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**Thermal Comfort in Post-Disaster Reconstructed Shelters: A Case  
Study of the 2023 Jajarkot Earthquake**

by

Adhish Kumar Khadka

A THESIS

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DEGREE OF MASTER OF SCIENCE IN  
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## DECLARATION

I hereby declare that the thesis entitled “**Thermal Comfort in Post-Disaster Reconstructed Shelters: A Case Study of the 2023 Jajarkot Earthquake**” submitted to the Department of Architecture in partial fulfilment of the requirement for the degree of Master of Science in Energy Efficient Buildings, is a record of an original work done under the guidance of Associate Prof. Dr. Sanjaya Uprety and Ar. Barsha Shrestha, Institute of Engineering, Pulchowk Campus. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.



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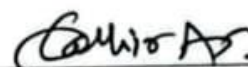


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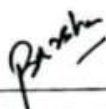
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## ABSTRACT

This study evaluated the thermal comfort of post disaster reconstructed shelters in Bheri-1, Rimna, an affected region of the 2023 Jajarkot earthquake. The study analyzed thermal performance, energy consumption patterns and thermal sensation of the respondents in the case study area. The research adopted a mixed-method approach, integrating qualitative and quantitative data collection, thermal monitoring, and energy modeling using DesignBuilder software.

A detailed thermal performance study conducted in a modern, a vernacular and a temporary house revealed the average room temperatures during night time as 16.9°C (vernacular), 13.6°C (modern), 11.1°C (temporary) while outdoor average temperature was 10.45°C. The external and indoor temperature showed strong correlation inside the modern RCC house ( $R^2=0.622$ ) and temporary shelters ( $R^2=0.616$ ), and a weak correlation in stone mud masonry vernacular house ( $R^2=0.202$ ). Thermal sensation vote revealed the mean comfort temperature inside temporary shelters as 18.7°C and 15.7°C (80% acceptability). The average clo value of respondents during study period was 0.89. The research findings indicate that firewood remains the dominant energy source for cooking and heating, with 85.7% of households relying on it. The use of LPG for cooking is minimal (14.28%). Almost all households (97.6%) had access to grid electricity, and 14.28% of households had installed solar home system as backup. LED lights were used for lighting. Average monthly spending on electricity for majority households ranged between Rs.51 to Rs. 150. Per capita electricity consumption was measured at 37 units. Findings indicate that locally available materials like stone, mud, CSEB and Ecobricks provide better thermal performance than conventional materials. Simulations show that optimizing window-to-wall ratio (WWR 20-40%) and south orientation enhances indoor comfort and reduces energy demand.

The study recommends integrating passive solar design, improving insulation, and adopting energy-efficient materials for future reconstruction to enhance thermal comfort, reduce energy costs, and promote sustainable housing solutions.

**Keywords:** Post-disaster reconstruction, thermal comfort, energy efficiency

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## ABBREVIATION

3D	Three Dimensional
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BES	Building Energy Simulation
BIM	Building Information Modeling
CGI	Corrugated Galvanized Iron
CFD	Computational Fluid Dynamics
CIN	Community Impact Nepal
CRS	Catholic Relief Services
CSEB	Compressed Stabilized Earth Blocks
DDA	Detailed Damage Assessment
DHM	Department of Hydrology and Meteorology
DDMC	District Disaster Management Committee
FCDO	Foreign, Commonwealth and Development Office
GLOF	Glacial Lake Outburst Flood
HDI	Human Development Index
HVAC	Heating, Ventilation and Air Conditioning
IEP	Institute of Energy Professionals
IFRC	International Federation of Red Cross and Red Crescent Societies

IOM	International Organization for Migration
ISO	International Organization for Standardization
IT	Information Technology
LED	Light Emitting Diode
LPG	Liquefied Petroleum Gas
MHT	Main Himalayan Thrust
MoHA	Ministry of Home Affairs
MS	Microsoft
NDRRP	Nepal Disaster Risk Reduction Portal
NEOC	National Emergency Operation Centre
NGO	Non-Governmental Organization
NHSRP	National Housing and Settlements Resilience Coordination Platform
NRA	Nepal Reconstruction Authority
NRCS	Nepal Red Cross Society
PDHR	Post-Disaster Housing Reconstruction
PDPC	Post-Disaster and Post-Conflict
PDR	Post-Disaster Recovery
PET	Polyethylene Terephthalate
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied

RCC	Reinforced Cement Concrete
SDG	Sustainable Development Goal
SOSEC	Social Service Centre
THT	The Himalayan Times
THU	Temporary Housing Unit
TSV	Thermal Sensation Vote
UK	United Kingdom
UN	United Nations
UNDRO	United Nations Disaster Relief Coordinator
UNISDR	United Nations Office for Disaster Risk Reduction
UNRCO	United Nations Resident Coordinator's Office
UPVC	Unplasticized Polyvinyl Chloride
USGS	United States Geological Survey
UTC	Universal Time Coordinated
WFP	World Food Programme
WHO	World Health Organization
WHH	Welt Hunger Hilfe
WWR	Window Wall Ratio
YARCN	Youth Awareness Raising Center Nepal

# CHAPTER 1: INTRODUCTION

## 1.1 Background

Natural disasters are a growing global challenge, causing significant damage to infrastructure, housing, and livelihoods (IEP, 2023). Nepal, one of the world's most disaster-prone nations, faces diverse hazards including earthquakes, landslides, floods, glacial lake outburst floods (GLOFs), and avalanches, all of which disproportionately affect vulnerable communities (NDRRP, 2024). The 2023 Jajarkot earthquake, with a magnitude of 6.4, exemplifies this vulnerability, claiming 154 lives, injuring 366 people, and affecting approximately 250,000 individuals (UNRCO, 2023). Over 62,000 houses and multiple public structures sustained damage, underscoring the critical need for effective post-disaster reconstruction strategies.

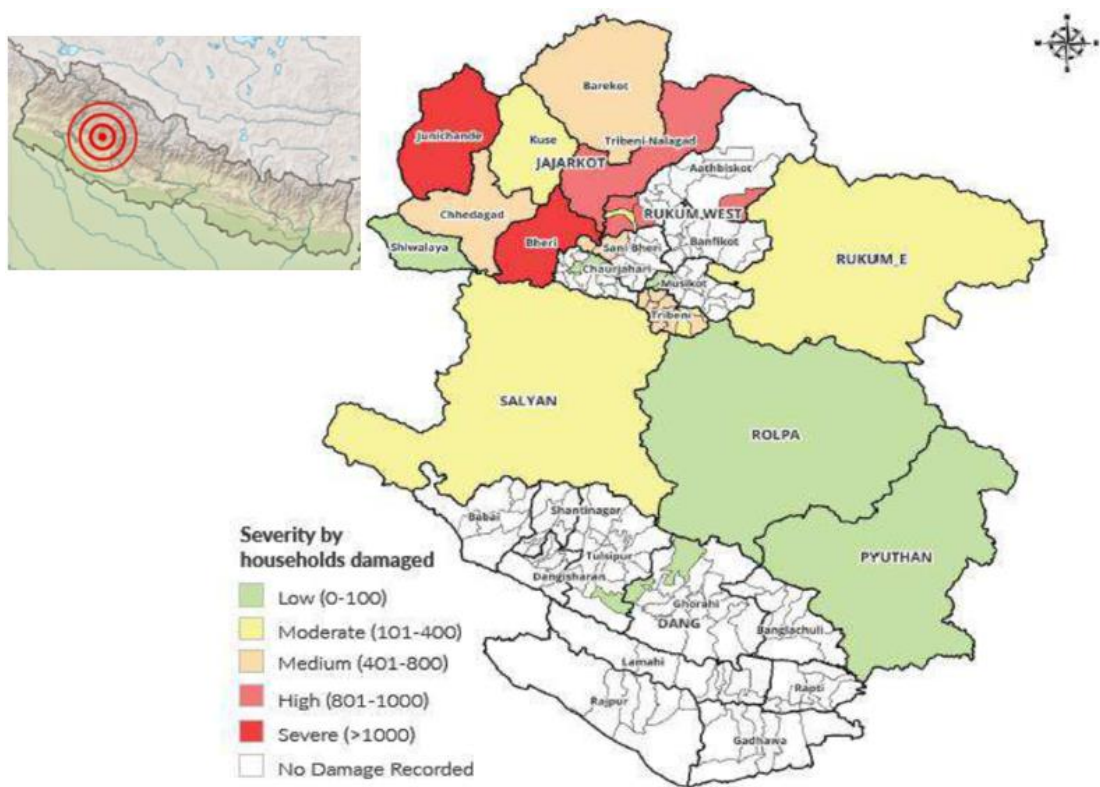


Figure 1 Affected region of 2023 Jajarkot earthquake

Source: NDRRMA, 2024

Post-disaster reconstruction shelters, in simpler words shelter after disaster (Burnell and Sanderson, 2011), are vital in addressing the immediate and long-term needs of disaster-affected populations, whether temporary or permanent. These structures provide not only essential protection but also an opportunity for sustainable recovery.

However, thermal comfort—defined by ASHRAE 55 as "that condition of mind that expresses satisfaction with the thermal environment"—is often overlooked in shelter design. Inadequate thermal comfort increases energy consumption, exacerbates health risks, and prolongs recovery periods.



Figure 2 Post disaster reconstruction shelter (IOM model house) in Rimna, Jajarkot

Source: Study team

Nepal's diverse climatic conditions necessitate region-specific shelter designs. However, reconstruction efforts frequently adopt standardized prototypes that fail to account for local contexts, such as climate, socio-cultural values, and regional development needs (UNDRO, 1982; Rokka and Singh, 2020). Such designs impose additional burdens on displaced populations through higher energy costs and environmental degradation. For instance, the 2015 Gorkha earthquake demonstrated that vernacular houses in Dolakha, constructed with traditional techniques and local materials, were 2.1°C to 2.6°C warmer in winter compared to standardized prototypes (Shrestha *et al.*, 2023). This signifies the value of integrating traditional knowledge with modern construction practices to enhance thermal comfort and sustainability.

