TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING,
PULCHOWK CAMPUS

Thesis No.: 076/MSEEB/014

ENHANCING THERMAL COMFORT IN POST DISASTER RESIDENTIAL RECONSTRUCTION: A CASE OF DOLAKHA TOWN

BY

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A THESIS
SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER'S IN
ENERGY EFFICIENT BUILDING

DEPARTMENT OF ARCHITECTURE

LALITPUR, NEPAL

OCTOBER 2022

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This thesis incorporates only work that I have accomplished with the exception for the consulted material which has been duly referenced and acknowledged.

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ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to Dr. Sanjaya Upreti, thesis supervisor and Ar. Barsha Shrestha, thesis co-supervisor for their continuous intellectual support and motivation. Their constant guidance, enthusiasm and suggestions throughout the research process have been invaluable for the preparation of this report.

My sincere appreciation also goes to the local people of Dolakha town for smooth and easy conduction of questionnaire survey and field study. I would like to thank Miss Gita Shrestha and Mr. Tirtha Narayan Joshi for their immense help during the study of their respective buildings. I am thankful to Er. Suresh Raut for providing me the necessary documents required for the research.

I would also like to extend my gratitude to Department of Architecture, Msc in Energy Efficient Building, IOE, Pulchowk Campus, my friends and family and to everyone who have helped me for conducting the research.

Thank You

Rajina Shrestha

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ABSTRACT

The research aims to learn about the thermal performance of traditional and post-disaster reconstructed residential buildings of Dolakha town and the ways to enhance thermal comfort through passive design strategies in terms of building envelope. One of the important aspects of building a house is to provide a specific level of desired thermal comfort. Earthquake 2015 and its subsequent aftershocks led to destruction of numbers of houses. The reconstructed buildings lag thermal comfort with modern architectural style. Because of their increased attention to seismic performance, many buildings have neglected the local climatic condition. Enhancement of thermal comfort and attaining energy efficiency is the first step to achieve sustainability in post disaster reconstruction.

Various passive design strategies and energy policies of Nepal are studied for energy efficiency in buildings. Szokolay’s Bioclimatic chart is used to determine different passive strategies to achieve thermal comfort in Dolakha town and results from Mahoney’s table are used. Ecotect energy simulation software is used to evaluate the thermal performance of traditional and post disaster reconstructed building. Seven case scenarios were created to optimize post disaster reconstructed building with change in infill wall material and construction technology and window wall ratio. The research concludes that optimizing window wall ratio with double glazed window helps in achieving thermal comfort by 4.37%. Changing infill wall to stone wall in cement mortar helps in optimizing by 22.31%, switching infill wall to cavity wall of Brick shiner wall on either side with air cavity improves efficiency by 18.05% and to cavity wall of half brick on either side with air cavity is improved by 21.56%. The cavity wall of hollow concrete block as inner leaf and half brick wall as outer leaf helps in improving thermal comfort by 19.25%. A residence design is proposed with the change in internal space arrangements, building form, building material and construction technology which is found to be optimized by 30.5% with brick cavity wall and by 32.6% with stone infill wall.

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1 Chapter 1: Introduction

1.1 Background

According to ASHRAE, thermal comfort is defined as “that condition of mind which expresses satisfaction with the thermal environment”. One of the important aspects of living in a house is the ability to achieve a desired level of thermal comfort (Rai, 2014). With the increase in energy consumption, climate change and global warming, making energy efficient has become a priority. This has led to the demand of passive strategies in promoting comfortable indoor environment. Thermal comfort can be achieved with passive design through which building features such as orientation, thermal mass, insulation, and glazing work together to take advantage of natural sources of heating and cooling such as sun and breezes, and to minimize unwanted heat gain and loss. (Australian Government, 2022).

The Earthquake of 2015 and the subsequent aftershocks led to massive destruction of lives and infrastructures mostly in hilly regions of Nepal. Post disaster recovery framework proposed different building typologies for the reconstruction of hilly settlements that focused more on seismic performance and, hence neglecting the local climate. Almost all the buildings constructed after earthquake has the problem of being overheated during summer and severe cold in winter season. According to Bajracharya, Shakya & Bajracharya (2014), Enhancement of thermal comfort and attaining energy efficiency is the first step to achieve sustainability in post disaster reconstruction. Sustainability is a major dimension in post-disaster housing reconstruction, largely justified by energy consumption and management, which is analyzed through an understanding of the energy performance of the building. Constructing large numbers of buildings after earthquake provides an opportunity to introduce the concept of Build Back Better.

According to (International Energy Agency, 2013), “Buildings are the largest energy consuming sector in the world and accounts for over one-third of total final energy consumption and an equally important source of carbon dioxide (CO2) emissions. Achieving significant energy and emissions reduction in the buildings sector is a challenging but achievable policy goal.” Since 2010, rising demand for energy services in buildings (particularly electricity for powering cooling equipment, appliances and connected devices) has been outpacing energy efficiency and decarbonization gains. For residential refrigerators and air conditioners, MEPS (Minimum Energy Performance Standards) covers more than 80% of global final energy use. Buildings are responsible for 37% of global final energy consumption. (International Energy Agency, 2021)

In Nepal, residential sector alone consumes 80.36% of the total energy consumption (WECS, 2014). This has largely attributed to residences constructed without considering the local climate and topography. Huge amount of energy is used for lighting, heating /cooling, ventilation, and others, depending on the type of building and its use. Improvement of energy efficiency in buildings is a sustainable way to reduce energy consumption and consequent environmental impacts. Nepal is in favorable location and receives ample amount of solar radiation i.e., sun shines for about 300 days a year (GON, WECS, 2013). This provides the opportunity make maximum use of solar energy in residential building.

The case area Dolakha is one of the worst affected districts of earthquake 2015. While the 25$^{th\ of}$ April earthquake caused widespread damage to the area, the second earthquake led to more severe damages and casualties in Dolakha and other eastern districts. About 87% of houses are fully or partially destroyed (50,284 houses fully damaged and 305 houses partially damaged) (Nepal Earthquake, 2015).

1.2 Need for the study

After the massive destruction led by devastating earthquakes of 25 April and 12 May 2015, new buildings and the settlement are being developed in haphazard way with the introduction of modern construction materials and technologies, imitating modern architecture style hence neglecting the local climatic conditions and its vernacular architecture. Despite the policy provisions, the reconstruction is largely focused only on seismic standards. According to Bajracharya, Shakya & Bajracharya (2014), energy efficient building is the first step to achieve sustainability in post disaster reconstruction. Reconstruction of buildings has allowed the concept of Build Back Better to be introduced in the residential sector while ensuring thermal comfort for the occupants. But the concept of Build Back Better is introduced only by enforcing safety guidelines and compliance of safer construction practices through knowledge building and awareness raising of homeowners, masons, and engineers (The World Bank, 2021).

Many researchers have studied about the thermal comfort and its improvement in the residential buildings of Kathmandu valley. Construction of passive solar building can significantly reduce the heating and cooling energy load and the contemporary buildings can be made energy efficient to some extent by improving building envelope, and window glazing (Bajracharya, Shakya, & Bajracharya, 2020). Most of the buildings being constructed has neglected the internal thermal comfort condition. As per the findings of (Rai, 2014), application of appropriate passive design strategies can improve the performance of building. (Chaulagain, Baral, & Bista, 2019), concluded that the quantification by the number of hours spent by occupants in uncomfortable indoor temperature range proves that present Nepalese building is not thermally comfortable for accommodation as per ASHRAE guidelines. Passive environmental controls can be used in the construction of modern buildings to enhance indoor thermal comfort and most of the vernacular buildings have inherited passive solar features in India (Chandel, Sharma, & Marwah, 2016). A necessary approach needs to be developed at the stage of architectural design phase. Energy consumption of a building can be reduced at different life cycle of the building viz. pre-building, building and post-building phase (Yüksek & Karadayi, 2017).

Studies have been done considering the seismic performance of traditional buildings of Dolakha. But the study area is fresh topic for research as there are no studies conducted in this area regarding thermal comfort, energy efficiency in the residential building. So this provides the need for study to enhance the indoor thermal comfort of the building occupants of residential building. The research will also help in Nepal’s goal to achieve net-zero emissions from 2020-2030.

1.3 Importance of the study

The research seeks to review and understand the thermal performance of traditional and prototype buildings for improving energy efficiency in residential buildings of Dolakha town with respect to the local climate. The prototype buildings of Dolakha town differs from that of other earthquake affected areas as it is also guided by Department of

Archeology. The study will aid in the integration of energy efficiency into the reconstruction of buildings and provide thermal comfort within the building environment. It will help the respective municipality and the ward community to build byelaws and implement it to enhance thermal comfort of building occupants. It will also benefit architects and engineers, planners, local administration, and policy makers in designing buildings and also the research communities for further studies.

1.4 Problem statement

Buildings of today's architectural style consume a lot of energy to provide indoor thermal comforts. In context of Nepal, indoor thermal comfort is achieved through various methods of clothing and food to accommodate in harsh weather (Chaulagain, 2020) rather than making the residence comfortable to live in. Introducing energy efficiency in building design can be taken as an advantage to minimize energy consumption and can be incorporated in the reconstruction of buildings. Modern architectural style has been widely accepted all over Nepal and the buildings are constructed in haphazard manner without considering the local climate and its architectural context. Regardless of different national policies, these has not included the energy guidelines for building sector.

The prototype buildings of Dolakha town are focused more on seismic standards and the aesthetic appearance to replicate the old Newar town without considering local climate and climate responsive design strategies. Bye laws were also developed and implemented considering the structure stability only and some measures were used to replicate the vernacular architecture of the area, but it has neglected the perspective of thermal comfort.

1.5 Objective of the study

The main objective of the research is to examine and compare the thermal comfort of traditional building and post disaster reconstructed buildings to enhance thermal comfort in residential buildings of Dolakha town, in terms of building envelope performance.

The specific objectives are:

- To study and analyze the building envelope in terms of construction material and techniques and architectural features (orientation, building layout space, opening size and placement, color, and texture)

- To study and analyze energy consumption pattern (heating, lighting, cooking,) and thermal sensitivity of material used

1.6 Validity of Topic

There are several research on thermal comfort of residential buildings, thermal performance of traditional buildings in Kathmandu valley and other regions of the world. Research and studies are more focused on urban sector rather than rural. But there are no such studies of Dolakha. The old Newar settlement of Dolakha town holds specific importance as it shows the history. The traditional Newar buildings of Dolakha differs from that of Kathmandu valley in terms of Building material and the incorporation of local climate so there seems to be need for the study to analyze the thermal performance of traditional buildings and post disaster reconstructed buildings.

Similarly, several studies related to post disaster reconstruction are only focused on seismic standards and how to make the building structurally stable but there is no research that depicts the importance of energy efficiency and indoor thermal comfort.

Therefore, it can be an effective and fresh research topic to introduce and enhance the use of energy efficiency in residential buildings of Dolakha town to ensure thermal comfort within the building as most of the buildings are being constructed after earthquake 2015.

1.7 Expected output

It is expected that the research will meet its objective of achieving energy efficiency in residential building in terms of building envelope performance through the comparison of thermal performance of traditional and reconstructed building of Dolakha town. The simulation of these buildings and the optimized building will provide guidance in formulating energy efficient design strategies for enhancing thermal comfort of building occupants. The research will also aid in minimizing the energy consumption reconstructed buildings.

1.8 Limitations of the research

The research is limited to residential buildings of core area of Dolakha town only. Due to the time limit of completing the research project, the field study of the research was performed during late June month i.e., summer season and early monsoon period. The measurements of air temperature and relative humidity data were recorded in the respective time period only. The study is focused on the energy performance of wall material and the optimization is carried out accordingly.

2 Chapter 2: Literature Review

2.1 Historical background

Natural disaster occurs frequently around the world and are responsible for heavy damage of lives and the property as well. Post disaster reconstruction is a part of sequential initiation of four identifiable post disaster periods: emergency, restoration, reconstruction, and betterment construction (Ismail, Majid, Roosli, & Samah, 2014). Despite of the negative impact, it can be an opportunity to transform the destructive area into sustainable community. Post disaster reconstruction helps in rebuilding a community as a model of sustainability through the means of reducing energy use, using energy more efficiently, incorporating more renewable energy and much more (U.S. Department of Energy, 2009). The housing reconstruction after hurricane Katrina 2004 in New Orleans, USA, and the reconstruction in Greensburg, Kansas after a devastating tornado in 2007 found that the reason for incorporating energy efficiency in reconstruction is compelling.

In context of Nepal, after devastating Earthquake of 2015 and the subsequent aftershocks, Government of Nepal established Nepal Reconstruction authority in response to oversee reconstruction activities. Housing was the largest need identified by Post Disaster Needs Assessment (PDNA) i.e., almost half of the total reconstruction needs.

Thermal performance of a building is the ability to maintain comfortable indoor environment with minimal energy demand regardless of outdoor weather scenario (Chaulagain, Baral, & Bista, 2019). Different studies of (Ahmad, Khetrish, & Abughres, 1985); (Algifri, Gadhi, & Nijaguna, 1992) ; (Rijal, Yoshida, & Umemiya, 2010); (Bajracharya, Shakya, & Bajracharya, 2020); (Kumar, Mathur, Mathur, Singh, & Loftness, 2016) have found that the traditional buildings have better thermal performance as compared to the newly constructed buildings.

2.2 Thermal comfort

There is no exact straight forward explanation of thermal comfort and cannot be expressed in degrees. According to American Society of Heating, Refrigeration and Air-Conditioning, (ASHRAE), “Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.” It is also defined by ISO 7730:2005, as that state of mind which reflects satisfaction with the thermal environment, i.e., the state of not being too hot or cold.

Thermal indoor environment is affected by the heat exchange between the human body and its environment that occurs mainly through radiation, convection, and evaporation (Moe, 2022). Various environmental factors such as air temperature, mean radiant temperature, air velocity, humidity and clothing level influence thermal comfort that must be maintained in a healthy balance for occupants to be satisfied with their surroundings (Designing Buildings, 2020). It differs from person to person within the same space depending on factors such as activity level, clothing, and humidity.

2.2.1 Comfort zone

Comfort zone is the range of climatic conditions within which a majority of persons would feel thermal comfort (Kumar, Mathur, Mathur, Singh, & Loftness, 2016).

There are several techniques and models developed to define thermal conditions to achieve thermal comfort. However, it can be expressed in terms of Predicted Mean Vote (PMV) method and Percentage People Dissatisfied (PPD) method, developed by Professor Ole Fanger, as suggested by BS EN ISO 7730 and BS EN ISO 1055 (Designing Buildings, 2020).

Predicted Mean Vote (PMV) method includes PMV index that is comprised of six variables i.e., psychological variables (clothing insulation, activity level and metabolic rate) and environmental variables (air temperature, wind speed, relative humidity, and radiation temperature). In order to measure the thermal comfort level, PMV value index uses seven scale ranging from -3 to +3 that represents one’s feeling from cold to hot. (H A & Arif, 2021)

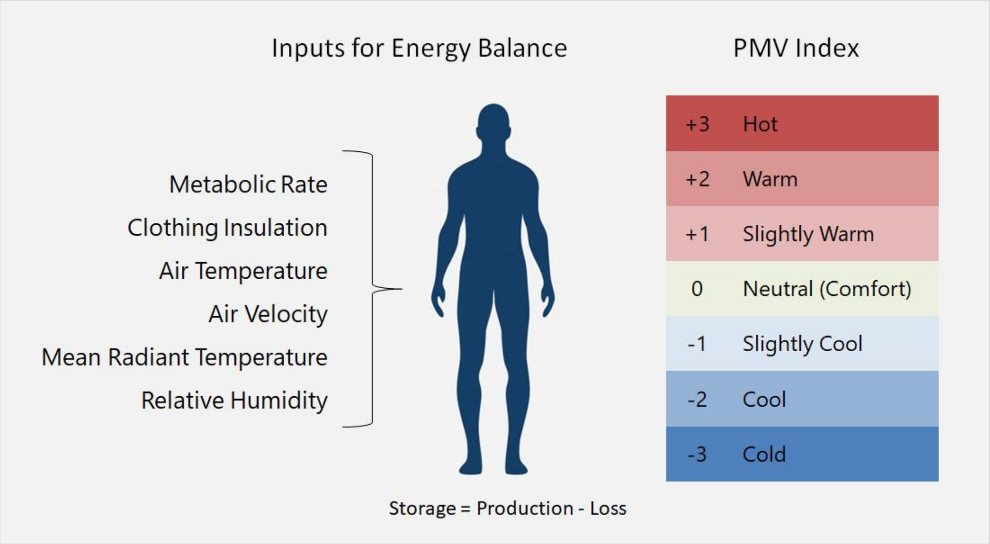


Figure 1 PMV Thermal Comfort Criteria

Source: (Kumar P. , 2019)

After the calculation of PMV, Percentage People Dissatisfied provides quantitative prediction of the percentage of thermally dissatisfied people who feel too cold or too hot. It gives the percentage of people that are expected to experience local discomfort. (Guenther, 2021)

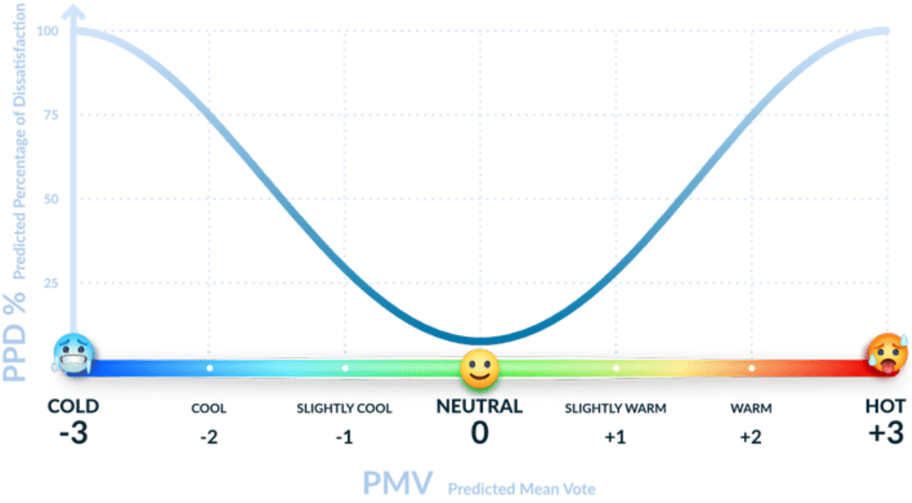


Figure 2 PPD and PMV

Source: (Guenther, 2021)

ASHRAE 55 states that thermal comfort can be achieved based on at least 80% occupant satisfaction rate using both the indices i.e., PMV and PPD. The recommended thermal limit on the seven-point scale of PMV is between -0.3 to +0.3 (Kumar P. , 2019). Depending on the calculated PMV, the PPD can range from 5% to 100% while the occupant's level of comfort will vary as per the location of them in the building (Guenther, 2021).

A graphic comfort zone is another method to evaluate thermal comfort that works by utilizing an overlay in psychrometric chart to indicate operative temperature and humidity. It is based on PMV model with the assumption of achieving thermal comfort with different level of clothing 1.0 clo in winter and 0.5 clo in summer. In addition, it is limited to applicability to conditions when the metabolic rate of occupants is between 1.0met to 1.3 met and the humidity ratio is below 0.012 Kg H_20/ Kg dry air. (ASHRAE-55, 2015)

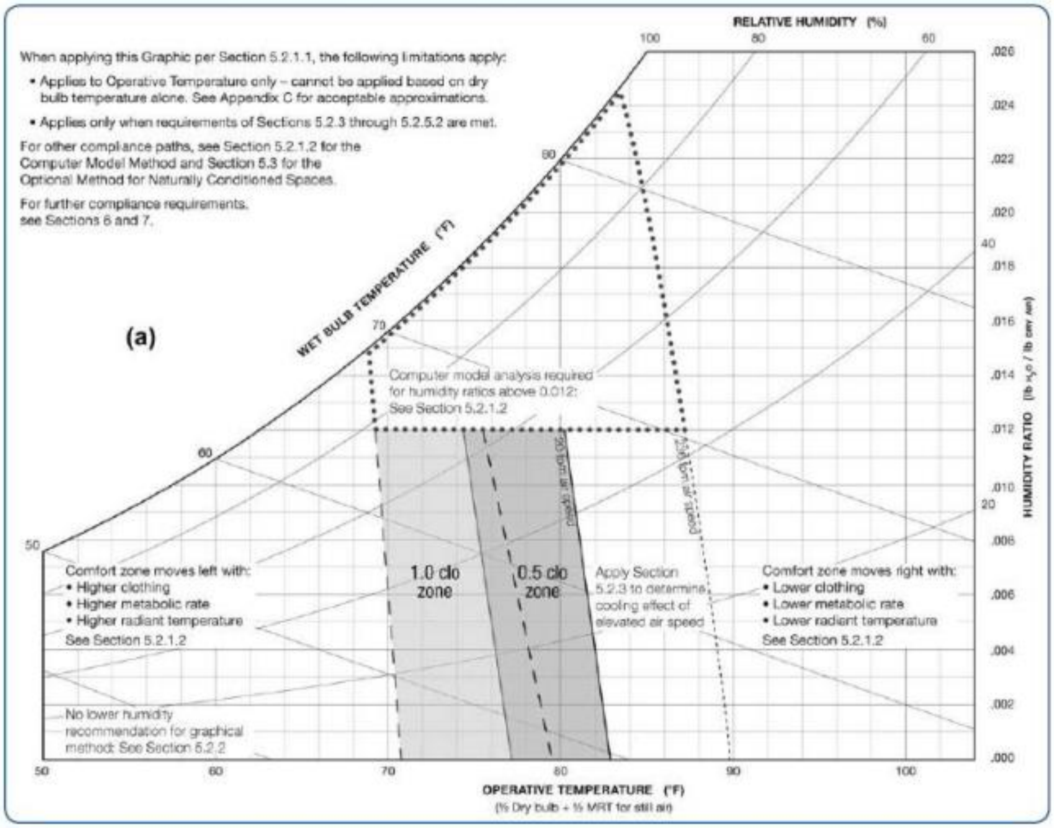


Figure 3 Graphic comfort zone method

Source: (Vergini, 2015)

2.2.2 Adaptive thermal comfort

Due to various complications and validity of above-mentioned methods, adaptive thermal comfort was developed to guide designers to determine the most comfortable operative internal air temperature in naturally ventilated buildings. In this module, internal air temperature is calculated by considering interactions of inhabitants with their surrounding environment and with the change in their clothing, opening/ closing of fenestrations, or other activities.

The main criteria of this model applicability are that the room under investigation must have operable fenestration to the outside that can be modified by occupants with no mechanical air-conditioning in use (Chaulagain, ENERGY EFFICIENT BUILDING DESIGN TO ADDRESS INDOOR THERMAL COMFORT IN NEPALESE RESIDENTIAL BUILDINGS, 2020). The model considers near sedentary physical activities of occupants with metabolic rate of 1.0 to 1.3 met where occupants are free to adapt their clothing as per the surrounding thermal condition. The model has fixed limits for prevailing outdoor temperature in which it is not applicable if the mean outdoor temperature falls below 10° C and rises above 33.5° C (ASHRAE, 2020). The adaptive model offers two sets of operative temperature limit, one with 80% acceptability and the other with 90% acceptability as shown in the figure below.

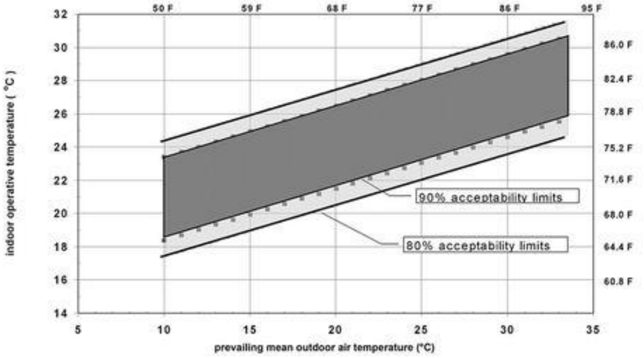


Figure 4 Adaptive model acceptable operative temperature for prevailing outdoor temperature

Source: (ANSI/ASHRAE,2004)

There are several other computer-based models to evaluate thermal comfort by using computer software like Autodesk Ecotect, Climate consultant, etc. that uses data inputs of climatic data of the required location.

2.3 Passive Design

Passive design is the method of designing and constructing buildings with the maximum use of natural resources of heating cooling, and ventilation to create a comfortable indoor condition of building (Designing Buildings, 2020). Use of passive design in homes leads to 85% less energy for heating and cooling than an average home (Environmental and Energy Study Institute, 2017). The passive house provides better living and working conditions to their occupants. According to Stauffer and Hooper (2000), it is the method of building design that maximizes the benefits of the local environment (such as sunlight) while reducing the adverse effects of climate (cold nighttime temperatures) on the comfort level of the building. The concept of passive design was introduced by German Physicist Wolfgang Feist and Swedish Professor Bo Adamsan (Shrestha S. M., 2017).

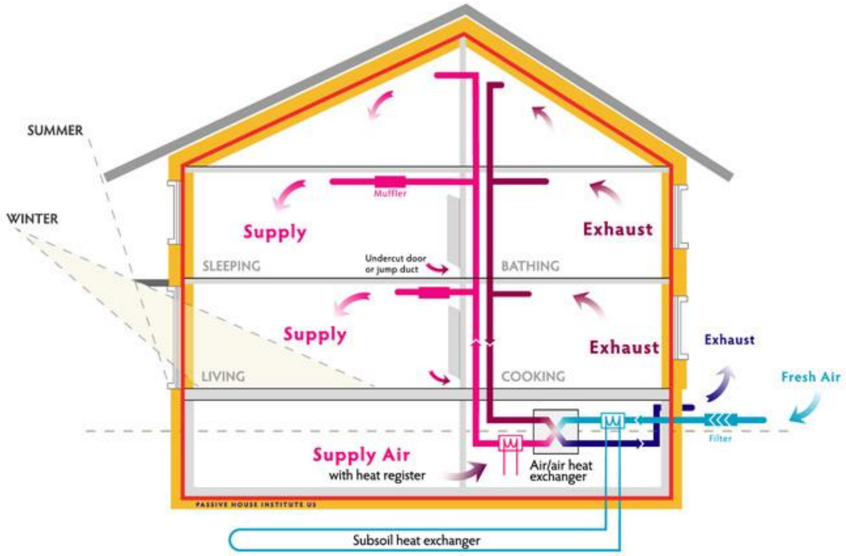


Figure 5 Basics of Passive House Building

Source: (Environmental and Energy Study Institute, 2017)

2.3.1 Passive Design Building Strategies

The main criteria for designing a building are its built form, orientation, wall area, window wall ratio, thermal mass, and thermal insulation. Various passive design strategies for energy efficiency in a building are studies as follows:

1. Site location
2. Slope and orientation
3. Building Orientation
4. Building form and compactness of building plan
5. Internal space arrangement
6. Openings
7. Window to wall ratio (WWR)

8. Thermal Insulation
9. Thermal mass
10. Air tightness
11. Shading
12. Ventilation
13. Material and technology
14. Color and Texture
15. Landscape

2.3.1.1 Site location

For the site selection, microclimatic advantages generated by topographical features should be considered. Site is chosen by considering two main criteria: the natural risks and the amount of natural and man-made objects that influence the shading of proposed building. While selecting the site, aspect should be considered which is the combined slope and orientation of the surface in relation to the sun (Tendulkar, 2017). A surface perpendicular to the solar rays receives most radiation per unit of surface area. Therefore, the south facing site receives more solar radiation whereas easterly slope receives morning sun and that facing west receives afternoon sun (Stauffer & Hooper, 2000).

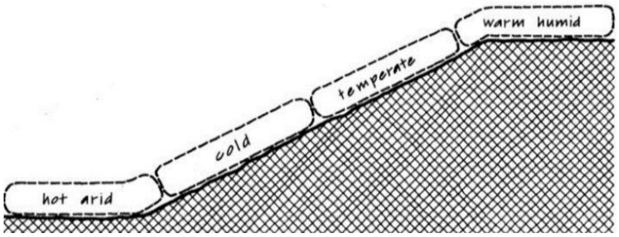


Figure 6 Solar radiation Varies with Terrains

Source: (Tendulkar, 2017)

Besides this, the amount of sunlight delivered to the building is affected by several factors including the presence and absence of obstruction that shade the building from sun. The presence of larges obstructions such as hills, trees, mountains, neighboring buildings, etc. can significantly reduce the amount of solar radiation in the building.

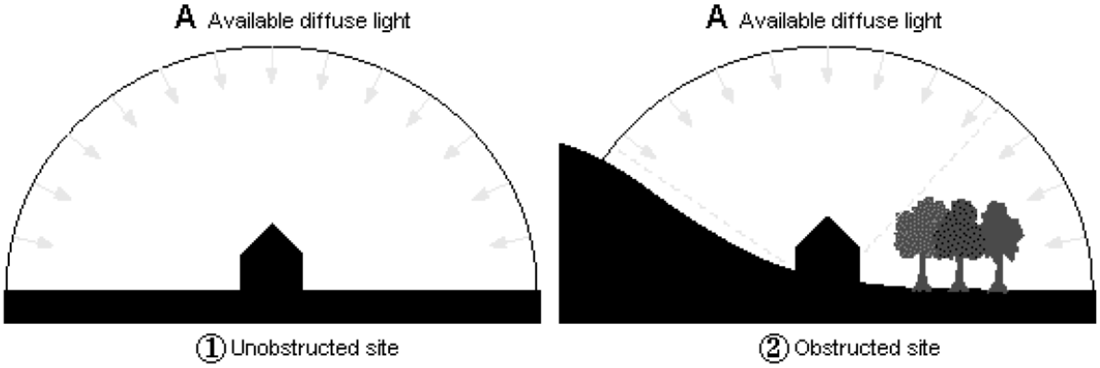


Figure 7 Effect of Obstruction on the amount of sunlight

Source: (Stauffer & Hooper, 2000)

2.3.1.2 Slope and Orientation

The amount of sunlight received on the surface is influenced by slope of the land. Horizontal surfaces receive more solar radiation in summer than in winter whereas vertical surfaces receive more or less radiation according to the angle of sun in the sky. South facing slope receives more solar radiation than in any other orientation, easterly slope receives morning sun and westerly slope receives afternoon sun rays (Tendulkar, 2017). Likewise, a horizontal window collects three times more sunlight than vertical windows. But vertical windows act well as the sun angle is higher during summer and horizontal windows collects more solar radiation making the interior hotter during summer while maximum amount of sunlight can still be provided through proper design of vertical windows (Stauffer & Hooper, 2000).

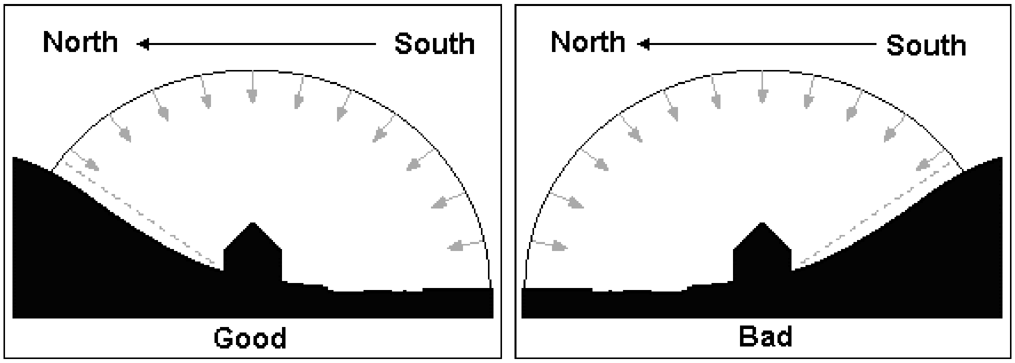


Figure 8 South facing slope recieves more sunlight

Source: (Stauffer & Hooper, 2000)

Figure 9 South Facing houses receives solar radiation while North facing houses overshadows

Source: (McGee, Reardon, & Clarke, 2020)

2.3.1.3 Building orientation

Building orientation is one of the basic principles of passive design that aims to absorb maximum amount of solar radiation during winter and utilize this heat to warm the interior (Stauffer & Hooper, 2000). Designing a house with proper shape and orientation with strategically located rooms can significantly reduce the amount of energy use for heating and cooling. Building oriented along east-west axis is ideal for passive house by increasing south facing walls to present the largest possible surface area to the sun. This also allows maximum solar glazing to the south for solar capture for heating. This orientation is also beneficial for summer cooling as it reduces east-west exposure to summer solar rays in the morning and afternoon (Tendulkar, 2017). Besides solar radiation, buildings should also be oriented across the prevailing wind.

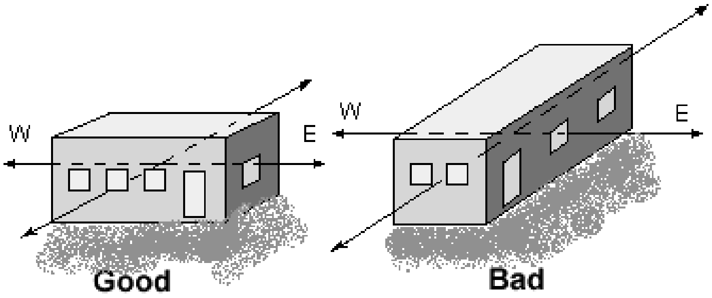


Figure 10 Buildings aligned along east-west to maximize surface area for solar radiation

Source: (Stauffer & Hooper, 2000)

Besides solar radiation, buildings should also be oriented across the prevailing wind

2.3.1.4 Building form and compactness of plan

Form and shape of the building plays a vital role in determining heat exchange with the exterior. Hence it is important to minimize the (surface area/ volume) ratio to limit the heat loss. In this regard, compact buildings with large surface area and several storeys are more efficient (Stauffer & Hooper, 2000). Buildings with simple geometrical shape like cuboids, cube has less surface area in relation to volume and thus has better Surface area/ Volume ratio.

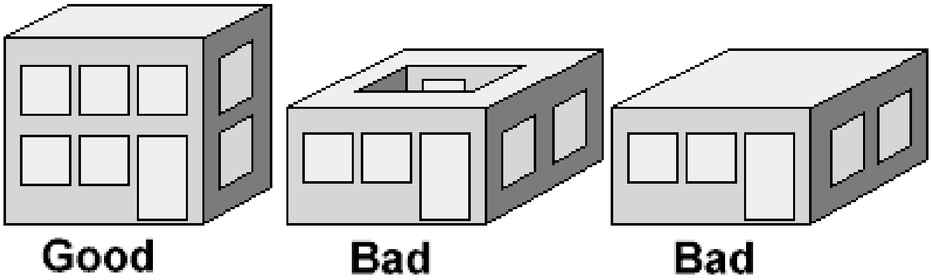


Figure 11 Surface area to volume ratio to be minimized for more efficiency

Source: (Stauffer & Hooper, 2000)

Compactness of building plan depends on the geometry of building and varies with the building typology. It minimizes external wall area. Therefore, lesser the area of exposure of external envelope to the outside, for a given floor area, lesser will be the heat transfer into the building (Bureau of Energy Efficiency, 2021). Similarly, elongated rectangular plan with single banked rooms help in achieving natural ventilation and are found to be more efficient. In the figure below, surface area to volume ratio increases from A to C as the built form gets more complicated and hence compactness reduces.

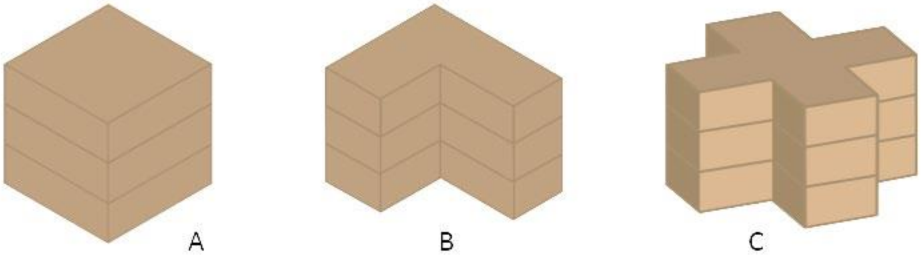


Figure 12 compactness reduces as the built form gets more complicated

Source: (Bureau of Energy Efficiency, 2021)

2.3.1.5 Internal Space Arrangement

Space arrangement is the process of determining the purpose, functional requirements, and layout of the building. The internal space should be arranged in such a way that rooms with high heating and lighting requirements are organized along the south wall (Tendulkar, 2017). In such case, the most habitable rooms to be heated (like living room, bedrooms, kitchen) should be arranged on the south direction for more solar gain. Similarly, the rooms that are least used (such as bathrooms, store, staircase, etc.) should be positioned on north direction that helps in creating a buffer zone (Stauffer & Hooper, 2000).

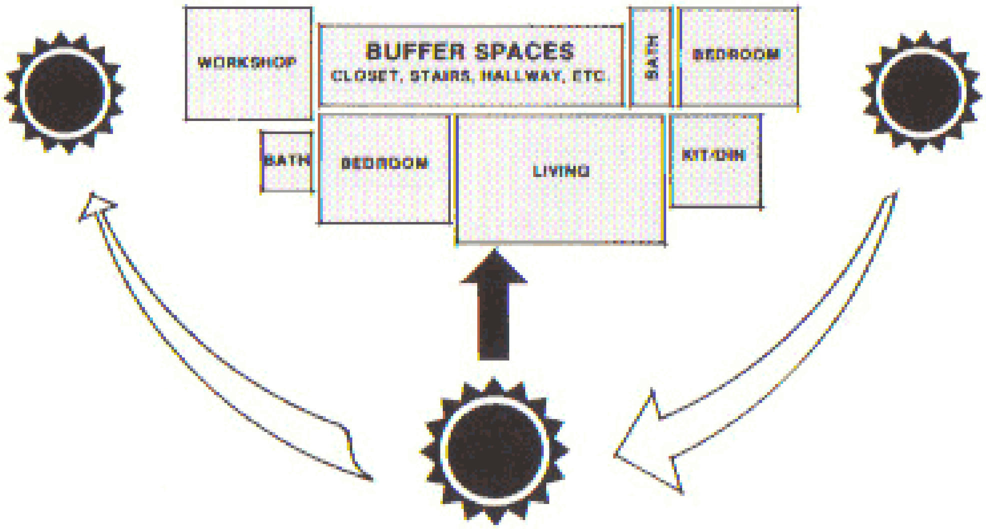


Figure 13 Interior Space Arrangement with habitable space along South and buffer zone along North walls

Source: (Stauffer & Hooper, 2000)

The rooms that are mainly used in the morning can be arranged along east facing walls. Likewise, rooms that are used in the evening can be positioned on west walls. In a multi-storey building, ground floor can be used for cattle and livestock, first floor for rooms mainly used in winter and rooms of second floor can be used for summer. (Stauffer & Hooper, 2000)

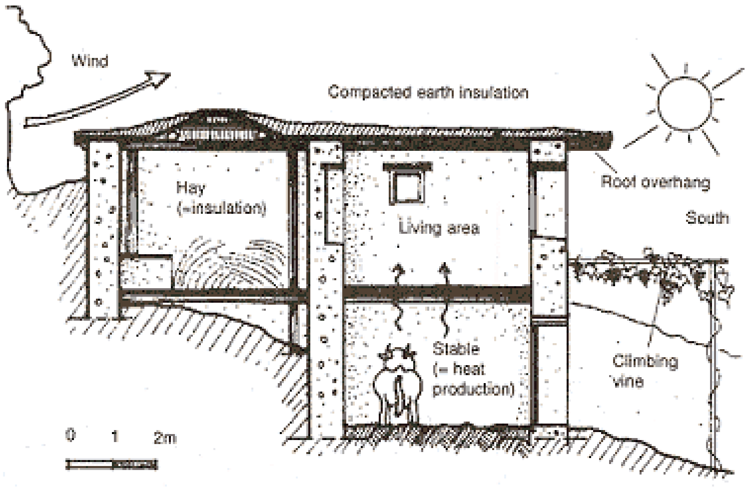


Figure 14 Rooms for cattle and livestock on ground floor to provide additional heating

Source: (Stauffer & Hooper, 2000)

2.3.1.6 Thermal insulation

Heat flows from building envelope as the indoor temperature differs with outdoor temperature. Heat flow needs to be controlled in order to maintain the indoor temperature within the comfort ranges. According to ASHRAE, thermal insulation provides hindrance to conductive, convective and\ or radiative heat transfer. Limiting heat flow between interior and exterior of the building creates a comfortable indoor environment and reduces the energy consumed by building that can be achieved by a well-insulated building. According to Passive Design Toolkit, the interior surface temperature of the building envelope is impacted by thermal insulation which directly affects thermal comfort (Rai, 2014). Insulating materials are the poor conductor of heat and hence form barrier for the flow of heat from inside to outside and vice-versa. Different insulating materials for passive buildings are aluminum foil, polyurethane, perlite, fibrous materials like glass wool, mineral wool, fiber glass, air cavity, etc. The thermal insulation capacity of a structure is indicated with U-value.

2.3.1.7 Thermal Mass

Thermal mass is the ability of material to absorb and store heat energy and increases time lag for heat transfer (JUAREZ, 2014). Use of thermal mass in buildings leads to improved thermal comfort and energy savings. Thermal mass is more effective when temperature variations are larger. Dense and heavy elements of the building like floors, masonry walls act as temperature stabilizer and the temperature variations of these are low in day and night cycle (Bureau of Energy Efficiency, 2021). High density materials reduce temperature fluctuations of the living space by storing heat within itself during daytime and re-radiating during night and hence reduce the heating and cooling load of the building (Chaulagain, 2020). These materials have high thermal mass like concrete, brick, tile, load bearing walls that are made up of dense materials such as mud, earth, and stone.

Thermal mass should be evenly distributed throughout the building envelope. The performance of thermal mass depends on its thickness, surface area, and the thermal properties of the materials use where direct solar gain is used (Roaf et.al., 2008). According to (Stauffer & Hooper, 2000), for each m^2 of south facing glass, at least $6m^2$ of thermal mass should be installed. Combining thermal mass with insulation provides more efficiency in heating the indoor as compared to direct solar gain designs.

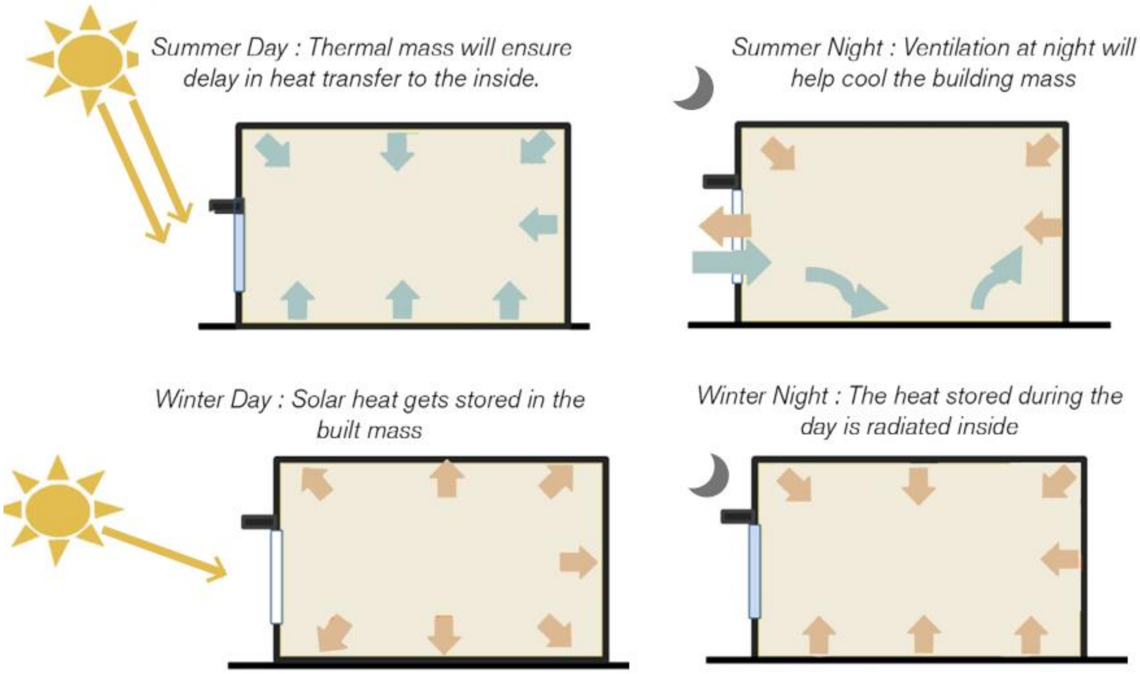


Figure 15 Use of thermal mass and Solar gain for comfortable indoors

Source: (Bureau of Energy Efficiency, 2021)

Table 1 Thermal Mass of Construction materials

Thermal mass material	Specific Heat Capacity	Thermal Conductivity	Density
Water	4200	0.60	1000
Stone	1000	1.8	2300

Brick	800	0.73	1700
Concrete	1000	1.13	2000
Unfired clay bricks	1000	0.21	700
Dense concrete block	1000	1.63	2300
Gypsum plaster	1000	0.5	1300
Air Crete block	1000	0.15	600
Steel	480	45	7800
Timber	1200	0.14	650
Mineral fibre insulation	1000	0.035	25

Source: (JUAREZ, 2014)

2.3.1.8 Air tightness

Air tightness is about eliminating all unintended gaps and cracks, holes, splits and tears through which air can move in or out of the conditioned space of the building (Cradden, 2019). It plays a significant role in reducing the energy performance of a building as the unwanted air-leakage leads to increase in space heating/ cooling requirement of the building. Air leakage occurs through cracks in the building envelope, use of doors and windows, roof, etc. a building can be airtight only if it consists of a uniform, intact, airtight enclosure wrapping around the whole house volume (Passive House Institute, 2006). Airtightness is necessary to fulfill the expectations of modern thermal comfort. Airtight homes are thermally comfortable and are free from both draughts and condensation, and future proof against extreme weather events caused by climate change. According to passive house standard, the average air tightness in a typical housing unit is below $1m^3/hr/m^2$ (Cradden, 2019).

2.3.1.9 Openings

The size and placement of openings in the building envelope has major impact on heat gain/loss to/from the building. windows on the south walls allows solar radiation directly to the living space throughout the day with the simple direct gain concept of passive solar design. It also helps in minimizing requirement of artificial lighting. Glazed door and windows allow light and fresh air into the building (Archi-Monarch, 2020). The size of openings on east and west walls should be minimized to reduce overheating due to heat gain in the early morning and late afternoon. This can be protected by shading devices. Openings should be placed as per prevailing wind breeze for natural airflow into the building to achieve air movement for evaporative cooling and air changes for driving out excess heat (Gibbs, 2019). Ventilation openings should be provided at the level of occupants to ensure thermal comfort. Heat loss through the building can be minimized by proper orientation, size, and placement of windows, glazing and frame type (Shrestha S. M., 2017).

2.3.1.10 Window to Wall ratio

Windows and openings are the weakest point in a building envelope regarding thermal resistance. Opaque masonry walls have low heat transfer rate as compared to windows and fenestrations. Larger the ratio of window area to wall area, there is greater heat flow from the building envelope to outside environment and vice versa (Bureau of Energy Efficiency, 2021).

2.3.1.11 Shading

Shading is one of the neglected design aspects for comfort and energy conservations in building. The most significant contributions to discomfort during warm and hot seasons are direct sunlight and indirect sky radiation entering the building through glazed window (Bureau of Energy Efficiency, 2021). Therefore, blockage of direct sunlight and filtering the diffused radiation is required. The south facing windows can overheat the building during summer. Hence overhangs and shading are important in passive design to reduce overheating during summer and allowing winter sun into the building.

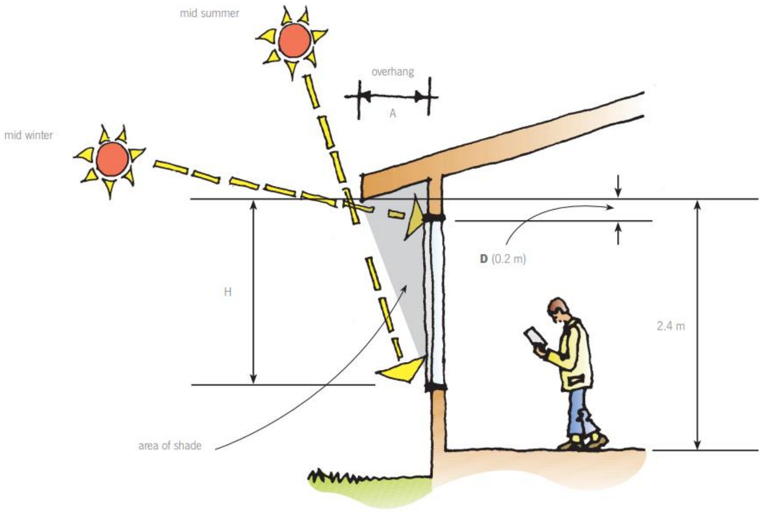


Figure 16 Shading by overhangs

Source: (Level,2022)

Internal Shading devices (curtains and blinds), and external shading devices (sun canopies, overhangs, shutters, etc.) control glare, minimizes the intensity of sunlight received, limit the ability of radiation penetration into the living space and improve the thermal and visual comfort.

Shading devices should be designed in such a way that it blocks the summer sun and allows winter sun into the building also taking into consideration of the solar movement along the year, given by solar altitude and azimuth angles. If the overhang on the south facing window protrudes to half of the window's height, the sun's rays will be blocked during summer yet still penetrates the building during winter (Williams, 2022).

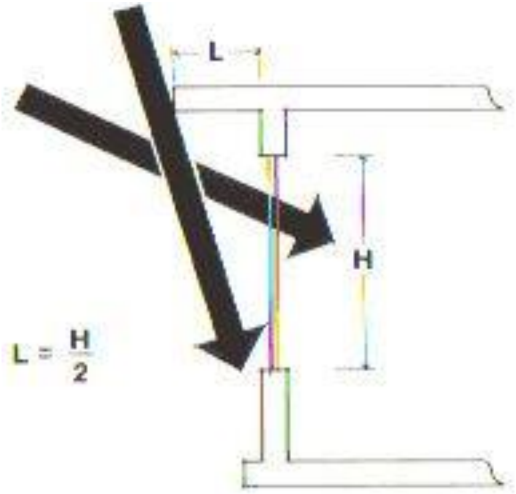


Figure 17 Overhang design for shading
Source: (Williams, 2022)

Overhangs helps to control direct sun rays in south façade, but east and west windows are very difficult to shade. Therefore, limited numbers of openings should be provided in east and west walls. Natural vegetation also acts as shading device for low rise buildings. Deciduous trees facilitate to block summer sun and permit winter sun into the building.

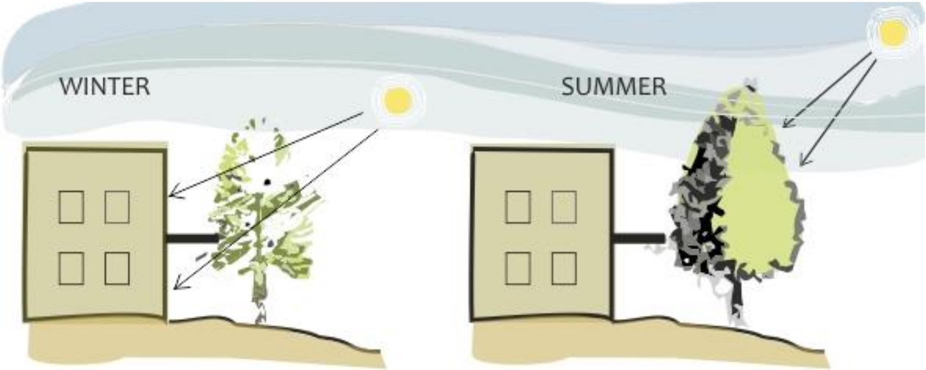


Figure 18 Deciduous trees allow sun penetration in winter and blocks sun access during summer
Source: (Prasad,2021)

2.3.1.12 Ventilation

Ventilation is the process of supplying or removing air to/ from a space for the purpose of controlling air contaminant levels, humidity, or temperature. Air movement is a major factor that influences indoor climate and should be considered during the initial design phase of building construction (Gut, Fislisbach, & Switzerland, 1993). Apart from solar radiation, the building design concept should also incorporate wind breeze direction. The regular wind pattern and the occasional wind flow should be distinguished for planning of a building.

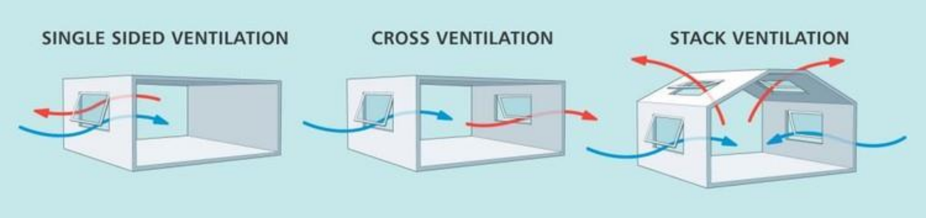


Figure 19 Different types of Natural ventilation

Source: (archdaily, 2022)

The main purpose of ventilation is to supply fresh air, remove odor, CO_2 and other contaminants, remove internal heat when $T_o < T_i$ and for psychological cooling (Chaulagain, ENERGY EFFICIENT BUILDING DESIGN TO ADDRESS INDOOR THERMAL COMFORT IN NEPALESE RESIDENTIAL BUILDINGS, 2020). Natural ventilation can be achieved by appropriately placing and sizing of window in the required climatic zone. Cross ventilation helps in admitting fresh and cool air in and remove stale or hot air out of the building.

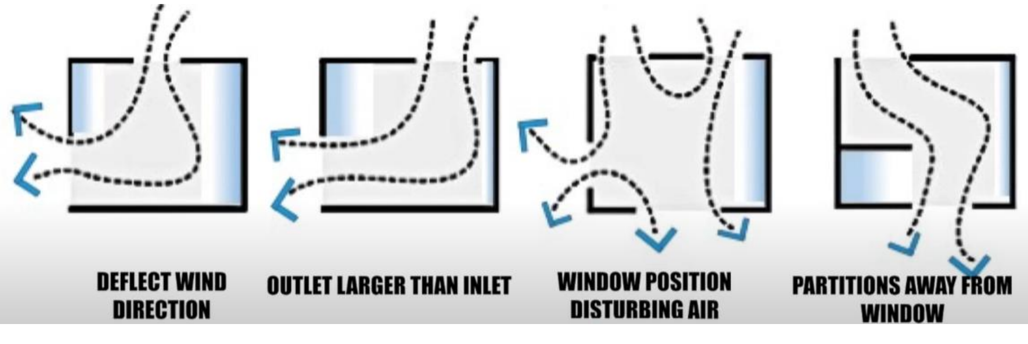


Figure 20 Placement of windows for Cross Ventilation

Source: (nzeb,2022)

2.3.1.13 Material

Different material has ability to exchange energy in different ways. In passive solar building, materials can be classified as dense material (brick, stone) and low-density (lightweight) material. Dense materials can conduct and store heat whereas low-density materials neither conduct heat nor store it. Denser materials are good conductor and hence mud-brick buildings are found to be warmer than that of stone because the heat is conducted more rapidly through stone and it also re radiates into the outside environment.

For an example, a 35cm thick mudbrick has time lag of 12 hours for heat conduction. So, this can be taken as an ideal choice for passive building which means the room gains heat from cold night during the day and heat of the day reaches to the room during night. Therefore, the room temperature is maintained at a comfortable level throughout a 24- hour period (Stauffer & Hooper, 2000).

Transparent materials like glass polyethylene transmits solar radiation through it. The transmittance is high when the sun is perpendicular (up to the angle of 30°) but decreases when the angle is over 50° (Stauffer & Hooper, 2000).

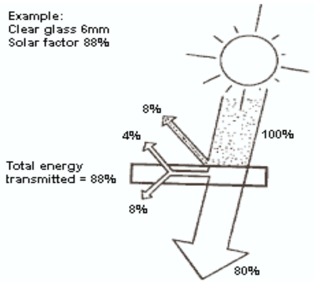


Figure 21 Transmittance of solar radiation through glass

Source: (Stauffer & Hooper, 2000)

2.3.1.14 Color and texture

External color and texture of material plays a vital role in absorbing solar energy and radiating heat or reducing heat gain by the building. The black color absorbs more amount of solar radiation while the white color reflects most of it. White buildings help to reduce energy required for lighting. For example, white ceiling and walls make electric lighting more efficient (Earthshipbiotecture, 2022).

Table 2 Absorptivity of different colors

Color	Absorptivity
white	0.25 to 0.40
Grey to Dark Grey	0.40 to 0.50
Green, Red, Brown	0.50 to 0.70
Brown to Dark Blue	0.70 to 0.80
Dark Blue to Black	0.80 to 0.90

Source: (Stauffer & Hooper, 2000)

Figure 22 Absorption of Solar radiation by color

Source: (Earthshipbiotecture, 2022)

The ability of a surface to absorb, emit and reflect heat also depends on texture. Rough texture material is found to absorb more solar radiation for longer period and results in heat gain while smooth surface reflects solar radiation and hence reduce heat by building (Archi-Monarch, 2020).

2.3.1.15 Landscaping

If properly designed, plants and trees can greatly assist passive design of buildings by providing shade during winter and allowing summer solar radiation into the building. For this, trees should be planted within a distance of 1.5m -6m from the building depending on their height and species (Vasiu, 2013). Planting deciduous trees on the south of the building will help to block summer sun and loose their leaves during winter through which winter sunrays can penetrate into the building.

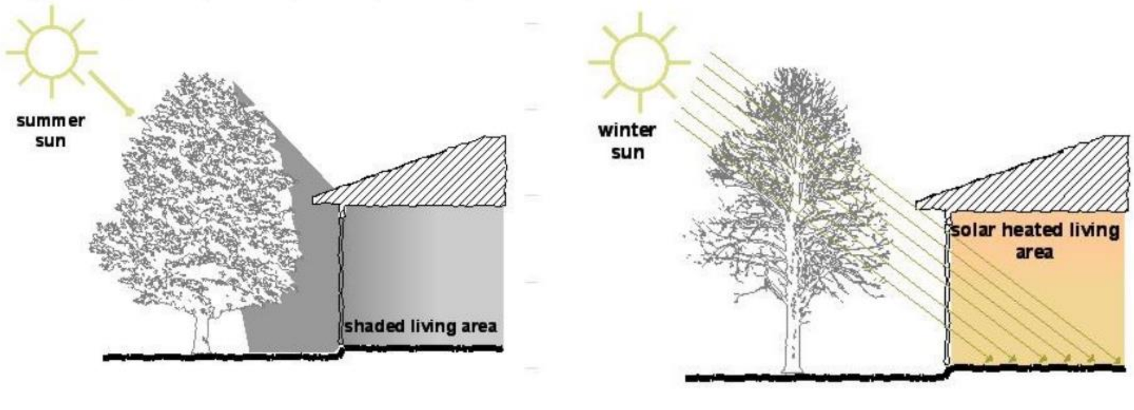


Figure 23 Effect of vegetation adjacent to building during summer and winter

Source: (Vasiu, 2013)

Moreover, one of the important function of trees is to provide breezes for cooling which can be achieved by creating green corridor to direct prevailing summer wind into the building. Similarly, during winter, the trees should act as shelter from intrusive winds. Planting trees either in concave or convex shape relative to that of the building provide viable solutions for both deflecting and damming the wind (Vasiu, 2013).

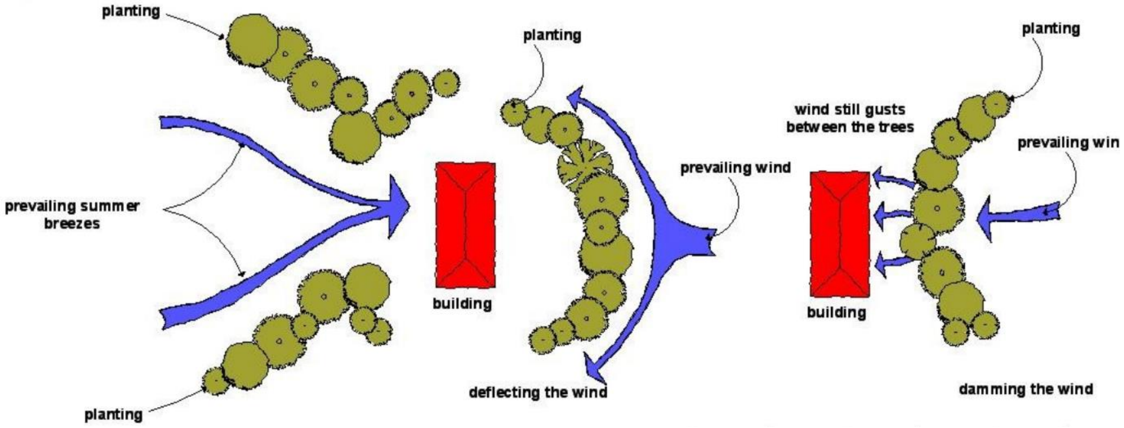


Figure 24 Use of vegetation to naturally cool buildings during summer and provide shelters from prevailing winter winds

Source: (Vasiu, 2013)

2.4 Disaster context

The devastating Earthquake of April and May 2015 in Nepal and the subsequent aftershock led not only to the loss of people and the physical infrastructure but also the historical, social, cultural, and economic aspects of the country and its population. Thirty-one out of country’s seventy-seven district were affected by the earthquake (National Planning Commision, 2015).

