, air temperature, humidity, wind, and precipitation are the main climatic factors to take into account when designing buildings for human comfort (Givoni, 1969).

2.2.1 Solar radiation

The range of solar radiation includes infrared, visible light, and ultraviolet. The latter, which manifests as heat, serves as the primary energy carrier. The sun's solar energy never changes. The amount of heat received at any particular location on Earth varies on the angle of incidence, the quality of the atmosphere, and the duration of the day. A specific region receives half as many sun rays at an angle of 30° as it does at a 90° angle. The energy that reaches the earth's surface is significantly reduced by this increased distance, especially if the atmosphere is dusty or wet. The seasons as well as the time of day have an impact on the angle of incidence. This is caused by how the earth orbits the sun. The weather and the amount of pollution in the atmosphere both have a significant impact on the amount of solar energy received. Similar to how energy is gained during the day, atmospheric conditions have a substantial effect on how much heat is lost to space at night. A heavy cloud cover prevents heat loss to the greatest extent when the sky is clear (Gut & Ackerknecht, 1993).

2.2.2 Air temperature

The primary factor affecting the temperature of the air above the globe is the speed at which its surface heats and cools. Since the air is nearly transparent to solar light, it only indirectly affects air temperature. Heat is carried to the upper layer of the atmosphere primarily through convection, along with turbulence and air eddies, from the air layer in direct contact with the warm earth. At night and in the winter, when the earth's surface is normally colder than the air, the net heat exchange is reversed, and air in contact with the ground is cooled (Givoni, 1969).

The temperature of the air is also influenced by altitude. Air mass moves from a upper to a lower pressure region as it climbs, like when it is propelled up a mountain, for example, expanding and cooling as it does so. A mass of air is heated and compressed when it descends, on the other hand. The rate of temperature changes is around 1 degree Celsius for every 100 meters of height, and these processes are known as adiabatic cooling and heating (Givoni, 1969).

2.2.3 Wind

The factors that cause winds to form are numerous and quite complicated. The unequal distribution of solar radiation over the world, however, is the fundamental cause. It leads to varying surface heating and temperatures. Due to these variations in air pressure, winds emerge. In some places, daily fluctuations in the heating and cooling of land and water surfaces (lakes, seas), mountainous and flat land areas, and bare and land covered with vegetation, cause regular wind patterns, such as sea winds or valley winds during the day and land winds or mountain winds during the night (Gut & Ackerknecht, 1993).

2.2.4 Humidity and precipitation

Water plays a significant role in climatic conditions. It manifests as clouds, rain, hail, snow, and vapour. The amount of water vapor in the atmosphere is referred to as atmospheric humidity. Through evaporation, water enters the atmosphere, predominantly from ocean surfaces, but also from humid surfaces, vegetation and small water bodies. The winds carry and disperse the vapour throughout the surface of the globe (Givoni, 1969).

The saturation point and air temperature change significantly throughout the day and night. The relative humidity fluctuates because the absolute humidity is unchanged. However, if the absolute humidity level reaches the saturation point, the excess water condenses and manifests as fog, clouds, dew, or precipitation. The similar thing happens when air rises and cools. Cumulus clouds are produced by strong thermodynamic upwind gusts, and clouds and precipitation are produced when winds pass mountains. The types and amounts of precipitation vary greatly due to geography, the placement of water bodies, and winds. Precipitation comes in many different forms, quantities, and seasonal distributions. For instance, rainfall might be especially strong and persistent during a specific time of the year in monsoon regions. In warm, humid areas, it can happen all year round with brief downpours virtually every day. In architectural features and building types, at least historically, these variations in precipitation patterns are reflected. Examples of typical buildings for various regions can help to clarify this (Gut & Ackerknecht, 1993). According to Gut and Ackerknecht

(1993) the amount of sweat a person produces depends on the humidity level. As a result, it also affects how temperatures are experienced. Low humidity allows for a tolerance for greater temperatures; high humidity lowers the maximum temperature that is tolerable. Humidity has little effect when the comfort level is at its lowest point. According to Gut and Ackerknecht (1993) the table below illustrates the range of comfort with light summer clothing in response to humidity.

Table 2.1: Summer comfort temperature in relation to humidity

Source: (Gut & Ackerknecht, 1993)

Humidity%	Day temperature °C	Night temperature °C
0-30	22-30	20-27
30-5-	22-29	20-26
50-70	22-28	20-26
70-100	22-27	20-25

2.3 Vernacular architecture in Nepal

According to Oliver (1997) vernacular architecture includes all homes and other structures built by individuals or groups of people using traditional building techniques

Figure 2.3: Typical Tharu house

Source:https://www.odynovotours.com/travelblog/chitwan-national-park-travel-guide.html

and related to their local environment and resource availability. In order to accommodate the values, economy, and way of life of the cultures that created them, vernacular architectural styles are created to satisfy particular needs. Vernacular architectural forms are distinctive and local technologies of construction with materials readily available and reflecting local customs. Without the required formal engineering training, vernacular architecture has been practiced for generations. However, our ancestors gave us a magnificent gift in the form of vernacular architecture. The buildings are ideally adapted to the living circumstances, the environment, and the socio-cultural aspects (Rijal, 2012).

The Tharu homes, including those in Chitwan and Rana Tharu's home in the western region's Kanchanpur district, are examples of sub-tropical vernacular architecture. Cane, lumber, and thatch are the primary local resources used. For hot and humid areas, settlements are typically laid out in a loose style to allow for air circulation. The most common building shape is rectangular, and one storey horizontal space arrangement. Materials for the roof and walls are typically air permeable and somewhat light in weight. The interior's height and near-undivided layout, along with wall and roof openings, improve the building's natural ventilation. In some homes, windows are positioned to enhance stack ventilation. Direct sunlight gain through walls and openings is reduced by widespread roof overhangs and the provision of enclosed veranda space (Bodach et al., 2014).

Figure 2.4: Traditional house at Siddhalek, Dhading

Source: (Government of Nepal, 2019)

The houses of the Newar in the Kathmandu valley, the hill houses of Dolakha, Dhading district, and the Indo-Nepalese house in central Nepal are examples of vernacular architecture in a temperate climate.

According to Bodach et al. (2014) the building characteristics of the various homes in Nepal's warm temperate environment are generally the same. The majority of traditional homes have a rectangular floor plan. To maximize solar advantages during the winter, the longer facade with the openings is frequently facing south. The large roof overhang shades the building's windows and facades in the summer. The clever layout of courtyards ensures solar passive heating in the winter and shading in the summer in the dense Newar communities. In this environment, homes typically have high thermal masses made of materials that are readily available. The thermal mass is particularly useful for storing solar heat gains from the day for colder nights during sunny winter days. Low ceilings limit the amount of air that needs to be heated during the winter. Because it generates barrier areas in the ground and higher level to keep the major living and sleeping rooms warm, the vertical internal space design of Newar houses is ideal for the chilly winter.

2.4 Climate-responsive design strategies for Nepal

Before beginning any pre-design analysis of a building, physical architectural designers, planners, and engineers should take the initial pre-design initiative, which should involve choosing an appropriate building site, well-drained landscape, and a location away from sources of pollution. It should also involve ensuring that the site has good solar access to enable an effective design that would extend the thermal envelop to the building's foundation (Rabah & Mito, 2003). Climate-related characteristics can be examined using the Mahoney tables and the bioclimatic chart. The climatic components of the chart in a bioclimatic diagram can be combined into one diagram. The comfort zone is depicted in the middle of the graph. The options to design in accordance with the local climate conditions are investigated by the bioclimatic approach. Lamsal et al. (2021) The following design suggestions were made for the development of Givoni's psychometric chart and Mahoney Table for the typical locations. Most of the months in the subtropical region are air movement months. In order to keep the indoor thermal climate, passive cooling solutions are strongly advised in the design. The ideal comfort zone is characterized by short-duration daytime temperatures in January, February, and March and short-duration nighttime temperatures in April. The passive solar heating zone has a brief drop in morning temperatures in January, February, March, November, and December. Since the temperature drops below 10°C at night in December, active heating is required. Passive heating methods are ineffective in this phase. May to October, the six months with the highest average daily temperatures, are the hottest months and call for the supply of air movement in building design plans. During this time, active cooling is required to keep

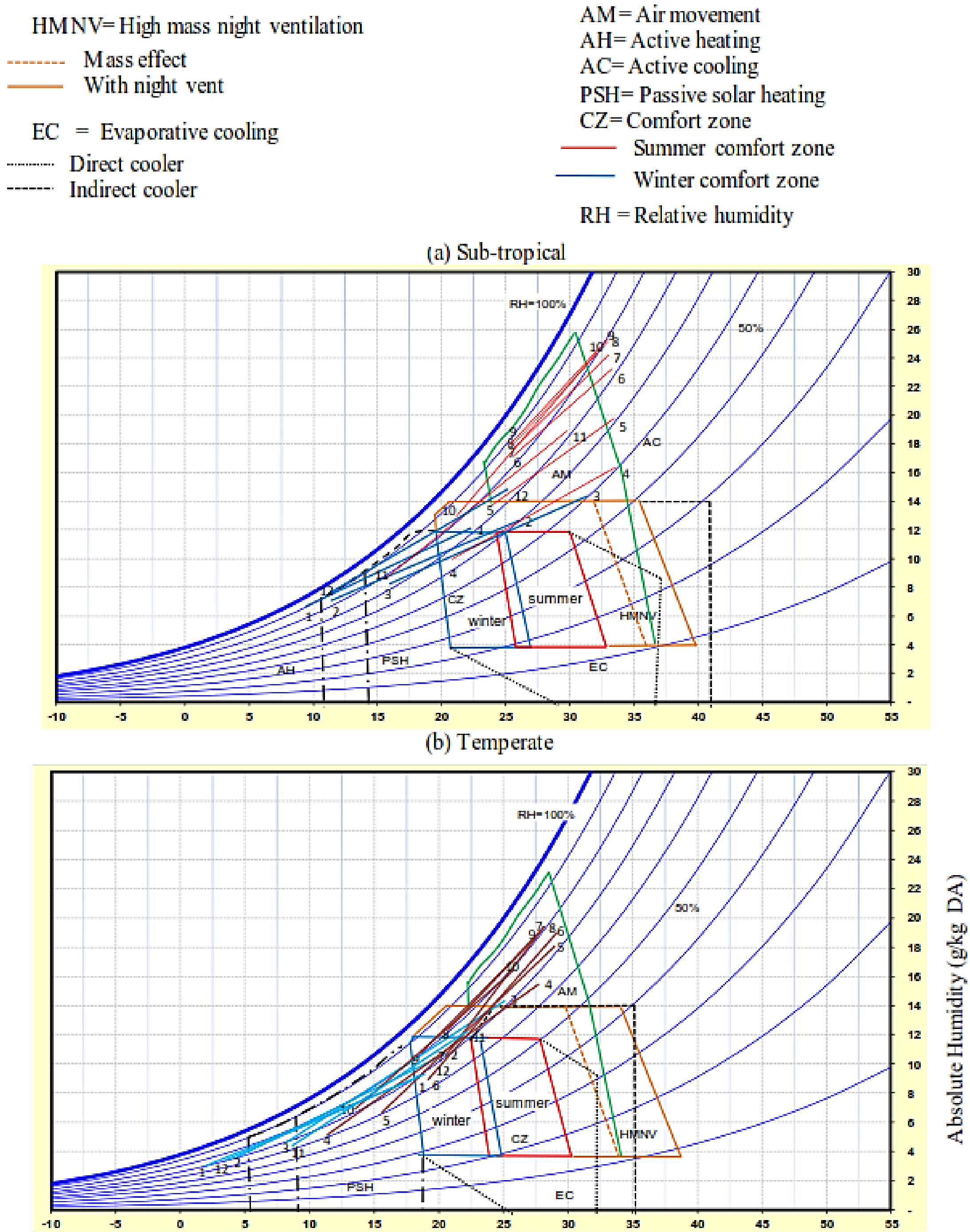


Figure 2.5: Bioclimatic chart for sub-tropical & warm temperate Climate

(Lamsal et al., 2021)

the room at a constant temperature because passive cooling methods are unable to meet the cooling requirement. In the high mass night ventilation zone, November to April is a brief period (Lamsal et al., 2021).

In Nepal's mild temperate environment, the wintertime temperature does not significantly decrease. As a result, the thermal mass of the building and solar radiation can work together to maintain a comfortable interior temperature. Buildings should be orientated with the longer façade facing south and have medium-sized openings; this will allow solar penetration of the south façade to provide solar heat gains in winter (when the sun angle is low) and reduce overheating in summer. For the summer, windows need to have shading mechanisms. Active solar heating or conventional heating may be somewhat necessary from December to January. The Mahoney Table suggests using thick internal and exterior walls as well as thin yet well-insulated roofs. Givoni's chart indicates that thermal mass, however, is only advantageous in April and May to balance the internal temperature variation. Air movement is a crucial bioclimatic design concept for Nepal's mild temperate environment during the humid summer months. As a result, single-banked room arrangements or other natural ventilation techniques are advised. Rainfall that is particularly heavy during the monsoon season calls for shelter and effective drainage (Bodach et al., 2014).

2.5 Passive design

Utilizing the sun's energy, local temperature factors, and carefully chosen building materials to directly maintain thermally comfortable conditions inside a built environment is known as passive solar building design (Morrissey et al., 2011). One of the most powerful energy-saving strategies for ensuring comfort in a building is passive design. It truly dates back to ancient times. Openings toward the south were once common in cave shelters in the northern hemisphere so that the sun could heat the interior rock during the day and release that heat into the cave at night (Seriki, 2015). Although the premise hasn't changed, passive design strategies are now more effective thanks to advancements in technology and building materials. A wide variety of strategies are used in passive design to maximize the flow of energy from the surrounding environment into the planning, building, and operation of a building. In order to create the best design of a building that is more climatically responsive and energy efficient, passive design solutions in architecture incorporate the use of nonenergized features. Solar energy is used where it is collected through passive design, not moved there (Seriki, 2015).

This means that in order for natural energy sources to properly fulfill a necessary function inside the building, they must first be strategically located. The interior of a structure will naturally be heated by the sun if it has many windows and receives a lot of sunlight, for instance; this is an example of solar energy being captured and used passively. The process can benefit from a wide range of elements, including the positioning of windows, the building's orientation, as well as the planting of flowers for landscaping. One of the most prevalent applications of passive design is the use of solar-powered landscape lighting. The key to designing a passive design building is to best take advantage of the local climate (Seriki, 2015). In the majority of climates, design that results in the provision of thermal comfort through passive means will lower the need for active control, and assuming equivalent occupational requirements, provides for a net reduction in energy use. (Haase & Amato, 2009). An appropriate passive solar design should take into account important building features such building orientation, plan proportion and shape, facade glazing design, and interference by nearby buildings (Morrissey et al., 2011).

2.6 Passive design principles

The use of passive design concepts has been demonstrated to be quite successful and can help reduce a building's heating and cooling load. In order to achieve energy efficiency and comfort in a building through design, Ahsan (2009) emphasized the existence of principles divided into planning aspects and building envelope.

2.6.1 Planning aspects

Site analysis

Wind flow, shading from nearby structures and trees, and other factors should all be considered when analyzing the construction site. Wind breakers are undesirable in mild temperate and hot tropical climates because they block pleasant breezes. However, the selection of a section of the site without windbreaks is not an option due to the density of housing projects and the growth of developed structures in urban areas. In metropolitan regions, plots typically lack open space or greenery while carefully selected sites and places can be found in rural and urban expansion zones. If possible, choose a location where the building can be oriented in the best way possible to take advantage of wind and shade. The shape of the building and the surrounding landscape can also be planned to manage the direction of natural breezes or to block excessive sunlight. (Özsen & Lee, 2010).

According to Markus and Morris (1980) the placement of buildings within the "leeward shadow" or suction area of other structures can also significantly affect the amount of moving air through the air inlets of naturally ventilated buildings. In order to prevent the "shadow" effect, the distance between the buildings must be at least six times the height of the first obstructing volume.

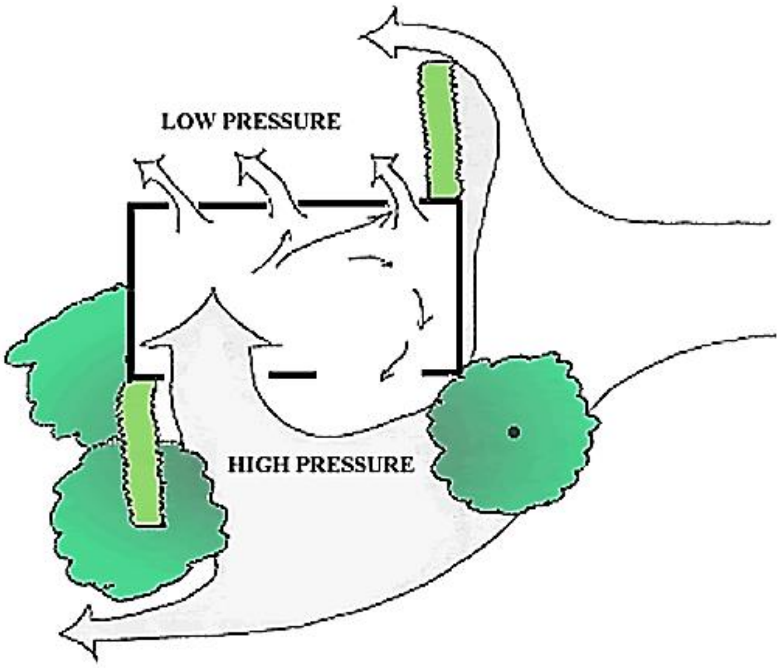


Figure 2.6: Example use of landscape to control flow of breezes into a building

Source: (Özsen & Lee, 2010)

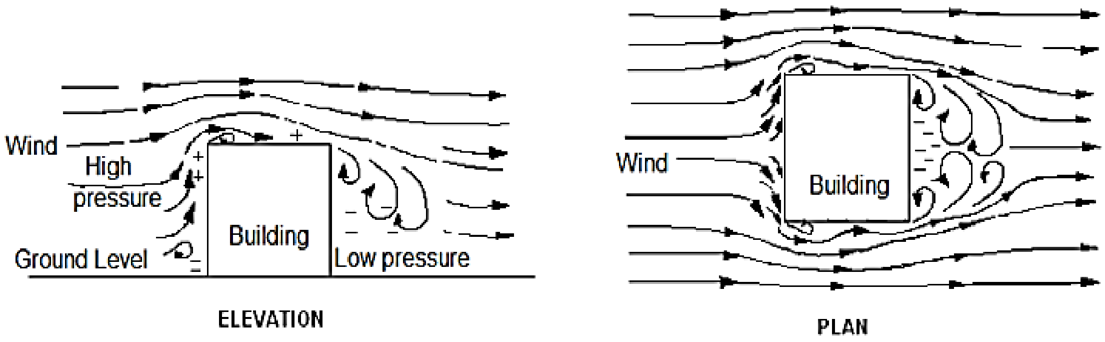


Figure 2.7: Airflow around a building

Source: (Bhatia, 2015)

Building form

The exposed surfaces play a major role in the heat exchange between the building and the outside environment. A small building loses less heat at night and gains less heat during the day. Consequently, a crucial consideration is the surface to volume ratio (Gut & Ackerknecht, 1993). Whether a building is meant to be mechanically air-conditioned or to rely primarily on natural ventilation will have a significant impact on the building's form. The building's compactness reduces the surface area of the building envelope, which lowers the amount of heat gain through the envelope (Givoni, 1998).

Orientation

The azimuth angle of a building surface in relation to true North is referred to as orientation. Regarding architectural design, a building's orientation can have a big impact on how well it can take advantage of prevailing breezes and how much solar radiation it receives. The amount of solar radiation varies depending on orientation (Özsen & Lee, 2010). The most fundamental and typically most straightforward parameter of passive solar design is optimal orientation (Morrissey et al., 2011). As a result, it is a crucial first step in the implementation of sound passive design techniques. The best orientation for passive cooling techniques keeps out undesired sun and hot winds while still ensuring access to cooler breezes.

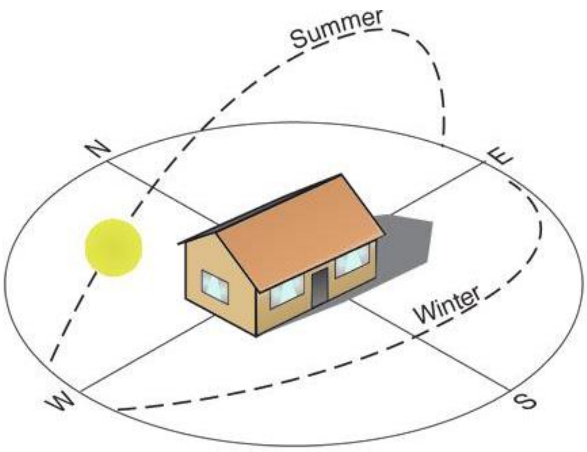


Figure 2.9: Building orientation East-West direction

Source: (Markus & Morris, 1980)

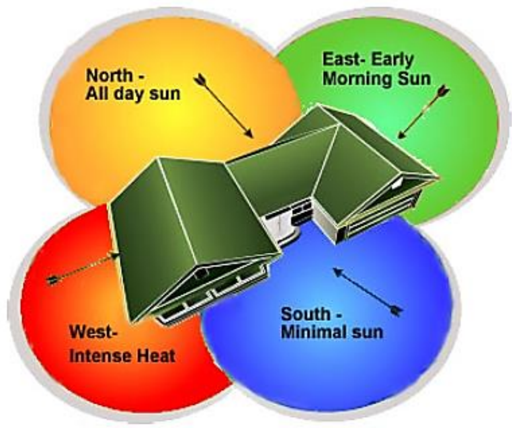


Figure 2.8: Solar radiation in different orientations

Source: (Özsen & Lee, 2010)

The strongest solar radiation occurs in the summer, when the sun is at a very high height. As a result, it is significantly simpler to properly implement passive design principles when the building's longest facade faces north. Utilizing covering overhangs to block the high angle light makes it easier to shade windows on façades that face north. But in the morning and afternoon, direct sunlight strikes the East and West facing facades (Özsen & Lee, 2010).

Landscaping, vegetation and greenery

The proper placement of trees, the use of vegetation for streetscapes, the management of water bodies and the application of the cooling impact of water are all examples of natural features in landscape design. Despite being one of the simplest and most effective ways to increase year-round comfort and energy efficiency, landscaping is the most neglected element of design. Using trees and bushes properly is one of the best ways to change the climate on a bigger scale. They are the most straightforward method of shading outdoor areas and a building's exterior, including the envelope. By draining moisture and providing shade, plants act as natural air conditioners and chill the environment (Koch-Nielsen, 2013). Almost the entire year, shade and freshness are provided through the utilization of vegetation. Buildings in hot areas can be protected from the sun's rays by having vegetative screens around them. Planting trees close to the building can reduce energy use, reduce noise and pollution, change air temperature and relative humidity, and assist people psychologically. According to a study on effective tree planting for energy savings, planting the right trees can cut a home's cooling demands by 10% to 40% (Raeissi & Taheri, 1999).

2.6.2 Building envelope

The building's exterior envelope divides the interior space from the surrounding environment, which modifies or eliminates the direct impact of climatic factors such as outdoor air temperature, humidity, wind, sun radiation, rain, etc. Although translucent materials are occasionally employed in various building parts, these envelopes are often made of two sorts of materials: opaque and transparent (Givoni, 1969). Buildings' surfaces, including the roof, walls, windows, and floor, are where heat enters and exits. The way internal walls, doors, and rooms are arranged has an impact on how heat is distributed inside a building. The term "building envelope" is frequently used to describe these building components. In order to achieve the greatest level of comfort and energy efficiency, envelope design integrates the building form and materials as a whole system. A good envelope design adapts to site and climate variables to improve a building's thermal performance. It can lessen running expenses, enhance indoor lifestyle and comfort, and lessen adverse environmental effects (Akande, 2010). The primary objective of building design in tropical areas is to reduce direct solar heat acquisition via radiation through openings and reduce internal surface temperature; as a result, openings and walls should be protected.

External wall

Interior and external walls can serve a variety of purposes. In addition to acting as a structural component and a means of space separation and partition, walls protect against heat, moisture, wind, dust, and light. As a result, the choice of wall materials should take into account the primary purposes of a wall. According to Gut and

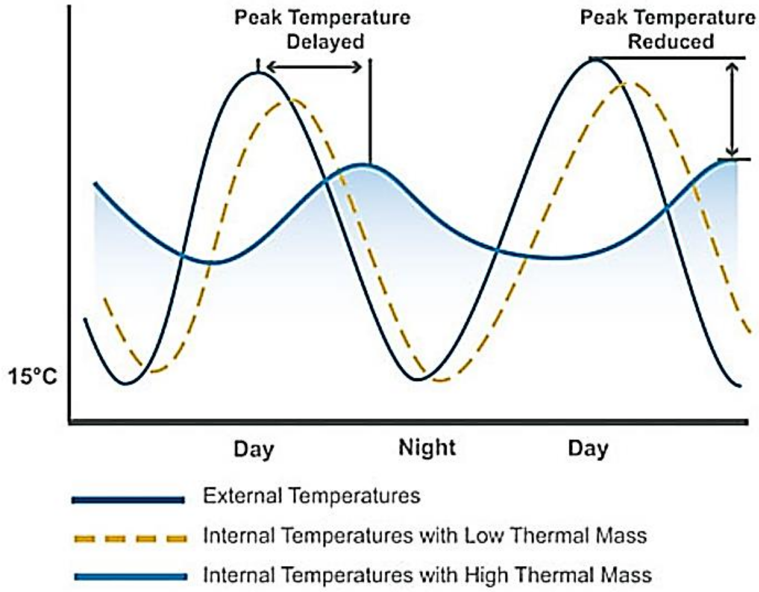


Figure 2.10: How thermal mass can moderate temperature fluctuations

Source: (Özsen & Lee, 2010)

Ackerknecht (1993) in hot, arid regions, the ideal building materials are those that are paired with few openings, a light exterior color, and heat emission at night to maximize the benefits of time lag. By making the roof overhangs far longer than the line of walls, the exterior walls can be protected. It is possible to save 12% on the annual cooling energy needed by reducing sun absorption by 30%. According to the study, external wall finishes in white or light colors can reduce cooling energy use by 12% (Cheung et al., 2005).

The term "thermal mass" is used in building design to explain how the "mass" of a building can be used to reduce internal temperatures and delay the entry of heat into a structure. When thermal mass is used properly, a building's comfort level and cooling costs can both be increased (Lamsal, 2016).