Moreover, reconstruction efforts often face institutional challenges, including bureaucracy, corruption, inadequate coordination, and pressures from government and humanitarian agencies (Ophiyaandri *et al.*, 2013; Sharma *et al.*, 2018). These constraints

frequently result in rapid solutions that prioritize quantity over quality, neglecting essential aspects such as thermal performance and energy efficiency (Shrestha et al., 2023).

Given that 83% of global disasters in the last decade were weather- and climate-related (IFRC, 2022), thermally sustainable designs are becoming increasingly important in post-disaster housing. This study focuses on evaluating the thermal performance and thermal comfort of houses in the 2023 Jajarkot earthquake affected area. By identifying effective design features, the research aims to recommend a building design with improved thermal comfort and reduced energy demands, contributing to the global discourse on sustainable post-disaster reconstruction. Aligning with the United Nations Sustainable Development Goals (SDG 11: Sustainable Cities and Communities and SDG 13: Climate Action), this study seeks to provide insights that are applicable to disaster-prone regions worldwide.

## **1.2 Importance of the Research**

This research addresses societal needs, environmental sustainability, and technological innovation in post-disaster housing reconstruction contributing to resilient, sustainable and energy-efficient housing solutions.

Energy efficient housing is essential for the well-being of displaced populations (Gueroui and Halada, 2024). Poor thermal conditions, especially in winter, can lead to health issues and reduced living standards (Ormandy and Ezratty, 2012). This research explores the thermal performance of shelters to improve livability and ensure equitable access to energy-efficient housing, particularly for marginalized communities.

Sustainable construction practices are crucial for minimizing energy consumption and reducing greenhouse gas emissions (Almusaed *et al.*, 2024). By advocating for low-carbon materials and passive design strategies, such as proper orientation and thermal mass, this research supports climate-responsive reconstruction that mitigates environmental impacts while enhancing resilience to climate variability.

This study advances knowledge in sustainable design by evaluating the thermal performance of reconstructed shelters and identifying interventions that balance affordability, safety, and comfort. It provides a replicable framework for integrating traditional and modern construction techniques, offering user-centered, energy-efficient solutions for disaster-prone regions globally.

### **1.3 Problem Statement**

Post-disaster housing reconstruction plays a critical role in recovery for disaster-prone regions like Nepal. Following the 2023 Jajarkot earthquake, 68,326 temporary shelters were constructed by November 2024 to house displaced populations (NDRRMA, 2024). However, these shelters often fail to provide adequate thermal comfort, especially during the winter months. Poor insulation, reliance on high U-value materials such as corrugated galvanized iron (CGI) sheets, and limited incorporation of passive design principles result in high heat loss and low occupant satisfaction (Evola and Lucchi, 2024).

In contrast, vernacular houses built with traditional materials like mud, stone, and slate demonstrate superior adaptation to local climates, offering better thermal performance and higher occupant satisfaction (Bajracharya, 2014). Despite these advantages, vernacular principles are often overlooked in post-disaster reconstruction due to the urgency of recovery efforts, resource constraints, and the lack of policy frameworks prioritizing climate-responsive design (Shrestha *et al.*, 2023).

Additionally, the rapid pace of reconstruction often neglects the cultural and social dimensions of housing design, further distancing affected communities from their traditional ways of life (Rokka and Singh, 2020). The gap between quick reconstruction and the implementation of sustainable housing solutions in Jajarkot earthquake affected area remains underexplored. This highlights an urgent need for research to identify and address the challenges in achieving both thermal comfort and cultural sensitivity in post-disaster housing.

### **1.4 Research Gap**

Despite significant efforts in post-disaster housing reconstruction, several critical gaps remain unaddressed in the context of thermally efficient and sustainable shelters, particularly in Jajarkot following the 2023 earthquake.

While the thermal performance of reconstructed shelters has been studied in other earthquake-affected regions, there is a lack of research specific to the shelters built after the Jajarkot earthquake. The distinct climatic and geographic conditions of Jajarkot necessitate localized investigations to assess the thermal environment of reconstructed housing.

The energy consumption patterns of post-disaster shelters in Jajarkot are yet unexamined. The lack of data on the energy demand for heating in poorly insulated prototype houses highlights a significant gap in understanding how to reduce energy consumption and associated costs in resource-constrained settings.

There is insufficient documentation of the experiences and preferences of residents living in post-disaster shelters in Jajarkot. Incorporating resident feedback is essential to designing housing that aligns with cultural, social, and thermal comfort expectations.

Current national and local policies prioritize structural safety and rapid deployment but lack comprehensive guidelines for ensuring thermal comfort, energy efficiency, and cultural relevance in post-disaster reconstruction. Addressing these gaps is crucial for promoting sustainable housing practices in disaster-prone regions.

### **1.5 Objectives**

The primary objective of this study is to examine the thermal comfort of shelters reconstructed after the 2023 Jajarkot earthquake, focusing on indoor thermal environments during winter.

To achieve this objective following specific objectives are determined:

- 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 analyze energy consumption patterns, particularly heating requirements and economic burdens on households.
- To find the actual conditions of thermal environment of post disaster reconstructed shelter.
- To propose recommendations for thermally comfortable and energy-efficient post-disaster housing.

### **1.6 Topic Validity**

Research on energy efficiency and thermal comfort on residential buildings in Nepal are primarily focused on urban areas.

Tuladhar (2011) explored strategies for sustainable residential building design in Kathmandu Metropolitan City. The thesis used literature reviews, analysis, and design

strategies to address energy issues, water and waste management, and the residential status of the region, promoting sustainable building practices.

Bajracharya (2014) assessed the thermal performance of traditional and modern residential buildings in Kathmandu Valley. Through field surveys and measurements, the study compared indoor and outdoor air temperatures, emphasizing the importance of traditional design elements in enhancing thermal comfort.

Rai (2014) conducted a study on residential buildings in Kathmandu, using computer simulations through Design Builder software to evaluate the impact of passive design strategies. The findings revealed that increasing window-to-wall ratios (WWR) improved indoor thermal comfort, while increasing the length of overhangs reduced overall operative temperatures. Enhanced airtightness was also found to significantly increase comfort levels.

Upadhyay *et al.* (2018) analyzed climate-responsive building design in the Kathmandu Valley. Employing tools like the bioclimatic chart, Mahoney's table, and design guidelines, the study proposed strategies for achieving thermal comfort and adapting vernacular architecture to contemporary needs.

Kirat & Singh (2019) examined the challenges and opportunities of incorporating energy-efficient principles in residential projects in Kathmandu from architects' perspectives. Using theoretical sampling and opinion surveys, the study highlighted key barriers and drivers to adopting energy-efficient housing practices.

Bajracharya *et al.* (2020) explored energy efficiency measures in contemporary residential buildings in Kathmandu Valley. The study used questionnaire surveys and data analysis to identify practical strategies for reducing energy consumption and promoting energy efficiency in residential architecture.

Shrestha & Uprety (2020) evaluated the energy efficiency of traditional Newari residential buildings in Bhaktapur, specifically in the Itachhen Tole area. Using literature reviews, sampling, and questionnaire surveys, the study assessed the energy consumption patterns and identified traditional design features contributing to energy efficiency.

Studies on post-disaster housing are conducted in case of Nepal, focusing on 2015 Gorkha earthquake affected regions, mostly prioritizing structural stability and seismic

standards. The critical aspects of energy efficiency and thermal comfort in post disaster reconstruction have been addressed in few researches.

Thapa & Rijal (2016) investigated the thermal environment and comfort of residents in temporary shelters following the 2015 Nepal earthquake. Surveys and measurements conducted over 30 days in autumn revealed that indoor air temperatures were low, and residents maintained thermal comfort through behavioral adaptations. The study highlighted the need for improved shelter designs to address thermal inadequacies.

Dangi (2018) focused on post-disaster reconstruction in Sindhupalchowk following the 2015 Gorkha earthquake. Through field surveys, focus group discussions, and secondary data from the National Reconstruction Authority (NRA), the study emphasized "build back better" approaches and highlighted the importance of linking reconstruction efforts with socioeconomic development.

Thapa (2020) evaluated the thermal performance of temporary shelters built after the 2015 Nepal earthquake, highlighting inadequate thermal comfort, especially in winter. Surveys and thermal measurements across five districts revealed a dependence on outdoor temperatures and dissatisfaction among residents due to poor indoor environments. The study proposed using affordable materials, like foam and clothing layers, to improve insulation and recommended guidelines for better thermal comfort in temporary shelters.

Shrestha (2022) analyzed the thermal performance of traditional and post-disaster reconstructed buildings in Dolakha, focusing on passive design strategies and building envelope improvements. Using energy simulations and passive design tools, the study highlighted how modifications in wall materials, construction techniques, and window design significantly enhanced thermal comfort and energy efficiency. A proposed optimized design demonstrated the potential for greater sustainability in post-disaster reconstruction.

Shrestha et al. (2023) conducted research on post-Gorkha earthquake-reconstructed prototype and traditional vernacular houses in the Dolakha district of Nepal and found that vernacular designs using local materials often outperform modern prototypes in ensuring indoor thermal comfort.

The Karnali region of western Nepal, specially Jajarkot, Rukum (West) and Salyan, was significantly affected by the 2023 Jajarkot earthquake. This region has been

underprivileged for decades, facing persistent socio-economic and developmental challenges (Loksom, 2021). Its unique climate, geographic characteristics, and lack of access to resources necessitate a tailored approach to post-disaster reconstruction.