Figure 25 Earthquake affected districts of Gorkha Earthquake 2015

Source: (Post Disaster Needs Assessment, 2015)

The destruction widely covered residential and public buildings, heritage sites, schools, health posts, roads, bridges, and other infrastructures. Entire settlements (Barpak, Laprak, Dolakha town, etc.) of severely hit districts were destructed by earthquake. More than half a million of houses were destroyed that exposed the weakness of house that did not have seismic-resistant features and were not built as per building codes (National Planning Commision, 2015).

2.4.1 Post Disaster Needs Assessment (PDNA)

In order to carry out a Damage and Loss Assessment (DLA), the Government of Nepal conducted a Post Disaster Needs Assessment (PDNA) in May-June 2015 under the broader concept of building back better. Aiming to enhance the resilience of the country, PDNA has listed some short term and medium term to long term priorities given to Disaster risk Reduction (DRR) for improvements. The government also developed seismic policy that includes revision of building codes, development of building byelaws for every municipality, application of mandatory rule of thumb (MRT), development of risk sensitive land use plans for all municipalities of the country. Several buildings acts like Nepal national building code, MRT were revised as per seismic performance after earthquake.

The concept of Build Back Better is introduced only by enforcing safety guidelines and compliance of safer construction practices through knowledge building and awareness raising of homeowners, masons, and engineers (The World Bank, 2021).

2.4.2 Prototype buildings

As per the indication of Government of Nepal, 602,275 houses were fully damaged, and 285,099 houses were partially damaged by Gorkha Earthquake 2015. Department of Urban Development and Building Construction (DUDBC) proposed different design catalogue for reconstruction of earthquake resistant houses for earthquake affected districts of Nepal. The catalogue was prepared with the objective to provide clear guidance for rural households regarding earthquake resistant construction techniques (DUDBC, 2015). The housing prototype and flexible design were provided with variety of options in terms of cost, size, layout, and typology ensuring that vernacular architecture and building practices can be maintained with the addition of earthquake resistant construction practices (DUDBC, 2015).

The second volume of design catalogue prepared by DUDBC includes architectural design, structural detailing and material estimate for the reconstruction of houses. This catalogue was provided with model design of seventeen houses under different technologies using alternative construction materials.

2.5 Policies integrating energy efficiency and Post Disaster Reconstruction

Energy policy is the scheme in which the government (or any organization) addresses the issues related to energy growth and usage including energy production, distribution and, consumption (Kohl, 2020). Energy efficiency and post-disaster settlement planning have some complementary policies, similar interest groups, regulatory systems, goals, and objectives. However, these two fields have not comprehensively converged, missing opportunities for greater positive impact on the economic and sustainable development of post-disaster societies. Initiation has been carried out by government of Nepal to formulate National Energy Strategy (NES) to address the challenges and for the development utilization of energy resources in sustainable manner (GON, WECS, 2013).

2.6 Nepal’s strategy for Energy Policies and Programs

The government of Nepal has built legislative and institutional mechanisms to carry out the long-term ambitions of Paris Agreement. Although there are no specific policies regarding building energy conservation by Nepal Reconstruction Authority (NRA), it has encouraged earthquake beneficiaries for the use of renewable solar energy in private housing reconstruction by granting incentives in final inspection. The major national-level policies of Nepal in the context of energy are listed below:

- National Climate Change Policy 2076, 2019
- Nepal National Adaptation Plan (NAP), 2021-2050
- Periodic Development plan
- National Environmental Policy, 2076
- Rural energy policy, 2006
- Renewable energy subsidy policy, 2073
- National Energy Strategy of Nepal, 2013
- National Energy Efficiency Strategy, 2075
- Nepal Energy Efficiency Programme (NEEP), 2010

One of the key elements of Nepal’s Long-term Strategy for Net-Zero Emissions by 2045 is to improve energy efficiency and maximize benefits by utilizing clean energy efficiently in residential industrial and transportation sector (Government of Nepal, 2021). It has clear link to the achievement of Sustainable Development Goals (SDGs) by 2030 and beyond. Regardless of different policies related to energy sector, these policies have not covered the problem of residential sector.

Post disaster Reconstruction Authority (PDNA), 2015 has revised building codes, developed byelaws in terms of seismic performance and aims to enhance the resilience of the country. Similarly, Post Disaster Reconstruction Framework (PDRF) has aim of reconstructing damaged cities and ancient villages in their original form by improving resilience of structure. It is more focused on disaster resilience but also encourages the use of locally available materials. According to (Nepal National Adaptation Plan, 2021), human settlements should be inclusive, safe, sustainable, and resilient. It helps in guiding climate resilient city planning and promoting climate resilient building practices. It encourages to explore and identify environment friendly building material and construction technologies. National Environment Policy, 2076 emphasizes on energy effective housing. As per Environmental and Social Management Plan (ESMP) under Earthquake Housing Reconstruction Plan (EHRP), for environmental enhancement in household level mitigations, it can be achieved through climate smart structures using locally available materials, awareness of improving indoor air pollution cause by cooking fuels. The project also collaborates with energy and building better. The fifteenth periodic plan by National Planning Commission promotes development and use of alternative use of energy like solar and hydroelectricity and emphasizes the use of sustainable and energy efficient technologies. Renewable energy subsidy policy, 2073 aims in achieving universal access to clean, reliable, and affordable renewable energy solutions by 2030. According to National Energy Efficiency Strategy (Ministry of Energy, Water Resources and Irrigation, 2019), public awareness campaigns should be conducted related to energy efficiency in household sector. Research and studies should be carried out on energy efficiency and demand side management as well as promote and develop energy efficient technologies.

2.7 Perspective of Energy Efficiency in Post-Disaster Reconstruction

Besides destruction and damage, the initial period of natural disaster also provides a valuable opportunity to rebuild and recover enhancing resiliency and saving energy. Many resiliency measures in the built environment overlap with energy efficiency measures which further benefit each household through energy savings and lower operating cost that reduce stress on energy infrastructure. Building energy efficiency in a new structure save more energy as compared to old buildings.

Post-Disaster Reconstruction helps in considering site-specific climatic features during planning, designing, and constructing buildings to promote energy efficiency, orienting buildings to limit or increase solar energy, provide wind protection if needed and take advantage of available shade (WWF Nepal, 2016). Energy and water efficiency measures can be incorporated in such as improved cooking stoves, biogas, solar power, micro-hydro, rainwater harvesting, and multiple use water systems. Locally and culturally appropriate designs can be integrated by using local construction technology while also ensuring safety.

2.8 Challenges and strategy to integrate energy efficiency in post disaster reconstruction

Integration of energy efficiency and disaster management has both benefits and challenges. Hence, combining these with public policy and programs would benefit the building occupants and the settlement as well. Lack of a clear and well-supported policy for reconstruction; limited governance capacity and negligence of municipal and ward level officials; financial restrictions to rebuild their homes; and the lack of a framework to support local community-driven rebuilding initiatives are the major hurdles that inhibit energy efficiency integration in the post-disaster reconstruction.

According to the National Association of State Energy Officials, 2015, the other challenges include motivating property owners and developers to value energy efficiency and disaster resilience during the process of reconstruction. To increase public awareness, campaigns should focus on three areas: value of residential energy efficiency and resilience; available state, utility, and federal programs; energy efficient and resilient building design and technologies. The buildings should follow appropriate orientation to suit the specific climatic condition of the site. In addition, the sizing and layout of space provided, position of door and window for adequate access, lighting and ventilation, and any internal subdivisions should reflect local practices and blend with the existing environment.

2.9 Vernacular and Traditional architecture

Vernacular architecture can be defined as an architectural style that is designed based on local needs, availability of construction materials, and reflecting local tradition (wikipedia). It mostly relies on the design skills, traditions, and workmanship of local builders. It evolves over time to reflect the environmental, cultural, technological, economic, and historical context in which it exists. Microclimate of the area in which the building is constructed is one of the most significant influences on vernacular architecture. These buildings have unique features that is aware of specific geographical and cultural aspects of the surrounding. It takes the advantage of local materials and resources which make them relatively energy efficient and sustainable (Designing Buildings, 2020). It also provides the connection between human and the environment in which they live in.

Traditional architecture is the way of designing buildings using recognizable symbols of a particular culture of unique people in a special way. According to Noble, traditional architecture is the architecture that is passed down from person to person, generation to generation, particularly orally but at any level of society not just by common people.

Although there are similarities between the two, vernacular is not to be mistaken with traditional architecture. The differences can be listed as below:

Table 3 Comparison of Traditional and Vernacular Architecture

S. No.	Comparison	Traditional	Vernacular
1.	Ideology	Formed by tradition passed down from person to person, generation to generation based on local culture and climate	Hereditary tradition but is outside physical or non-physical influence, forms of development traditional architecture.
2.	Principle	Closed form the changing times, adrift on one of the cultures of the region and has a thick religious rule and norm.	It reflects the environment, culture, and history of the area. i.e., transformation of a homogeneous into a heterogeneous cultural situation.
3.	Design Ideas	More concerned façade, or shape ornament as a necessity.	Complementary ornaments, leave local values but can serve community activities.

Source: (Irawan, D, 2017)

2.10 Energy Modelling

Energy Modeling is a process of using software to build a virtual replica of a building and predict the energy use of the building. Energy modeling is a virtual, computerized simulation of a building or complex that focuses on energy consumption and life cycle costs of various energy-related items such as HVAC, lights, and hot water. Energy models simulate the consumption process of energy by all users in a building. Energy Modeling is best for Relative comparisons between Designs.

Autodesk Ecotect Energy Analysis software is used for the simulation of case models. It is an environmental analysis tool that allows designers to simulate building performance from the earliest stages of conceptual design. Ecotect Software has been used to calculate a building's energy consumption by simulating its context within the environment. It combines analysis functions with a display that presents analytical results directly within the context of the building model. The analysis software of ECOTECT can provide a scientific basis for energy-saving planning of the buildings. Ecotect is different from other analysis tools as it targets the earliest stages of design, a time when simple decisions can have far-reaching effects on the final project. Building simulation in Ecotect requires few climatic parameters to run its weather tool and analyze the efficiency of the building.

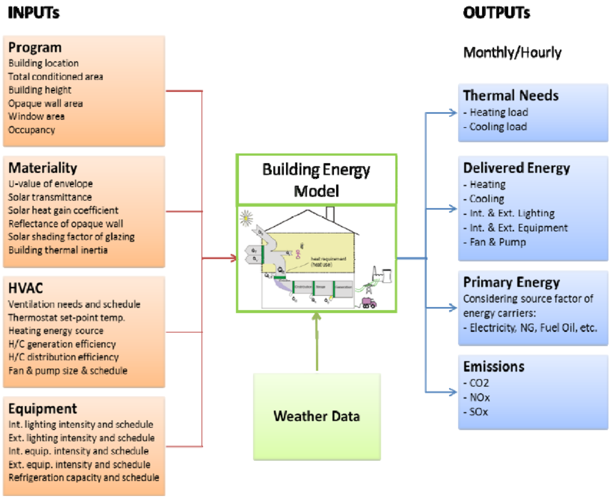


Figure 26 Inputs required for Ecotect Analysis

Source: Building energy model, Volume I,2013

2.11 Literature overview

Many research have been carried out on thermal comfort and its improvement on residential building. The table below shows the research title, findings and the methods used for research.

Table 4 Overview of Literature on the related topics

S.No	Titles of Paper	Researcher	Keywords	Emphasis of Papers	Testing Methods
1.	**Improving indoor thermal comfort in residential buildings in Nepal using Energy Efficient Building Techniques**	(Borgkvist, 2017)	Energy efficient techniques, thermal comfort, long-term sustainable development	Locally available building materials and passive solar heating and cooling serve well in maintaining thermal comfort in building	-Interviews -IDA-ICE, software used for the indoor climate simulations

2.	**Improving thermal comfort of residential buildings in Kathmandu- Using Passive Design Strategies**	(Rai, 2014)	Kathmandu, residential building, thermal comfort, passive strategies, computer simulation	-Increase in WWR, increases thermal comfort inside the building. -Increasing length of overhangs decrease overall operative temperature of the building -Improved Air tightness led to increased comfort level	-Design Builder to simulate thermal comfort
3.	**Energy Efficient Building in Kathmandu Valley - A Case Study of Passive and Contemporary Residential Building**	(Bajracharya, Shakya, & Bajracharya, 2020)	energy efficiency, energy audit, energy consumption.	-Discover energy efficiency in contemporary residential buildings -Energy efficiency measures	-Questionnaire survey -Case study -Data analysis
4.	**A Study of Challenges and Opportunities of Energy Efficient Housing in Kathmandu: Architects' Perspective**	(Kirat & Singh, 2019)	Energy Efficient Housing, Architects, Drivers and Barriers	-Identify issues in residential projects to incorporate energy efficiency principles from the perspective of architects in Kathmandu.	-Theoretical Sampling -Opinion survey to cross-validate
5.	**The Thermal Performance of Traditional Residential Buildings in Kathmandu Valley**	Bajracharya S.B (2014)	Traditional, Modern, Residential building, Indoor, Outdoor, Air temperature	Thermal performance of traditional and modern buildings of Kathmandu valley	-Field survey -Measurements
6.	**A framework approach to the design of energy efficient residential buildings in Nigeria**	(Ochedi & Taki, 2022)	Framework, Energy consumption, Energy efficient buildings, Simulation Case study,	-Achieve energy efficiency in buildings -Bioclimatic architectural design approach -Thermal comfort in buildings	-Measurement and observational survey -Case studies -Simulation

			Lokoja/Nigeria		
7.	**Energy Efficiency in Traditional Newari Residential Buildings: A Case of Bhaktapur (Itachhen Tole)**	(Shrestha & Upreti, 2020)	Energy efficiency, Residential Energy consumption, Traditional Newari buildings, Passive solar design, Kobo Toolbox, SPSS analysis, correlation	-Assess energy efficiency of traditional residential Newari houses -Residential energy consumption pattern -Traditional features of Newari houses through extensive literature reviews	-Literature review -Sampling -Questionnaire Survey
8.	**Climate Responsive Building Design in the Kathmandu Valley**	(Upadhyay, Yoshida, & Rijal, 2018)	climate; comfort; vernacular architecture; energy efficiency; design guidelines	-Comfort analysis and strategies to achieve comfortable conditions -Bioclimatic Chart -Mahoney's Table -Design Guidelines	-Overview of vernacular architecture
9.	**Developing strategies for sustainable residential building design: Kathmandu Metropolitan City, Nepal**	(Tuladhar, 2011)	Thesis Report	-Sustainable Building Design -Residential Status in Kathmandu -Energy Issue in Kathmandu -Water & Waste Management in Kathmandu	-Literature Review -Analysis -Design Strategies
10.	**Post Disaster Reconstruction in Sindhupalchok after Earthquake 2015: Problem and Prospects**	(Dangi, 2019)	Disaster; earthquake 2015; PDR; NRA; build back better	-Build back better -Linking reconstruction with development and economic activities are the fundamental element of successful reconstruction. -Socioeconomic condition of people can be enhanced by adopting appropriate measures in PDR	-Field survey -Focus Group Discussion -Data collection from a secondary source (NRA)

11.	**Long-term satisfaction of post disaster resettled communities The case of post tsunami – Sri Lanka**	(Dias, Keraminiyage, & DeSilva, 2016)	Success factors; Community satisfaction; Post tsunami; Resettlements	Resettlement program should re-establish the socio-economic and cultural life of people. look into the indicators which can convert a house into a home and the surrounding into a neighborhood.	Data collection in two phase (interviews with officers) & interviews with community members
12.	**Some design aspects of sustainable post-disaster housing**	(Tucker, Gamage, & Wijeyesekera, 2016)	Sustainable Development; Environment; Case study; Post-disaster reconstruction; Design Methods; Post-disaster housing	Design factor should consider site & settlement pattern, climate and thermal strategy, traditional techniques & material, and community acceptance encourage designers to take inspiration from traditional examples of housing	-Case study to approach toward sustainable design -Structured approach
13.	**Disaster resilient vernacular housing technology in Nepal**	(Gautam, Prajapati, Paterno, Bhetwal, & Neupane, 2016)	Disaster; Vernacular housing technology; Resilience; Earthquake; Flood; Nepal	Resilient features are instrumental in assuring safety, serviceability, cultural comfort, Vernacular constructions incorporate cost effectiveness with proper use of local materials and cultural reflections in housing units.	-Field visit -Comparative Case study

3 Chapter 3: Research Methodology

3.1 Research Paradigm

Every research is based on a philosophical framework called ‘Research Paradigm’. A pattern of beliefs and understandings is offered from which the theories and practices of the research operate. The study will be carried out in mixed method case study research and belongs to pragmatic research paradigm. According to Creswell (2003), the pragmatic paradigm implies with mixing of data collection method and data analysis procedures within the research process. In this research, a quantitative approach is taken to review the comfort and satisfaction of building occupants of traditional and newly constructed house.

The ontological claim of the research is due to the lack of awareness and policy provision regarding energy efficiency, newly constructed buildings lack thermal comfort. There are multiple reasons such as building design and planning are more focused on seismic performance and stability, choosing inefficient construction materials, blindly believing modern architectural trend in design.

The epistemological claim of the research is that the energy behavior and the thermal comfort condition of the building occupant will be obtained through quantitative research which can be perceived through energy survey of occupants and case studies of the study area.

3.2 Research Approach

The study will be carried out in mixed method research approach that includes qualitative and quantitative research. The qualitative method is based on interpretation of literature review from different related articles, reports, and documents based on thermal comfort, energy efficiency, post disaster reconstruction and passive design strategies for the temperate climatic zone will be studied and analyzed. This helps to achieve the aim of first research objective. Perspective of energy efficiency in post-disaster reconstruction will be studied that will help to provide an overview of the study area.

Similarly quantitative method is used to achieve the second objective. This includes questionnaire survey, interviews with the local people, case studies of the case Area

Dolakha town. Heating and cooling load of the case buildings and the overall energy performance of the building will be obtained through energy simulation from Autodesk Ecotect Software.

To achieve the third goal of the research, data logger is employed in the traditional and post disaster reconstructed building to determine the temperature variation and relative humidity among these two buildings. This helps in characterizing the thermal performance of these buildings. The temperature variations and relative humidity of both the buildings were compared to obtain the thermal comfort condition of these buildings.

3.3 Research methodology

The process of research methodology is carried out in three stages:

3.3.1 First Stage:

The first step towards research started with literature review with the aim of developing research objectives and generating ideas related to research topic. The interpretation of literature review was done through several related documents, articles, research papers and reports. Theoretical study of different passive design strategies for enhancing thermal comfort and achieving energy efficient building were done. Different policies integrating energy and post disaster reconstruction, Nepal's strategy for energy policies and programs were studied and analyzed that provides the pathway to conduct the research.

3.3.2 Second stage:

Identification of case area and the on-site field measurement is the second step. The old Newar settlement of Dolakha town is selected as case area to study and measure the thermal performance of traditional and prototype residence and compare these with the optimized house. Climatic data from Department of Hydrology and Meteorology was used for the detail study of climate. Variations in temperature and humidity was obtained by using thermos-hygrometer in traditional and post disaster reconstructed building. Szokolay's Bioclimatic chart was prepared that provides thermal comfort zone of the area. Moreover, Mahoney's table was used for design recommendation for Dolakha. Similarly, vernacular architecture, and newly developed Byelaws for the study area were studied and analyzed. A questionnaire survey was carried out in the study area related to thermal comfort of the occupants living in traditional building and the newly constructed houses. The questions incorporated Location, Demographic details, Family information, Spatial Detail, Building Details, Energy Consumption pattern, Thermal Sensitivity, Occupant behavior, etc. Interviews were carried out with the concerned authority and officials, Engineers and architects who worked on reconstruction of buildings. The traditional and newly constructed houses that are constructed at similar plot size and has same floor area space was examined in response to thermal comfort. Planning, use of construction materials and other housing details was also analyzed that helped for comparative analysis.

3.3.3 Third stage

In third stage, data collection and analysis were done from the literature review and study of case area to draw the findings and conclusion using energy simulation software. The data collected from field measurements were used for energy simulation through Ecotect. Case model of traditional and newly constructed house was prepared for simulation that act as a base model for optimization. Autodesk Ecotect Energy Simulation software was used for the simulation of traditional and post disaster reconstructed houses to calculate the energy and thermal performance. Different scenarios were created and compared depending upon different key parameters of building envelope, to design an optimized building envelope for the case area.

Based on the recommendations from literature review, bioclimatic chart and Mahoney’s table, and different scenarios from energy simulation, a residence design was proposed. Hence, energy efficient strategies enhancing thermal comfort for residential design is delivered with conclusive findings and recommendations.

3.4 Methods of Data collection

3.4.1 Sampling

In order to collect the field data of this research, questionnaire survey of forty households including all toles of the core area of Dolakha town was done through Kobo toolbox. Out of these households, a household representing the common post disaster reconstructed building was chosen for detail study and simulation. Since most of the traditional houses were demolished by earthquake 2015 and some were not in use, the existing habitable traditional building was selected for detail study and simulation of traditional building.

3.4.2 Operationalization

The selected two households were studied in detail. Measurements were taken for the preparation of building drawings and simulation.

3.4.3 Data collection

Instruments like temperature data logger and thermos-hygrometer were used for the measurements of air temperature and relative humidity. The instrument was calibrated in Department of Hydrology and Meteorology, and it was found that the temperature measured by these instruments varies in ±0.3°C and about 3-5 % Relative humidity. The other required data were obtained from observations, interviews, and questionnaire survey.

3.4.4 Data Analysis

The air temperature and relative humidity were recorded from the instrument of the selected buildings. The Kobo toolbox software was used to analyze the recorded data and different related graphs and charts were prepared using MS- Excel. Energy Simulation was performed in Autodesk Ecotect Software creating base case and various scenarios to determine the energy performance of the building. The findings from the simulation, field study and literature will be used for providing recommendations to improve thermal comfort in post disaster reconstruction of residential buildings of Dolakha town.

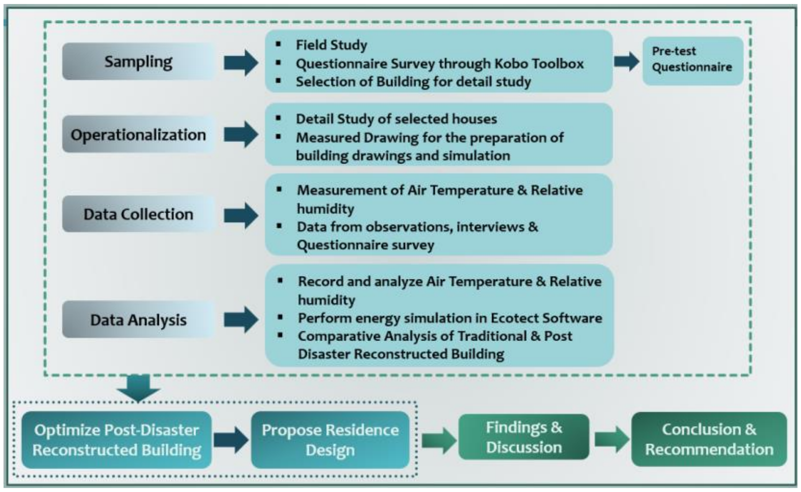


Figure 27 Methodology flowchart for the project

4 Chapter 4: Case Area: Dolakha Town, Dolakha

Dolakha district is a part of Bagmati province with Charikot as headquarter. It covers an area of 2191 Km^2 and had a population of 186,557 according to 2011 Nepal census *(Wikipedia).* Its geographical location is latitude 27°47′37.68″ North, longitude 86°11′03.48″ East and at an altitude of 1700m. Dolakha lies in temperate climatic region of Nepal.

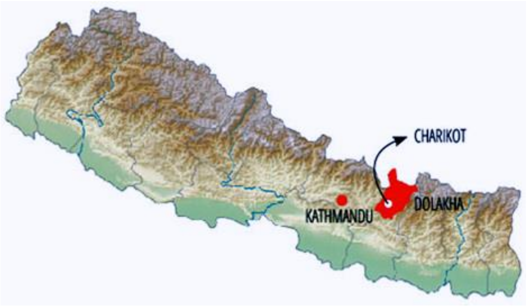


Figure 28 Map of Nepal showing Dolakha
Source:

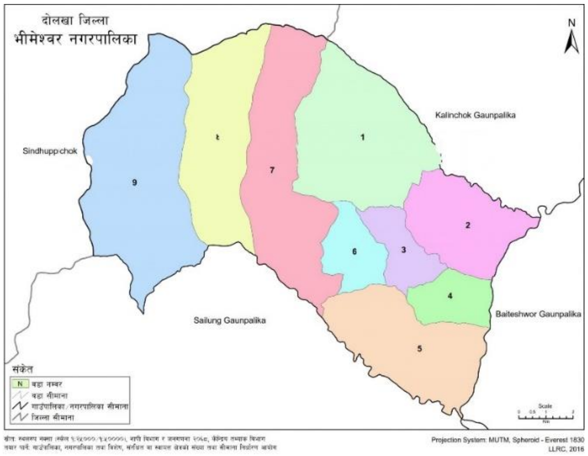


Figure 29 Map of Bhimeshwor Municipality
Source: (Bhimeshwor Municipality, 2016)

Dolakha is one of the worst affected districts of earthquake 2015. While the 25th of April earthquake caused widespread damage to the area, the second earthquake led to more severe damages and casualties in Dolakha and other eastern districts. About 87% of houses are fully or partially destroyed (50,284 houses fully damaged and 305 houses partially damaged) (Nepal Earthquake, 2015).

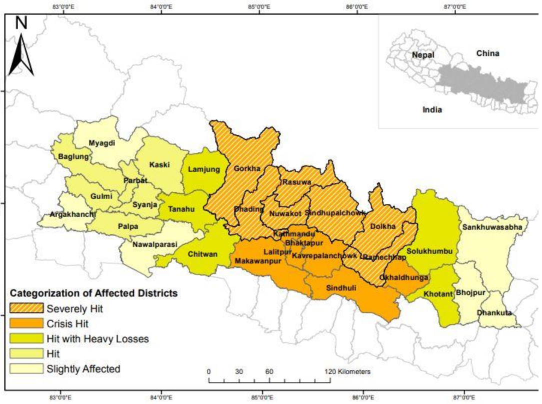


Figure 30 Categorization of Earthquake 2015 affected districts of Nepal

Source: (Post Disaster Needs Assessment, 2015)

4.1 Dolakha Town

Dolakha town is the village of Dolakha district located about 4.5Km North- East of Charikot in Bhimeshwor Municipality ward 2. It is inhabited by Newar community. Dolakha bazaar is full of heritage sites dating back to the Lichchhavi, Malla and Shah eras featuring monuments, traditional and old Newar settlements. Dolakha being an oldest town has great historic value. It covers an area of 20 hectares i.e., 0.2 $Km^{2.}$ According to 1988 census data, population of Dolakha town was 5,645 and according to census data of 2011, population was 5,531 (Bhimeshwor Municipality, 2016). It is assumed that out of 297 families of the town, 215 families have emigrated to Kathmandu valley and other districts and foreign countries as well. As per the household survey by Bhimeshwor municipality in 2012, the total number of houses were 1,124 in Dolakha town and 338 households in core area of Dolakha town.

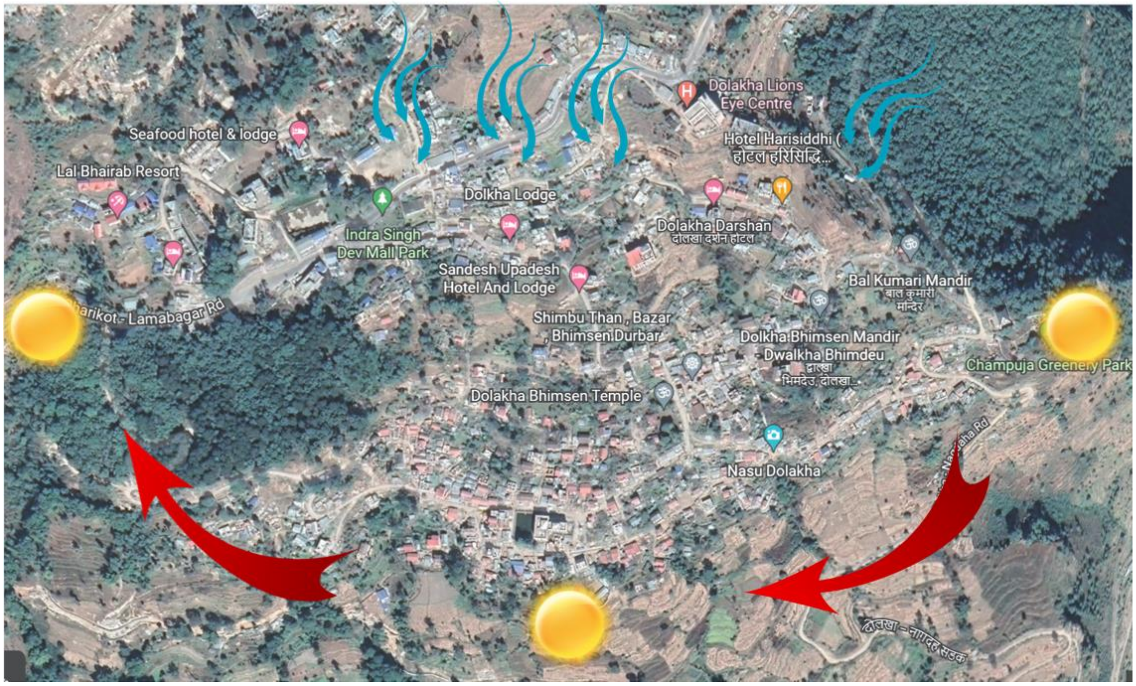


Figure 31 Map of Dolakha Town with Sun Path and Wind-flow Diagram
(Source of Map: Google Earth)

4.2 Disaster Context and Post Disaster Reconstruction

After Gorkha Earthquake 2015, household survey was conducted by Bhimeshwor municipality, technically helped by National Society for Earthquake Technology (NSET) and Building Code Implementation Program in Municipalities (BCIPN). The total number of households in core area of Dolakha town was found to be 338.

4.2.1 Household Survey in accordance to type of construction material

From the survey it was found that there were 307 households built in stone and mud mortar, one of stone with cement mortar, one of brick with mud mortar, two of brick with cement mortar, seven of mixed type of construction and 20 houses in RCC frame structure (Bhimeshwor Municipality, 2016). This shows that majority of the houses were constructed in load bearing structure of stone and mud mortar.

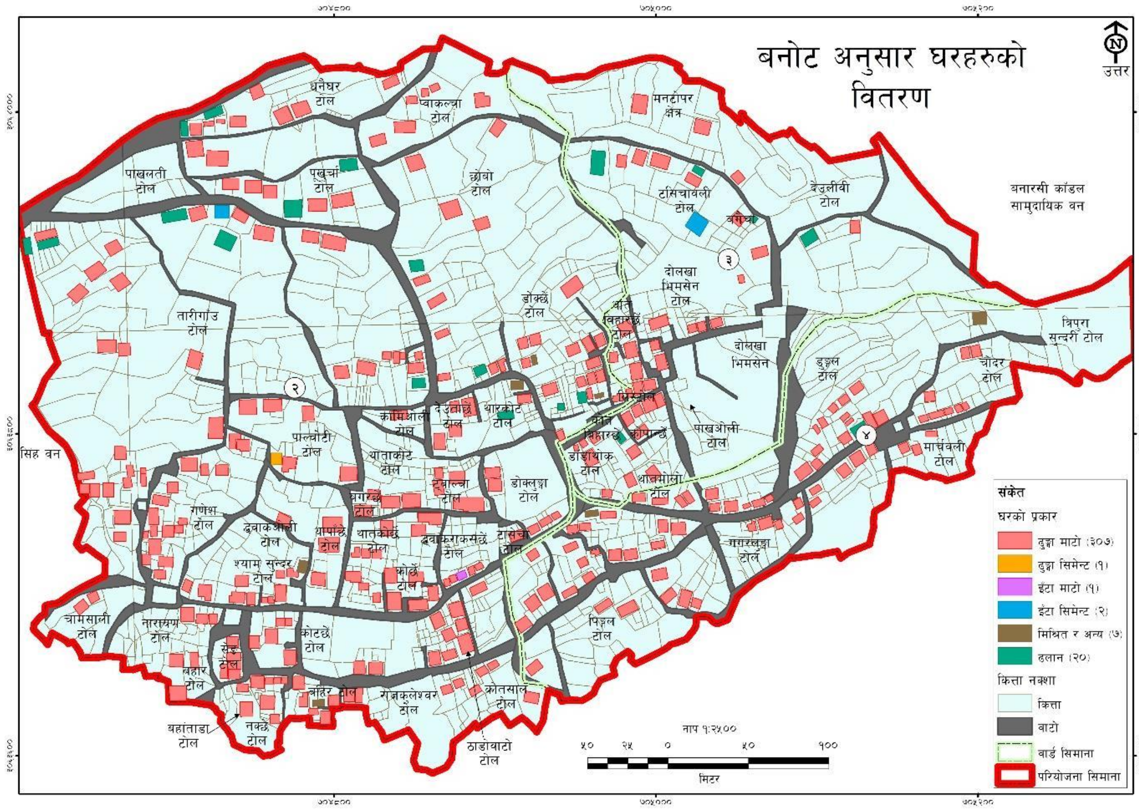


Figure 32 Mapping of Dolakha Town according to type of Construction

Source: (Bhimeshwor Municipality, 2016)

4.2.2 Household survey in accordance with number of storeys

As per the survey conducted, out of 338 household, there were nine houses of one storey, 102 houses of two storey, 170 houses of three storey, 56 houses of four storey and one household of five storey. This shows that the majority of houses were of three storey. (Bhimeshwor Municipality, 2016)

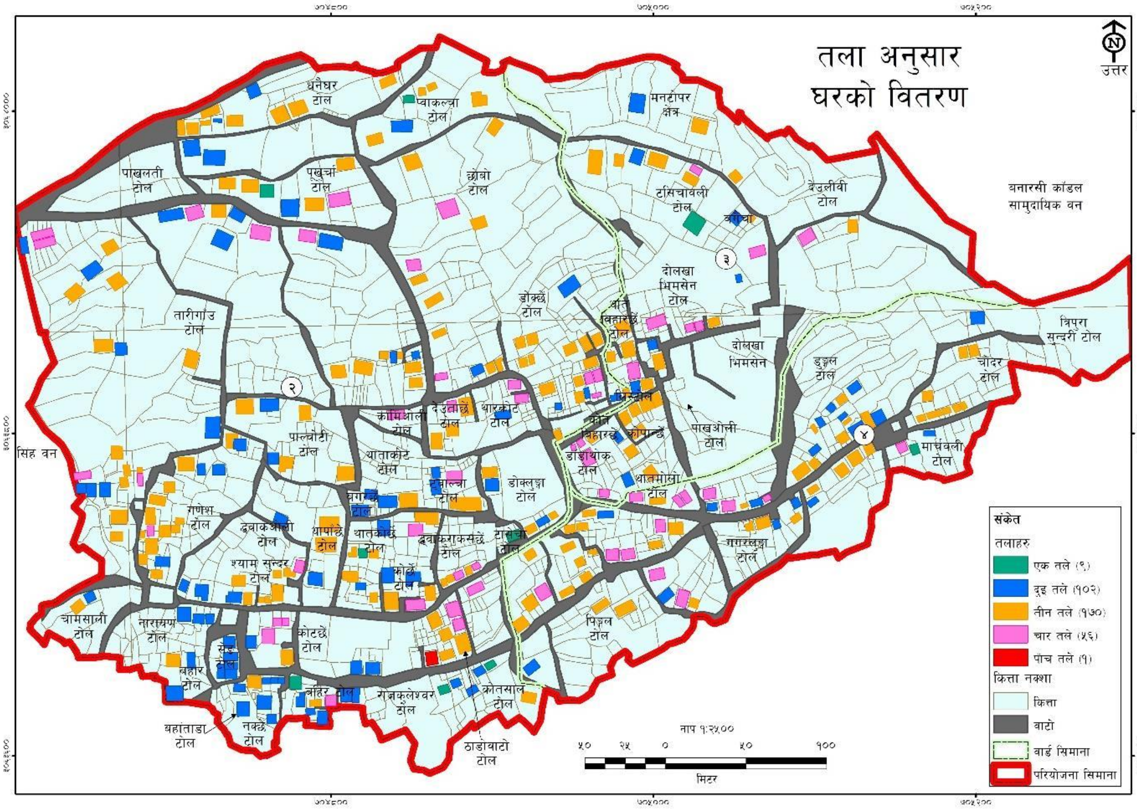


Figure 33 Mapping of Dolakha Town in accordance with number of storeys

Source: (Bhimeshwor Municipality, 2016)

4.2.3 Household survey in accordance with plinth area

According to the survey on plinth area of houses, there were thirty-seven houses of less than 300 Sq.ft., ninety-eight households with plinth area (301 to 500 sq.ft.), 151 households with plinth area of (501 to 900 Sq.ft.), forty-eight households of plinth area (901 to 1500 Sq.ft.) and four houses with plinth area more than 1500 Sq.ft. This shows that most houses have plinth area of 501- 900 Sq.ft. (Bhimeshwor Municipality, 2016)

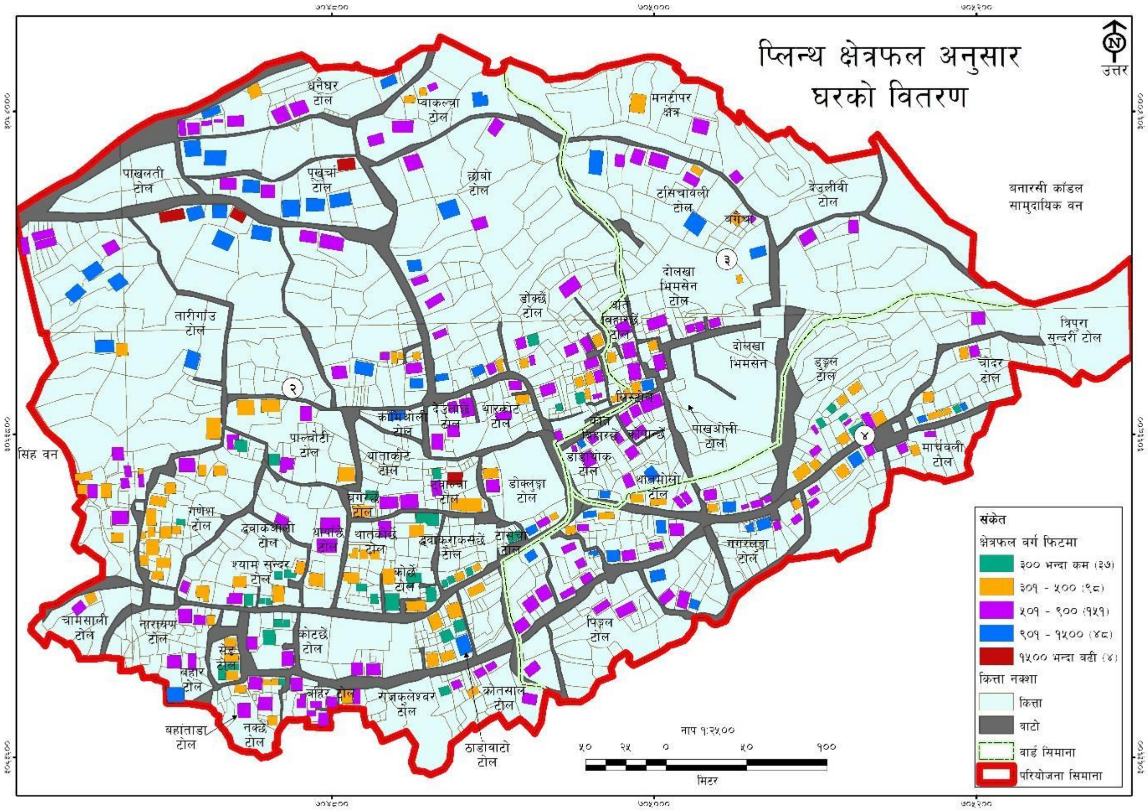


Figure 34 Mapping of Dolakha Town in accordance with Plinth area

Source: (Bhimeshwor Municipality, 2016)

4.2.4 Household survey in accordance with destruction by earthquake 2015

From the survey, it was found that there were 15 households that are least affected, houses that are affected and needs repairment are of thirty-three numbers, fifty-seven houses can be used after retrofitting, 188 houses should be demolished for reconstruction and number of demolished houses were forty-five. The survey shows that most of the houses needs demolishment. (Bhimeshwor Municipality, 2016)

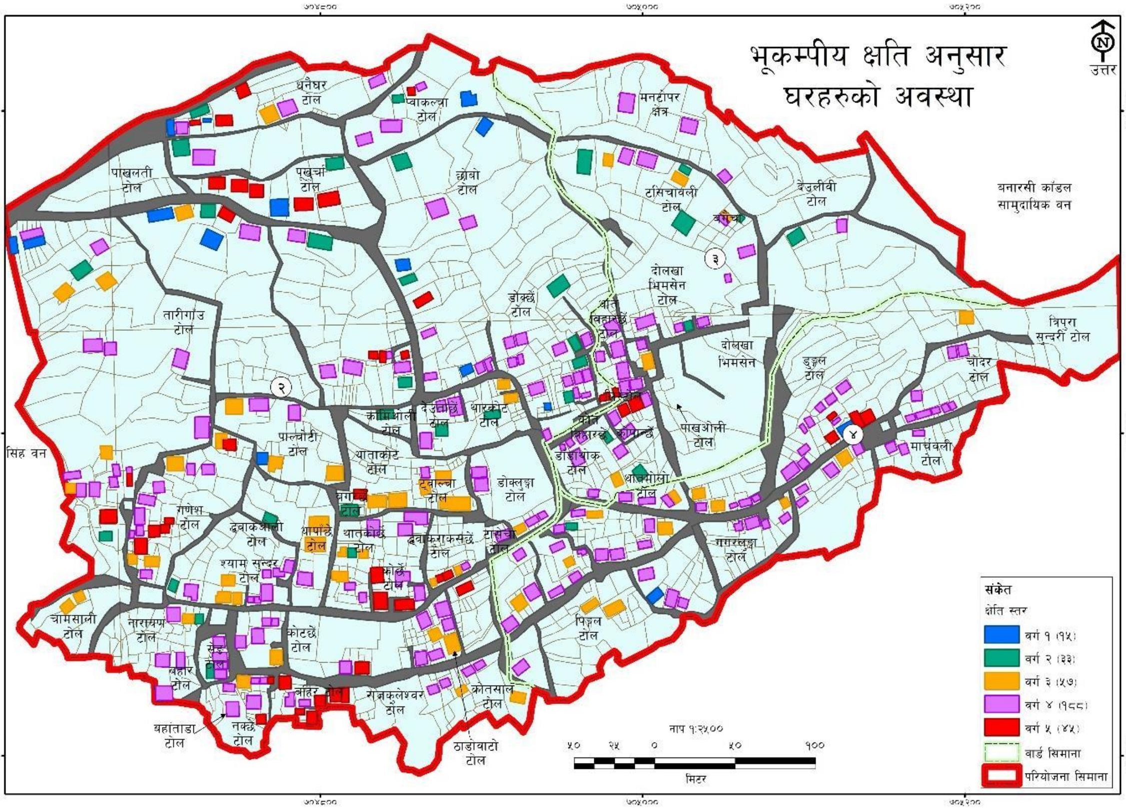


Figure 35 Mapping of Dolakha Town in accordance with household destroyed by earthquake 2015

Source: (Bhimeshwor Municipality, 2016)

4.2.5 Settlement of Dolakha Town before Earthquake 2015

Figure 36 Settlement of Dolakha Town before Earthquake 2015

4.3 Vernacular architecture

4.3.1 Settlement Pattern

The old Newar town is located on the south facing slope that helps in gaining solar radiation. It is of cluster type and the new linear settlements are developed guided by Charikot- Singati road. Farmlands are located towards south of the settlement.

Figure 37 Present Settlement in Dolakha

(Source: Anil Chandra Shrestha)

4.3.2 Orientation

Most of the dwellings of Dolakha is South oriented and some towards East that helped to gain solar radiation in the buildings. Houses that have road on the north side has open space called aagan towards the south which also helps in performing daily activities with the entry of solar radiation in the site area. The orientation of house is also governed by the land topography that mostly suggests south.

Figure 38 South Facing House
(Source: Anil Chandra Shrestha)

4.3.3 Building Layout and Space Use

A traditional Dolakha house is of rectangular plan with gable roof. The house is East-west elongated. Height of tradition houses are mostly three and half storey including attic space. Timber balconing is provided at the second floor on the longer façade. Plinth level of the house is elevated that acts as damp proof. Ground floor acts as multifunctional area with public space called Marcha/ Dalan at the entry of the house, living area, kitchen and some has shed for animals. The upper floors were used as bedroom and the attic space was used for storing grains and other house stuffs. Straight staircase connects the floor that is located towards North of the house. Large openings are provided on the East, West and South walls whereas small and less number of openings are provided on North walls.

4.3.4 Materials and Texture

Locally available stones were used with mud mortar (liun) in walls and footing. Timbers were used as structural support and for doors and windows, comprised of wooden shutter. Gable roof of wooden shingles, thatch or slate were used supported by timber structure. Later those roofs were replaced by CGI sheets. The exterior and interior walls of the house are usually rendered with Kamero mato that increases the thermal mass of the wall. Flooring in ground floor is of rammed earth with mud plaster. Open space in front of the house called 'Aagan' are either mud plastered or has stone flooring.

Figure 39 Traditional House rendered with Kamero

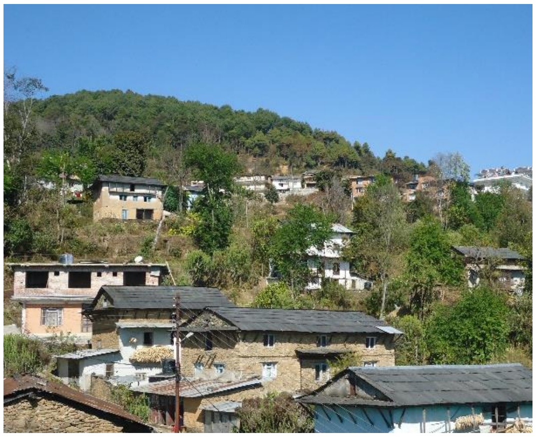


Figure 40 Gable roof with slate

(Source: Fb page of Anil Chandra Shrestha)

4.4 Bye laws for the Dolakha town

After Earthquake 2015, new byelaws were developed for the core area of Dolakha town for reconstruction.

Table 5 Building Construction Criteria for settlement

Building Construction Criteria for settlement		
1.	Ground Coverage	100% for constructing house on the same site of demolition and 90% for new site area (0-2-2-0) and 80% for more.
2.	Height of the building	35 feet including ridge of the roof and No provision of FAR
3.	Maximum floor	3 storey excluding staircase cover and attic space
4.	Floor height	2.44m (8 feet)
5.	Set Back	1.5m for openings
6.	Front Façade	brick cladding to the exterior wall
7.	Cantilever/ rain protection	3feet projection at third floor for rain and sun protection
8.	Door/ window	should be made of timber. 50% of wall area
9.	Roofing	should be traditional gabled roof of 25–30-degree slope
10.	Terrace	1/3rd of total roof area

(Source: Bhimeshwor Municipality ward 2)

4.5 Buildings after Earthquake 2015

The new buildings were constructed considering the Byelaws. Houses are built in frame structure with brick façade and timber doors and windows. Most of the houses have ground floor for commercial purpose and upper floors for residential purpose. Gable roof of CGI sheet is used for roofing. While the temples are reconstructed with load bearing structure with stone façade and timber door and windows.

Figure 41 Residential Buildings after Earthquake 2015

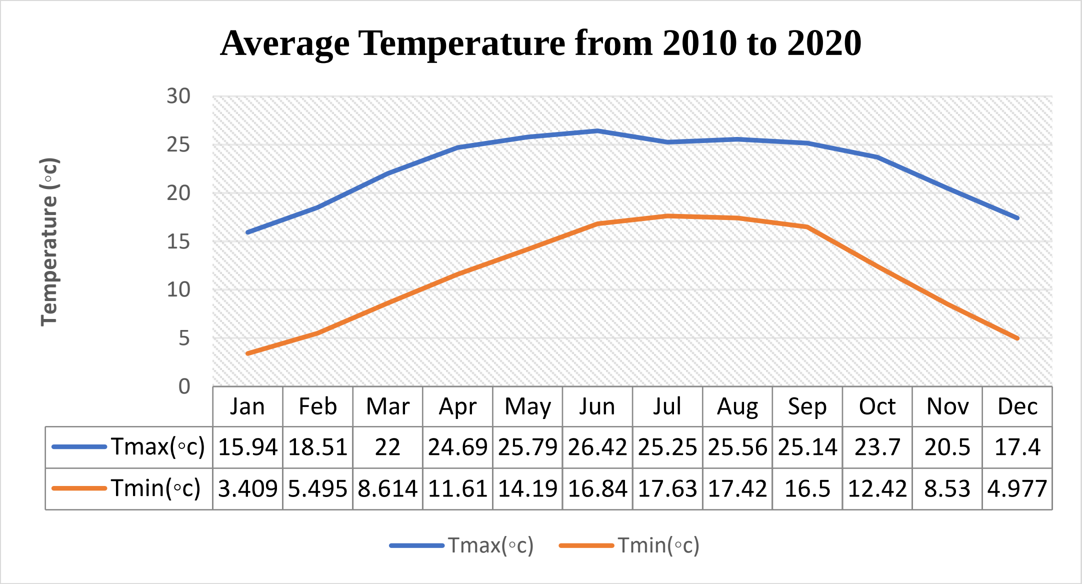
(Source: Anil Chandra Shrestha)

5 Chapter 5: Data collection and Analysis

5.1 Climatic study of Dolakha

The meteorological data of Dolakha was collected from the Department of Hydrology and Meteorology; Babarmahal, Kathmandu from the year 2010- 2020 A.D. Through the collective data, we analyzed various climatic factors of Dolakha. Data like solar radiation and wind direction were missing and thus collected from secondary sources.

5.1.1 Temperature data of Dolakha



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax(◦c)	15.94	18.51	22	24.69	25.79	26.42	25.25	25.56	25.14	23.7	20.5	17.4
Tmin(◦c)	3.409	5.495	8.614	11.61	14.19	16.84	17.63	17.42	16.5	12.42	8.53	4.977

Chart 1: Yearly average maximum and minimum temperature data of Dolakha from 2010-2020

(Source: Department of Hydrology and Meteorology, Kathmandu, Nepal)

From the year 2010-2020; the yearly **average maximum temperature is found to be 26.4 °C** in June whereas the average **minimum temperature is found to be 3.4 °C** in January.

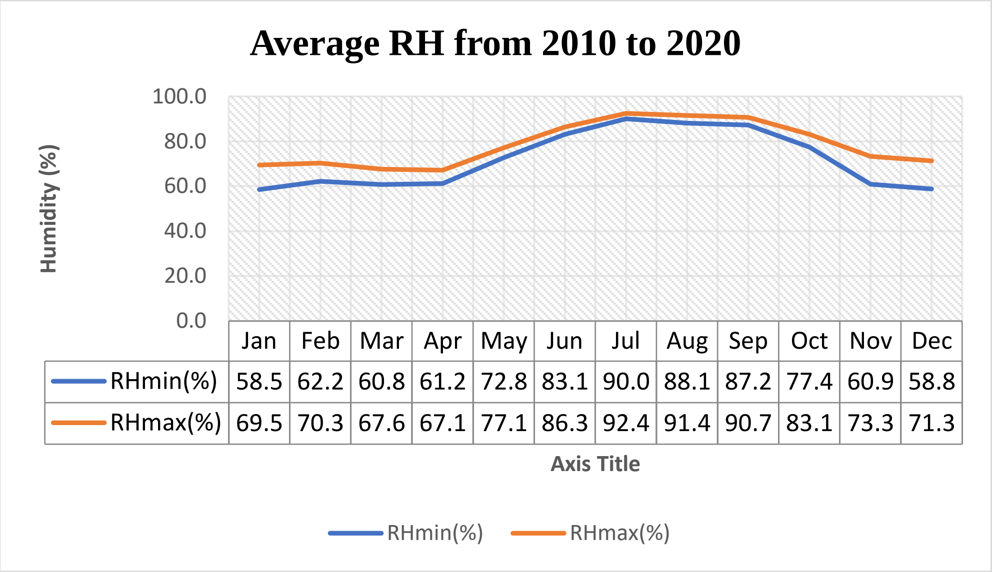
5.1.2 Solar radiation of Dolakha

Since the solar radiation data could not be obtained from the Department of Hydrology and Meteorology, we obtained it from the secondary source which is mentioned below.

Annual Global Solar radiation – 4.490 Kwh/m^2/day

(Source: Solar and Wind Energy Resource Assessment in Nepal (SWERA), 2008)

5.1.3 Relative Humidity of Dolakha



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RHmin(%)	58.5	62.2	60.8	61.2	72.8	83.1	90.0	88.1	87.2	77.4	60.9	58.8
RHmax(%)	69.5	70.3	67.6	67.1	77.1	86.3	92.4	91.4	90.7	83.1	73.3	71.3

Chart 2: Average maximum and minimum relative humidity data of Dolakha from 2010-2020 A.D.

(Source: Department of Hydrology and Meteorology, Babarmahal, Kathmandu, Nepal)

The chart above shows the maximum and minimum relative humidity data of Dolakha from the year 2010-2020 A.D.

Maximum relative humidity- 92.4% in July.

Minimum relative humidity- 58.5 % in January.

5.1.4 Rainfall data of Dolakha

In the figure below, the month of July has the highest amount of rainfall i.e., **624.41 mm** whereas the minimum amount of rainfall is **2.77 mm** in December.

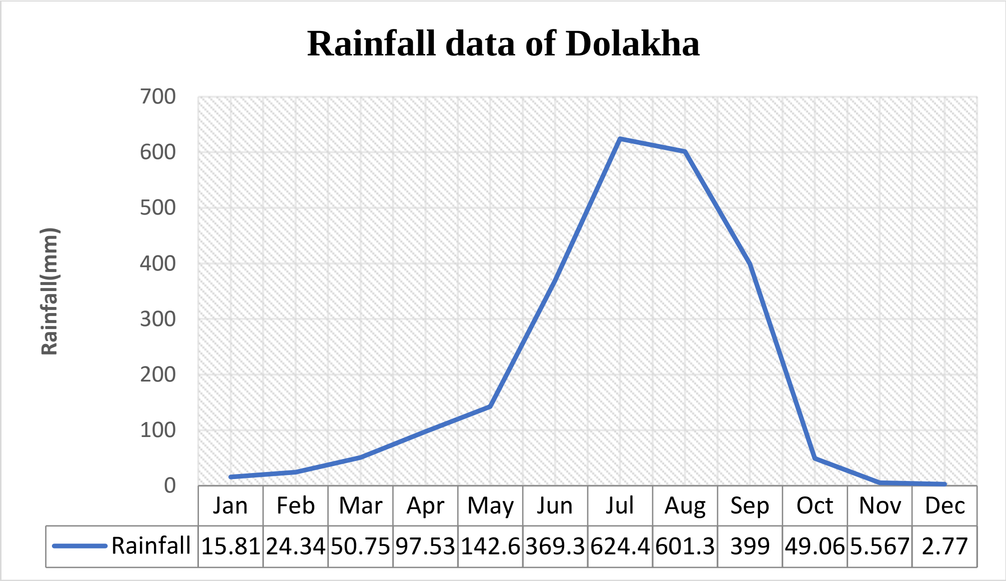


Chart 3: Average rainfall data of Dolakha from 2010-2020 A.D.

(Source: Department of Hydrology and Meteorology, *Kathmandu, Nepal)*

5.1.5 Wind velocity of Dolakha

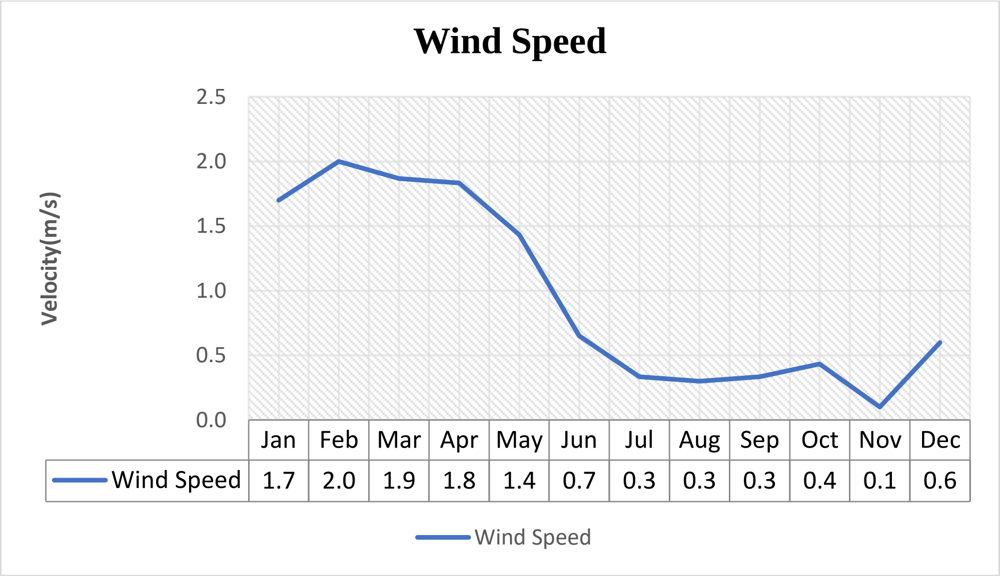


Chart 4: Wind velocity in m/s data of Dolakha of the year 2010-2020 A.D.

(Source: Department of Hydrology and Meteorology, *Kathmandu, Nepal)*

From the figure above, we know that **the maximum wind velocity is 2.0 m/s** and **the minimum wind velocity is 0.1 m/s**.

5.1.6 Wind rose of Dolakha

The wind rose diagram from meteoblue shows that the maximum wind flow is through North direction but according to the local people, wind mostly flows through South east and south west.

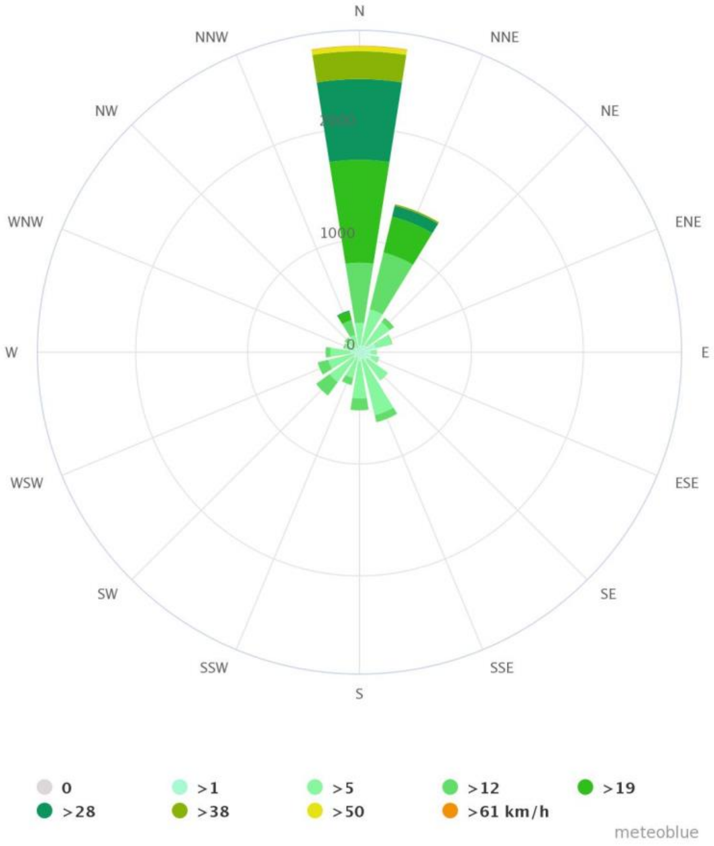


Chart 5: Wind rose of Dolakha

Source: (meteoblue,2021)

5.2 Bioclimatic chart for Dolakha

5.2.1 Szokolay Bioclimatic Chart

The various Control Potential Zone (CPZ) were calculated by using the guidelines of Szokolay **Invalid source specified.**. The detailed process of calculation for different CPZ is shown below.

Data Collection and Arrangement

At first, we collected the data of the Dolakha metrological station and found the mean temperature of the warmest and coldest months (Tav) from the Meteorological department. We found Warmest month was in June and the Coldest month was in January with a minimum temperature of 3.4 °C and a Maximum temperature of 26.4 °C.