Thermal insulation

According to Gut and Ackerknecht (1993) because it minimizes heat movement to and from the buildings, thermal insulation is one of the most effective energy-saving strategies for cooling and heating in buildings. There are two aspects to thermal insulation. Insulation decreases the amount of excess heat that enters the building during the day but prevents the building from cooling off at night. They contend that insulation is inappropriate for structures with natural climate control because of its dual nature. The indoor temperature would constantly be quite close to the exterior temperature in the hypothetical scenario of a well-insulated building with no heat storage capacity because the minimum ventilation that is always necessary would bring in air that is at the outdoor temperature. Limited thermal insulation is occasionally still necessary, for instance in roof structures that experience extremely hot days because of solar radiation. If thermal insulation is used in conjunction with heat-storing materials, the heat-storage mass must be within, such as in a substantial shell structure, internal walls, or floor slabs (Gut & Ackerknecht, 1993).

Roof

Because a roof receives more radiant heat than any other vertical surface and has a greater capacity for re-emission than other surfaces, its reflectivity quality is of particular significance. Therefore, choosing a roof should be done with caution. The delay should normally be at least 8 hours if an absorbent roofing material is employed. Reflective surfaces along with thermal insulation or a vented ceiling should be present on lightweight roofs (Gut & Ackerknecht, 1993). Since this area of the structure receives the majority of the solar radiation and is challenging to shade, the roof is a crucial architectural component when it comes to energy conservation. According to Vijaykumar et al. (2007) Indian concrete roofs in one- or two-story buildings with 150 mm of reinforced cement concrete (RCC) thickness and a weathering course (WC) with 75-100 mm thick lime brick mortar account for about 50% to 70% of total heat transmitted into the occupant zone and account for the majority of the electricity bill in air-conditioned buildings. It is important to consider the thermal qualities of the materials being considered when choosing a roof so that the best option can be made given the local climate. The solar heat gain factor is a crucial factor to consider when assessing exposure to solar radiation, particularly in the case of the roof. It matters more than the U-value (Gut & Ackerknecht, 1993).

Opening

When designing and constructing buildings, it is important to take air flow into consideration as one of the key factors affecting the inside environment. The direction of current winds should also be taken into consideration during the design phase, much like the sun's radiation. As far as concerns of natural illumination allow, openings in hot, arid regions should be small or adjustable in size by shutters, and the view shouldn't be aimed at the glare. It is important to examine how the sun's angle varies seasonally (Gut & Ackerknecht, 1993). It is important to make the openings as airtight as possible. Openings in warm, humid climates should be as large as feasible, with views directed toward the nearby plants and roof overhangs or sun breakers blocking the sky. Vegetation shouldn't obstruct the building's air circulation. There is no requirement for an airtight structure. Outlet openings ought to be placed higher up, where hot air tends to collect. Bedroom windows should ideally be positioned at bed height or on pivots to direct airflow toward the sleeping body. Louvers are an appropriate addition to help direct airflow (Gut & Ackerknecht, 1993).

The size and geometry of openings play a key role in controlling the airflow inside structures. An angled wind incident to the inlet can often increase ventilation rate for buildings with openings in opposite walls (Givoni, 1998). If the outlet windows are larger than the intake windows, higher airflow rates are typically achieved as well. However, the opposite is also true if air speed is dispersed more evenly throughout the area when the output is smaller than the input (Givoni, 1998).

Shading device

By obstructing up to 90% of the sun's direct rays, shading can lower summertime temperatures, enhancing comfort and reducing energy use (Özsen & Lee, 2010). Provide shading on the east and west façades in hot regions to lessen solar heat gains, especially in the morning and afternoon. Moving blinds and curtains should be used with caution as they obstruct airflow, which is preferred in hot and humid areas. It is effectively shaded by overhangs and louvers. Porticos may offer comparable shading (Lamsal, 2016). When creating a shade structure next to the sun's path, several things should be taken into account. The shading effect is influenced by the surface's material, treatment, and color in addition to the geometric shape and orientation of the fixtures (Gut & Ackerknecht, 1993). Particularly on south facades, horizontal shade is highly effective against strong midday sun (Faisal & Aldy, 2016). It can take the shape of a slab projection, verandas, permanent or moveable louvers, or a roof overhang. The best protection against low sun is vertical screening, thus east and west facades (Faisal & Aldy, 2016). Movable shading components can be used to achieve maximum efficiency. Shutters and doors for windows and doors can also be used to create a straightforward vertical screening.

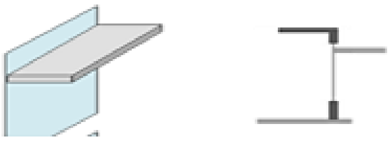
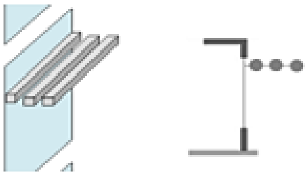
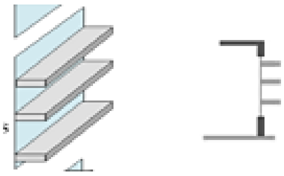
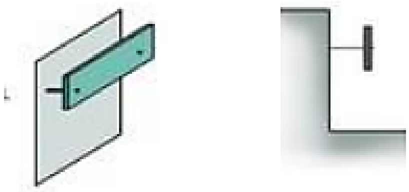
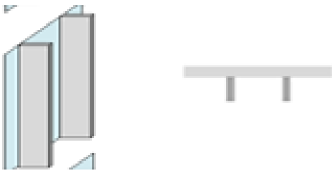
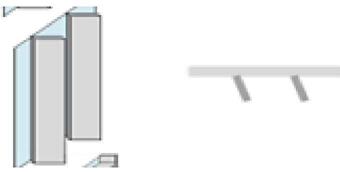
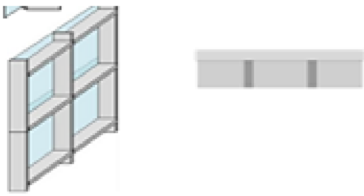
	3D-View	*Best Orientation*
Overhang		south, west, east
Overhang Horizontal Louver s		south, west, east
Overhang Multiple Blades		south, west, east
Overhang Vertical panel		south, west, east
Vertical Fin		west, east, north
Slanted Vertical Fin		west and east
Eggcrate		west and east

Figure 2.11: External Shading Devices

Source: (Faisal & Aldy, 2016)

Natural Ventilation

Movement of air is ventilation. Natural ventilation is a term used to describe a set of guidelines for increasing air circulation in a building without the aid of mechanical devices. When designing and constructing buildings, air flow should be taken into account as it has a significant impact on indoor climate. Existing winds should also be considered in the design concept, much like solar radiation. Differentiating between consistent wind patterns and sporadic winds is crucial for planning purposes. Designing the building must take into account sporadic winds, such as those that occur during storms, to ensure that it is strong enough. The only essential winds for climatic design are regular breezes (Gut & Ackerknecht, 1993).

Wind-effect ventilation or temperature differences are the two main sources of natural ventilation (stack effect ventilation). Warm inside air exits the building through the

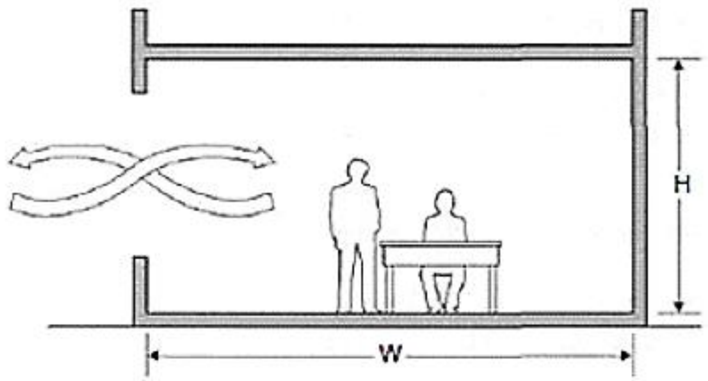


Figure 2.12: Wind effect (pressure driven) ventilation: Single-sided ventilation (wind-driven)
Source: (Özsen & Lee, 2010)

same entrance in single-sided ventilation, which allows cooler outside air to enter. Only specific depths of the room are suitable for single-sided ventilation. As a general rule, a room's maximum depth for single-sided ventilation should be 2.5 times the height from floor to ceiling, with at least 1/20 of the space accessible to the air (Özsen & Lee, 2010).

Cross-ventilation is the natural ventilation of a room or building through windows that can be opened on either side of the room or building. The pressure difference between the side of the building that faces the wind (the windward side) and the side that faces away from the wind causes cross ventilation (leeward side). Air moves through the structure as a result of the positive pressure on the windward side and/or the negative pressure (vacuum effect) on the leeward side. Air enters the building from the windward side and exits from the leeward side (Özsen & Lee, 2010).

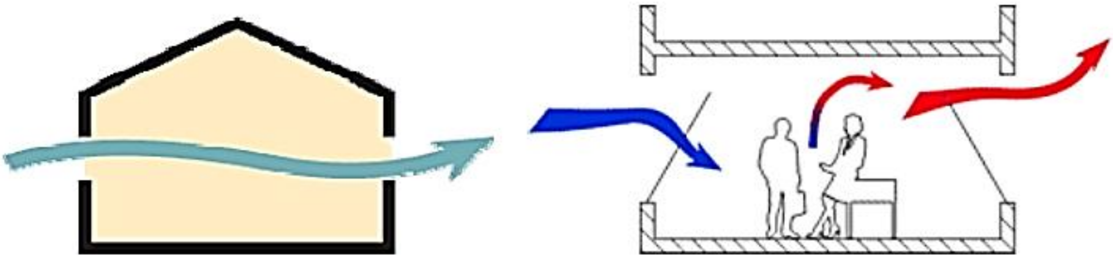


Figure 2.13: Examples of cross ventilation

Source: (Özsen & Lee, 2010).

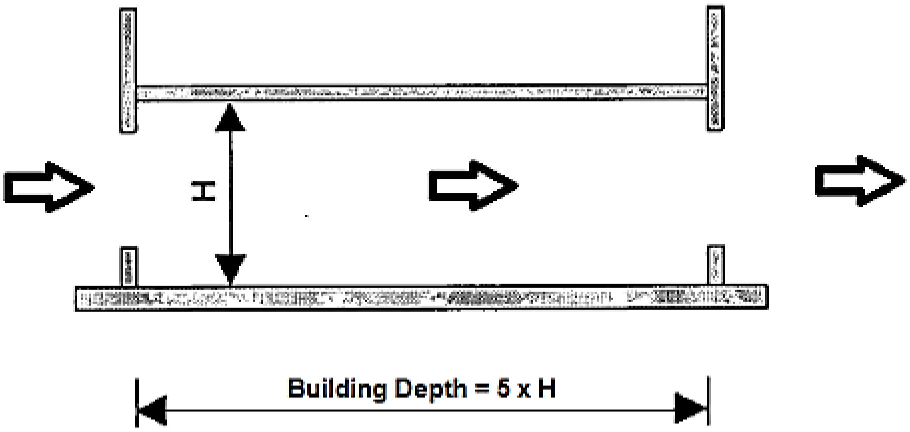


Figure 2.14: For effective cross ventilation

Source: (Bhatia, 2015)

The maximum room depth for efficient cross ventilation, per general guidelines, is five times the height from floor to ceiling (Bhatia, 2015).

2.7 Building materials

The Industrial Revolution and the Modern Movement both saw an increase in the use of new, industrially produced, and standardized materials, which resulted in the homogenization of many construction methods that had previously depended on locally accessible materials. Due to their widespread use, conventional methods and materials started to be abandoned in favor of these modern ones. Modern architecture is based on the use of industrially produced materials with low thermal resistance, especially large glass surfaces. Buildings today are extremely vulnerable to changes in the outside temperature and reliant on air conditioning systems to maintain comfortable indoor conditions, which represents a significant energy consumption (Fernandes et al., 2014).

The way a building is designed, how it is used, and how it is organized all have the potential to make the most of the sun or to provide shade. The materials used to construct the building and the site, however, have the power to alter, improve, or even negate climatic benefits (Cofaigh et al., 1996). Additionally, the way heat interacts with materials affects thermal perception. The exchange of heat with the environment, radiation from which the surface temperature is important, convection, which is influenced by air temperature and air movement, and evaporation, which is controlled by relative humidity and air speed, all play a role in how an individual perceives the thermal environment (Cofaigh et al., 1996).

The usage of materials for traditional architectural building depends on their availability in that specific place. Local materials typically have less environmental impact during maintenance operations because there is no need for transportation, the production process uses less energy, and as a result, there are fewer embodied energies and carbon dioxide emissions. They are also natural materials, frequently organic, renewable, and biodegradable (Fernandes et al., 2014). Some of the building materials which have been in use in traditional buildings are stone, timber, bamboo, grass/thatch, clay, etc.

2.7.1 Stone

For millennia, stone has been a crucial component in building infrastructure and other structures. Some of the most significant monuments and buildings in the world have been built using stone masonry. These structures range from significant cultural and historical structures, frequently constructed by highly skilled stonemasons, to straightforward homes built by their owners in developing nations where stone is a readily available and reasonably priced building material for residential construction (Bothara & Brzev, 2012). Given that they are readily available in the area, stones are employed for masonry construction in hilly and mountainous areas of Nepal. Indo-Nepalese homes also use stone roofing materials like slate. Stone masonry homes are typically constructed by the property owners themselves or by untrained local craftsmen.

2.7.2 Timber

Timber is employed as one of the natural resources that are easily accessible in many regions of Nepal. Both structural and non-structural building components made of wood are employed in construction. Construction of load-bearing walls, frames, etc. uses structural timbers. On the other side, non-structural timbers are typically utilized for non-structural projects like wall cladding, ceilings, and floors. Among its many appealing qualities are its durability, long-lasting ability to tolerate fires, excellent thermal conductivity and expansion, and attractiveness (Agyekum et al., 2020).

2.7.3 Bamboo

Eco-friendly, renewable bamboo is a common building material in most nations. In the tropical and subtropical parts of the world, it is extremely common as a building material. It is extremely adaptable, strong, and light. It is frequently utilized as a building material for walls in the Terai region. Its hollow tubular structure gives it its strength. Due to its growth, harvest, and transportation rates, it has been categorized as a relatively economical building material. Despite the many benefits of its qualities, it is prone to buckling. However, studies demonstrate that this flaw is easily remedied (Agyekum et al., 2020).

2.7.4 Earth

Earth is another significant and long-used vernacular material. It has been considered to include uncemented mineral-grain soils, which are often created by the weathering of rocks with the help of water, organic matter, and other elements. When compared to traditional building materials, earthen materials, when utilized and managed properly, do not cause resource depletion, a rise in pollution, or biological changes. One of the most innovative technologies in the current hunt for housing that is both economically and environmentally sustainable is the use of earthen construction materials (Agyekum et al., 2020). Among other items, earthen building materials include rammed earth, clay soil, and adobe blocks. Clay is primarily utilized in Nepal's hilly regions to build stone walls as mortar and to install flooring.

2.7.5 Thatch

Thatch is a readily available natural material produced from grass in the area that has a high level of insulation. It is constructed from grasses that are chopped from the thatching grass stalk and loosely bound with a thong of twisted thread. Strong winds and sand blowing in from the breeze won't damage it. In Tarai and hilly areas of Nepal, thatch roofs are frequently used. Thatch is utilized in Northern Portugal to combat the country's chilly winters, cut down on heat loss, and benefit from sun radiation (Fernandes et al., 2014).

2.8 Thermo physical properties of building materials

Conduction, convection, radiation, and evaporation are the four methods through which heat can be transferred in a building. Heat may switch modes of transport during the process of heat flow. So, radiation from the sun strikes a wall, is absorbed at the exterior surfaces, and then moves through the materials via conduction. If an air space exists between the external surfaces, heat will move through it by convection and radiation, proceed by conduction, and then transfer to the indoor air and other internal surfaces by convection and radiation (Givoni, 1969). According to Givoni (1969) the following are the characteristics of materials that influence the rate of heat transmission into and out of a structure, and as a result, the thermal conditions inside the building and the comfort of its occupants:-

- Thermal conductivity, resistance and transmittance.
- Surface characteristics with respect to radiation-absorptivity, reflectivity and emissivity.
- Surface convection coefficient of materials
- Heat capacity of materials
- Transparency to radiation of different wavelengths

The ability of a substance to transfer heat over a unit temperature gradient through conduction through a unit thickness of that material determines its thermal conductivity. The thermal conductivity and resistivity reciprocals are unaffected by the size and thickness of the construction materials. The actual heat transfer through a given building component is influenced by the thickness of the component in addition to the material's thermal conductivity. The rate of heat flow will be slower the thicker it is (Givoni, 1969).

Table 2.2: U-value of different materials

Source: (Borgkvist, 2017), (Lamsal, 2016)

Elements of construction	**Material**	**Thickness(m)**	**Heat transfer coefficient ,U-value (W/m².C)**
Wall	Stone	0.4	3.30
Wall	Brick	0.23	1.93
Wall	Rammed earth	0.450	0.37
Roof	Slate	0.015	5.71
Roof	Concrete	0.110	2.87

Elements of construction	Material	Thickness(m)	Heat transfer coefficient ,U-value (W/m².C)
Window	Glass	Single glazed	5
Window	Wood	0.025	2.87
Door	Wood	0.035	2.38

Any opaque material's external surface has three characteristics that affect how it reacts to heat exchange from radiation: emissivity, reflectivity, and absorptivity. A absolutely black surface will completely absorb radiation, while a perfect reflector will completely reflect radiation impinging on it. However, most surfaces only partially absorb input radiation, reflecting the remaining amounts (Givoni, 1969). Many construction materials' solar reflectance and remittance are displayed in the table below.

Table 2.3: Color-reflectivity classification for opaque building materials

Source: (Al-Saadi, 2006)

Color Code	Solar Reflectivity	Solar Absorptivity.
Very Light	0.75	0.25
Light	0.65	0.35
Medium	0.45	0.55
Dark	0.25	0.75
Very Dark	0.10	0.9

Very Light	Smooth building material surfaces covered with a fresh or clean stark white paint or coating
Light	Masonry, textured, rough wood, or gravel roof surfaces covered with a white paint or coating
Medium	Brick, concrete block, or painted surfaces that are off-white, cream, buff, or another light tint, as well as roofs that are covered in white-chip marble

Dark	Walls and roofs with gravel, red tile, stone, or tan to brown shingles, brown, red, or other dark colored brick, concrete block, painted or unfinished wood, and walls.
Very Dark	Painted, coated, or shingled surfaces that are dark brown, dark green, or any extremely dark hue

Depending on their specific heat and density, different materials are heated by the same amount of heat in different ways. A specific heat is the amount of energy needed to raise a unit mass of material's temperature by a unit. More heat will be absorbed by a substance for a given rise in temperature the higher its specific heat is (Gut & Ackerknecht, 1993). Only when temperature conditions are fluctuating do the materials' heat capacity become significant. Heat capacity has little impact on internal thermal conditions when conditions are close to a steady state, such as when there is a significant gap between the indoor and external temperatures (Givoni, 1969).

2.9 Secondary case study

To study the climate responsive design in sub tropic and temperate climate secondary field study cases are taken.

2.9.1 A case of Jhapa

Located in the vast Terai plains, Jhapa is the easternmost district of Nepal. It is part of the Outer Terai. Jhapa shares boundaries with the Indian states of Ilam (north), Morang (west), Bihar (south), and West Bengal (east) as well as the Tibetan province of Ilam. It is situated at latitudes 26o20' to 26o50' north and longitudes 87o39' to 88o12' east, covering a total area of 1,606 km2 (620 sq mi). A subtropical climate prevails in Jhapa (Pokharel et al., 2020).

The types of houses investigated are as follows.

Table 2.4: Investigated houses (Case I: Jhapa)

Source: (Pokharel et al., 2020).

Region	House Code	Floor Area (sq.mt)	Floor Type	Wall Thickness(m)	Material of Wall	Window Area(sq.m)	Ratio of window area to floor area	Ceiling	Roof

Sub-tropical	**B1**	16	Earth floor	0.25	Timber Panels	0.54	0.135	Bamboo	Pitched roof of zinc sheets
	B2	15	Earth floor	0.76	Timber & Bamboo	0.54	0.123	Bamboo	Pitched roof of zinc sheets
	B3	17.5	Earth floor	0.13	Brick & Cement plaster	1.25	0.16	Bamboo & Timber	Pitched roof of zinc sheets

Wood panels with tiny vertical spaces between them make up the walls of the B1 home. Bamboo strips were loosely interlaced to create the B2 home, which had thin cement plaster on both sides. The B3 home's wall was constructed of cement-plastered bricks. B3 had 1.25 m2, but B1 and B2 only have 0.54 m2 opening ratio.

Figure 2.15: Investigated house B3 (Sub-tropical climate)
(Pokharel et al., 2020)

During the measurement period of measurement, outdoor air temperature in subtropical region ranges from 5.5-21.5°C with an average 11.7°C. The average measured indoor air temperature was 12.8°C and lowest value of indoor air temperature is 5.9°C (Pokharel et al., 2020).

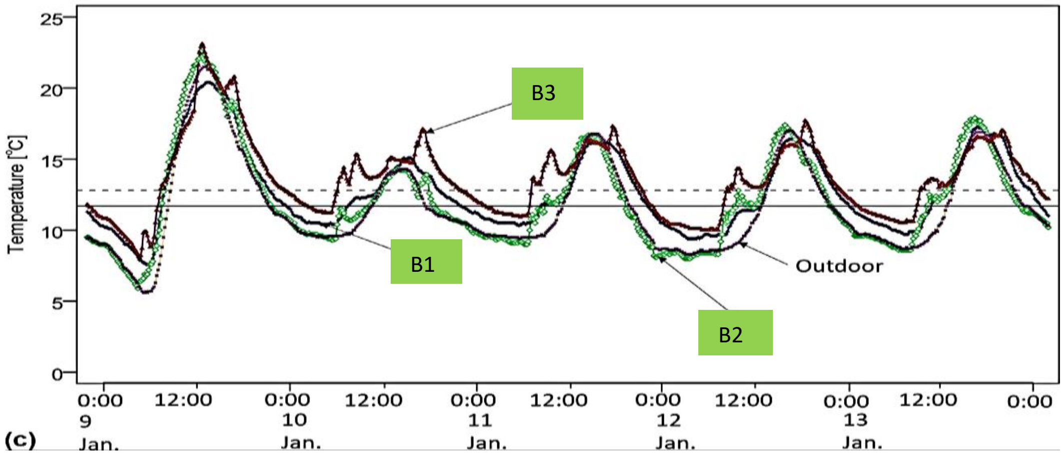


Figure 2.16: Indoor and outdoor temperature variation

(Pokharel et al., 2020)

During the experiment, it was discovered that, due to the ventilation effect, indoor air temperature variations in buildings in subtropical regions are relatively close to those of outside air temperature. In the winter, B3 had the greatest indoor air temperature compared to B1 and B2. B3's brick walls covered in cement plaster, a thermally dense material, are to responsible for the greater indoor air temperature than B1 and B2 (Pokharel et al., 2020).

2.9.2 A case of Dang-Deukheri

At a height of 300–2000 meters, Dang's climate ranges from lower tropical to subtropical. The parallel inner Terai valley surrounds ranges of hills and mountains in the area's geography. Summertime temperatures average 31.57°C during the day and 23.86°C at night, while wintertime temperatures average 21.33°C during the day and 8.35°C at night (Tharu et al., 2019).

The research has been carried out to assess the thermal performance of Tharu house of Terai region of Nepal taking Gobardiya village of Dang-Deukhuri district as a case area. The research has limitation that the thermal performance of only two seasons i.e. summer and winter is incorporated (Tharu et al., 2019).

The types of houses investigated are as follows.

Table 2.5: Investigated houses (Case II: Dang)

Source: (Tharu et al., 2019)

S. N.	Typology	Orientation	Wall	Roof	Construction	Opening
1.	Traditional	North-South	Mud	Thatch(Slope)	Load bearing	6%
2.	Traditional CGI	North-South	Mud	Thatch to CGI	Load bearing	8%
3.	Modern	North-South	modern frame structure building with brick wall	RCC roof(Flat)	Frame structure	20%
4.	Modern-mixed	East-West	storied load bearing	CGI roof in half portion and laminated false ceiling in another half.	Load bearing	16%

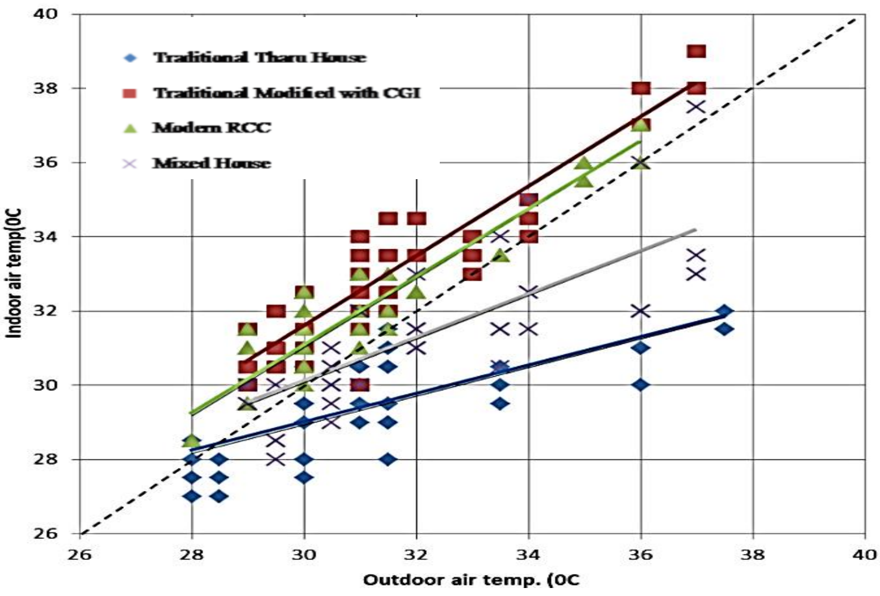


Figure 2.17: Regression analysis of indoor and outdoor air temperature of four different houses in summer

Source:- (Tharu et al., 2019)

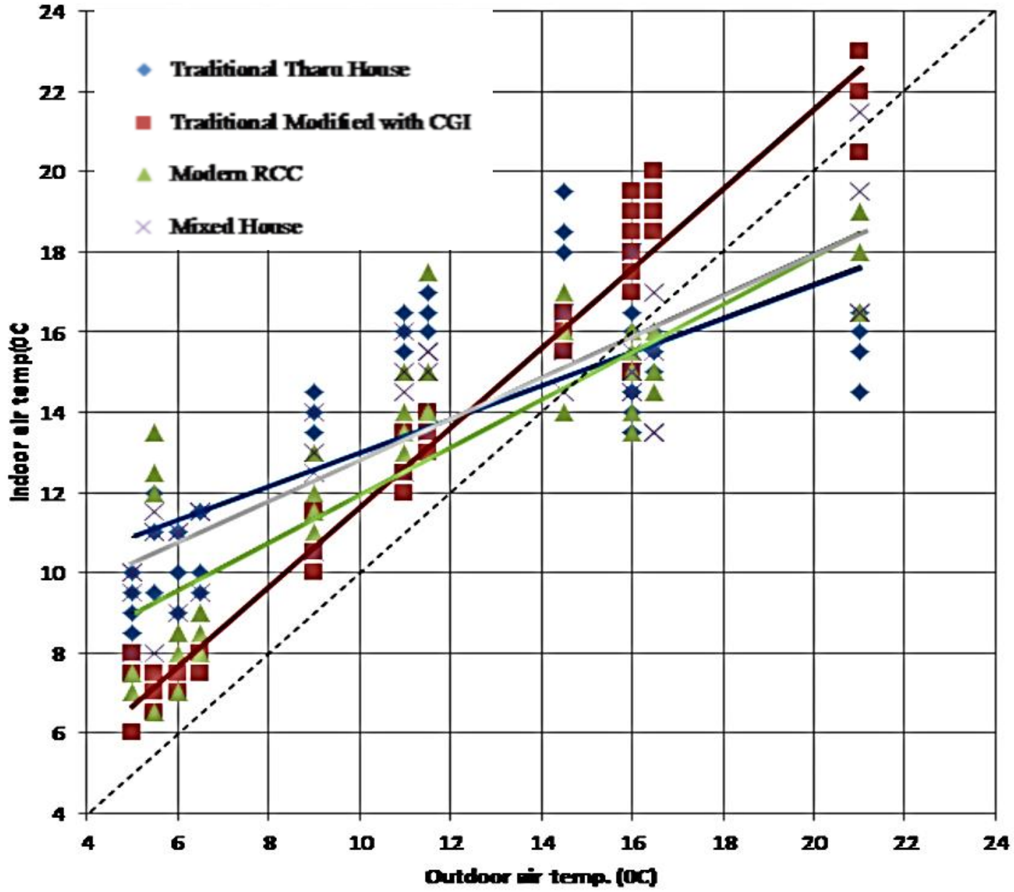


Figure 2.18: Regression analysis of indoor and outdoor air temperature of four different houses in winter

Source:- (Tharu et al., 2019)

House 1 was Traditional Tharu house with single storied with mud wall and thatch roof. House 2 was Traditional but modified (Thatch to CGI) Traditional Tharu house with CGI roof. House 3 was Modern RCC house with single storied modern frame structure building with brick wall and RCC roof. House 4 was mixed house with single storied load bearing with CGI roof in half portion and laminated false ceiling in another half. The investigation was based on the indicators like measurement of air temperature, orientation of houses, size of openings and materials used in the house. On the basis of these parameters the findings has been formulated. The air temperature was taken 3 times a day for four consecutive days in both summer and winter. The findings was, Tharu house maintain 3.5°C less temperature as compare to other houses in summer and 2.13 °C more temperature as compare to other houses in winter (Tharu et al., 2019).