While previous research has provided valuable insights into thermal comfort and post-disaster housing, the specific challenges faced by Jajarkot earthquake affected areas remain unaddressed. This research aims to bridge these gaps by analyzing thermal comfort in reconstructed shelters in Jajarkot earthquake affected areas. By shifting focus to an underserved area like Karnali, this study not only builds on existing frameworks but also introduces a novel perspective. The findings are expected to provide valuable insights into improving living conditions and guiding future reconstruction efforts in similar underprivileged settings.

## CHAPTER 2: LITERATURE REVIEW

### 2.1 Historical Background

Natural disasters pose an escalating global challenge, causing significant damage to infrastructure, housing, and human livelihoods (IEP, 2023). Beyond physical destruction, these events weaken social and organizational structures, heightening vulnerabilities in affected populations (Pérez-Sales, 2004). Developing countries, due to limited risk management capacities, bear a disproportionate burden of natural disasters, such as earthquakes and floods, which are becoming increasingly frequent (UNISDR, 2004).

Nepal ranks among the world's most disaster-prone nations, owing to its diverse topography and elevation-dependent climate (NDRRP, 2024). The country regularly experiences various natural hazards, including earthquakes, landslides, floods, glacial lake outburst floods (GLOFs), and avalanches, which disproportionately affect its vulnerable communities (NDRRP, 2024). In this context, post-disaster reconstruction plays a pivotal role in recovery, offering a unique opportunity to rebuild communities sustainably and enhance their resilience against future disasters.

Nepal faces significant risks from natural disasters, particularly climate change, earthquakes, and flooding (Dangal, 2011). As per HDI Index, approximately 25.2% of its population lives below the poverty line, with high poverty levels especially concentrated in rural areas. This has led to extensive migration, with 44% of households reporting at least one absentee family member working in urban centers or abroad. Consequently, concerns have risen regarding the social and economic vulnerability of women who remain in remote, hilly, and mountainous regions, especially after the devastating 2015 earthquakes.

The 2023 Jajarkot earthquake, with a magnitude of 6.4, underscored Nepal's vulnerability. The disaster claimed 154 lives, injured 366 people, and affected approximately 250,000 individuals (UNRCO, 2023). According to the Ministry of Home Affairs (MoHA), over 62,000 houses were damaged across 13 affected districts (26,557 fully and 35,455 partially), alongside 50 government and public buildings (16 fully and 34 partially damaged). This event highlighted the urgent need for effective post-disaster reconstruction strategies—not only to restore housing but also to ensure thermal comfort, energy efficiency, and resilience against future disasters.

While the reconstruction of damaged infrastructure presents an opportunity for transformative change (Ozdogan and Lizarralde, 2024), the process often encounters numerous challenges. These include institutional bureaucracy, corruption, inadequate coordination, and a lack of expertise in construction management (Ophiyaandri *et al.*, 2013; Sharma *et al.*, 2018).

Resettlement following disasters is a multidimensional challenge, addressing the physical, social, and cultural disruptions caused by displacement. Such processes frequently lead to additional crises for affected communities, rather than alleviating vulnerabilities (Oliver-Smith, 1991). A common constraint in post-disaster reconstruction is the emphasis on rapid solutions, which prioritize quantity over quality and often neglect critical aspects such as design considerations and thermal sustainability (Shrestha *et al.*, 2023).

For instance, the 2023 Türkiye-Syria earthquake offers a parallel case study. While reconstruction efforts in Türkiye are ongoing, policy constraints and the prioritization of rapid reconstruction have resulted in efforts that focus more on quantity than quality (Ozdogan and Lizarralde, 2024). Such global examples serve as a cautionary tale, emphasizing the need to balance urgency with sustainability, ensuring that housing reconstruction efforts address both immediate needs and long-term resilience.

## **2.2 Definition of key terminologies**

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. Factors affecting thermal comfort includes environmental factors such as air temperature, mean radiant temperature, air velocity, humidity and personal factors such as clothing level and metabolic rate (Fanger, 1970). For the measurement of thermal comfort in any settings, measurement of these influencing factors is crucial.

Thermal sensation vote (TSV) is a key parameter in thermal comfort studies, used to quantify individuals' subjective perception of their thermal environment. It is standardized in ISO 7730 and ASHRAE Standard 55, typically employing a seven-point scale ranging from -3 (cold) to +3 (hot), though some studies extend it to -4 (very

cold) to +4 (very hot) for broader sensitivity. TSV is closely linked to the Percentage of People Dissatisfied (PPD) metric, helping assess overall thermal satisfaction.

Energy efficiency refers to using less energy to provide the same service, which can be achieved through better appliances, improved building designs, and modern technologies (IEA, 2014). Enhanced energy access involves providing reliable and affordable energy services to underserved populations.

Energy poverty, defined as a situation where households lack access or are unable to afford essential energy services (Certomà *et al.*, 2023), is a pervasive issue affecting billions worldwide. This phenomenon encompasses a range of challenges, including inadequate access to electricity and clean cooking facilities, which significantly impacts health, education, and economic development (Banerjee *et al.*, 2021). Globally, energy poverty hinders progress towards achieving sustainable development goals, perpetuating cycles of poverty and limiting opportunities for growth and improvement in living standards (IEA, 2020).

### **2.3 Limitations of Reconstruction Efforts in Disaster-Affected Communities**

Reconstruction projects initiated by organizations with limited understanding of local contexts frequently fail to address the true needs of affected communities (Rahmani, 2012). Emergency aid efforts often concentrate on addressing immediate effects, neglecting the long-term recovery and requirements of populations impacted by disasters (WHO, 1997). A common issue is the lack of engagement with affected populations, resulting in culturally and socially irrelevant designs that alienate communities and hinder recovery (Dev and Das, 2020).

The challenges in reconstruction efforts are multifaceted and include fraudulent use of funds, poor planning, and failure to consider sociocultural dimensions (Sadiqi *et al.*, 2015). Non-participatory approaches exacerbate these issues, leading to resource wastage and loss of community trust (Sadiqi *et al.*, 2015). Overemphasis on rapid solutions often neglects the complexities of social, cultural, and economic adaptations, causing problems such as site abandonment or failure of resettlement programs (Razani, 1984). Furthermore, inadequate shelter designs that do not address essential needs, such as thermal comfort, frequently result in dissatisfaction and poor acceptance among displaced populations (Dev and Das, 2020).

### **2.4 Passive design strategies**

The researchers have studied essential aspects of building design, such as site location, orientation, form, materials, natural elements, solar gain optimization, and heat loss reduction, to achieve the desired heating, cooling, and ventilation in a passive manner. By integrating these principles, architects and builders can create sustainable, energy-efficient spaces that enhance occupant comfort while minimizing environmental impact. The key passive design strategies for improving energy efficiency and thermal comfort in buildings has been summarized in Table 1.

Table 1 Passive design strategies for a building

S.N.	Strategy	Description
1.	Site Location	Consider microclimatic advantages, natural risks, and the presence of shading objects (trees, hills, etc.). South-facing sites receive more solar radiation; east and west slopes receive morning and afternoon sun, respectively. (Stauffer and Hooper, 2000; Tendulkar, 2017)
2.	Slope and Orientation	Land slope impacts solar radiation; horizontal surfaces receive more solar radiation in summer. South-facing slopes receive maximum solar radiation. Vertical windows reduce overheating by limiting summer sunlight penetration. (Stauffer and Hooper, 2000; Tendulkar, 2017)
3.	Building Orientation	Orient buildings along the east-west axis to maximize solar gain during winter and reduce exposure in summer. Design should align rooms with solar and wind patterns. (Stauffer and Hooper, 2000; Tendulkar, 2017)
4.	Building Form & Compactness	Simple, compact geometries minimize the surface area-to-volume ratio, reducing heat exchange. Multi-storey and rectangular plans promote natural ventilation and energy efficiency. (Stauffer and Hooper, 2000; Bureau of Energy Efficiency, 2021)

5.	Internal Space Arrangement	Arrange high-use rooms (e.g., living rooms, bedrooms) on the south for solar gain and utility spaces (e.g., bathrooms, storage) on the north for a buffer. Morning-use rooms face east; evening-use rooms face west. Multi-storey buildings can allocate functions by floor. (Stauffer and Hooper, 2000; Tendulkar, 2017)
6.	Thermal Insulation	Use materials like glass wool, mineral wool, polyurethane, and air cavities to minimize heat flow. Effective insulation maintains indoor temperature, enhances comfort, and reduces energy use. (Rai, 2014)
7.	Thermal Mass	High-density materials (e.g., brick, concrete, stone) stabilize temperatures by absorbing heat during the day and releasing it at night. Combine thermal mass with insulation for optimal efficiency. (Stauffer and Hooper, 2000; Bureau of Energy Efficiency, 2021)
8.	Air Tightness	Prevent air leakage through gaps in the building envelope to enhance thermal comfort and reduce energy demand. Standards recommend an air tightness below 1 m <sup>3</sup> /hr/m <sup>2</sup> . (Cradden, 2019)
9.	Openings	Position windows for maximum solar gain and ventilation while minimizing heat loss or gain through east and west walls. Optimize size and placement for natural airflow. (Archi-Monarch, 2020; Gibbs, 2019; Shrestha, 2017)
10.	Window to Wall Ratio (WWR)	Lower ratios limit heat loss/gain. Opaque walls have better thermal resistance than windows and openings.(Bureau of Energy Efficiency, 2021)
11.	Shading	Use internal (curtains, blinds) and external (overhangs, vegetation) shading devices to control sunlight intensity and reduce overheating in summer. Design shading for seasonal

		solar movement. (Bureau of Energy Efficiency, 2021; Williams, 2022)
12.	Ventilation	Promote natural ventilation by sizing and placing windows based on climatic zones and wind patterns. Cross ventilation removes stale air and ensures thermal comfort. (Gut and Fislisbach, 1993; Chaulagain, Baral and Bista, 2019)
13.	Material	Choose dense materials (e.g., brick, stone) for heat storage or lightweight materials for minimal heat conduction. Mudbrick offers time lag for comfortable temperature regulation. Transparent materials like glass transmit solar radiation effectively. (Stauffer and Hooper, 2000)
14.	Color & Texture	Light-colored materials (e.g., white walls) reflect solar radiation, reducing heat gain. Smooth textures reflect radiation, while rough textures absorb and retain heat. (Archi-Monarch, 2020)
15.	Landscaping	Plant deciduous trees for summer shading and winter sunlight access. Green corridors can guide summer breezes; planting trees strategically shelters buildings from wind. (Vasiu, 2013)

## 2.5 Thermal Comfort in Post-Disaster Housing

Housing designs in resettlement projects often fail to address thermal performance adequately, with shortcomings such as insufficient insulation and inappropriate material choices worsening seasonal discomfort (Razani, 1984). This neglect of thermal and energy efficiency needs not only increases dissatisfaction among beneficiaries but also exacerbates health issues, particularly in vulnerable populations (Sadiqi *et al.*, 2015).