Table 6: Average month temperature from 2010 to 2020

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	15.93	18.51	22.00	24.69	25.78	26.42	25.24	25.55	25.14	23.70	20.49	17.40
Min	3.4	5.49	8.61	11.61	14.19	15.30	17.62	17.42	16.49	12.41	8.53	4.97
Average	9.66	12	15.30	18.15	19.98	20.87	21.43	21.48	20.81	18.05	14.51	11.18

(Source: Department of Hydrology and Meteorology)

Comfort Zone

We have done calculation of comfort CPZ for both summer and winter and found the set of area for each summer and winter.

Summer month

Average temperature (T_{avg}) =20.87 °C

Neutral temperature (T_n) = 17.6 + 0.31 x $T_{avg\ °C}$

=17.6 + 0.31 x 20.87

= 24.27 °C

Lower Limit (T_L) = T_n - 2.5 = 24.27 -2.5 =21.77 °C

Upper Limit (T_U) = T_n + 2.5= 24.27+2.5= 26.77 °C

Absolute Humidity for Lower Limit (AH_L) = 8.09 g/kg

Absolute Humidity for Upper Limit (AH_U) = 10.95 g/kg

$X_L = T_L + 0.023 \text{ x } (T_L-14) \text{ x } AH_L$

= 21.77 x 0.023 x (21.77-14) x 8.09

=23.22 °C

$X_U = T_U + 0.023 \text{ x } (T_U-14) \text{ x } AH_U$

= 26.77 x 0.023 x (26.77 -14) x 10.95

=29.99 °C

<u>Winter month</u>

Average temperature (T_{avg}) = 9.67 °C

Neutral temperature (T_n) = 17.6 + 0.31 x $T_{avg\ °C}$

=17.6 + 0.31 x 9.67

= 20.80 °C

Lower Limit (T_L) = T_n - 2.5 = 20.80 -2.5 =18.30 °C

Upper Limit (T_U) = T_n + 2.5= 20.80 +2.5= 23.30 °C

Absolute Humidity for Lower Limit (AH_L) = 6.51 g/kg

Absolute Humidity for Upper Limit (AH_U) = 8.88 g/kg

$X_L = T_L + 0.023 \text{ x } (T_L-14) \text{ x } AH_L$

= 18.30 x 0.023 x (18.30-14) x 6.51

=18.94 °C

$X_U = T_U + 0.023 \text{ x } (T_U-14) \text{ x } AH_U$

= 23.30 x 0.023 x (23.30-14) x 8.88

=25.20 °C

Passive solar Heating Zone (PSH)

Solar Radiation = 4490.00 wh/m^2.day

For normal design, $T_{limit} = T_L$-0.0036 x Dv.360 = 18.3 -0.0036 x 4490 = 2.14 °C

For specific design, $T_{limit} = T_L$-0.0036 x Dv.360 = 18.3 -0.05 x 4490 = -4.15 °C

The passive solar heating limiting line for normal design condition lies vertically from 2.14 °C and specific design consideration for solar design lies vertically at -4.15 °C with an upper limit 95% relative humidity line up to the winter comfort zone shown in the chart.

Mass Effect with Night Ventilation Zone (HEMV)

For Dolakha,

Summer

Maximum Temperature (T_{max})= 26.42 °C

Minimum Temperature (T_{min})= 15.30 °C

Average temperature (T_{avg})= 20.63 °C

Neutral temperature (T_n)= 24.27 °C

Upper Limit (T_U)= 26.77 °C

For mass effect,

Amplitude= (T_{max} -T_{min}) = 11.12 °C

dT= amplitude x 0.3 = 11.12 x 0.3 = 3.34 °C

Limiting temperature (T_{limit})= T_U + dT = 26.77 + 3.34 = 30.11 °C

AH_{50}=13.34 g/kg

$X_{SM} = T_{Limit} + 0.023 \times (T_{Limit}-14) \times AH_{50}$

= 30.11 x 0.023 x (30.11-14) x 13.34

= 35.05 °C

For mass effect with Night Ventilation,

Amplitude= (T_{max} -T_{min}) = 11.12 °C

dT= amplitude x 0.6 = 11.12 x 0.6 = 6.67 °C

Limiting temperature (T_{limit})= T_U+dT = 26.77 + 6.67 = 33.44 °C

AH_{50}=16.18 g/kg

$X_{SM} = T_{Limit} + 0.023 \times (T_{Limit}-14) \times AH_{50}$

= 33.44 x 0.023 x (33.44-14) x 16.18

= 40.68 °C

<u>Winter</u>

Maximum Temperature (T_{max})= 15.94 °C

Minimum Temperature (T_{min})=3.41 °C

Average temperature (T_{avg})= 9.67 °C

Neutral temperature (T_n)= 20.80 °C

Upper Limit (T_U)= 23.30 °C

For mass effect,

Amplitude= (T_{max} -T_{min}) = 12.53°C

dT= amplitude x 0.3 = 12.53 x 0.3 = 3.76 °C

Limiting temperature (T_{limit})= T_U+ dT = 23.30 + 3.76 = 27.06 °C

AH_{50}=11.14 g/kg

$X_{SM} = T_{Limit} + 0.023 \times (T_{Limit}-14) \times AH_{50}$
= 27.06 x 0.023 x (27.06-14) x 11.14
= 30.40 °C

For mass effect with Night Ventilation,

Amplitude= (T_{max} -T_{min}) = 12.53 °C

dT= amplitude x 0.6 = 12.53 x 0.6 = 7.52 °C

Limiting temperature (T_{limit})= T_U+ dT = 23.30 + 7.52 = 30.82 °C

AH_{50}=13.90 g/kg

$X_{SM} = T_{Limit} + 0.023 \times (T_{Limit}-14) \times AH_{50}$

= 30.82 x 0.023 x (30.82-14) x 13.90

= 36.19 °C

The High mass zone limiting line lies at the SET line of 30.11 °C and with addition to night ventilation goes up to the SET line of 33.44 °C for summer. Similarly, The High mass zone limiting line lies at the SET line of 27.06 °C and with addition to night ventilation goes up to SET line of 30.82 °C for winter with upper and lower absolute humidity limit of 4 and 14 g/kg as shown in chart with upper humidity of line of relative humidity of left top edge of the comfort zone.

Air movement Zone (AM)

For Dolakha,

Maximum Temperature (T_{max})= 26.42 °C

Minimum Temperature (T_{min})=15.30 °C

Average temperature (T_{avg})= 20.63 °C

Neutral temperature (T_n)= 24.27 °C

Upper Limit (T_U)= 26.77 °C

Limiting temperature (dT) = T_u+3.8 =26.77 + 3.8 = 30.57 °C

AH_{50}=13.70 g/kg

$X_{L\ (Below\ 50\ \%)} = T_L + 0.023 \text{ x } (T_L - 14) \text{ x } AH_{50}$

$=30.57 + 0.023 \text{ x } (30.57 - 14) \text{ x } 13.70$

=35.79 °C

$X_{U\ (above\ 50\ \%)} = T_L + (0.023 \text{ x } (T_L - 14) \text{ x } AH_{50})/2$

$=30.57 + 0.023 \text{ x } (30.57 - 14) \text{ x } 13.70/2$

=33.18 °C

The Air moment limiting line lies at the SET line of 30.57 °C up to 50 % relative humidity and follows the line inclined with dry bulb temperature 33.18 °C with an upper relative humidity boundary of 95%. The left limiting boundary for Air movement is a vertical line drawn from the left top edge of the comfort zone to 95% relative humidity.

Evaporative Cooling Zone (EC)

For Dolakha,

Maximum Temperature (T_{max})= 26.42 °C

Minimum Temperature (T_{min})=15.30 °C

Average temperature (T_{avg})= 20.63 °C

Neutral temperature (T_n)= 24.27 °C

Limiting temperature for Direct cooling= T_n + 11 = 24.27 +11 = 35.27 °C

Limiting temperature for Indirect cooling= T_n + 14 = 24.27 +14 = 38.27 °C

Lower Limit (T_L)= 21.77 °C

50 % Absolute humidity for T_L(AH_{50}) = 8.09 g/kg

Absolute Humidity difference (ΔAH) = AH_{50} – 4 = 4.09 g/kg

S- point = T_L+0.023 x (T_L-14) x ΔAH

= 21.77 + 0.023 x (21.77-14) x 4.09

=22.50 °C

X-intercept =S+ AH x (2501 - 1.805 x T)/1000

= 22.50 + 4.09 x (2501-1.805 x 21.77)/1000

=32.61 °C

Plotting Climatic Data

Plotting the month data on Szokolay bioclimatic chart of maximum mean temperature with humidity of evening (PM) and minimum mean temperature with humidity of morning (AM) in prepared Szokolay bioclimatic chart.

Table 7: Average month temperature (°C) from 2010 to 2020

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	15.93	18.51	22.00	24.69	25.78	26.42	25.24	25.55	25.14	23.70	20.49	17.40
Min	3.40	5.49	8.61	11.61	14.19	16.83	17.62	17.42	16.49	12.41	8.53	4.97

Table 8: Average Monthly Relative Humidity from 2010 to 2020

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

AM	69.5	70.3	67.6	67.1	77.1	86.3	92.4	91.4	90.7	83.1	73.3	71.3
PM	58.5	62.2	60.8	61.2	72.8	83.1	90.0	88.1	87.2	77.4	60.9	58.8

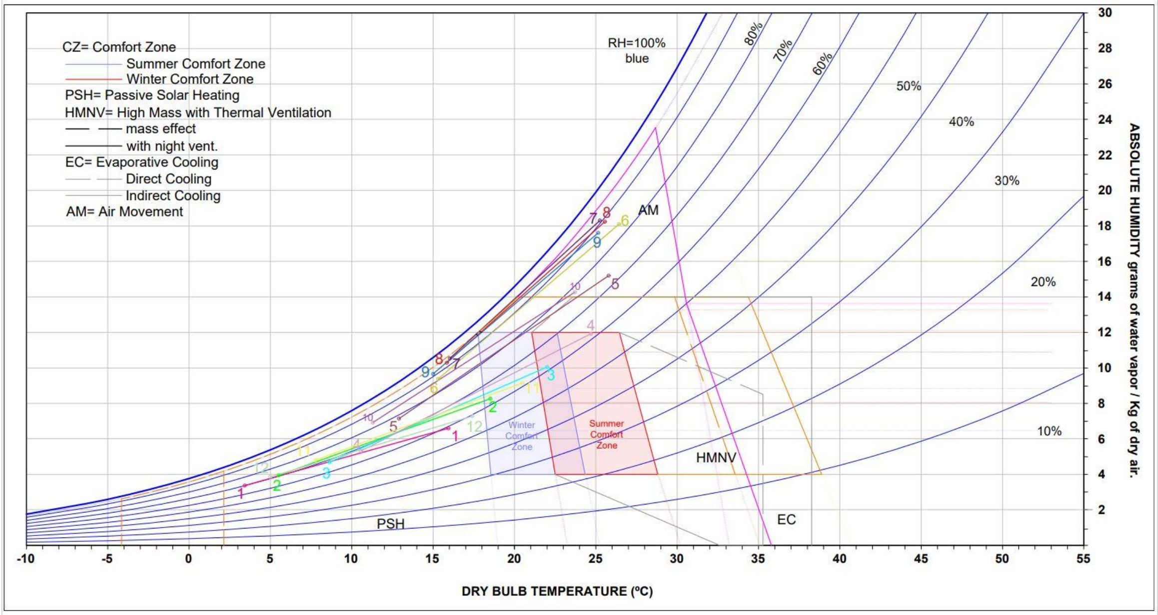


Chart 6 Szokolay Bioclimatic chart for Dolakha

5.2.2 Results & Findings

5.2.2.1 Szokolay Bioclimatic chart for Dolakha

After plotting the month data of maximum mean temperature with humidity of evening (PM) and minimum mean temperature with humidity of morning (AM) in Szokolay bioclimatic chart it was found that different strategies are to be used for the various month which can be graphically seen in the figure:

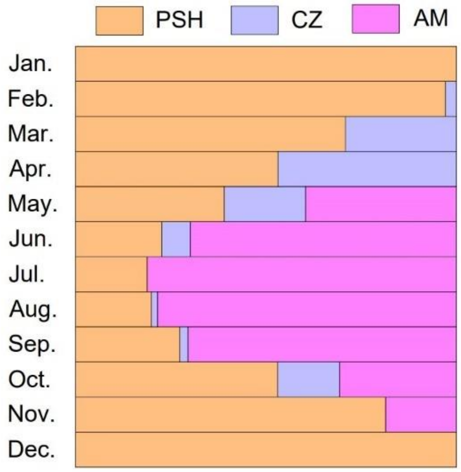


Figure 42: Different strategies for various months from Szokolay bioclimatic chart

Passive Solar Heat is needed to be considered as a design priority for an overall year as the temperature in Dolakha is cool temperate. From October to December and January to April passive solar heat is highly required. High thermal mass must be incorporated for the month

March to June including September and November. Air movement is mostly required starting from May to November for achieving thermal comfort. It is comfortable from May to September and also some parts of October and December.

5.3 Mahoney's table

Monthly mean maximum, and minimum temperature data along with corresponding afternoon (PM) and morning (AM) humidity from the Department of meteorology are tabulated along with rainfall for finding the suggestion for the design.

5.3.1 The result from Mahoney's table

After tabulating the data in Mahoney's table, the following set of suggestion was found as shown in the given figure below:

Table 6: Results from Mahoney's Table

1	**Layout**	**Orientation north and south (long axis east-west)**
2	**Spacing**	The compact layout of estates
3	**Air movement**	Rooms double-banked, temporary provision for air movement
4	**Openings**	Medium openings, 20–40%
5	**Walls**	Heavy external and internal walls
6	**Roofs**	Heavy roofs, over 8h time-lag
7	**Outdoor sleeping**	Not required
8	**Rain protection**	Protection from heavy rain necessary
9	**Size of opening**	Small openings, 15–25%
10	**Position of openings**	As above, openings also in internal walls
11	**Protection of openings**	Protection from rain
12	**Walls and floors**	Heavy, over 8h time-lag
13	**External features**	Adequate rainwater drainage

5.4 Questionnaire Data Analysis

The questionnaire survey was conducted to study the building envelope detail and identify the occupant's behavior and thermal comfort of the residents. The energy consumption pattern of Dolakha town was also studied through questionnaire. A sampling survey of forty houses was done. Houses were selected from each tole of Dolakha town that has significant housing typology and represent the post disaster reconstructed buildings. Moreover, the selected household intends to incorporate all the different building typology used in post disaster reconstruction. The traditional buildings that are being used as residence were selected for household survey.

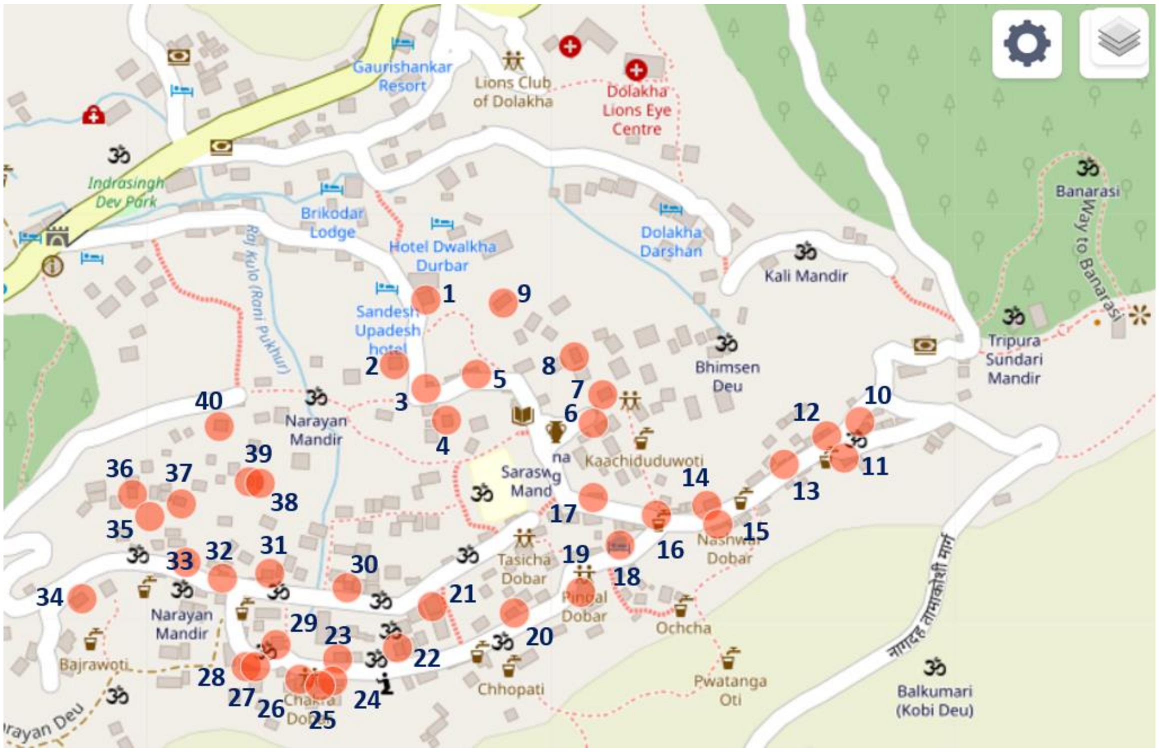


Figure 43 Map of Dolakha town with surveyed household

5.4.1 Demographic and socio-economic data analysis

From the survey data, it is observed that most of the respondents were male (i.e., 65%) of age group (30- 59) years (i.e., 57.5%). The remaining 37.5% belong to respondents of age group (60-79) years and 5% of age group (18-29) years.

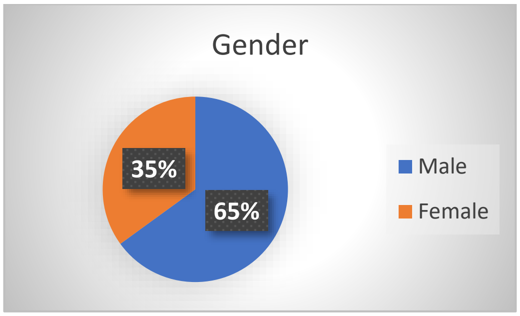


Chart 7 Respondents of Survey

Out of 40 household surveyed, 34 families were nuclear (85%) and 6 were joint (15%). 30 household had joint family (75%) before earthquake and are separated to nuclear family and 25% of the households were nuclear before earthquake. It is found that majority of the families are indulged in agriculture (77.5%) and followed by service, livestock, and business.

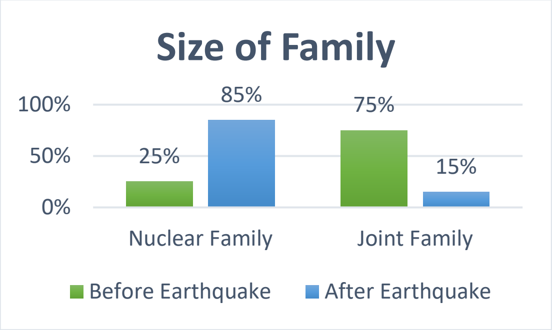


Chart 8 Chart showing Size of Family before and after earthquake 2015

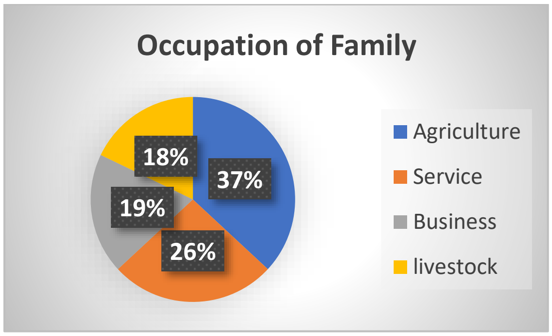


Chart 9 Chart Showing Occupation of Family surveyed

5.4.2 Analysis of Spatial detail of households

The residential plot size varies to great extent from 343 sq.ft. to 2335.77 sq.ft. It is found that out of 40 households, 35 were built in situ and five houses away from the original. The plinth area of the surveyed households ranges from 256 sq.ft. to 1071 sq.ft. Majority of the houses were of two storey and attic floor. 36 respondents have been staying for 1-5 years while 3 respondents have been staying in the house for more than 15+ years which is the traditional house. A single house was found which stayed for 6-11 years and is repaired after earthquake.

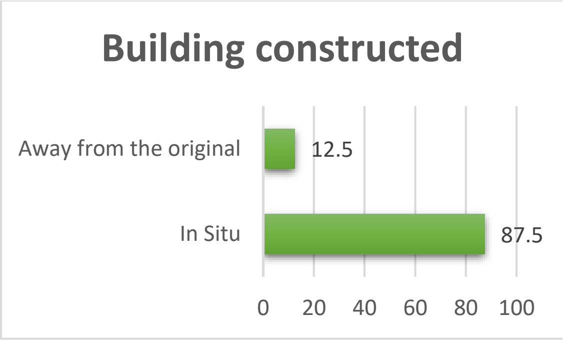


Chart 10 Chart showing Building constructed after earthquake

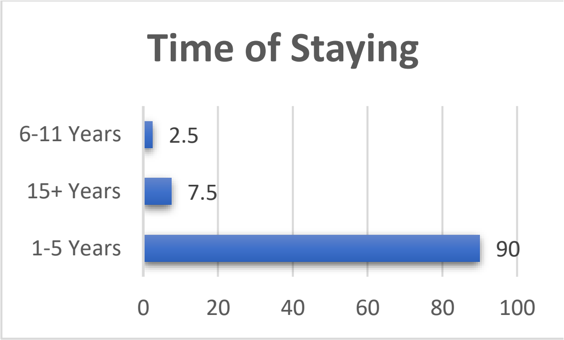


Chart 11 Chart showing Time of stay in the house

5.4.3 Analysis of building detail of households

From the survey data, it is found that majority of the demolished houses used stone in mud mortar (37 houses i.e., 92.5%) as building material, two houses in brick with cement mortar and a house with brick in mud mortar.

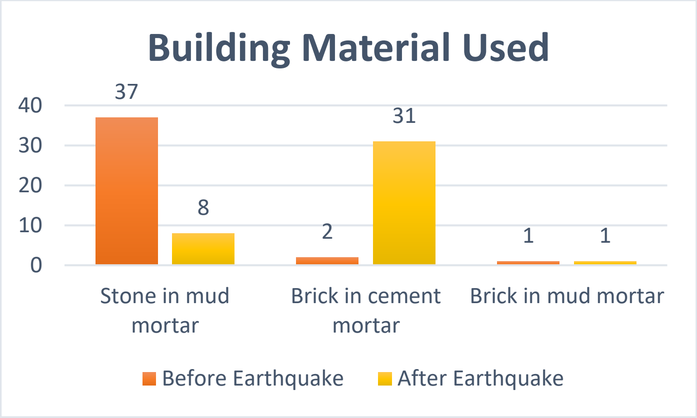


Chart 12 Chart showing Building material used in construction before and after earthquake

Most of the buildings are solely used as residential (30 houses i.e., 75%) and the rest 10 houses are used as residential cum commercial purpose. Most of the demolished houses were of three storey including attic floor (25 houses i.e., 62.5%), seven houses of more than three floors and four houses of two storey. Majority of the building envelope (85%) has been changed to brick and RCC frame structure.

The percentage of south oriented houses are higher (55%), followed by 20% of north oriented houses with open space towards south and 6 houses oriented towards east and 4 houses west oriented.

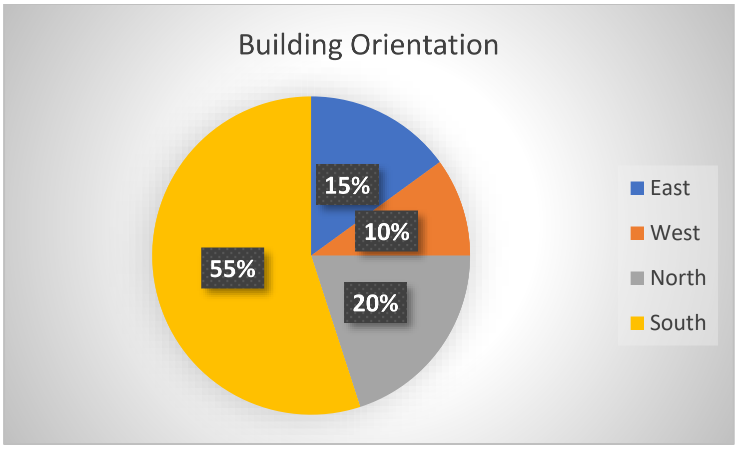


Chart 13 Chart showing orientation of surveyed building

27 houses are built in RCC frame structure, eight houses are of load bearing structure in stone in mud mortar and five houses are of load bearing structure with brick and cement mortar. 33 houses have windows of timber frame with glass and the rest seven houses have timber frame with timber shutter.

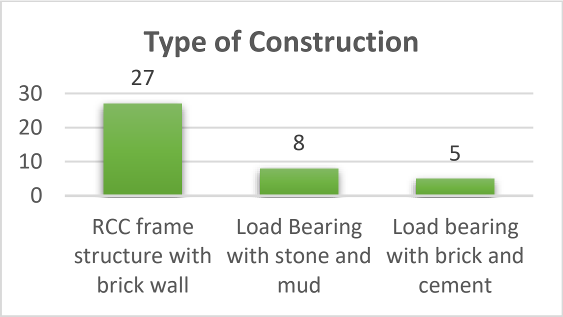


Chart 14 Chart showing type of construction of surveyed house

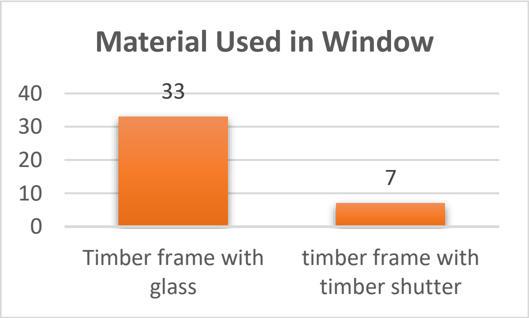
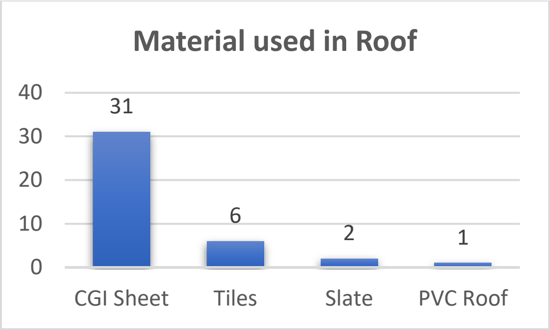


Chart 15 Chart showing material used in window

31 houses use CGI sheet for roofing, six houses are with roof tiles and two with slate roofing. 20 houses have gable roof+ flat roof, 17 houses with gable roof only and three houses have flat roof.



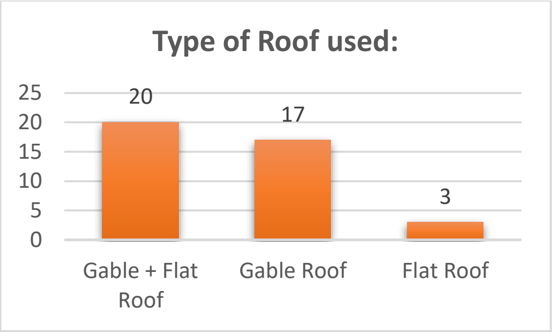


Chart 16 Chart showing material used in roof

Chart 17 Chart showing type of roof used

5.4.4 Analysis of thermal sensation

Out of 40 households, 28 houses (70%) require room heating in January and 33 houses (82.5%) does not require room cooling.

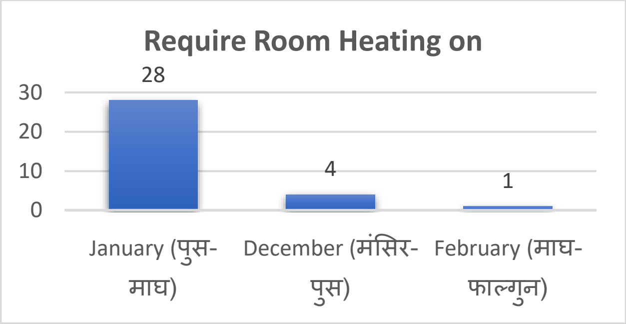


Chart 18 Chart showing requirement of room heating

During the time of survey, 28 respondents (70%) felt neutral thermal sensation in the room, 9 respondents felt slightly warm, and the rest felt slightly cold.

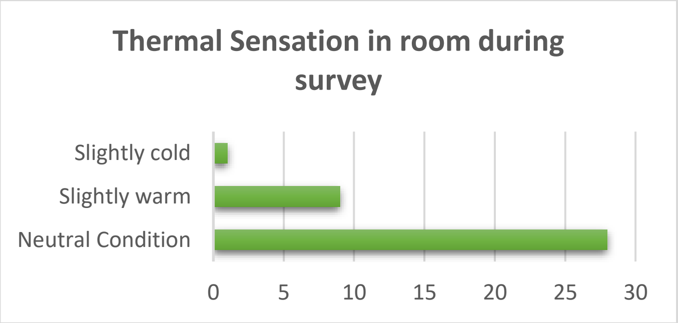


Chart 19 Chart showing thermal sensation in the room during survey

It is figured out that the house has more air movement during April. According to the respondents, the extremely hot months are June and July, and the extremely cold months are December and January.

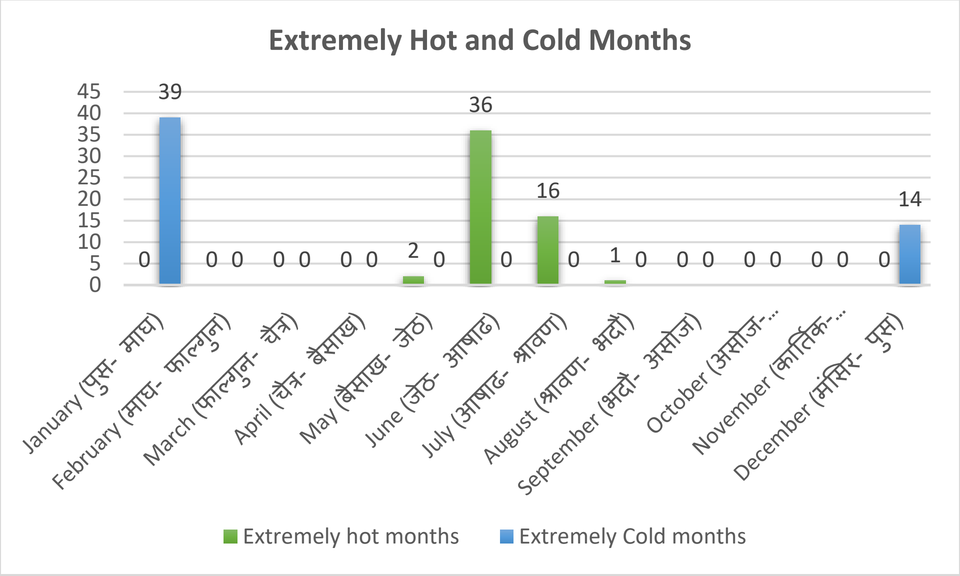


Chart 20 Chart showing extreme hot and cold months

25 respondents feel cold during winter, 12 respondents feel okay and three feel very cold. 35 respondents feel comfortable to live in during summer and the rest felt uncomfortable and the reason is conduction from building envelope. 20 respondents do not feel comfortable to live in the house during winter season due to infiltration of cold breezes and conduction from building envelope while 16 respondents feel comfortable to live in.

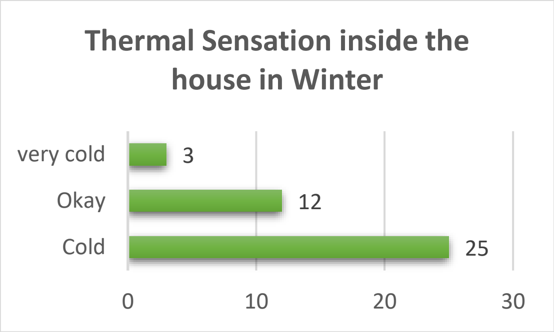


Chart 21 Chart showing Thermal sensation inside the house in winter

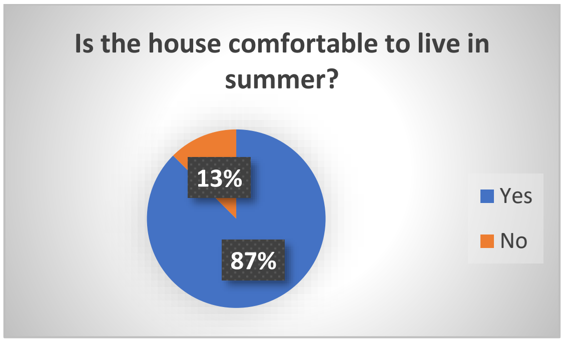


Chart 22 Chart showing percentage of resident feeling comfortable in summer

In the house surveyed, most of them has generally two members (14 household) residing in the house, 11 household has three members, nine households have four members, three household has single member and more than four members. 20 household spend 7 hours inside the house in summer, and 8,7,4, and 1 household spend 5hours, 8 hours, more than 8 hours, and 6 hours respectively.

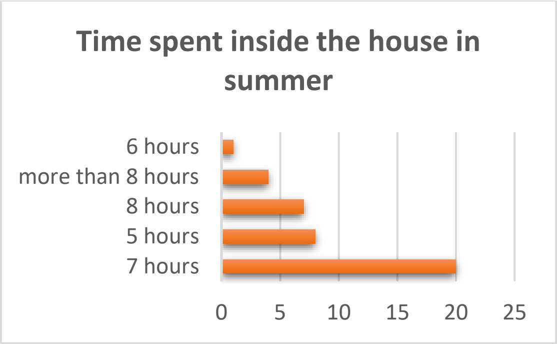


Chart 23 Chart showing Time spent inside the house in summer

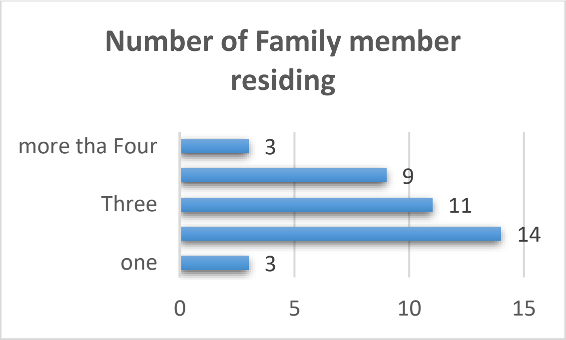


Chart 24 Chart showing Number of Family member residing in the house

Among the 40 surveyed houses, it is found that 28 households open windows for 5-6 hours, 8 households for 3-4 hours and 4 households for more than 6 hours during day to achieve thermal comfort inside the building. Similarly, to maintain the thermal comfort inside the building, 27 household open windows for 3-4 hours, 9 houses for 5-6 hours, 3 houses for 1-2 hours and one household for more than 6 hours.

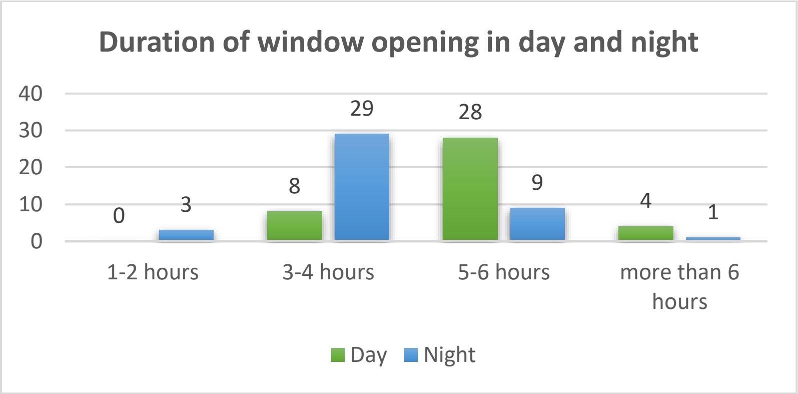


Chart 25 Duration of window opening in day and night to achieve thermal comfort

5.4.5 Energy consumption

Hydroelectricity is the main source of lighting for carrying out daily activities in all the household. The electricity is supplied by Nepal Electricity authority. Tube lights of (20-30 watt) and LED lights (3 watt to 15watt) were installed in each room and for outdoor lighting fixture, LED and CFL lights were used. Out of 40 household, single house was seen to be using solar panel for emergency lighting. However, all the houses were fully dependent on electricity provided by NEA. Most of the houses have minimum monthly charge i.e., Rs 30 only and the monthly cost range from Rs (30-900) only.

37 out of 40 household rely on LPG gas for cooking purpose and kept one as stock and 29 households use traditional stoves of coal and firewood used for emergency purpose only. 21 houses were found to be using electric rice cooker for 2-3 hours per day. 28 household use TV for about 4-6 hours and radio was used by 12 households. The number of households using Laptops and electric iron are low i.e., 4 houses use laptop/computer, and 6 houses use electric iron. Refrigerators are used by 11 households. 100% of household use mobile phones and charger.

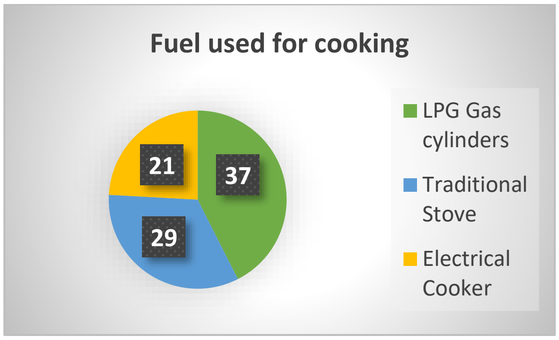


Chart 26 Chart showing fuel used for cooking

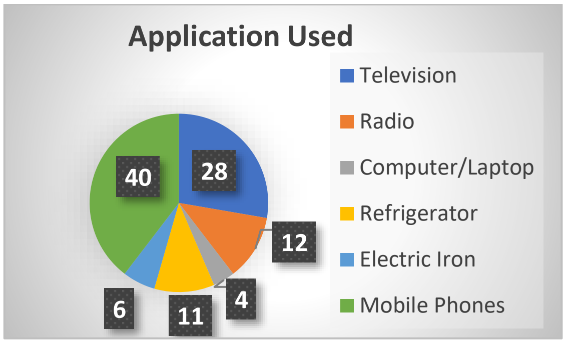


Chart 27 Chart showing applications used in surveyed house

For water heating purpose 19 household use traditional stove for water heating, 3 household have provision of solar water heater and 10 household use LPG gas geyser for water heating. For the room heating purpose, 9 out of 40 household use electric heater and 7 household used traditional stove for space heating. However, the rooms are not equipped with any heating or cooling appliances, but the occupants add some clothing value and lit fire to keep themselves warm during winter.

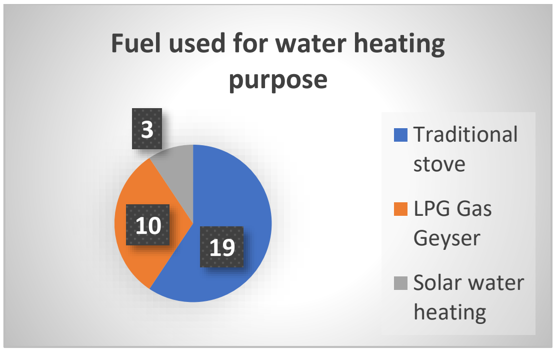


Chart 28 Chart showing Fuel used for water heating purpose

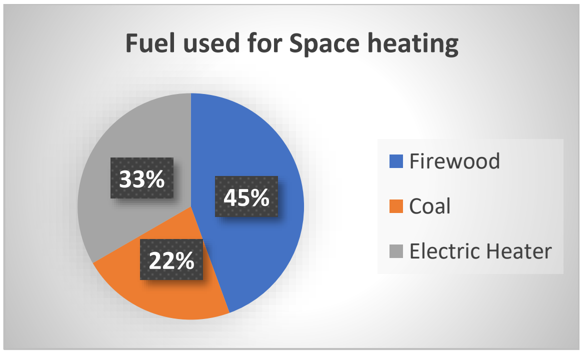


Chart 29 Chart Showing fuel used for space heating

39 out of 40 houses have provision of separate kitchen and 30 household have natural ventilation. As per survey carried out, 20 respondents faced health problem like tiredness, cough, allergy, and dryness of eyes after shifting to new house. The major problem in the house is excessive cold in winter and the building layout of having gable roof compulsory has created problem of placing overhead tank and solar panel for water heating.

During the household survey, sky condition for most of the period was cloudy and rainy and the outdoor air temperature range from 24 to 30°C and the relative humidity range from 61% to 81%.

Out of forty household surveyed, two residences a traditional and post disaster reconstructed building (representing typical and mostly used building typology) was chosen for detail study to evaluate the thermal comfort considering architectural design and building envelope. The post disaster reconstructed building was chosen as per similar ground floor area, number of storey and orientation as compared to that of traditional building.

Table 7 Details of Selected house

House Owner	House Type	Ground Floor Area (Sq.ft.)	No. of Floor	Orientation	Construction type
Miss Gita Shrestha	Traditional	641.25	Two and attic space	South	Load Bearing with Stone and mud Mortar
Mr. Tirtha Narayan Joshi	Post Disaster Reconstructed	638	2.5 with gable and flat roof	South	RCC Frame Structure

5.5 Case 1: The Traditional Building

A detail study of traditional building of Miss Gita Shrestha was carried out. The building layout, envelope study and its construction type, building material and texture is studied in detail. The building is oriented towards south direction and has open space in front. Flowers and plants are planted at aagan and towards east of the house.

Figure 44 Case 1: Traditional House of Dolakha town

5.5.1 Building Layout and Space Use

The house has a simple rectangular plan of (28’-6” x 20’6”) sq.ft. with gabled roof of slate. It is of three storey including attic floor. The ceiling height of the building is 6feet and 10 inches. Ground floor acts as multifunctional area. The semi-open space called ‘Dalan’ on the southeast side of the house acts as living area and is a semi-public space. The room of Southwest was used as guest room before and now is used as kitchen.

Figure 45 Ground Floor Plan of Traditional House with sun path diagram

A straight flight of staircase located on the north connects the upper floors. Space on the north is used as lobby and storage while room of Northwest is used as shed for goats and hens. The rooms towards south of first floor is used as bedrooms while the room of North-east is used as store for rice. The attic space was divided with timber partition for storage of grains and utensils. The southeast portion was used as Kitchen. Shading is provided above the windows of CGI sheet. Latrine was located towards the southwest side of aagan.

Figure 46 Staircase connecting upper floors

Figure 47 First and Attic Floor Plan of Traditional building

5.5.2 Construction type

The building is of load bearing structure of stone masonry wall with mud mortar. Timber posts called 'Tham' are used on dalan area of ground floor and attic space as a structural member. Timber structure called nidhal acts as beam. Struts are used as sill and lintel band in openings.

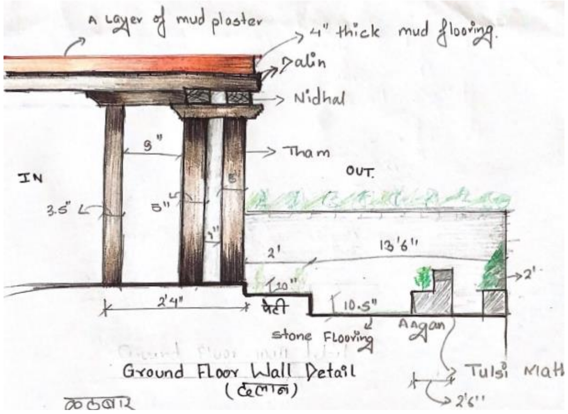


Figure 48 Timber wall detail of Traditional House

Figure 49 Timber boards for Partition wall

Timber boards are used for partition wall in which the joints are plastered with mud. Timber structure with post, rafter, purlin and tudal on attic supports the slope roof of slate. Dalins are arranged horizontally above the stone wall and timber planks are laid over it for flooring of first and second floor. About 4" thick mud mixture (soil+ cow dung+ rice husk) is laid over the timber planks and is mud plastered for smooth floor finish. Doors and windows are made with timber frame and timber shutter. Staircase is also made of timber.

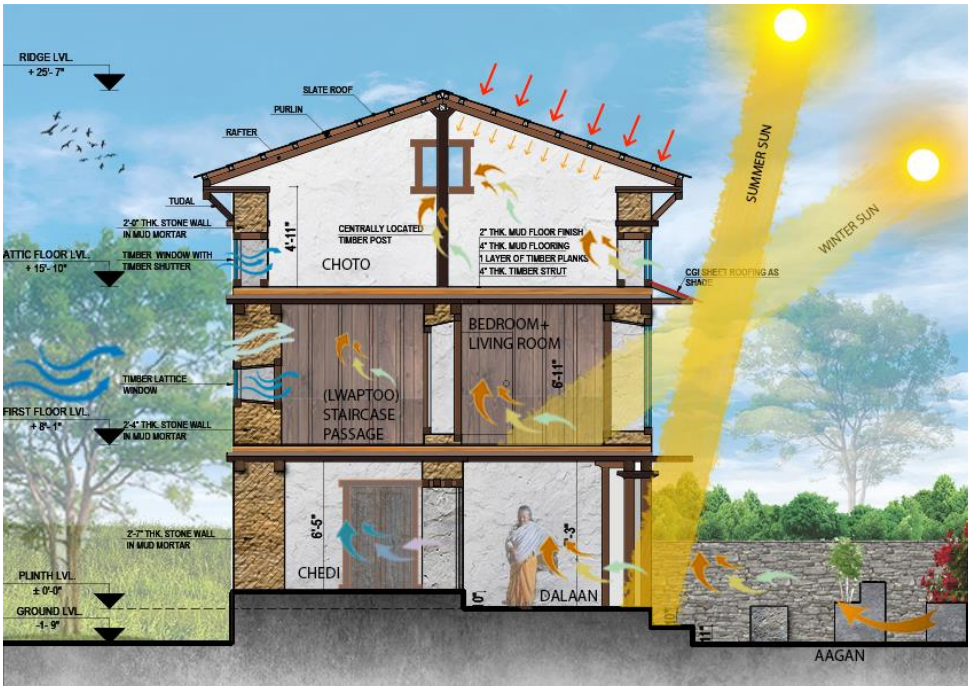


Figure 50 Section of Traditional House

5.5.3 Window wall Ratio

South walls are provided with large windows on first floor whereas the north walls are provided with smaller number of windows. Openings from the south walls help to admit solar radiation into the building and helps in providing visual comfort as well as enhancing daylight inside the building. The rooms located towards north lack daylight and requires artificial lighting.

Figure 51 Fenestration on south wall

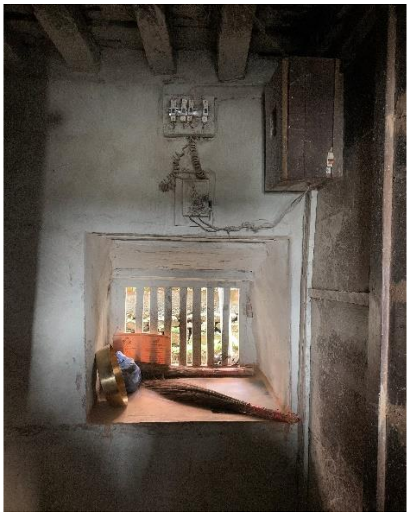


Figure 52 Fenestration on north wall

Table 8 Window Wall Ratio of Traditional building

S.No.	Size	East	West	North	South
1.	3’1” x 5’2”	G.F=1	0	0	G.F=1 F.F.=2
2.	2’4” x 5’2”	F.F.= 1	G.F.=2 F.F.=1	0	0
3.	2’10” x 1’9”	0	0	F.F=1 Attic F. = 1	G.F=2
4.	2’0” x 1’9”	F.F=1 Attic F. = 1	F.F=1 Attic F. = 1	G.F=1	Attic F. = 1
5.	2’10” x 5’	0	0	0	F.F=3
	Total WWR in %	1.64%	1.64%	2.27%	23.29%

5.5.4 Building Material

Locally available stone is used for wall construction with mud mortar. The walls are rendered with mud plaster on both the sides and are finished with kamero mato available just below the town (Nagdaha and Selap). Timbers from nearby forests are used as structural member and for doors and windows. Slates for roofing were brought from Aalampu (the nearby village). CGI sheets are used as shading above the windows. Stone flooring has been used in open front space.

Figure 53 Stone Wall with mud mortar

Figure 54 Internal wall surface rendered with Kamero mato

Figure 55 External wall surface rendered with Kamero mato

Figure 56 Timber as Structural member

Figure 57 Slate roof Supported by timber structure

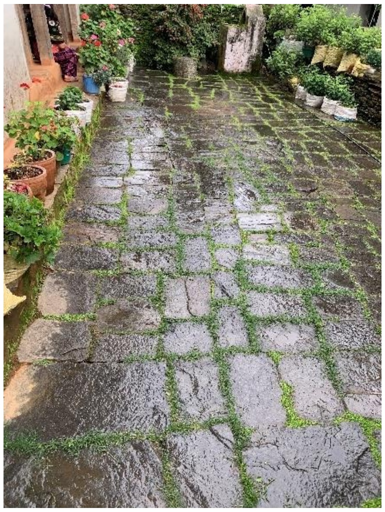


Figure 58 Stone flooring in aagan

5.5.5 Materials color and Texture

The exterior and interior of the house is painted with white kamero mato. The walls have rough and irregular surface. Roofing is of grey rough surfaced slate. Rough textured roof and walls helps in absorbing solar radiation for longer period and increases the thermal time lag.

Figure 59 Irregular and rough wall surface

Figure 60 Rough textured Slate roof

5.5.6 Temperature and humidity measurement

Indoor temperature and humidity were recorded through thermo-hygrometer in 3-time sections i.e., 7 am, 1pm and 7 pm. The device was centrally located on first floor of the building for a week.

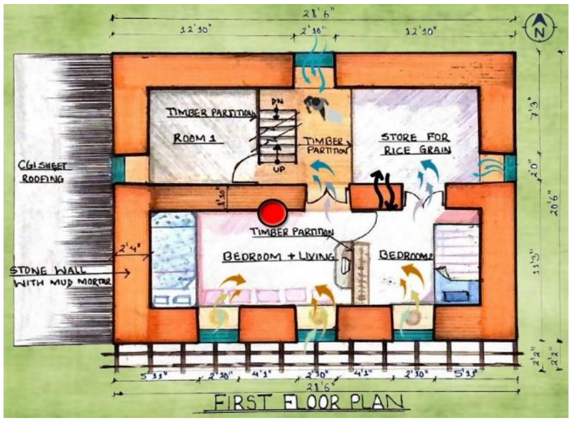


Figure 61 The red dot shows the location of data logger in traditional building

Figure 62 Data logger inside the traditional building

5.5.7 Comparison of Indoor and outdoor temperature of traditional Building

The indoor and outdoor air temperature difference in traditional building is 0.27°, 3.17° and 1.01° at 7 AM, 1PM and & 7PM respectively in average.

Table 9 Comparison of Indoor and outdoor Air temperature of Traditional Building

Date	7 AM		1PM		7PM	
	Indoor Temp (°C)	Outdoor Temp (°C)	Indoor Temp (°C)	Outdoor Temp (°C)	Indoor Temp (°C)	Outdoor Temp (°C)
3rd July 2022	21.96	22.1	21.88	24.9	22.61	22.1
4th July 2022	21.62	21.2	24.92	27.8	23.03	24.4
5th July 2022	22.35	22.1	24.97	28.6	23.83	22.69

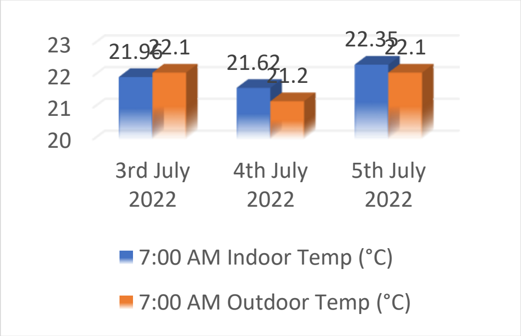


Chart 30 Indoor & Outdoor Air temperature of Traditional Building at 7:00AM

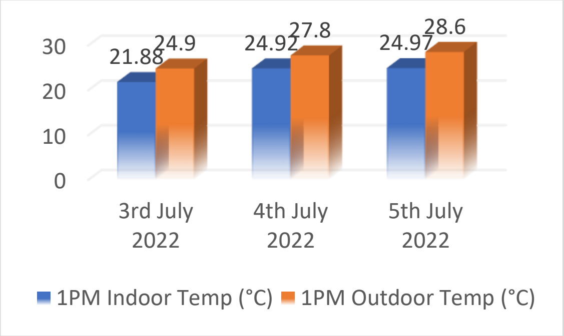


Chart 31 Indoor & Outdoor Air temperature of Traditional Building at 1:00PM

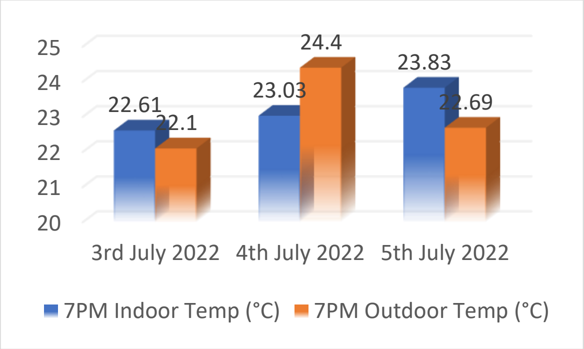


Chart 32 Indoor & Outdoor Air temperature of Traditional Building at 7:00PM

5.5.8 Comparison of Indoor and outdoor Relative Humidity of Traditional Building

Table 10 Comparison of Indoor and outdoor Relative Humidity of Traditional Building

Date	**7 AM**		**1PM**		**7PM**	
	Indoor Relative Humidity (%)	Outdoor Relative Humidity (%)	Indoor Relative Humidity (%)	Outdoor Relative Humidity (%)	Indoor Relative Humidity (%)	Outdoor Relative Humidity (%)
3rd July 2022	66	79	63	69	65	79
4th July 2022	69	81	63	64	71	76
5th July 2022	61	73	58	64	64	94

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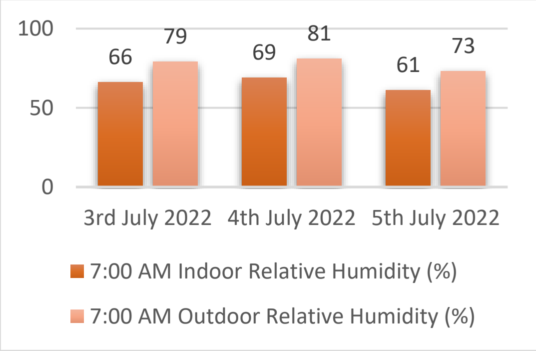


Chart 33 Relative Humidity indoor and outdoor of Traditional House at 7:00AM

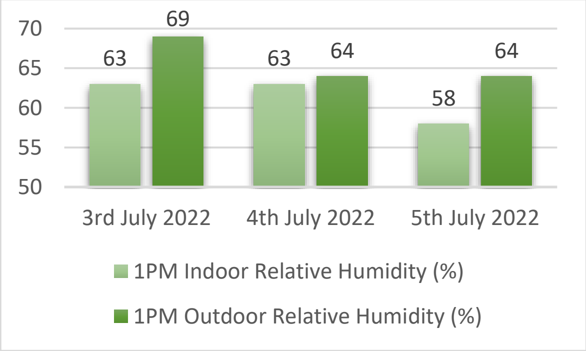


Chart 34 Relative Humidity indoor and outdoor of Traditional House at 1:00PM

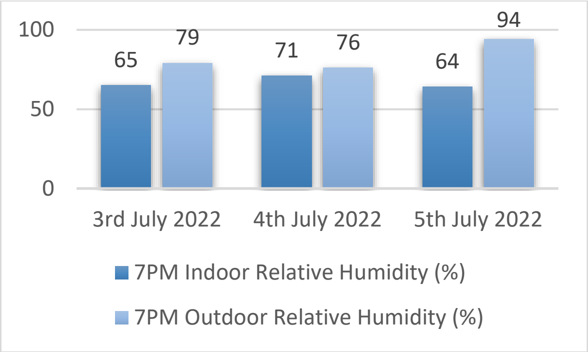


Chart 35 Relative Humidity indoor and outdoor of Traditional House at 7:00PM

5.6 Case 2: Post Disaster Reconstructed Building

Similarly, post disaster reconstructed building of Mr. Tirtha Narayan Joshi was chosen for detail study. The selected building represents the majority of post disaster reconstructed building of Dolakha town. It is oriented towards south and has open space in front of the house.

Figure 63 Case 2: Post Disaster Reconstructed Building

5.6.1 Building Layout and Space use

The building has a rectangular plan of (29’-0” x 22’-0”) sq.ft. It is comprised of two and half storey with half gable roof and flat roof. The ceiling height of the building is 7’10” feet.

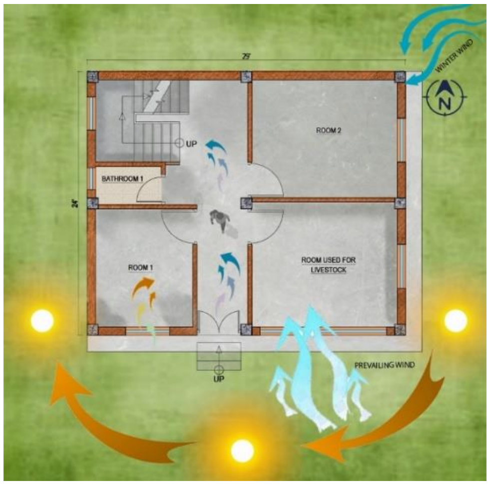


Figure 64 Ground Floor Plan of Post Disaster Reconstructed Building

Ground floor is comprised of three rooms, out of which the southeast room is used for livestock and rest for storage. The rooms of first floor are used as living and bedrooms. The attic room at the top is used as kitchen and is located towards west. Flat roof is provided towards east direction. Bathrooms are located towards west and dog-legged staircase located towards northwest connects the upper floors.

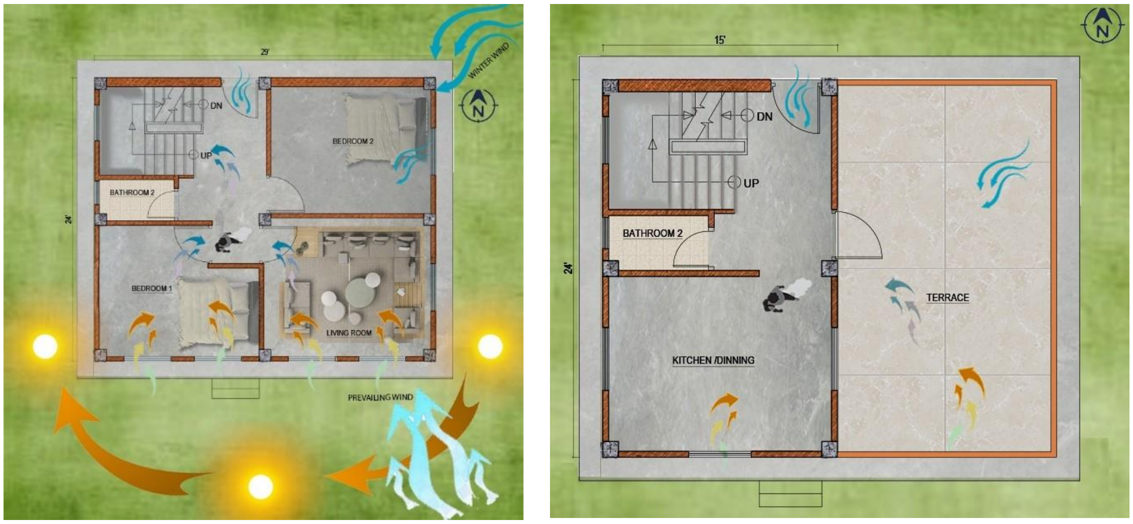


Figure 65 First Floor and Top Floor Plan of Post disaster Reconstructed Building

5.6.2 Construction type

The building is of RCC frame structure with Brick wall in cement mortar. 9” thick brick wall is used for exterior wall of Ground Floor and the upper floors have 4” thick brick wall. The exterior surface of the house has brick façade on front and east façade and the other sides are plastered with cement. Brick façade on the exterior surface of the house is guided by Byelaws. The internal surface is plastered with cement and sand. All the partition walls are of 4” thick brick wall plastered on both the sides. Floors are of RCC slab with 2” of cement screed and a layer of cement punning. CGI sheet is used for roofing supported by steel truss.