2.9.3 A case of Panchthar

The Panchthar district is one of the 14 districts that make up Province No. 1 in Nepal's eastern hilly area. Eastern Nepal's hilly region contains it. 1,241 km2 (479 sq mi) is the total area of the district. There were 191,817 people surveyed in 2011. District headquarters is in Phidim. Because of its elevation above sea level, which ranges from 300 to 5000 meters, the district has subtropical, temperate, and alpine climates. Pokharel et al. (2020) Studied house of temperate climate within the district.

The types of houses investigated are as follows.

Table 2.6: Investigated houses (Case III: Panchthar)

Source: (Pokharel et al., 2020).

Region	House Code	Floor Area (sq.mt)	Floor Type	Wall Thickness(m)	Material of Wall	Window Area(sq.m)	Ratio of window area to floor area	Ceiling	Roof
Temperate	**T1**	17.9	Earth floor	0.456	Stone & mud with mud plaster	0.13	0.014	Timber & mud	Pitched roof of zinc sheets
	T2	18.5	Earth floor	0.456	Stone & mud with mud plaster	None	-	Timber & mud	Pitched roof of zinc sheets
	T3	18	Earth floor	0.456	Stone & mud with mud plaster	none	-	Timber & mud	Pitched roof of zinc sheets

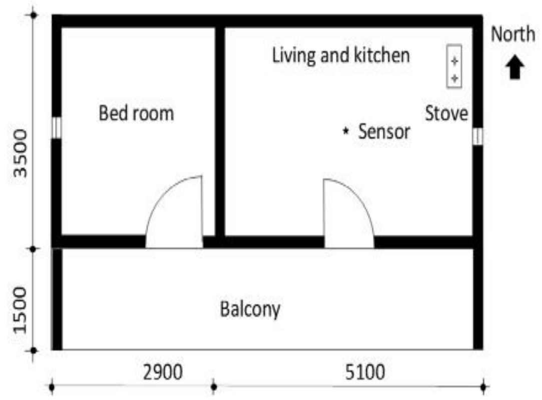


Figure 2.19: Investigated House B3 (Temperate climate)

Source:- (Pokharel et al., 2020)

The dwellings in temperate regions also had stone and mud walls that were plastered with mud. The T1 home had two tiny 0.13 m2 windows in the shorter facade. The T2 home featured one tiny 0.25-meter-diameter smoke vent located above the cook stove, however the doors were not airtight. The only opening in the T3 home was the door. Two elderly residents of T3 residence constantly maintained a fire in the stove to boil water.

Outdoor air temperatures in the temperate zone varied from 4.1 to 22.1 °C with an average of 10.5°C, over the measurement period. The lowest observed interior air temperature in temperate zones was 6.5°C, while the average measured indoor air temperature was 13.9°C. In three residences in a temperate zone, T3 displays the greatest interior air temperature, T1 the middle, and T2 the lowest. The T2 house may have the lowest indoor air temperature since it has a bigger floor area than the other two houses and has air-leaking window and door frames. T3 was a tiny, tight area with no windows or other openings save from a few holes in the ceiling; this home is likely to have the highest internal air temperature. The usage of firewood throughout the day, as described in the preceding section, must be the main reason for the high interior air temperature in T3, especially at night. It is logical to assume that the two elderly residents of T3 maintain a fire going in the stove all day since the researcher observed that they regularly drank hot tea there. T1 had a medium-sized floor space and only one small-sized hole for a smoke vent. People living in T1 were observed keeping the door closed; for this reason, the indoor air

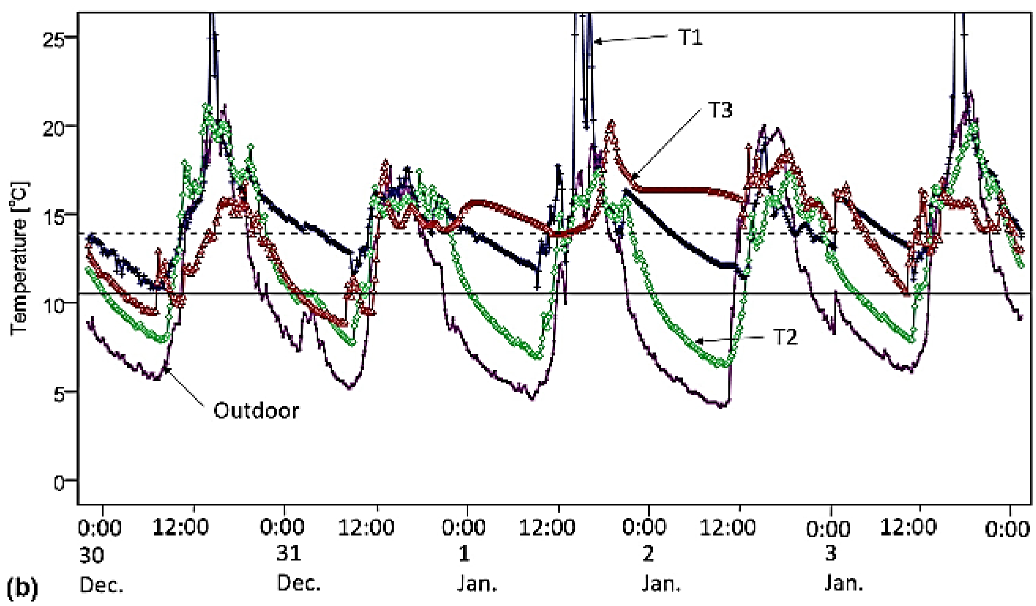


Figure 2.20: Indoor and outdoor temperature variation

Source:- (Pokharel et al., 2020)

temperature must have not dropped down to the values of outdoor air temperature (Pokharel et al., 2020).

2.10 Finding from articles climate responsive design and thermal performances

In order to justify rationale and research objective, various national and international journal articles and books related to climate responsive design and thermal performance of building have been studied. Some of the main articles and books that has been studied has been summarized in table below.

Table 2.7: Summary from literature reviews

S.N.	Title	Author/Published date	Key Findings
1.	Thermal Improvements of the Traditional Houses in Nepal for the Sustainable Building Design	Rijal (2012)	Closing doors, windows, and other openings to make the structure airtight, as well as insulating the roof with local materials and technology, are also very efficient methods for increasing the building's thermal efficiency.
2.	Winter Thermal Improvement of a Traditional House in Nepal	Rijal and Yoshida (2005)	Closing doors, windows, and other openings to make the structure airtight, as well as insulating the roof with local materials and technology, are also very efficient methods for increasing the building's thermal efficiency.
3.	The Thermal Performance of Residential Buildings in Kathmandu Valley	Bajracharya (2014)	Traditional structures were 1-2°C hotter in the winter and cooler in the summer than modern structures, which

S.N.	Title	Author/Published date	Key Findings
			reduced cooling and heating energy consumption by 10–20% in Kathmandu.
4.	Climate Responsive Building Design Strategies of Vernacular Architecture in Nepal	Bodach et al. (2014)	According to bioclimatic study, recommendations for warm temperate climate zones include medium-sized windows with shade in summer, high thermal mass, increased air flow, protection from the cold and rain, solar passive heating in winter, and protection from the sun during the rainy season. Passive design strategies are fully or partially applied in the studied vernacular houses.
5.	Guidelines for Climate Responsive Building Design in Three Regions of Nepal	Lamsal et al. (2021)	Using a bioclimatic chart, Mahoney tables, and considerations of traditional architecture, broad climatic design standards for three distinct climatic zones were produced in this study. In temperate climatic region (Lalitpur), passive heating strategies are recommended for most of the months to incorporate in the design.

S.N.	Title	Author/Published date	Key Findings
			Vernacular architecture were climate responsive and fallow design strategies recommended by Mahoney table and bioclimatic chart.
6.	Man, Climate and Architecture	Givoni (1969)	Solar radiation, long-wave radiation to the sky, air temperature, humidity, wind, and precipitation are the main climatic factors to take into account when designing buildings for human comfort. The rate of heat movement into and out of the building is influenced by the thermo-physical characteristics of the materials. Water content decreases the heat resistance of the outside walls, which lowers interior surface temperatures and promotes condensation.
7.	Thermal Performance of Bedrooms in a Multi-storey Residential Building in Southern Brazil	Ghisi and Massignani (2007)	In the study, many parameters are examined using multiple variables, including surface color, window shadow, and the thermal characteristics of walls and windows.

S.N.	Title	Author/Published date	Key Findings
			According to the research, to enhance the internal thermal environment in the summer, heating transmittance and building exterior area have the biggest impact on the maximum temperature. In contrast, during the winter, heat capacity and thermal time lag have the largest link with the minimum temperature, thus they should be increased to enhance the comfort of the thermal environment.
8.	Passive Houses for Different Climate Zones	Schnieders et al. (2015)	The design methods of passive housing, such as envelope design, air tightness, cooling coil operation, heat recovery equipment, and supply of air temperature, were analyzed and compared using typical analysis models. To provide the appropriate design criteria for passive structures, houses from various cities throughout the world were designed. The design and construction of a passive home are

S.N.	Title	Author/Published date	Key Findings
			influenced by the local climate, the building's form and orientation, the amount of shade, and other factors.
9.	Design and Realization of The Passive House Concept in Different Climate Zones	Schnieders et al. (2020)	In milder climates, modest insulation is adequate, together with better window quality, but summer building performance need further considerations. Buildings that used passive cooling solutions did well because they allow for reduced summertime exterior heat loads. The summer comfort seems to be superior in the highly insulated structures than the typical ones.
10.	An Investigation on Climate Responsive Design Strategies of Vernacular Housing in Vietnam	Nguyen et al. (2011)	In Vietnam, vernacular housing has adapted fairly well to climatic conditions in different locations by using low energy design principles, however not all vernacular buildings have perfect building physics. The most often used solutions were sun shading, natural ventilation, building

S.N.	Title	Author/Published date	Key Findings
			orientation, and building design. Earth cooling and large thermal mass were unsuitable. To increase natural lighting and airflow, the placement and arrangement of the openings should be changed.

CHAPTER 3. METHODOLOGY

3.1 Research methodology

A subset of social science research known as qualitative research gathers and analyzes non-numerical data with the goal of interpreting the meaning in order to better understand social life by focusing on specific groups or locations. The research process entails developing questions and techniques, data collection that typically takes place in the participant's environment, inductive data analysis that builds from specifics to broad themes, and the researcher's evaluation of the significance of the findings. By analyzing the relationship between variables, quantitative research can be used to test objective theories. For the purpose of employing statistical techniques to examine numeric data, these variables can be quantified, often using instruments. Analyzing the climate-responsive structures in the research region is the goal of the study. The study's climatic conditions and the building's performance in that climate are relevant to the study's nature. In order to accomplish the research's goal, a mixed method strategy has been chosen. Research using mixed methods incorporates or links both qualitative and quantitative forms of data. In order to make a study's overall strength better than either qualitative or quantitative research, it therefore takes more than just gathering and analyzing both types of data. It also involves using both methodologies (Creswell, 2009).

3.2 Conceptual framework

The tactics, procedures, or techniques used in the gathering of data or evidence for analysis in order to unearth new knowledge or develop a better grasp of a topic are known as research methods. The study of climate responsive architecture was based on a mixed method approach using concurrent procedure. According to Creswell (2009), there are three strategies in a mixed method approach i.e. sequential procedure, concurrent procedure and transformative procedure. Using a concurrent process, one can provide a thorough examination of the study problem by combining quantitative and qualitative data. This approach simultaneously collects both quantitative and qualitative data during the course of the investigation, and then incorporates the information to interpret the overall finding.

When the distinctions between phenomena and context are hazy or unclear, the case study technique can be thought of as an empirical investigation that explores a current phenomenon within its actual environment. It's a method that relies on observing phenomena in their natural environments, especially when the boundaries between the phenomenon and its surroundings are not immediately obvious. (Yin, 2009). Case studies can be seen as a method that has been specifically chosen to address certain contextual conditions, such as the phenomenon's complex relationships with its context or the existence of many more interesting variables than data points. The case study approach is primarily a method that enables researchers to preserve the comprehensive and significant aspects of actual events when studying a particular phenomenon. Such a comprehensive approach is necessary to observe the theoretical framework within the context of a design process in order to prevent the decrease of potential correlations between the numerous variables included in the scenarios under study. (De Souza, 2019).

The study were conducted in stages until the conclusion of the overall research were completed. The initial stage involved the literature review. For the literature, this research analyze articles, which were related to climate responsive vernacular materials, construction techniques, climate responsive design strategies and building features. First part of literature review is about climate analysis, which outlined some features and classifications of climate in Nepal. Second part of literature is about building design strategies and features on those climatic region. Vernacular architecture, passive design strategies, climate responsive design strategies and properties of different building materials were studied as a part of literature.

The further step involve the of collection primary and secondary data. The climate data of 10 years was collected from the Department of Hydrology and Meteorology of the nearest station from the study area. The data collected included air temperature, relative humidity and rain fall. Bioclimatic chart and Mahoney table were developed from the collected climatic data. The primary data were collected through measurement and observation of the selected residential building. In next stage case studies were selected as an approach to analyze the climate responsiveness in the selected building. In this stage climate responsiveness of the selected building were analyzed and examined with the reference to the collected data and literature review. This research selected the various building features to assess the residential houses of study area in a qualitative and qualitative manner like settlement pattern, building form and orientation, building stories and internal space arrangement, design and construction materials of walls, roof, floors, ceilings and openings. In the last stage conclusion and recommendation were drawn base on the analysis and finding from literature and the collected data. Also the design guidelines for climate responsive buildings is proposed from this study.

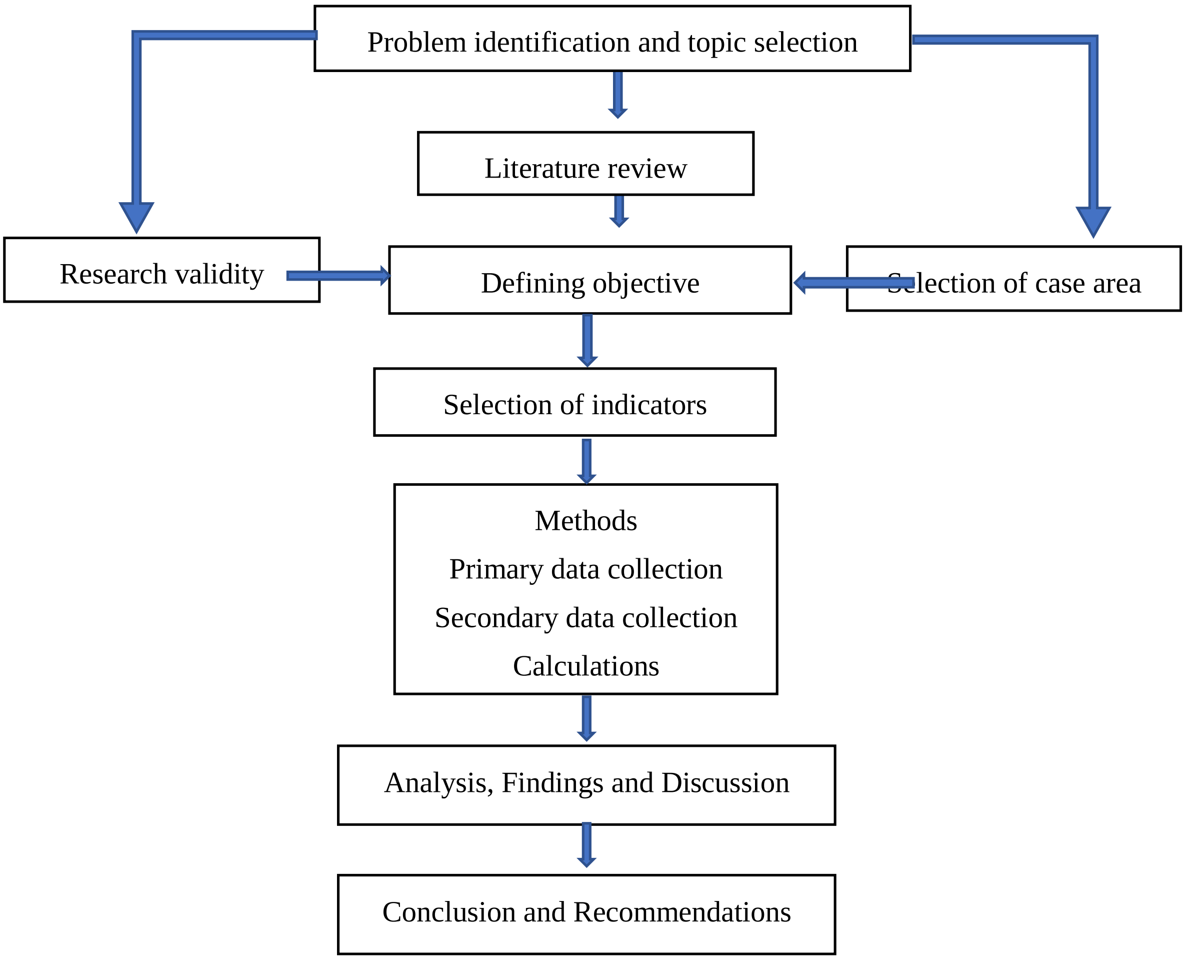


Figure 3.1: Conceptual framework

3.3 Selection of case area

In order to fulfil the defined objective, the study area has be chosen in such a place where there is ample numbers of traditional as well as modern residential buildings for investigation of climate responsiveness of buildings. For the study Neelakantha municipality which lies in Dhading district has been choosen. The study area is in Pipley, ward number 7 of Neelkantha municipality where most of the people are of Brahman. Most of the building within the study area used to be of timber and mud mortar- stone buildings before 2015 earthquake. But after earthquake the trend of cement mortar-brick and RCC type of building construction is rapid.

Figure 3.2: Study area

Source: Google earth (2020)

3.4 Selection of research indicator

Based on the literature review, there are various indicator to access the climate responsiveness of buildings. The indicators include design variable in planning and envelope design. For example in planning phase site analysis, building form, orientation and landscaping has to be assessed where as in building envelope design external wall, thermal insulation, roof, openings, shading devices and ventilations has to be studied. The climatic factor lie solar radiation, humidity, rainfall, air temperature etc., also affect the performance of building. In order to fulfil the objective the indicators mentioned above are studied.

3.5 Measurement of air temperature

The measurement of air temperature and humidity has been recorded to access the climate responsiveness of residential building in Dhading. For the comparison both traditional and modern houses were taken for study. In total five traditional and four modern buildings were selected for the study. The study was conducted from May 5 to June 23, which is hottest month throughout the year. Three different time readings were taken i.e. morning, day and evening time. For temperature recording digital thermometer were used which also show the humidity level. The thermometer was place at 5ft. height from floor level.

The thermometer was placed in such a place that it was not directly in front of window or any kind of openings inside the room. Also it was not placed any heat emitting source like fireplace, electronic gadget like television, refrigerator, heater, fans etc.

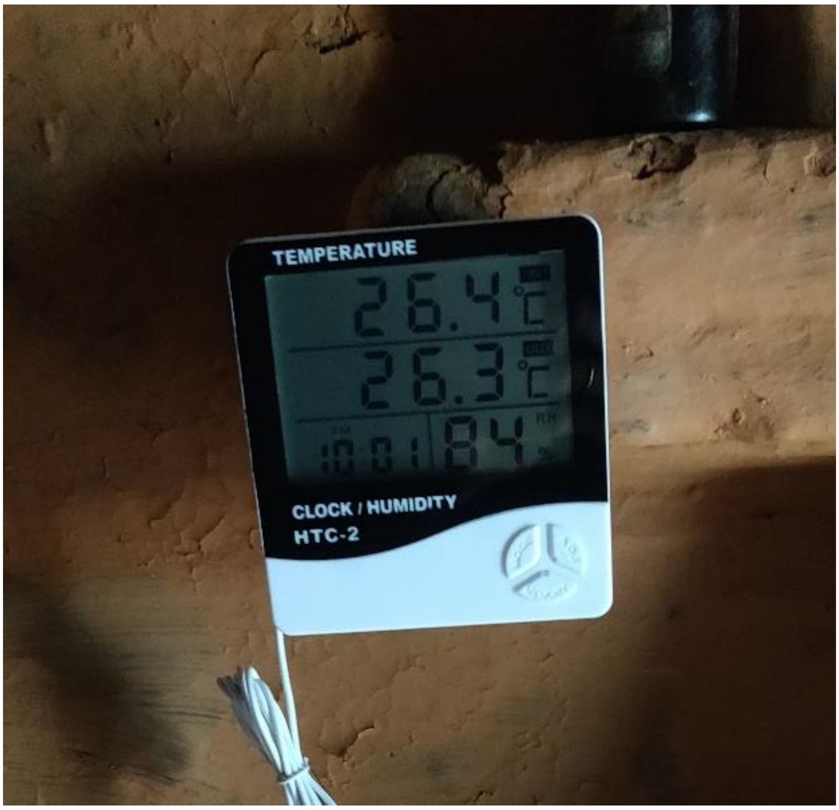


Figure 3.3: Air temperature and humidity measurement

HTC-2 digital temperature and humidity measurement device

3.6 Data collection

To answer specified research questions, test hypotheses, and assess results, data collecting is the act of acquiring and analyzing information on variables of interest in an organized, methodical manner. (Kabir, 2014). Two types of data were collected during the study i.e. primary data and secondary data.

3.6.1 Primary data collection

The primary data collection included the measurement of air temperature which was carried out in the field using digital thermometer. The selected indicator which was identified from literature like settlement pattern, orientation, openings, material used etc were studied. Also to calculate floor-opening ratio, measurement of the studied houses were carried out and plan, section were drawn using AUTOCAD software.

3.6.2 Secondary data collection

The secondary data collection mainly include the literature review through relevant documents, articles, books, reports etc to fulfil the desired objective. Since the objective is related to climate and its elements, climatic data of ten years of nearest metrological station was collected from Department of Hydrology and Metrology. The climatic data included monthly minimum and maximum temperature, monthly rainfall and humidity of the location. These data are used to develop Mahoney Table and biometric chart for the study area.