The impact of inadequate shelter extends beyond physical discomfort, intensifying social and psychological vulnerabilities. This makes the integration of thermal comfort considerations an essential aspect of reconstruction design (Cueto *et al.*, 2015). Post-disaster reconstruction efforts that fail to prioritize energy efficiency and thermal

performance leave affected communities more exposed to harsh environmental conditions, further deepening their vulnerabilities (Shafique and Warren, 2015).

Historically, traditional housing designs have evolved to meet the thermal and functional needs of local environments. However, these effective and culturally relevant features are often overlooked in post-disaster resettlement designs (Oliver-Smith, 1991). Incorporating local materials and passive design strategies into reconstruction efforts offers a sustainable way to enhance both the energy efficiency and thermal comfort of shelters, ensuring more resilient and acceptable solutions for affected populations (Oliver-Smith, 1991; Cueto *et al.*, 2015; Sadiqi *et al.*, 2015).

Shrestha *et al.* (2023) examined the thermal satisfaction and indoor thermal environment of post-disaster houses - prototype and traditional vernacular - in Dolakha, Nepal. The study compared indoor and outdoor temperatures across two settlements, Panipokhari and Jillu, during the coldest winter months. Findings revealed that indoor temperatures in the prototype houses were consistently lower at night compared to the vernacular houses, with a difference between them being 2.1°C in Panipokhari and 1°C in Jillu. This disparity was attributed to the thermal properties of locally available materials, such as stone masonry and thick mud plaster, used in vernacular houses, which provided better insulation and thermal mass. The study also highlighted that vernacular house exhibited more stable indoor temperatures and higher occupant satisfaction, primarily due to their climate-responsive design features and low window-to-wall ratios. Adaptive strategies employed by occupants included wearing extra layers of clothing, staying under quilts, and minimizing window openings during cold weather. Shrestha *et al.* (2023) emphasized the need for post-disaster housing policies to integrate vernacular design principles to improve indoor thermal comfort and reduce energy dependency.

Coorey *et al.* (2017) investigated thermal comfort conditions in post-disaster housing along the southern coast of Sri Lanka, specifically in Boosa, Dadella, Madihe, and Kirinda. The study aimed to identify features contributing to overheating and strategies to mitigate it. Findings revealed that the lack of consideration for thermal comfort in post-tsunami housing design led to significant discomfort during extreme climate conditions. The study highlighted the importance of the building envelope, including roofing materials, ventilation provisions, and shading devices, in mitigating indoor overheating. Houses in Boosa and Kirinda demonstrated better thermal comfort due to

insulated panel walls, terracotta tile roofs, and better cross-ventilation opportunities, whereas Madihe houses, with RCC slab roofs, exhibited higher indoor temperatures and lower comfort hours. The study emphasized the role of neighborhood context, including vegetation and building orientation, in achieving thermal comfort. Adaptive measures by occupants included using external shading structures, keeping spaces well-ventilated, and leveraging natural ventilation for cooling. Coorey *et al.* (2017) highlighted the necessity for neighborhood-level design guidelines focusing on shading, ventilation, and material selection to improve thermal comfort in post-disaster housing.

Shrestha & Uprety (2020) investigated thermal and visual comfort in post-disaster reconstructed school buildings in Lalitpur, Nepal, following the 2015 Gorkha earthquake. The study assessed naturally ventilated classrooms across four schools using both simulation tools and field surveys. Findings revealed significant discomfort hours in winter, with 732.6 hours recorded annually in the baseline scenario (Case A). The primary causes of heat gain were solar radiation (72.4%), while heat loss was mainly through ventilation (72.1%). Subsequent design optimizations in Case C, including the use of rammed earth walls, improved insulation, and better ventilation strategies, reduced discomfort hours to 569.5 annually. Visual comfort assessments showed adequate natural lighting levels due to high window-to-floor ratios and bilateral openings, although occasional glare issues were noted on task surfaces. Field surveys with students and teachers revealed that most respondents felt cold during winter, while airflow was generally perceived as adequate. The study emphasized the importance of optimizing building envelopes, insulation, and ventilation strategies to enhance indoor environmental quality in post-disaster school buildings. Shrestha & Uprety (2020) concluded that integrating passive design strategies, such as appropriate material selection and improved glazing systems, is crucial for achieving thermal and visual comfort in school classrooms.

Zuhri *et al.* (2024) explored building performance strategies to achieve thermal comfort in the post-disaster housing designs in Indonesia. Their research highlights the significance of parameters such as natural lighting, airflow, thermal performance, and the building's orientation and openings. The study emphasizes adaptive buildings as a solution for enhancing energy efficiency and comfort. These buildings incorporate natural ventilation and insulation materials to address solar radiation and temperature

variations effectively. Analyses using tools like Revit-based computational fluid dynamics (CFD) demonstrated the importance of building orientation and opening placement in optimizing thermal conditions. For instance, a wall envelope with a 10 cm calciboard layer and air-holes maintained heat transfer within permissible limits, achieving thermal comfort standards (SNI 6389:2020). Utilizing materials with air cavities reduced heat absorption into interior spaces, ensuring both thermal and energy efficiency. Additionally, modular and adaptive design approaches proved practical and resilient for post-disaster settings, leveraging local materials and efficient spatial arrangements.

## **2.6 Community Participation in Reconstruction**

A lack of community involvement often undermines the sustainability and acceptance of reconstruction projects. Poor communication between project implementers and affected populations can lead to frustration and widespread dissatisfaction with post-disaster efforts (Christoplos, 2006; Sadiqi *et al.*, 2015). Successful reconstruction requires the integration of community input, empowering affected populations to participate in planning and construction processes actively (Lamping, 1984).

Community participation fosters a sense of ownership and ensures that reconstruction aligns with the cultural and functional needs of local communities (Sadiqi *et al.*, 2015). Engaging the community in defining recovery priorities enhances their competence, efficacy, and long-term resilience (Ortiz-Torres, 1999).

Sadiqi *et al.* (2016) examine the barriers to community participation in post-disaster reconstruction, focusing on Afghanistan. Their study highlights that lack of effective community involvement can result in poorly planned projects, lack of community support, and unsustainable outcomes. The research identifies nine key barriers to community participation: opaque reconstruction processes, sponsors' pressure for hasty outcomes, low community capacity, gender inequality, insufficient NGO competence, community weaknesses, slow land acquisition, ineffective government policies, and inadequate security. These barriers hinder effective collaboration and contribute to dissatisfaction among stakeholders. The study emphasizes the need for transparent communication, gender inclusivity, and building local capacity to enhance community involvement. Addressing these factors is vital to ensure that reconstruction projects

meet the needs of the affected communities and lead to sustainable development outcomes.

Cueto *et al.* (2015) focus on community participation and strengthening in the reconstruction context following the 2007 earthquake in Peru. Their work emphasizes the importance of identifying community needs, addressing power imbalances, and fostering inclusive participation. The study underscores that rebuilding efforts often reveal pre-existing vulnerabilities and interpersonal issues, such as weak social networks and gender inequalities, which can impede collective recovery efforts. Effective participatory strategies, such as involving communities in defining their priorities and leveraging local leadership, are highlighted as critical for successful reconstruction.

Shafique & Warren (2015) analyze the significance of community participation in post-disaster reconstruction projects in developing countries. Their study on the New Balakot City Development Project in Pakistan reveals that disengagement of local communities led to substantial delays, resource wastage, and project failure. Key issues included lack of consultation with affected populations, socio-economic impacts of relocation, and disputes with local stakeholders. The authors emphasize that meaningful community participation is essential at every project stage to ensure sustainability, ownership, and success of reconstruction initiatives.

Davidson *et al.* (2007) categorize community involvement in housing reconstruction projects into five levels: manipulation, information, consultation, collaboration, and empowerment. Among these, empowerment, where communities have a decisive role in reconstruction planning and execution, is identified as the most effective approach for achieving sustainable and resilient post-disaster recovery. This framework highlights the importance of involving affected communities not only in decision-making but also in the co-creation of solutions, as this fosters a sense of ownership and alignment with local needs.