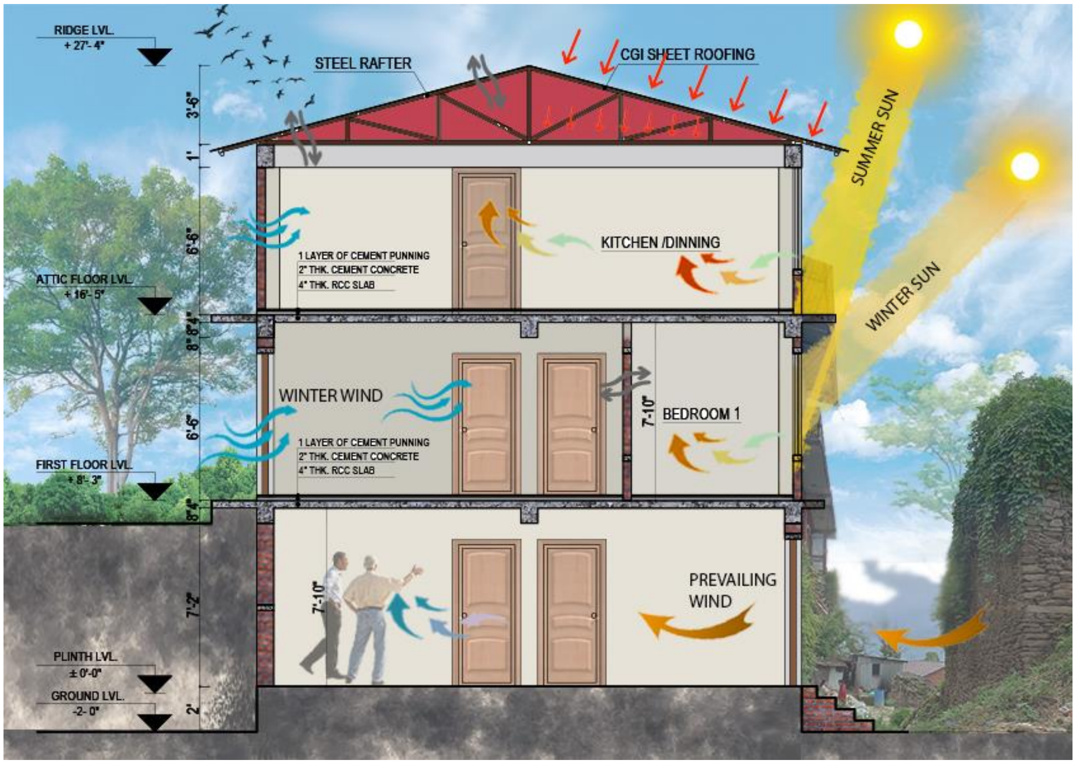


Figure 66 Section of Post Disaster Reconstructed building

5.6.3 Window wall Ratio

The window wall ratio on east walls are higher as compared to other wall. WWR of west wall is 15.76% and that of South wall is 15.58%.

Table 11 Window Wall Ratio of Post Disaster Reconstructed Building

S.No.	Size	East	West	North	South
1.	4’-0” x 4’-6”	G.F=2 F.F.=2	G.F.=1 F.F.=1 T.F.=2	0	G.F=1 F.F.=4 T.F.=1
2.	2’-0” x 2’-6”	0	G.F.=1 F.F.=1 T.F.=1	0	0
	Total WWR in %	18.75%	15.76%	0	18.64%

5.6.4 Building Material

Brick masonry wall in cement mortar was used. Bricks were brought from Bhaktapur and has standard size of 230mm x 110mm x 55mm. Sand was brought from Tamakoshi river. The other building materials like cement, steel reinforcement bars, CGI sheets were brought from Kathmandu valley.

5.6.5 Material Color and Texture

The brick façade provides rough texture which allows in absorption of solar radiation but also allows air leakage in the building envelope. The internal walls are plastered that provides smooth surface. The color of CGI sheet is red as guided by Byelaws of Dolakha town.

Figure 67 External brick facade

Figure 68 Internal Plastered walls

5.6.6 Temperature and humidity measurement

Indoor temperature and humidity were recorded through thermo-hygrometer in 3-time sections i.e., 7 am, 1pm and 7 pm. The device was centrally located on first floor of the building for a week.

Figure 69 Yellow dot shows the location of data logger in post disaster reconstructed building

Figure 70 Thermo-Hygrometer inside the building of Post Disaster reconstructed building

5.6.7 Comparison of Indoor and outdoor Air temperature of Post Disaster Reconstructed Building

Table 12 Comparison of Indoor and outdoor Air temperature of Post Disaster Reconstructed Building

Date	7 AM		1PM		7PM	
	Indoor Temp (°C)	Outdoor Temp (°C)	Indoor Temp (°C)	Outdoor Temp (°C)	Indoor Temp (°C)	Outdoor Temp (°C)
6th July 2022	23.18	21.75	26.32	25.95	26.91	22.86
7th July 2022	24.39	27.53	29.3	29.9	28.3	22.43
8th July 2022	23.2	22.01	28.2	27.93	24.7	22.43
9th July 2022	22.03	20.80	26.93	25.18	21.93	18.79

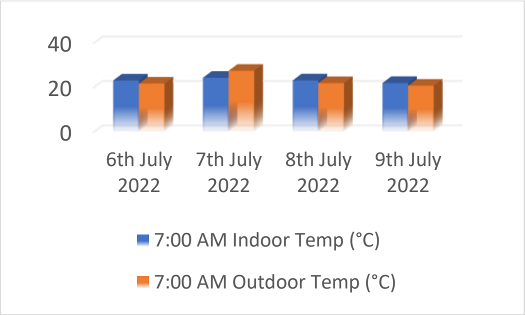


Chart 36 Indoor & Outdoor Air temperature of Post disaster reconstructed building at 7:00AM

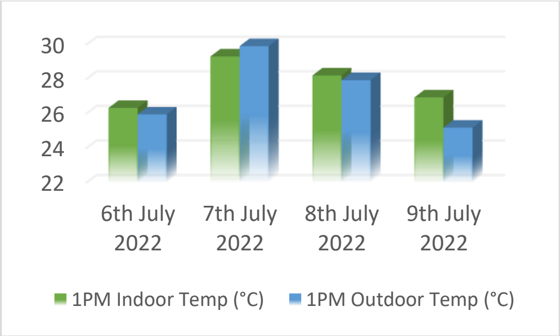


Chart 37 Indoor & Outdoor Air temperature of Post disaster reconstructed building at 1:00PM

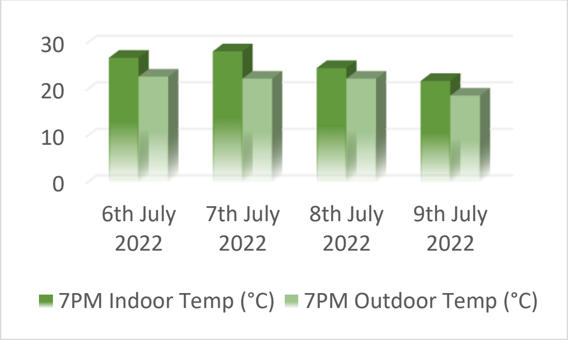


Chart 38 Indoor & Outdoor Air temperature of Post disaster reconstructed building at 7:00PM

5.6.8 Comparison of Indoor and outdoor Relative Humidity of Post Disaster Reconstructed Building

Table 13 Comparison of Indoor and Outdoor Relative Humidity of Post Disaster Reconstructed Building

Date	**7 AM**		**1PM**		**7PM**	
	Indoor Relative Humidity (%)	Outdoor Relative Humidity (%)	Indoor Relative Humidity (%)	Outdoor Relative Humidity (%)	Indoor Relative Humidity (%)	Outdoor Relative Humidity (%)
6th July 2022	81	93	64	87	59	76
7th July 2022	74	71	60	58	63	76
8th July 2022	70	84	59	63	64	94
9th July 2022	75	84	63	58	71	74

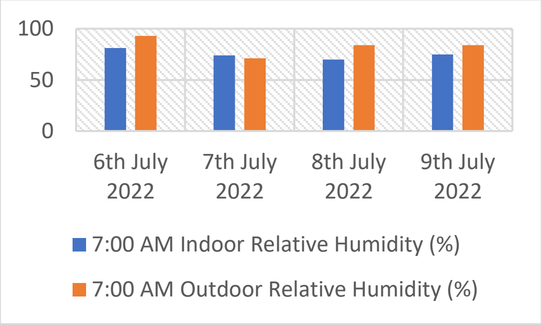


Chart 39 Indoor and Outdoor Relative Humidity of Post Disaster Reconstructed building at 7:00AM

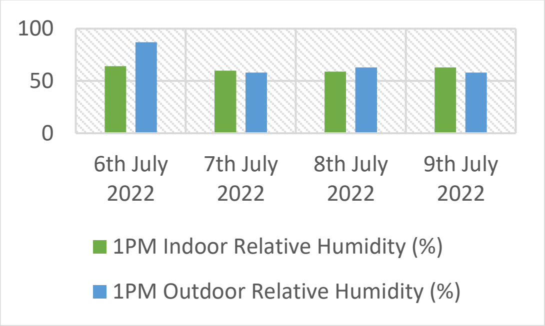


Chart 40 Indoor and Outdoor Relative Humidity of Post Disaster Reconstructed building at 1:00PM

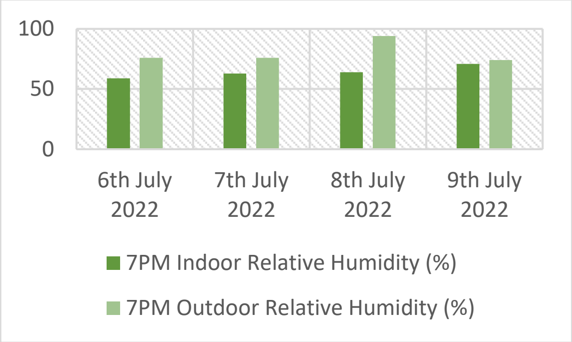


Chart 41 Indoor and Outdoor Relative Humidity of Post Disaster Reconstructed building at 7:00PM

5.7 Indoor air temperature and relative humidity comparison of traditional building and post disaster reconstructed building

The indoor air temperature and relative humidity was measured for a week in traditional building and post disaster reconstructed building with the use of data logger and thermo-hygrometer. The measurement was recorded in 3-time section, 7am, 1pm and 7pm in both the houses.

5.7.1 Indoor air temperature

Table 14 Comparison of indoor air temperature of traditional and post disaster reconstructed building

Indoor Room Air Temperature in (°C)						
Date	7 AM		1PM		7PM	
	Traditional	PDR	Traditional	PDR	Traditional	PDR
26th June 2022	21.32	21.9	23.29	25.1	23.08	26.3
27th June 2022	21.15	21.4	22.18	24.8	21.83	25.12
28th June 2022	20.93	21.2	21.62	23.8	20.50	22.8
29th June 2022	20.37	20.8	20.59	21.6	20.72	21.6
30th June 2022	20.16	20	22.52	23.8	21.53	23.8
1st July 2022	21.49	21.8	23.29	27.6	22.31	27.3
2nd July 2022	21.10	22	23.08	26	23.16	28.7

5.7.2 Relative humidity

Table 15 Comparison of indoor relative humidity of traditional and post disaster reconstructed building

Indoor Relative humidity in (%)						
Date	7 AM		1PM		7PM	
	Traditional	PDR	Traditional	PDR	Traditional	PDR
26th June 2022	68	82	63	74	58	72
27th June 2022	68	83	61	73	57	69
28th June 2022	66	83	61	75	59	78
29th June 2022	69	84	68	83	67	81
30th June 2022	69	84	61	71	58	73
1st July 2022	67	83	63	65	62	63
2nd July 2022	59	72	62	67	62	59

6 Chapter 6: Modelling and Simulation

The software used for the simulation of this project is Autodesk Ecotect 2011. After loading the weather file of Dolakha town in Ecotect, thermal analysis was done to study the thermal comfort level of the house. Energy modelling of base model of traditional building and post disaster reconstructed building was carried out for comparative analysis. For this, a few parameters were set and calculated to study the energy performance of the building. Parameters such as hourly heat gain/ loss, the monthly load of the active system, fabric gain/loss, and passive solar breakdown were calculated for thermal analysis.

6.1 Ecotect Simulation

6.1.1 Weather analysis of the Case Area: Dolakha Town

6.1.1.1 Monthly climatic Data

The monthly climatic data was obtained from weather tool from Autodesk Ecotect software. The chart below shows the average temperature, daylight hours, radiation in (W/m^2), wind speed and direction and heating, cooling, and solar excess degree hours of each month.

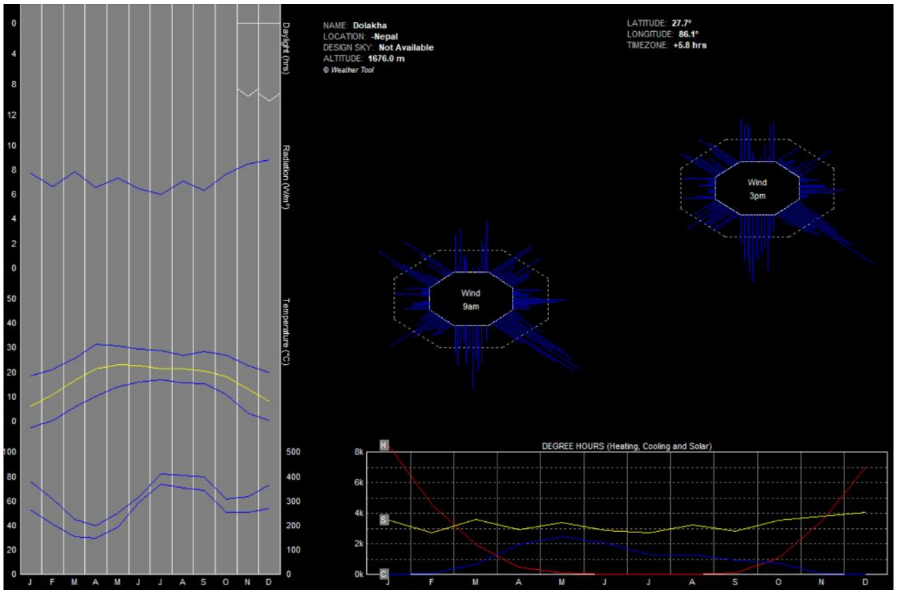


Chart 42 Monthly Climatic data of Dolakha town from Ecotect

6.1.1.2 Monthly Diurnal averages for Dolakha Town

The chart below shows the monthly diurnal averages for Dolakha town. It is seen that most of the winter months require heating in order to achieve thermal comfort.

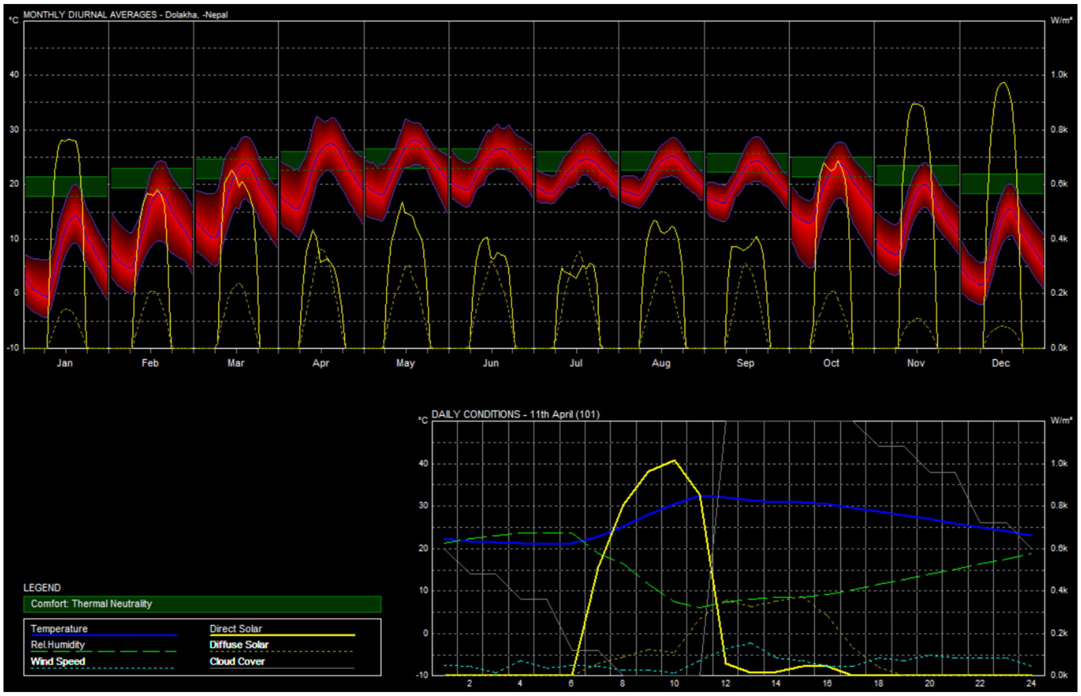


Chart 43 Monthly Diurnal averages for Dolakha Town

6.1.2 Psychrometric Chart from Ecotect

The chart below is the Psychrometric chart in light activity with multiple passive techniques. It shows that most of the months in a year require passive solar heating denoted by red boundary and thermal mass effect denoted by blue boundary. The pink boundary line denotes natural ventilation and purple line denotes direct evaporative cooling. Similarly, the green boundary indicates indirect evaporative cooling. The yellow boundary denotes the comfort zone.

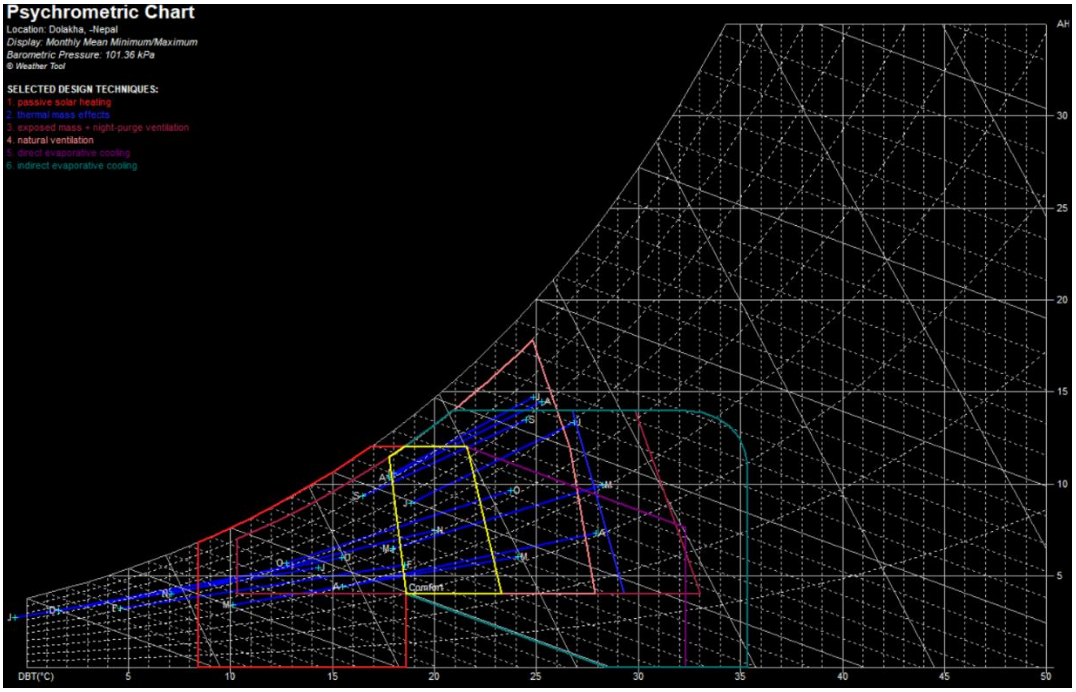


Chart 44 Psychrometric Chart with multiple passive techniques for Dolakha town from Ecotect

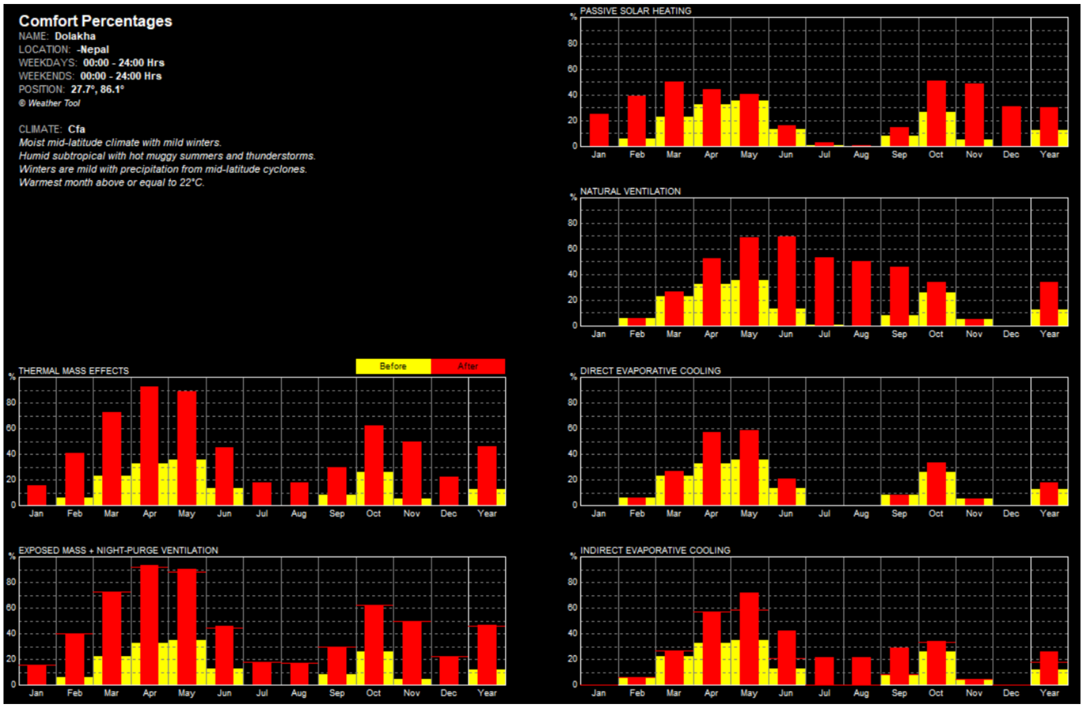
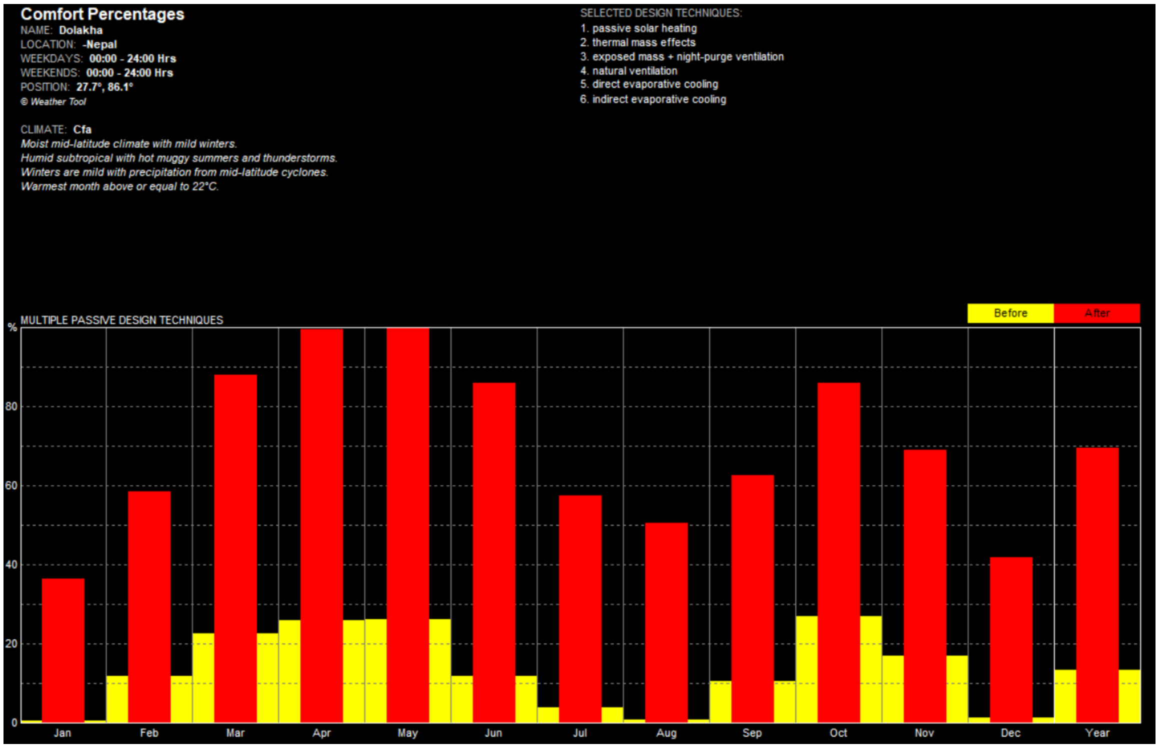


Chart 45 Comfort percentages of different passive techniques


Comfort Percentages
NAME: Dolakha
LOCATION: -Nepal
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 27.7°, 86.1°
© Weather Tool

CLIMATE: Cfa
Moist mid-latitude climate with mild winters.
Humid subtropical with hot muggy summers and thunderstorms.
Winters are mild with precipitation from mid-latitude cyclones.
Warmest month above or equal to 22°C.

SELECTED DESIGN TECHNIQUES:
1. passive solar heating
2. thermal mass effects
3. exposed mass + night-purge ventilation
4. natural ventilation
5. direct evaporative cooling
6. indirect evaporative cooling

Chart 46 Comfort percentages of multiple passive design techniques

6.2 Simulation

The simulation starts from fixing the location of the building and giving the weather file of the respective location. Firstly, the weather file of Dolakha was used in Autodesk Ecotect and different climatic data of the location was analyzed, such as temperature, humidity, rainfall, etc. After using the solar data, the best and worst orientation of the building was analyzed in Ecotect.

Modeling of the building was done at first for detailed energy analysis. Different components of building such as roof, wall, floor, etc. were drawn including door, window, and voids as a replication of traditional and post disaster reconstructed building. Materials were assigned as original for different building components.

6.2.1 Orientation analysis

The annual incident solar radiation was examined for different orientations in the Ecotect weather tool for analyzing best and worst-case scenarios for the Dolakha Town. The orientation analysis suggests best orientation as south and the worst orientation is 3.5° south from east direction.

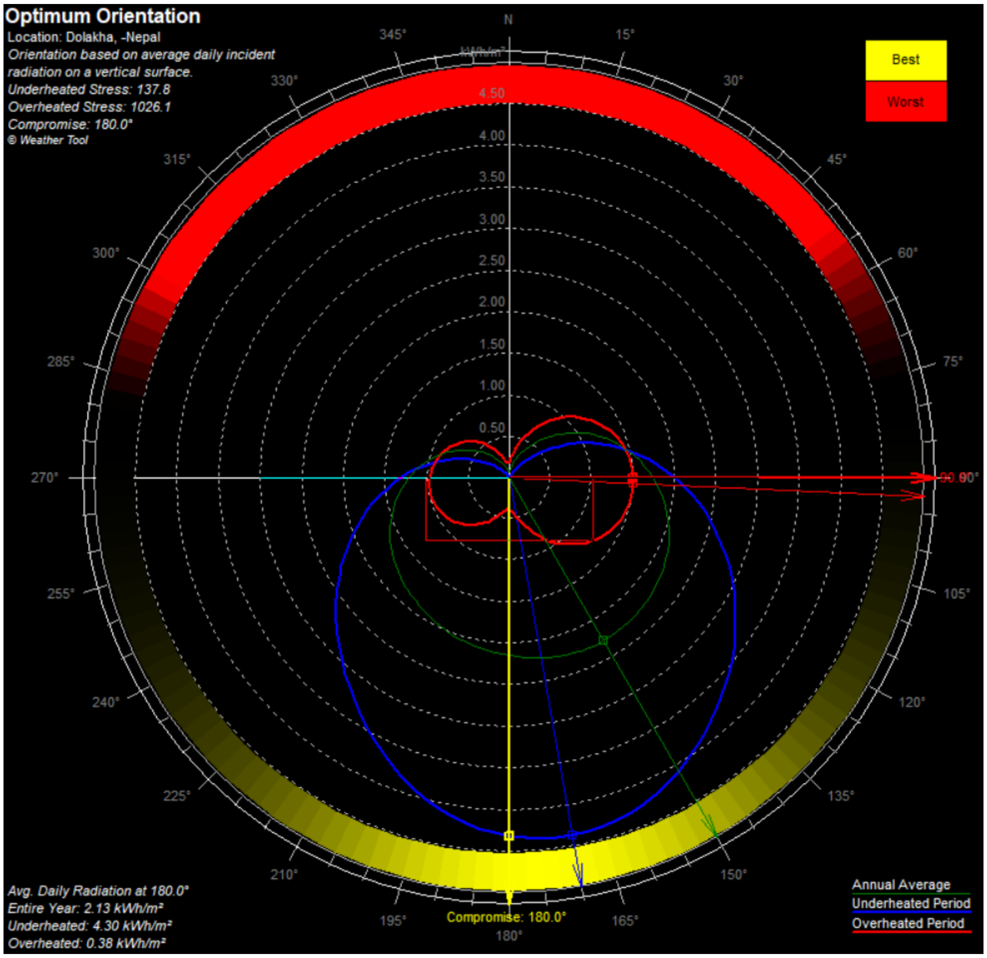


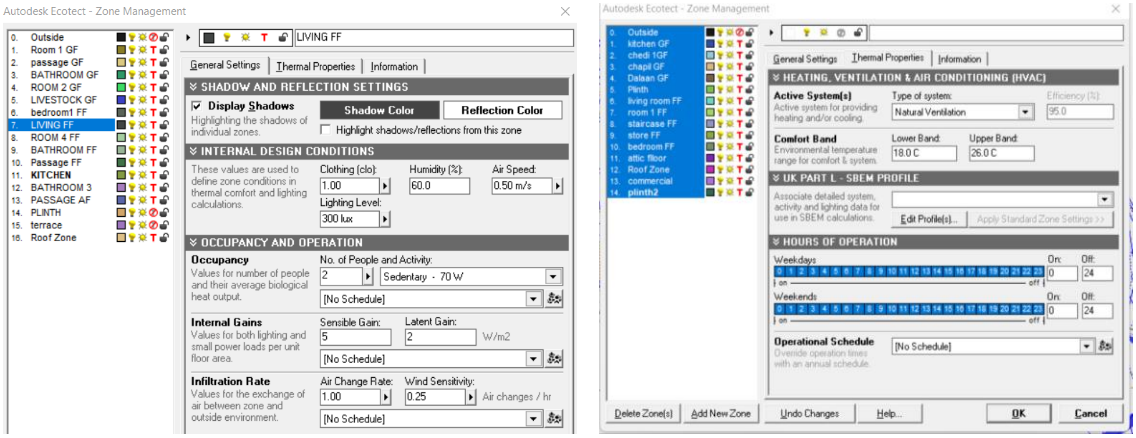
Chart 47 Optimum orientation by Ecotect for Dolakha town

Table 16 Annual Solar Incident Radiation for different orientation

Orientation	Total Annual Collection (kWh/m^2)	Under-heated Period (kWh/m^2)	Overheated Period (kWh/m^2)
North (0°)	373.12	45.59	136.66
South (180°)	1082.25	413.20	146.05
East (+90°)	610.10	111.30	170.14
West (-90°)	1147.60	280.45	283.40
Best	1082.25	413.20	146.05
Worse	625.43	118.22	170.84

6.2.2 Zone Settings in Ecotect

Zone setting in Ecotect is the initial step before analysis. General settings and thermal properties were assigned in Ecotect for all the scenarios of simulations as follows:



LIVING FF

SHADOW AND REFLECTION SETTINGS

☑ Display Shadows
Highlighting the shadows of individual zones.
☐ Highlight shadows/reflections from this zone

INTERNAL DESIGN CONDITIONS

These values are used to define zone conditions in thermal comfort and lighting calculations.
Clothing (clo): 1.00
Humidity (%): 60.0
Air Speed: 0.50 m/s
Lighting Level: 300 lux

OCCUPANCY AND OPERATION

Occupancy
Values for number of people and their average biological heat output.
No. of People and Activity: 2 Sedentary - 70 W
[No Schedule]

Internal Gains
Values for both lighting and small power loads per unit floor area.
Sensible Gain: 5
Latent Gain: 2 W/m2
[No Schedule]

Infiltration Rate
Values for the exchange of air between zone and outside environment.
Air Change Rate: 1.00
Wind Sensitivity: 0.25 Air changes / hr
[No Schedule]

HEATING, VENTILATION & AIR CONDITIONING (HVAC)

Active System(s)
Active system for providing heating and/or cooling.
Type of system: Natural Ventilation
Efficiency (%): 95.0

Comfort Band
Environmental temperature range for comfort & system.
Lower Band: 18.0 C
Upper Band: 26.0 C

UK PART L - SBEM PROFILE

Associate detailed system, activity and lighting data for use in SBEM calculations.

HOURS OF OPERATION

Weekdays 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 on off On: 0 Off: 24
Weekends 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 on off On: 0 Off: 24

Operational Schedule
Override operation times with an annual schedule.
[No Schedule]

Figure 71 General setting and Thermal properties in Zone settings for simulation

6.3 Case Scenario 1: Base model of Traditional Building

The traditional building of Dolakha town was modeled as per the actual site measurements. This base case scenario was modeled in the best possible way to represent the actual building.

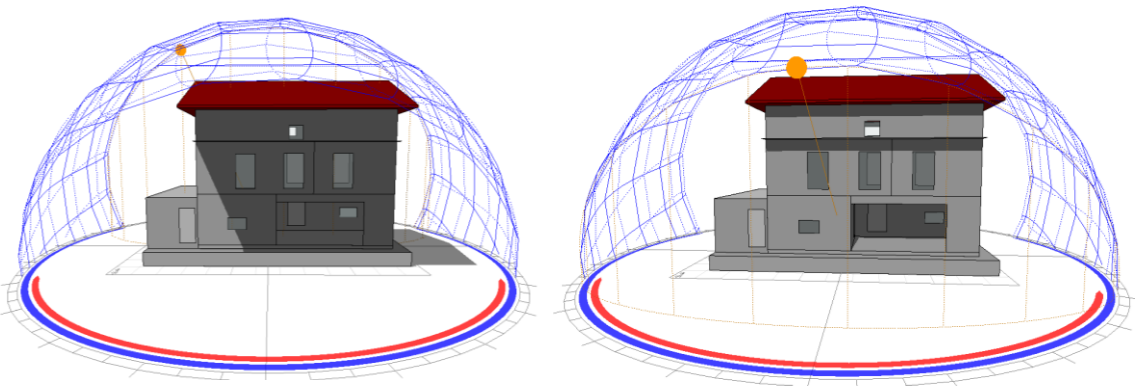


Figure 72 Base case model of Traditional building during summer and winter solstice

The specifications for the modeling used in the traditional courtyard house includes flooring, external and partition walls. roof, floor heights, and openings and outdoor courtyard space that are listed in the table below:

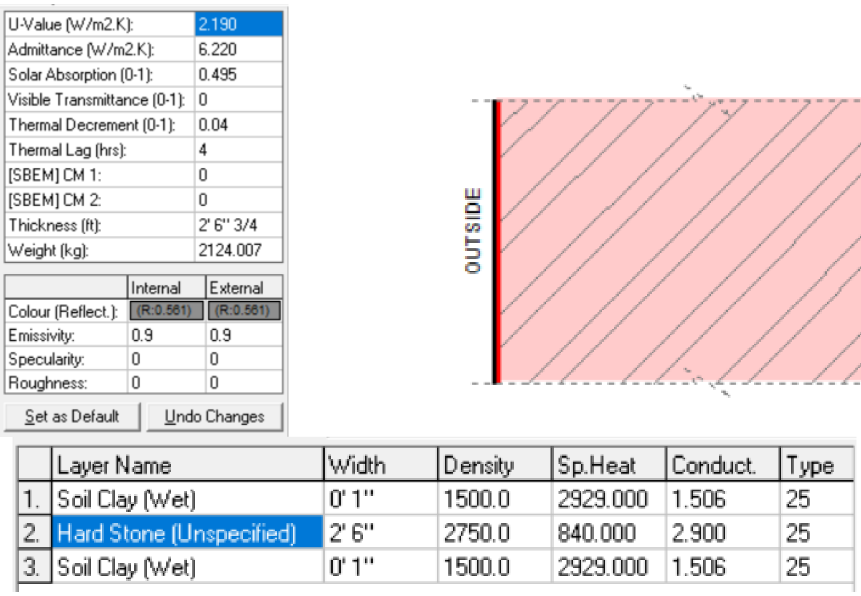
Table 17 Specifications used during modeling of Traditional Building

Specifications for Traditional house	
External and internal Walls	2’-7” thick stone wall with mud mortar is used for external walls in Ground floor The central wall of Ground floor is of 2’-1”. 2’-4” thick stone wall with mud mortar is used for external walls in first floor and attic floor. The central wall of Ground floor is of 2’-1”.

	Walls are plastered with mud.
Partition walls	2” thick Timber boards as partition wall
Flooring of Ground Floor	Elevated plinth level at 2’-0” Comprised of Earth compaction, stone soling, and mud flooring with the mixture of straw, and rice husk
Flooring of Upper floors	0’-4” thick timber strut with one layer of timber board and 0’4” thick mud mixture is laid over and topped by mud floor finish
Floor Height	7’3” in Ground floor 6’11” in first floor
Windows	Wooden shutter in wooden frame 2’10” x 1’-9” and 2’10” x 5’0” on South walls (23.29% WWR) 2’10”x 1’-9” on North Walls (2.27 % WWR) 2’0”x 1’-9” on East, and West walls (1.64% WWR) 2’10”x 1’-9” on Attic floor
Doors	Wooden shutter in wooden frame
Opening	12’-8” x 6’7” opening on Ground floor on southeast sides
Roof	Traditional Gable roof with 25-degree slope
Rain Protection	2’-0” on all sides of Roof

6.3.1 Walls

The wall section, properties of materials and the layers of materials in walls are as follows:

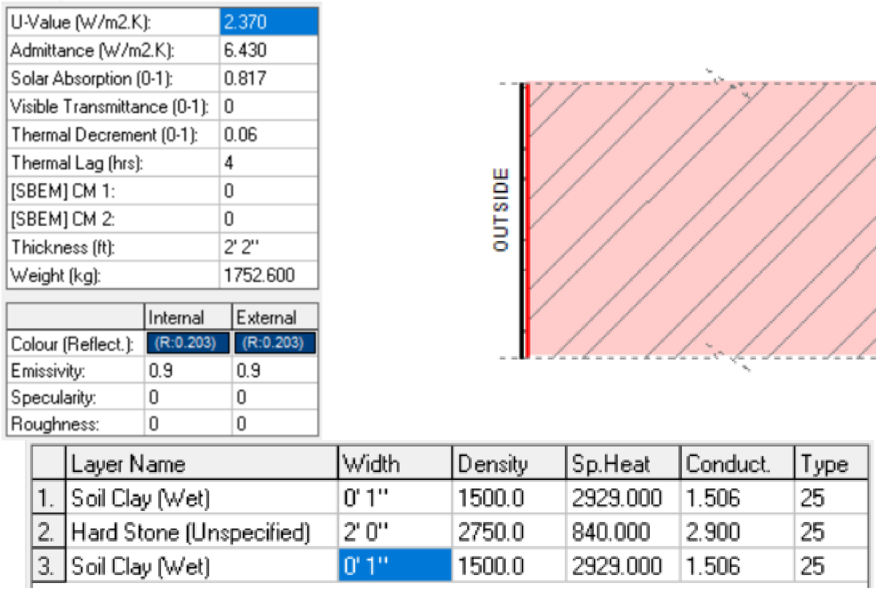


U-Value (W/m2.K):	2.190
Admittance (W/m2.K):	6.220
Solar Absorption (0-1):	0.495
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.04
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	2' 6" 3/4
Weight (kg):	2124.007

	Internal	External
Colour (Reflect.):	(R:0.561)	(R:0.561)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Soil Clay (Wet)	0' 1"	1500.0	2929.000	1.506	25
2.	Hard Stone (Unspecified)	2' 6"	2750.0	840.000	2.900	25
3.	Soil Clay (Wet)	0' 1"	1500.0	2929.000	1.506	25

Figure 73 Wall Section, Material properties and layers of External Walls of Ground Floor



U-Value (W/m2.K):	2.370
Admittance (W/m2.K):	6.430
Solar Absorption (0-1):	0.817
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.06
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	2' 2"
Weight (kg):	1752.600

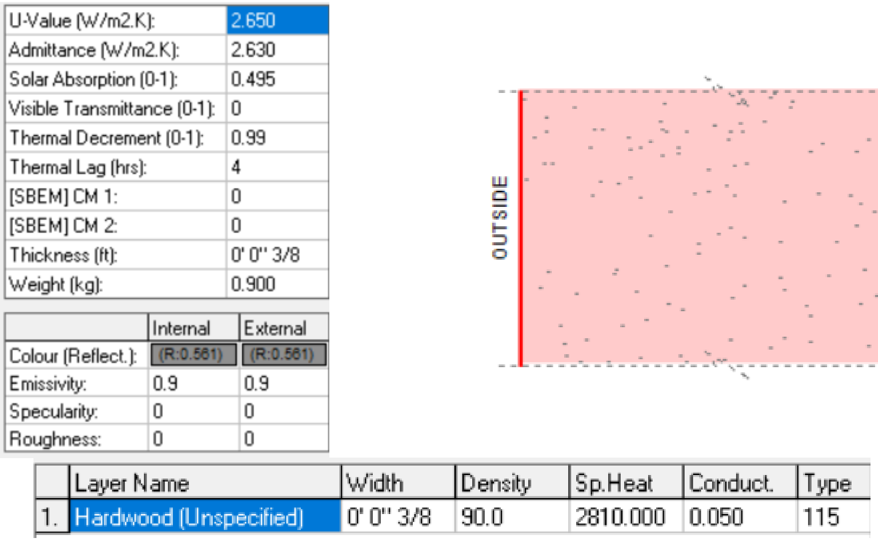
	Internal	External
Colour (Reflect.):	(R:0.203)	(R:0.203)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Soil Clay (Wet)	0' 1"	1500.0	2929.000	1.506	25
2.	Hard Stone (Unspecified)	2' 0"	2750.0	840.000	2.900	25
3.	Soil Clay (Wet)	0' 1"	1500.0	2929.000	1.506	25

Figure 74 Wall Section, Material properties and layers of External Walls of First and attic Floor

6.3.2 Partition Walls

Timber boards of 2” thickness is used as partition walls. The wall section, properties of material and the layers of material used are as follows:



U-Value (W/m2.K):	2.650
Admittance (W/m2.K):	2.630
Solar Absorption (0-1):	0.495
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.99
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 0" 3/8
Weight (kg):	0.900

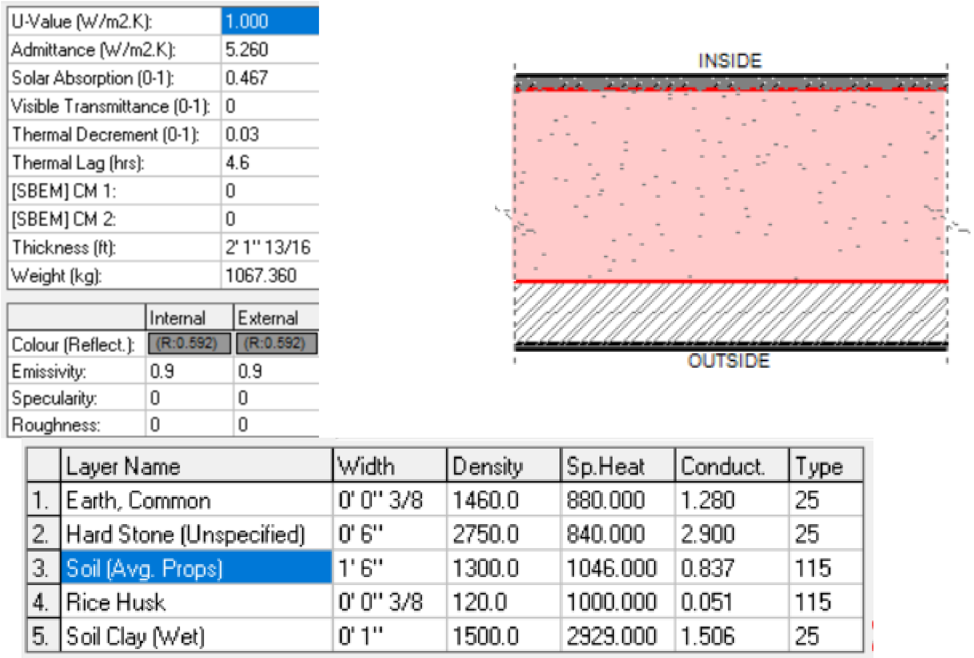
	Internal	External
Colour (Reflect.):	(R:0.561)	(R:0.561)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Hardwood (Unspecified)	0' 0" 3/8	90.0	2810.000	0.050	115

Figure 75 Material properties, section and the layer of material used of timber partition

6.3.3 Flooring

The ground floor consists of elevated plinth of 2 feet and is comprised of Earth compaction, stone soling, and a layer of mud flooring with the mixture of cow dung, and rice husk and is rendered with red mud plaster. Floors of upper floors have 4” thick timber strut, layer of timber board, 4” thick mud flooring and is rendered with red mud. The properties of materials, section of floor and the layers of material used in ground floor and upper floors are as follows:

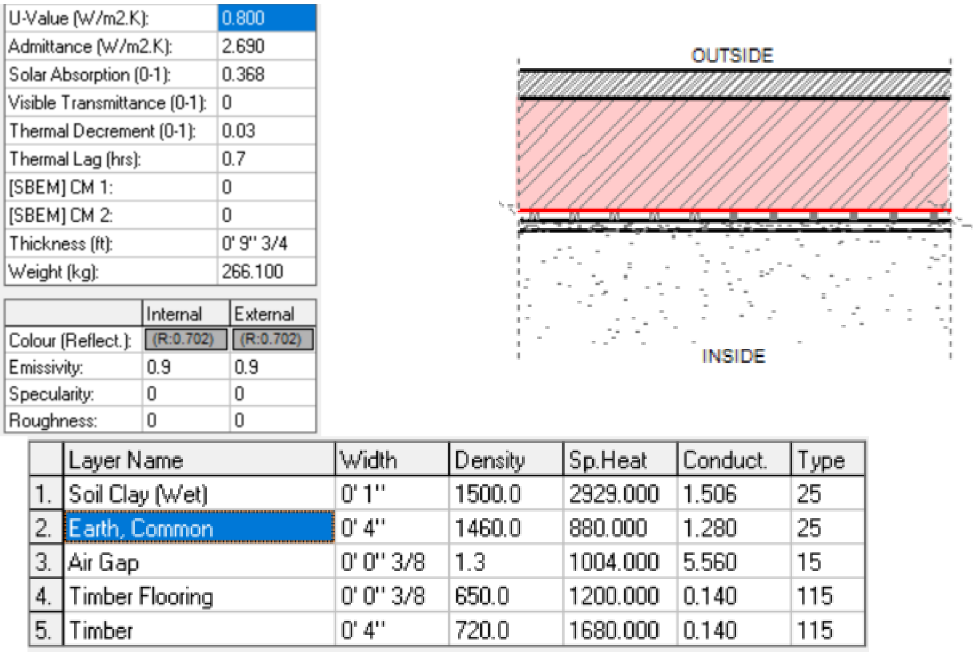


U-Value (W/m2.K):	1.000
Admittance (W/m2.K):	5.260
Solar Absorption (0-1):	0.467
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.03
Thermal Lag (hrs):	4.6
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	2' 1" 13/16
Weight (kg):	1067.360

	Internal	External
Colour (Reflect.):	(R:0.592)	(R:0.592)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Earth, Common	0' 0" 3/8	1460.0	880.000	1.280	25
2.	Hard Stone (Unspecified)	0' 6"	2750.0	840.000	2.900	25
3.	Soil (Avg. Props)	1' 6"	1300.0	1046.000	0.837	115
4.	Rice Husk	0' 0" 3/8	120.0	1000.000	0.051	115
5.	Soil Clay (Wet)	0' 1"	1500.0	2929.000	1.506	25

Figure 76 Material properties, section and the layer of material used in flooring of Ground floor



U-Value (W/m2.K):	0.800
Admittance (W/m2.K):	2.690
Solar Absorption (0-1):	0.368
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.03
Thermal Lag (hrs):	0.7
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 9" 3/4
Weight (kg):	266.100

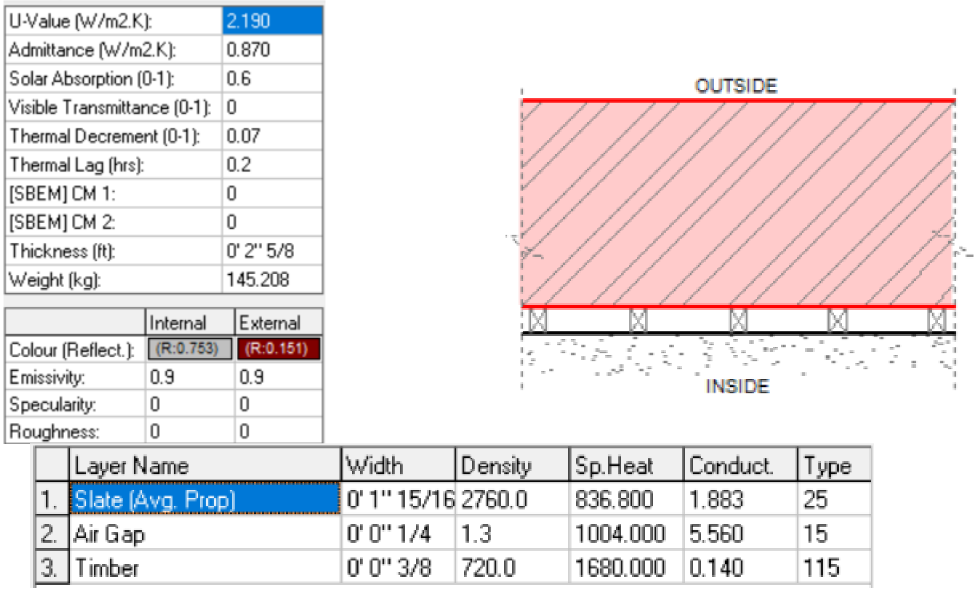
	Internal	External
Colour (Reflect.):	(R:0.702)	(R:0.702)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Soil Clay (Wet)	0' 1"	1500.0	2929.000	1.506	25
2.	Earth, Common	0' 4"	1460.0	880.000	1.280	25
3.	Air Gap	0' 0" 3/8	1.3	1004.000	5.560	15
4.	Timber Flooring	0' 0" 3/8	650.0	1200.000	0.140	115
5.	Timber	0' 4"	720.0	1680.000	0.140	115

Figure 77 Material properties, section and the layer of material used in flooring of upper floors

6.3.4 Roofing

Gable roof of slate with 25° slope is used for roofing. The material properties, roof section, and the layer of materials used in roofing is as follows:



U-Value (W/m2.K):	2.190
Admittance (W/m2.K):	0.870
Solar Absorption (0-1):	0.6
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.07
Thermal Lag (hrs):	0.2
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 2" 5/8
Weight (kg):	145.208

	Internal	External
Colour (Reflect.):	(R:0.753)	(R:0.151)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Slate (Avg. Prop)	0' 1" 15/16	2760.0	836.800	1.883	25
2.	Air Gap	0' 0" 1/4	1.3	1004.000	5.560	15
3.	Timber	0' 0" 3/8	720.0	1680.000	0.140	115

Figure 78 Material properties, section and the layer of material used in roofing

6.3.5 Simulation results of base case model of traditional building

6.3.5.1 Monthly Load Discomfort

The graph shows the thermal discomfort period during the entire months of the year in the traditional house in total hours of discomfort. The thermal comfort range has been set to 18°C to 26°C. According to the calculation made by Ecotect Analysis, the chart shows too hot degree hours and too cool degree hours of traditional building. Winter discomfort load ranges from 0 Deg hrs. from April to September to 1414 Deg hrs. in January. Summer discomfort load range from 2991 Deg hrs. in January to 4444 Deg hrs. in May. This indicates that the building is warm.

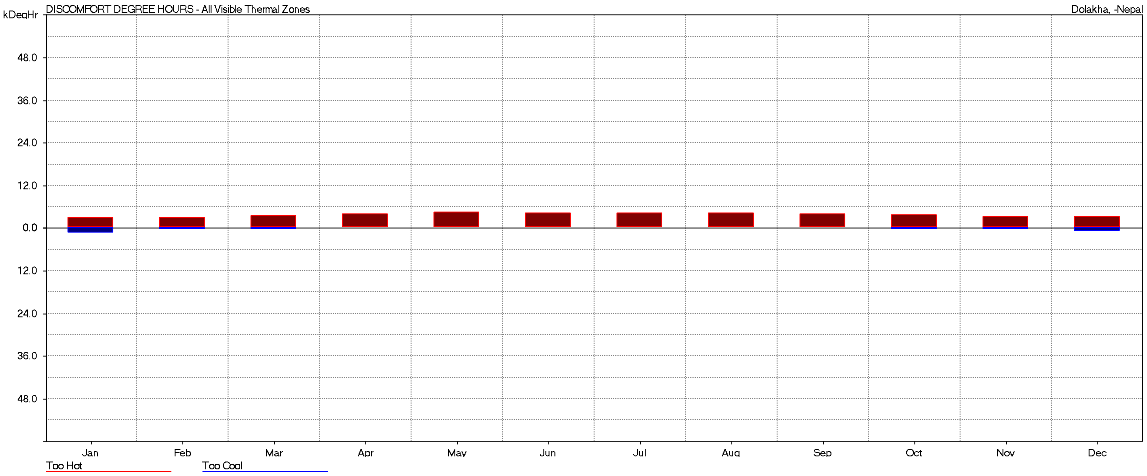


Chart 48 Monthly Load/ Discomfort period of Traditional house of Dolakha town

6.3.5.2 Passive Gains Breakdown

The graph below represents the monthly passive gains and losses through different categories of the traditional building. High heat gains are through internal heat gains followed by solar, interzonal and sol-air temperature while high loss come through ventilation, fabric, and inter-zonal.

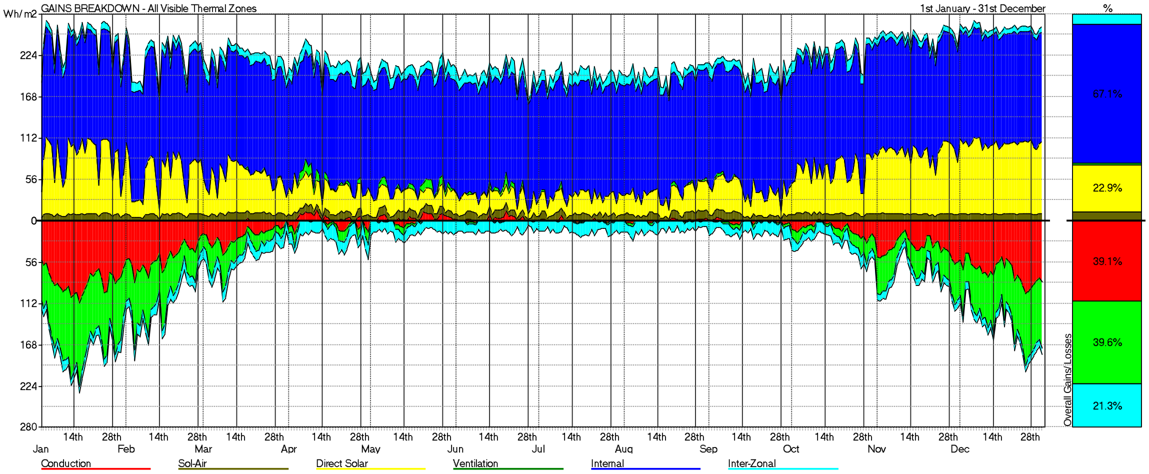


Chart 49 Passive Gains Breakdown from 1st January to 31st December in traditional Building

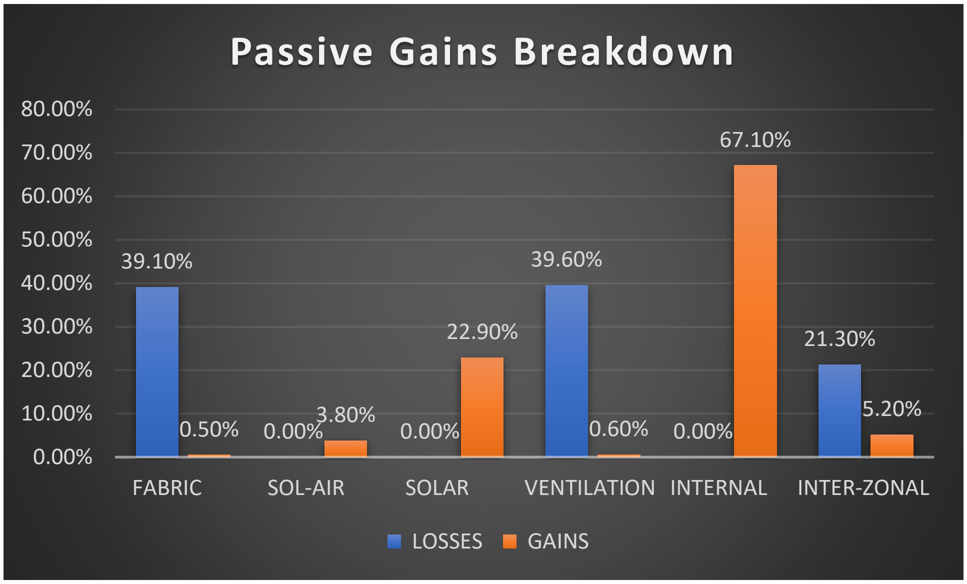


Chart 50 Passive gains breakdown of Traditional building

6.3.5.3 Monthly Degree Days

The graph below represents the monthly degree days of traditional building. The maximum heat degree days is in January with 287.08dd and the maximum cool degree days is in May with 18.2dd. Heat loss range from 0Wh (April to October) to 1638Wh on January while heat gain range from 2743Wh in January to 5515Wh in May.

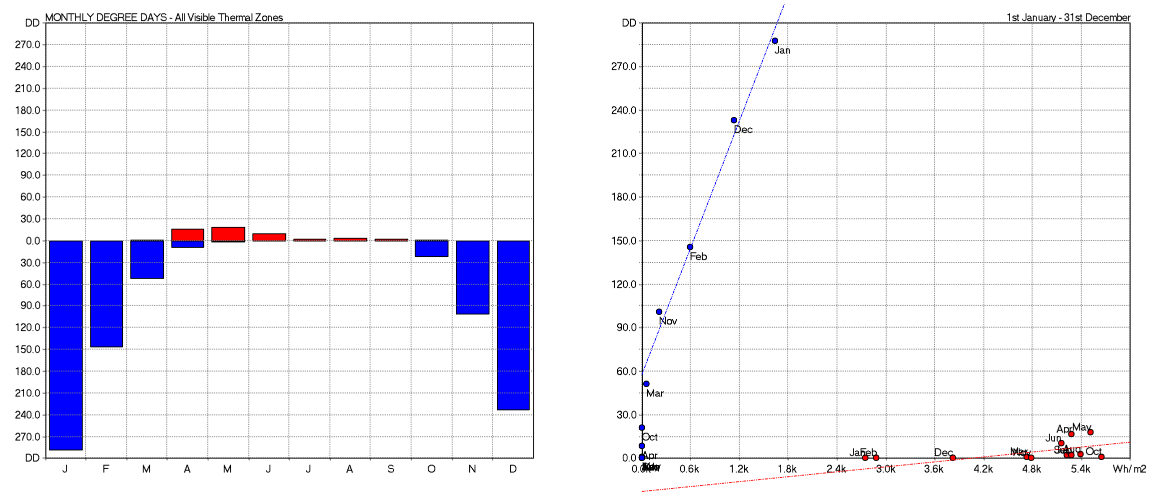


Chart 51 Monthly Degree Days with heating and cooling

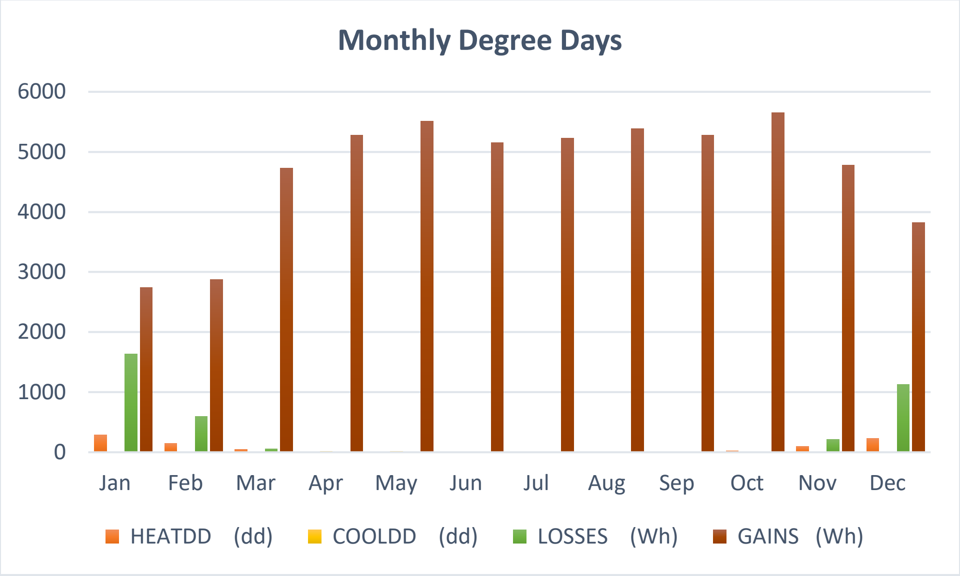


Chart 52 Monthly Degree Days of Traditional Building with Heat (dd), Cool (dd), Heat loss and gain in WH

6.4 Case Scenario 2: Base model of Post Disaster Reconstructed Building

The post disaster reconstructed building of Dolakha town was modeled as per the actual site measurements. This base case scenario was modeled in the best possible way to represent the actual building.