CHAPTER 4. CASE STUDY AND DATA PRESENTATION

4.1 Study Area

Neelakantha municipality in Nepal's Dhading district, which spans from the Himalaya in the north to the Mahabharat range in the south, serves as the research area. On May 8, 2014, the Nepalese government decided to create this municipality by merging together four former village development committees: Neelakantha, Sankosh, Muralibhanjyang, and Sunaulabazar. It was later reorganized in 2017 by adding three additional village development committees, Jyamrung, Khalte, and Dhuwakot, to create the current municipality. The former village development committee is responsible for the name "Neelakantha." Neelakantha is the result of combining the terms "Neela" (Blue) and "Kantha" (Throat). According to Hindu legend, Lord Shiva (Mahadev) swallowed all the poison created during the Great War and saved the world. Hindu mythology holds that Lord Shiva (Mahadev) turned blue in the throat after consuming

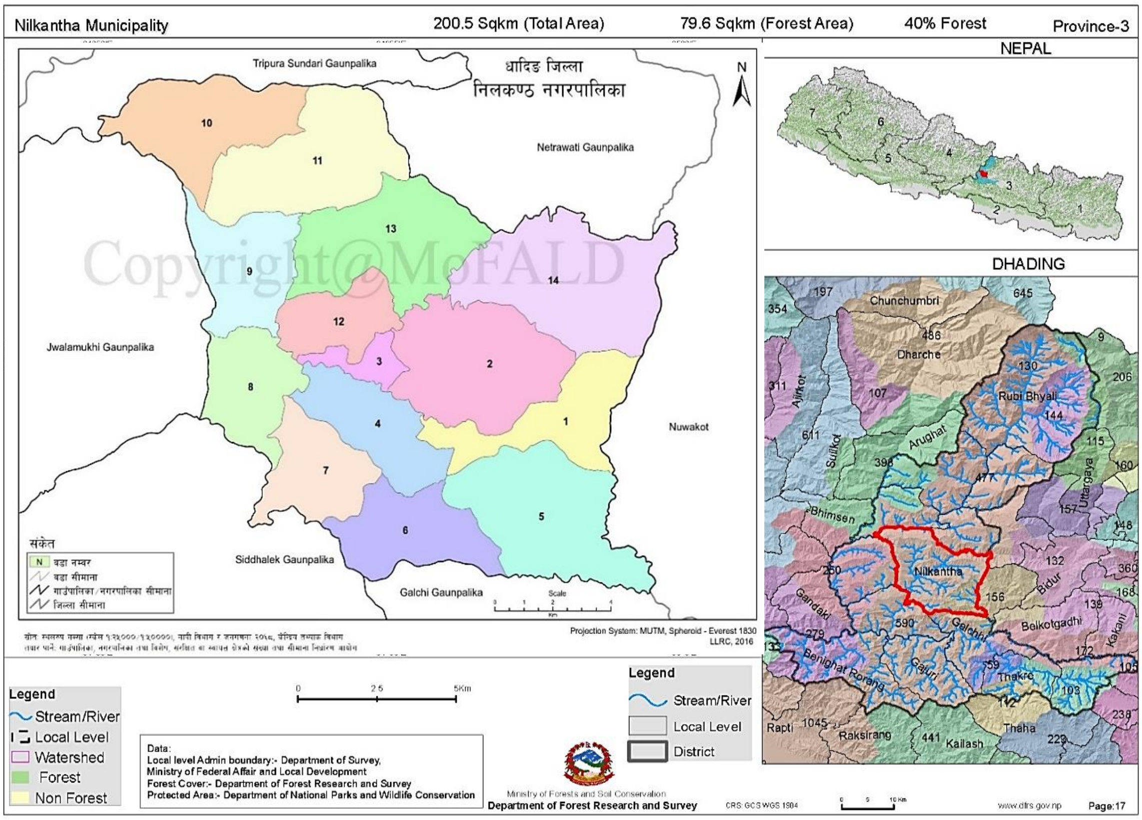


Figure 4.1: Location map of study area

Source:- https://sthaniya.gov.np/gis/

all the poison created during the sea churning procedure in order to preserve the planet. Thus, Lord Shiva is the inspiration for the name "Neelakantha." (Municipality, 2019).

The municipality is 16 kilometers from Malekhu, a location on the Prithvi Highway, and 90 kilometers west of Kathmandu. The municipality is bordered to the east by the Nuwakot district, to the west by the rural municipalities of Jwalamukhi and Siddhalekh, to the north by the rural municipalities of Netrawati and Tripurasundari, and to the south by the rural municipalities of Galchhi and Siddhalekh. It takes up 10% of the district's overall space. 99.31 square kilometers, or approximately 50%, of the municipality's total area of 199.85 square kilometers, are covered in forest. The terrain is more terraced and sloping. Neelakantha Municipality is located between longitudes of 84°58'49.98 and 84°56'41.37 east and latitudes of 27°50'45.442 to 27°58'1.27 north (Municipality, 2019). According to the census of 2011, the total population of this municipality is 58,515 and the Annual House Hold Survey 2015-2016 reports this to be 71,131. This municipality holds 17% of total population of the district. Among fourteen wards, ward no 3 is more advanced with infrastructure development and developed as main city of the municipality. It has high rate of population growth that is 3.4 according to the census 2011 and high population density compared to other wards which have negative growth rate (Municipality, 2019).

4.2 Climatic Parameters of Dhading

Ten years (2012-2021) data of temperature, humidity and rain fall was collected from Department of Hydrology and Meteorology. According to last ten years data, the climate is generally warm from March to October during day time. The summer months have a mean maximum outdoor air temperature 31.5 °C during day and maximum at night is about 22.4 °C. The cool season lasts from November to February. The mean

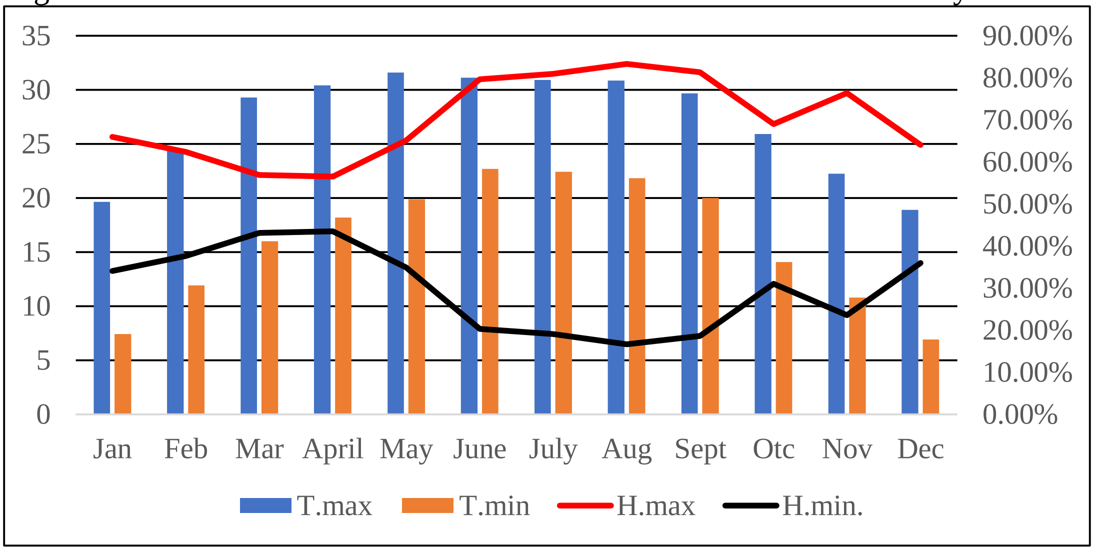


Figure 4.2: Mean temperature and relative humidity of Dhading

Source: Department of Hydrology and Meteorology minimum outdoor temperature is 6.9 °C in winter month of December, with mean high with 18.9 °C in daytime of same month. It has composite climate which changes from season to season, altering between longer hot periods to cool period and concentrated rainfall with moderate humidity. The total rainfall is more than 1451 mm in a year. But mostly rainfall occurs during only monsoon season. The relative humidity is high during monsoon season. The yearly average maximum relative humidity is more than 70% during monsoon period (June, July, August and September) in the last ten years (2012-2021) according to Meteorological Department of Government of Nepal.

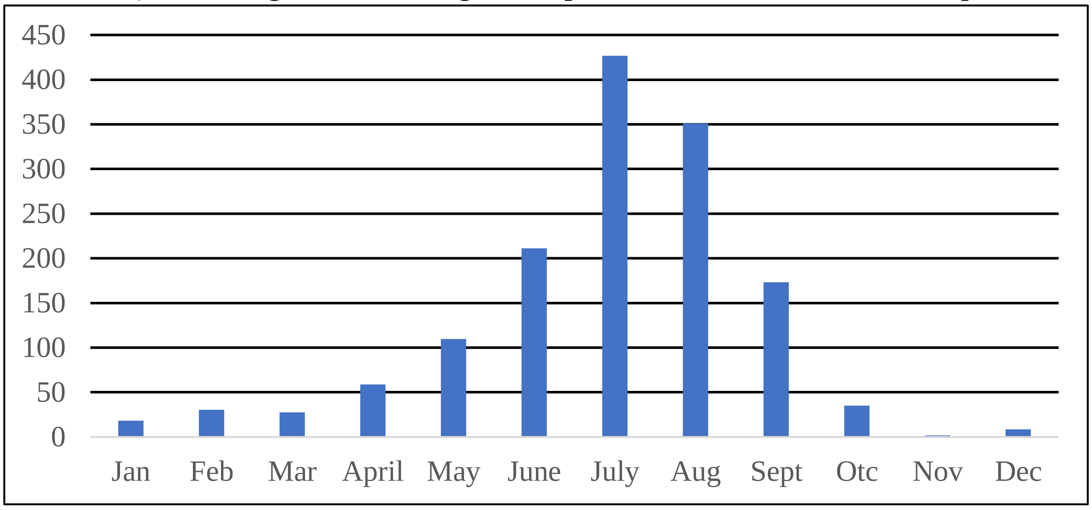


Figure 4.3: Mean rainfall of Dhading

Source: - Department of Hydrology and Meteorology

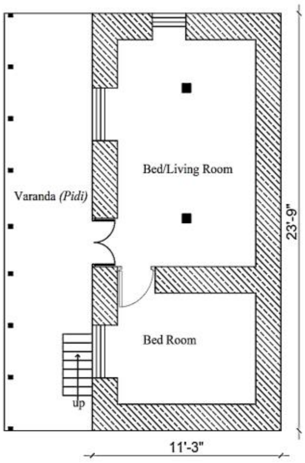
4.3 An overview of the case study houses

A total number of 9 houses were selected for case study. Out of nine five of them are traditional houses where as 4 are recently built modern houses. For the study, traditional houses are symbolized as T1, T2, T3, T4 and T5 whereas for modern houses M1, M2, M3 and M4 symbol are assigned. All the traditional houses were built before 2050 B.S., whereas all modern houses were built after 2015 Gorkha earthquake.

4.3.1 Traditional architecture of Dhading

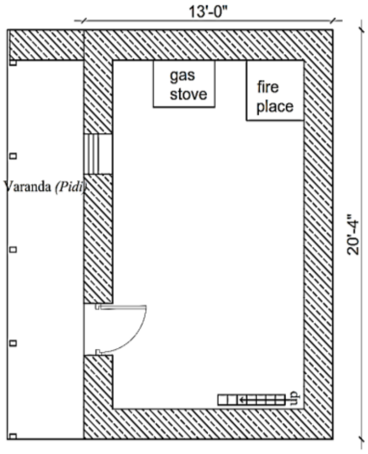
Site and settlement

In past, the area used to be a farm land and people used to live miles away in highland. Because of the availability of irrigation system and fertile land they come daily working on the field. Later on people used to build animal shed and after 2047 BS people from upper part of the district migrate there. They built the house on their own land. As in past people used to own large plot of land themselves hence the settlement were scattered. After a while family members get separated and family own land were also divided among the brothers. They started to build new house nearby and cluster of houses were formed which ultimately formed a '*tole'*.



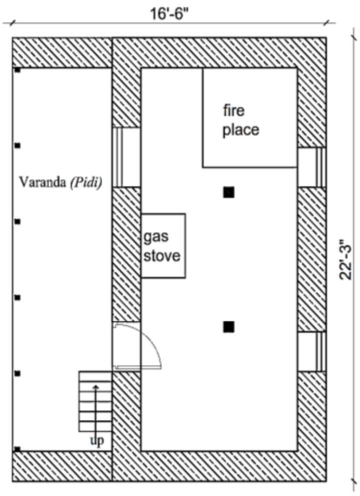
GROUND FLOOR PLAN
Area: 267.187 sq.ft.

House



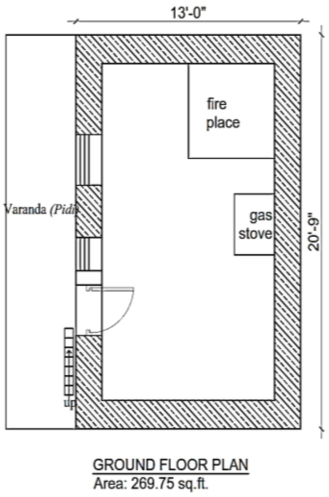
GROUND FLOOR PLAN
Area: 264.33 sq.ft.

House

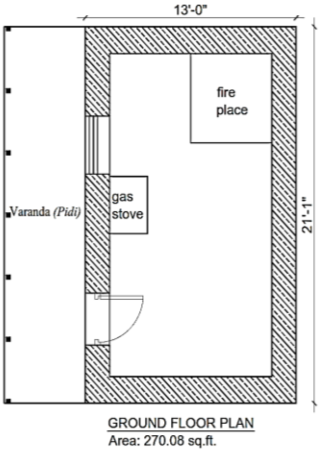


GROUND FLOOR PLAN
Area: 250.31 sq.ft.

House



House



House

Figure 4.4: Investigated traditional houses

In all the above studied houses their neighbors are their brother or closed member of the family. T1 house is separated by his brother house by five feet in north side. T2 house is distance apart from other house but recently he built modern RCC house adjacent to the old traditional house after earthquake. House T3, T4 and T5 are dispersed in random way but forming cluster.

The terrain face to west side, so all the houses are orientated to west side respecting the original topography of land. Minimal intervention can be seen while constructing the houses in the area. In front of every house open space called *"agan"* can be observed were people used to dry grains and other agricultural product and also perform rituals and festivals in there. Also the *"agan"* act as buffer area between animal shade and agricultural field. Nearby every house animal shade can be observed. In front of the house T1, there was delicious tree shading the *'agan'* and a portion of the house in west façade. In other building there was no such trees or vegetation which directly shade the building.

Building form and orientation

There are several types of building forms strongly depending on settlement density and ethnicity. All the studied houses have a rectangular floor plan as in figure above. All the elongated plan is situated on the sunny slope of the hills with the longer facade facing towards the west and south-west. Larger windows are placed in the longer facade, i.e. facing the sun.

Building stories and internal space arrangement

It was observed that traditional houses in Dhading have two to three stories, depending on economic status and requirements. House T1, T2 and T3 are two storey building with additional attic space. T4 and T5 house are two storey building. In T1 house ground floor is used as bed room. Generally in traditional building ground floor is used for kitchen, but in this house they built separate kitchen at back of the house. First floor is used as bed room and storage whereas attic space is used for storage or grains and agriculture. In other traditional houses T2, T3, T4 and T5 ground floor is used as kitchen. The fire place called *"chulo"* is placed at the corner of the room. These days in all of the studied house LPG stove can be absorbed. Mainly fire wood is used to cook animal feedings and to boil milk. Other cooking are done by using Liquefied petroleum gas.

The upper floors are used as bed room and storage for agricultural products. In T1, T3 and T4 house ladder is provided at corner of *"pidi"* which leads to the upper floor of the house. In T2 and T4 house ladder is provide in front of main door inside the house. A very important part of the house which is the veranda called *"pidi"* which is a semi-open space in front of longer façade normally covered by the roof or the balcony. This semi open space act as living spaces where wooden planks are fixed in form of bench or bed for sitting when visitor arrived. These verandas and balconies often have semi closed sides to provide protection from cold wind, summer sun and heavy rain during monsoon.

Also there used to be another building called *'Dhansar'* which is built next to the or in front of the main house before earthquake. Most of this types of buildings were collapsed during the 2015 earthquake. This building used to be of two storey. The ground floor was semi open and used for animal husbandry and agricultural equipment store. The upper floor was used as sleeping space. The first floor in this building used to have wooden partitions, dividing the space into small rooms.

Walls

The walls of all traditional houses are made of locally available stones. Clay and earth are used as mortar. Random rubble masonry are very common type. In all studied houses the exterior walls are 45cm thick with both side plaster with mud. In T1 house only front façade i.e. west wall was plaster by mud inside and outside, where all three wall are left unplaster from outside. Whereas other T2, T3, T4 and T5 houses are plastered in all side from in and outside. But only front façade walls are well maintained and looks repaired time to time. East, west and north wall are in bad shape due to maintenance problems.

Roof

The typical roof type applied in vernacular architecture in Dhading is the pitched roof supported by a timber structure and covered by locally available hatch or stone slates. All the studied house have two way slope roof made of timber and slate. There used to be a slate mine few kilometers away, so slate was locally available in the past. In all traditional building roof overhang of minimum 60 cm can be observed which protects the walls from the heavy monsoon rain and avoids solar penetration of the facade during summer.

Floors and ceiling

The ceilings are very low (not more 1.82 m) to reduce the air volume that needs to be heated during the cold season. In studied houses a wooden pillars and beams is used to

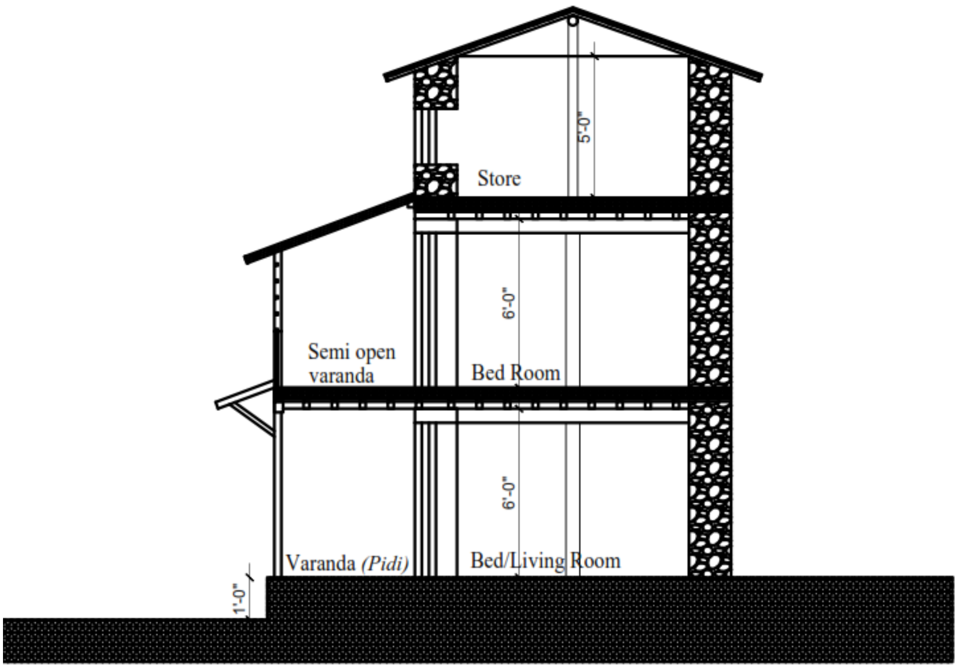


Figure 4.5: Typical section

support the ceilings. Wooden beam support the wooden batten and on top 6 inch thick mud is placed making thick layer of ceiling. In the studied houses earth is used for flooring. In T5 house cement plaster was done in front veranda of the house. Wood was widely available in the area and is, therefore, used as structural as well as covering material. During investigation the ground floor and wall upto height 1.2m seems damp in houses T1, T2, T4 and T5. The plinth height was less than 300mm in all those investigated traditional houses.

Openings

The openings in investigated houses of are small and less in number. The windows are mainly located in the longer facade that faces downhill and is mostly oriented southwards. The side and the back wall have often no openings except a small hole from the kitchen which is used as smoke outlet. In only house T1 and T3 there were small windows other than front (west) façade. The openings are also not sufficient for light and ventilation, as all of the rooms seems dark even in mid daylight. Also in all traditional houses, there was no any kind of shutter in windows.

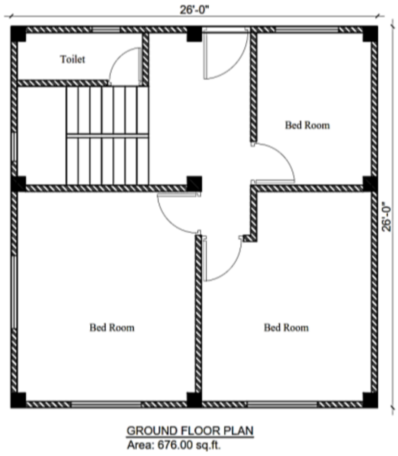
The features of the investigated traditional houses are summarized in following table.

Table 4.1: Summary of investigated traditional houses

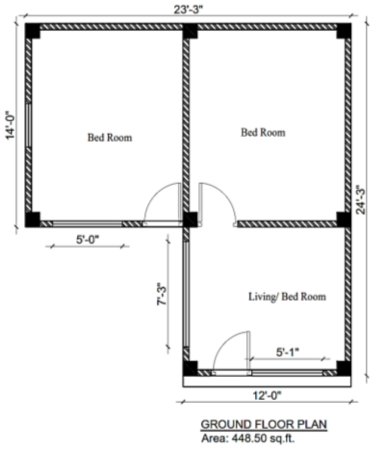
Design Features	Houses				
	T1	T2	T3	T4	T5
Settlement pattern	Dispersed	Scattered	Scattered	Scattered	Scattered
Building form	Rectangular floor plan	Rectangula r floor plan	Rectangular floor plan	Rectangular floor plan	Rectangular floor plan
Building orientation	West	West	West	West	West
Building stories	Two and attic space	Two and attic space	Two and attic space	Two storey	Two storey

Design Features	Houses				
	T1	T2	T3	T4	T5
Internal space arrangement	Ground floor: sleeping/living First floor: storage & sleeping Attic: Storage	Ground floor: Kitchen & storage First floor: storage Attic: Storage	Ground floor: sleeping/living First floor: storage Attic: Storage	Ground floor: sleeping/living First floor: storage	Ground floor: sleeping/living First floor: storage
Semi-open spaces	Shaded veranda	Shaded veranda	Shaded veranda	Shaded veranda	Shaded veranda
Wall material	Stone & mud with mud plaster in front facade	Stone & mud with cement plaster in all facade	Stone & mud with mud plaster in all facade	Stone & mud with mud plaster in all facade	Stone & mud with mud plaster in all facade
Wall thickness	0.45	0.45	0.45	0.45	0.45
Roof materials	Pitched roof of slate	Pitched roof of slate on top, CGI in veranda roof	Pitched roof of slate	Pitched roof of slate	Pitched roof of slate
Ceiling	Wooden structure with lathwork and mud covering	Wooden structure with lathwork and mud covering	Wooden structure with lathwork and mud covering	Wooden structure with lathwork and mud covering	Wooden structure with lathwork and mud covering
Openings %	10.26	3.82	6.65	5.32	5.76

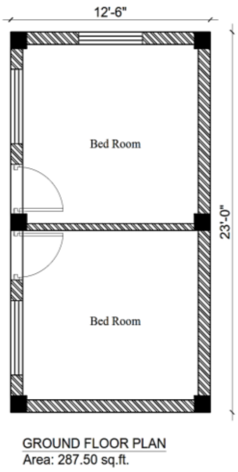
4.3.2 Contemporary residential building in Dhading



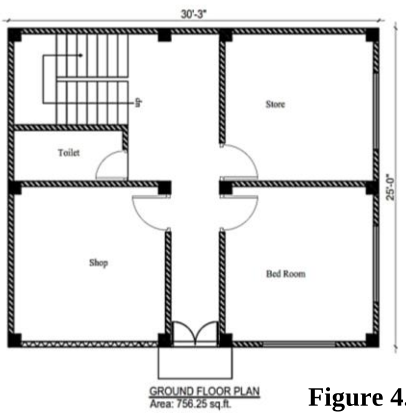
House M1



House M2



House M3



House M4

Figure 4.6: Investigated modern houses

Site and settlement

Contemporary settlements in Dhading are scattered and dispersed in fringe area where as in town buildings are attached to each other. Most of the investigated modern buildings are built after 2015 A.D. Gorkha earthquake. Houses M1, M2 and M3 are built adjacent to the old traditional house, so that they can use old houses for uses of kitchen and storage of agricultural products and other equipment. M4 house was sifted from its original site to nearby road. In only M4 house plain cement concrete was laid in the front open space *'aagan'*. In other building natural ground was observed. Around the invistigated buildings there were no remarkable big trees which could shade the façade of the building.

Building form and orientation

All the investigated houses have a rectangular plan. The size of the houses (length and breadth) are depends on the size of the available plots. Generally modern houses are oriented towards the primary access of the road. In investigated houses, all buildings were orientated towards west side as per terrain and topographical features of the land.

Building stories and internal space arrangement

It was observed that modern houses in Dhading have two to three stories, depending on economic status and requirements. Also after earthquake single storey houses with provision of future expansion can be observed in the area. In two and half storied residential buildings, ground floor consists of living rooms, kitchen, dining, a common bathroom and lobby space. Also the ground floor is used for commercial purpose if the houses are built along the road. First floor is used for sleeping and contains bedrooms. Top floor consists of extra rooms for storage and bedrooms as well as terrace.

Among investigated house only house M4 was two and half storey, other houses are only two storey. In house M4 one room in ground floor is uses as shop. In house M1, M2 and M3 there is no kitchen provided in whole building as they use old traditional building as kitchen. All the room in these houses are used for living and sleeping space. In M4 house kitchen is placed in top floor.

Walls

The walls of modern houses in Dhading are mostly made of brick and concrete. Reinforced cement concrete frame structure is very common type of construction. The exterior wall is 230mm thick but 100mm wall are also very common. Walls are plastered in both sides with cement but in some houses rear wall are not plastered exposing brick facing. Use of bright color is very common on those plastered surfaces. Among four houses only M3 house has 230mm thick outer wall, where as other houses have 100mm thick outer wall. All internal partition wall was 125mm thick in studied buildings. Only in house M1, all side wall was plastered. House M1, M2 and M3 were painted white in front and side façade. In house M4 dark color were used in front façade.

Roof

Typically modern building have flat roof, which acts as terrace, where people have washing area. Also in some agriculture based family houses roof are used to dry agricultural products. A large roof overhang of minimum 60cm protects the walls from the heavy monsoon rain and avoids solar penetration of the facade during summer. All studied buildings has flat roof with overhangs in top. In house M1 the projection is less than 100mm in north side. In other buildings the projection can be seen in façade where windows are provided. No projection can be seen in roof and floor level where there is blank wall.

Figure 4.7: Contemporary building in Dhading

Floors and ceiling

The height of ceilings are almost similar in every houses i.e. 9 ft. In some rooms like bed room and living room ceiling fans are installed. The floor and ceiling are of RCC with plaster and punning.

Openings

The openings in investigated houses of are larger in size and numbers. In M1 house openings are provided in other than east direction. In M2 house large openings are provided in south and west direction. In M3 house windows are provided in north and west façade. In M2 and M3 houses there were no permanent shutter provided in windows, only metal grill and soft cotton were used as shown in above. In M4 house windows are provided only in east and west directions.

The features of the investigated modern houses are summarized in following table.