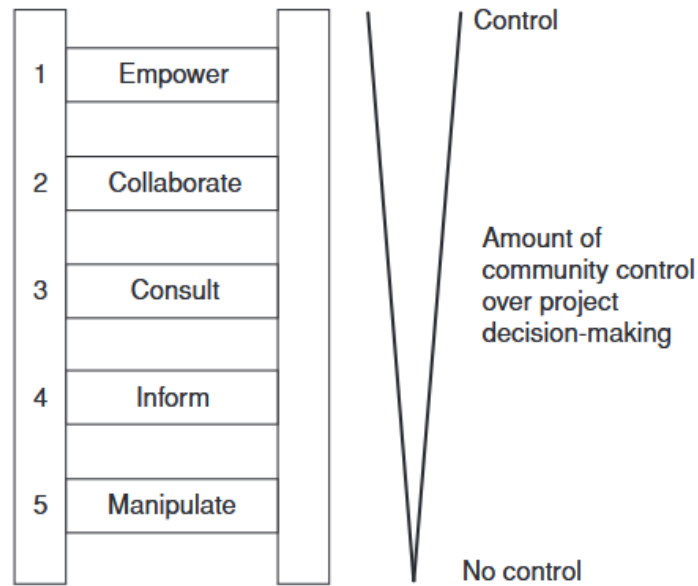


Figure 3 Ladder of community participation

Source: Davidson et al. (2007)

## 2.7 Socio-Cultural Dimensions of post disaster reconstruction

Disregarding socio-cultural practices in the design and planning phases of reconstruction projects can lead to community resistance and significantly reduce their effectiveness (Sadiqi *et al.*, 2015). Pre-existing power dynamics within communities often influence reconstruction outcomes, as unequal relationships can hinder meaningful participation and create barriers to equity (Serrano-García and López Sánchez, 1990).

Integrating local traditions, cultural practices, and social structures into the reconstruction process not only fosters collective ownership but also promotes the preservation of cultural identity (Rodriguez, 2005). Such an approach ensures that reconstruction efforts resonate with the community's unique social fabric, enhancing acceptance and long-term sustainability.

Disara *et al.* (2019) highlight the critical role of cultural considerations in post-disaster reconstruction (PDR) projects, particularly in developing countries. They argue that insufficient attention to community cultural continuity often leads to unsustainable outcomes. The study identifies four core components of PDR projects—site, layout, construction, and policies—as being significantly influenced by community culture. Poor site selection, incompatible housing layouts, and neglect of traditional practices in construction often result in dissatisfaction and failure. The study recommends

increasing community participation and cultural sensitivity at every stage of PDR project to enhance their success and sustainability.

Boen & Jigyasu (2005) illustrates the importance of cultural continuity in reconstruction efforts by revisiting post-disaster cases in Flores, Indonesia, and Marathwada, India. Their findings highlight how inadequate consideration of local customs and socio-cultural systems led to relocation failures and resistance among affected populations. In Indonesia, barrack-style housing designs disconnected fisherfolk from their livelihoods, driving many to return to their original coastal settlements. Similarly, in Marathwada, the shift from traditional clustered village layouts to urban grid patterns disrupted community dynamics and rendered housing impractical for daily rural life. These examples reinforce the need for culturally adaptive strategies in post-disaster planning.

Rahmayati (2016) explores the socio-cultural implications of post-disaster housing reconstruction in Aceh following the 2004 tsunami. Her study emphasizes the necessity of integrating local socio-cultural factors into housing design to restore survivors' ways of life. The research critiques top-down approaches that prioritize speed and cost over community preferences, resulting in housing designs that fail to address cultural and social needs. Issues such as inadequate kitchens, lack of verandas, and restricted space for communal activities disrupted daily routines and diminished community bonds. Rahmayati (2016) advocates for synergy between "hardware" actors (e.g., architects, engineers) and "software" actors (e.g., anthropologists, sociologists) to effectively translate cultural insights into technical housing designs that meet the needs of disaster-affected communities.

Barenstein (2015) examines the long-term impacts of agency-driven reconstruction in post-earthquake Gujarat, India. Using a longitudinal approach, the study investigates how relocated communities adapted to standardized housing and settlement patterns designed by external agencies. The findings reveal that while agency-built houses often disregarded cultural and functional needs, communities exhibited resilience and ingenuity by modifying these houses to better align with traditional lifestyles. Key adaptations included extending living spaces, constructing outdoor kitchens, and re-establishing caste-based neighborhoods. The study highlights the importance of involving communities in the design process and respecting socio-cultural practices to enhance the sustainability and acceptance of reconstruction efforts.

## 2.8 Policy Frameworks and Institutional Challenges

Reconstruction policies often prioritize rapid implementation, neglecting sustainability and the importance of community participation (Beristain and Donà, 1999). Prototype housing designs that enforce uniformity frequently disregard local cultural and social contexts, resulting in dissatisfaction among displaced households (Shrestha *et al.*, 2023). Case studies, such as the post-disaster reconstruction in Balakot, Pakistan, highlight the detrimental impact of political instability and conflicting priorities between national and provincial governments on the progress of reconstruction efforts (Shafique and Warren, 2015).

Humanitarian standards, such as those outlined in the *Sphere Handbook*, stress the importance of culturally and socially relevant designs that meet minimum requirements for shelter, including thermal comfort, durability, and ease of assembly (Sphere Project, 2011). However, institutional challenges, such as poor coordination between humanitarian agencies and local governments, often impede effective implementation (Dev and Das, 2020).

Gender dynamics also significantly influence reconstruction processes. Women frequently bear disproportionate caregiving responsibilities post-disaster, yet are often excluded from decision-making processes (Carrario, 2008). This exclusion is guided by the misconception that women are unable to contribute meaningfully to reconstruction efforts, ignoring their potential to participate effectively and lead initiatives (Ariyabandu, 2009; Juran, 2012). Recognizing and addressing these institutional and societal barriers is critical to fostering inclusive, sustainable recovery efforts.

Montalbano & Santi (2023) investigate the sustainability of Temporary Housing Units (THUs) in post-disaster scenarios, focusing on the interplay between policy challenges and institutional frameworks. The study identifies critical deficiencies in top-down approaches to disaster recovery planning, highlighting their impact on economic, social, and environmental dimensions of housing projects. Key shortcomings include the limited engagement of local communities, the overreliance on imported materials, and the disregard for cultural and climatic specificity. A central discussion in the study revolves around the duality of top-down versus bottom-up planning paradigms. Top-down models are often criticized for imposing standardized designs that neglect local needs, creating housing solutions that are poorly integrated with the affected

community's lifestyle and environment. Bottom-up approaches, however, emphasize stakeholder engagement, leveraging local expertise and resources to achieve culturally sensitive and sustainable housing outcomes.

Alshawawreh *et al.* (2020) examined the challenges and opportunities in designing sustainable post-disaster and post-conflict (PDPC) shelters. The study highlights significant barriers, including a lack of universal terminology, inconsistent categorization of shelter types, and insufficient integration of sustainability considerations into shelter planning processes. These gaps hinder effective policy-making and operational frameworks in disaster response. The authors reviewed the disparity between "novel designs" developed by researchers and "existing solutions" implemented in real-world scenarios and found that novel designs often prioritize innovation without field validation, while existing solutions, though tested, are constrained by resource limitations and fail to meet comprehensive social, environmental, and economic goals. Policy challenges such as misaligned funding structures, lack of community involvement, and regulatory hurdles exacerbate the sustainability deficit in PDPC shelters. This research advocates for evidence-based policy interventions to close the gap between theoretical designs and practical implementation, ensuring holistic and equitable disaster recovery.

## **2.9 Computer Simulations for Post-Disaster Shelter Design**

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 modelssimulate the consumption process of energy by all users in a building. Energy Modeling isbest for relative comparisons between designs.

Costa *et al.* (2023) conducted an analysis of thermal insulators for post-disaster temporary shelters in tropical climates, utilizing Building Energy Simulation (BES) tools. The study focused on repurposing 40-ft high cube shipping containers as shelters and evaluated the effectiveness of two insulation materials: PET wool and mineral wool. The researchers used BES to simulate various scenarios, comparing energy performance in real-world climate conditions. By leveraging BIM tools to create precise 3D models of the container and exporting data into BES software, they assessed

thermal resistance, energy consumption, and cooling needs across different seasons. This integration of simulation tools allowed for a detailed analysis of insulation performance, providing quantitative insights that would have been challenging to achieve through experimental methods alone. For instance, simulations revealed mineral wool's superior thermal performance, reducing energy consumption by 42.8% compared to a non-insulated model. PET wool, while less effective overall, offered cost advantages for short-term applications with a 30.98% reduction.

Kuchai *et al.* (2020) explored the potential for computational IT tools to optimize shelter design in post-disaster scenarios. Their study addressed a critical gap: the lack of computational tools used by aid workers during shelter planning. Through a two-stage methodology, they developed and tested shelter-specific tools to assess daylighting and environmental impacts. The researchers surveyed 30 aid workers from 19 countries, revealing that none employed building simulation tools for shelter design. Responding to this, they created a web-based environmental impact tool and a daylight calculation spreadsheet. The tools were tested by 48 participants in a follow-up survey, with 97% identifying the need for such technologies in shelter design. Most preferred web applications for accessibility and ease of use. The findings highlight the transformative potential of simulation-based methodologies in shelter planning. By bridging the gap between computational design and field applications, these tools demonstrated their ability to enhance decision-making, optimize design strategies, and adapt to diverse climatic and cultural contexts.