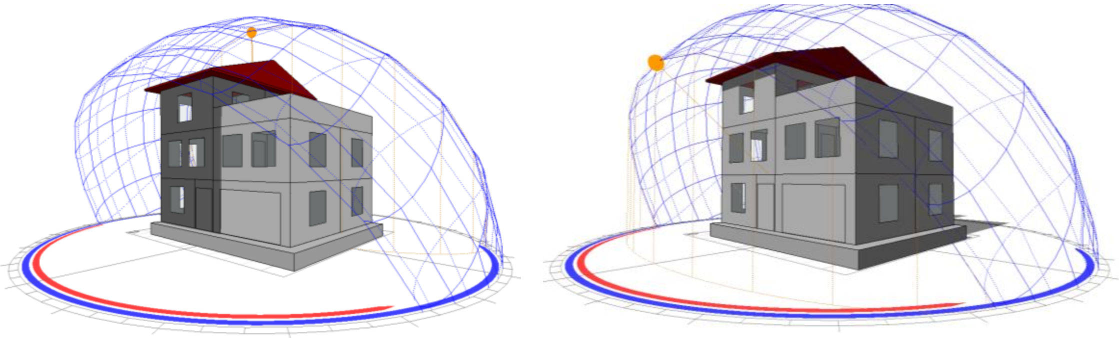


Figure 79 Base case model of Post Disaster Reconstructed Building in summer and Winter Solstice

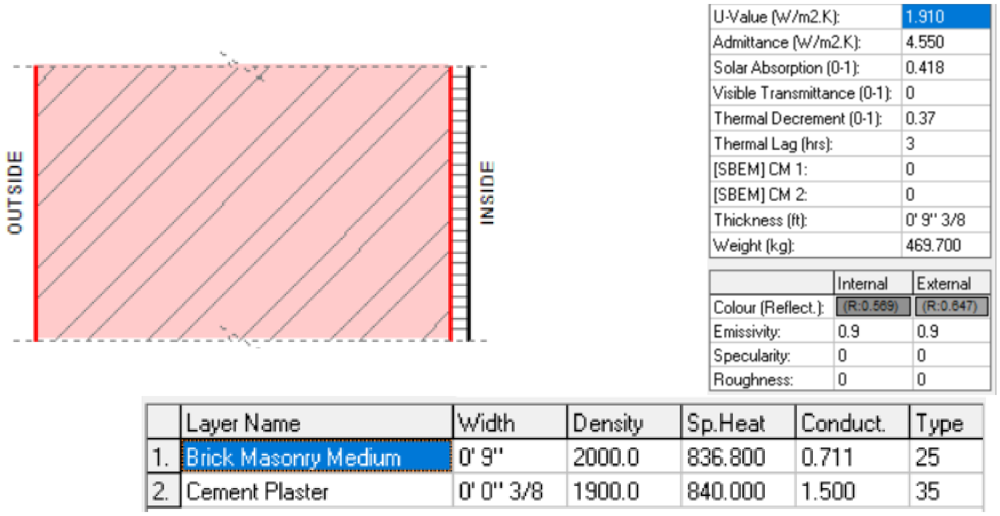
The specifications for the modeling used in the traditional courtyard house includes flooring, external and partition walls. roof, floor heights, and openings and outdoor courtyard space that are listed in the table below:

Table 18 Specifications used in modelling of Post disaster reconstructed building

Specifications for Post Disaster Reconstructed house	
External and internal Walls	9’-0” thick brick wall with cement mortar plastered on internal surface is used for external walls in Ground floor 4” thick brick wall with cement mortar plastered on internal surface is used for external walls in first floor and attic floor.
Partition walls	4” thick brick wall plastered on both the sides is used as partition wall
Flooring of Ground Floor	Elevated plinth level at 2’-0” Comprised of Earth compaction, stone soling, and concrete flooring and floor finish with cement screed
Flooring of Upper floors	0’-4” thick RCC floor and finished with a layer of cement screed
Floor Height	7’10”
Windows	Single glazed window with timber frame 4’0” x 4’-6” on South walls (18.64% WWR) No windows on North Walls 4’0” x 4’-6” on East Walls (16.81% WWR) 4’0” x 4’-6” on West walls (18.75% WWR)
Doors	Wooden shutter in wooden frame
Opening	11’-6” x 6’6” opening on Ground floor on southeast sides
Roof	Traditional Gable roof with 18-degree slope
Rain Protection	2’-0” on all sides of Roof

6.4.1 Walls

External wall of ground floor is of 9” thick brick wall in cement mortar plastered on internal surface and the external surface is of brick façade on east and south walls while the walls of north and west are plastered on both the sides. The external walls of upper floors are of 4” thick brick wall plastered on internal surface on East and south sides and the rest are plastered on both the sides. Partition walls are all of 4” thick brick wall plastered on both the sides. The wall section, properties of material and the layers of material used are as follows:

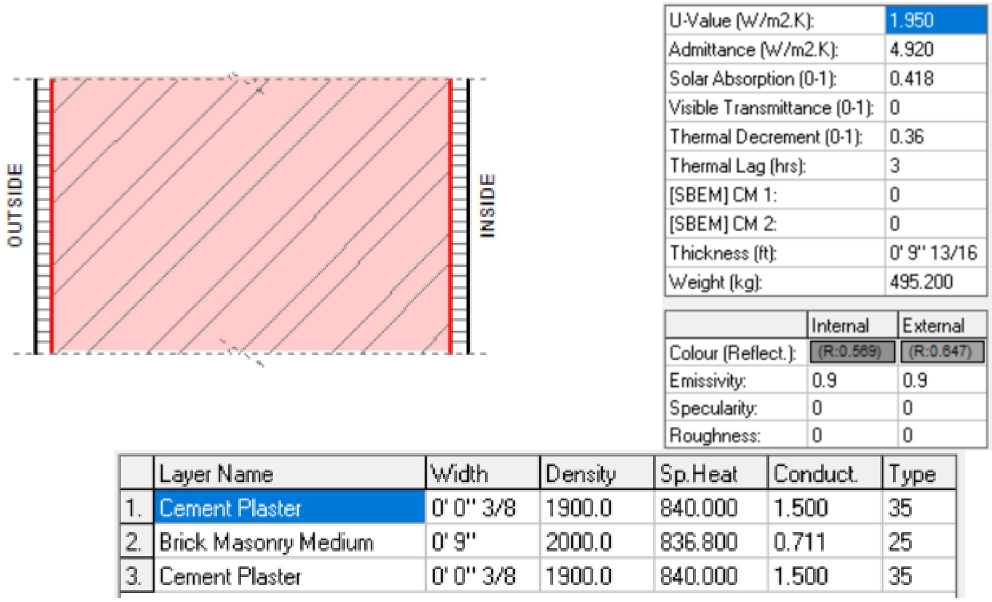


U-Value (W/m2.K):	1.910
Admittance (W/m2.K):	4.550
Solar Absorption (0-1):	0.418
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.37
Thermal Lag (hrs):	3
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 9" 3/8
Weight (kg):	469.700

	Internal	External
Colour (Reflect.):	(R:0.569)	(R:0.647)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Brick Masonry Medium	0' 9"	2000.0	836.800	0.711	25
2.	Cement Plaster	0' 0" 3/8	1900.0	840.000	1.500	35

Figure 80 Wall Section, Material properties and the layers of East and South walls of Ground floor

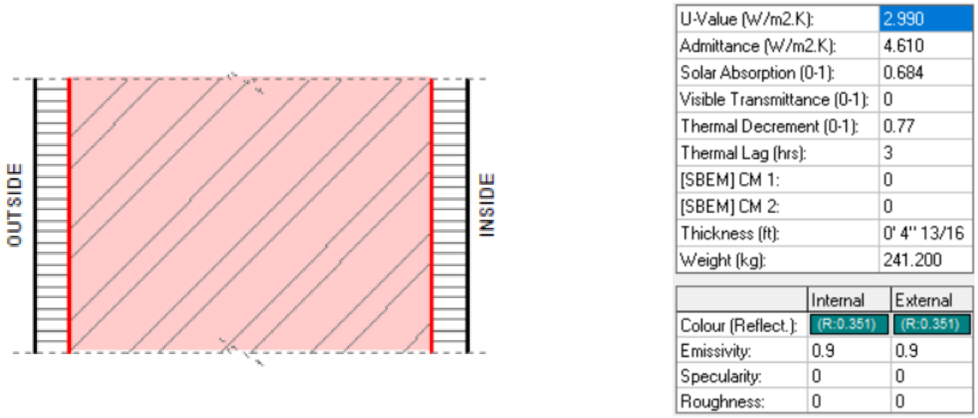


U-Value (W/m2.K):	1.950
Admittance (W/m2.K):	4.920
Solar Absorption (0-1):	0.418
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.36
Thermal Lag (hrs):	3
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 9" 13/16
Weight (kg):	495.200

	Internal	External
Colour (Reflect.):	(R:0.569)	(R:0.647)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

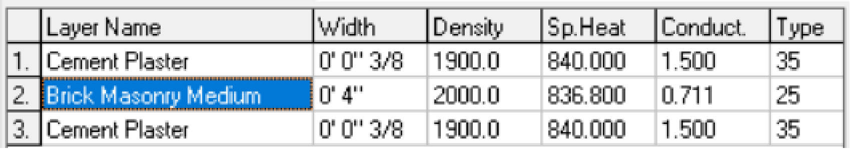
	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Cement Plaster	0' 0" 3/8	1900.0	840.000	1.500	35
2.	Brick Masonry Medium	0' 9"	2000.0	836.800	0.711	25
3.	Cement Plaster	0' 0" 3/8	1900.0	840.000	1.500	35

Figure 81 Wall Section, Material properties and the layers of North and West walls of Ground floor



U-Value (W/m2.K):	2.990
Admittance (W/m2.K):	4.610
Solar Absorption (0-1):	0.684
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.77
Thermal Lag (hrs):	3
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 4" 13/16
Weight (kg):	241.200

	Internal	External
Colour (Reflect.):	(R:0.351)	(R:0.351)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

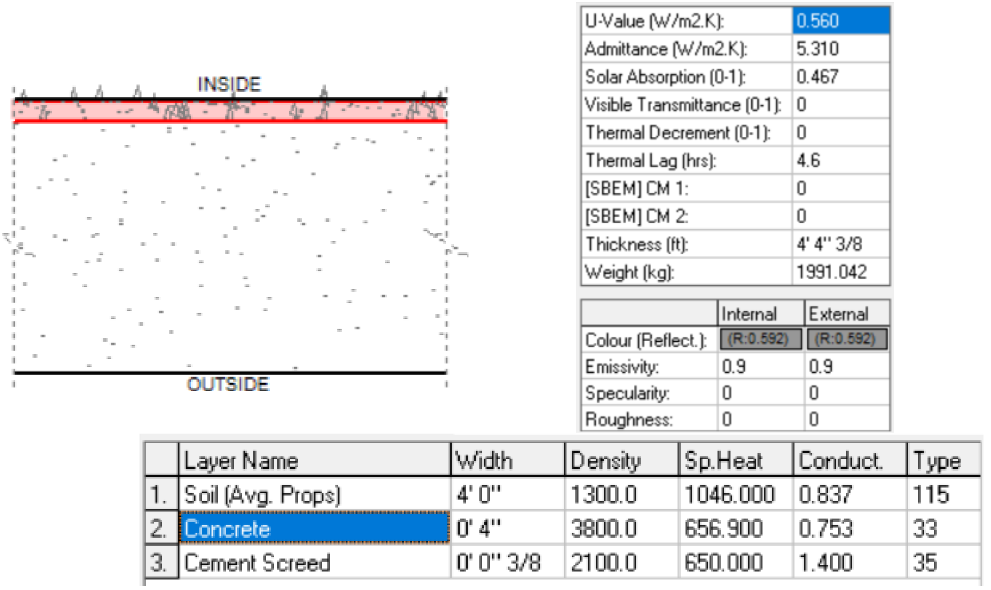


	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Cement Plaster	0' 0" 3/8	1900.0	840.000	1.500	35
2.	Brick Masonry Medium	0' 4"	2000.0	836.800	0.711	25
3.	Cement Plaster	0' 0" 3/8	1900.0	840.000	1.500	35

Figure 82 Wall Section, Material properties and the layers of partition walls

6.4.2 Flooring

The ground floor has elevated plinth of 2’-0” which is comprised of earth compaction, stone soling, RCC floor and finished by cement screeding. The upper floors have RCC floor with cement screed as floor finish. The floor section, properties of material and the layers of material used are as follows:

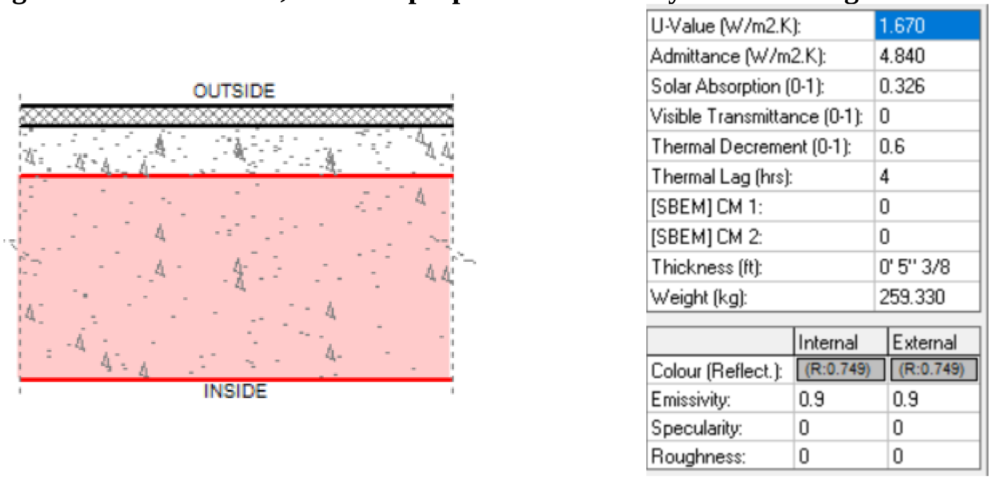


U-Value (W/m2.K):	0.560
Admittance (W/m2.K):	5.310
Solar Absorption (0-1):	0.467
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0
Thermal Lag (hrs):	4.6
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	4' 4" 3/8
Weight (kg):	1991.042

	Internal	External
Colour (Reflect.):	(R:0.592)	(R:0.592)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

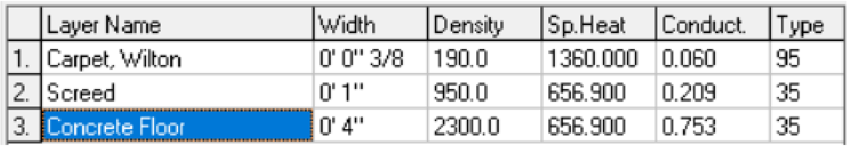
	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Soil (Avg. Props)	4' 0"	1300.0	1046.000	0.837	115
2.	Concrete	0' 4"	3800.0	656.900	0.753	33
3.	Cement Screed	0' 0" 3/8	2100.0	650.000	1.400	35

Figure 83 Floor Section, material properties and the layers of flooring of Ground Floor



U-Value (W/m2.K):	1.670
Admittance (W/m2.K):	4.840
Solar Absorption (0-1):	0.326
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.6
Thermal Lag (hrs):	4
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 5" 3/8
Weight (kg):	259.330

	Internal	External
Colour (Reflect.):	(R:0.749)	(R:0.749)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

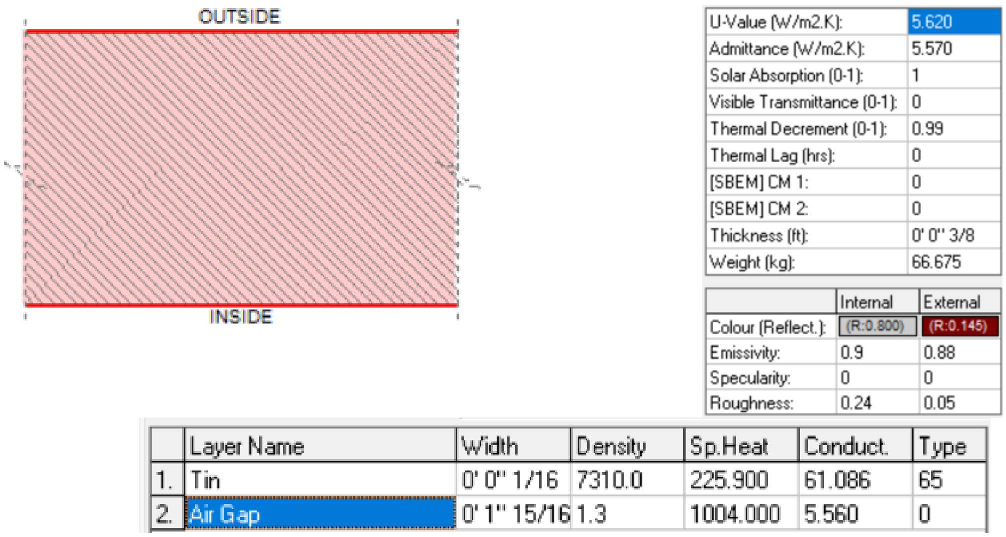


	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Carpet, Wilton	0' 0" 3/8	190.0	1360.000	0.060	95
2.	Screed	0' 1"	950.0	656.900	0.209	35
3.	Concrete Floor	0' 4"	2300.0	656.900	0.753	35

Figure 84 Floor Section, material properties and the layers of flooring in upper floors

6.4.3 Roofing

Gable roof of 18° slope is used for roofing. The roof is of red CGI sheet supported by metal truss as structural member. The roofing section, material property and the layer of CGI roofing used is as follows:



U-Value (W/m2.K):	5.620
Admittance (W/m2.K):	5.570
Solar Absorption (0-1):	1
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.99
Thermal Lag (hrs):	0
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 0" 3/8
Weight (kg):	66.675

	Internal	External
Colour (Reflect.):	(R:0.800)	(R:0.145)
Emissivity:	0.9	0.88
Specularity:	0	0
Roughness:	0.24	0.05

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Tin	0' 0" 1/16	7310.0	225.900	61.086	65
2.	Air Gap	0' 1" 15/16	1.3	1004.000	5.560	0

Figure 85 Roofing section, material properties and the layers of roofing

6.4.4 Simulation results of base case model of traditional building

6.4.4.1 Monthly Load Discomfort

The graph shows the thermal discomfort period during the entire months of the year in the traditional house in total hours of discomfort. The thermal comfort range has been set to 18°C to 26°C. According to the calculation made by Ecotect Analysis, the chart shows too hot degree hours, too cool degree hours and the total degree hours of post disaster reconstructed building. Winter discomfort load ranges from 0 Deg hrs. in June to 3590 Deg hrs. in January. Summer discomfort load range from 0 Deg hrs. in November, December. January and February to 599 Deg hrs. in May.

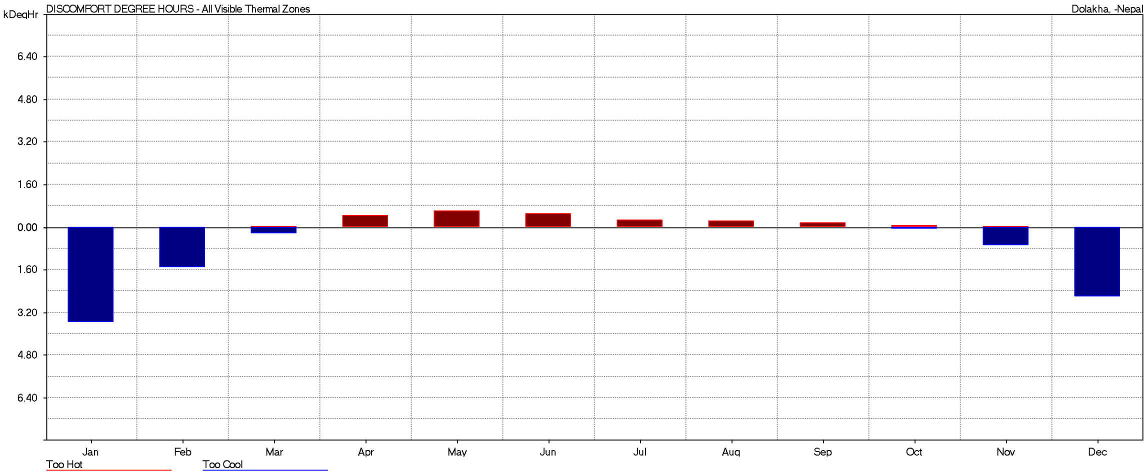


Chart 53 Monthly Load/ Discomfort period of Post disaster Reconstructed building house of Dolakha town

6.4.4.2 Passive Gains Breakdown

The monthly passive gains and losses from several categories of the post disaster reconstructed building are shown in the graph below. Sol-air temperature is the main source for highest heat gains. Inter heat and solar also contributes to heat gain. Highest heat loss is due to fabric. Ventilation and inter-zonal also supports in heat loss.

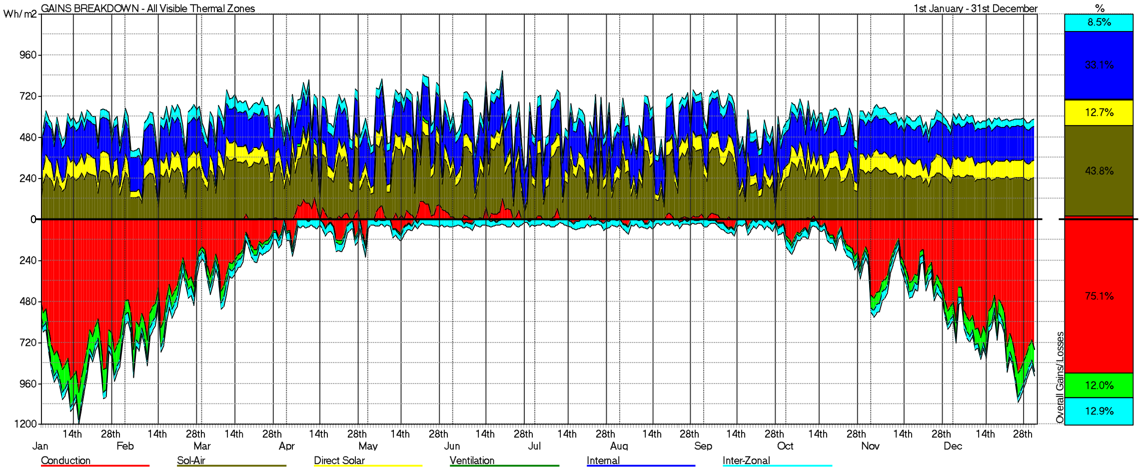


Chart 54 Passive Gains Breakdown for Post Disaster Reconstructed Building of Dolakha town

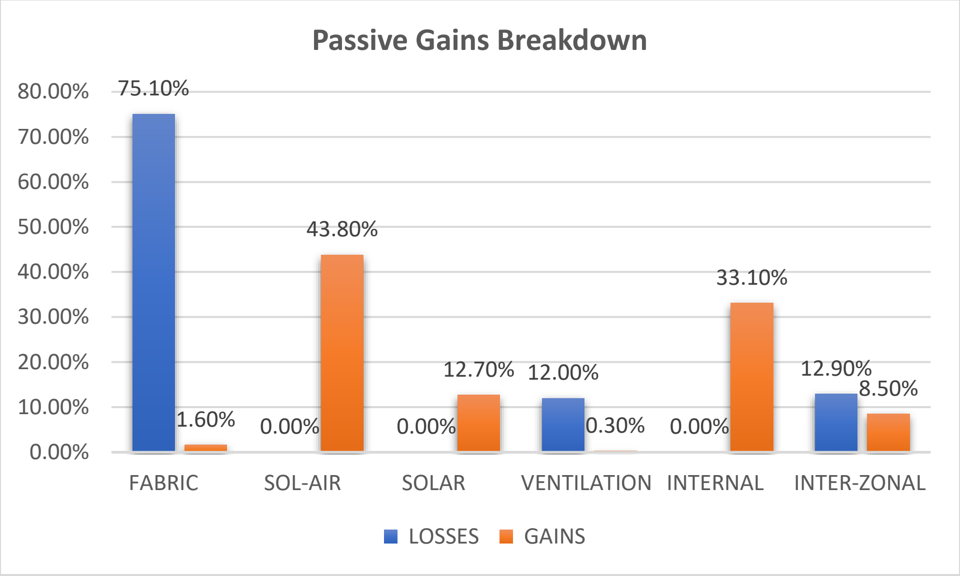


Chart 55 Passive Gains Breakdown from 1st January to 31st December of Post Disaster Reconstructed building

6.4.4.3 Monthly Degree Days

The monthly degree days for post disaster reconstructed building is shown in the graph below. The highest number of heating occur in January with 287.08dd and the maximum cool degree days is in May with 18.2dd. Heat loss range from 0Wh (April to October) to 1638Wh in January while heat gain range from 2743Wh in January to 5515Wh in May.

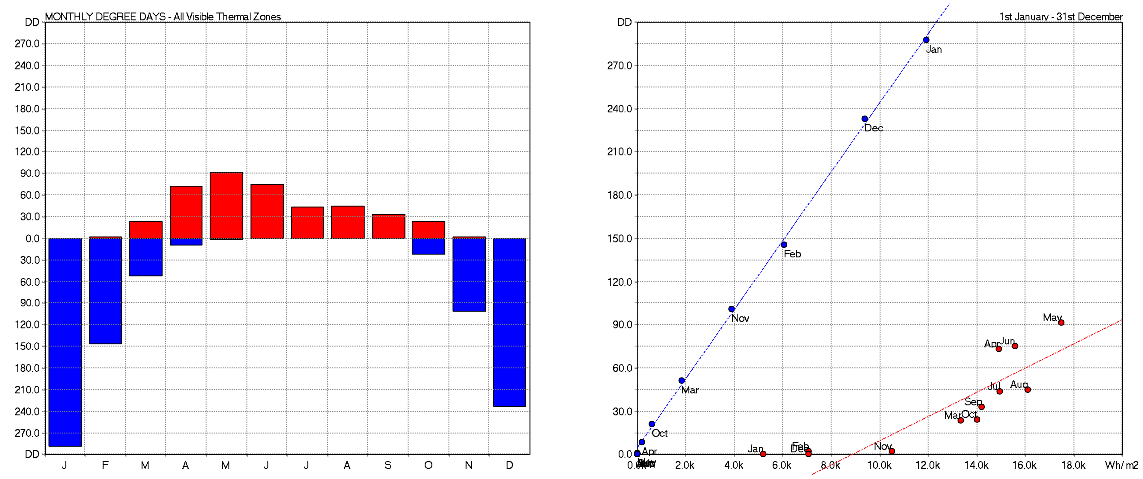


Chart 56 Monthly degree days for Post Disaster Reconstructed Building

6.5 Comparison of traditional and Post Disaster Reconstructed building

Comparative analysis between traditional and post disaster reconstructed house was done considering the results from monthly discomfort load and passive gains breakdown from Ecotect software.

6.5.1 Summer discomfort:

From the chart below, it is observed that summer discomfort load is higher in post-disaster reconstructed as compared to that of traditional building in May.

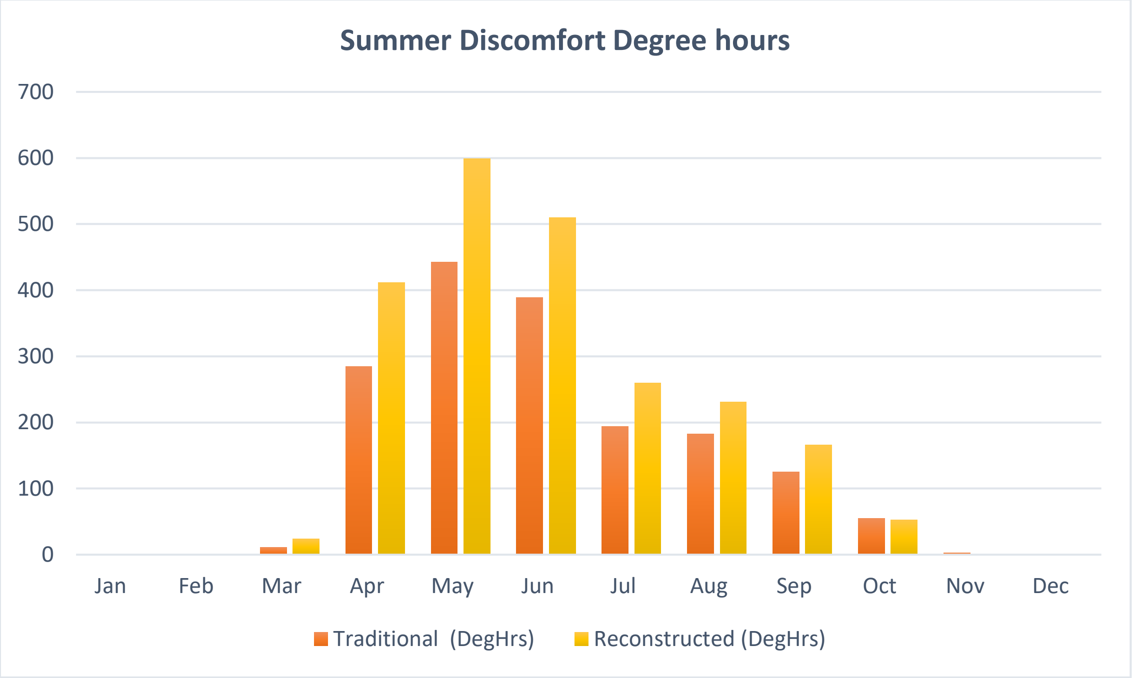


Chart 57 Comparison of Summer Discomfort period of Traditional & Reconstructed house for Dolakha Town

6.5.2 Winter Discomfort:

According to the chart below, it is seen that winter discomfort load in post-disaster reconstructed building is significantly higher in comparison to that of traditional building. December and January have higher winter discomfort load.

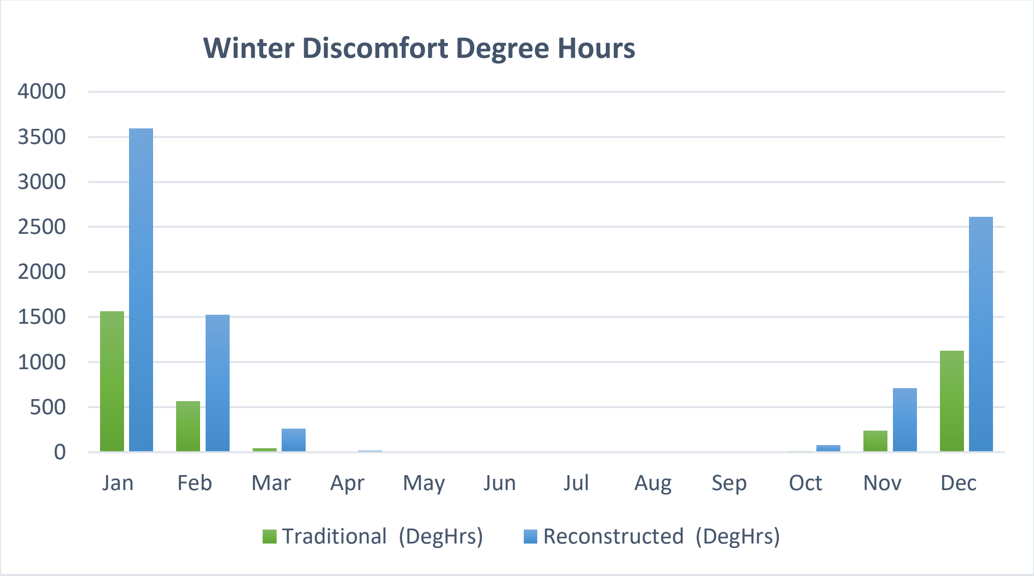


Chart 58 Comparison of Winter Discomfort period of Traditional & Reconstructed house for Dolakha Town

6.5.3 Summer, Winter, and Total Discomfort hours

As per the chart below, post-disaster reconstructed building has higher summer, winter and total discomfort hours compared to that of traditional building.

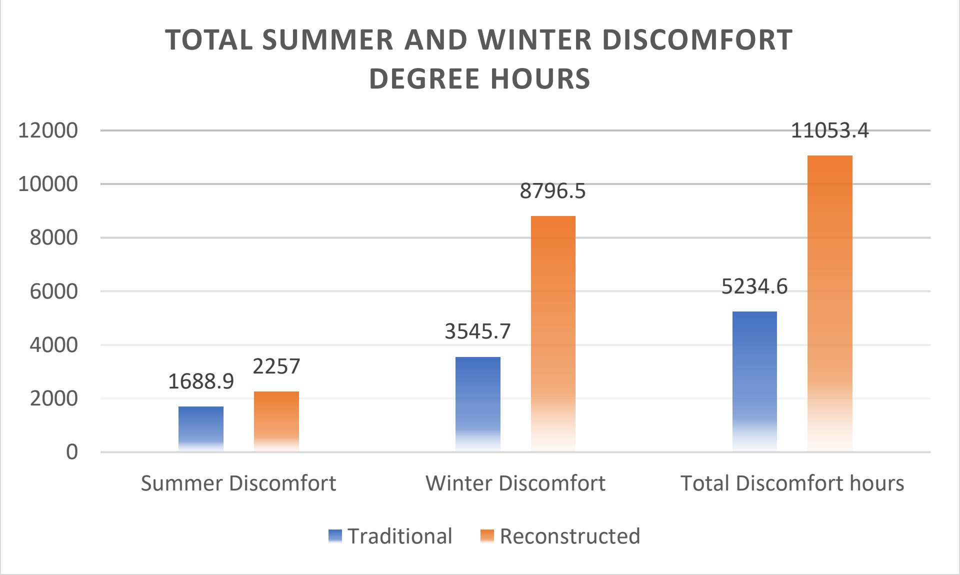


Chart 59 Comparison of Total summer and winter discomfort Traditional & Reconstructed house for Dolakha Town

6.5.4 Passive Gains Breakdown

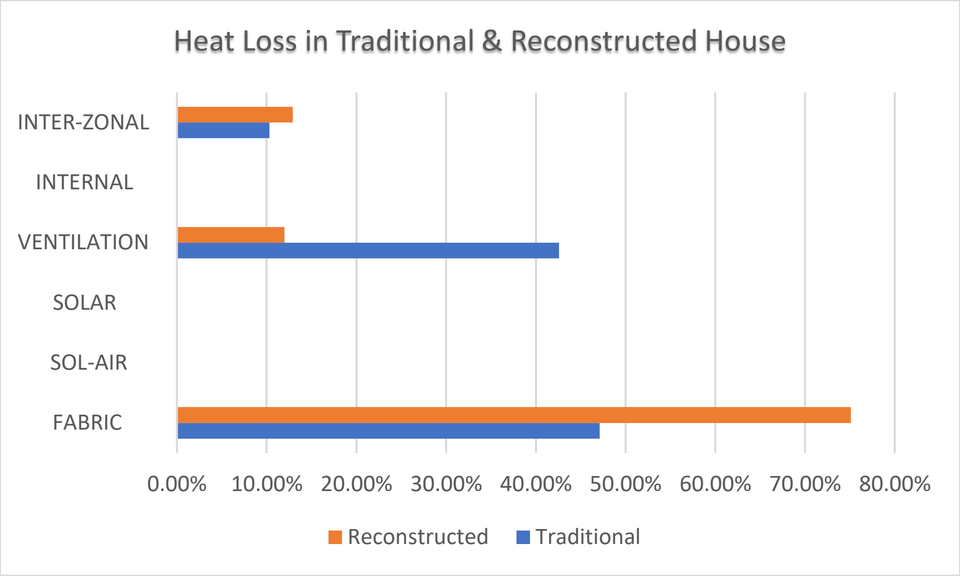


Chart 60 Comparison of Heat loss in Traditional & Post Disaster Reconstructed house of Dolakha town

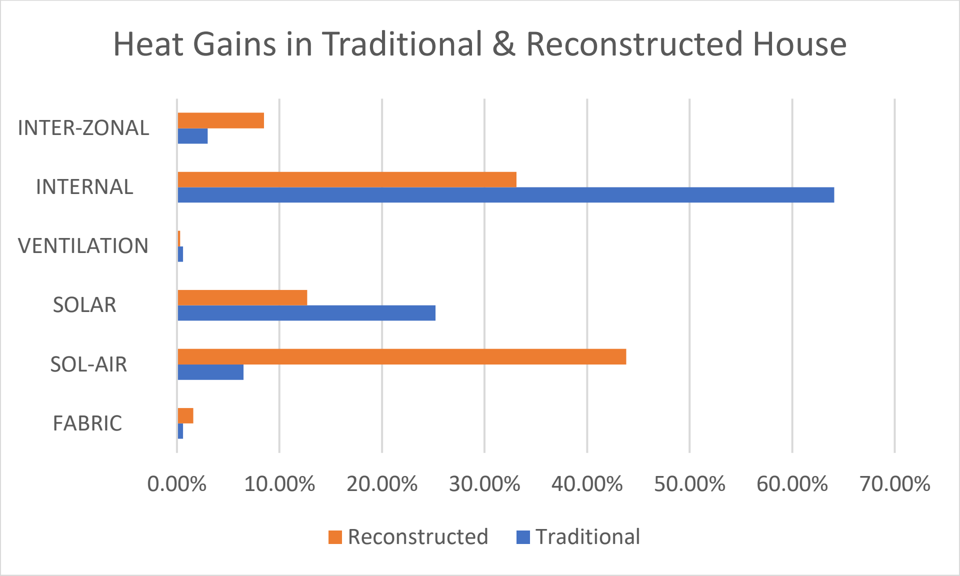


Chart 61 Comparison of Heat gains in Traditional & Post Disaster Reconstructed house of Dolakha town

6.6 Case Scenario 3: Interchanging building envelope materials of Post Disaster Reconstructed Building to Traditional Building

The traditional building was modeled by interchanging the material and construction technology of building envelope from post disaster reconstructed building to know about the energy performance of the building with the same spatial layout and building form and window wall ratio.

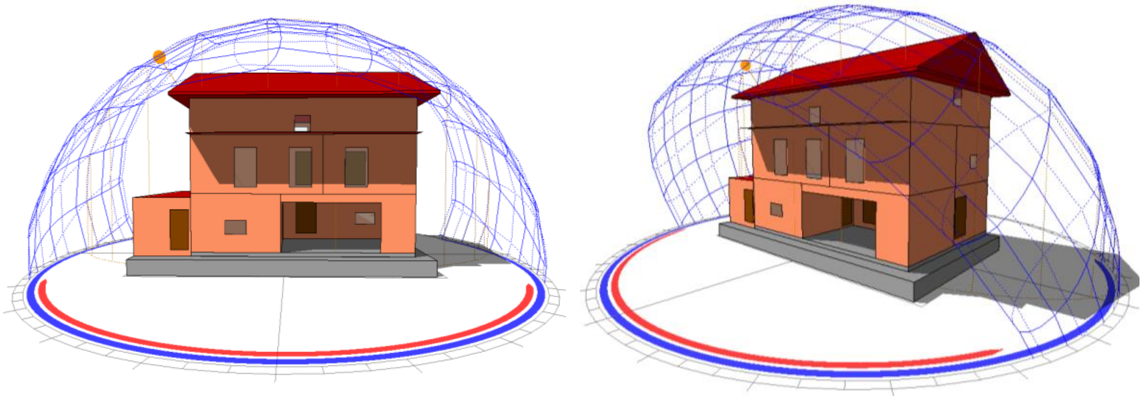


Figure 86 Ecotect Model of Traditional Building with Interchanged materials

6.6.1 Simulation results of Scenario 3: Interchanging materials of Post disaster reconstructed building to traditional building

6.6.1.1 Monthly Load Discomfort

The graph below shows the thermal discomfort period during the entire months of the year in the traditional house with interchanged materials. The thermal comfort range has been set to 18°C to 26°C. According to the calculation made by Ecotect Analysis, Summer discomfort load ranges from 0 Deg hrs. in December, January and February to 594 Deg hrs. in May. Winter discomfort load range from 0 Deg hrs. from April to September in May to 1826 Deg hrs. in January. This shows that the winter discomfort period is higher as compared to summer discomfort period.

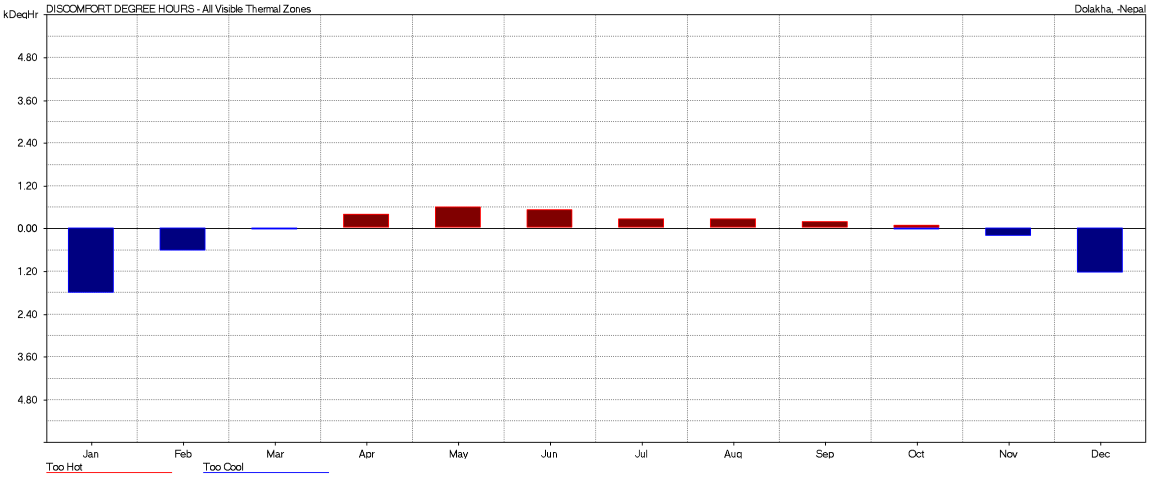


Chart 62 Monthly load Discomfort of Scenario 3

6.6.1.2 Passive Gains Breakdown

The graph below represents the monthly passive gains and losses through different categories of the traditional building. High heat gains are through internal heat gains followed by solar, and sol-air temperature while high losses come through fabric and then ventilation. Inter-zonal also contributes in passive heat loss.

Table 19 Passive Gains Breakdown

CATEGORY	LOSSES	GAINS
FABRIC	59.60%	1.30%
SOL-AIR	0.00%	16.90%
SOLAR	0.00%	19.60%
VENTILATION	18.70%	0.50%
INTERNAL	0.00%	51.10%
INTER-ZONAL	21.70%	10.70%

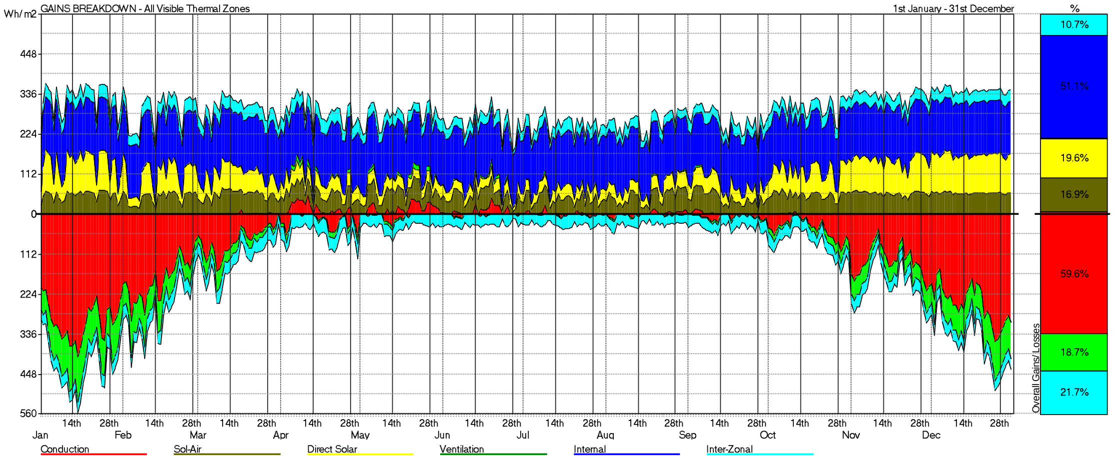


Chart 63 Passive Gains Breakdown of Scenario:3

6.7 Case Scenario 4: Interchanging building envelope materials of Traditional Building to Post Disaster Reconstructed Building

The post disaster reconstructed building was modeled by interchanging the material and construction technology of building envelope from traditional building to determine the energy performance of the building with the same spatial arrangement and building form and window wall ratio. The structure of the house remains unchanged i.e., RCC frame structure.

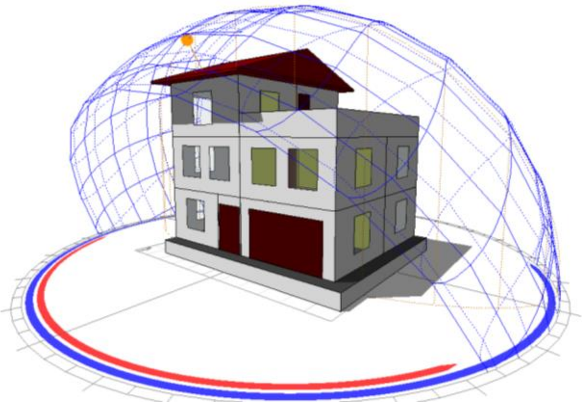


Figure 87 Ecotect Model of Post Disaster Reconstructed model with interchanged material

6.7.1 Simulation results of Scenario 3: Interchanging materials of traditional building to Post disaster reconstructed building

6.7.1.1 Monthly Load Discomfort

The graph below shows the thermal discomfort period during the entire months of the year in the traditional house with interchanged materials. The thermal comfort range has been set to 18°C to 26°C. According to the calculation made by Ecotect Analysis, winter discomfort load ranges from 0 Deg hrs. in June to 3204 Deg hrs. in January. Summer discomfort load range from 0 Deg hrs. in November, December, January, and February to 412 Deg hrs. in May.

Although the materials are changed the window size and window wall ratio is kept intact.

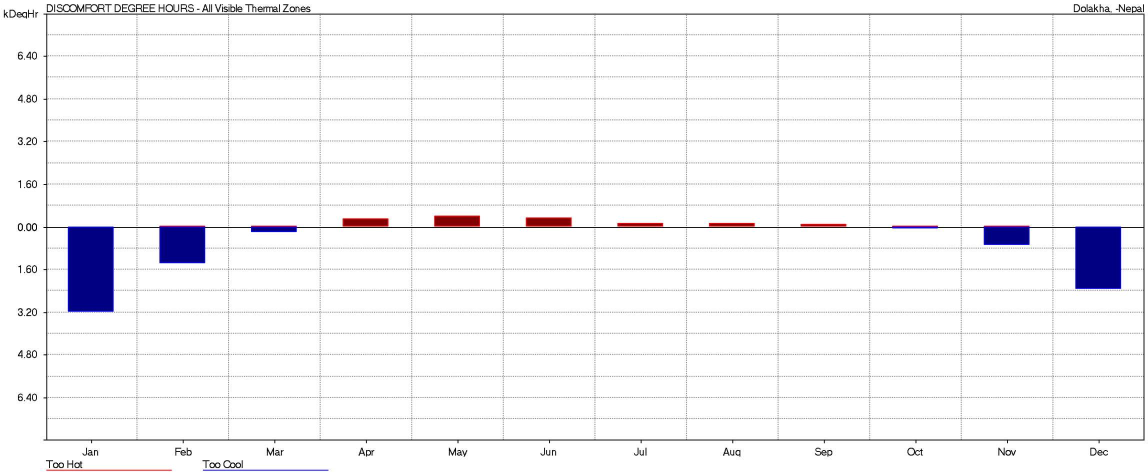


Chart 64 Monthly Discomfort Degree hours of Scenario:4

6.7.1.2 Passive Gains Breakdown

The monthly passive gains and losses through different categories of the traditional building are shown in the graph.78.30% of fabric and 21.60% ventilation contributes to heat loss while high gains come through internal heat gain and sol-air temperature. Another factor in passive heat gain is solar with 14.30%.

Table 20 Passive Gains Breakdown

CATEGORY	LOSSES	GAINS
FABRIC	78.30%	1.10%
SOL-AIR	0.00%	39.60%
SOLAR	0.00%	14.30%
VENTILATION	21.60%	0.40%
INTERNAL	0.00%	40.80%
INTER-ZONAL	0.10%	3.70%

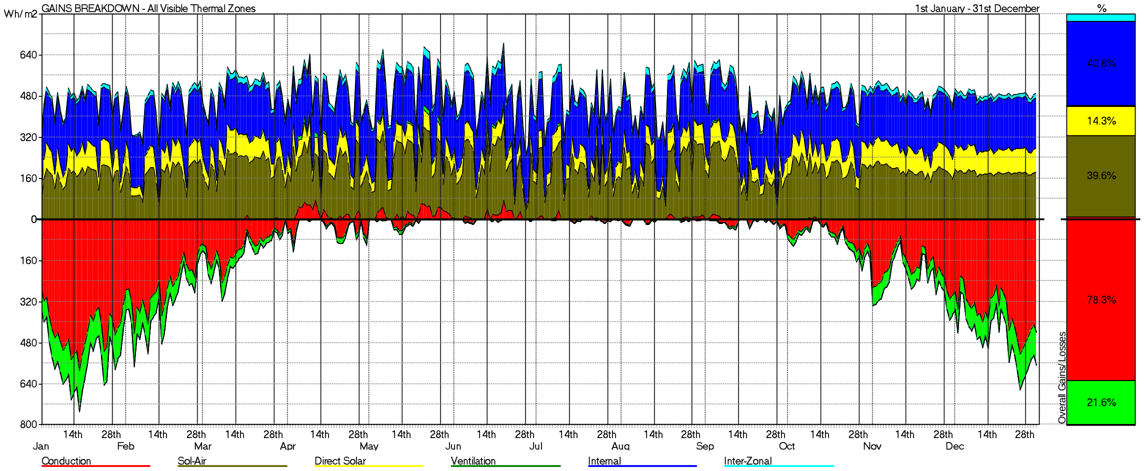


Chart 65 Passive Gains Breakdown of Scenario:4

6.8 Case Scenario 5: Optimizing Window Wall ratio in Post Disaster Reconstructed Building

The window wall ratio of the existing post disaster reconstructed house has been increased on south from 18.64% to 27.18% and east wall from 18.75% to 23.44%. The window size has been increased from 4’0” x 4’6” to 5’0” x 4’6”. The material of window is changed from single glazed in timber frame to double glazed in timber frame. The details of window wall ratio are as follows:

Table 21 Window Wall Ratio for optimization

Walls	Existing Window size	Optimized window size	Number of windows	WWR %
East	4’0” x 4’-6”	5’0” x 4’6”	4	23.44%
West	4’0” x 4’-6” & 2’0” x 2’6”	5’0” x 4’6” & 2’0” x 2’6”	6 3	29.9%
North	No window	4’0” x 4’-6”	3	9.32%
South	4’0” x 4’-6”	5’0” x 4’6”	7	27.18%

6.8.1 Simulation results of Scenario 5: Optimizing Window Wall ratio in Post Disaster Reconstructed Building

6.8.1.1 Monthly Load Discomfort

The graph below shows the thermal discomfort period during the entire months of the year in the traditional house with interchanged materials. According to the calculation made by Ecotect Analysis, the building’s heating load is 3441 Deg hrs. in January (the coldest month), while the cooling load is 547 Deg hrs. in May.

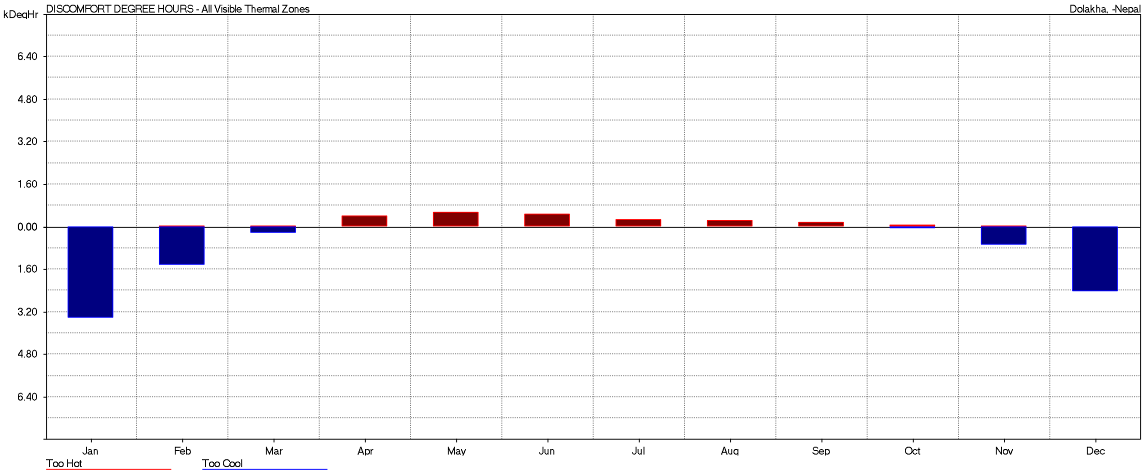


Chart 66 Monthly discomfort degree hours of Case scenario 5

6.8.1.2 Passive Gains breakdown

The monthly passive gains and losses through different categories of the post disaster reconstructed building with optimized WWR are shown in the graph. Heat loss is caused by 73.20% of fabric and 13.30% inter-zonal while high gains come through sol-air temperature 44.90% and internal with 34.30%.

Table 22 Passive Gains Breakdown for case scenario 5

CATEGORY	LOSSES	GAINS
FABRIC	73.20%	1.50%
SOL-AIR	0.00%	44.90%
SOLAR	0.00%	9.90%
VENTILATION	13.60%	0.30%
INTERNAL	0.00%	34.30%
INTER-ZONAL	13.30%	8.90%

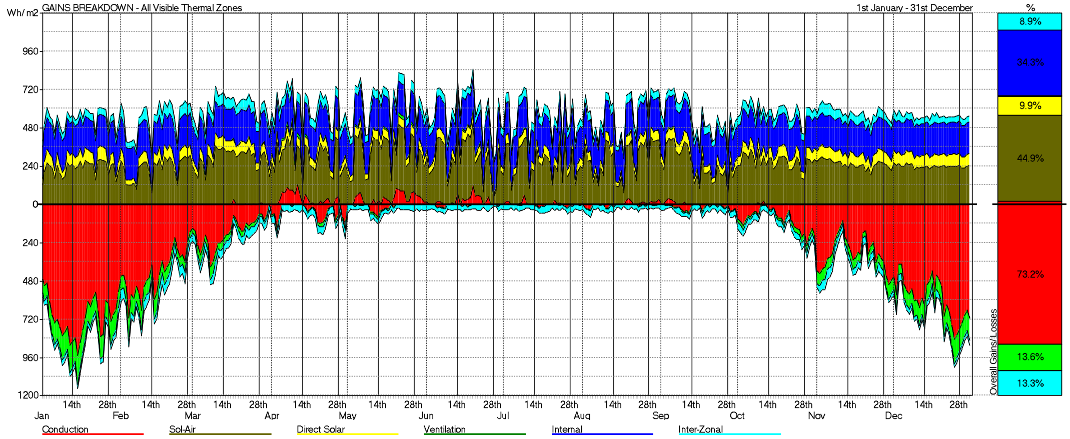
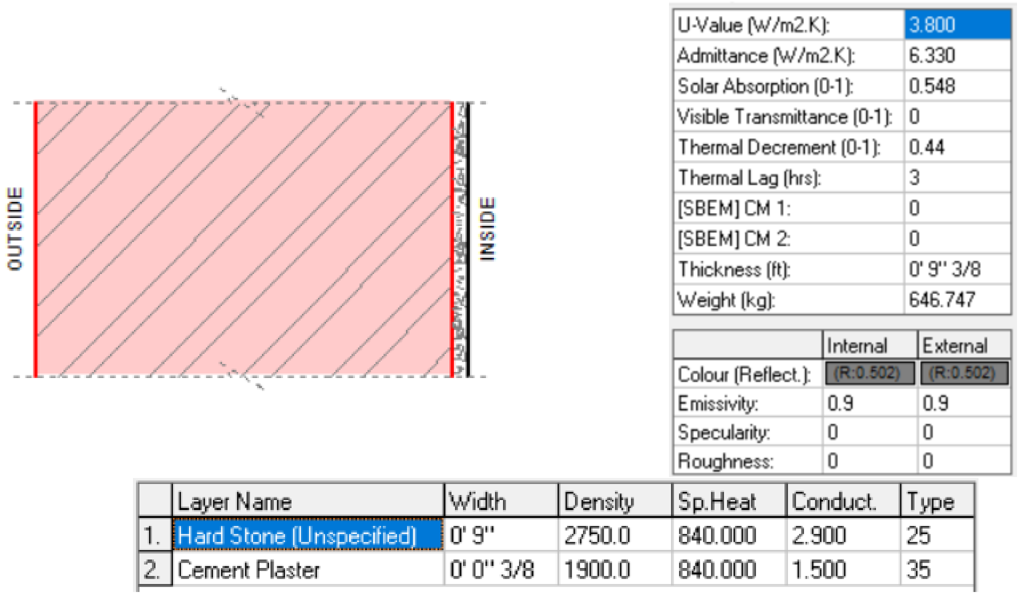


Chart 67 Passive Gains Breakdown for Case scenario 5

6.9 Case Scenario 6: Changing infill wall material of Post Disaster Reconstructed Building with stone wall and optimized WWR

The infill wall of post disaster reconstructed building is changed to 9” thick stone wall in cement mortar. The internal wall surface is plastered with cement and the outer surface is stone exposed for more traditional appearance. Similarly, the window material of single glazing in timber frame is replaced with double glazed in timber frame to enhance thermal performance. The RCC frame structure remains unchanged. The wall section, material property and the layer of wall material used is as follows:



U-Value (W/m2.K):	3.800
Admittance (W/m2.K):	6.330
Solar Absorption (0-1):	0.548
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.44
Thermal Lag (hrs):	3
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 9" 3/8
Weight (kg):	646.747

	Internal	External
Colour (Reflect.):	(R:0.502)	(R:0.502)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Hard Stone (Unspecified)	0' 9"	2750.0	840.000	2.900	25
2.	Cement Plaster	0' 0" 3/8	1900.0	840.000	1.500	35

Figure 88 Wall section, material property and the layer of material used in post disaster reconstructed building

6.9.1 Simulation results of Scenario 6: Changing infill wall material of Post Disaster Reconstructed Building with stone wall and optimized WWR

6.9.1.1 Monthly Load Discomfort

The graph below shows the thermal discomfort period during the entire months of the year in the traditional house with interchanged materials. According to the calculation made by Ecotect Analysis, the building’s heating load is 2520 Deg hrs. in January (the coldest month), while the cooling load is 641 Deg hrs. in May.

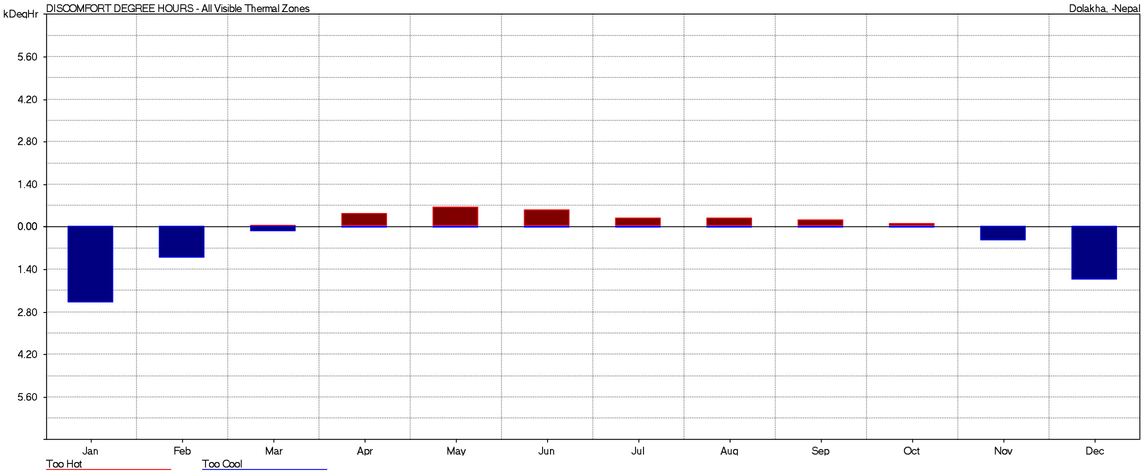


Chart 68 Monthly discomfort degree hours for case scenario 6

6.9.1.2 Passive Gains Breakdown

The monthly passive gains and losses through different categories of the post disaster reconstructed building with brick cavity wall are shown in the graph. Heat loss is caused by 68.30% of fabric and 16.00% ventilation while high gains come through sol-air temperature 44.70% and internal with 34.90%.