Table 4.2: Summary of investigated modern houses

Design Features	Houses			
	M1	**M2**	**M3**	**M4**
Settlement pattern	Scattered	Scattered	Scattered	Scattered
Building form	Rectangular floor plan	Rectangular floor plan	Rectangular floor plan	Rectangular floor plan
Building orientation	West	West	West	West
Building stories	Two	Two	Two	Two and half
Internal space arrangement	Ground floor: Sleeping First floor: Sleeping	Ground floor: Sleeping First floor: Sleeping	Ground floor: Sleeping First floor: Sleeping	Ground floor: sleeping/living+ Rental space First floor: sleeping Top floor: Kitchen and sleeping
Semi-open spaces	Veranda and balcony in upper floor	Veranda and balcony in upper floor	Veranda and balcony in upper floor	Veranda and balcony in upper floor
Wall material	Brick and cement wall with cement plaster	Brick and cement wall with cement plaster	Brick and cement wall with cement plaster	Brick and cement wall with cement plaster
Wall thickness	0.127	0.127	0.230	0.127
Roof materials	RCC flat roof	RCC flat roof	RCC flat roof	RCC flat roof
Ceiling	RCC	RCC	RCC	RCC

Design Features	Houses			
	M1	**M2**	**M3**	**M4**
Openings %	14.15	14.89	16.11	19.78

CHAPTER 5. ANALYSIS, RESULTS AND DISCUSSION

5.1 Data Presentation

Five traditional houses were investigated in the month of May and June for 32 days. Temperature and humidity of individual houses were collected three time a day i.e. 7AM, 2PM and 7PM using digital thermometer. The table below shows the average outdoor and indoor temperature of investigated traditional houses in Dhading. The maximum outdoor temperature was 32.33°C and minimum outdoor temperature was 24.48°C. The average outdoor maximum humidity was 86% and minimum was 69% as shown in table below. The average indoor maximum temperature was 27.08°C and average minimum temperature was 24.28°C in traditional house. Similarly average indoor maximum humidity was 89% in morning and minimum was 83% during day time. The 32 days average outdoor temperature was 28.10°C and outdoor average humidity was 77% in month of May and June. 15 days out of 32 days of data collection the sky was cloudy and was raining either in morning, mid-day or in evening time.

Table 5.1: Outdoor and indoor air temperature of traditional house (°C)

S.N.	Outdoor Temp (7AM)	Indoor Temp (7AM)	Outdoor Temp (2PM)	Indoor Temp (2PM)	Outdoor Temp (7PM)	Indoor Temp (7PM)	Average Indoor Temp
T1	24.16	24.54	32.57	27.57	26.96	26.48	**26.20**
T2	24.48	23.12	32.66	26.68	27.00	26.37	**25.39**
T3	24.48	25.04	32.02	26.88	27.71	27.31	**26.41**
T4	24.58	24.74	31.89	26.21	27.55	26.25	**25.73**
T5	24.69	23.98	32.52	28.08	27.53	26.77	**26.28**
Average	**24.48**	**24.28**	**32.33**	**27.08**	**27.35**	**26.64**	**26.00**

Table 5.2: Outdoor and indoor humidity of traditional house (RH %)

S.N.	Outdoor Humidity (7AM)	Indoor Humidity (7AM)	Outdoor Humidity (2PM)	Indoor Humidity (2PM)	Outdoor Humidity (7PM)	Indoor Humidity (7PM)	Average Indoor Humidity
T1	86%	89%	66%	79%	79%	83%	**84%**
T2	85%	89%	65%	87%	76%	87%	**87%**
T3	86%	88%	72%	83%	78%	84%	**85%**

T4	87%	88%	70%	84%	79%	86%	**86%**
T5	85%	88%	71%	82%	78%	84%	**85%**
Average	**86%**	**89%**	**69%**	**83%**	**78%**	**85%**	**85%**

In modern houses also, data were taken in the month of May and June for 32 days. Temperature and humidity of individual houses were collected three time a day as traditional houses using digital thermometer. The table below shows the average outdoor and indoor temperature of investigated modern houses in Dhading. The maximum outdoor temperature was 32.38°C and minimum outdoor temperature was 24.56°C. The average outdoor maximum humidity was 85% and minimum was 68%. In modern house the average maximum indoor temperature was 28.13 °C and minimum indoor temperature was 25.41°C. Similarly average indoor maximum humidity in modern house was 83% and minimum indoor humidity was 78%.

Table 5.3: Outdoor and indoor air temperature of modern house (°C)

S.N.	Outdoor Temp (7AM)	Indoor Temp (7AM)	Outdoor Temp (2PM)	Indoor Temp (2PM)	Outdoor Temp (7PM)	Indoor Temp (7PM)	Average Indoor Temp
M1	24.47	24.73	32.53	27.99	26.91	27.44	**26.72**
M2	24.47	25.09	32.25	28.10	27.67	27.1	**26.76**
M3	24.68	26.24	32.14	28.20	27.96	27.80	**27.41**
M4	24.6	25.56	32.61	28.25	27.51	27.82	**27.21**
Average	**24.56**	**25.41**	**32.38**	**28.13**	**27.51**	**27.54**	**27.03**

Table 5.4: Outdoor and indoor humidity of modern house (RH %)

S.N.	Outdoor Humidity (7AM)	Indoor Humidity (7AM)	Outdoor Humidity (2PM)	Indoor Humidity (2PM)	Outdoor Humidity (7PM)	Indoor Humidity (7PM)	Average Indoor Humidity
M1	85%	85%	65%	79%	76%	77%	**80%**
M2	86%	82%	72%	80%	78%	80%	**81%**
M3	85%	78%	70%	77%	78%	78%	**78%**
M4	84%	81%	65%	76%	76%	76%	**77%**
Average	**85%**	**82%**	**68%**	**78%**	**77%**	**78%**	**79%**

5.2 Data analysis

5.2.1 Air temperature and humidity in traditional houses

In the figure below indoor temperature and humidity of the investigated traditional houses are presented. During investigation it was found that T3 house has highest 26.41°C indoor temperature, whereas T2 house has lowest 25.39°C temperature. But T2 house has highest humidity level with 87%, whereas T1 has minimum level of humidity with 84%. The average indoor temperature difference of investigated houses is 1.02°C and humidity differences is 3% which is between house T3 and T2 and T2 and T1 respectively. The average outdoor temperature of the day was 28.05°C. In an average the indoor and outdoor temperature differences was 2.05°C. The average indoor humidity level is high with 3%.

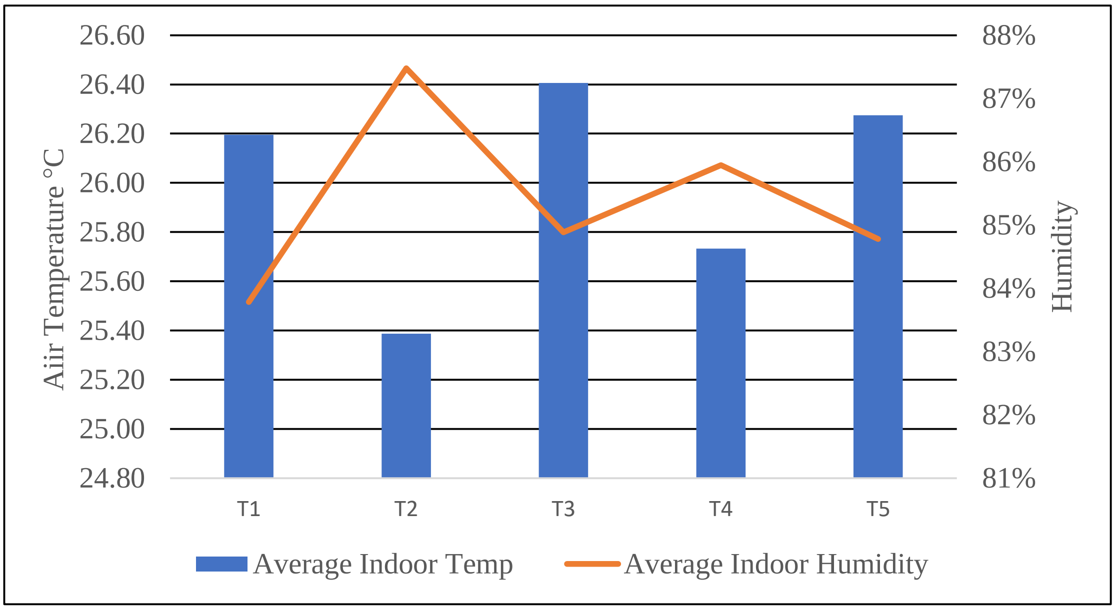


Figure 5.1: Average indoor temperature and humidity of traditional houses

5.2.2 Air temperature and humidity in modern houses

In investigated modern houses the temperature and humidity level of 32 days are plotted in graph below. During the investigation it was found that M1 house has lowest average indoor temperature with 26.72°C and maximum of house M3 with 27.41°C. The average indoor humidity level was high in M2 house with reading 81% and low of house M4. The differences of highest and lowest average temperature and humidity level was between house M1 and M3 with reading 0.69°C and M2 and M4 with 4% respectively. In an average outdoor and indoor temperature difference in modern building was 1.12°C. The average indoor humidity level was high with 2% than outdoor humidity level in modern building.

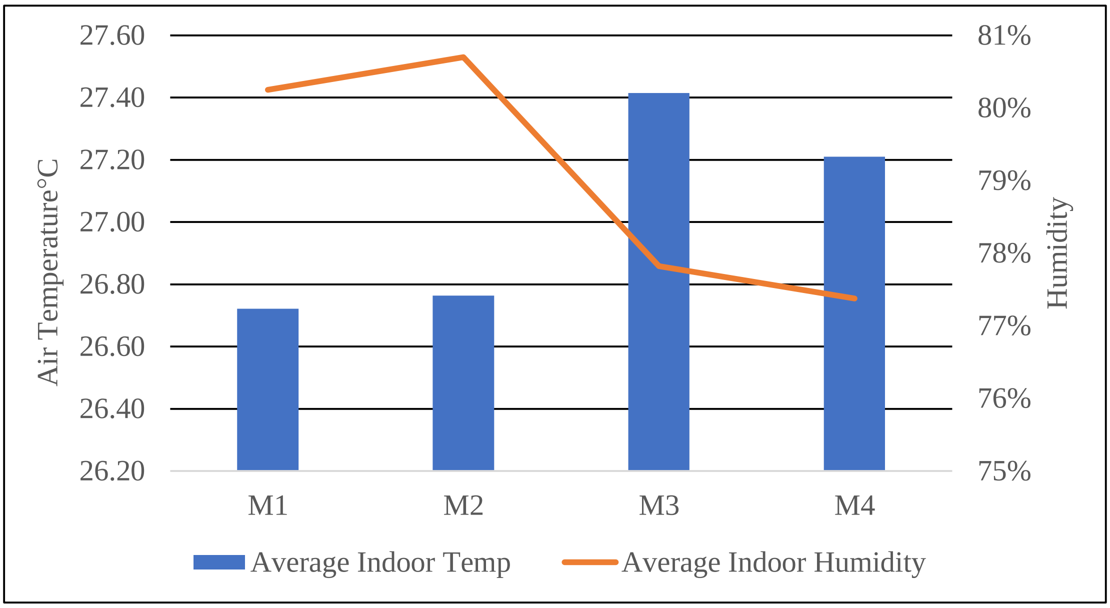


Figure 5.2: Average indoor temperature and humidity of modern houses

5.2.3 Comparison of indoor air temperature and humidity in traditional and modern house

The collected data of temperature and humidity was compared between traditional and modern house are present in figure below. In the chart below all traditional houses have less indoor average temperature than modern house. The minimum indoor temperature is in morning time which is recorded at 7AM and the highest is during day time which

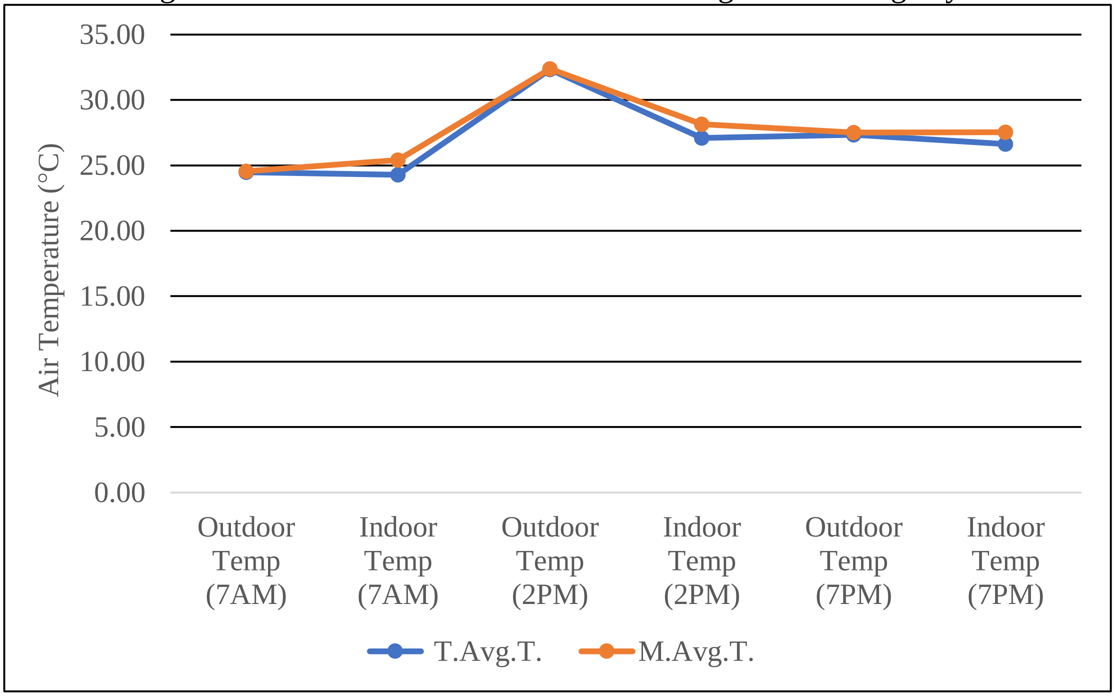


Figure 5.3: Average temperature of traditional and modern houses

is recorded at 2PM. In morning time there is 0.08°C indoor temperature differences between modern and traditional houses which is negligible. In day time the indoor temperature differences was 1.05°C. Likewise in the evening time the indoor temperature differences is 0.9°C. In an average indoor air temperature of traditional building was 26°C and average indoor air temperature of modern buildings was 27.03°C. The average air temperature difference between modern and traditional house is 1.03°C. This show that traditional houses are cooler than modern houses.

During the investigation at was found that the average indoor humidity level was high in traditional buildings than modern houses by 2%. The average indoor humidity level in traditional building was 81% and 79% in modern building. In morning and evening time the humidity level was high in both indoor and outdoor. The differences in humidity level in modern and traditional houses was up to 7% in morning and evening time.

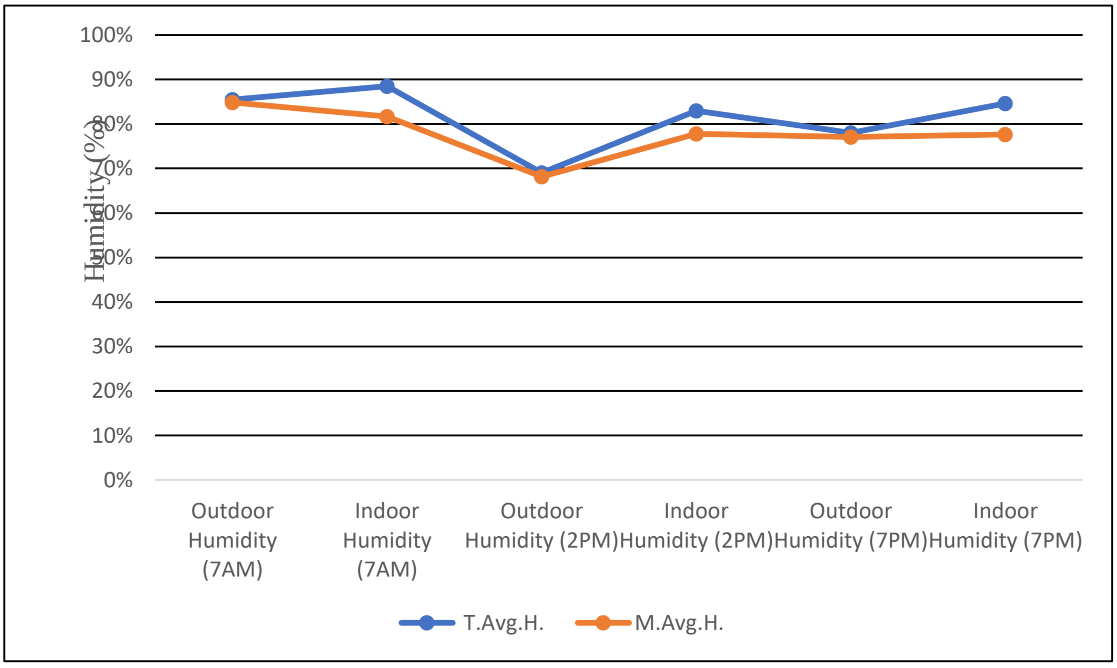


Figure 5.4: Average humidity of traditional and modern houses

5.3 Bioclimatic Chart for Dhading

By plotting climatic data of Dhading in the chart, it is confirmed that most of the months are relatively cool and passive solar heating strategies must be incorporated in the

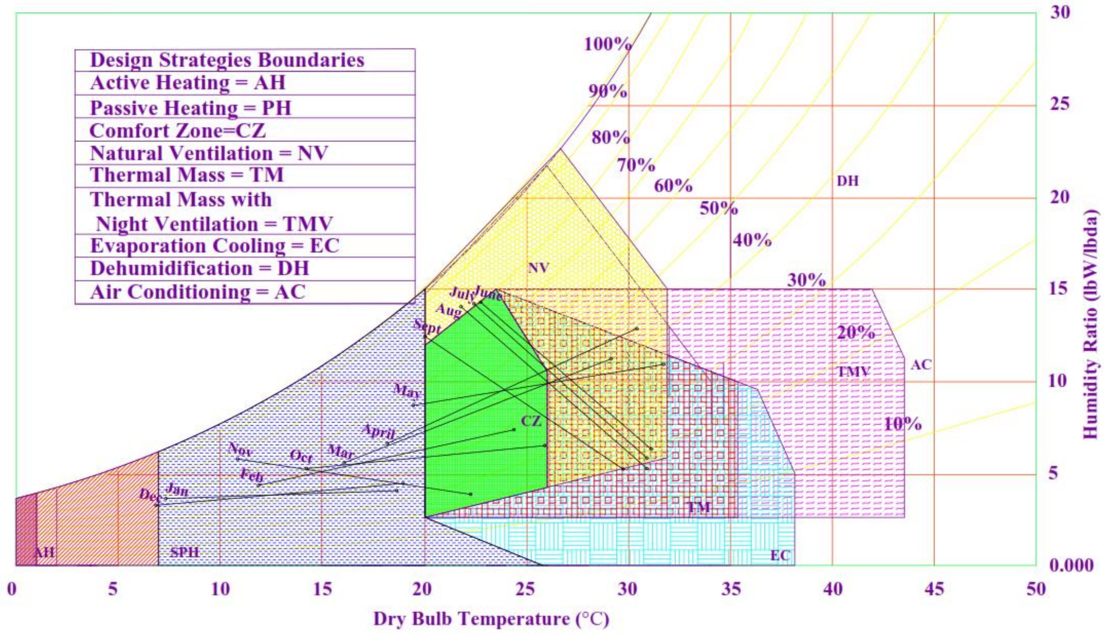


Figure 5.5: Biometric chart of Dhading

design. Day time temperature in October and February falls in the ideal comfort zone but night during these months are still cold. A short duration of night time temperature in May to September falls in the ideal comfort zone. Five months (May to September) are hot and humid, and building design strategies should make provision for air movement. For the month of January and December solar passive heating is required. In this month night temperature remaining below 12°C, where month of January and December temperature come close to 8 °C. To maintain room temperature in this period the passive heating strategies should be applied.

5.4 Mahoney table for Dhading

The recommendations from Mahoney table provide preliminary design recommendations. From the data available from Department of Hydrology and Meteorology of ten years, Mahoney table was developed for Dhading. The result from the Mahoney table are presented below.

Table 5.5: Mahoney table for Dhading

Air temperature °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	High

Monthly mean max.	19.6	24.3	29.3	30.4	31.6	31.1	30.9	30.9	29.7	25.9	22.2	18.9	31.6
Monthly mean min.	7.4	11.9	16	18.2	19.9	22.7	22.4	21.8	20	14.1	10.8	6.9	22.7
Monthly mean range	12.2	12.4	13.3	12.2	11.7	8.42	8.52	9.05	9.67	11.9	11.4	12	Low
Rainfall mm	18	30	28	59	110	211	427	351	173	35	2	9	1453

Relative humidity %	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Humidity Group:**	
Monthly mean max am	66	62	57	57	65	80	81	83	81	69	76	64	**1**	<30%
Monthly mean min pm	34	38	43	43	35	20	19	17	19	31	24	36	**2**	30-50%
Average	50	50	50	50	50	50	50	50	50	50	50	50	**3**	50-70%
Humidity group	3	3	3	3	3	3	3	3	3	3	3	3	**4**	>70%

Diagnosis °C	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**AMT**
Monthly mean max	19.6	24.3	29.3	30.4	31.6	31.1	30.9	30.9	29.7	25.9	22.2	18.9	27.1
Day comfort, upper	29	29	29	29	29	29	29	29	29	29	29	29	
Day comfort, lower	23	23	23	23	23	23	23	23	23	23	23	23	
Thermal stress, day	**C**	**O**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**O**	**C**	**C**	
Monthly mean min	7.4	11.9	16	18.2	19.9	22.7	22.4	21.8	20	14.1	10.8	6.9	
Night comfort, upper	23	23	23	23	23	23	23	23	23	23	23	23	
Night comfort, lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress, night	**C**	**C**	**C**	**O**	**O**	**O**	**O**	**O**	**O**	**C**	**C**	**C**	

	H- Hot	O- Comfort	C- Cold	

Meaning	Indicator	Thermal stress			Rainfall		Humidity group		Monthly mean range
		Day	Night						
Air movement essential	**H1**	H					4		
		H					2–3		<10°C
Air movement desirable	**H2**	O					4		
Rain protection necessary	**H3**				>200mm				
Thermal capacity necessary	**A1**						1–3		>10°C
Outdoor sleeping desirable	**A2**		H				1–2		
		H	O				1–2		>10°C
Protection from cold	**A3**	C							

Indicators	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Air movement essential						1	1	1	1				**4**
Air movement desirable													**0**
Rain protection necessary						1	1	1					**3**
Thermal capacity necessary	1	1	1	1	1					1	1	1	**8**
Outdoor sleeping desirable													**0**
Protection from cold	1										1	1	**3**

List of Recommendations

Table 5.6: List of Recommendations from Mahoney table

Indicator totals from data sheet					
H1	H2	H3	A1	A2	A3
4	0	3	8	0	3

						Layout	
			0–10				

Indicator totals from data sheet							
			11–12		5–12	X	Orientation north and south (long axis east–west)
					0–4		Compact courtyard planning
						Spacing	
11–12							Open spacing for breeze penetration
2–10						X	As above, but protection from hot and cold wind
0–1							Compact layout of estates
						Air movement	
3–12						X	Rooms single banked, permanent provision for air movement
1–2			0–5				
			6–12				Rooms double banked, temporary provision for air movement
0	2–12						
	0–1						No air movement requirement
						Openings	
			0–1		0		Large openings, 40–80%
			11–12		0–1		Very small openings, 10–20%
Any other conditions						X	Medium openings, 20–40%
						Walls	
			0–2				Light walls, short time-lag
			3–12			X	Heavy external and internal walls
						Roofs	
			0–5				Light, insulated roofs
			6–12			X	Heavy roofs, over 8h time-lag
						Outdoor sleeping	
				2–12			Space for outdoor sleeping required
						Rain protection	
		3–12				X	Protection from heavy rain necessary

Indicator totals from data sheet							
						Size of opening	
			0–1		0		Large openings, 40–80%
					1–12		Medium openings, 25–40%
			2–5				
			6–10			X	Small openings, 15–25%
			11–12		0–3		Very small openings, 10–20%
					4–12		Medium openings, 25–40%
						Position of openings	
3–12						X	In north and south walls at body height on windward side
1–2			0–5				
			6–12				As above, openings also in internal walls
0	2–12						
						Protection of openings	
					0–2		Exclude direct sunlight
		2–12				X	Provide protection from rain
						Walls and floors	
			0–2				Light, low thermal capacity
			3–12			X	Heavy, over 8h time-lag
						Roofs	
10–12			0–2				Light, reflective surface, cavity
			3–12				Light, well insulated
0–9			0–5				
			6–12			X	Heavy, over 8h time-lag
						External features	
				1–12			Space for outdoor sleeping
		1–12				X	Adequate rainwater drainage

Summary of design Recommendation for Dhading from Mahoney table are as follows

- Layout: Orientation north and south (long axis east-west)
- Spacing: Open spaces for breeze penetration, but protection from hot and cold wind
- Air movement: Rooms single blanked permanent provision of air movement
- Openings: Medium Openings, 20-40%
- Position of Openings: In north and south walls at body height on windward side
- Protection of openings: Provide protection from rain
- Walls: Heavy external and internal walls
- Walls and floors: Heavy, over 8h time-lag
- Roofs: Heavy, over 8h time-lag
- External features: Adequate rainwater drainage

5.5 Climate-responsive design strategies applied on investigated houses

Residential buildings both modern and traditional were studied as a part of climate responsive architecture in Dhading. For this both qualitative and quantitative study was carried out. Total of nine traditional and modern buildings were studied and individual buildings features were studied. In table below climate-responsive or solar passive design strategies parameters which were identified from literature reviews are checked in individual buildings. The indicator '+' are used if the climate-responsive strategies are fully applied in the buildings. Likely '±' indicator are used if the building partially applied the strategies and '-' if the design strategies are not applied. After studying the result are shown in following table.

Table 5.7: Climate-responsive design strategies applied on investigated houses in Dhading

Climate-responsive design strategy	Recommendation	Investigated houses								
		T1	T2	T3	T4	T5	M1	M2	M3	M4
Layout	Long axis east-west	-	-	-	-	-	-	-	-	-
Spacing	Open spaces for breeze penetration,	±	±	±	±	±	±	±	±	±

Climate-responsive design strategy	Recommendation	Investigated houses								
		T1	T2	T3	T4	T5	M1	M2	M3	M4
	but protection from hot and cold wind									
Air movement	Rooms single blanked permanent provision of air movement	+	+	+	+	+	-	-	+	-
Opening	Medium Openings, 20-40%	-	-	-	-	-	-	-	-	-
Walls	Heavy external and internal walls	+	+	+	+	+	-	-	±	-
Roofs	Heavy	+	+	+	+	+	-	-	-	-
Rain protection	Protection from heavy rain necessary	±	±	±	±	±	±	±	±	±
Position of opening	In north and south walls at body height on windward side	-	-	-	-	-	±	±	±	-
Walls and Floors	Heavy	+	+	+	+	+	-	-	-	-
External features	Adequate rainwater drainage	±	±	±	±	±	±	±	±	±
Legend: + applied - not applied ± partly applied										

5.6 Discussion

The research is about investigation of climate responsive residential architecture in Dhading. As a part of investigation primary climate data from field and secondary from of 10 years (2012-2021) were collected from Department of Hydrology and

Meteorology. Climate data available from Department of Hydrology and Meteorology shows that seven month from March to September, the maximum temperature remains above 29°C. The primary data was collected in month of March and June for 32 days, three times a day i.e. morning 7AM, day time 2PM and evening 7PM. The average maximum and minimum outdoor temperature measured during field study was 32.6°C and 24.52°C. The average maximum and minimum outdoor temperature was 31.36°C and 21.29°C for the month of May and June as per Department of Hydrology and Meteorology. The average maximum humidity for the month was 72% as per data available from Department of Hydrology and Meteorology and as per field recorded data, the average humidity was 77%.