Asfour (2019) conducted a detailed investigation of sheltering solutions in the Gaza Strip, utilizing computational simulations to optimize thermal comfort in temporary housing. The study evaluated shipping containers as potential shelter options and analyzed their thermal performance using DesignBuilder and Ecotect software. Both tools provided consistent outputs, highlighting critical thermal weaknesses in uninsulated steel container housing, such as poor thermal comfort in extreme temperatures. Parametric modeling tested three strategies: reducing solar absorption, unit grouping for surface exposure minimization, and applying thermal insulation. Simulations revealed that thermal insulation significantly improved comfort by reducing heat gains in summer and losses in winter. For instance, insulated units showed a 52–65% reduction in summer heat gains and a 44–57% reduction in winter heat losses, with corresponding improvements in thermal comfort indices. This study

emphasizes the value of advanced computational tools for assessing and optimizing design interventions in challenging post-disaster contexts. The results demonstrate how simulations guide effective shelter design, addressing climatic challenges while emphasizing resource-efficient and scalable solutions.

Montalbano & Santi (2023) explore the sustainability of Temporary Housing Units (THUs) in post-disaster scenarios, emphasizing a requirement-based design approach. The study identifies critical challenges associated with current THUs, including economic, social, and environmental shortcomings, while proposing an innovative framework for creating more sustainable units. These challenges include the high initial costs of implementing sustainable materials, logistical barriers in the deployment of prefabricated systems, limited adaptability of designs to diverse cultural and climatic conditions, and insufficient engagement of affected communities during the planning and design phases. Their methodology, as it enables the evaluation of design variables under diverse scenarios is suitable for computer simulation-based analyses which strengthens iterative design processes. By emphasizing modular prefabrication systems and local material use, the study allows simulations to test economic efficiency, thermal performance, and environmental adaptability. The research concludes that simulation-driven analyses validate proposed designs against key sustainability parameters, illustrating the practicality and scalability of THUs.

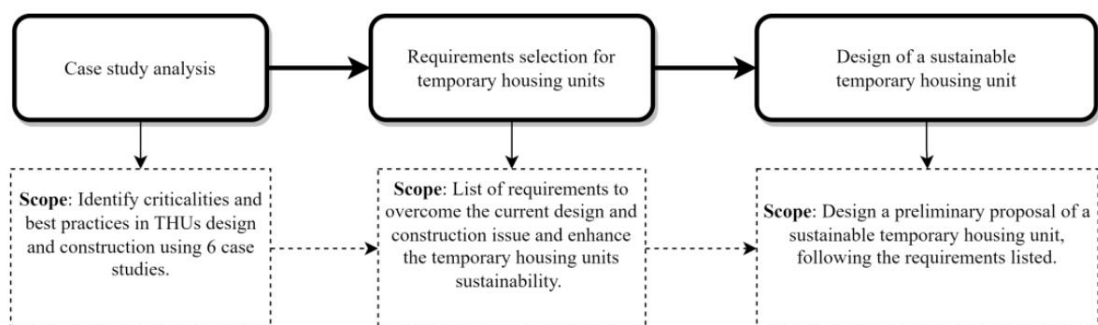


Figure 4 Methodology as proposed by Montalbano & Santi (2023)

Simulation tools have shown potential for optimizing shelter designs. However, their use in low-income and resource-constrained reconstruction projects is minimal, mainly due to the lack of user-friendly, accessible tools for non-experts.

## 2.10 Residential satisfaction in post disaster reconstruction

Residential satisfaction, often termed as housing satisfaction, in post-disaster contexts is defined as a reflection of how well housing meets the goals, needs, and desires of its

residents (Danquah, Attippoe and Ankrah, 2014) and is the feeling of contentment when one has or achieves what one needs or desires in a house (Shrestha, Uprety, & Pokharel, 2023).

Capell & Ahmed (2021) examined community consultation practices in post-disaster housing reconstruction (PDHR) projects within the Global South. Through a qualitative approach, the researchers analyzed relevant literature and case studies to highlight key indicators influencing satisfaction, such as cultural alignment, socio-economic considerations, and stakeholder engagement. The findings reveal that traditional project management approaches often overlook these critical aspects, leading to misaligned designs and reduced satisfaction. In response, the authors propose a comprehensive framework for effective community consultation, recommending inclusive, culturally sensitive practices to ensure beneficiary needs are accurately reflected.

Okazaki (2017) examined residential satisfaction and housing modifications in disaster-induced resettlement sites in Cagayan de Oro, Philippines, following Typhoon Washi. The study evaluates how residents perceive the adequacy of permanent housing, contrasting pre- and post-disaster living conditions and exploring the reasons behind housing modifications. The research employed mixed methods, including surveys, interviews, and field observations, across four resettlement villages with different housing designs and management practices. The findings reveal that while residents appreciated the enhanced safety and basic services of post-resettlement housing, dissatisfaction arose from limited alignment with local cultural practices and daily living requirements. Specific concerns included inadequate thermal comfort, insufficient space for livelihood activities, and restricted opportunities for self-modifications due to occupancy regulations. Key challenges stemmed from the entirely top-down resettlement process, which prioritized compliance with minimum technical standards over cultural and social considerations. This led to a disconnect between the provided housing and residents' needs, prompting unregulated housing modifications to improve functionality and comfort. Notably, villages with greater post-occupancy support from NGOs experienced higher satisfaction levels and fewer precarious modifications. The findings highlight the importance of balancing technical compliance with cultural relevance and facilitating planned modifications to support resident-driven improvements. These insights emphasize the role of participatory approaches in achieving sustainable resettlement solutions.

Shrestha *et al.* (2022) examined residential satisfaction in the Thakle Integrated Settlement, a resettlement project for 31 displaced households in Sindhupalchok, Nepal, following the 2015 Gorkha Earthquake. The study utilized a 5-point Likert scale to assess satisfaction across indicators like planning and design, plot size, number of rooms, architecture style, building material, construction quality, and thermal comfort. High satisfaction was reported for planning and design (score: 99), construction quality and technology (97), and building materials (91), which the authors attribute to community consultation during the planning and construction phases. However, the study highlighted dissatisfaction with thermal comfort (score: 70) and the number of rooms (score: 83). Poor thermal performance was linked to non-climatic CGI roofing and inadequate ventilation, while the "one-size-fits-all" house design failed to meet the socio-cultural needs of rural Tamang communities. This led to modifications like expanding rooms, adding attic spaces for grain storage, and creating outdoor spaces for kitchen gardens and cultural practices such as flagpoles for Lhosar celebrations.

Shrestha *et al.* (2023) investigated factors influencing housing satisfaction in post-disaster resettlement housing in Nepal, using the Panipokhari Integrated Settlement as a case study. The study employs a mixed-methods approach, combining surveys, interviews, and field observations, to assess critical factors such as thermal comfort, need-based design, cultural considerations, and space for livelihood activities. Key findings indicate that inadequate thermal comfort, lack of flexibility for house modifications, and insufficient provisions for traditional practices and livelihoods are major sources of dissatisfaction. However, residents appreciated the earthquake-resistant construction and sanitation facilities. The factors influencing residential satisfaction as identified by the research are housing design, housing construction, housing performance and socio-cultural and psychological factors.

Uprety and Shrestha (2024) explored place attachment in the Panipokhari Integrated Settlement, a resettlement project for Thami households in Dolakha, Nepal, following the 2015 Gorkha earthquake. Using residential satisfaction as a measure of functional place dependence, the study identified factors influencing residents' attachment to the settlement. Social connectivity, represented by proximity to relatives, showed the highest correlation ( $r = 0.720$ ,  $p = 0.000$ ), emphasizing the importance of familial and community ties. Similarly, settlement planning elements like kitchen gardens ( $r = 0.623$ ,  $p = 0.000$ ), open spaces ( $r = 0.578$ ,  $p = 0.000$ ), and cattle sheds ( $r = 0.574$ ,  $p =$

0.000) were critical for fostering attachment. Housing design factors such as spaces for life cycle rituals ( $r = 0.771$ ,  $p = 0.000$ ), winter thermal comfort ( $r = 0.600$ ,  $p = 0.000$ ), and spaces for social events ( $r = 0.663$ ,  $p = 0.000$ ) also demonstrated strong positive correlations. However, dissatisfaction emerged from inadequate house sizes and standardized designs that overlooked cultural needs, leading to low satisfaction with immediate exterior spaces and thermal performance.

Residential satisfaction in post-disaster reconstruction emerges as a multifaceted concept influenced by housing design, cultural considerations, community engagement, and functionality. The reviewed studies highlight that while factors such as earthquake-resistant construction, sanitation facilities, and community consultation positively contribute to satisfaction, significant gaps remain in addressing thermal comfort, cultural alignment, and flexibility for modifications. Studies reveal that community engagement, culturally sensitive designs, and provisions for traditional practices are critical to enhancing satisfaction, yet challenges such as inadequate thermal comfort, limited space for modifications, and standardized housing designs persist.

## **2.11 Theoretical Framework**

This research is grounded in theories related to passive design strategies, socio-cultural dimensions of housing, community participation, energy efficiency, and the Build Back Better approach, which collectively guide the study of thermal comfort and energy performance in post-disaster reconstructed shelters.

Passive design strategies focus on minimizing energy use while optimizing indoor thermal comfort. Theories from Fanger (1970) and ASHRAE standards form the basis for evaluating thermal environments. These principles include orientation, shading, thermal mass, and natural ventilation, which are critical in post-disaster housing reconstruction. Rahmayati (2016) and Barenstein (2015) emphasize the role of cultural relevance in reconstruction projects. This study integrates theories of cultural sustainability, ensuring the proposed designs align with community traditions and practices. The framework considers Davidson et al's (2007) ladder of community participation, which underscores empowerment as a critical level for achieving sustainable reconstruction. The research focuses on active involvement from stakeholders and residents in the design process. Building on the work of Shrestha et al. (2023) and Kuchai et al (2020), this framework explores the connection between

building envelope characteristics and indoor thermal comfort. It integrates computational energy modeling tools to evaluate and enhance the energy efficiency of post-disaster reconstructed shelters, ensuring optimized performance and occupant well-being. The study aligns with the "Build Back Better" philosophy, emphasizing not only the restoration of housing but also improvements in resilience, sustainability, and comfort. This approach is central to Nepal's post-disaster reconstruction policies.