Table 23 Passive Gains Breakdown for Case scenario 6

CATEGORY	LOSSES	GAINS
FABRIC	68.30%	1.20%
SOL-AIR	0.00%	44.70%
SOLAR	0.00%	9.30%
VENTILATION	16.00%	0.30%
INTERNAL	0.00%	34.90%
INTER-ZONAL	15.80%	9.40%

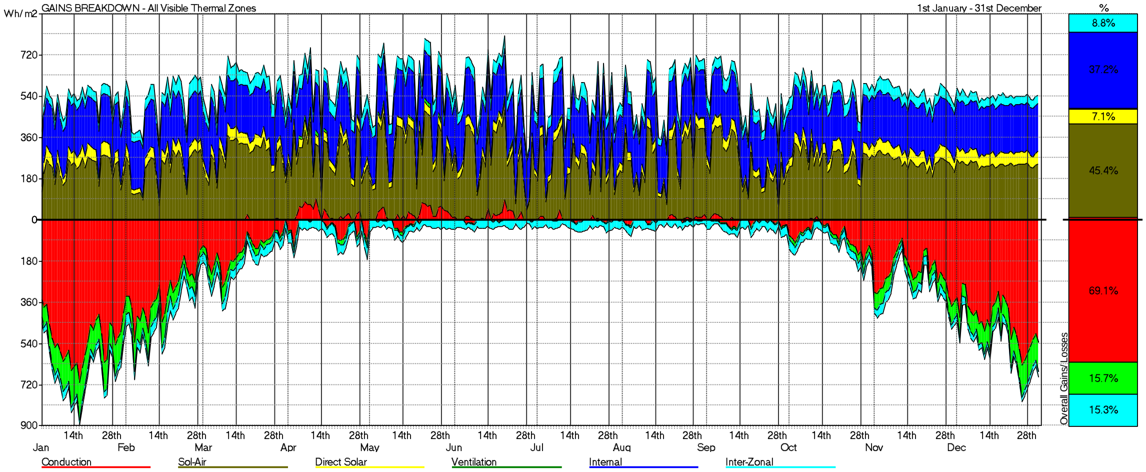
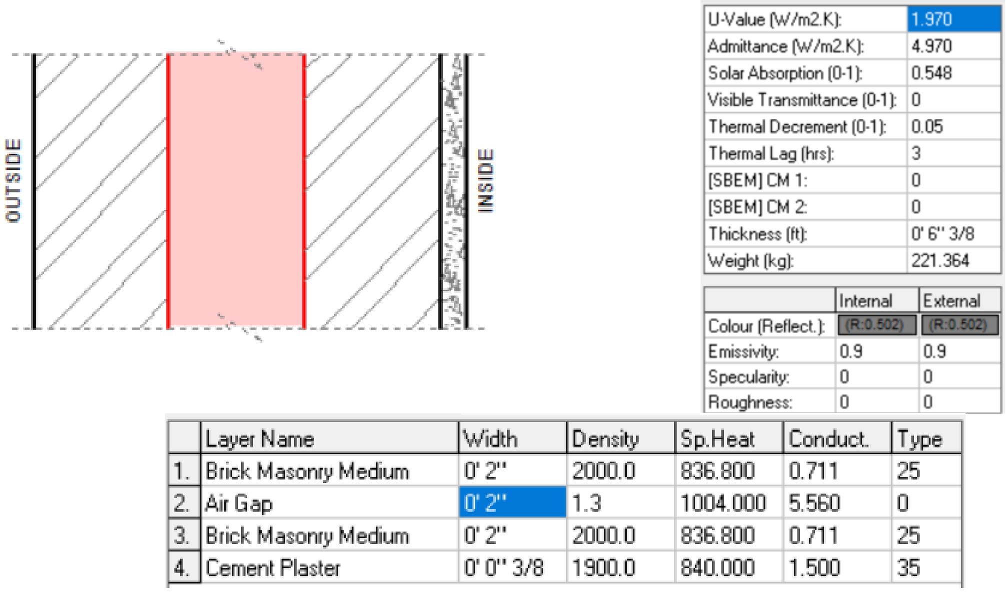


Chart 69 Passive Gains Breakdown for case scenario 6

6.10 Case Scenario 7: Optimizing Post Disaster Reconstructed Building with cavity wall of 2” thick shiner brick wall

The infill walls of post disaster reconstructed house are changed to 2” thick brick shiner wall on either side with air cavity of 2”. The inner leaf of the cavity wall is plastered with cement to provide smooth surface while the external leaf is brick exposed. It is used to improve the thermal performance of infill wall without increasing the wall thickness. The wall section, property of material and the layers of wall material are shown below:



U-Value (W/m2.K):	1.970
Admittance (W/m2.K):	4.970
Solar Absorption (0-1):	0.548
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.05
Thermal Lag (hrs):	3
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 6'' 3/8
Weight (kg):	221.364

	Internal	External
Colour (Reflect.):	(R:0.502)	(R:0.502)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Brick Masonry Medium	0' 2''	2000.0	836.800	0.711	25
2.	Air Gap	0' 2''	1.3	1004.000	5.560	0
3.	Brick Masonry Medium	0' 2''	2000.0	836.800	0.711	25
4.	Cement Plaster	0' 0'' 3/8	1900.0	840.000	1.500	35

Figure 89 wall section, property of material and the layers of wall material for case scenario 7

6.10.1 Simulation results of Scenario 6: Optimizing Post Disaster Reconstructed Building with cavity wall of 2” thick shiner brick wall

6.10.1.1 Monthly Load Discomfort

The graph below shows the thermal discomfort period during the entire months of the year in the traditional house with interchanged materials. According to the calculation made by Ecotect Analysis, the heating load of the building is 2692 Deg hrs. in January (the coldest month), while the cooling load is 697 Deg hrs. in May.

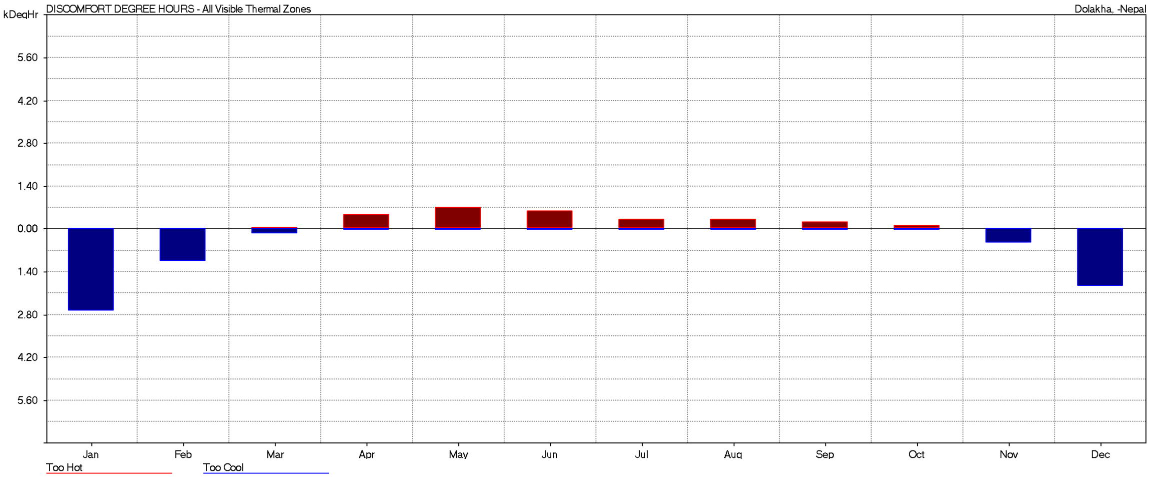


Chart 70 Monthly Discomfort Hours for case scenario 7

6.10.1.2 Passive Gains Breakdown

The graph below displays the monthly passive gains and losses through different categories of the post disaster reconstructed building with cavity wall of Shiner Brick wall on either side with air gap in between. 68.30% of fabric and 16.00% ventilation contributes to heat loss while high gains come through sol-air temperature 44.00% and internal with 36.20%.

Table 24 Passive Gains Breakdown for Case scenario 7

CATEGORY	LOSSES	GAINS
FABRIC	68.30%	1.20%
SOL-AIR	0.00%	44.00%
SOLAR	0.00%	9.00%
VENTILATION	16.00%	0.30%
INTERNAL	0.00%	36.20%
INTER-ZONAL	15.70%	9.20%

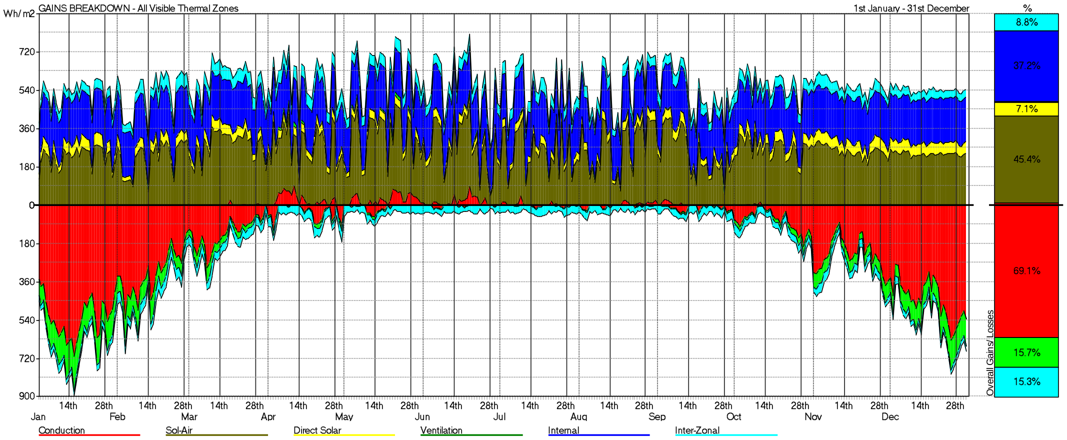


Chart 71 Passive Gains Breakdown for Case scenario 7

6.11 Case Scenario 8: Optimizing Post Disaster Reconstructed Building with Brick cavity wall

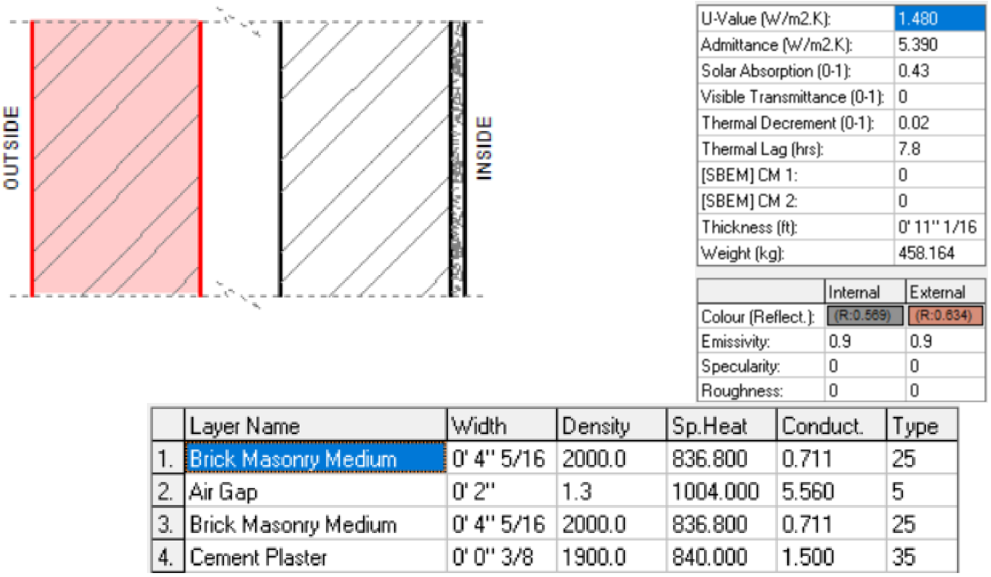
The post disaster building was modeled in Ecotect by changing wall material to brick cavity wall. It is used as an alternative to stone wall to increase thermal mass of the existing reconstructed building and improve the thermal performance of the building to achieve thermal comfort inside the building. the outer wall surface is brick exposed to meet the requirement of byelaws while the internal wall is plastered with cement to provide smooth surface. The other building materials are kept same.

Table 25 Specifications for optimized Post Disaster Reconstructed house with brick cavity wall

Specifications for optimized Post Disaster Reconstructed house with brick cavity wall	
External Walls	0’-4” thick brick wall in cement mortar on either side with 2” air gap in between. The internal brick wall is cement plastered
Partition walls	4” thick brick wall plastered on both the sides is used as partition wall
Flooring of Ground Floor	Elevated plinth level at 2’-0” Comprised of Earth compaction, stone soling, and concrete flooring and floor finish with cement screed
Flooring of Upper floors	0’-4” thick RCC floor and finished with a layer of cement screed
Floor Height	7’10”
Windows	Double glazed window with timber frame 5’0” x 4’-6” on South walls (27.18% WWR) 4’0” x 4’-6” on North Walls (9.32% WWR) 5’0” x 4’-6” on East Walls (23.44% WWR) 5’0” x 4’-6” on West walls (29.9% WWR)
Doors	Wooden shutter in wooden frame
Opening	11’-6” x 6’6” opening on Ground floor on southeast sides
Roof	Gable roof of UPVC with 18-degree slope
Rain Protection	2’-0” on all sides of Roof

6.11.1 Walls

The existing brick wall of post disaster reconstructed building is replaced by 0’-4” thick brick wall in cement mortar on either side with 2” air gap in between. The internal brick wall is cement plastered while the external wall is brick exposed to follow byelaws of the town. The wall section, properties of material and the layers of material used are as follows:



U-Value (W/m2.K):	1.480
Admittance (W/m2.K):	5.390
Solar Absorption (0-1):	0.43
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.02
Thermal Lag (hrs):	7.8
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	0' 11" 1/16
Weight (kg):	458.164

	Internal	External
Colour (Reflect.):	(R:0.569)	(R:0.634)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0

	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Brick Masonry Medium	0' 4" 5/16	2000.0	836.800	0.711	25
2.	Air Gap	0' 2"	1.3	1004.000	5.560	5
3.	Brick Masonry Medium	0' 4" 5/16	2000.0	836.800	0.711	25
4.	Cement Plaster	0' 0" 3/8	1900.0	840.000	1.500	35

Figure 90 Wall section, properties of material and the layers of material of Brick Cavity wall used in Case scenario 8

6.11.2 Simulation results of Scenario 8: Optimizing Post Disaster Reconstructed Building with Brick cavity wall

6.11.2.1 Monthly Load Discomfort

The graph below shows the thermal discomfort period during the entire months of the year in the traditional house with interchanged materials. According to the calculation made by Ecotect Analysis, the heating load of the building is 2318 Deg hrs. in January (the coldest month), while the cooling load is 738 Deg hrs. in May.

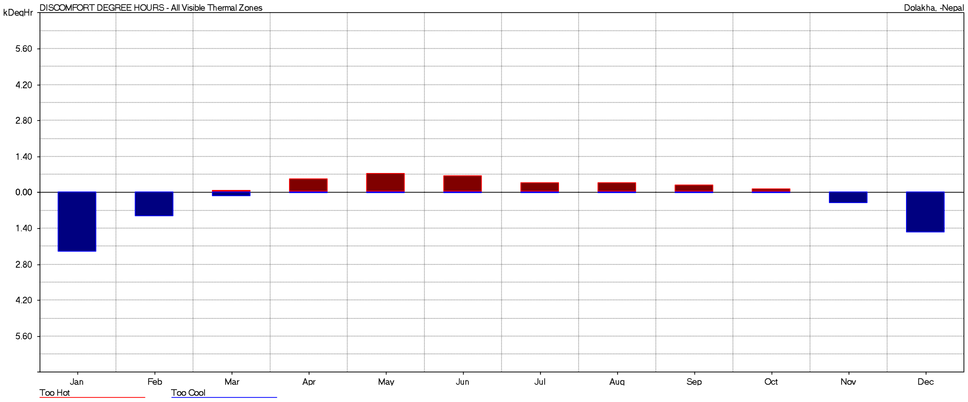


Chart 72 Monthly Load Discomfort Degree hours of Case Scenario 8

6.11.2.2 Passive Gains Breakdown

The monthly passive gains and losses through different categories of the post disaster reconstructed building with brick cavity wall are shown in the graph. 68.20% of fabric and 16.10% ventilation contributes to heat loss while high gains come through sol-air temperature 44.60% and internal with 35.10%.

Table 26 Passive Gains Breakdown for Case Scenario 8

CATEGORY	LOSSES	GAINS
FABRIC	68.20%	1.20%
SOL-AIR	0.00%	44.60%
SOLAR	0.00%	9.40%
VENTILATION	16.10%	0.30%
INTERNAL	0.00%	35.10%
INTER-ZONAL	15.60%	9.30%

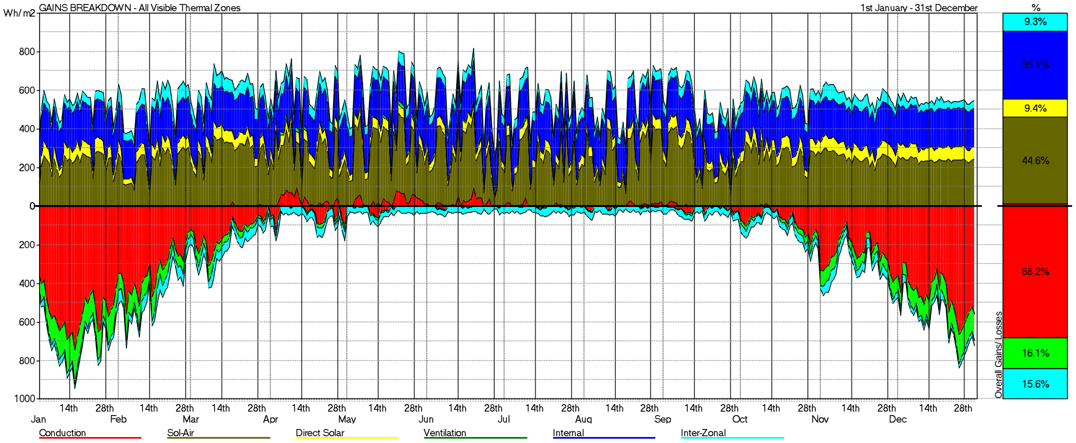


Chart 73 Passive Gains Breakdown for Case Scenario 8

6.12 Case Scenario 9: Optimizing Post Disaster Reconstructed Building with cavity wall of Hollow concrete block and brick wall

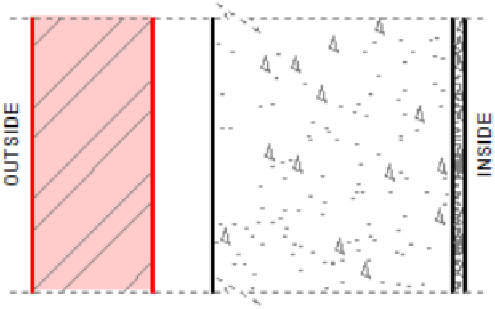
The post disaster building was modeled in Ecotect by changing wall material to cavity wall with hollow concrete block as inner leaf and brick wall as outer leaf with air gap in between. The wall can be used as an alternative to stone wall to increase thermal mass of the existing reconstructed building and enhance its thermal performance to provide thermal comfort inside the building. The outer wall surface is brick exposed to comply with byelaws requirement while the internal wall is plastered with cement to provide smooth surface. The other building materials remain unchanged.

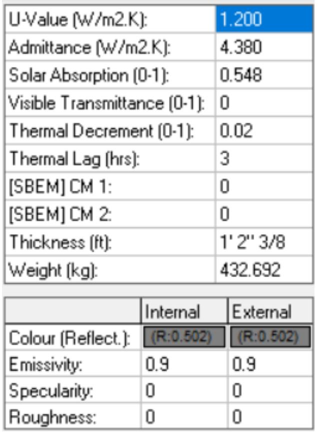
Table 27 Specifications for optimized Post Disaster Reconstructed house with cavity wall of Hollow concrete block and brick wall

Specifications for optimized Post Disaster Reconstructed house with cavity wall of Hollow concrete block and brick wall	
External Walls	0'-8" thick hollow concrete block as inner leaf and 0'-4" thick brick wall in cement mortar as outer leaf of the cavity wall 2" air gap as cavity in between the walls The internal wall is cement plastered while the external wall is brick exposed.
Partition walls	4" thick brick wall plastered on both the sides is used as partition wall
Flooring of Ground Floor	Elevated plinth level at 2'-0" Comprised of Earth compaction, stone soling, and concrete flooring and floor finish with cement screed
Flooring of Upper floors	0'-4" thick RCC floor and finished with a layer of cement screed
Floor Height	7'10"
Windows	Double glazed window with timber frame 5'0" x 4'-6" on South walls (27.18% WWR) 4'0" x 4'-6" on North Walls (9.32% WWR) 5'0" x 4'-6" on East Walls (23.44% WWR) 5'0" x 4'-6" on West walls (29.9% WWR)
Doors	Wooden shutter in wooden frame
Opening	11'-6" x 6'6" opening on Ground floor on southeast sides
Roof	Gable roof of UPVC with 18-degree slope
Rain Protection	2'-0" on all sides of Roof

6.12.1 Walls

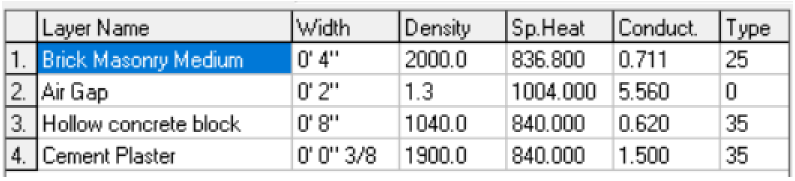
The wall section, properties of material and the layers of material used are as follows:





U-Value (W/m2.K):	1.200
Admittance (W/m2.K):	4.380
Solar Absorption (0-1):	0.548
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.02
Thermal Lag (hrs):	3
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (ft):	1' 2'' 3/8
Weight (kg):	432.692

	Internal	External
Colour (Reflect.):	(R:0.502)	(R:0.502)
Emissivity:	0.9	0.9
Specularity:	0	0
Roughness:	0	0



	Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1.	Brick Masonry Medium	0' 4"	2000.0	836.800	0.711	25
2.	Air Gap	0' 2"	1.3	1004.000	5.560	0
3.	Hollow concrete block	0' 8"	1040.0	840.000	0.620	35
4.	Cement Plaster	0' 0" 3/8	1900.0	840.000	1.500	35

Figure 91 Wall section, properties of material and the layers of material of Brick Cavity wall used in Case scenario 9

6.12.2 Simulation results of Scenario 9: Optimizing Post Disaster Reconstructed Building with Brick cavity wall

6.12.2.1 Monthly Load Discomfort

The graph below shows the thermal discomfort period during the entire months of the year in the traditional house with interchanged materials. According to the calculation made by Ecotect Analysis, the heating load of the building is 2132 Deg hrs. in January (the coldest month), while the cooling load is 842 Deg hrs. in May.

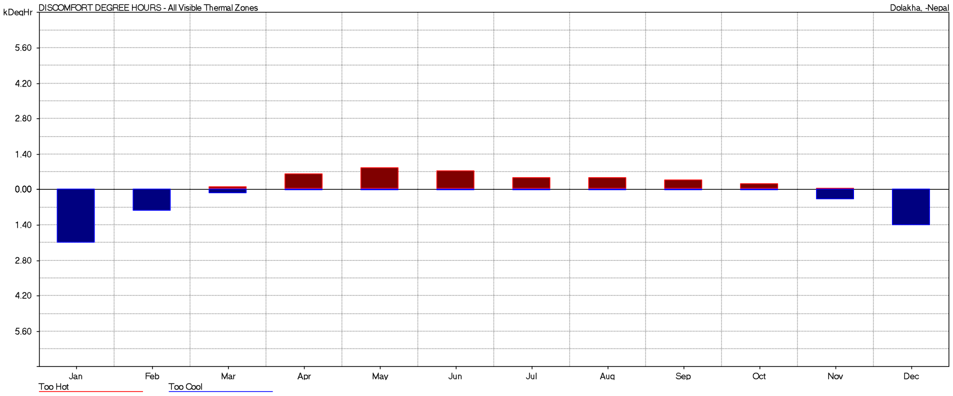


Chart 74 Monthly Load Discomfort degree hours for case scenario 9

6.12.2.2 Passive gains breakdown

The graph below displays the monthly passive gains and losses through different categories of the post disaster reconstructed building with cavity wall of hollow concrete block and brick wall. 67.60% of fabric, 16.30% inter-zonal and 16.10% ventilation contributes to heat loss while high gains come through sol-air temperature 43.90%.

Table 28 Passive Gains breakdown for Case scenario 9

CATEGORY	LOSSES	GAINS
FABRIC	67.60%	1.20%
SOL-AIR	0.00%	43.90%
SOLAR	0.00%	9.70%
VENTILATION	16.10%	0.30%
INTERNAL	0.00%	35.20%
INTER-ZONAL	16.30%	9.60%

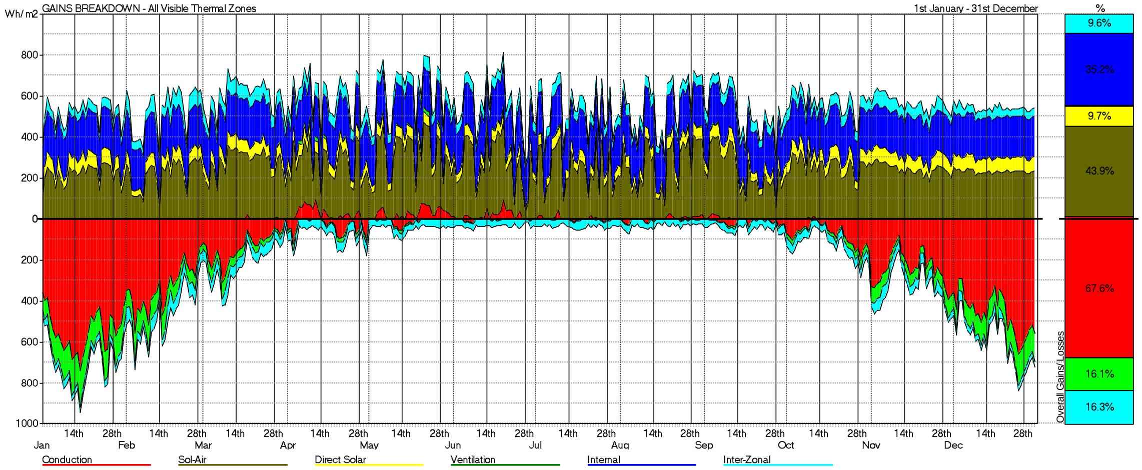
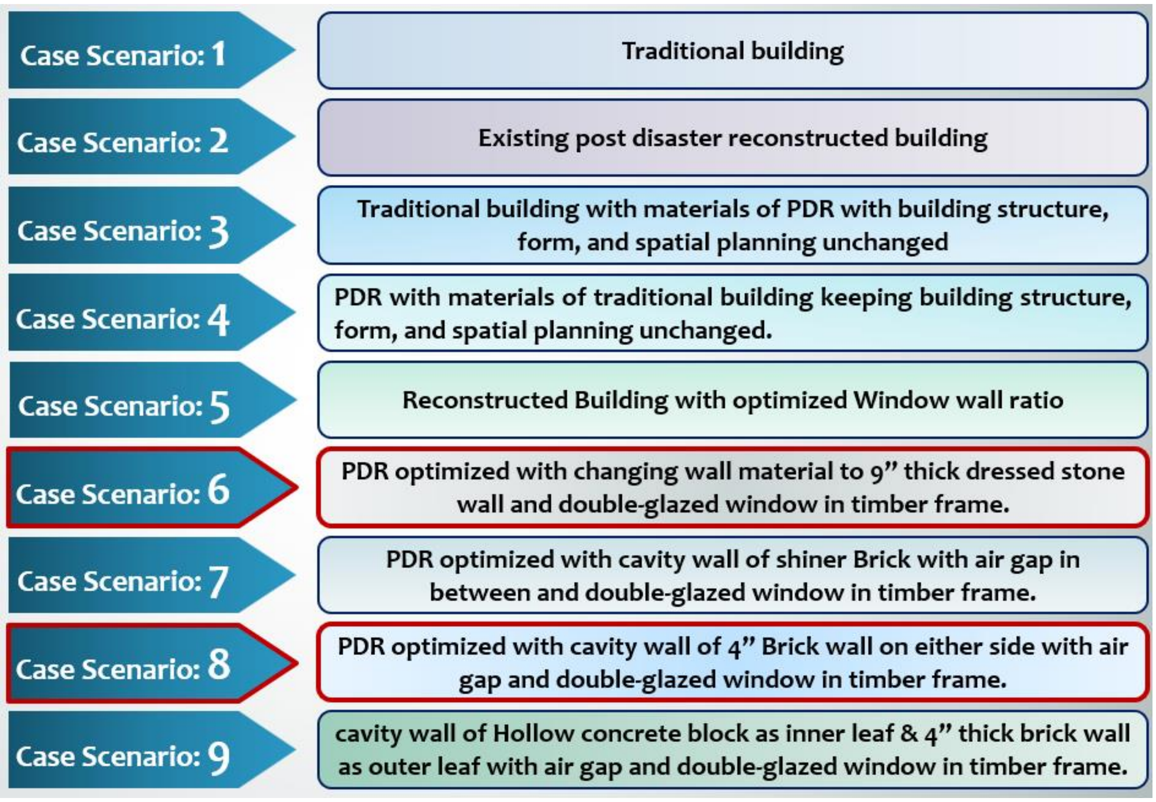


Chart 75 Passive gains breakdown for Case scenario 9

6.13 Comparative Analysis between different scenarios



Case Scenario: 1	Traditional building
Case Scenario: 2	Existing post disaster reconstructed building
Case Scenario: 3	Traditional building with materials of PDR with building structure, form, and spatial planning unchanged
Case Scenario: 4	PDR with materials of traditional building keeping building structure, form, and spatial planning unchanged.
Case Scenario: 5	Reconstructed Building with optimized Window wall ratio
Case Scenario: 6	PDR optimized with changing wall material to 9" thick dressed stone wall and double-glazed window in timber frame.
Case Scenario: 7	PDR optimized with cavity wall of shiner Brick with air gap in between and double-glazed window in timber frame.
Case Scenario: 8	PDR optimized with cavity wall of 4" Brick wall on either side with air gap and double-glazed window in timber frame.
Case Scenario: 9	cavity wall of Hollow concrete block as inner leaf & 4" thick brick wall as outer leaf with air gap and double-glazed window in timber frame.

Figure 92 Different Case Scenarios

The post disaster reconstructed building was optimized by changing the infill wall material and roof material without changing the building structure i.e., RCC frame structure to ensure earthquake resistance of building. Single glazed windows were replaced by double glazed windows in timber frame to provide traditional appearance.

Different case scenarios are compared to analyze the thermal performance of building envelope materials in post disaster reconstructed building. The monthly discomfort degree hours with summer discomfort and winter discomfort are compared. Similarly, the passive gains breakdown through different categories are compared. Different case scenarios and the details are as follows:

6.13.1 Comparison of Summer Discomfort degree hours.

The graph below shows the comparison of summer discomfort degree hours from the results of simulation in Ecotect software. It indicates that the summer discomfort load is higher in case scenario 9 i.e., 3900 Deg hrs. and lowest in case scenario 4 i.e., 1412.3 Deg hrs.

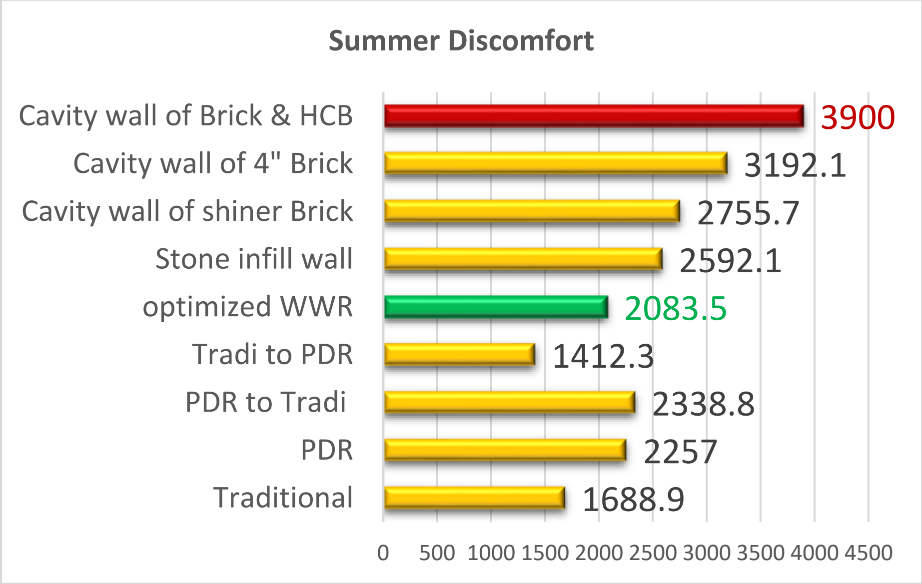


Chart 76 comparison of summer discomfort degree hours of different scenarios

6.13.2 Comparison of Winter Discomfort Degree hours

The graph below shows the comparison of winter discomfort degree hours from the results of simulation in Ecotect software. It indicates that winter discomfort load is higher in case scenario 5 i.e., 8487.3 Deg hrs. and lowest in case scenario 1 i.e., 3545.7 Deg hrs.

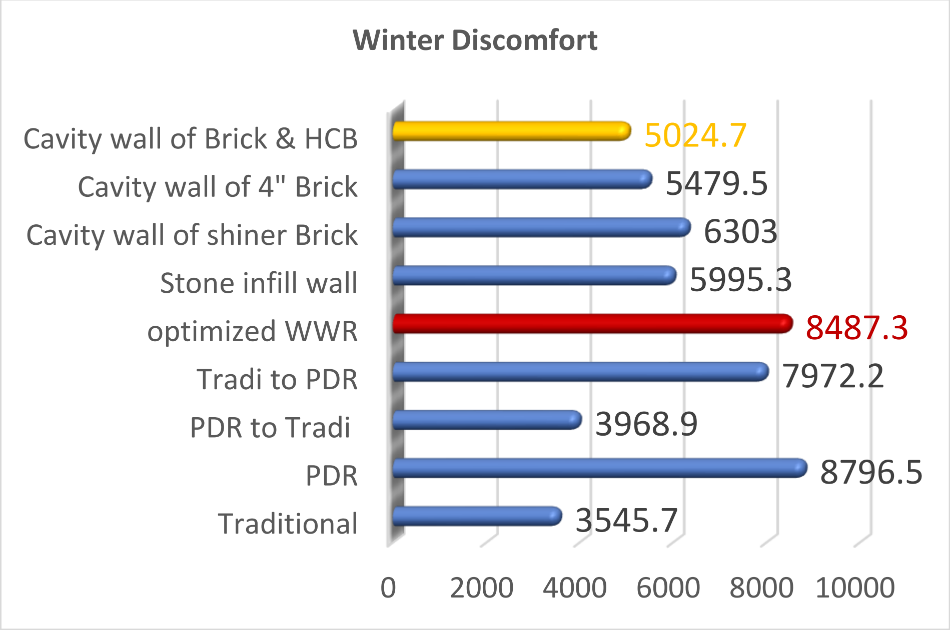


Chart 77 Comparison of Winter Discomfort Degree hours of Different scenarios

6.13.3 Comparison of Total Discomfort Degree hours

The chart below shows that discomfort hours are higher in post disaster reconstructed building and among the optimization changing infill wall with stone and optimized WWR with double-glazed window has lowest discomfort hours.

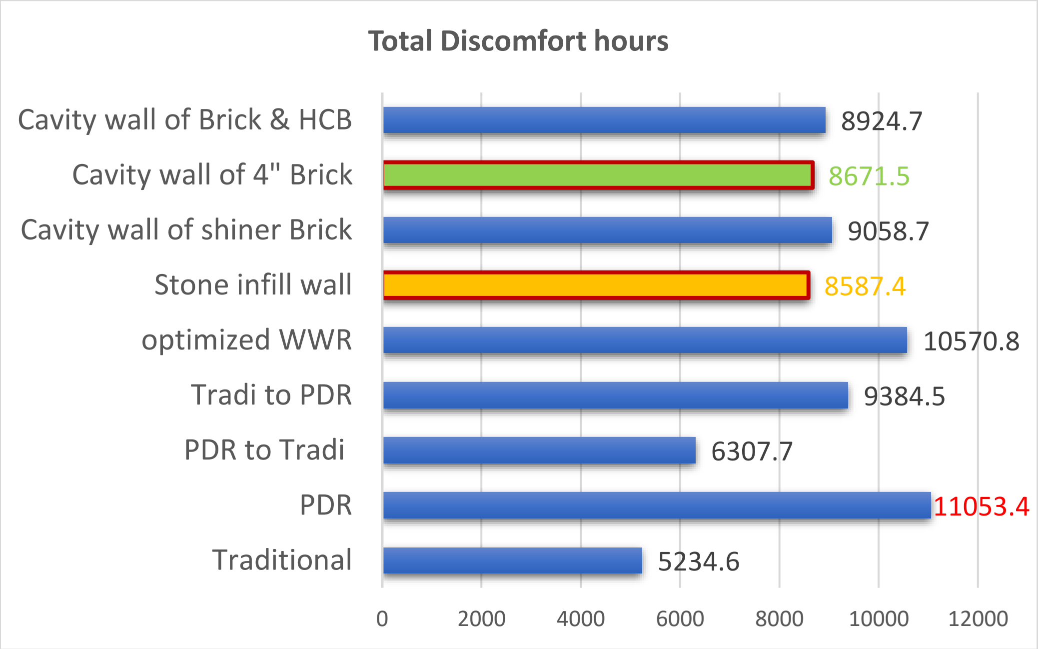


Chart 78 Comparison of Total Discomfort Degree hours of different scenarios

7 Chapter 7: Proposed design of Residence for Dolakha town

A residence design is proposed prioritizing the vernacular architecture of Dolakha town, with maximum use of locally available materials in context to the local climate and considering the structural stability of the building. Guidance from Bioclimatic chart and recommendations from Mahoney table is used for the design of residential house. Results from optimization in post-disaster reconstructed building through energy simulation is also used for residence design.

Figure 93 Proposed Residence design with stone wall and brick cavity wall

The proposed shelter design is of frame structure which is commonly used after earthquake to insure structural stability. The infill wall is either of 9” thick stone wall in cement mortar or cavity wall of 4” brick on either side with air cavity in between. The house has rectangular plan of (25’x24’) sq.ft. same as selected post-disaster reconstructed building with change in internal space arrangement. It is of two storeys with partial attic and terrace space.

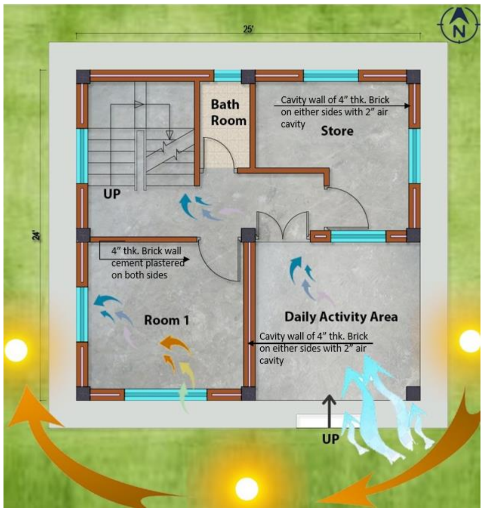


Figure 94 Ground Floor plan of Proposed Residence design

The layout of the internal space is designed as per the socio-cultural aspect of Newar people of Dolakha town. Ground floor is comprised of semi-open space, located towards southeast direction that resembles dalan area of traditional building where daily activities are carried out. This helps to allow solar radiation from east and south into the semi open area. U-shaped staircase towards north-west connects the upper floors. First floor has living and bedrooms where habitable rooms are located towards south and east and buffer space like staircase and bathrooms are located towards north. A balcony or solar space is provided for south-east room. Attic space has kitchen area and terrace towards south so that the room has enough solar rays inside. Rain protection is provided in every floor.

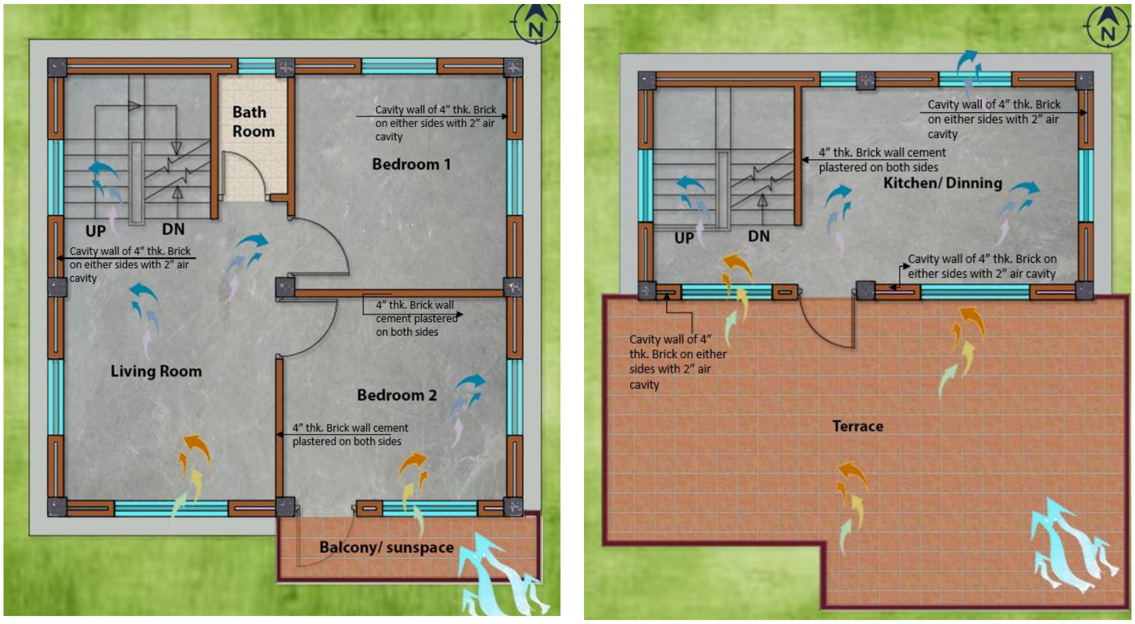


Figure 95 First and Attic floor plan of Proposed Residence design

Large windows of (5'x4'6") are provided towards south wall and openings of (4'x4'6") are provided towards east and west walls for cross ventilation.

Table 29 Window wall ratio for Proposed Residence Design

Wall	Window size	Window wall ratio (%)
East	4'x4'6"	18.4
West	4'x4'6" & 4'x3'	14.8
North	4'x4'6" & 2'2"	11
South	5'x4'6"	22.32

Building material and construction technology which is found to be energy efficient is used for wall construction i.e., either stone wall in cement mortar or cavity wall of 4" brick on either side with air cavity in between. Attic space is covered with UPVC roofing on timber structure with a layer of insulating material. Flooring is of 4" thick RCC concrete with cement punning as floor finish. Double glazed window in timber frame is used to provide traditional look of the house.

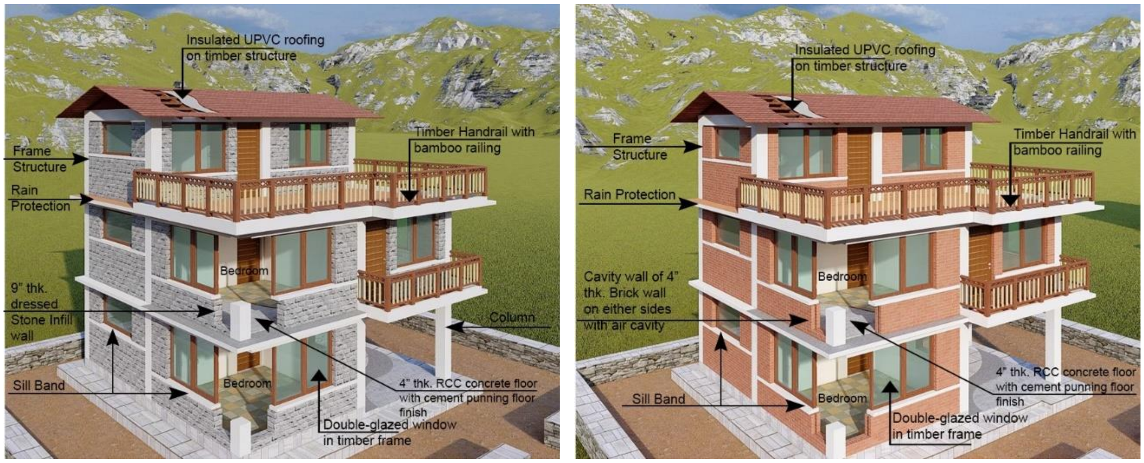


Figure 96 3D section of proposed Residence design

7.1 Energy simulation

Energy efficiency of the proposed residence was investigated using energy simulation through Ecotect software. The above-mentioned architectural design was replicated through energy modelling with brick cavity wall. As per the calculation made by Ecotect Analysis, highest summer discomfort load is 408 Deg hrs. in May and higher winter discomfort load is 2441 Deg hrs. in January. Total summer discomfort hour is 1610.9 deg hrs. while total winter discomfort hours is found to be 6070.1 Deg hrs.

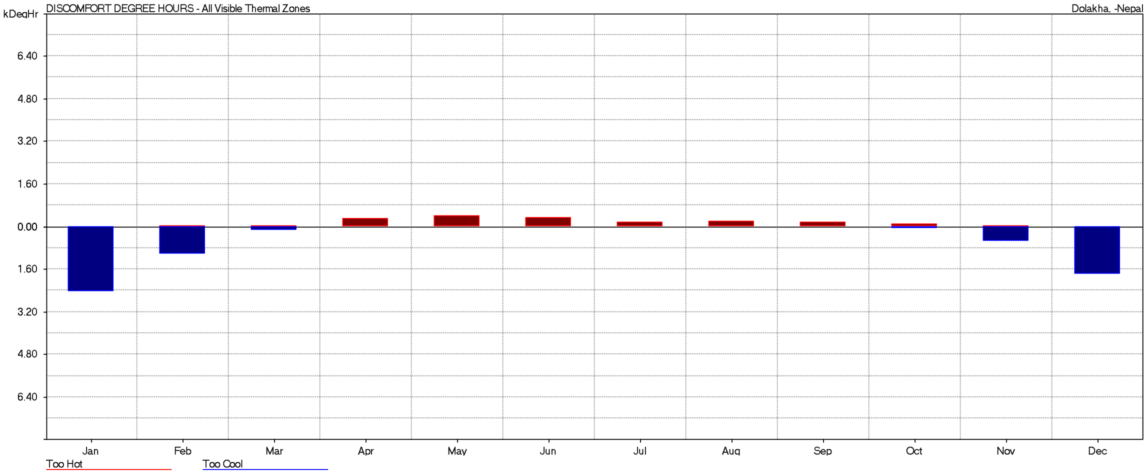


Figure 97 Monthly discomfort load of Proposed Residence design with brick cavity wall

With stone wall as infill wall, the total summer discomfort hour is found to be 1959.4 deg hrs. while total winter discomfort hours is found to be 5489.5 Deg hrs.

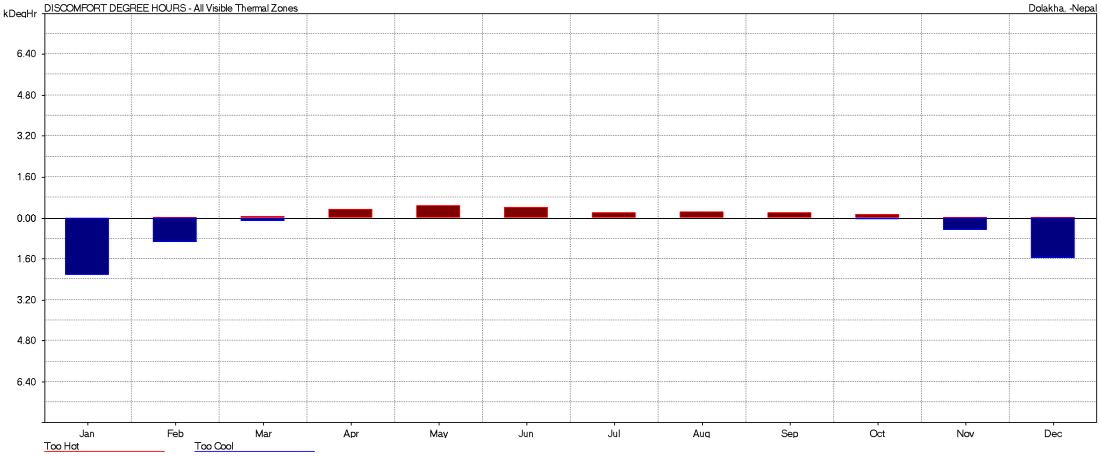


Figure 98 Monthly discomfort load of Proposed Residence design with stone infill wall

8 Chapter 8: Findings and Discussion

The study was carried out to evaluate and compare the thermal comfort of traditional and post disaster reconstructed building to improve thermal comfort in the residential building of Dolakha town in terms of building envelope performance. It is seen that the reconstructed building differs from traditional building in terms of building envelope material and construction technology and the building form. From the field study it is found that the internal temperature of traditional building is lower as compared to that of reconstructed building. The indoor air temperature in traditional building is 0.37°, 2.3° and 3.21° at 7 AM, 1PM and & 7PM respectively lower than that of reconstructed building in average. Similarly, indoor relative humidity of traditional building is also lower than that of reconstructed building by 13%, 9.8% and 10.28% at 7 AM, 1PM and & 7PM respectively. As per the result from Ecotect simulation, summer and winter discomfort degree hours are high on post disaster reconstructed building in May and January respectively. The heating load of traditional building is 3545.7 Deg Hrs. whereas the post disaster reconstructed building is 8796.5 Deg hrs. Similarly, the cooling load of traditional building is 1688.9 Deg hrs. while that of post disaster reconstructed building is 2257 Deg hrs. This demonstrates that traditional building is thermally comfortable to live in as compared to reconstructed buildings.

The second objective was to observe and evaluate the building envelope in terms of construction material and techniques and architectural features. Initial observations were done through field study in which it was found that newly constructed buildings have changed its building form. Traditional buildings are of two storey and attic floor while reconstructed buildings have two storey with half attic floor and terrace. Due to its east-west elongation, both the buildings benefit from increased solar exposure. Building materials used in traditional building are stone wall with mud mortar and plastered with white kamero mato on both sides and roof is of dark colored slate. This provides rough texture on wall surface as well as roof that helps to absorb solar radiation for longer period of time. Post-disaster reconstructed buildings are built in RCC frame structure with brick wall in cement mortar. The internal space arrangement of both the buildings are similar with habitable space like living room, bedroom located towards south and buffer zones like staircase and stores located towards north. Window wall ratio in traditional building is 23.29% on south wall, 2.27% on north wall and only 1.67% on east and west walls. This has been increased on reconstructed building to provide visual comfort and admit natural lighting inside the building with 18.64% on south wall, 18.75% on east wall. 15.67% on west wall and no openings on north wall. This manifests that increase in thermal discomfort load in post-disaster building is due to the performance of building envelope material and construction technology.

Exploring energy consumption pattern and thermal sensitivity of material used in Dolakha town was the third goal of the research. It has been discovered from the results from questionnaire survey that most of the people living in the town are of old and of age group 30-59. Young people are seen to emigrate to Kathmandu or foreign countries for study or employment opportunities. Number of people living in the house in most of the time are two-four. This has reduced the usage of energy through different sources. Almost all the houses have used energy efficient lights like CFL, and LED. Use of incandescent lights were not seen during household survey. LPG gas is the primary source of energy for cooking with electricity being used for electric rice-cookers. Traditional stoves were used for cooking for cattle. Even if the survey's data indicates that people use different fuels like coal, firewood, electric heater, etc., to heat their homes during winter, thermal comfort is nevertheless maintained by wearing multiple layers of clothing. The use of solar water heater is very limited due to the use of slope roof of CGI sheets.

It is learned from the field study that the main reason for not using traditional material in the reconstruction of buildings is lack of space as the walls are thick and requires large space for construction. Thick stone walls are avoided since lands has been divided into small plot size as a result of family division. Another reason is difficulty in dressing of stone for wall construction and is time consuming. The thermal mass of traditional stone wall is the main criteria that helps in increasing the thermal time lag and helps in maintaining the indoor temperature.

Different case scenarios were created to optimize post disaster reconstructed building in terms of energy efficiency. From the energy simulation by Ecotect, in comparison to different case scenarios, higher summer discomfort was seen in case scenario 9 i.e., reconstructed building with cavity wall of hollow concrete block and brick wall with optimized WWR and the lowest is case scenario 4 i.e., reconstructed building with interchanged building material from traditional building. Optimization in window wall ratio with double glazed window help in achieving energy efficiency in reconstructed building by 4.37%. The post-disaster reconstructed building is optimized by 22.31% by changing infill wall to stone wall and optimized WWR with double glazed window. Similarly, the reconstructed building is optimized by 21.56% by switching infill wall to cavity wall of 4" thick brick wall on eithers sides with air 2" thick air cavity and optimized WWR with double glazed window. Cavity wall of shiner brick wall with air cavity helps in optimizing by 18.05% along with optimized WWR and double-glazed windows. Using cavity wall of 4" thick brick wall as outer leaf and hollow concrete block as inner leaf with air cavity in between helps in achieving thermal comfort in post reconstructed building by 19.25%.

With the change in internal space arrangement, building form, building material and construction technology within same rectangular plan of post-disaster reconstructed building, new residential design was proposed. It is found that the proposed building is optimized by 30.5% with brick cavity wall and by 32.6% with stone infill wall. Although the use of stone for wall construction is limited in use due to its high cost, it acts better for energy efficiency.

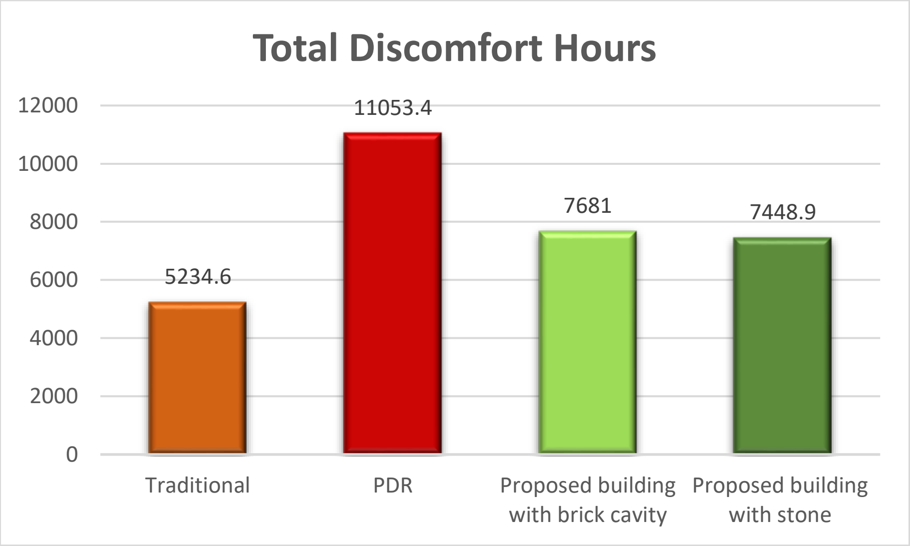


Chart 79 Comparison with proposed residence design

9 Chapter 9: Conclusion

Newly constructed houses do not comply with traditional buildings and are built haphazardly without considering local context and climate. These buildings lack in providing and maintaining thermal comfort inside the house that mostly focused on seismic standards to make the building earthquake resistant. Taking advantage of reconstructing the buildings in present scenario, the concept of Build Back Better can be emphasized in terms of thermal comfort inside the building with the implementation of passive design strategies. This can help to reduce the energy consumption by residential buildings used for heating or cooling and lighting the living space.

As per the result from questionnaire survey, field study and energy simulation of two selected buildings for detail study, it is found that traditional buildings are thermally comfortable to live in as compared to post-disaster reconstructed building. The performance of building envelope in traditional and reconstructed building was analyzed through which it is found that with certain changes in wall material and construction technology helps in enhancing thermal comfort inside the building. Replacing single glazed window by double glazed window also improves thermal performance of the building. Large windows are provided towards south walls while north walls are either provided with small numbers or with no openings. Rough textured and dark exterior wall surface helps in absorbing solar radiation for longer period of time which helps in increasing thermal time lag of building envelope. The research found that the energy consumption pattern is characteristics of cooking, heating, and lighting. Hydroelectricity is the major source for lighting and for cooking and water heating purpose LPG gas, accounts for most of the energy use. Only a small percentage of homes use solar water heaters. For room heating purpose coal and firewood are extensively used which has several environmental and public health risks. This shows that the town is completely dependent on non-renewable energy sources like LPG gas. The households do not focus much on the utilization of renewable resources. Solar energy can be utilized for water heaters and space heating.

The research concludes that the alternatives for thermal mass of thick stone wall in traditional buildings can be made by using stone infill wall where it is locally available or brick cavity wall to improve thermal comfort in new building construction. However, with simple approach to integrate passive design strategies and use of energy efficient building envelope material and construction technology certainly enhance the thermal comfort in residential building.

10 Chapter 10: Recommendations

Reconstruction can be taken as an opportunity to ensure energy efficiency in residential buildings. Following recommendations can be incorporated in new construction of residential buildings in order to improve thermal comfort.

Design Perspective

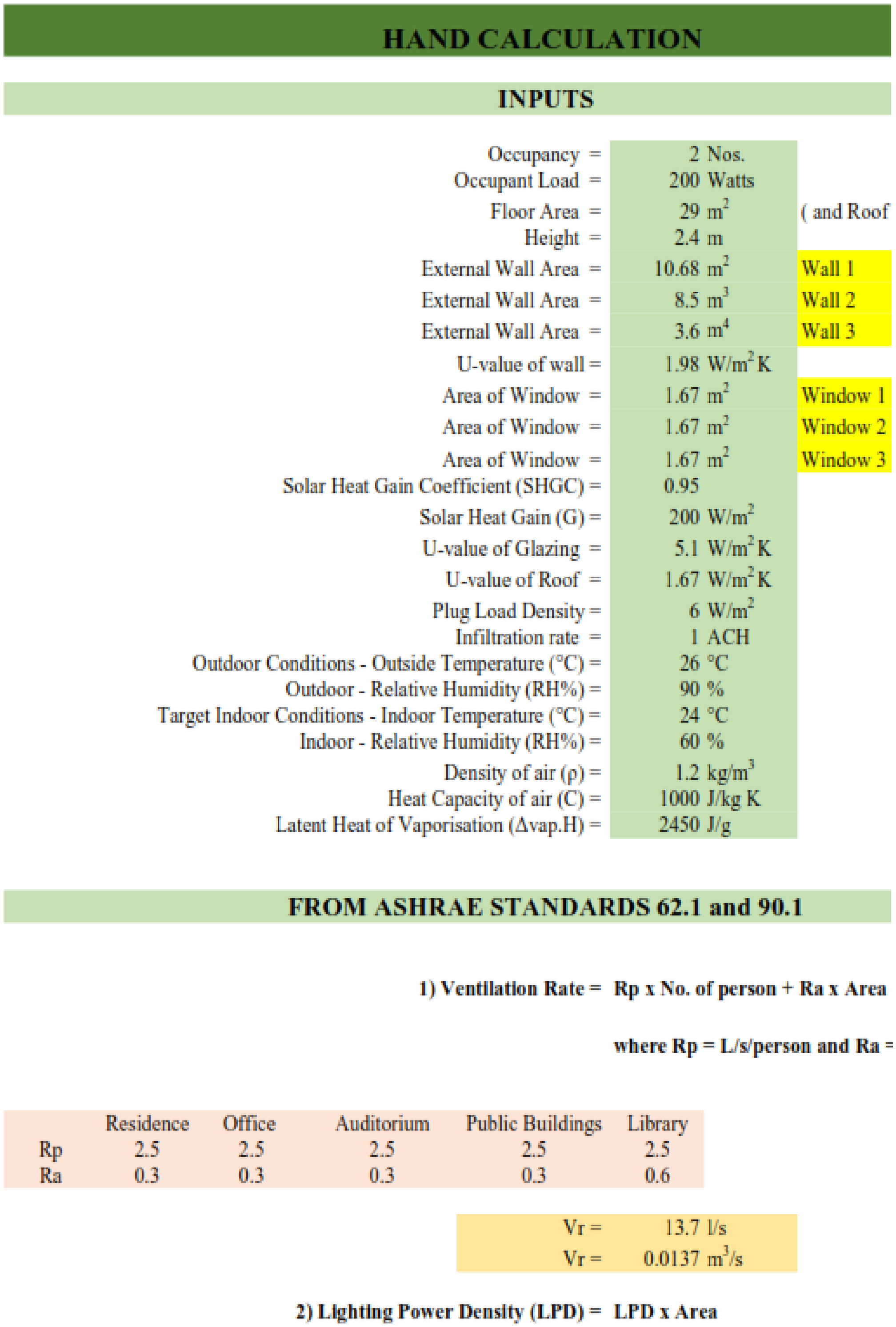
Local climate should be considered from the initial phase of construction starting from site selection, orientation, spatial planning, material choice and construction technology. Buildings should orient towards south with east-west elongated so that the building has larger surface area to receive solar radiation. Habitable rooms like living room, bedroom should be located towards south with buffer space like staircase, bathrooms and stores located towards north. Proper placement of fenestrations helps in cross ventilation which helps to maintain the indoor temperature of the residence. Use of stone for wall construction should be encouraged for new construction of buildings in areas like Dolakha where stones are locally accessible and are employed in vernacular architecture, combined with the provision of modern living amenities. In the places where stone is not available, commonly used bricks can be used for cavity wall. Brick cavity wall can also be replaced by rat bond brick wall construction suggested by DUDBC housing type R.T.B. 7.1. Window wall ratio of 22-23% should be provided on south wall for better efficiency and 11-18% WWR on other walls for cross ventilation. In addition to thermal comfort, visual comfort should also be taken into account when constructing residential buildings which can be achieved with the use of double-glazed windows. Dark colors and rough textured exterior surface can be provided in the buildings which helps to absorb solar radiation for longer period and increase thermal time lag of building envelope.