Investigation done in five traditional shows that average indoor temperature was 26°C. The minimum average indoor temperature was in the morning 7AM i.e. 24.28°C, highest at day 2PM i.e. 27.08°C. During the investigation the indoor and outdoor temperature variation in morning and evening time is very low i.e. 0.20°C and 0.71°C. But during day time when the average outdoor temperature was 32.33°C and the indoor temperature was 27.08°C. Which shows during day time indoor temperature is 5.25°C cooler than outdoor temperature. In an average inside of traditional houses are 1.05°C cooler than outdoor. According to Rijal et al. (2010) the study done including Dhading, the comfort temperature is 15.2°C to 25.6°C for winter and summer in temperate region. However a study done by Lamsal et al. (2021) shows that comfort temperature in temperate climate rage between 22.8-27.8°C and 18.5-23.5°C for summer and winter respectively. The average indoor temperature is very close to upper limit of comfort temperature. However the average indoor humidity is 81% in traditional houses. This shows that due to higher level of indoor humidity the houses are not comfortable. This result shows that in traditional houses natural ventilation is very essential during summer season.

Likewise, in four investigated modern houses the average indoor average temperature was 27.03°C. In modern houses average indoor temperature is higher than outdoor temperature in morning 7AM and evening 7PM by 0.84°C and 0.03°C respectively. But in day time 2PM the average indoor temperature was 28.13°C, which is less than 4.25°C than outdoor air temperature. The average outdoor humidity was 77% and which is less than 3% indoor humidity level. In modern buildings also the indoor temperature and humidity level is above the comfort level.

The indoor temperature in traditional building is less by 1.03°C but humidity level is high compared to modern buildings. According to Bajracharya (2014), traditional buildings were 1-2°C hot in winter and cool in summer, which saves 10-20% energy load for cooling and heating in Kathmandu compared to modern houses. The investigation done on both traditional and modern houses in Dhading shows that, both types of houses are not comfortable in summer season. This shows that in both types of building architecture intervention is needed to achieve thermal comfort in the buildings.

The bioclimatic chart for Dhading shows that natural ventilation is very essential for five month i.e. May, June, July, August and September. These are the hottest month of the year in Dhading according to climatic data also. The humidity is high in these months. Also short period of day, natural ventilation is essential in the month of March and April. For the month of December and January, solar passive heating is essential. Also in October and November, majority time are cold hence passive heating needed. Mahoney table also suggest from June to September, air movement is essential. Protection from cold is essential for the month of November, December and January. According to Mahoney table rain protection is needed for the month of June, July and August which is peak monsoon time as per climatic data of Dhading.

During the investigation it was found that, climate responsive design strategies were fully or partially followed by traditional houses more than modern houses. All the building has rectangular floor plan facing west as per nature of the land terrace. To orient longer axis east-west direction as suggested by Mahoney table, site intervention is required.

In vernacular building the semi open veranda in ground and first floor level helps to shade the front (west) façade from direct heat gain in the building. Generally, houses in this climate are of high thermal mass using locally available materials like stone, mud, timber and bamboo. The thermal mass is advantageous for storing solar heat gains from the day for colder nights, especially during sunny winter days. The amount of air that needs to be heated during the winter is less due to the low ceiling height (Bodach et al., 2014). Kitchen is placed in ground floor, from where heat is radiate in upper portion of the building. Also in monsoon the heat from burnt firewood helps to keep the ground floor dry. Middle floor is used for sleeping which is more comfortable compared to ground floor and top floor of the house because in summer solar heat from roof do not directly transmit to the middle floor and in winter and monsoon season, the heat from ground floor (burn firewood) transfer to the middle floor keeping the space warm.

Frame structure are very common in newly built modern houses. The material used in contemporary buildings are kiln burnt bricks, cement, sand, reinforcement bars etc which are very energy intensive and not environmental friendly (Penttala, 1997). The external wall in most of houses are very thin (five inches), from which heat loss and gain in winter and summer is very high. The internal space arrangement and uses in modern houses are random and differ from one another. The ground floor are used for rental purposes from same family or from outsiders. The upper floors are used as living, sleeping and kitchen rooms in those houses. Shading devices are provided in contemporary buildings also but because of large window it does not shade properly. In contemporary building there are open veranda which shade the lower portion of the wall/ floor but itself exposed to direct sun. In summer time these area gain so much heat that it is inhabitable during day time.

During the investigation it was found that in traditional buildings, the main problem was in openings. The opening size of traditional houses are small and are only on longer (west) façade. Also there was no any kind of shutter in the windows. Making the building airtight by closing doors, windows, etc. using locally available materials and technology are highly effective for thermal improvement of the building (Rijal, 2012). From the study it can be said that the percentage of opening (area wise) in modern buildings seems close to suggested from Mahoney table, but still there is lack of cross ventilation system in modern building.

In traditional building, without any kind of damp proofing course and mud as a main flooring material, the indoor space of the house seem wet. Also the plinth height was less than 300mm. Moisture from ground during monsoon season come to plinth level due to capillary action making indoor air humid and discomfort for living. Also the poor maintenance of rain water drainage system in front open space *(Aagan)* and back of the house (*Karsa)*, water get inside the house through the wall. Rough texture and unplaster outer wall in ground floor also hold moisture in wall mortar, making indoor air more humid.

5.7 Passive solar building design strategies for Dhading

Climate data available from Department of Hydrology and Meteorology shows that seven month from March to September, the maximum temperature remains above

29°C. Bioclimatic chart of Dhading shows that, most of the months are relatively hot and passive solar cooling strategies must be incorporated in the design. Four months (June to September) are hot and also maximum relative humidity remains above 75% hence building design strategies should make provision for air movement. Air movement can be achieved by cross ventilation. The followings are detail design recommendations for Dhading.

5.7.1 Site planning

The settlement with open space planning is better in Dhading for most of the month. The building layout and the landscape around it can also be designed in such a way that it do not control the flow of natural breezes but protection from hot and cold wind is essential.

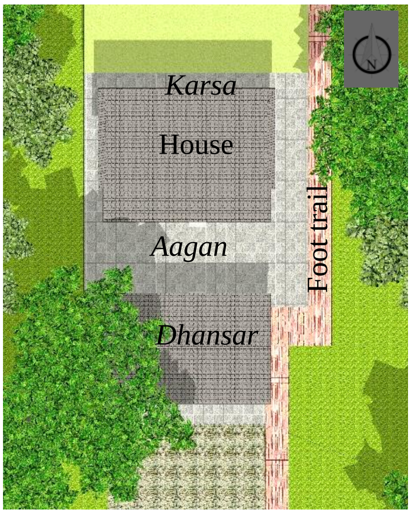


Figure 5.6: Example of proposed site planning for Dhading

Deciduous trees should be located in east and west direction to prevent from low angle sun. The disturbance to flow of air outside the building affects the actual airflow rate inside the building. The trees/bushes should be located in such a manner that will affect the airflow pattern.

The plinth of the building has to raise and damp proof course should be laid in ground floor. In most of the traditional building the ground floor seems damp due to low plinth height. Also the back of the house called *'Karsa'* has to be maintained with proper slope for rain water drainage. The paving of front open space called *'Aagan'* using stone is highly recommended.

5.7.2 Building orientation

The building should be in elongated plan. According to Mahoney table also the orientation of the building should be north and south (long axis east-west) so that the only small surface area of the building envelope are affected by direct sun rays in the east and west directions. If the building axis is located on the east-west direction with its longest facade facing the north-south, this reduces the exposure to the sun.

5.7.3 Openings

During the investigations done in Dhading it was found that one of the major problem within the traditional residential houses was in the openings. Opening should be located in such a way that, the circulation of air in the building is increased by natural ventilation. The measured climate data also shows that the indoor humidity level was high in traditional buildings, hence the size and number of openings should be increased. From Mahoney table, the size of the openings is 20-40% that of floor area is suggested. During the investigation it was observer that in traditional building, the shutter in window was missing, which is very crucial to stop easy in and out heat flow. For cross ventilation opening should be provided in all façade. But maximum number and of bigger size windows should be provided in south and north direction which is longer façade of the building. These openings should be protected by roof overhang so that is prevent direct solar radiations entering the building.

Figure 5.7: Typical proposed traditional building in Dhading

5.7.4 Shading device

The window has to be protected from summer sun and also prevent monsoon rain either by roof projections or by other kinds of shading elements. So it is necessary to design proper shading devices in a building for long hot and monsoon season in Dhading. As stated before, in most of the traditional buildings, openings are provided only in front façade. The opening in ground and first floor is protected by veranda provided in first floor. Shading is required mainly in second or attic floor, which is shaded by roof overhang. Hence the proper length of overhang should be designed for effective shading in front (south) façade.

For window facing towards south, following calculation shall be done.

Time & Date = 10 a.m. on 1st April

Window height, H = 1.58 m

i. Solar altitude angle (γ), = 47.2°

ii. Solar azimuth angle (a) = 120°

iii. Wall azimuth angle (ω) for south facing (ω) = 180° (from North)

iv. Horizontal shadow angle (δ) = azimuth difference

d = ω - a = 180°-120° = 60°

From Tangent equation,

Tan ϵ = Tan γ x Sec δ = 2.15

From triangle, I f X = Horizontal projection in front of wall

Tan ϵ = p/b, or, Tan ϵ = 1.58 m/X

Or, X = 0.734m, i.e. X= 735mm

Hence the size of the roof overhang should be 735mm.

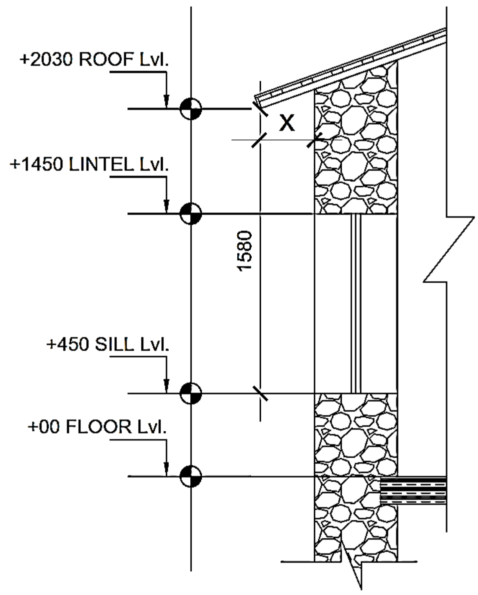


Figure 5.8: Calculation of shading device

5.7.5 Material and technology

Materials and technology of wall, roof, floor and partition should be constructed such that it should have 8h time lag with low U value which was also suggested in the Mahoney table. As stone is easily available in Dhading, stone and mud cab be used as wall material. If stone is used as wall material, mud plaster should be applied in all interior and exterior surface of the wall. Rammed earth wall is also a better option as it has low U-value than stone wall and mud is also easily available in the area.

5.7.6 Building color and texture

Radiation impinging on an opaque surface may absorbed or reflected, only perfectly black surface fully and fully reflected by perfect reflector. Most surfaces however absorb only part of the incident radiations, reflecting the remainder. Lighter the surface higher the solar reflectivity and lower the absorptivity. For residential building in Dhading, the exterior color in roof and wall should be light and smooth to reflect solar radiation. Instead of *'Rato Mato'* red mud and cement plaster with chemical paints, '*Kamero'* (white mud) can be applied in external wall of traditional building as a paint which is available within the area.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Climate responsive building design has become the growing issue for researcher all over the world for achieving thermal comfort and saving active use of energy. Climate-responsive design is considered to be one of the major requirements to drive the building sector towards sustainable development. Elements like air temperature, relative humidity, wind and rainfall these elements affect the climate responsive design for that region.

Climate responsiveness of residential architecture depends upon various indicators that have been discussed in the literature review. It was not possible to incorporate all the indicators in this research due to limitation of time and resources. Hence the study has been limited only on collection of temperature and humidity data from the field in summer season. The data available from Department of Hydrology and Meteorology of ten years shows that most of the month are hot in Dhading. The research has presented the result and findings of air temperature and humidity in the field regarding the indoor and outdoor environment of the traditional and modern houses in Dhading. The data of air temperature and humidity are compared with traditional and modern houses. The research from the field study shows that traditional houses are 1.03°C cooler than modern houses but humidity is high in traditional houses.

By plotting climatic data of Dhading in the chart, it shows that most of the months are relatively hot and passive cooling strategies must be incorporated in the design. Day time temperature in October and February falls in the ideal comfort zone but night during these months are still cold. A short duration of night time temperature in May to September falls in the ideal comfort zone. Six months (April to September) are hot and humid, and building design strategies should make provision for air movement and passive cooling strategies should be applied. For the month of January and December solar passive heating is required. In this month night temperature remaining below 12°C, where month of January and December temperature come close to 8°C. To maintain room temperature in this period the passive heating strategies should be applied.

Vernacular architecture considers local climate and is in consonance with climate responsive design strategies recommended by Mahoney's table and bioclimatic chart such as high thermal mass, open spaces for breeze penetration, single blanked, heavy walls and roofs etc. in Dhading. But the modern construction practice is neglecting local climate by adopting uniform design and building materials and techniques.

Traditional architecture considers local climate and is in consonance with climate responsive design strategies recommended by Mahoney's table and bioclimatic chart such as high thermal mass, open spaces for breeze penetration, single blanked, heavy walls and roofs etc. in Dhading.

As a passive design strategies the longer axis of the building should face north-south. The settlement should be loose rather than dens for easy flow of air. As the climate of Dhading is hot and humid in monsoon season, the size of the opening should be maximum in windward direction. To achieve comfort in the building, cross ventilation should be provided. Shading devices of minimum 735mm should be provided to protect from direct solar radiation. Stone wall with mud plaster on both side is preferable as it is easily available and have higher thermal mass. The external surface of the building should kept smooth and light color should be applied so that summer solar radiation get reflected, which help to lower down the indoor temperature level.

6.2 Recommendations

The study on climate responsive architecture of a building incorporating all the parameters and indicators requires a rigorous research. As climate responsive architecture is related to passive design techniques which ultimately saves active use of energy, it is growing issues all over the world. The research is the first of its kind with regard to climate responsive residential architecture in Dhading, which has tried to quantitatively and qualitatively validate the research objective. . The research could not incorporate all the climatic parameters and passive design building features due to time and resources constrains. Based on the analysis, the recommendations have been provided to researcher, designer and stakeholders.

6.2.1 For researcher

The research that has been carried out in this work have not incorporated all climatic and building design parameters. Also the field data of summer seasons were only collected in this research. Hence for further study all climatic elements and all four seasons could validate the research objective more accurately. Also method like questioner surveys, perception survey can be done in the topic for validation. Further work can be carried out by incorporating macro and micro climatic factors like radiation, local winds directions etc. More advanced measurement equipment like data logger could be helpful for more precision measurement.

6.2.2 For stakeholders

The primary stakeholder of the concerned research is the people residing in the houses as they are directly affected by climate responsiveness of the buildings. Hence the primary stakeholders need to be provided with knowledge about the importance of passive design techniques in the area. During the field visit it was found that most of the traditional building lack maintenance, hence those who inhabit are recommended to carry out regular maintenance work. Also the research findings need to be discussed with secondary stakeholders like local government, policy makers to encourage passive design building techniques for energy saving.

6.2.3 For designers

Designers are the most influential for energy efficient building design and construction. Energy efficiency of the buildings is influenced by passive design techniques. For passive design it is necessary to study detail climatic parameters of the particular area. The designer should be aware of benefits of constructions of energy efficient buildings and its necessity for sustainable development. In building sector climate responsive architecture are the key factors for sustainable development. Designer should always aware of material and technology used for building design and construction. The use of local material and building technology is crucial for climate responsive building design. Also the designer should encourage traditional building form incorporating modern technologies will always benefit socially, economically, environmentally.

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APPENDIX

APPENDIX A: Climate data of Dhading (2012-2021)

Average monthly maximum temperature of Dhading (GON, 20012-2021)

Months/Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Jan	19.16	21.05	21.24	19.72	19.6	20.11	17.56	19.59	19.56	18.83
Feb	24.03	27.61	22.42	24.72	25.74	23.99	25.76	20.94	21.75	26.51
Mar	30.9	30.5	31.61	29.88	29.48	28.27	28.68	26.58	29.87	26.99
April	33.13	17.83	34.88	29.11	36.42	33.17	27.88	31.78	27.99	31.95
May	35.53	28.49	33.32	34.41	30.05	30.81	31.89	32.31	28.76	30.34
June	31.96	30.87	32.43	31.54	30.87	32.34	30.49	31.16	29.39	30.16
July	31.16	32.37	32.36	29.75	29.53	31.86	29.95	30.56	30.13	31.63
Aug	32.01	31.04	30.68	31.58	30.85	31.82	29.21	31.35	31.07	29.1
Sept	30.24	28.06	27.73	31.11	29.74	30.58	31.18	26.98	30.08	31.08
Otc	26.52	25.01	24.21	25.37	24.55	22.11	28.11	26.22	29.17	28.04
Nov	20.41	23.34	20.97	23.15	21.15	20.64	23.2	22.57	23.21	23.79
Dec	19.23	18.86	18.58	19.81	18.58	20.61	18.92	18.05	18.83	17.59

Average monthly minimum temperature of Dhading (GON, 20012-2021)

Months/Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Jan	6.77	8.61	9.41	5.64	7.66	9.4	7.02	5.95	6.85	6.72
Feb	11.17	11.66	11.39	14.18	12.13	11.58	13.64	8.54	9.62	15.16
Mar	16.92	15.51	16.7	15.99	15.29	18.92	14.87	15.23	14.41	16.2
April	17.77	19.39	22.82	17.04	19.23	14.35	16.48	20.13	16.96	17.87
May	23.56	19.04	20.56	21.36	18.33	16.77	20.05	19.11	19.66	20.27
June	21.94	21.99	22.48	26.83	22.26	22.18	22.12	22.68	22.22	22.33
July	22.59	22.71	22.3	21.18	21.57	24.28	22.39	22.96	22.47	21.67
Aug	22.84	21.84	21.8	22.26	21.18	21.54	21.48	22.11	22.35	20.84
Sept	20.95	19.63	20.51	19.63	20.16	21.31	19.71	19.06	19.93	19.19
Otc	12.49	14.08	13.92	13.81	13.16	14.02	14.53	15.36	15.56	13.88
Nov	9.12	11.33	9.9	11.39	10.95	9.95	14.1	11.17	10	10.12
Dec	7.02	6.13	7.33	7.57	8.78	8.13	5.84	5.53	6.11	6.58

Average monthly minimum temperature of Dhading (GON, 20012-2021)

Months/Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Jan	26.9	15.6	5.4	12.4	0	0	8	26	86.2	0
Feb	42.2	45.3	19.4	39.7	20.3	1.3	6.2	93.2	32.8	2.2
Mar	19.4	8	46	29.6	10.8	64.6	21.8	49.2	15.7	10.2
April	86.4	54.6	2.2	106.5	1.6	50.4	46.6	98	85.2	54.4
May	60.4	207.1	102.6	27.3	122.4	107.8	99.4	100	102.6	168.3
June	193	360.7	136.4	102.5	177.6	100.3	173.5	203.2	415.6	249.8
July	552.1	292.8	403	339.9	351.2	484.9	441.5	578.3	393.3	430.8
Aug	458.8	596.1	301	251.9	159.1	257.5	446	302.1	360.5	377.7
Sept	243.5	63.8	238	33.2	255.6	108.9	162.8	318.5	166	139.6
Otc	0	87.7	79.2	36	37	2	0	13.2	0	97.1
Nov	16.4	0	0	0	0	1.6	0	0	0	0
Dec	0	0	25.4	0	0	0	0	30.2	0	30.1

Average monthly maximum relative humidity of Dhading (GON, 20012-2021)

Months/Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Jan	55.76	59.43	58.91	65.26	70.38	73.19	72.76	65.88	79.91	57.97
Feb	66.22	51.58	64.99	51.73	68.26	62.21	66.88	66.88	62.49	62.3
Mar	45.76	64.04	31.07	66.47	61.39	71.21	52.22	69.69	49.13	57.72
April	59.94	69.73	41.89	67.25	23.16	48.88	83.53	58.17	62.81	49.94
May	68.61	72.01	60.23	49.81	67.81	60.01	68.98	59.52	73.97	70.38
June	70.16	76.57	87.23	73.24	91.11	73.36	74.83	80.03	80.49	89.9
July	86.07	79.33	76.02	94.24	81.07	84.85	77.64	70.32	78.93	80.84
Aug	81.68	90.41	86.59	80.4	84.3	80.52	87.21	79.6	73.92	88.71
Sept	79.81	86.22	83.03	77.22	79.07	79.59	81.57	83.97	77.53	85.5
Otc	60.21	76.57	74.34	68.36	66.03	71.12	54.1	73.31	67.47	78.26
Nov	71.79	111.3	80.09	75.91	75.41	74.28	65.5	68.9	60.92	79.95
Dec	63.75	67.18	60.2	57.29	72.36	64.48	54.91	50.68	69.56	79.87

Average monthly maximum relative humidity of Dhading (GON, 20012-2021)

Months/Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Jan	44.24	40.57	41.09	34.74	29.62	26.81	27.24	34.12	20.09	42.03
Feb	33.78	48.42	35.01	48.27	31.74	37.79	33.12	33.12	37.51	37.7
Mar	54.24	35.96	68.93	33.53	38.61	28.79	47.78	30.31	50.87	42.28
April	40.06	30.27	58.11	32.75	76.84	51.12	16.47	41.83	37.19	50.06
May	31.39	27.99	39.77	50.19	32.19	39.99	31.02	40.48	26.03	29.62
June	29.84	23.43	12.77	26.76	8.89	26.64	25.17	19.97	19.51	10.1
July	13.93	20.67	23.98	5.76	18.93	15.15	22.36	29.68	21.07	19.16
Aug	18.32	9.59	13.41	19.6	15.7	19.48	12.79	20.4	26.08	11.29
Sept	20.19	13.78	16.97	22.78	20.93	20.41	18.43	16.03	22.47	14.5
Otc	39.79	23.43	25.66	31.64	33.97	28.88	45.9	26.69	32.53	21.74
Nov	28.21	-11.3	19.91	24.09	24.59	25.72	34.5	31.1	39.08	20.05
Dec	36.25	32.82	39.8	42.71	27.64	35.52	45.09	49.32	30.44	20.13

APPENDIX B: Field measured air temperature and humidity data of Dhading

Traditional House (T1)

Time		7AM				2PM				7PM			
S. N.	Date	Outdoor Temp	Indoor Temp	Outdoor Humidity	Indoor Humidity	Outdoor Temp	Indoor Temp	Outdoor Humidity	Indoor Humidity	Outdoor Temp	Indoor Temp	Outdoor Humidity	Indoor Humidity
1	5-May	22.5	23.3	88%	86%	32.9	27.2	64%	73%	27.2	25.8	70%	76%
2	6-May	23.3	23.9	86%	88%	25.7	23.8	81%	90%	22.1	24	93%	89%
3	7-May	21.3	23.1	89%	91%	35.2	26.6	47%	76%	27	25.1	73%	83%
4	8-May	22.5	23.5	91%	90%	37.5	26.1	42%	72%	27	25.7	69%	81%
5	9-May	21.9	23.6	89%	89%	36.7	28.2	39%	69%	27.9	26.5	61%	72%
6	10-May	23	24.7	88%	87%	36.8	28.7	48%	68%	28.9	27.3	73%	77%
7	11-May	24.7	25.1	85%	88%	35.4	28.5	48%	74%	26.6	26.9	85%	89%
8	12-May	25	25.3	93%	90%	34.2	28.2	51%	78%	27.6	27.1	90%	82%
9	13-May	24	25.1	90%	89%	31.6	27.2	54%	73%	27.5	27.1	75%	81%
10	15-May	22.3	24.8	92%	90%	28	26.5	77%	91%	27	26.5	93%	89%
11	16-May	26.5	25.1	85%	89%	30.3	28.6	78%	86%	23.4	24.7	83%	88%
12	17-May	22.2	24	86%	88%	34.2	28	49%	74%	27.5	27.5	77%	82%
13	18-May	24	24.5	75%	85%	35.2	28.8	47%	66%	27.9	27.6	56%	70%
14	19-May	22.9	23.4	75%	83%	34.5	27.8	51%	72%	27.6	27	74%	78%
15	20-May	23	24.3	81%	86%	31.9	27.3	56%	79%	22.7	24.5	86%	84%
16	21-May	22.1	24.9	94%	92%	32	23.9	64%	96%	26.2	26.4	72%	80%
17	22-May	22.6	23.7	82%	88%	26.9	23.9	72%	80%	26.1	25.5	74%	77%
18	23-May	24.7	25.3	72%	88%	34	24.9	66%	74%	24.9	22.3	92%	94%
19	24-May	24.1	23.5	81%	88%	30	27.6	60%	75%	26.3	25.4	84%	85%
20	25-May	24.9	25.8	88%	92%	31.4	29	71%	85%	28.8	27.5	73%	87%
21	26-May	22.6	21.7	80%	89%	31.6	27.7	78%	75%	26.2	25.2	80%	83%
22	27-May	25	25.7	86%	93%	28.6	27.7	81%	89%	28	27.5	77%	84%
23	28-May	26	25.1	86%	90%	32.9	28.4	80%	83%	28.4	27.2	75%	85%

24	29-May	26.6	24.7	87%	92%	33.2	29.2	71%	86%	28.2	27	74%	86%
25	30-May	26.3	25.1	90%	85%	36.8	28.9	81%	77%	28.2	28	78%	82%
26	31-May	26.3	25.2	79%	86%	31.8	28.8	78%	87%	28.7	27	80%	82%
27	1-Jun	26.2	25	92%	89%	29.5	28.6	79%	87%	27	26.8	93%	84%
28	2-Jun	25.1	25.6	86%	90%	32.3	28.4	80%	69%	27.7	28.7	78%	82%
29	3-Jun	25	25	87%	91%	27.9	26.3	89%	89%	27.2	27.9	84%	85%
30	4-Jun	26.1	25.9	90%	87%	36.3	29.8	82%	79%	26.3	25.9	80%	84%
31	5-Jun	25	24.2	82%	89%	33	28.6	80%	86%	28.1	27.9	82%	90%
32	6-Jun	25.5	25.1	83%	90%	33.9	28.9	80%	85%	28.4	28	85%	91%