## **CHAPTER 3: RESEARCH METHODOLOGY**

### **3.1 Research Paradigm**

The aim of this study is to evaluate thermal comfort and energy efficiency in post-disaster reconstructed shelters in the Jajarkot district following the 2023 earthquake. The research adopts a pragmatic paradigm, integrating both qualitative and quantitative methods within a mixed-method case study approach. This methodological framework ensures a comprehensive understanding of the interplay between technical performance and socio-cultural preferences in post-disaster housing.

The central research questions guiding this study are:

1. What is the thermal comfort in post disaster reconstructed shelters during winter?
2. How do socio-cultural preferences and building features influence thermal comfort and energy efficiency in post-disaster shelters?
3. What design improvements can be proposed to enhance thermal comfort and energy efficiency in the affected region?

To address these questions, the research methodology incorporates an extensive review of literature, on-site data collection, stakeholder engagement, and energy simulations to propose design strategies aligned with the principles of thermal comfort, sustainability, and cultural relevance.

### **3.2 Research Philosophy**

The study aligns with the pragmatic research paradigm, emphasizing the practical integration of diverse data collection and analysis techniques to derive actionable solutions (Creswell, 2003). Pragmatism supports the combination of objective, measurable data with subjective insights to address complex real-world problems effectively.

#### **3.2.1 Ontology**

The research assumes that the lack of awareness, less community participation, inadequate policy frameworks, and resource constraints contribute to the poor thermal comfort in post-disaster shelters. The ontological claim of this study is that prototype houses fail to meet thermal and cultural needs due to a "one-size-fits-all" design approach, ignoring local climatic and socio-economic contexts.

### **3.2.2 Epistemology**

The epistemological approach is grounded in the collection and analysis of both quantitative and qualitative data. The study assumes that knowledge of thermal comfort, energy consumption, and resident satisfaction can be derived through objective field measurements, surveys, and simulations, complemented by subjective insights from community engagement.

### **3.2.3 Axiology**

This research adopts a value-driven approach, recognizing the importance of inclusivity, cultural relevance, and community participation in reconstruction practices. It seeks to ensure that the proposed solutions not only enhance thermal comfort and energy efficiency but also align with the socio-cultural values of the affected communities.

## **3.3 Research Design**

The study adopted a mixed-method research approach that combines qualitative and quantitative methods to effectively achieve the research objectives. This approach ensured a holistic understanding of thermal comfort, energy efficiency, and socio-cultural preferences in post-disaster reconstructed shelters in the case study area.

### **3.3.1 Qualitative Method**

The qualitative research method employed in this study was designed to thoroughly understand the social, cultural, and experiential dimensions of post-disaster housing reconstruction. This approach prioritized the voices, perceptions, and lived realities of affected individuals and communities, with a particular focus on how they manage and influence the post-disaster reconstruction process. The goal was to understand not only what was rebuilt, but also why certain decisions were made and how these reflect deeper sociocultural values and environmental responses.

**Literature Review:** A comprehensive review of existing literature, technical reports, and academic papers was conducted to establish a solid theoretical and contextual foundation for the study. This review focused on multiple interconnected topics, such as thermal comfort in residential buildings, domestic energy consumption patterns, and established practices in post-disaster housing reconstruction. Particular attention was paid to studies emphasizing passive design strategies, sustainable and low-carbon

building techniques, and the sociocultural dimensions that often influence reconstruction decisions. The literature review helped identify knowledge gaps, understand global and regional best practices, and align research objectives with current academic and practical discourses in the field of disaster reconstruction and sustainable architecture.

**Semi-Structured Interviews:** To obtain direct input from the community and stakeholders in the reconstruction process, a series of semi-structured interviews were conducted. These interviews included local residents, field technicians, elected representatives, and other key stakeholders directly or indirectly involved in the reconstruction efforts. The semi-structured nature of the interviews allowed for flexibility to explore various topics while maintaining a consistent framework across participants. These conversations aimed to reveal the following dimensions:

- i. Residents' experiences regarding thermal comfort, indoor environmental quality, and daily energy consumption, both in temporary shelters and in reconstructed homes.
- ii. Individual and collective perceptions of housing needs, architectural preferences, and aspirations for future housing.
- iii. Stakeholder perspectives on critical aspects such as material availability, design decision-making, construction challenges, and the prioritization of structural over cultural elements in reconstruction efforts.

**Community-Driven Design:** As a participatory element of the qualitative method, selected key informants and a few representative respondents were invited to visualize their ideal home. This exercise consisted of drawing or verbally describing their preferred house design. The process helped extract valuable information about common floor plans, spatial layout, optimal building orientation, and the choice of culturally rooted materials. These responses revealed the community's collective preferences and expectations, offering insight into what a socially accepted and contextually relevant reconstruction might look like. This bottom-up approach ensured that design considerations were grounded in the realities and aspirations of the affected population, rather than being externally imposed.

In short, the qualitative method adopted in this study served to contextualize the research, embedding it within the social fabric of the study area. It provided a rich and

nuanced understanding of the cultural, experiential, and practical challenges that arise in post-disaster reconstruction, highlighting the importance of human-centered and culturally sensitive design for building back better.

### **3.3.2 Quantitative Method**

The quantitative research method adopted in this study aimed to investigate the measurable and empirical aspects of post-disaster housing reconstruction, focusing specifically on thermal performance, energy consumption, and resident satisfaction. Through the use of structured data collection tools and analytical methods, the quantitative approach provided objective information that complemented the qualitative findings, offering a comprehensive understanding of both human experiences and environmental performance.

**Thermal Satisfaction Assessment:** To assess the subjective thermal comfort of occupants during the winter season, a structured questionnaire survey was administered to residents in the case study area. The survey tool was adapted from the work of (Shrestha *et al.*, 2023), which had been previously validated in similar climatic and socio-cultural contexts. The questionnaire aimed to capture a broad spectrum of resident experiences, including their level of satisfaction with indoor thermal conditions, perceptions of cold discomfort, clothing insulation practices, and behavioral adaptations such as use of heating appliances or changes in activity patterns. This data was instrumental in understanding the extent to which existing dwellings meet or fall short of acceptable thermal comfort standards.

**Thermal Sensation Vote:** A precise and timely assessment of thermal satisfaction can be measured using Thermal Sensation Vote (TSV). TSV is collected using a structured questionnaire survey. For this study, a separate structured questionnaire survey was designed to record occupants' immediate thermal sensations at different times of the day. This enabled the collection of dynamic data reflecting real-time thermal experiences under various indoor and outdoor conditions. The TSV questionnaire translated into Nepali for better understanding and ease of response, was adapted from the methodology developed by (Thapa, Rijal and Shukuya, 2018). Repeated sampling of the same respondents throughout the day helped identify fluctuations in thermal perception and their correlation with diurnal environmental variations, clothing type, and activities.

**Energy Consumption Analysis:** To understand the community's overall energy consumption patterns, a household energy consumption survey was conducted in the study area. The survey collected detailed information on the types and quantities of energy sources used for various household functions, such as cooking, heating, lighting, and electrical appliances. This included data on the wattage of commonly used electrical appliances, average daily usage duration, and monthly consumption of other fuels, such as firewood, LPG, or kerosene. By analyzing this data, the study sought to construct a representative profile of energy consumption behavior in the region, offering insights into environmental impacts and residents' concerns regarding energy affordability.

**Thermal Performance Evaluation:** To validate and complement the findings obtained through structured surveys and occupant feedback, objective environmental measurements were conducted using digital data loggers. These instruments were deployed to continuously record indoor and outdoor temperature, as well as relative humidity levels, over a defined monitoring period. The measurement campaign took place from January 29 to February 22, 2025, capturing environmental conditions during winter, a period that typically presents thermal discomfort problems for households in the region.

Two representative houses were selected to reflect the contrasting housing typologies observed in the post-disaster context. The first was a vernacular house, built using stone and mud masonry techniques, which characterize indigenous construction practices and the availability of materials in the area. The second was a modern house built with reinforced cement concrete (RCC), representing the emerging trend for seismic safety. By selecting one house from each category, the study sought to evaluate and compare the thermal behavior of traditional and modern architectural forms under similar climatic conditions.

Inside each home, data loggers were installed at a height of 1.5 meters above ground level on the first level. This specific height was chosen because it approximates the average height at which the human body perceives indoor environmental conditions, whether standing or sitting. It is generally considered the most relevant elevation for measuring the thermal comfort experienced by building occupants. This location aligns with human-centered environmental assessment protocols and ensures that the data collected reflects the thermal conditions that most directly affect residents.

In addition to indoor monitoring, an outdoor data logger was installed to record ambient climate conditions. It was carefully positioned on the north facade of the home, a strategic decision to avoid direct solar radiation, which could artificially elevate temperature readings and distort the accuracy of outdoor thermal data. This sensor provided a continuous record of outdoor temperature and relative humidity, offering a baseline for assessing indoor conditions.

The collected data served as the primary basis for evaluating the thermal performance of two housing types. By analyzing this data, the study was able to draw comparisons between the heat retention and humidity control capabilities of vernacular and modern homes. These findings were crucial for understanding how different building materials and design approaches influence indoor comfort during winter and how they align, or fail to align, with the thermal needs of local residents.

### **3.4 Research Methodology**

The research methodology adopted for this study was comprehensive, interdisciplinary, and phased, ensuring a systematic exploration of the interrelated topics of energy efficiency, thermal comfort, and post-disaster housing reconstruction. The approach was divided into three distinct stages, each building on the results of the previous one, allowing for a gradual transition from conceptual understanding to practical application. This multistage framework ensured both depth and breadth of research, integrating theoretical perspectives, field data, and performance-based simulations to derive contextual recommendations.