Policy perspective

Although government in PDRF has addressed on sustainable and resilient settlement planning, energy efficient building material and technology, new building construction has given least attention towards it. Therefore, minimum attention should be given to climate resilient building practices in further reconstruction process. The material and construction technology used for the optimization in post-disaster reconstructed building like (stone infill wall, cavity wall of 4”/ 2” brick on either sides and cavity wall of brick and hollow concrete block) can be incorporated in further guidelines and energy policies. Insulation can be added in roofing to further increase thermal time lag and achieve thermal comfort within the building environment.

Further studies can be done in energy performance of residential building with optimization in floor construction. The study is only focused on thermal comfort hence visual comfort of traditional and post-disaster reconstructed building can be carried out.

11 Chapter 11: Conclusion Validity



HAND CALCULATION

INPUTS

Occupancy = 2 Nos.
Occupant Load = 200 Watts
Floor Area = 29 m^2 (and Roof
Height = 2.4 m
External Wall Area = 10.68 m^2 Wall 1
External Wall Area = 8.5 m^3 Wall 2
External Wall Area = 3.6 m^4 Wall 3
U-value of wall = 1.98 $W/m^2 K$
Area of Window = 1.67 m^2 Window 1
Area of Window = 1.67 m^2 Window 2
Area of Window = 1.67 m^2 Window 3
Solar Heat Gain Coefficient (SHGC) = 0.95
Solar Heat Gain (G) = 200 W/m^2
U-value of Glazing = 5.1 $W/m^2 K$
U-value of Roof = 1.67 $W/m^2 K$
Plug Load Density = 6 W/m^2
Infiltration rate = 1 ACH
Outdoor Conditions - Outside Temperature (°C) = 26 °C
Outdoor - Relative Humidity (RH%) = 90 %
Target Indoor Conditions - Indoor Temperature (°C) = 24 °C
Indoor - Relative Humidity (RH%) = 60 %
Density of air (ρ) = 1.2 kg/m^3
Heat Capacity of air (C) = 1000 J/kg K
Latent Heat of Vaporisation (Δvap.H) = 2450 J/g

FROM ASHRAE STANDARDS 62.1 and 90.1

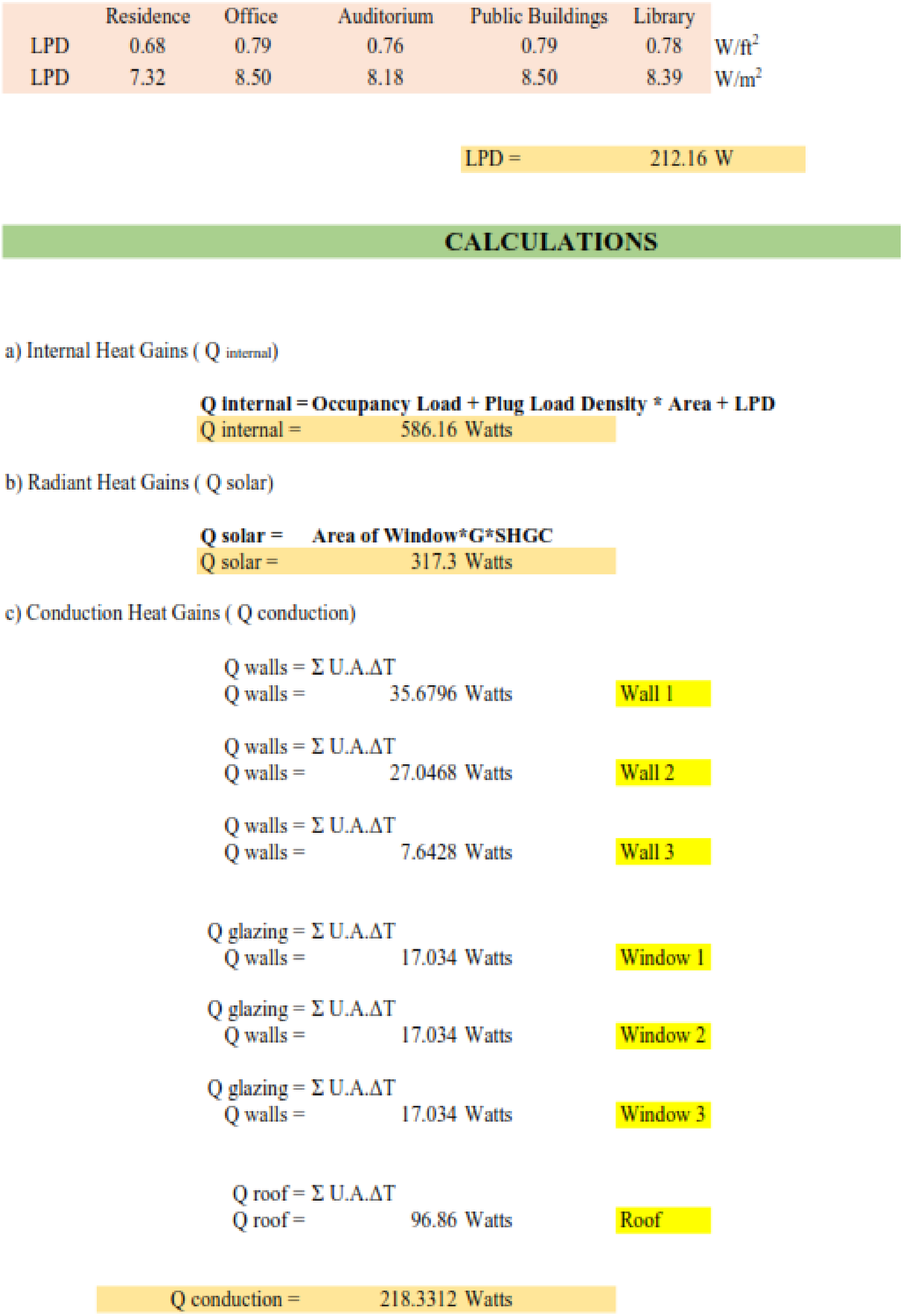
1) Ventilation Rate = Rp x No. of person + Ra x Area

where Rp = L/s/person and Ra =

	Residence	Office	Auditorium	Public Buildings	Library
Rp	2.5	2.5	2.5	2.5	2.5
Ra	0.3	0.3	0.3	0.3	0.6

Vr = 13.7 l/s
Vr = 0.0137 m^3/s

2) Lighting Power Density (LPD) = LPD x Area



	Residence	Office	Auditorium	Public Buildings	Library	
LPD	0.68	0.79	0.76	0.79	0.78	W/ft^2
LPD	7.32	8.50	8.18	8.50	8.39	W/m^2

LPD = 212.16 W

CALCULATIONS

a) Internal Heat Gains (Q $_{\text{internal}}$)

Q internal = Occupancy Load + Plug Load Density * Area + LPD

Q internal = 586.16 Watts

b) Radiant Heat Gains (Q solar)

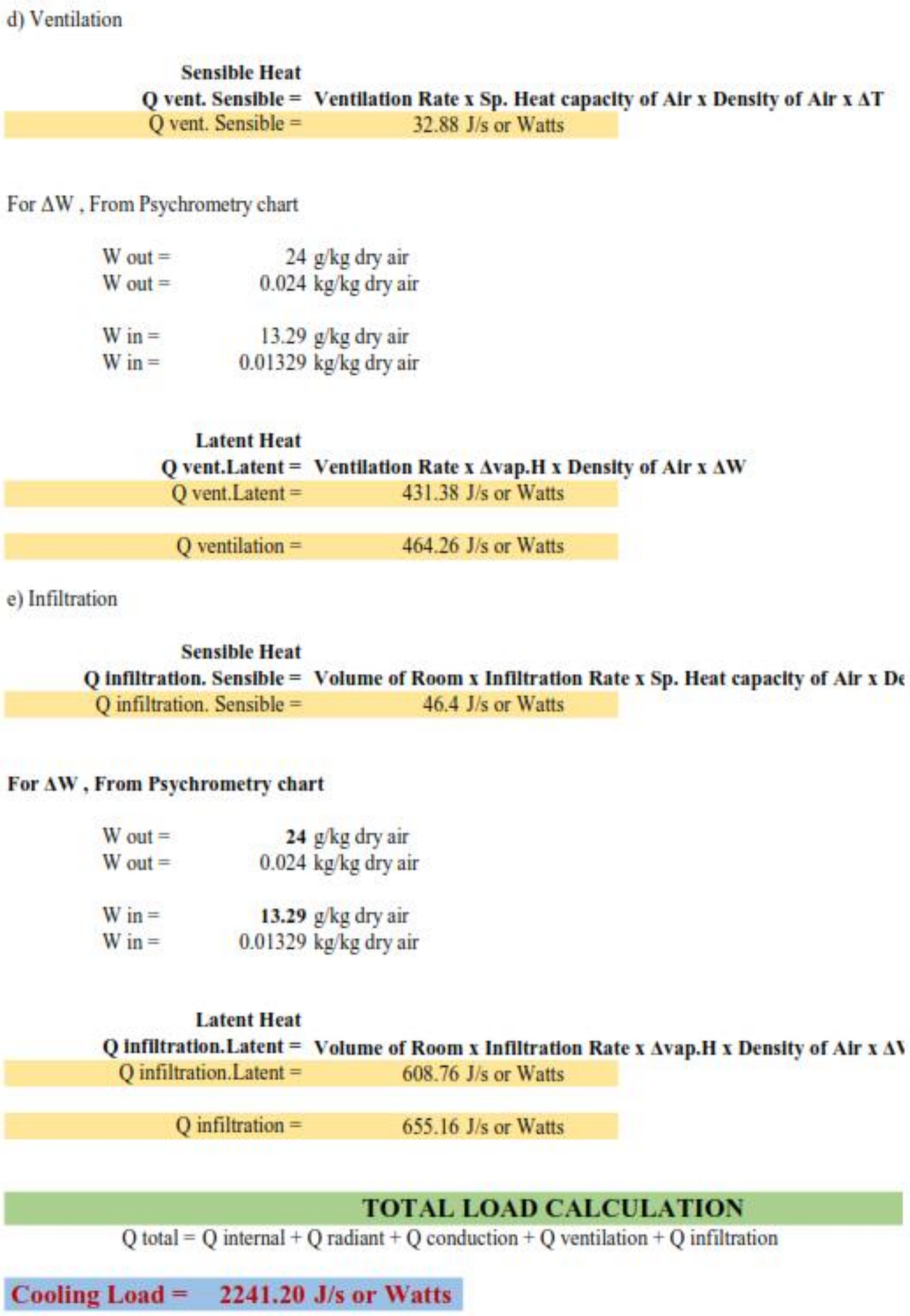
Q solar = Area of Window*G*SHGC

Q solar = 317.3 Watts

c) Conduction Heat Gains (Q conduction)

Q walls = Σ U.A.ΔT Q walls = 35.6796 Watts		Wall 1
Q walls = Σ U.A.ΔT Q walls = 27.0468 Watts		Wall 2
Q walls = Σ U.A.ΔT Q walls = 7.6428 Watts		Wall 3
Q glazing = Σ U.A.ΔT Q walls = 17.034 Watts		Window 1
Q glazing = Σ U.A.ΔT Q walls = 17.034 Watts		Window 2
Q glazing = Σ U.A.ΔT Q walls = 17.034 Watts		Window 3
Q roof = Σ U.A.ΔT Q roof = 96.86 Watts		Roof

Q conduction = 218.3312 Watts



d) Ventilation

Sensible Heat

Q vent. Sensible = Ventilation Rate x Sp. Heat capacity of Air x Density of Air x ΔT

Q vent. Sensible = 32.88 J/s or Watts

For ΔW , From Psychrometry chart

W out = 24 g/kg dry air
W out = 0.024 kg/kg dry air

W in = 13.29 g/kg dry air
W in = 0.01329 kg/kg dry air

Latent Heat

Q vent.Latent = Ventilation Rate x Δvap.H x Density of Air x ΔW

Q vent.Latent = 431.38 J/s or Watts

Q ventilation = 464.26 J/s or Watts

e) Infiltration

Sensible Heat

Q infiltration. Sensible = Volume of Room x Infiltration Rate x Sp. Heat capacity of Air x De

Q infiltration. Sensible = 46.4 J/s or Watts

For ΔW , From Psychrometry chart

W out = **24** g/kg dry air
W out = 0.024 kg/kg dry air

W in = **13.29** g/kg dry air
W in = 0.01329 kg/kg dry air

Latent Heat

Q infiltration.Latent = Volume of Room x Infiltration Rate x Δvap.H x Density of Air x Δ

Q infiltration.Latent = 608.76 J/s or Watts

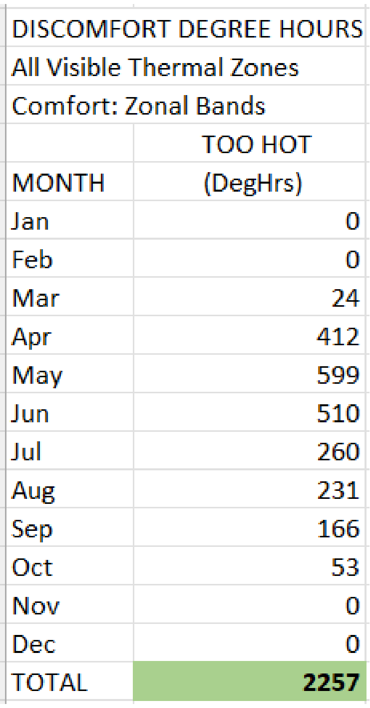
Q infiltration = 655.16 J/s or Watts

TOTAL LOAD CALCULATION

Q total = Q internal + Q radiant + Q conduction + Q ventilation + Q infiltration

Cooling Load = 2241.20 J/s or Watts

Calculation by Ecotect energy Simulation:



DISCOMFORT DEGREE HOURS	
All Visible Thermal Zones	
Comfort: Zonal Bands	
	TOO HOT
MONTH	(DegHrs)
Jan	0
Feb	0
Mar	24
Apr	412
May	599
Jun	510
Jul	260
Aug	231
Sep	166
Oct	53
Nov	0
Dec	0
TOTAL	**2257**

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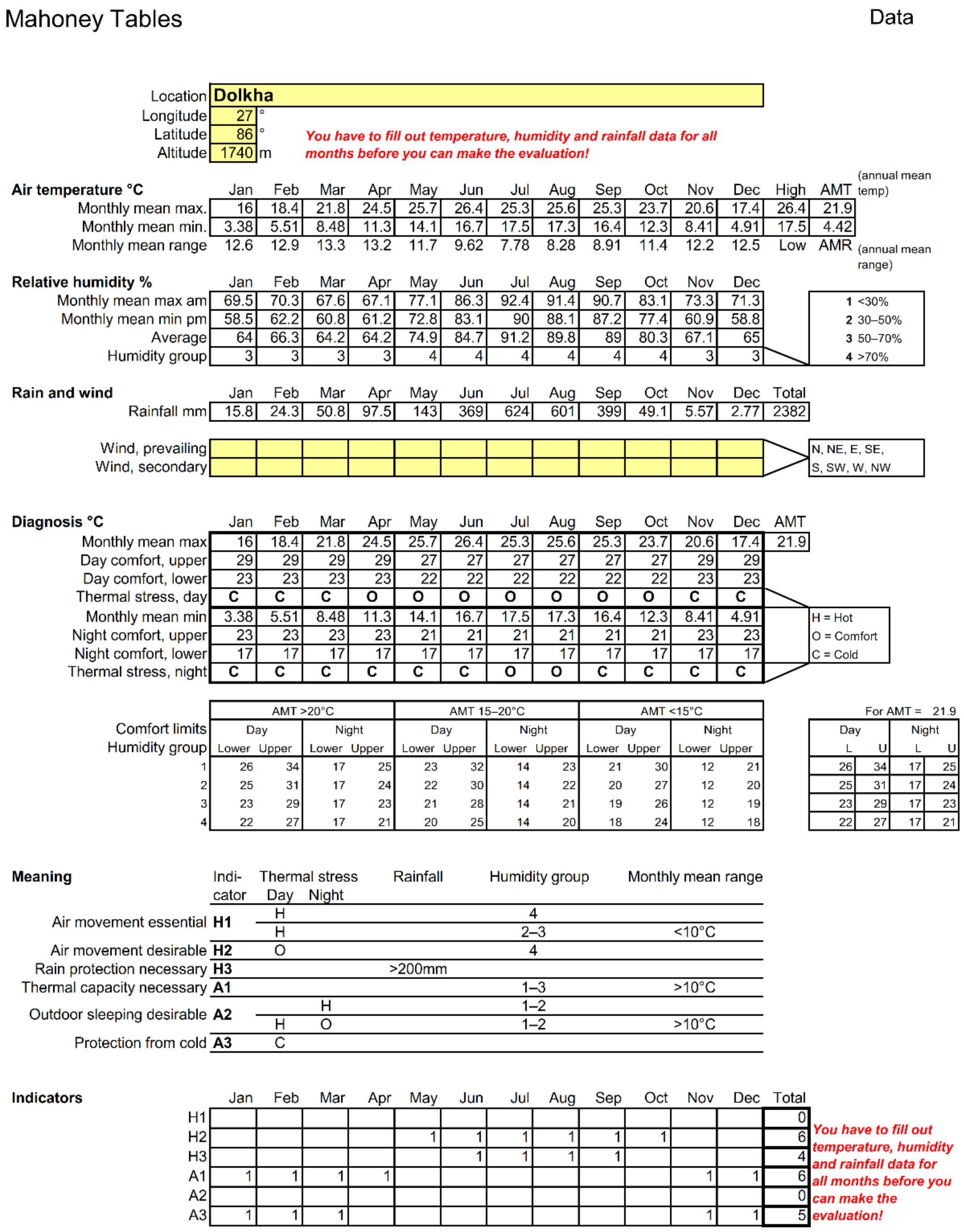
ANNEX-I: Result from Mahoney's Table



Mahoney Tables

Data

Location	Dolkha	
Longitude	27	°
Latitude	86	°
Altitude	1740	m

You have to fill out temperature, humidity and rainfall data for all months before you can make the evaluation!

Air temperature °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	High	AMT	(annual mean temp)
Monthly mean max.	16	18.4	21.8	24.5	25.7	26.4	25.3	25.6	25.3	23.7	20.6	17.4	26.4	21.9	
Monthly mean min.	3.38	5.51	8.48	11.3	14.1	16.7	17.5	17.3	16.4	12.3	8.41	4.91	17.5	4.42	
Monthly mean range	12.6	12.9	13.3	13.2	11.7	9.62	7.78	8.28	8.91	11.4	12.2	12.5	Low	AMR	(annual mean range)

Relative humidity %	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Monthly mean max am	69.5	70.3	67.6	67.1	77.1	86.3	92.4	91.4	90.7	83.1	73.3	71.3	**1** <30%
Monthly mean min pm	58.5	62.2	60.8	61.2	72.8	83.1	90	88.1	87.2	77.4	60.9	58.8	**2** 30–50%
Average	64	66.3	64.2	64.2	74.9	84.7	91.2	89.8	89	80.3	67.1	65	**3** 50–70%
Humidity group	3	3	3	3	4	4	4	4	4	4	3	3	**4** >70%

Rain and wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall mm	15.8	24.3	50.8	97.5	143	369	624	601	399	49.1	5.57	2.77	2382

Wind, prevailing													N, NE, E, SE,
Wind, secondary													S, SW, W, NW

Diagnosis °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AMT
Monthly mean max	16	18.4	21.8	24.5	25.7	26.4	25.3	25.6	25.3	23.7	20.6	17.4	21.9
Day comfort, upper	29	29	29	29	27	27	27	27	27	27	29	29	
Day comfort, lower	23	23	23	23	22	22	22	22	22	22	23	23	
Thermal stress, day	**C**	**C**	**C**	**O**	**O**	**O**	**O**	**O**	**O**	**O**	**C**	**C**	
Monthly mean min	3.38	5.51	8.48	11.3	14.1	16.7	17.5	17.3	16.4	12.3	8.41	4.91	H = Hot
Night comfort, upper	23	23	23	23	21	21	21	21	21	21	23	23	O = Comfort
Night comfort, lower	17	17	17	17	17	17	17	17	17	17	17	17	C = Cold
Thermal stress, night	**C**	**C**	**C**	**C**	**C**	**C**	**O**	**O**	**C**	**C**	**C**	**C**	

	AMT >20°C				AMT 15–20°C				AMT <15°C			
Comfort limits	Day		Night		Day		Night		Day		Night	
Humidity group	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	26	34	17	25	23	32	14	23	21	30	12	21
2	25	31	17	24	22	30	14	22	20	27	12	20
3	23	29	17	23	21	28	14	21	19	26	12	19
4	22	27	17	21	20	25	14	20	18	24	12	18

For AMT = 21.9

Day		Night	
L	U	L	U
26	34	17	25
25	31	17	24
23	29	17	23
22	27	17	21

Meaning	Indi-cator	Thermal stress Day	Thermal stress Night	Rainfall	Humidity group	Monthly mean range
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
H1													0
H2					1	1	1	1	1	1			6
H3						1	1	1	1				4
A1	1	1	1	1							1	1	6
A2													0
A3	1	1	1								1	1	5

You have to fill out temperature, humidity and rainfall data for all months before you can make the evaluation!

Mahoney Tables

Results

Dolkha
Latitude 86°N

Indicator totals from data sheet					
H1	H2	H3	A1	A2	A3
0	6	4	6	0	5

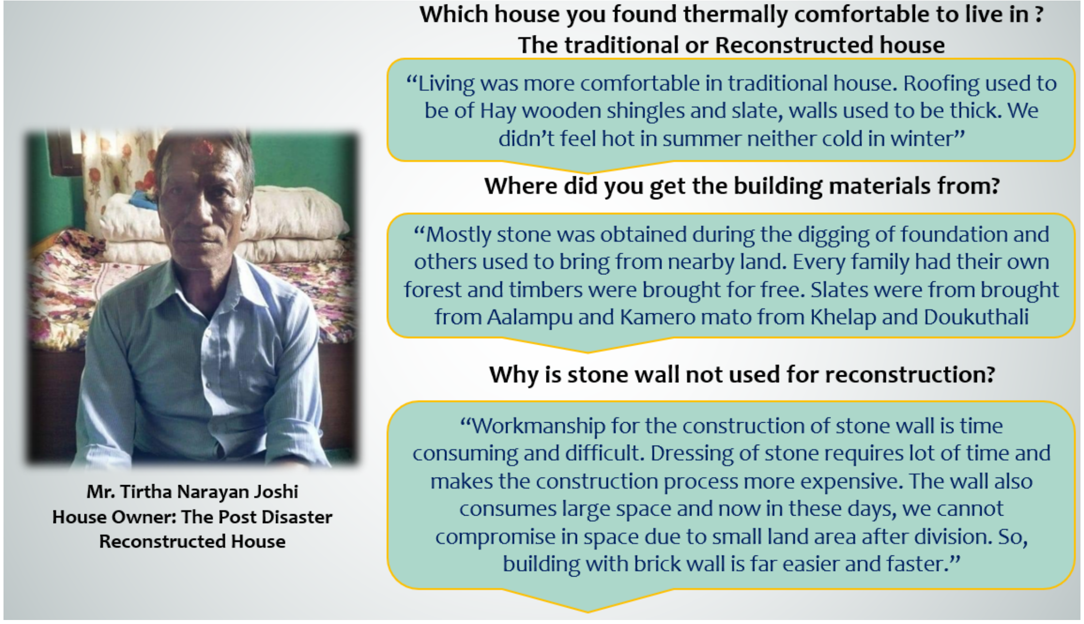
						Layout	
			0–10			X	Orientation north and south (long axis east–west)
			11–12		5–12		
					0–4		Compact courtyard planning
						Spacing	
11–12							Open spacing for breeze penetration
2–10							As above, but protection from hot and cold wind
0–1						X	Compact layout of estates
						Air movement	
3–12							Rooms single banked, permanent provision for air movement
1–2			0–5				
			6–12			X	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, insulatted 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
						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							In north and south walls at body height on windward side
1–2			0–5				
			6–12			X	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

ANNEX-II: Interview with House Owners

Do you feel thermally comfortable to live in the house ?

"Everyone says its too cold or too hot in new buildings. But I Feel comfortable inside the building during summer as well as winter and all over the year. Adding a layer of warm cloth during winter helps in maintaining thermal comfort but we need heater or fire to keep warm in buildings of Brick and cement. During summer too, it feels cool and comfortable entering the building from hot outside environment"

Miss Gita Shrestha
House Owner: The Traditional House



Which house you found thermally comfortable to live in ? The traditional or Reconstructed house

"Living was more comfortable in traditional house. Roofing used to be of Hay wooden shingles and slate, walls used to be thick. We didn't feel hot in summer neither cold in winter"

Where did you get the building materials from?

"Mostly stone was obtained during the digging of foundation and others used to bring from nearby land. Every family had their own forest and timbers were brought for free. Slates were from brought from Aalampu and Kamero mato from Khelap and Doukuthali

Why is stone wall not used for reconstruction?

"Workmanship for the construction of stone wall is time consuming and difficult. Dressing of stone requires lot of time and makes the construction process more expensive. The wall also consumes large space and now in these days, we cannot compromise in space due to small land area after division. So, building with brick wall is far easier and faster."

Mr. Tirtha Narayan Joshi
House Owner: The Post Disaster Reconstructed House

ANNEX-III: Article IOEGC

IOE Graduate Conference
[Placeholder for
Publication
Information]

Energy Consumption Pattern of Post Disaster Reconstructed Residential Building: A case of Dolakha Town

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Abstract

Buildings are the greatest energy consumer of the world making up more than one-third of all final energy consumption and 37 percent of global final energy use [1]. In Nepal, residential sector accounts for 80.36 percent of total energy use [2]. The energy consumption in the building sector has increased because of our increasingly modern lifestyle and blindly imitating modern architectural style. After Gorkha earthquake 2015, post disaster recovery framework offered various building typologies for the building reconstruction that focused more on seismic standards. The reconstructed buildings lack thermal comfort inside the building in both summer and winter season. The purpose of the research was to examine overall energy consumption pattern of post disaster reconstructed residential building of Dolakha town which is one of the worst affected areas. The study method used was survey research that included random sampling of fifteen post-disaster reconstructed residential building from several toles of Dolakha town. Most of the young people of Dolakha have emigrated which has limited the use of energy in the building. The research found that the energy consumption pattern is characteristics of cooking, heating, and lighting. Number of people residing in the reconstructed building are two-four and are of age group (30-59). As a result, the study comes to the conclusion that hydroelectricity is the major source for lighting and for cooking and water heating purpose LPG gas, accounts for the majority of energy use. Only a small percentage of homes use solar water heaters. For room heating purpose coal and firewood are extensively used which has several environmental and public health risks. This shows that the town is completely dependent on non-renewable energy sources like LPG gas. The households do not focus much on the utilization of renewable resources. Solar energy can be utilized for water heaters and space heating.

Keywords

Energy consumption pattern, post-disaster reconstruction, residential building, Dolakha town

1. Introduction

Energy pattern can be defined as how it is used overall [2]. Energy consumption pattern includes consumption of commercial source like crude oil, petroleum products, etc. and non-commercial source of energy like firewood, cow dung, agricultural residues, etc. World's largest energy consumer are buildings that make up more than one third of ultimate energy consumption and 37 percent of all final energy used globally [1]. In Nepal, residential sector alone consumes 80.35 percent of the total energy consumption [3].

Huge amount of energy is used for lighting, cooking,

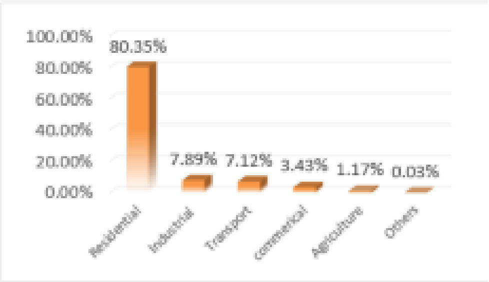

Figure 1: Energy consumption by residential and other economic sector Year (2011/12) Source: [3]

heating/cooling, and ventilation. The increasing modern lifestyle and imitation from modern architectural style in the building construction has also increased the energy consumption in building sector. Enhancing building's energy efficiency is a sustainable strategy to lower energy usage and its ensuing environmental impacts.

Gorkha earthquake 2015 and its subsequent aftershocks led to massive destruction of lives and infrastructures mostly in hilly regions of Nepal. Post disaster recovery framework proposed different building typologies for the reconstruction of hilly settlements that focused more on seismic performance and neglected the local climate and context. Almost all the buildings constructed after earthquake has the problem of being overheated during summer and severe cold during winter months. The increase in energy consumption is the result of building's inadequate thermal construction. Sustainability is a major dimension in post-disaster housing reconstruction, largely justified by energy consumption and management, which is analyzed through an understanding of the energy performance of the building.

The research aims to study and analyze overall energy consumption pattern of post disaster reconstructed residential building of Dolakha town.

2. Policies integrating energy efficiency and post-disaster reconstruction

A government's (or any organization's) approach to addressing challenges linked to the growth and utilization of energy, including its production, distribution and, consumption is known as energy policy [4]. Initiation has been carried out by government of Nepal to develop National Energy Strategy (NES) to address the obstacles and for the establishment and make sustainable use of energy resources [5]. The government of Nepal has built legislative and institutional mechanisms to carry out the long-term ambitions of Paris Agreement. Although there are no specific policies regarding building energy conservation by Nepal Reconstruction Authority (NRA), it has encouraged earthquake beneficiaries for the use of renewable solar energy in private housing reconstruction by granting incentives in final inspection. One of the key elements of Nepal's Long-term Strategy for Net-Zero Emissions by 2045 is to improve energy efficiency and maximize benefits by utilizing clean energy efficiently in residential industrial and transportation sector [6]. It has clear link to the achievement of Sustainable Development Goals (SDGs) by 2030 and beyond. Regardless of different policies related to energy sector, these policies have not covered the problem of residential sector.

Besides destruction and damage, the initial period of natural disaster also provides a valuable opportunity to rebuild and recover enhancing resiliency and saving energy. Numerous energy efficiency and resilience measures can be combined together in the built environment which further benefit each household through energy savings and minimize operating cost that reduce stress on energy infrastructure. Building energy efficiency in a new structure save more energy as compared to old buildings.

Lack of a clear and encouraging reconstruction policy; poor governance at the municipal and ward level officials; budgetary constraints to rebuild their homes; and the lack of a scheme and structure to facilitate local community-driven reconstruction activities are the major hurdles that inhibit energy efficiency integration in the post-disaster reconstruction.

3. Methodology

The study was carried out in mixed method research approach that included quantitative and qualitative research. The qualitative method was based on interpretation from literature review through different related articles, reports, documents. Similarly, quantitative research was done through questionnaire survey, interviews with the local people and study of case area.

The first step towards research started with literature review with the aim of developing research objective and generating ideas related to the research topic. Different policies related to energy efficiency and post-disaster reconstruction were studied and analyzed thoroughly. Similarly, Nepal's strategy for energy policies and programs were also studied that provided the pathway to conduct research. The old Newar settlement of Dolakha town was selected as case area. Climatic data from Department of Hydrology and Meteorology was used for detail study of climatic data of Dolakha. Structured and semi-structured questionnaire was prepared in Kobo Toolbox and tested that includes (demographic, building, and energy consumption pattern) details.

Sample survey of ten houses were done including all the toles of core area of Dolakha town using the random sampling distribution method. Moreover, the selected household intends to incorporate all the different building typology used in post disaster reconstruction Buildings constructed after earthquake 2015 was selected to conduct survey. Data were collected from questionnaire and the results are analyzed. Findings and conclusions are drawn from the analyzed data. The methodological approach of the study is illustrated in the figure below.

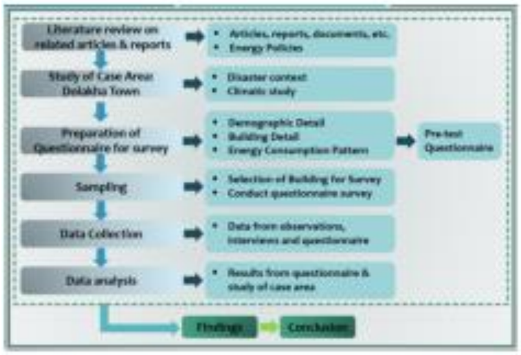

Figure 2: Methodological Approach

4. Limitations

The study is limited to the post-disaster reconstructed residential buildings of traditional core area of Dolakha town as the byelaws for the area is different from that of Bhimeshwor municipality. Since, survey was carried out using random sampling distribution method, the data interpretation will not contain the entire population but will instead show the energy consumption pattern of the settlement.

5. Research Setting

The case area Dolakha is a part of Bagmati province with Charikot as headquarter. It covers an area of 2191 sq. km and had a population of 186,557 according to Nepal census 2011. Its geographical location is latitude 27°4737.68 North, longitude 86°1103.48 East and at an altitude of 1700m. Dolakha lies in temperate climatic region of Nepal.

The research area Dolakha town is the village of Dolakha district located about 4.5Km North- East of Charikot in Bhimeshwor Municipality ward 2. It is inhabited by Newar community. Dolakha being an oldest town has great historic value. It covers an area of 20 hectares i.e., 0.2 Km2. According to 1988 census data, population of Dolakha town was 5,645 and according to census data of 2011, population was 5,531 [8]. It is assumed that out of 297 families of the town, 215 families have emigrated to Kathmandu valley and other districts and foreign countries as well. As per the household survey by Bhimeshwor municipality in 2012, the total number of houses were 1,124 in Dolakha town and 338 households in core area of Dolakha town. [8]

Figure 3: Map of Nepal showing Dolakha source: [7]

6. Disaster context and Post disaster Reconstruction

After Gorkha Earthquake 2015, household survey was conducted by Bhimeshwor municipality, technically helped by National Society for Earthquake Technology (NSET) and Building Code Implementation Program in Municipalities (BCIPN). The total number of households in core area of Dolakha town was found to be 338.

Figure 4: Mapping of Dolakha town in accordance with household destroyed by earthquake 2015 Source: [8]

From the survey, it was found that there were 15 households that are least affected, houses that are affected and needs repair are of thirty-three numbers, fifty-seven houses can be used after retrofitting, 188 houses should be demolished for reconstruction and number of demolished houses were forty-five. The survey shows that most of the houses needed demolishment. [8]

7. Data Sets and Analysis

The results of the household survey conducted in Dolakha town are as follows:

7.1 Demographic Details

Only 13 percent of the respondents were of age group (18-29) years and 27 percent of (60-79) years while 60 percent were of (30-59) age group. From the survey data, it is observed that 80 percent of the families were joint before earthquake with 20 percent nuclear families. After the earthquake, there are now 27 percent of joint family and 73 percent of nuclear family.

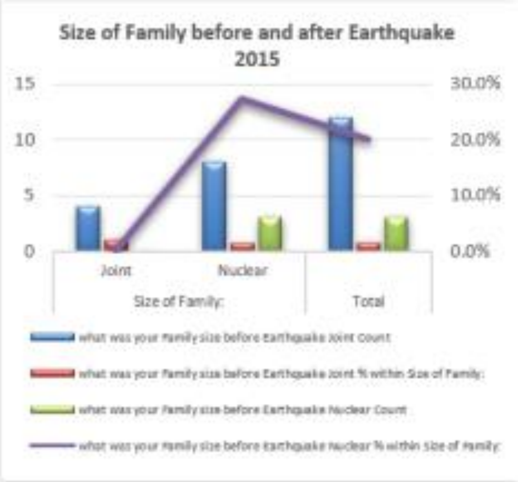

Figure 5: Size of Family before and after Earthquake

32.3 percent of the respondents are indulged in agriculture and service. 22.6 percent of the respondents have business as their occupation compared to 12.9 percent who have livestock farming.

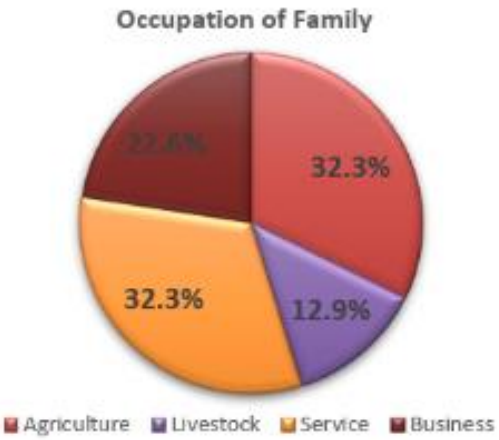

Figure 6: Occupation of Households

7.2 Building Details

74 percent of the reconstructed buildings are of RCC frame structure with brick wall. Buildings with load bearing structure of stone wall with mud mortar is of 13 percent and the same percentage goes to load bearing structure of brick wall in cement mortar.

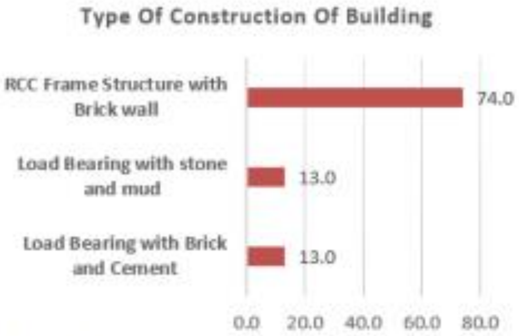

Figure 7: Type of construction of Reconstructed Building

As per the survey result, it is seen that 40 percent of the surveyed houses are of one storey and attic floor. 34 percent of them are of two storey and attic floor whereas 13 percent are of one storey with attic floor and the remaining 13 percent of three storey with attic floor respectively.

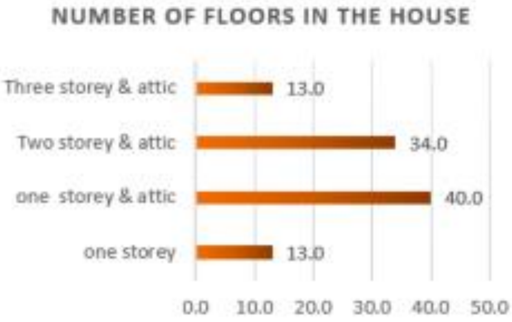

Figure 8: Number of floors of Post disaster reconstructed building

7.3 Energy consumption Pattern

7.3.1 Energy Use for Lighting

It is found that hydroelectricity, supplied by Nepal Electricity Authority is the main source of lighting for carrying out daily activities in all the household. Moreover, it is mostly used for lighting rather than using other appliances. Tube lights of (20-30 watt) and LED lights (3 watt to 15watt) were installed in each room of every household. For outdoor lighting fixture, LED and CFL lights were used.

7.3.2 Energy used for Cooking

All the houses use LPG gas for cooking purpose with every household keeping one extra cylinder as stock. 72.5 percent of the houses use traditional stoves of coal and firewood for emergency purpose and secondary fuel for cooking. 25 percent of the households were found to be using electric rice cooker for 2-3 hours daily.

7.3.3 Applications Used

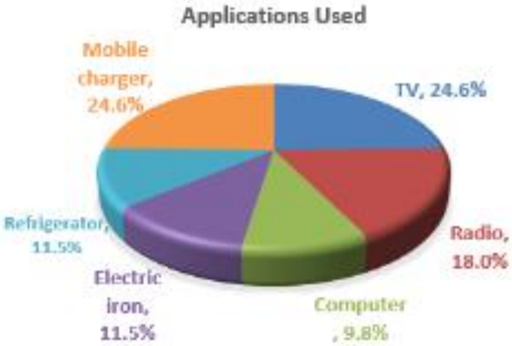

Figure 9: Applications Used in Surveyed Household

All the surveyed households have television and mobile charger that operate for 4-6 hours and 3 hours a day respectively. 18 percent households use radio. 11.5 percent of the surveyed houses have refrigerator and electric iron each. Only 9.8 percent of the respondents have computer/ laptop.

7.3.4 Energy Used for room heating purpose

For room heating purpose, 44 percent of the respondents said they heat their room by burning coal to achieve thermal comfort. Only 4 percent use LPG heater, 17 percent use electric heater and 35 percent use firewood.

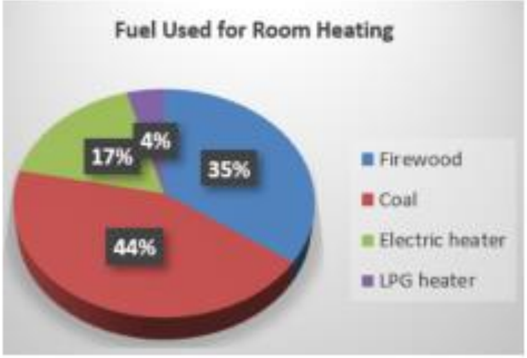

Figure 10: Fuel used for Room Heating

7.3.5 Energy Used for Water heating purpose

According to the surveyed result, 46 percent of the household use LPG gas for water heating while 29 percent use traditional fuel like firewood. 17 percent use LPG gas geyser and only 8 percent use solar water heater.

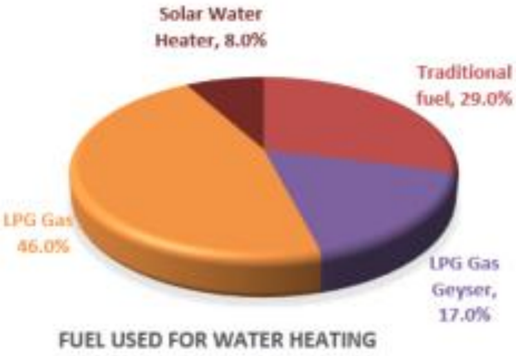

Figure 11: Fuel Used for Water Heating Purpose

7.3.6 Electricity bill per month

40.10 percent of the households have monthly electricity bill of Rs. (301-600) while 33.30 percent pay minimum charge of monthly electricity bill i.e., Rs 30.

Figure 12: Monthly Electricity Bill

8. Findings and Discussion

The investigation of the energy consumption pattern of post-disaster reconstructed residential buildings of old Newari town of Dolakha has been the main subject of the research. Although different energy policies have encouraged post-disaster building reconstruction to use renewable source of energy like solar power, it is not in use.

It has been discovered from the conducted research that most of the people living in the town are of old age or of age group 30-59. Young people are seen to emigrate to Kathmandu or foreign countries for study or employment opportunities. Number of people living in the house in most of the time are two-four. This has reduced the usage of energy through different sources. The buildings constructed after earthquake are mostly RCC frame structure with brick wall in cement mortar and are one storey excluding attic floor. Almost all the houses have used energy efficient lights like CFL, and LED. Use of incandescent lights were not seen during household survey. LPG gas is the primary source of energy for cooking with electricity being used for electric rice-cookers. Traditional stoves were used for cooking for cattle. Even if the survey's data indicates that people use different fuels like coal, firewood, electric heater, etc., to heat their homes during winter, thermal comfort is nevertheless maintained by wearing multiple layers of clothing. The use of solar water heater is very limited due to the use of slope roof of CGI sheets that can be justified by the chart below.

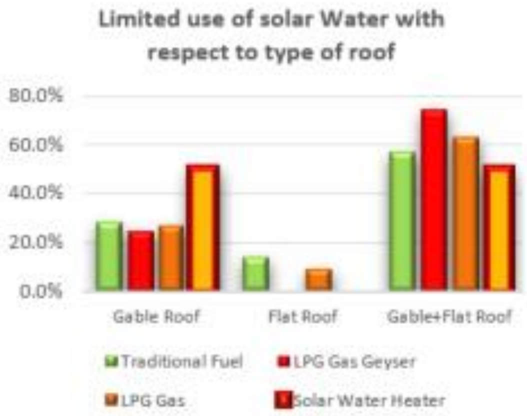

Figure 13: Roof Type and the fuel used for water heating purpose

As shown in the chart below, the electricity bill varies according to the number of stories of the building. Due to the smaller number of people residing in the building, maximum houses have minimum monthly electricity bill i.e., Rs 30.

Figure 14: Comparison of monthly electricity bill with number of floors

9. Conclusion and Recommendation

The overall energy consumption pattern of post-disaster reconstructed residential building was studied through questionnaire survey and analyzed. The research found that the energy consumption pattern is characteristics of cooking, heating, and lighting. As a result, the study concludes that hydroelectricity is the major source for lighting and for cooking and water heating purpose LPG gas, accounts for most of the energy use. Only a small percentage of homes use solar water heaters. For room heating purpose coal and firewood are extensively used which has several environmental and public health risks. This shows that the town is completely dependent on non-renewable energy sources like LPG gas. The households do not focus much on the utilization of renewable resources. Solar energy can be utilized for water heaters and space heating.

Solar water heaters can be used for water heating purpose that reduces the need of LPG gas heat water. Energy efficient building material and construction technology should be focused to reduce heating load in the building.

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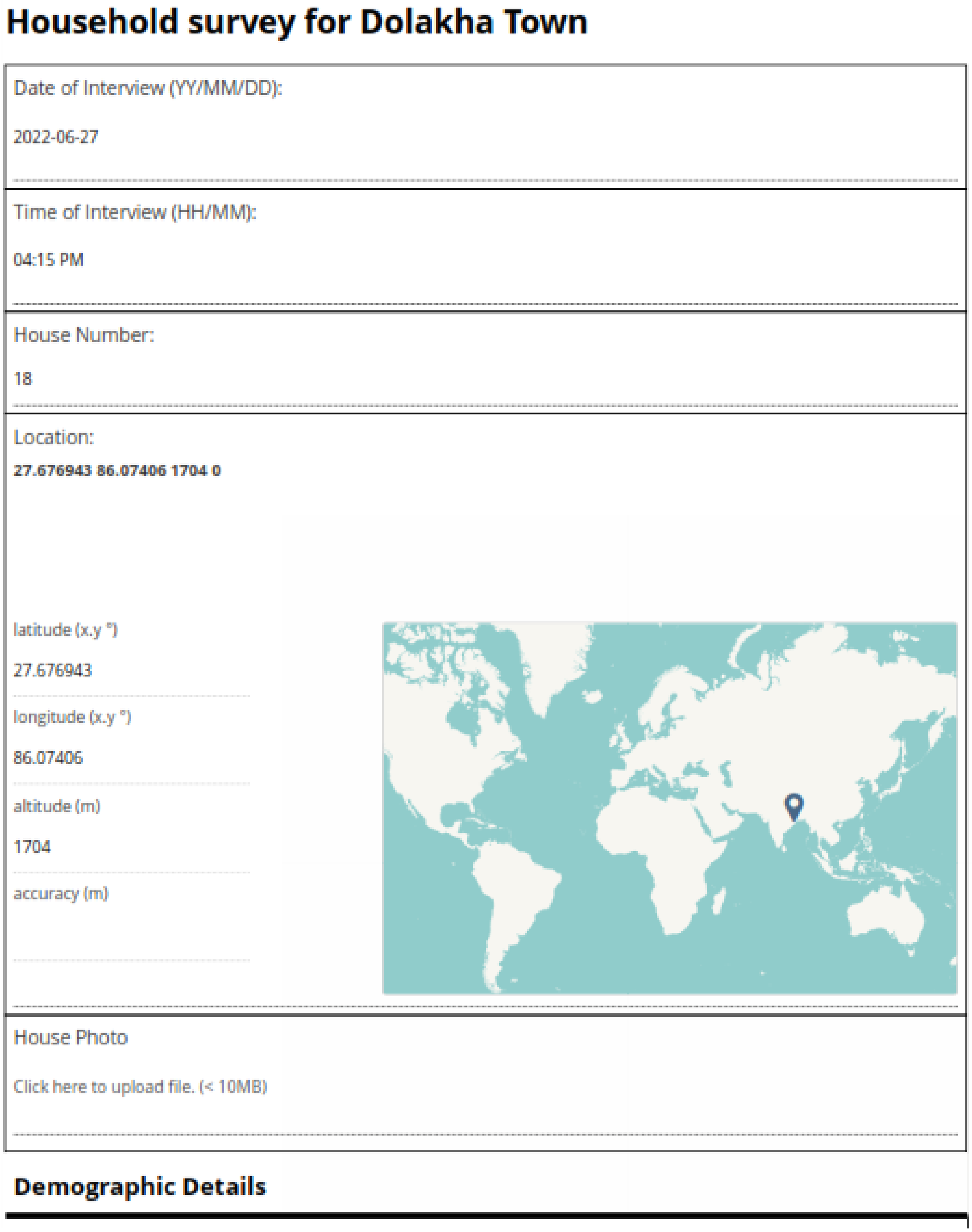
ANNEX-IV: Questionnaire



Household survey for Dolakha Town

Date of Interview (YY/MM/DD):

2022-06-27

Time of Interview (HH/MM):

04:15 PM

House Number:

18

Location:

27.676943 86.07406 1704 0

latitude (x.y °)

27.676943

longitude (x.y °)

86.07406

altitude (m)

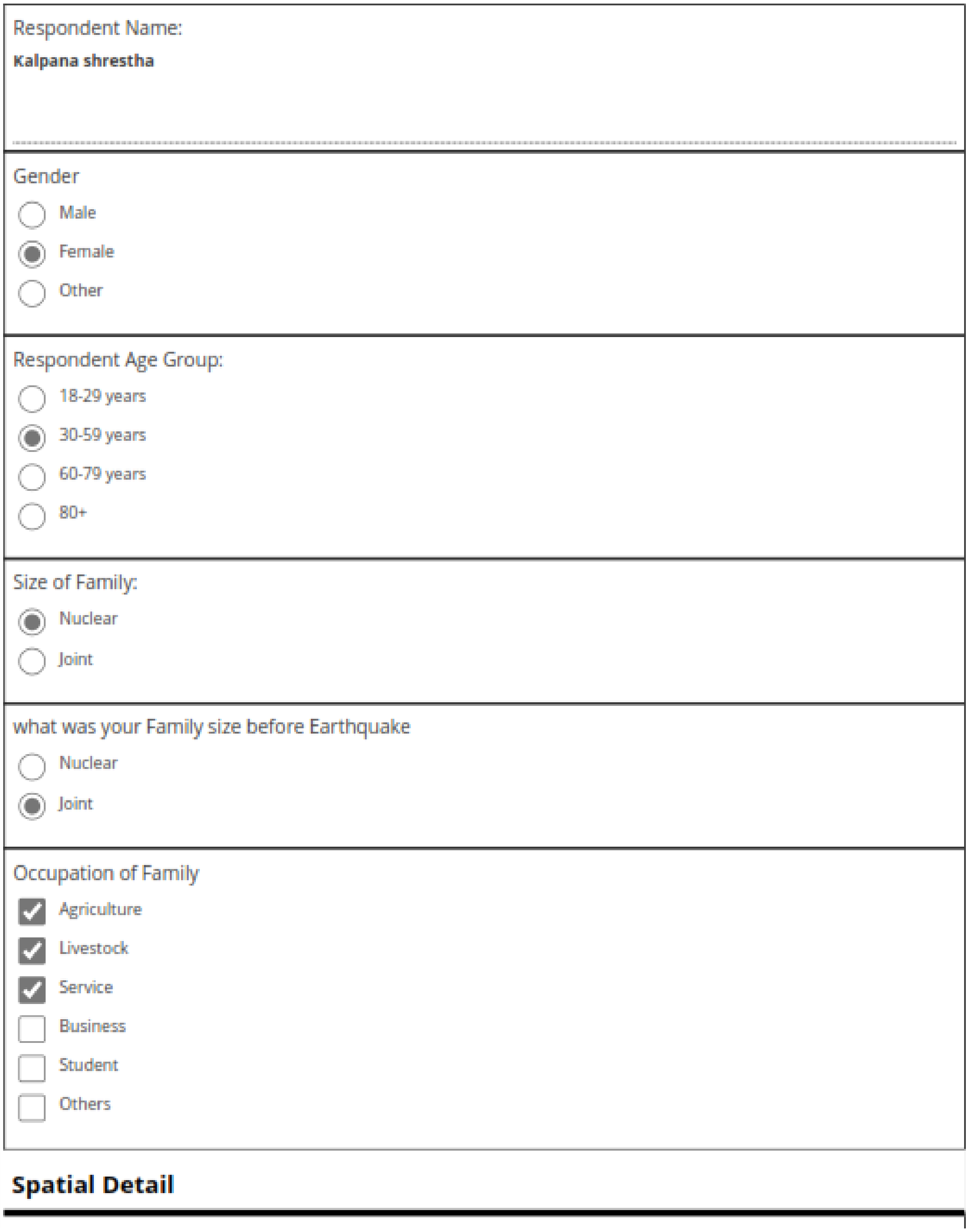
1704

accuracy (m)

House Photo

Click here to upload file. (< 10MB)

Demographic Details



Respondent Name:

Kalpana shrestha

Gender

○ Male

● Female

○ Other

Respondent Age Group:

○ 18-29 years

● 30-59 years

○ 60-79 years

○ 80+

Size of Family:

● Nuclear

○ Joint

what was your Family size before Earthquake

○ Nuclear

● Joint

Occupation of Family

☑ Agriculture

☑ Livestock

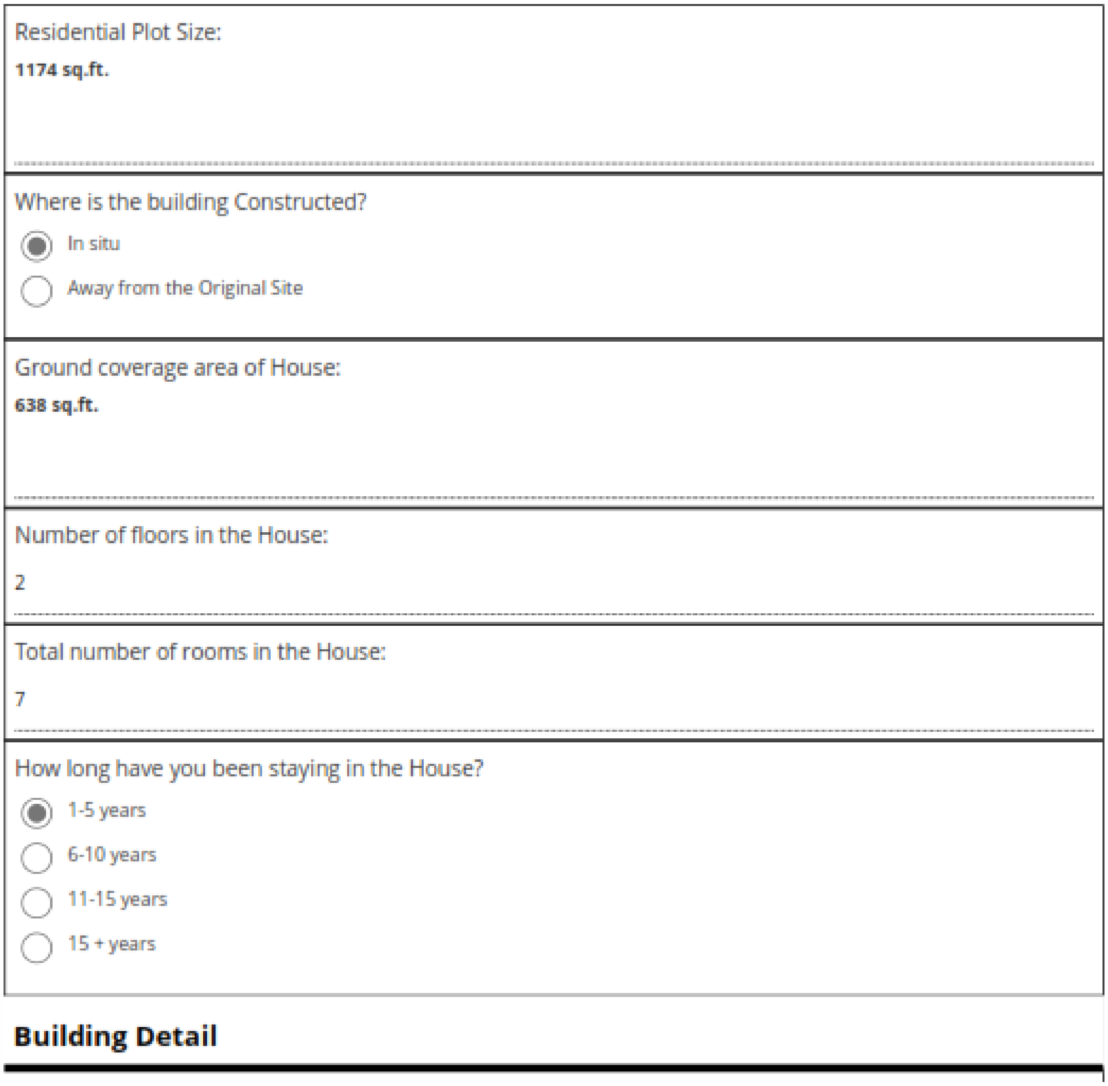
☑ Service

☐ Business

☐ Student

☐ Others

Spatial Detail



Residential Plot Size:

1174 sq.ft.

Where is the building Constructed?

● In situ

○ Away from the Original Site

Ground coverage area of House:

638 sq.ft.

Number of floors in the House:

2

Total number of rooms in the House:

7

How long have you been staying in the House?