Traditional House (T2)

Time		**7AM**				**2PM**				**7PM**			
S. N.	**Date**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**
1	5-May	23	23.7	86%	84%	32.5	25.2	62%	80%	27.1	25.1	72%	79%
2	6-May	23.9	22.7	88%	84%	24.7	23.9	87%	86%	22.1	24.1	89%	86%
3	7-May	21.4	21.9	93%	88%	35.9	25.9	45%	82%	27.5	24.9	66%	84%
4	8-May	22.7	22.4	87%	88%	38	24.8	43%	84%	27.8	25.2	70%	80%
5	9-May	22.6	21.4	84%	86%	39.5	26.4	35%	81%	28.9	25.5	57%	79%
6	10-May	23.2	23.1	86%	86%	40.1	28.3	45%	80%	28	26.3	71%	82%
7	11-May	26.1	24.6	86%	90%	34.4	28.2	52%	85%	26.8	26.1	85%	89%
8	12-May	24.1	23.3	89%	89%	31.1	26	76%	92%	28	26.6	69%	88%
9	13-May	24.1	23.4	86%	89%	30.8	26	68%	88%	28.5	26.1	78%	80%
10	15-May	22.5	21.2	91%	92%	27.7	26.2	81%	92%	27.2	26.3	84%	92%
11	16-May	25.9	24.1	91%	89%	31.1	27.3	79%	92%	24.3	26.7	77%	89%
12	17-May	22.3	23.4	88%	89%	33.5	26.6	55%	90%	28.2	26.7	77%	89%
13	18-May	24.7	23.5	72%	89%	35.3	27.8	48%	82%	28.4	26.9	60%	83%
14	19-May	23.3	22.2	75%	85%	33.9	29.1	56%	87%	28	26.5	73%	70%
15	20-May	24	21.9	85%	91%	32.6	26.6	65%	86%	23.3	24.4	83%	81%
16	21-May	21.8	23.5	89%	85%	32.6	26.8	72%	99%	26	25.2	75%	76%
17	22-May	22.9	23.2	81%	89%	26.8	24.4	75%	76%	25.5	29	74%	92%

18	23-May	24.9	23.3	75%	80%	33	23.5	62%	79%	23.8	22.3	85%	99%
19	24-May	23.8	22.9	81%	90%	30.2	25.8	62%	87%	27.3	26.7	80%	90%
20	25-May	26.7	22.6	90%	89%	30.3	27.9	79%	94%	28.1	27	81%	94%
21	26-May	22.3	21.3	82%	91%	33	26	74%	89%	26.7	26.9	76%	90%
22	27-May	25	23.7	81%	90%	28.6	26.8	83%	89%	29.7	26.9	76%	91%
23	28-May	25.6	22.9	83%	93%	33.1	26.5	58%	89%	26.9	25.7	73%	83%
24	29-May	26.9	23.7	80%	92%	32.3	27.3	86%	90%	28	26.8	76%	90%
25	30-May	27.2	24.9	81%	89%	36.4	28.7	48%	92%	28.1	27.6	77%	90%
26	31-May	26.5	22.4	81%	89%	32	28	75%	89%	27.3	26.7	80%	89%
27	1-Jun	25.8	22.8	90%	89%	29.7	28	79%	89%	27.1	27	84%	89%
28	2-Jun	25.6	23.9	88%	91%	33	26.3	79%	75%	25.5	27.9	76%	90%
29	3-Jun	25.8	23.7	84%	94%	28.8	26.6	79%	89%	26.9	27.2	76%	89%
30	4-Jun	26.9	22.8	80%	89%	36.7	28.9	59%	93%	26.6	26	78%	89%
31	5-Jun	25.8	25.1	89%	90%	33.5	27	69%	92%	27.7	27.9	83%	89%
32	6-Jun	26	24.3	83%	91%	34.1	26.9	56%	90%	28.6	29.5	81%	89%

Modern House (M1)

Time		**7AM**				**2PM**				**7PM**			
S. N.	**Date**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**
1	5-May	23.3	22.8	80%	81%	32.6	27.6	62%	72%	27.1	26.9	72%	70%
2	6-May	23.9	24.1	88%	85%	24.9	23.6	87%	88%	22.3	23.3	99%	89%
3	7-May	21.3	22.1	93%	92%	35.4	28.6	44%	81%	26.8	26.4	70%	78%
4	8-May	22.8	23.2	87%	86%	36.5	29.7	45%	74%	27.8	27.2	70%	66%
5	9-May	22.5	23.8	84%	82%	37	29.9	35%	72%	28.8	28	58%	63%
6	10-May	23.1	24.6	86%	81%	36.5	29.7	45%	72%	28.1	28.5	71%	71%
7	11-May	26.1	24.9	86%	84%	37.2	29.5	50%	72%	26.8	28.1	85%	81%
8	12-May	24.1	25.5	89%	86%	31.1	28.5	76%	77%	28	28.8	69%	71%
9	13-May	23.9	25.8	89%	83%	33.9	28.9	69%	82%	28.4	28.7	70%	73%
10	15-May	22.5	22.8	91%	90%	27.7	26.7	84%	88%	27.2	27.1	84%	89%
11	16-May	25.8	25.9	92%	93%	31.1	27.5	79%	84%	24.3	24.7	77%	78%

12	17-May	22.5	22.5	90%	87%	33.7	27.3	56%	78%	28.2	27.7	77%	79%
13	18-May	24.7	24.9	72%	78%	35.3	29.3	48%	64%	28.4	28.9	60%	66%
14	19-May	23.5	24.4	75%	76%	33.9	28.3	56%	73%	28	29	73%	70%
15	20-May	24	25.5	84%	80%	32.9	27.3	65%	78%	23.3	26.9	83%	74%
16	21-May	22.3	23.9	89%	90%	32.6	27.2	72%	72%	24.1	25.4	71%	70%
17	22-May	22.9	23	81%	87%	27.3	24.1	71%	83%	25.5	25.8	74%	75%
18	23-May	24.9	23.9	75%	79%	29.8	24.5	63%	71%	23.5	23.9	82%	89%
19	24-May	23.8	23.7	81%	84%	30.2	27.2	62%	75%	27.3	27.9	80%	75%
20	25-May	26.7	26.5	90%	87%	30.3	27.4	79%	83%	28.1	28.7	81%	81%
21	26-May	22.2	21.4	82%	90%	33	29.5	74%	82%	26.7	26.9	76%	78%
22	27-May	25	25.1	81%	88%	28.6	27.3	83%	82%	29.7	28.8	76%	74%
23	28-May	25.6	25.2	82%	85%	33.1	28.3	59%	76%	26.9	27	73%	70%
24	29-May	26.1	26.9	80%	89%	32.3	27.8	86%	84%	28	28.2	78%	85%
25	30-May	27.2	25.9	81%	84%	36.4	29.7	48%	75%	28.1	29.5	77%	73%
26	31-May	26.5	26.9	82%	86%	32	29.1	75%	79%	27.3	28.2	80%	83%
27	1-Jun	25.8	26.9	90%	89%	29.7	27.3	79%	89%	27.1	28	84%	84%
28	2-Jun	25.6	26	88%	87%	33	29.2	79%	87%	25.5	28.7	76%	78%
29	3-Jun	25.8	25.9	84%	88%	28.8	26	79%	88%	26.9	27.7	76%	79%
30	4-Jun	26.9	25.9	80%	86%	36.7	29.7	57%	78%	26.6	26.9	78%	79%
31	5-Jun	25.8	26	89%	86%	33.5	29.3	69%	79%	27.7	28.4	83%	83%
32	6-Jun	26	25.6	83%	81%	34.1	29.6	56%	78%	28.6	28	81%	84%

Traditional House (T3)

Time		**7AM**				**2PM**				**7PM**			
S. N.	**Date**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**
1	5-May	23.9	22.2	85%	78%	32.6	25.2	60%	76%	26.1	26.2	74%	79%
2	6-May	24.7	24.1	90%	86%	24.9	24	87%	87%	23	24.1	87%	87%
3	7-May	21.9	23.7	89%	88%	29.2	25.9	68%	85%	28.3	25.6	66%	82%
4	8-May	22.9	24.4	89%	88%	33	26.2	59%	78%	30	27.3	63%	78%
5	9-May	23.7	23.9	90%	86%	38.2	26.8	42%	80%	31.5	26.9	48%	78%

6	10-May	24	24.6	84%	86%	35.7	27.3	54%	80%	28.2	27.9	72%	79%
7	11-May	24.5	25.8	84%	88%	34.5	27.4	63%	80%	27.7	27.9	81%	86%
8	12-May	24.3	25.5	89%	90%	30.8	26.8	68%	86%	30.7	28.8	69%	86%
9	13-May	24.5	26.4	83%	94%	33.9	27.1	59%	82%	30.5	27.8	61%	86%
10	15-May	23.1	26.3	93%	89%	27.3	26.7	89%	89%	27.9	28.5	84%	89%
11	16-May	25.5	28.3	89%	89%	30.1	26	84%	87%	24.2	26.1	81%	86%
12	17-May	21.5	24.3	91%	89%	32.3	26.4	78%	87%	28.8	27.8	85%	86%
13	18-May	25	24.6	79%	86%	36.5	27.9	59%	75%	30	28.3	73%	77%
14	19-May	23.7	24.1	75%	83%	34.5	27.4	71%	71%	28.3	27.4	75%	78%
15	20-May	23.8	25.1	80%	87%	32.9	26.8	79%	82%	24.1	29	80%	85%
16	21-May	22.3	23.2	89%	92%	33.4	24	71%	79%	26.8	25.3	79%	70%
17	22-May	23.1	25.3	82%	83%	26.8	25.9	68%	74%	26.5	26.4	73%	74%
18	23-May	23.2	23.6	72%	89%	31.3	24.9	69%	73%	23.8	23.2	82%	80%
19	24-May	24	25.1	86%	89%	28.8	25.9	64%	81%	28	26.4	83%	87%
20	25-May	26.4	26.1	89%	94%	29.9	27.8	78%	90%	28	28.1	83%	89%
21	26-May	21.5	23.1	89%	88%	31.6	26.9	77%	78%	27.6	28	82%	86%
22	27-May	25.9	24.8	89%	89%	27.9	28.1	81%	89%	28.4	28.2	83%	88%
23	28-May	25.9	24.8	85%	90%	32.6	29.9	80%	83%	27.4	28.9	77%	75%
24	29-May	25	26.2	89%	89%	32.5	28.1	90%	90%	28.4	28	83%	86%
25	30-May	26.5	26.9	84%	94%	37.3	27.9	49%	88%	28.1	27	77%	90%
26	31-May	26.8	26.6	86%	88%	31.6	28.8	93%	91%	27.2	29.6	86%	88%
27	1-Jun	26	26.6	91%	89%	29.9	26.7	81%	89%	27.8	27.2	92%	87%
28	2-Jun	26.1	25.3	84%	89%	32.9	28	89%	77%	28.6	28.3	79%	84%
29	3-Jun	26.3	25.5	89%	90%	28	26.4	95%	89%	27.9	26.8	78%	86%
30	4-Jun	26	24.9	82%	88%	37	27.6	50%	83%	27	28.2	83%	84%
31	5-Jun	25.5	24.9	83%	89%	33	26.6	79%	83%	27.8	27	82%	89%
32	6-Jun	25.7	25	85%	91%	33.6	28.6	82%	85%	28	27.6	83%	89%

Modern House (M2)

Time	7AM	2PM	7PM

S. N.	Date	Outdoor Temp	Indoor Temp	Outdoor Humidity	Indoor Humidity	Outdoor Temp	Indoor Temp	Outdoor Humidity	Indoor Humidity	Outdoor Temp	Indoor Temp	Outdoor Humidity	Indoor Humidity
1	5-May	23.7	23.1	80%	81%	32.5	27.5	62%	77%	27.3	25.7	74%	77%
2	6-May	24.7	24.2	88%	83%	24.1	23.9	92%	86%	22.7	23.8	88%	86%
3	7-May	21.9	22.9	89%	86%	29.1	25.7	62%	85%	28	25.4	64%	80%
4	8-May	22.9	23.9	88%	83%	32.8	28.1	56%	74%	29.9	26.5	61%	74%
5	9-May	23.8	24.3	85%	81%	38.5	29.1	39%	74%	30.5	27	52%	72%
6	10-May	23.8	25.3	84%	80%	38.9	29.7	50%	77%	27.8	27.7	73%	78%
7	11-May	24.7	26.1	90%	81%	37.1	29.9	62%	73%	27.6	27.4	81%	84%
8	12-May	24.3	26	89%	84%	33.2	28.9	75%	77%	30.5	27.9	69%	79%
9	13-May	24.2	26.1	85%	81%	34	29.8	56%	76%	30.3	28.1	69%	79%
10	15-May	22.1	24.3	92%	85%	27.4	27.1	87%	84%	27.8	27.1	86%	86%
11	16-May	25.4	26.2	89%	89%	30.5	28.3	83%	83%	24.5	26.1	82%	78%
12	17-May	22.1	24	93%	81%	33.1	28.5	76%	77%	28.5	27.3	85%	93%
13	18-May	25	25.1	76%	75%	36.8	29.3	54%	68%	29.3	28	80%	77%
14	19-May	23.6	24.3	76%	73%	33.3	28.4	69%	71%	28.3	27.3	77%	77%
15	20-May	23.9	25.1	80%	76%	31.6	27.5	76%	80%	23.9	26.1	83%	76%
16	21-May	21.8	23.5	89%	89%	33.6	28.6	69%	82%	23.9	24	78%	86%
17	22-May	23.1	23.9	82%	80%	26.2	24.3	78%	86%	26.5	25.9	74%	78%
18	23-May	23.6	24.9	70%	72%	32.3	28.6	70%	70%	25.6	24	89%	70%
19	24-May	23.1	24.3	86%	81%	28.9	26.5	66%	76%	27.6	27.9	81%	82%
20	25-May	26.9	26.7	89%	84%	30	27.1	75%	82%	28.6	27.7	83%	84%
21	26-May	21.5	22.6	89%	81%	31.2	28.1	73%	75%	28	28.3	81%	79%
22	27-May	25.5	25.7	94%	86%	28.9	27.7	83%	85%	28.7	28.3	82%	82%
23	28-May	25.7	25.2	89%	82%	32.9	28.7	79%	80%	26.8	26.7	77%	77%
24	29-May	26.1	26.3	93%	86%	31.9	27.5	90%	83%	28.4	27.8	82%	84%
25	30-May	26.5	27.5	84%	82%	37.5	29.8	48%	83%	29	28.7	79%	81%
26	31-May	26.7	27	84%	75%	31.4	28.5	83%	94%	27.3	28.3	80%	83%
27	1-Jun	26.1	26.3	93%	88%	28.9	28.2	83%	84%	27.3	28	89%	84%
28	2-Jun	26	26.2	84%	86%	32.7	29.1	88%	71%	28.6	28.7	81%	78%
29	3-Jun	26.5	26.3	86%	88%	28.7	27.3	89%	88%	28.1	27.4	80%	85%

30	4-Jun	26.2	25	85%	86%	37.3	29.9	60%	88%	27.6	28.3	81%	79%
31	5-Jun	25.9	25.5	85%	86%	32.7	28.2	82%	80%	28.2	27.8	86%	80%
32	6-Jun	25.8	25.1	87%	80%	33.9	29.4	80%	79%	28.2	28	82%	80%

Traditional House (T4)

Time		**7AM**				**2PM**				**7PM**			
S. N.	**Date**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**
1	5-May	23.6	22.5	86%	87%	32.5	24.9	67%	81%	26.2	25	75%	80%
2	6-May	27.7	23.6	90%	90%	24.7	23.3	89%	90%	22.7	23.3	91%	90%
3	7-May	21.4	22.6	94%	89%	29.8	26	61%	81%	27.5	24.6	70%	84%
4	8-May	23	23.1	87%	91%	32.7	24.6	51%	83%	29.4	25.4	57%	79%
5	9-May	23.5	23.7	87%	90%	38.8	26.7	36%	73%	29.9	26	56%	78%
6	10-May	23.6	24.2	84%	90%	37.6	27.3	46%	77%	28.1	27.1	76%	79%
7	11-May	24.8	25.3	92%	88%	34.6	28	60%	85%	27.5	27.4	82%	89%
8	12-May	24.2	25.4	88%	90%	33.9	27.2	73%	81%	29.7	26.6	76%	85%
9	13-May	24	25.3	86%	89%	34.2	27.3	53%	81%	30	26.9	70%	83%
10	15-May	21.9	24	89%	89%	27.5	26.1	85%	90%	27.9	26.3	90%	91%
11	16-May	25.8	25.3	89%	89%	29.5	27.2	89%	87%	24.6	25.2	85%	87%
12	17-May	22.5	23.5	89%	90%	33.2	26	70%	87%	29.7	26.7	83%	89%
13	18-May	25	24.1	75%	88%	35.6	28	54%	71%	28.6	27.3	80%	80%
14	19-May	23.5	23.8	76%	85%	33.2	26	66%	80%	28.7	26.2	76%	84%
15	20-May	24.3	23.9	83%	87%	31.6	25.7	74%	88%	24	24.6	90%	86%
16	21-May	22.3	23.4	89%	92%	35.3	24.2	69%	84%	25.9	24.2	65%	80%
17	22-May	23.7	23.9	82%	90%	26.9	24.5	65%	80%	26.8	25.1	76%	79%
18	23-May	23.8	26	75%	73%	27.3	24.9	72%	69%	23.7	24.9	94%	92%
19	24-May	23.5	24.1	86%	91%	27.9	25.6	64%	84%	28.2	27.1	81%	89%
20	25-May	26.4	25.6	95%	93%	29.3	26.4	76%	92%	28.1	27	82%	89%
21	26-May	22	23.3	87%	91%	30.5	24.2	71%	82%	27.4	27.1	79%	83%
22	27-May	25.1	24.9	91%	92%	28.9	26.7	86%	92%	28.4	27.2	79%	86%
23	28-May	25.7	27.1	86%	89%	32.1	26.5	75%	80%	26.7	25.9	78%	87%

24	29-May	26.2	25.6	90%	93%	31.6	26.4	83%	91%	28.5	27	81%	86%
25	30-May	26.7	26.2	95%	92%	36.7	27.7	58%	89%	29	27.5	80%	86%
26	31-May	25.9	26	77%	79%	31.9	27.5	91%	89%	27.5	27	88%	89%
27	1-Jun	26.1	26	93%	89%	29.5	27.5	84%	89%	27.4	27	91%	89%
28	2-Jun	25.8	26.2	79%	84%	32.3	25.1	84%	84%	28.4	27.3	81%	85%
29	3-Jun	27	25.5	86%	83%	28.7	26.5	89%	88%	27.3	26.9	80%	86%
30	4-Jun	26	25.6	89%	92%	36.5	27.3	56%	83%	26.7	26	77%	89%
31	5-Jun	25.5	25	91%	86%	32.6	26.6	78%	89%	28	26.9	87%	89%
32	6-Jun	25.9	27	84%	88%	33.1	26.8	76%	82%	29.1	27.3	84%	92%

Traditional House (T5)

Time		**7AM**				**2PM**				**7PM**			
S. N.	**Date**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**
1	5-May	23.9	22.3	90%	87%	32.3	28.1	60%	77%	27.3	26	73%	79%
2	6-May	24.9	23.1	93%	89%	24.3	23.7	87%	93%	23.2	24	85%	89%
3	7-May	22.1	22.5	89%	93%	28.3	26.9	73%	82%	29	25.7	61%	82%
4	8-May	22.9	22.7	83%	90%	34	29.3	60%	80%	30.3	26.8	57%	74%
5	9-May	23.1	22.7	91%	88%	38.8	29.8	45%	79%	28	26.7	68%	77%
6	10-May	24.3	23.7	80%	89%	37.1	29.5	56%	51%	28.7	27.4	74%	79%
7	11-May	24.9	24.4	81%	89%	34.5	29.2	65%	78%	28.4	27	79%	89%
8	12-May	24.3	24.6	86%	92%	34.2	28.8	51%	78%	28.3	27.1	78%	83%
9	13-May	25.3	25.1	93%	91%	35.1	29.7	59%	79%	29	27.7	79%	86%
10	15-May	23	22.1	83%	89%	27.8	26.1	91%	93%	27.1	26.3	84%	89%
11	16-May	26.7	25.5	85%	89%	29.5	26.1	89%	80%	23.2	24.1	83%	86%
12	17-May	24.1	22.9	88%	89%	33.2	28.7	47%	81%	28.5	27.3	81%	84%
13	18-May	24.7	23.1	71%	85%	38.3	29.7	56%	73%	30	27.9	76%	77%
14	19-May	23.7	22.2	74%	83%	35.4	29.3	71%	77%	28	26.9	76%	81%
15	20-May	23.9	23.1	79%	86%	33.6	28.7	80%	85%	24.8	26.1	75%	81%
16	21-May	22.6	24	92%	90%	35.6	28.9	78%	79%	25.4	25.9	76%	87%
17	22-May	22.7	22.4	86%	88%	27.1	25.9	66%	75%	26.9	23.9	77%	70%

18	23-May	23.9	24	78%	86%	28.9	26.8	69%	76%	23.3	25.1	92%	81%
19	24-May	26.1	22.6	86%	89%	28.2	26.3	66%	82%	27.1	27.5	72%	89%
20	25-May	25.3	25.1	87%	94%	30.5	27.9	75%	91%	28.5	27.3	83%	89%
21	26-May	21.7	21.3	91%	90%	33.9	28.3	80%	80%	27.9	27.6	80%	85%
22	27-May	26.3	25	79%	89%	27.9	26.9	81%	93%	28	27.3	88%	87%
23	28-May	26.1	25.2	86%	90%	33	28.2	78%	85%	27	26.8	75%	89%
24	29-May	25.5	24.6	90%	89%	32.3	27.9	89%	91%	28.5	27	81%	86%
25	30-May	26	25.6	86%	89%	36.3	29.4	45%	85%	28.1	27.6	76%	83%
26	31-May	25.5	24.9	80%	83%	35.1	28.1	88%	92%	27.9	28.7	80%	82%
27	1-Jun	26.3	25.5	91%	89%	29.9	27.3	78%	90%	28	28.8	87%	92%
28	2-Jun	26	25	80%	93%	33.2	28.3	84%	75%	27.9	28	74%	81%
29	3-Jun	26.4	25.8	84%	89%	28.2	26.9	86%	82%	28	27.6	83%	86%
30	4-Jun	25.9	25	89%	85%	36.7	29.9	59%	85%	26.9	25.8	78%	86%
31	5-Jun	25.9	25	90%	89%	33.4	28.8	74%	89%	29	27.9	81%	90%
32	6-Jun	26	26.2	82%	80%	34	29.1	77%	82%	28.6	26.9	82%	91%

Modern House (M3)

Time		**7AM**				**2PM**				**7PM**			
S.N.	**Date**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**
1	5-May	23.9	24.9	77%	79%	32.3	26.7	60%	71%	27.3	27	73%	72%
2	6-May	24.7	25.7	88%	78%	24.3	25.3	87%	93%	23.1	25	85%	82%
3	7-May	22.1	24	89%	82%	28.3	25.7	74%	78%	29	27	62%	76%
4	8-May	22.8	25.1	83%	78%	34.2	29.1	58%	71%	30.3	28.3	57%	65%
5	9-May	23.5	26	93%	74%	38.9	29.5	45%	71%	28.1	28.3	68%	67%
6	10-May	24.1	26.6	80%	74%	37	29.9	56%	67%	30.4	29.4	74%	70%
7	11-May	24.8	27.5	82%	75%	34.9	29.5	65%	68%	28.4	26.9	84%	81%
8	12-May	24.3	27.3	86%	78%	34.2	29.1	51%	74%	28.3	28.5	78%	78%
9	13-May	25.3	27	94%	79%	35	29.5	59%	69%	29	29.1	79%	75%
10	15-May	23	26.7	83%	84%	27.7	27.1	91%	80%	27.7	27.7	84%	86%
11	16-May	26.7	26.9	85%	87%	29.6	26.1	80%	76%	23.3	27	83%	74%

12	17-May	24.1	25.7	88%	78%	33.4	28.1	47%	84%	28.3	28.1	81%	81%
13	18-May	24.7	26.5	71%	72%	36.3	29.7	56%	62%	30.7	28.3	76%	73%
14	19-May	23.8	26	73%	67%	35.4	29.1	71%	68%	28	28.1	76%	75%
15	20-May	23.4	26.5	79%	72%	23.7	27.5	80%	76%	24.8	26.5	76%	73%
16	21-May	22.6	25	92%	82%	35.6	29.2	78%	73%	23.1	25.7	76%	80%
17	22-May	22.1	25.1	86%	76%	27.1	24.9	66%	75%	26.9	26	77%	73%
18	23-May	23.9	24.3	76%	72%	28.2	27.3	69%	83%	26.3	26	75%	80%
19	24-May	26.1	25.2	86%	77%	27.9	26.9	66%	74%	27.1	28.1	72%	81%
20	25-May	26.3	27.5	87%	82%	30.5	27.8	75%	81%	28.5	28.6	83%	81%
21	26-May	21.7	23.7	91%	78%	33.9	29.1	80%	74%	27.9	28	80%	78%
22	27-May	26.3	26.9	89%	80%	27.9	27.8	81%	83%	28	28.7	88%	81%
23	28-May	26.1	26.5	86%	77%	33	28.6	78%	89%	27	28	75%	81%
24	29-May	25.5	27.5	89%	82%	32.3	28.3	89%	82%	28.5	28.3	86%	80%
25	30-May	26	26.9	86%	81%	36.3	29.9	45%	75%	38.1	27.9	76%	79%
26	31-May	25.5	27	80%	74%	35.1	29.2	88%	92%	27.9	28.7	80%	89%
27	1-Jun	26.3	27.5	86%	91%	29.9	28.5	78%	85%	28.8	28.3	80%	82%
28	2-Jun	26	26.8	80%	76%	33.2	28.2	84%	81%	27.3	28.9	74%	80%
29	3-Jun	26.4	27	84%	82%	28.2	26.9	86%	78%	28	28.3	83%	75%
30	4-Jun	25.9	26.3	89%	82%	36.7	29.9	59%	75%	26.9	27.9	78%	76%
31	5-Jun	25.9	27.2	90%	80%	33.4	29.2	74%	80%	29	28.3	81%	84%
32	6-Jun	26	26.9	82%	80%	34	28.8	77%	80%	28.6	28.8	82%	86%