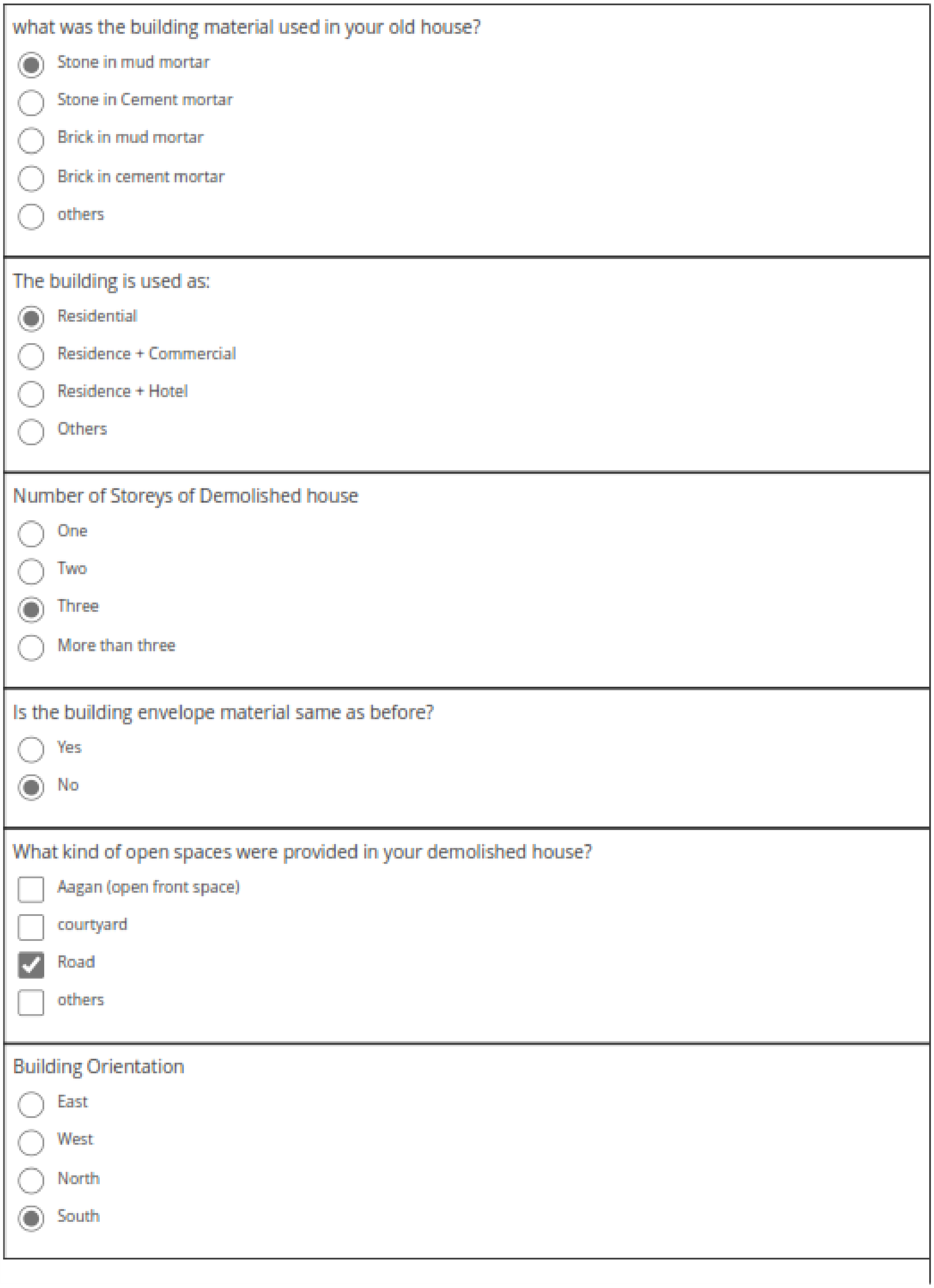
● 1-5 years

○ 6-10 years

○ 11-15 years

○ 15 + years

Building Detail



what was the building material used in your old house?

● Stone in mud mortar
○ Stone in Cement mortar
○ Brick in mud mortar
○ Brick in cement mortar
○ others

The building is used as:

● Residential
○ Residence + Commercial
○ Residence + Hotel
○ Others

Number of Storeys of Demolished house

○ One
○ Two
● Three
○ More than three

Is the building envelope material same as before?

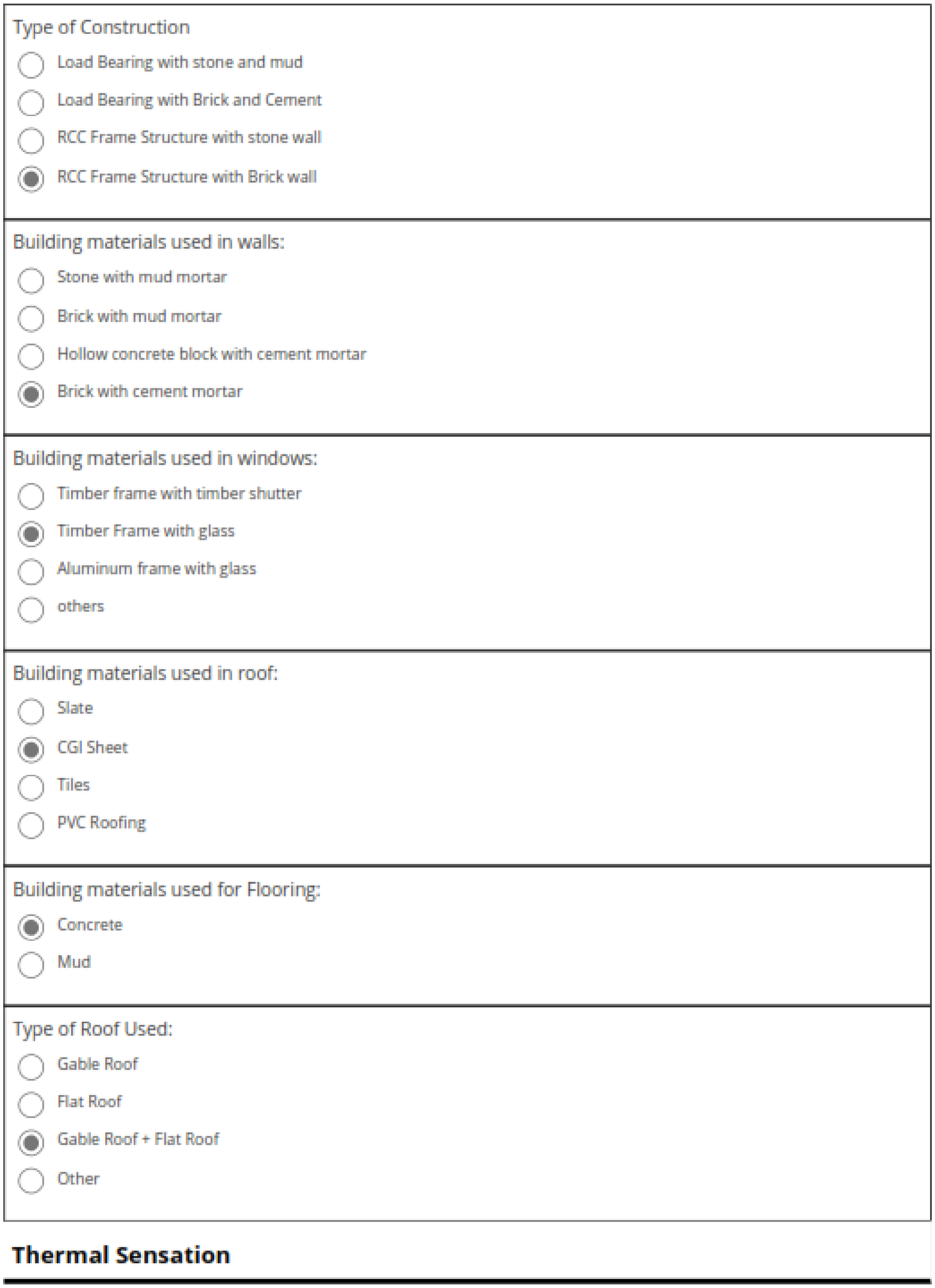
○ Yes
● No

What kind of open spaces were provided in your demolished house?

☐ Aagan (open front space)
☐ courtyard
☑ Road
☐ others

Building Orientation

○ East
○ West
○ North
● South



Type of Construction

○ Load Bearing with stone and mud
○ Load Bearing with Brick and Cement
○ RCC Frame Structure with stone wall
● RCC Frame Structure with Brick wall

Building materials used in walls:

○ Stone with mud mortar
○ Brick with mud mortar
○ Hollow concrete block with cement mortar
● Brick with cement mortar

Building materials used in windows:

○ Timber frame with timber shutter
● Timber Frame with glass
○ Aluminum frame with glass
○ others

Building materials used in roof:

○ Slate
● CGI Sheet
○ Tiles
○ PVC Roofing

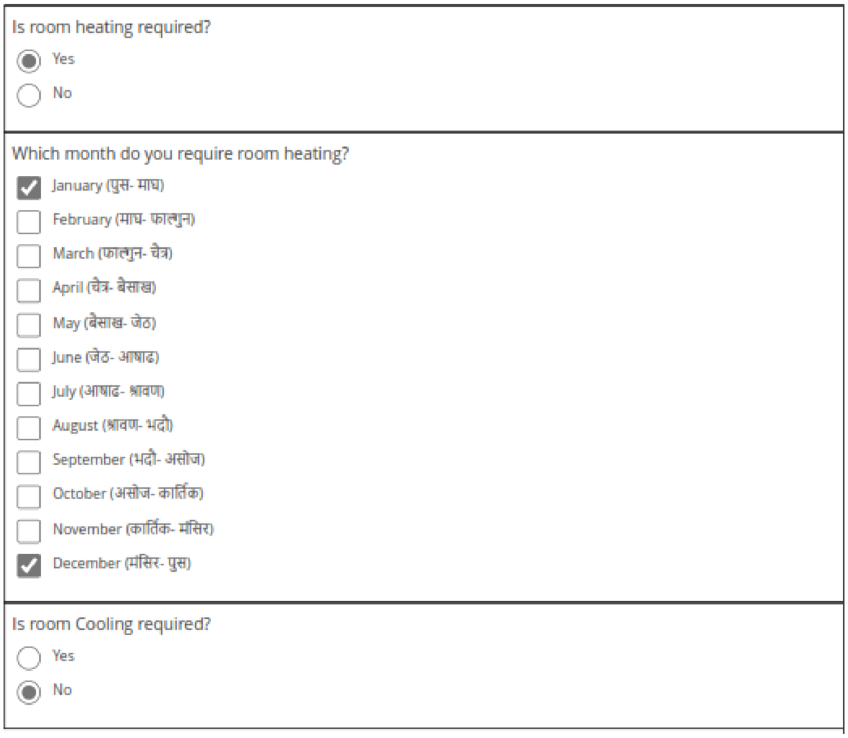
Building materials used for Flooring:

● Concrete
○ Mud

Type of Roof Used:

○ Gable Roof
○ Flat Roof
● Gable Roof + Flat Roof
○ Other

Thermal Sensation



Is room heating required?

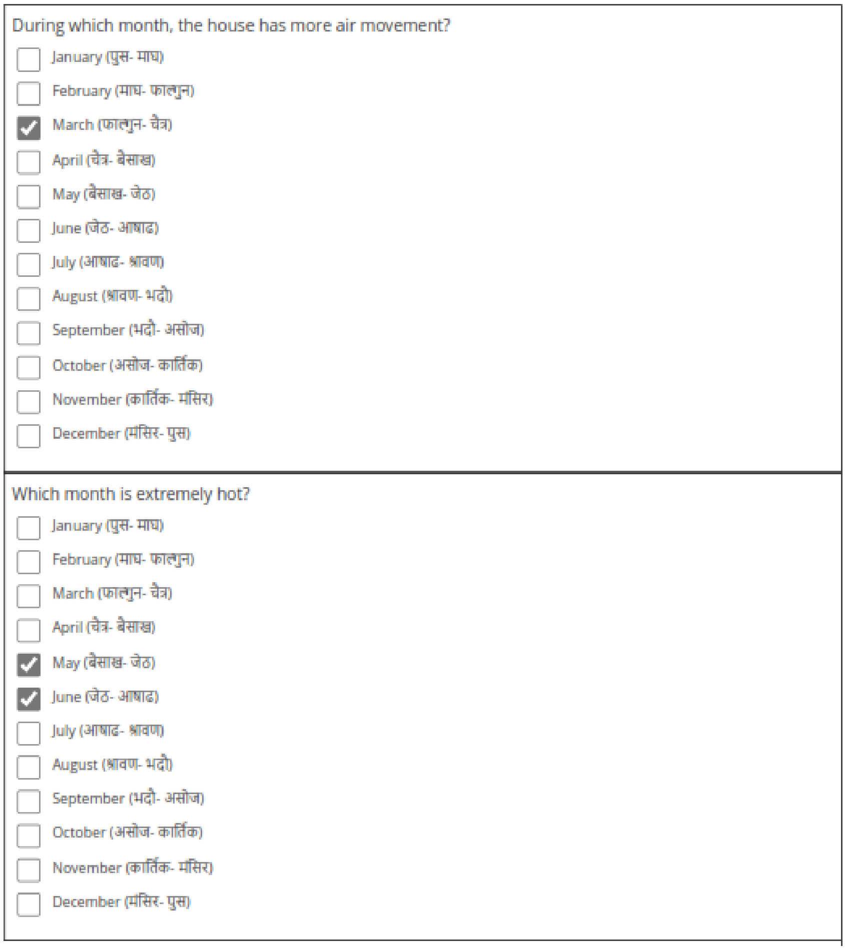
● Yes
○ No

Which month do you require room heating?

☑ January (पुस- माघ)
☐ February (माघ- फाल्गुन)
☐ March (फाल्गुन- चैत्र)
☐ April (चैत्र- बैसाख)
☐ May (बैसाख- जेठ)
☐ June (जेठ- आषाढ)
☐ July (आषाढ- श्रावण)
☐ August (श्रावण- भदौ)
☐ September (भदौ- असोज)
☐ October (असोज- कार्तिक)
☐ November (कार्तिक- मंसिर)
☑ December (मंसिर- पुस)

Is room Cooling required?

○ Yes
● No

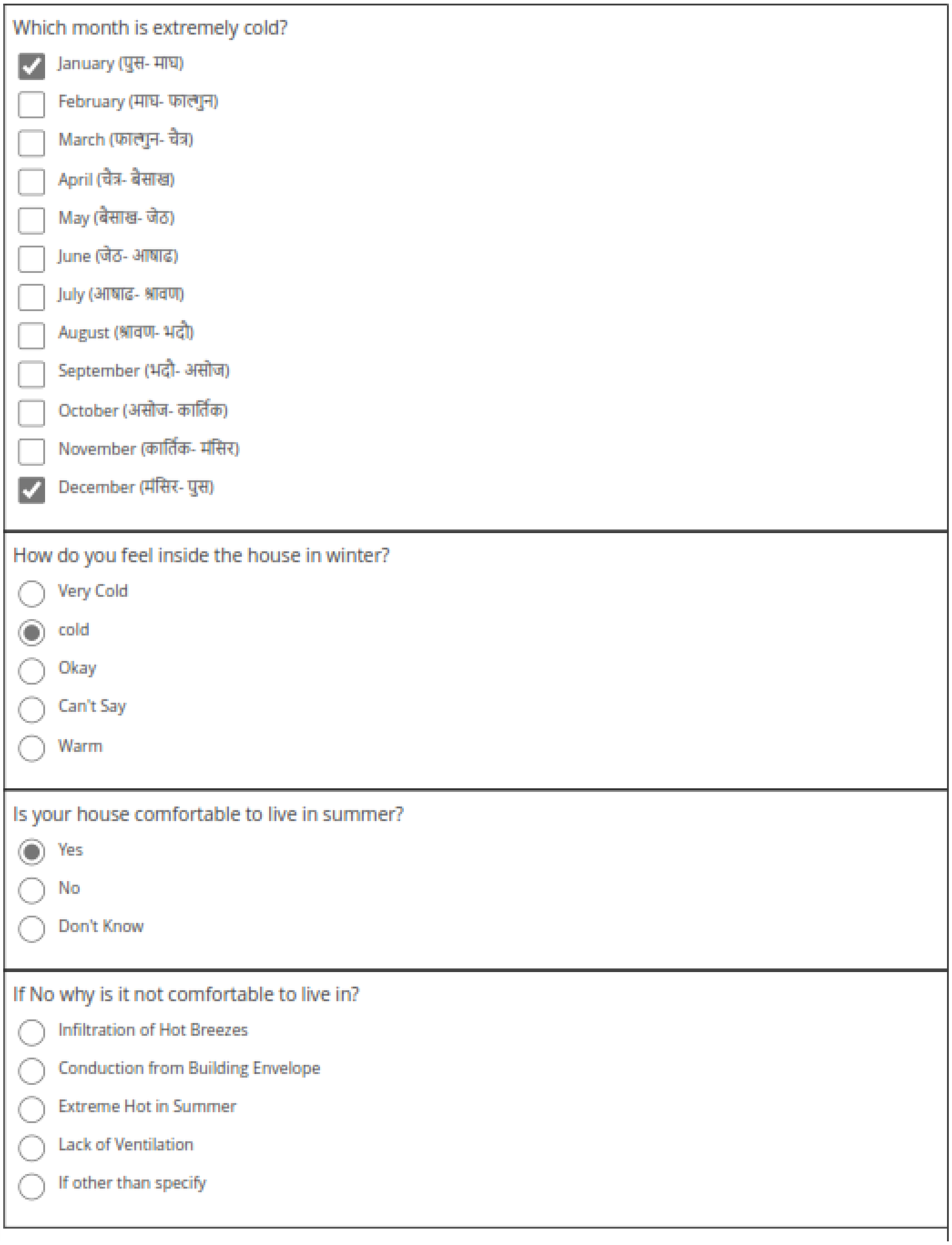


During which month, the house has more air movement?

☐ January (पुस- माघ)
☐ February (माघ- फाल्गुन)
☑ March (फाल्गुन- चैत्र)
☐ April (चैत्र- बैसाख)
☐ May (बैसाख- जेठ)
☐ June (जेठ- आषाढ)
☐ July (आषाढ- श्रावण)
☐ August (श्रावण- भदौ)
☐ September (भदौ- असोज)
☐ October (असोज- कार्तिक)
☐ November (कार्तिक- मंसिर)
☐ December (मंसिर- पुस)

Which month is extremely hot?

☐ January (पुस- माघ)
☐ February (माघ- फाल्गुन)
☐ March (फाल्गुन- चैत्र)
☐ April (चैत्र- बैसाख)
☑ May (बैसाख- जेठ)
☑ June (जेठ- आषाढ)
☐ July (आषाढ- श्रावण)
☐ August (श्रावण- भदौ)
☐ September (भदौ- असोज)
☐ October (असोज- कार्तिक)
☐ November (कार्तिक- मंसिर)
☐ December (मंसिर- पुस)



Which month is extremely cold?

☑ January (पुस- माघ)
☐ February (माघ- फाल्गुन)
☐ March (फाल्गुन- चैत्र)
☐ April (चैत्र- बैसाख)
☐ May (बैसाख- जेठ)
☐ June (जेठ- आषाढ)
☐ July (आषाढ- श्रावण)
☐ August (श्रावण- भदौ)
☐ September (भदौ- असोज)
☐ October (असोज- कार्तिक)
☐ November (कार्तिक- मंसिर)
☑ December (मंसिर- पुस)

How do you feel inside the house in winter?

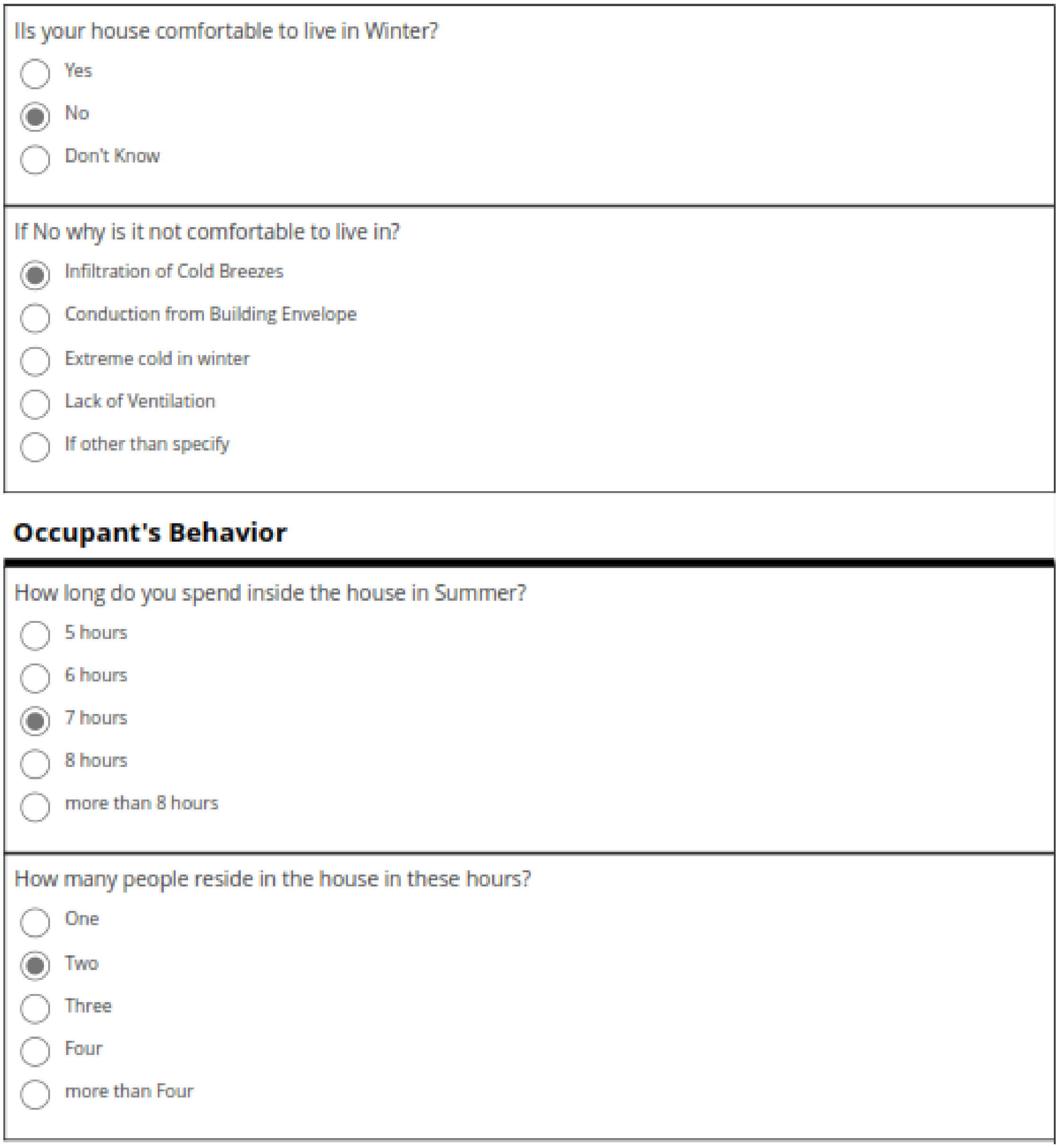
○ Very Cold
● cold
○ Okay
○ Can't Say
○ Warm

Is your house comfortable to live in summer?

● Yes
○ No
○ Don't Know

If No why is it not comfortable to live in?

○ Infiltration of Hot Breezes
○ Conduction from Building Envelope
○ Extreme Hot in Summer
○ Lack of Ventilation
○ If other than specify



Ils your house comfortable to live in Winter?

○ Yes

● No

○ Don't Know

If No why is it not comfortable to live in?

● Infiltration of Cold Breezes

○ Conduction from Building Envelope

○ Extreme cold in winter

○ Lack of Ventilation

○ If other than specify

Occupant's Behavior

How long do you spend inside the house in Summer?

○ 5 hours

○ 6 hours

● 7 hours

○ 8 hours

○ more than 8 hours

How many people reside in the house in these hours?

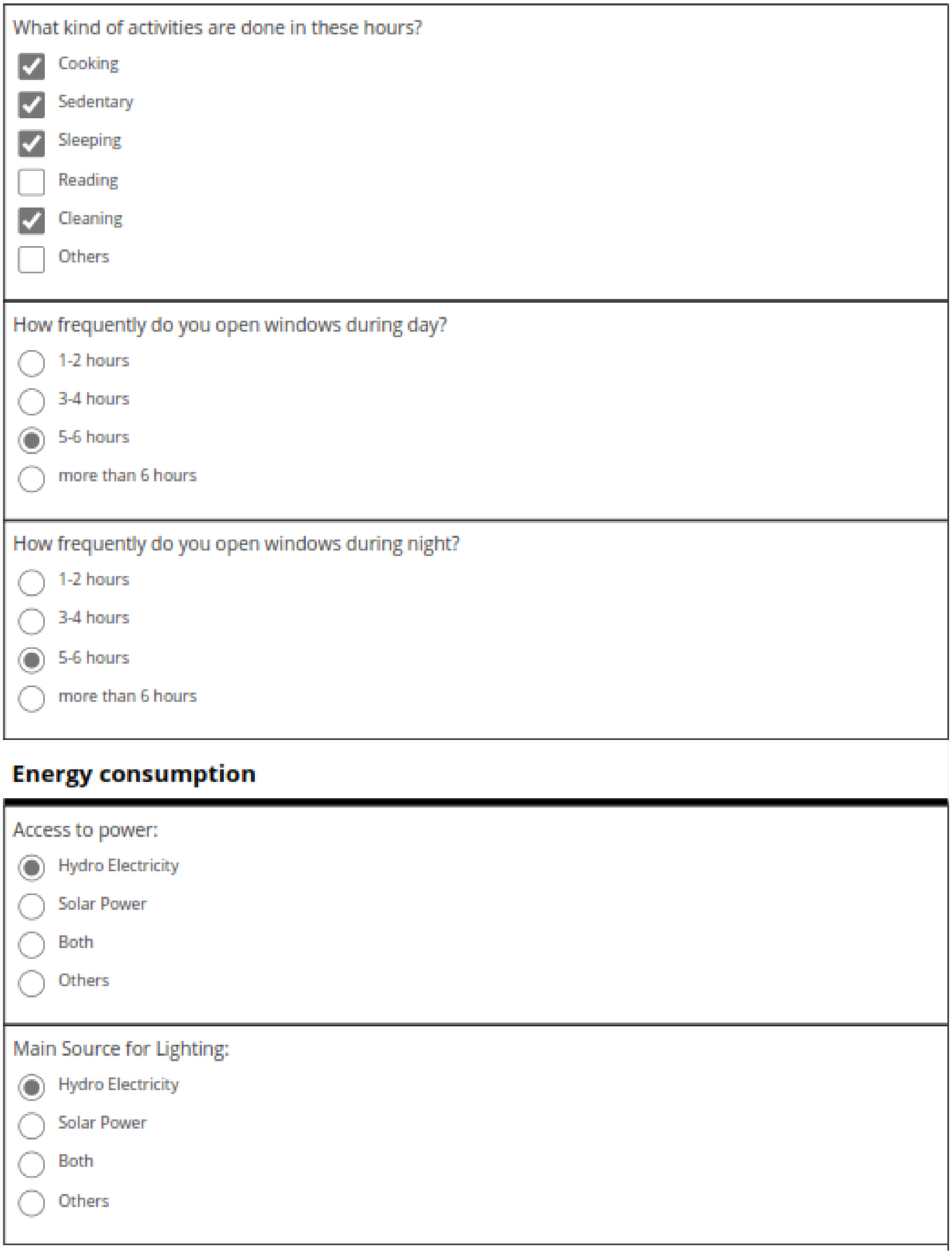
○ One

● Two

○ Three

○ Four

○ more than Four



What kind of activities are done in these hours?

☑ Cooking
☑ Sedentary
☑ Sleeping
☐ Reading
☑ Cleaning
☐ Others

How frequently do you open windows during day?

○ 1-2 hours
○ 3-4 hours
● 5-6 hours
○ more than 6 hours

How frequently do you open windows during night?

○ 1-2 hours
○ 3-4 hours
● 5-6 hours
○ more than 6 hours

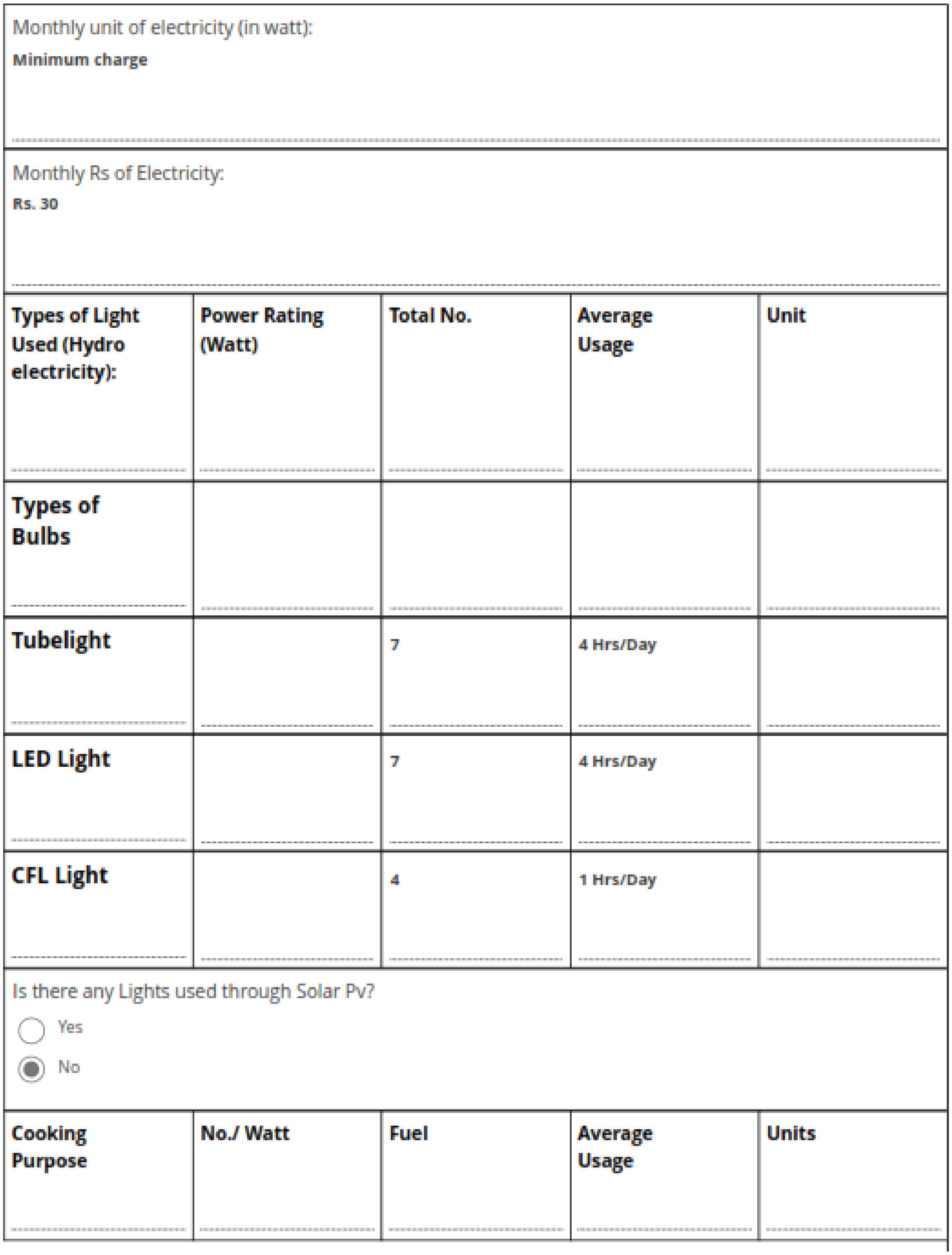
Energy consumption

Access to power:

● Hydro Electricity
○ Solar Power
○ Both
○ Others

Main Source for Lighting:

● Hydro Electricity
○ Solar Power
○ Both
○ Others



Monthly unit of electricity (in watt):
Minimum charge

Monthly Rs of Electricity:
Rs. 30

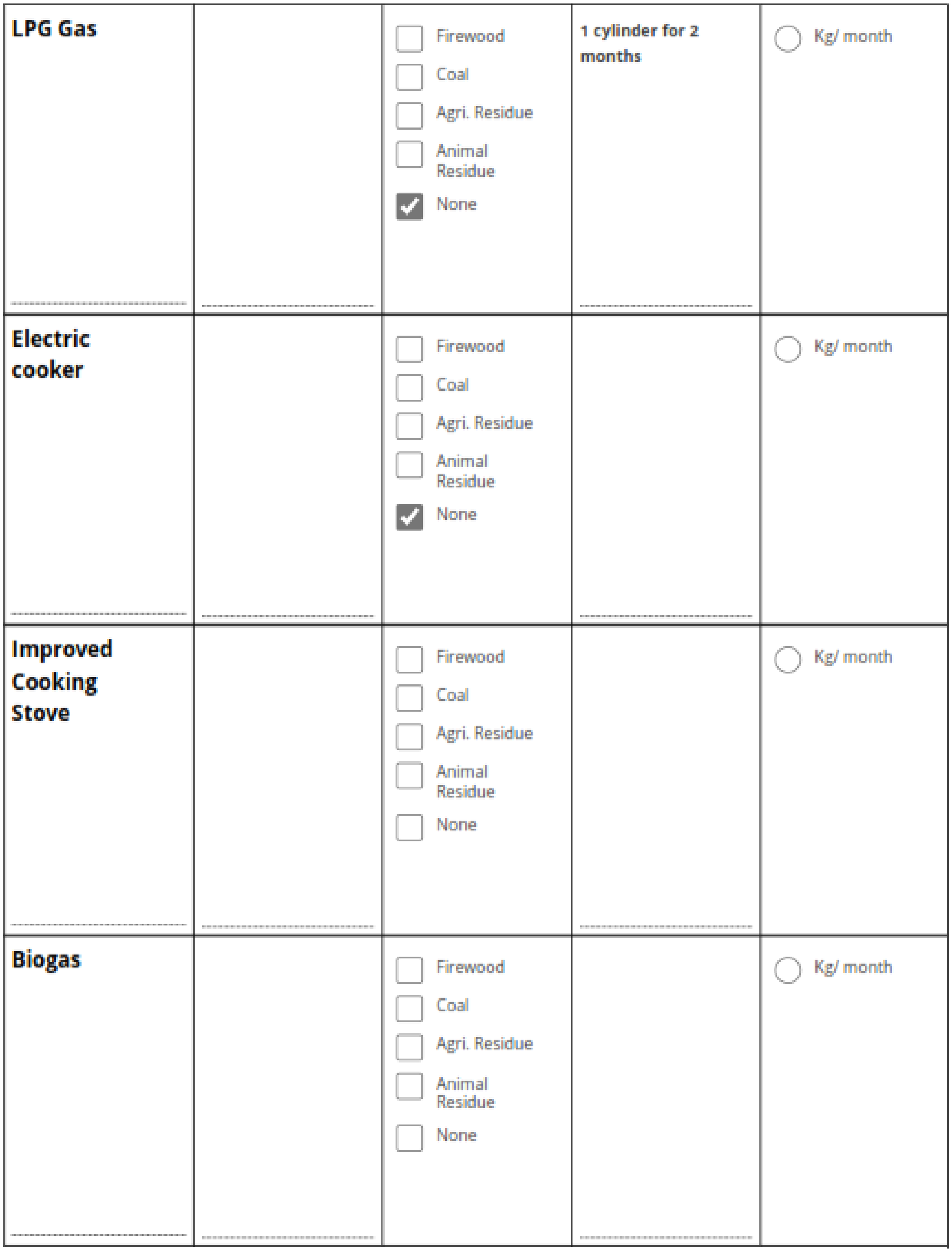
Types of Light Used (Hydro electricity):	**Power Rating (Watt)**	**Total No.**	**Average Usage**	**Unit**
Types of Bulbs				
Tubelight		7	4 Hrs/Day	
LED Light		7	4 Hrs/Day	
CFL Light		4	1 Hrs/Day	

Is there any Lights used through Solar Pv?

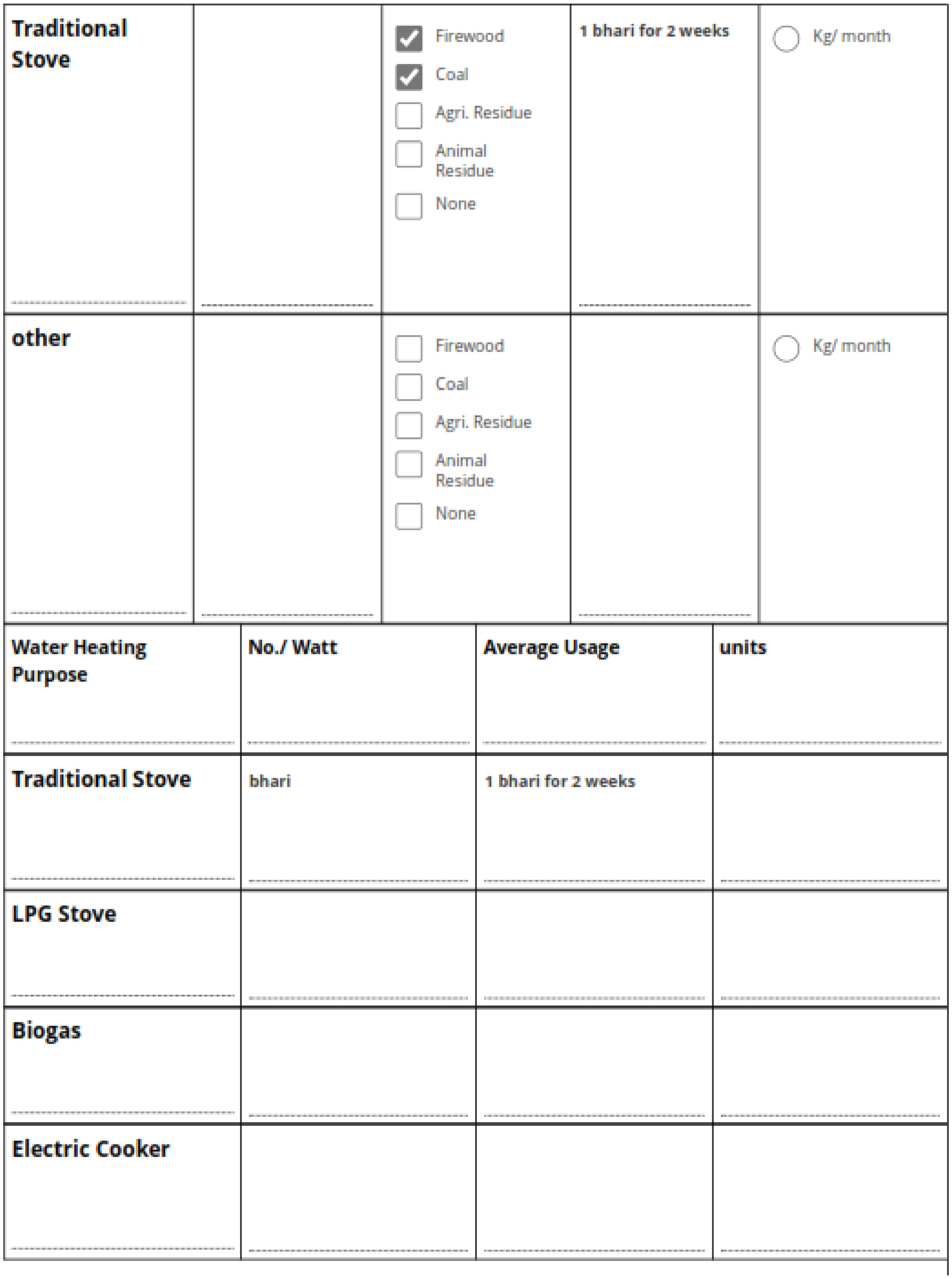
○ Yes

● No

Cooking Purpose	**No./ Watt**	**Fuel**	**Average Usage**	**Units**

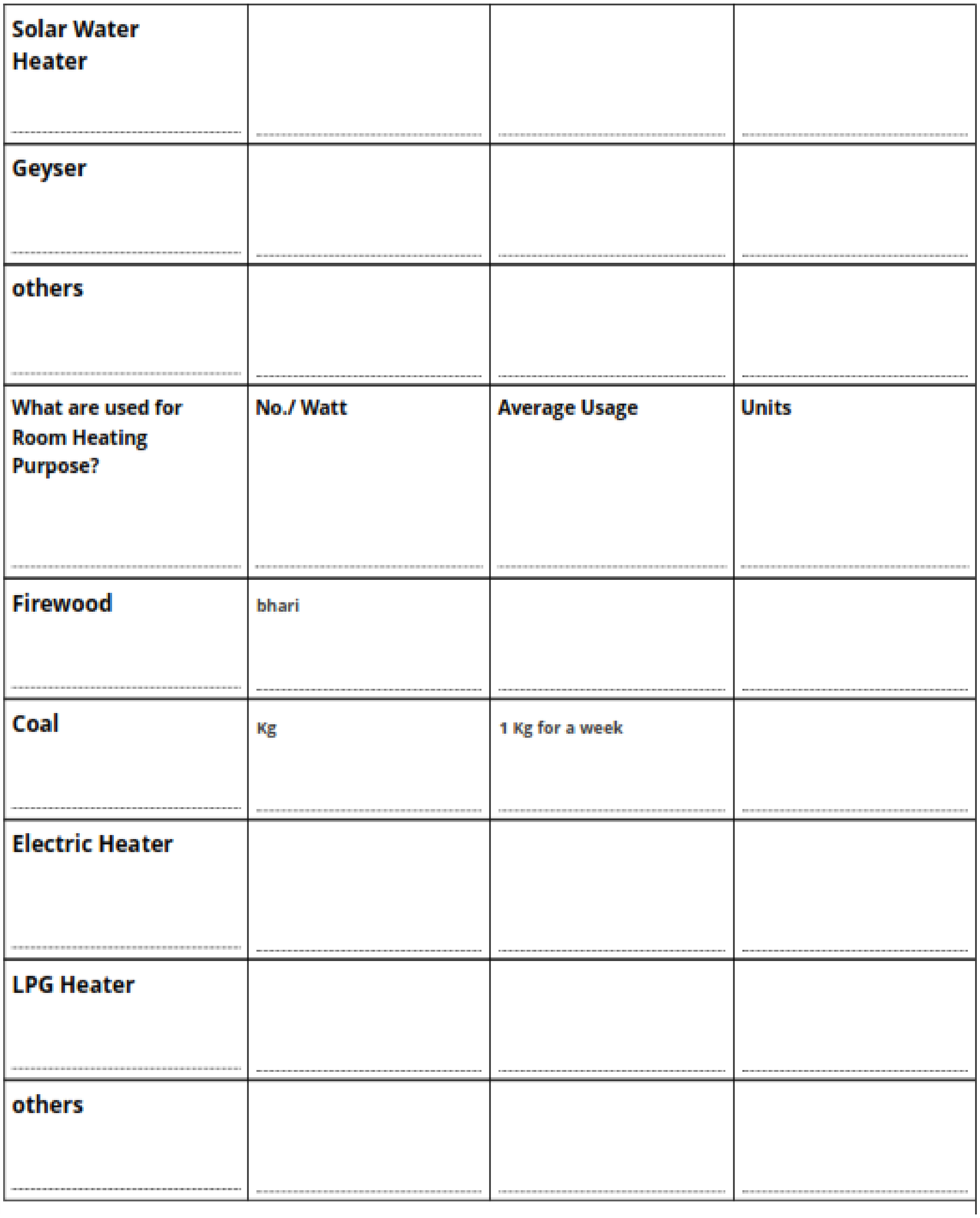


LPG Gas		☐ Firewood ☐ Coal ☐ Agri. Residue ☐ Animal Residue ☑ None	**1 cylinder for 2 months**	○ Kg/ month
Electric cooker		☐ Firewood ☐ Coal ☐ Agri. Residue ☐ Animal Residue ☑ None		○ Kg/ month
Improved Cooking Stove		☐ Firewood ☐ Coal ☐ Agri. Residue ☐ Animal Residue ☐ None		○ Kg/ month
Biogas		☐ Firewood ☐ Coal ☐ Agri. Residue ☐ Animal Residue ☐ None		○ Kg/ month

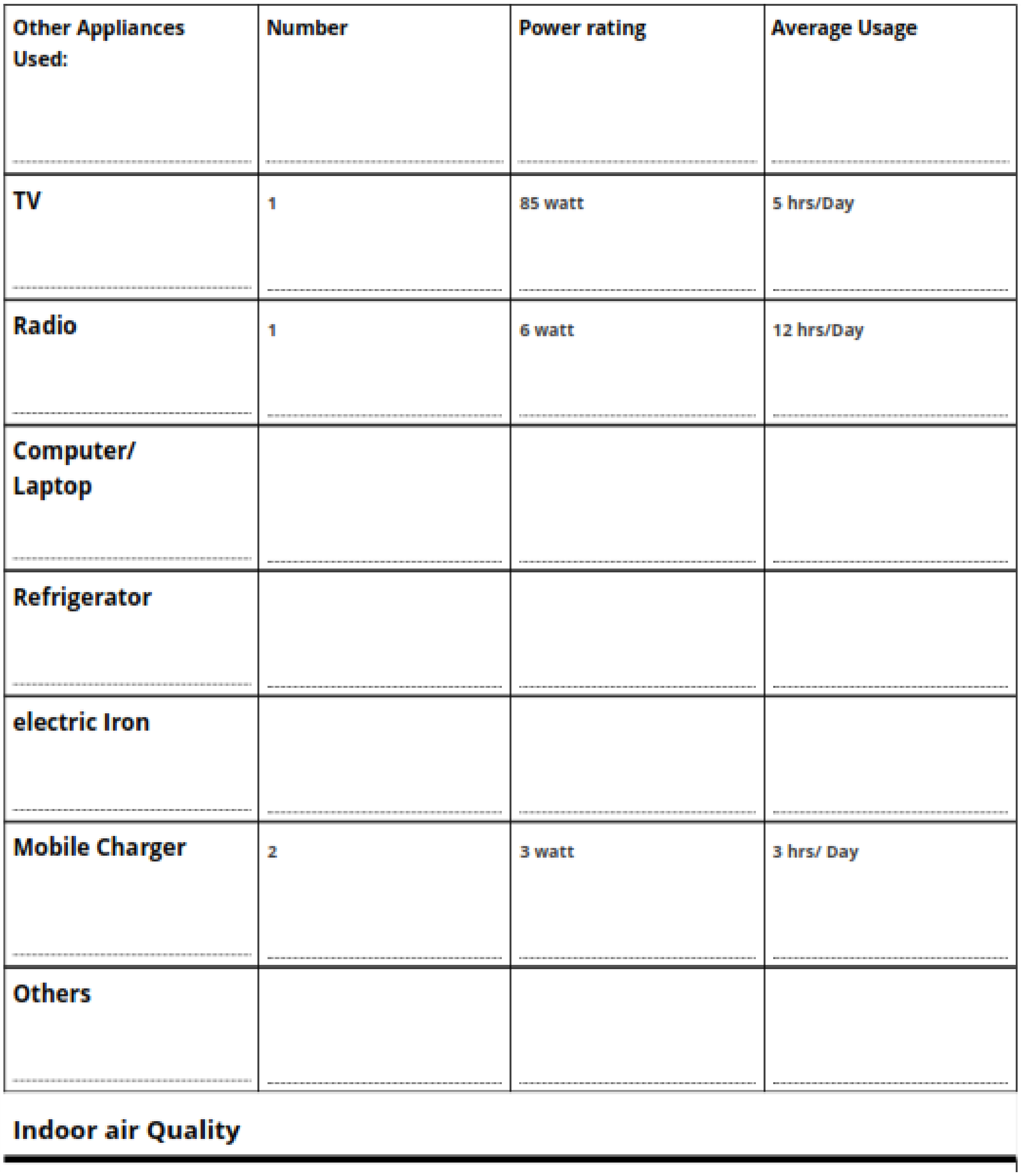


Traditional Stove		☑ Firewood ☑ Coal ☐ Agri. Residue ☐ Animal Residue ☐ None	1 bhari for 2 weeks	○ Kg/ month
other		☐ Firewood ☐ Coal ☐ Agri. Residue ☐ Animal Residue ☐ None		○ Kg/ month

Water Heating Purpose	**No./ Watt**	**Average Usage**	**units**
Traditional Stove	bhari	1 bhari for 2 weeks	
LPG Stove			
Biogas			
Electric Cooker			

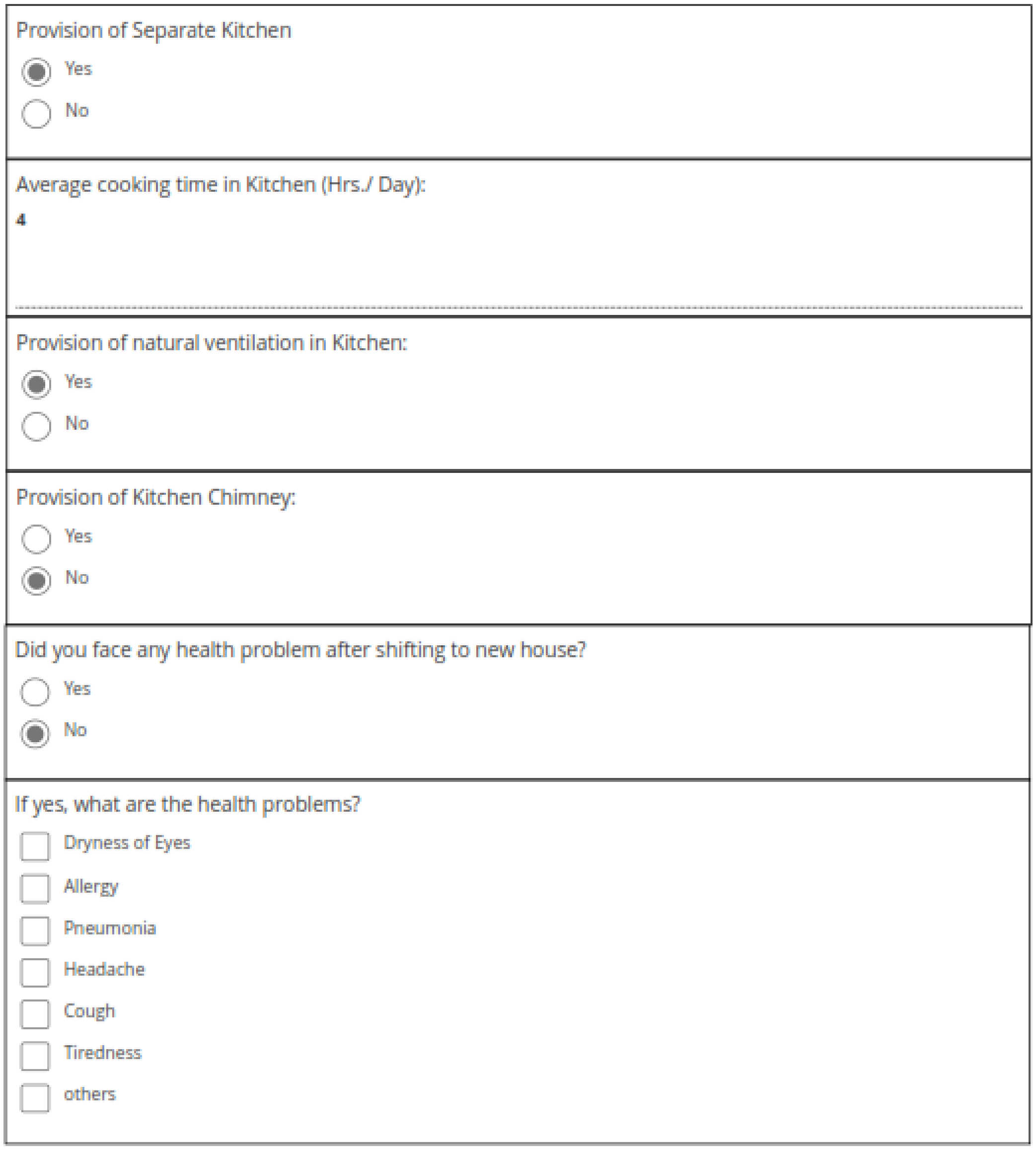


Solar Water Heater			
Geyser			
others			
What are used for Room Heating Purpose?	**No./ Watt**	**Average Usage**	**Units**
Firewood	bhari		
Coal	Kg	1 Kg for a week	
Electric Heater			
LPG Heater			
others			



Other Appliances Used:	Number	Power rating	Average Usage
TV	1	85 watt	5 hrs/Day
Radio	1	6 watt	12 hrs/Day
Computer/ Laptop			
Refrigerator			
electric Iron			
Mobile Charger	2	3 watt	3 hrs/ Day
Others			

Indoor air Quality



Provision of Separate Kitchen

● Yes

○ No

Average cooking time in Kitchen (Hrs./ Day):

4

Provision of natural ventilation in Kitchen:

● Yes

○ No

Provision of Kitchen Chimney:

○ Yes

● No

Did you face any health problem after shifting to new house?

○ Yes

● No

If yes, what are the health problems?

☐ Dryness of Eyes

☐ Allergy

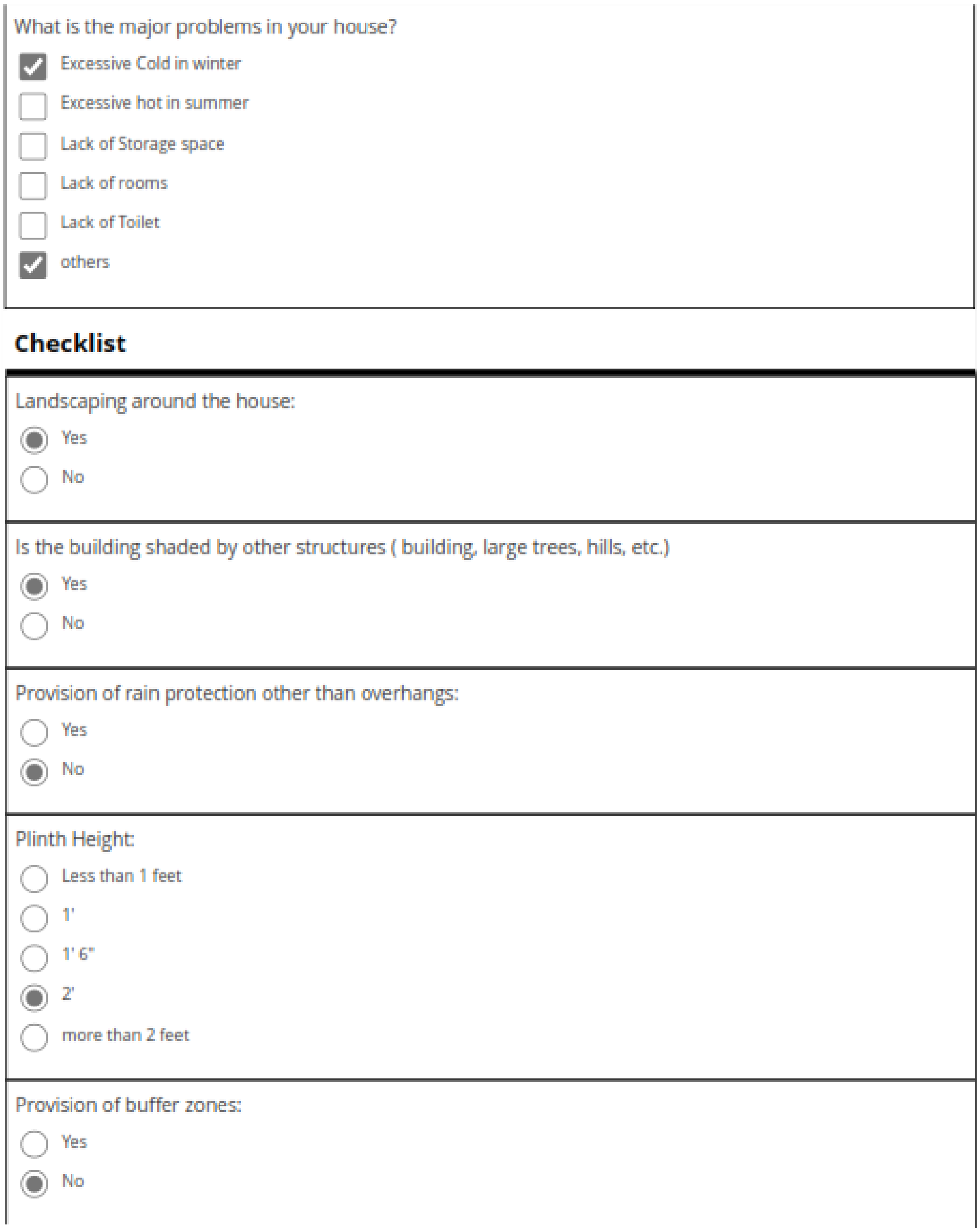
☐ Pneumonia

☐ Headache

☐ Cough

☐ Tiredness

☐ others



What is the major problems in your house?

- ☑ Excessive Cold in winter
- ☐ Excessive hot in summer
- ☐ Lack of Storage space
- ☐ Lack of rooms
- ☐ Lack of Toilet
- ☑ others

Checklist

Landscaping around the house:

- ● Yes
- ○ No

Is the building shaded by other structures (building, large trees, hills, etc.)

- ● Yes
- ○ No

Provision of rain protection other than overhangs:

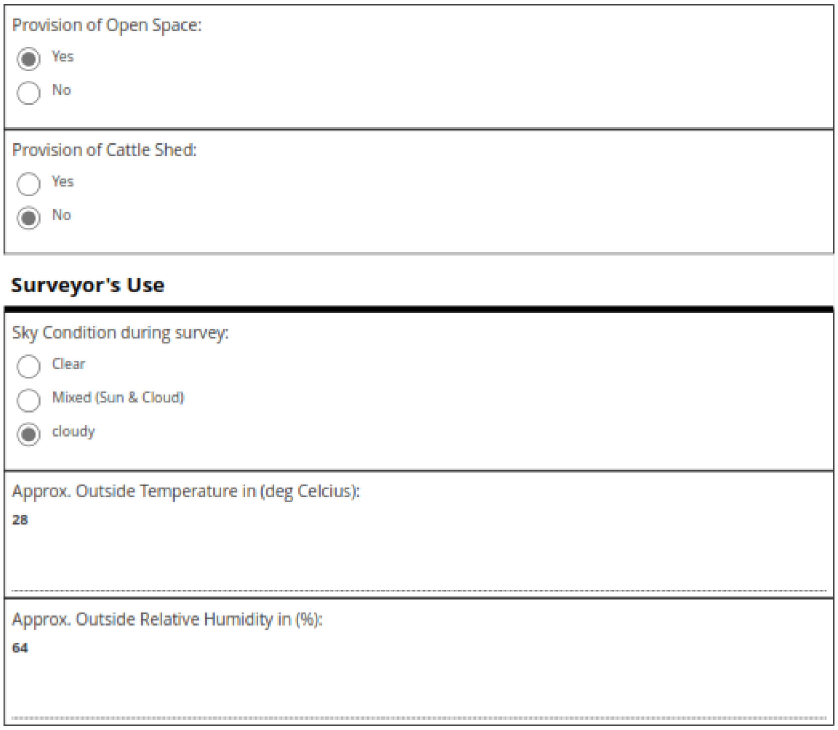
- ○ Yes
- ● No

Plinth Height:

- ○ Less than 1 feet
- ○ 1'
- ○ 1' 6"
- ● 2'
- ○ more than 2 feet

Provision of buffer zones:

- ○ Yes
- ● No



Provision of Open Space:

● Yes
○ No

Provision of Cattle Shed:

○ Yes
● No

Surveyor's Use

Sky Condition during survey:

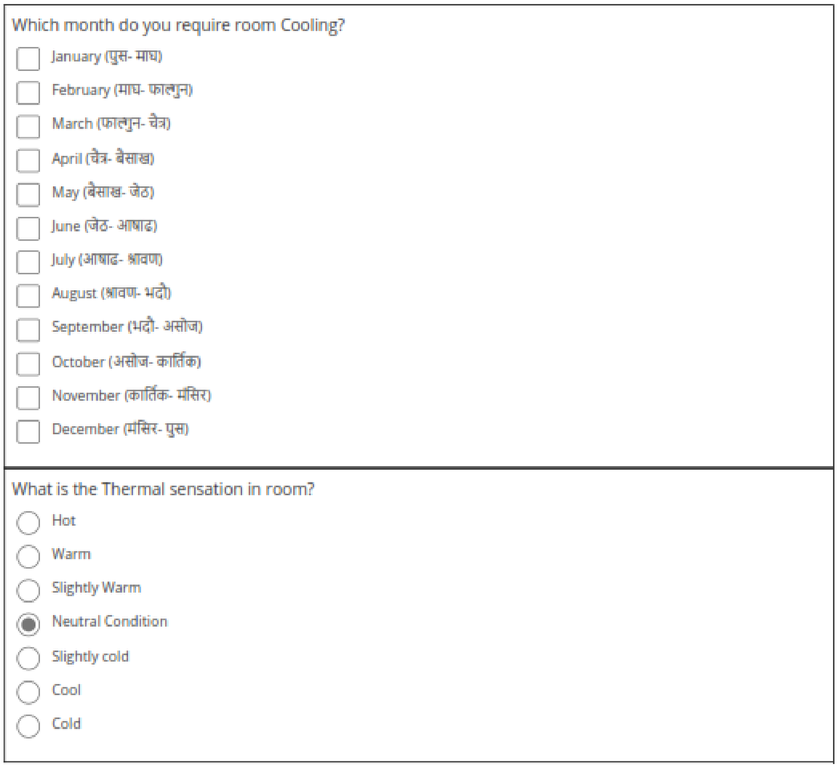
○ Clear
○ Mixed (Sun & Cloud)
● cloudy

Approx. Outside Temperature in (deg Celcius):

28

Approx. Outside Relative Humidity in (%):

64



Which month do you require room Cooling?

☐ January (पुस- माघ)
☐ February (माघ- फाल्गुन)
☐ March (फाल्गुन- चैत्र)
☐ April (चैत्र- बैसाख)
☐ May (बैसाख- जेठ)
☐ June (जेठ- आषाढ)
☐ July (आषाढ- श्रावण)
☐ August (श्रावण- भदौ)
☐ September (भदौ- असोज)
☐ October (असोज- कार्तिक)
☐ November (कार्तिक- मंसिर)
☐ December (मंसिर- पुस)

What is the Thermal sensation in room?

○ Hot
○ Warm
○ Slightly Warm
● Neutral Condition
○ Slightly cold
○ Cool
○ Cold