Modern House (M4)

Time		**7AM**				**2PM**				**7PM**			
S. N.	**Date**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**	**Outdoor Temp**	**Indoor Temp**	**Outdoor Humidity**	**Indoor Humidity**
1	5-May	24.3	23.7	75%	79%	34.2	28.1	50%	71%	27.3	27	74%	69%
2	6-May	24.2	25.1	86%	79%	25.5	25	92%	81%	23	24.7	90%	81%
3	7-May	21.4	23.5	94%	83%	32.9	27.6	60%	77%	26.8	26.6	70%	77%
4	8-May	23	24.3	85%	81%	36.1	28.4	45%	72%	28.9	28	60%	69%
5	9-May	23.1	24.7	84%	77%	38.7	29.7	34%	71%	29.1	28.3	57%	69%

6	10-May	23.3	25.8	86%	77%	37.1	29.5	45%	71%	29.4	29.2	72%	70%
7	11-May	24.8	26.6	89%	78%	35.3	29.2	54%	72%	27.1	29	83%	76%
8	12-May	24.3	26.5	87%	80%	33.9	26.1	56%	75%	28.8	29.3	68%	73%
9	13-May	24	26.7	78%	89%	33.2	28.4	49%	70%	29.3	29	67%	72%
10	15-May	24.1	25.2	88%	83%	27.7	27.9	85%	80%	27.6	28	84%	81%
11	16-May	26	26.7	94%	86%	30	28.5	82%	82%	24.5	26.1	84%	79%
12	17-May	23.5	24.6	88%	81%	34.5	28.3	57%	76%	27.9	28.4	79%	77%
13	18-May	24.9	25.3	75%	76%	35.7	30.1	50%	67%	28.5	28.5	67%	70%
14	19-May	23.8	24.5	74%	73%	37.3	29.9	52%	69%	27.5	27.8	72%	72%
15	20-May	24.1	25.1	81%	75%	30.7	28	64%	74%	24	26.5	80%	75%
16	21-May	22	24.1	89%	82%	34.9	28.8	78%	73%	23.7	25.8	82%	78%
17	22-May	23.1	24.3	78%	82%	27.3	25.6	65%	70%	27.2	26	75%	70%
18	23-May	24.1	25.1	77%	82%	29.3	25.9	73%	74%	27.3	25	73%	69%
19	24-May	22	24.6	82%	80%	28.4	26.9	65%	76%	28.1	28.6	80%	79%
20	25-May	26	26.9	85%	83%	31	27.6	73%	82%	28	29	80%	80%
21	26-May	22	23	86%	82%	33.6	28.6	63%	76%	28	28.3	78%	75%
22	27-May	25.2	26	87%	84%	28.5	27.6	82%	84%	29.2	28.3	78%	73%
23	28-May	26	26.9	82%	79%	32.7	28.1	64%	74%	27.2	27.8	70%	77%
24	29-May	26.7	26.5	87%	83%	31.7	28	70%	81%	29.2	28.7	79%	79%
25	30-May	26.7	26.6	85%	89%	36.3	30.3	50%	76%	28.3	29.7	80%	77%
26	31-May	26.7	26.3	79%	76%	33	29.9	89%	90%	27.5	28.8	82%	81%
27	1-Jun	26	26.9	93%	84%	30.2	29.3	78%	81%	26.6	27	86%	81%
28	2-Jun	26.7	26.1	79%	77%	32.9	28.9	72%	73%	28.5	29.2	74%	75%
29	3-Jun	26.6	26.3	86%	80%	27.9	26.8	86%	75%	26.9	28	73%	74%
30	4-Jun	26.3	26.5	86%	80%	36.3	29.3	53%	76%	27.3	26	73%	79%
31	5-Jun	26.2	26.6	86%	83%	32.9	28.5	69%	78%	28.6	28.3	83%	80%
32	6-Jun	26.1	27	84%	78%	33.8	29.2	76%	80%	29.1	29.3	79%	83%

APPENDIX C: Thesis Originality Report

076March006_Jyoti Dhamala_Final Report.pdf

ORIGINALITY REPORT

11%
SIMILARITY INDEX

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1	d-nb.info Internet	476 words — 1%
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APPENDIX D: Journal article submitted to IOEGC, 2022

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फोन- ५५२१५३१, फ्याक्स- ५५२५८३०

Date: September 21, 2022

To Whom It May Concern

This is to confirm that the paper titled "*Climate Responsive Residential Architecture in Dhading*" submitted by **Jyoti Dhamala** with Conference ID **12150** has been accepted for presentation at the 12th IOE Graduate Conference being held in October 19 – 22, 2022 at Thapathali Campus, Kathmandu.

Khem Gyanwali, PhD
Convener,
12th IOE Graduate Conference

IOE Graduate Conference
[Placeholder for
Publication
Information]

Climate Responsive Residential Architecture in Dhading

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Abstract

Climate responsive design is considered to be one of the major requirements to drive the building sector towards sustainable development. Elements like air temperature, relative humidity, wind, irradiation, and rainfall these elements affect the climate responsive design of a certain region. Nepal has high varying topography which is leading to a variety of climatic conditions within short distance. With the introduction of modern construction technologies introduced in the country, the building sector has adopted uniform design and building techniques which is neglecting local climate and rely on energy intensive mechanical means to provide comfort within the building. For the study primary quantitative and qualitative field data and secondary quantitative climate data was collected from Department of Hydrology and Meteorology and developed bioclimatic chart and Mahoney table which gives the different design strategies for Dhading. This paper reviews examples of traditional and modern residential architecture and its building features in Dhading and analyses in a qualitative manner. Climatic data from Dhading shows that most of the month in a year are hot. From bioclimatic chart it was found that the summer temperature is high in day time hence passive cooling strategies are recommended. From Mahoney table also heavy walls and roof with permanent provision of air movement is recommended. From the study it was found that traditional building have less indoor air temperature but have high indoor humidity level. However traditional building materials and design features applied in Dhading are climate responsive than contemporary buildings.

Keywords

Climate responsive, residential building, climate, air temperature, humidity

1. Introduction

Climate responsive architecture is defined as architecture aimed at achieving occupant thermal and visual comfort with little or no recourse to nonrenewable energy sources by incorporating the elements of the local climate efficiently [1]. One of the essential requirements for guiding the construction sector toward sustainable development is climate-responsive design [2]. Climate responsive design uses climatic elements in formulating design approaches. The greatest use of climate elements like air temperature, relative humidity, wind, irradiation and rainfall can reduce the heating and cooling energy within buildings. Buildings are designed to achieve and produce an environment that is comfortable for people [3]. As a result, this refers to architecture that preserves the ecosystem of which it is a part while minimizing its adverse effects on the environment.

Buildings are now the world's biggest energy consumer and are crucial to attempts to combat climate change. Buildings consume an unexpectedly large 40 percentage of the world's energy, and the accompanying carbon footprint is much more than that of all forms of transportation combined [4]. This percentage will rise to more than 50 percentage if the energy used in the production of building materials like glass, cement, aluminum, and steel is taken into account. Energy demand in the building sector has increased by 2 percentage annually due to urbanization and wealth growth in developing nations and sub-urbanization in industrialized nations [5]. In Nepal, the residential sector alone consumes 89 percent of the total energy consumption, which is large attribute [3].

Buildings with high levels of energy efficiency improve the living conditions for occupants while minimizing their negative effects on the environment. On the other hand, the fundamental principle of climate responsive design is the assessment of climatic influence and the enhancement of building environmental performance [6]. In other words, trying to cooperate with the external climate to reduce resource consumption and negative environmental impact. So, without sacrificing contemporary living standards, climate responsive architecture can significantly contribute to lowering building energy use [6]. Truly, a building's ability to respond to climatic elements like wind and sun affects how comfortable its occupants feel within. Consequently, there is a relation between sustainability and climate responsive design, as both aim to reduce on active energy use while providing residents of the building with comfort [7]. Additionally, the usage of climate responsive design would be able to go further steps in sustainability and minimize energy consumption which is a nowadays discussion.

The climate of a given region plays a great role in building design. In order to design a building responding to environment all factors that effect on the external environment as well as all aspects of internal environment should be considered [8]. Potential saving of energy can be gained by activating specific, energy-efficient technologies but more so through careful design of urban environments and individual buildings: all naturally occurring resources should be integrated into planning and building and in such a way that their location, form and structure promote energy saving [9]. Many vernacular techniques of traditional architecture of Nepal are energy efficient and sustainable, though none of them is used in today's modern building design. Regrettably many traditional architectural values into designing with climate have been gradually lost in contemporary architecture [10].

The objective of the study is to study climate responsive design features and analyze climate responsive design strategies adopted in residential architecture in Dhading.

2. Methodology

The study was done in traditional and modern buildings located in Dhading. In order to fulfill the objective, this paper has adopted quantitative and qualitative method. For primary data indoor and outdoor air temperature and humidity were recorded for 32 days in the month of May and June. As secondary quantitative data, climatic data (air temperature, relative humidity and rain fall) of 10 years (2012-2021) were collected from Department of Hydrology and Meteorology of Dhading. The collected data has been analyzed through the bio-climatic chart and Mahoney table. Monthly data of minimum and maximum relative humidity and temperature are plotted onto the chart for each month in bio-climatic chart. The Mahoney table methodology is a set of reference tables that use monthly climate data of temperature, relative humidity and precipitation to calculate indicators for heat and cold stress as well as humid and arid conditions for each month [11]. The recommendation from the Mahoney table and bio-climatic chart were critically examined and compared with the design features and limitations of studied residential buildings.

In next step both traditional and modern residential buildings were analyzed in respect to their design and construction to determine the applied climate-responsive design strategies. For the analysis of residential building the approach of [11, 12, 13] was adapted. All these study use a set of building features to analyze the design and construction techniques of buildings in regard to climate responsiveness. Also the recorded indoor and outdoor air temperature and humidity were compared within the studied buildings.

2.1 The study area

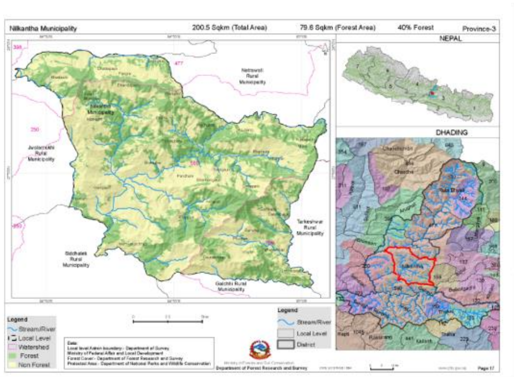

Figure 1: Location map of study area

source: https://nepalindata.com/resource/Local-Resource-Map—Nilkantha-Municipality/

In order to fulfil the defined objective, the study area has be chosen in such a place where there is ample numbers of traditional as well as modern residential buildings for investigation of climate responsiveness of buildings. The study area is in Pipley, ward number 7 of Neelkantha municipality, Dhading where most of the people are of Brahman. Most of the building within the study area used to be of timber and mud mortar- stone buildings before 2015 earthquake. But after earthquake the trend of cement mortar-brick and RCC type of building construction is rapid ("Ward Profile").

2.2 Measurement of air temperature and humidity

The measurement of air temperature and humidity has been recorded to access the climate responsiveness of residential building in Dhading. For the comparison both traditional and modern houses are taken for study. The study was conducted from May 5 to June 23, which is one of the hottest month throughout the year. Three different time readings were taken i.e. morning 7AM, day 2PM and evening 7PM. For temperature recording digital thermometer were used which also show the humidity level. The thermometer was place at 5ft. height from floor level. The thermometer was placed in such a place that it was not directly in front of openings or any kind of heat generating sources in the room.

2.3 Investigated buildings

In total nine houses were selected for case study. Out of nine, five of them are traditional houses where as four were recently built modern houses. As a house code 'T' is used for traditional and 'M' as modern building. All the traditional houses were built before 2050 B.S., whereas all modern houses were built after 2015 Gorkha earthquake.

2.4 Climate of Dhading

Ten years (2012-2021) data of temperature, humidity and rain fall was collected from Department of Hydrology and Meteorology. According to last ten years data, the climate is generally warm from March to October during day time. The summer months have a mean maximum outdoor air temperature 31.5°C during day and maximum at night is about 22.4°C. The cool season lasts from November to February. The mean minimum outdoor temperature is 6.9°C in winter month of December, with mean high with 18.9°C in daytime of same month. It has composite climate which changes from season to season, altering between longer hot periods to cool period and

Table 1: Summary of investigated houses

Design features	Houses	
	Traditional	Modern
Settlement pattern	Scattered	Scattered
Building form	Rectangular floor plan	Rectangular floor plan
Building orientation	West	West
Building stories	Two- two and attic floor	Two-two and half floor
Internal space arrangement	Ground floor: Kitchen, sleeping First floor: Sleeping, storage Attic floor: Storage	Ground floor: Rental, sleeping First floor: Sleeping, living Top floor: Kitchen
Semi-open space	Shaded veranda	Veranda and balcony in upper floor
Wall material	Stone and mud with mud plaster in front facade	Brick and cement wall with cement plaster
Wall thickness	0.45	0.127
Roof material	Pitched roof of slate	RCC flat roof
Floor and ceiling	Wooden structure with lathwork and mud covering	RCC
Average opening percent	6.36	16.23

Figure 2: Sample of investigated traditional and modern residential buildings

concentrated rainfall. The total rainfall is more than 1451 mm in a year. But mostly rainfall occurs during

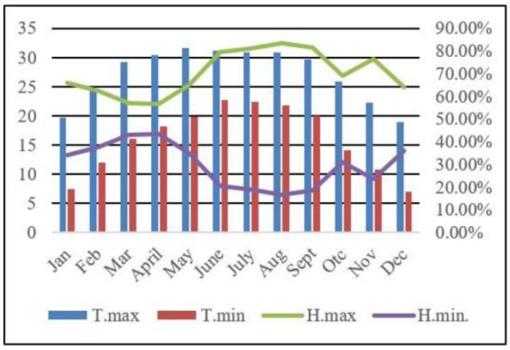

Figure 3: Mean temperature and relative humidity of Dhading

only monsoon season. The yearly average maximum relative humidity is more than 70 percentage during monsoon period (June, July, August and September) in the last ten years (2012-2021) according to Meteorological Department of Government of Nepal.

3. Data Presentation and Analysis

3.1 Air temperature and humidity in traditional houses

In the figure below indoor temperature and humidity of the investigated traditional houses are presented. During investigation it was found that T3 house has highest 26.41°C indoor temperature, whereas T2 house has lowest 25.39°C temperature. But T2 house has highest humidity level with 87 percent, whereas T1 has minimum level of humidity with 84 percentage. The average indoor temperature difference of investigated houses is 1.02°C and humidity differences is 3percentage which is between house T3 and T2 and T2 and T1 respectively. The average outdoor temperature of the day was 28.05°C. In an average the indoor and outdoor temperature differences was 2.05°C. The average indoor humidity level is high with 3 percentage.

3.2 Air temperature and humidity in modern houses

In investigated modern houses the temperature and humidity level of 32 days are plotted in graph above. During the investigation it was found that M1 house has lowest average indoor temperature with 26.72°C

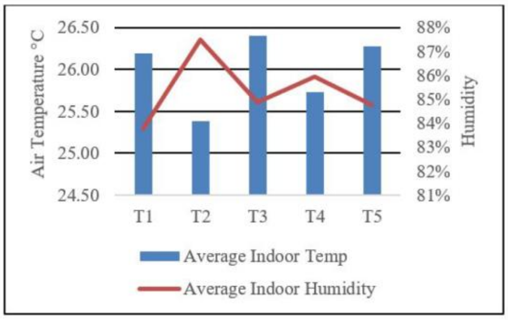

Figure 4: Average indoor temperature and humidity of traditional houses

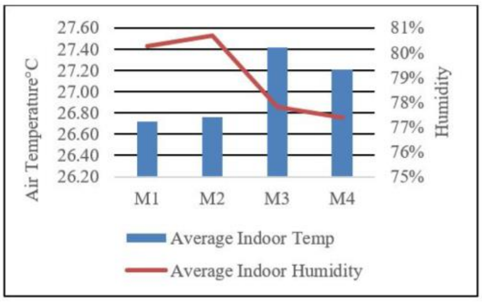

Figure 5: Average indoor temperature and humidity of modern houses

and maximum of house M3 with 27.41°C. The average indoor humidity level was high in M2 house with reading 81 percent and low of house M4. The differences of highest and lowest average temperature and humidity level was between house M1 and M3 with reading 0.69°C and M2 and M4 with 4 percent respectively. In an average outdoor and indoor temperature difference in modern building was 1.12°C. The average indoor humidity level was high with 2 percent than outdoor humidity level in modern building.

3.3 Comparison of indoor air temperature and humidity in traditional and modern house

The collected data of temperature and humidity was compared between traditional and modern house. In the chart below all traditional houses have less indoor average temperature than modern house. The minimum indoor temperature was in morning time which is recorded at 7AM and the highest is during day time which is recorded at 2PM. In morning time there is 0.08°C indoor temperature differences between modern and traditional houses which is negligible. In day time the indoor temperature differences was 1.05°C. Likewise in the evening time the indoor temperature differences is 0.9°C. In an average indoor air temperature of traditional building was 26°C and average indoor air temperature of modern buildings was 27.03°C. The average air temperature difference between modern and traditional house is 1.03°C. This show that traditional houses are cooler than modern houses. During the investigation it was found that the average indoor humidity level was high in traditional buildings than modern houses by 2 percentage. The average indoor humidity level in traditional building was 81 percentage and 79 percentage in modern building. In morning and evening time the humidity level was high in both indoor and outdoor. The differences in humidity level in modern and traditional houses was up to 7 percentage in morning and evening time.

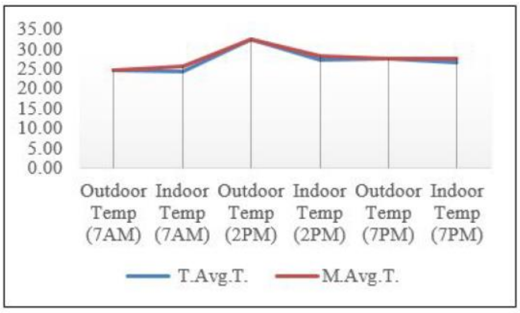

Figure 6: Average temperature of traditional and modern houses

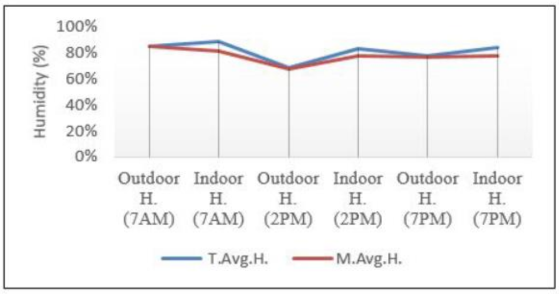

Figure 7: Average humidity of traditional and modern houses

3.4 Mahoney table for Dhading

The recommendations from Mahoney table provide preliminary design recommendations. From the data available from Department of Hydrology and Meteorology of ten years, Mahoney table was developed for Dhading. The Mahoney table suggest that the orientation of building should be north and south (long axis east-west) direction. Single blanked room with permanent provision of air movement is essential. Medium opening with 20-40 percentage is recommended in north and south wall at body height on windward direction. The opening should be protected and adequate rainwater drainage features should be applied for heavy rain.

3.5 Bioclimatic Chart for Dhading

By plotting climatic data of Dhading in the chart, it shows that most of the months are relatively hot and passive cooling strategies must be incorporated in the design. Day time temperature in October and February falls in the ideal comfort zone but night during these months are still cold. A short duration of night time temperature in May to September falls in the ideal comfort zone. Six months (April to September) are hot and humid, and building design strategies should make provision for air movement. For the month of January and December solar passive heating is required. In this month night temperature remaining below 12°C, where month of January and December temperature come close to 8°C. To maintain room temperature in this period the passive heating strategies should be applied.

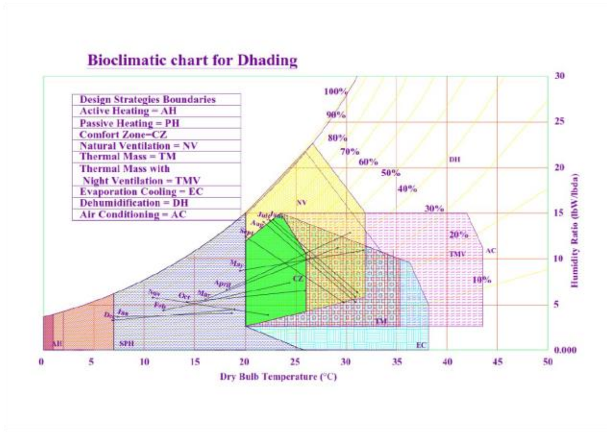

Figure 8: Givoni's Bioclimatic chart for Dhading

3.6 Climate-responsive design strategies applied on investigated houses

Residential buildings both modern and traditional were studied as a part of climate responsive architecture in Dhading. In table below climate-responsive or solar passive design strategies parameters which were identified from literature reviews were checked in individual buildings. After studying the result are shown in following table. '+' applied, '±' partially applied, '-' not applied

Table 2: Climate responsive design strategy applied in investigated houses

Climate responsive design strategy	Recommendation	Traditional houses	Modern houses
Layout	Long axis east west	-	-
Spacing	Open spaces for breeze penetration but protection from hot and cold wind	+	±
Air movement	Rooms single blanked permanent provision of air movement	±	-
Opening	Medium openings,20-40 percentage	-	-
Walls and floors	Heavy external and internal walls	+	-
Rain protection	Protection from heavy rain necessary	±	-
Position of opening	In north and south walls at body height on windward side	-	±
External features	Adequate rainwater drainage	±	±

4. Discussion

Climate data of 10 years (2012-2021) available from Department of Hydrology and Meteorology shows that seven month from March to September, the maximum average temperature remains above 29°C. The primary data was collected in month of March and June for 32 days. The average maximum and minimum outdoor temperature measured during field study was 32.6°C and 24.52°C. The average maximum and minimum outdoor temperature was 31.36°C and 21.29°C for the month of May and June as per Department of Hydrology and Meteorology. The average maximum humidity for the month was 72 percentage as per data available from Department of Hydrology and Meteorology and as per field recorded data, the average humidity was 77 percentage.

Investigation done in traditional houses shows that average indoor temperature was 26°C. During day time when the average outdoor temperature was 32.33°C, indoor temperature was 5.25°C cooler than outdoor temperature. In an average inside of traditional houses are 1.05°C cooler than outdoor. According to Rijal, Yoshida [14] the study done including Dhading, the comfort temperature is 15.2°C to 25.6°C for winter and summer in temperate region. However a study done by Lamsal, Bajracharya [3] shows that comfort temperature in temperate climate rage between 22.8-27.8°C and 18.5-23.5°C for summer and winter respectively. The average indoor temperature is very close to upper limit of comfort temperature. However the average indoor humidity is 81 percentage which makes indoor environment not comfortable. This result shows that in traditional houses natural ventilation is very essential during summer season. Likewise, in modern houses the average indoor average temperature was 27.03°C. In day time the average indoor temperature was 28.13°C, which is less than 4.25°C than outdoor air temperature. The average outdoor humidity was 77 percentage and which is less than 3 percentage indoor humidity level. In modern buildings the indoor temperature and humidity level is above the comfort level.

The indoor temperature in traditional building is less by 1.03°C but humidity level is high by 2 percentage. This shows more than 10 percentage energy can be saved for cooling in traditional houses [14]. The investigation done in Dhading shows that, both types of houses are not comfortable in summer season. This shows that in both types of building design intervention is needed to achieve comfort within the buildings. The bioclimatic chart for Dhading shows that natural ventilation is very essential for five month i.e. May, June, July, August and September. These are the hottest month of the year in Dhading according to climatic data also. The humidity is high in these months. Also short period of day, natural ventilation is essential in the month of March and April. For the month of December and January, solar passive heating is essential. Also in October and November, majority time are cold hence passive heating is needed. Mahoney table also suggest that from June to September, air movement is essential. Protection from cold is essential for the month of November, December and January. According to Mahoney table rain protection is needed for the month of June, July and August which is peak monsoon time as per climatic data of Dhading.

During the investigation it was found that, climate responsive design strategies were fully or partially followed by traditional houses more than modern houses. All the building has rectangular floor plan facing west as per nature of the land terrace. To orient longer axis east-west direction as suggested by Mahoney table, site intervention is required.

In traditional buildings the semi open veranda in ground and first floor level helps to shade the front (west) façade from direct heat gain in the building. Generally, houses in this climate are of high thermal mass using locally available materials like stone, mud, timber and bamboo. Particularly, during sunny winter days the thermal mass is favorable to store solar heat gains of the day for cooler nights [11].

The material used in contemporary buildings are kiln burnt bricks, cement, sand, reinforcement bars etc which are very energy intensive and not environmental friendly [15]. The external wall in most of houses are very thin (five inches), from which heat loss and gain in winter and summer is very high. In contemporary building there are open veranda which shade the lower portion of the wall/ floor but during summer season these area gain so much heat that it is inhabitable during day time. The opening size of traditional houses are small and are only on longer façade. But in modern buildings the size of openings are huge and can be observed in most of the direction. From the study it can be said that the percentage of opening (area wise) in modern buildings seems close enough as suggested from Mahoney table. But still there is lack of cross ventilation system in modern building.

5. Conclusion

Climate responsive building design has become the growing issue for researcher all over the world for achieving indoor comfort and saving active use of energy. Climate-responsive design is considered to be one of the major requirements to drive the building sector towards sustainable development. Elements like air temperature, relative humidity, wind and rainfall these elements affect the climate responsive design for that region. The research has presented the result and findings of air temperature and humidity in the field regarding the indoor and outdoor environment of the traditional and modern houses in Dhading. The research from the field study shows that traditional houses are 1.03°C cooler than modern houses. Traditional architecture considers local climate and is in consonance with climate responsive design strategies recommended by Mahoney's table and bioclimatic chart such as high thermal mass, open spaces for breeze penetration, single blanked, heavy walls and roofs etc. in Dhading.

6. Recommendations and Further Works

It is recommended to researchers to incorporate air temperature and humidity of all four season to validate research more accurately. Further work can be carried out by incorporating macro and micro climatic factors like radiations, local wind directions etc. During the field visit it was found that most of the traditional building lack maintenance, hence those who inhabit are recommended to carry out regular maintenance work. For designer it is recommended to use locally available materials. Also the position, area of opening and air tightness in traditional buildings are highly recommended.

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