#### **3.4.1 First Stage**

The research began with a comprehensive and critical review of the existing literature, which served to establish the theoretical framework and guide the development of the research objectives. This initial stage was essential to clarify the scope of the study, identify research gaps, and refine the central questions.

Academic research articles, technical reports, policy documents, and case studies related to thermal comfort, energy-efficient architecture, and post-disaster reconstruction were thoroughly analyzed. Particular emphasis was placed on studies that included passive design strategies, vernacular building practices, and thermal performance assessments in rural or mountainous regions similar to the case study area.

These sources provided a conceptual basis from which key variables and performance criteria were extracted.

In addition, national and local policy documents relevant to energy efficiency, building codes, post-earthquake reconstruction strategies, and environmental sustainability in Nepal were reviewed. This included examining guidelines provided by the Government of Nepal and relevant international frameworks to ensure the research was informed by and responsive to the prevailing policy environment. Overall, this phase laid the intellectual foundation for the research and justified the need for an integrated approach that combined social, environmental, and architectural perspectives.

### **3.4.2 Second Stage**

The second stage involved identifying the study area, followed by on-site data collection and community engagement. Rimna Village, Bheri-1 Municipality, Jajarkot, one of the region's most severely affected by the 2023 Jajarkot earthquake, was selected as the primary study location. The selection was based on the extent of destruction, ongoing reconstruction activities, and the presence of diverse housing typologies, including vernacular and modern building.

In this stage, a climate analysis was conducted using historical data obtained from the Department of Hydrology and Meteorology (DHM) and EnergyPlus. This helped understand local climatic conditions and identify the guideline for design recommendation using Mahoney's Table. This analysis was instrumental in determining what type of passive design strategies would be most appropriate for the local context.

Field measurements were taken by installing temperature and relative humidity data loggers in selected homes. These devices recorded environmental conditions for three weeks, providing continuous data on indoor and outdoor thermal behavior throughout the winter. In parallel, structured household surveys were conducted to collect demographic information, energy consumption patterns, thermal comfort experiences, and opinions on the perceived room temperature at different times of the day.

To obtain qualitative information, semi-structured interviews were conducted with a wide range of key stakeholders, including local residents, community leaders, elected representatives, engineers, and architects. These interviews provided valuable insights into reconstruction priorities, material preferences, traditional building practices, and

challenges faced during the reconstruction process. As part of a participatory design approach, selected participants were invited to draw or verbally describe their ideal home, highlighting the floor plan, spatial layout, building orientation, and preferred material selection. Observations were also made on construction techniques, spatial organization, and accessibility to resources, factors that influence thermal performance and energy demand.

### **3.4.3 Third Stage**

The final stage of the research involved the synthesis and analysis of the various data collected during the first two phases. This included comparing the findings from the literature review, climate data analysis, survey responses, thermal measurements, and interviews to draw comprehensive conclusions about the thermal and energy performance of different housing types.

To explore opportunities for improvement, energy simulation modeling was conducted using DesignBuilder, a dynamic building simulation software. A base model of a typical home was developed using field data, and multiple design iterations were tested by modifying key parameters such as wall insulation, roof materials, window-to-wall ratio (WWR), glazing type, and natural ventilation strategies. The objective was to assess how these design variations influenced annual energy demand for heating and cooling, as well as indoor thermal comfort levels.

Scenario-based simulations were compared with thermal performance data collected from actual homes to validate the models and understand performance gaps. The analysis was complemented by feedback from community members and technical stakeholders, ensuring that the proposed designs were not only energy-efficient but also socially acceptable, economically viable, and culturally appropriate.

Based on the results of this phase, the study proposed a set of climate-responsive, energy-efficient, and thermally comfortable building design tailored to post-disaster reconstruction in rural and mountainous regions of Nepal. These recommendations aim to guide future reconstruction efforts, contribute to sustainable reconstruction practices, and improve housing resilience in disaster-prone areas.

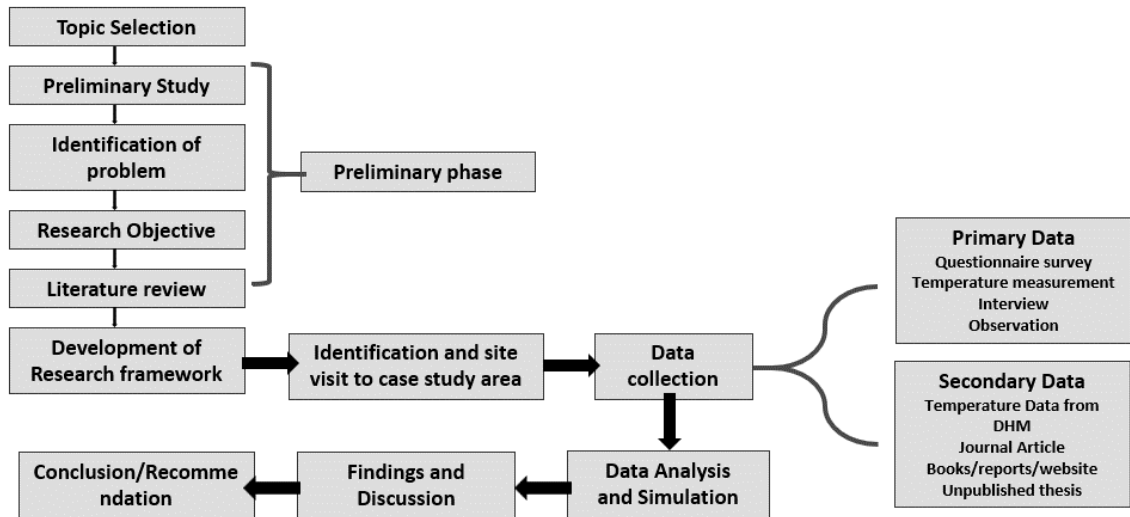


Figure 5 Methodological framework of the research

### 3.5 Methods of data collection

#### 3.5.1 Survey

In order to collect the field data of this research, questionnaire survey of 50 households was done through Kobo toolbox. Although the survey was aimed at covering all 57 households, it was only conducted in 50 households as not all families were available during data collection schedule.

#### 3.5.2 Operationalization

The detailed study and measurement of the selected houses was conducted to facilitate an in-depth understanding of their thermal performance and design characteristics. This involved preparing accurate building layouts and drawings, documenting architectural features, material usage, and construction techniques and establishing baseline data for energy simulations.

#### 3.5.3 Data Collection

Various data loggers were used to record air temperature and relative humidity (Table 2). These instruments were calibrated for accuracy before deployment. Weather data from the Department of Hydrology and Meteorology was used to contextualize field measurements.

Table 2 Instruments used in the study

S.N.	Parameters measured	Name of the instruments	Range	Accuracy
1.	Air temperature and Relative humidity	Hobo Onset UX100-003	-20° to 70°C, 15% to 95% RH	±0.21°C from 0° to 50°C, ±3.5% from 25% to 85% including hysteresis at 25°C (77°F); below 25% and above 85% ±5% typical
		Hobo MX2302A	-40 to 70°C, 0 to 100% RH	+/- 0.2C° and +/- 2.5% RH
		T&D RTR-576	0 to 55°C, 10-95% RH	±0.5°C and ±5%RH at 25°C, 50%RH
2.	Radiant temperature	T&D TR52i Thermo recorder	-60 to 155°C	±0.3°C at -20 to 80°C

Observations, interviews, and responses from structured questionnaires provided insights into occupant behavior, energy usage patterns, and satisfaction with thermal comfort. Respondents were asked to sketch or describe their ideal house designs, contributing to culturally relevant and widely accepted housing recommendations. Based on theoretical framework and literatures, the research has followed a framework for proposing housing design for the case study area (Fig. 6).

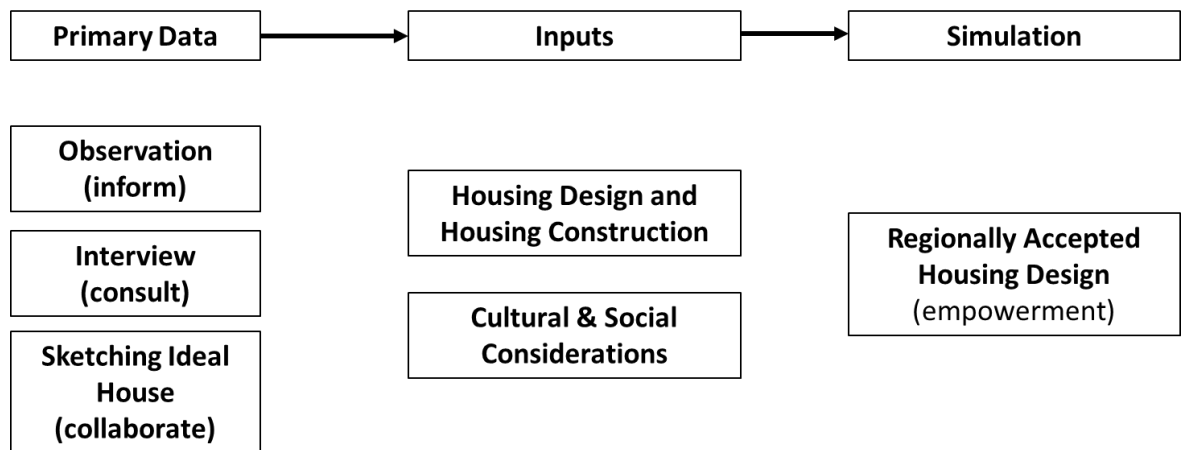


Figure 6 Participatory framework for housing design

Source: Study team

### 3.5.4 Data Analysis

Data on air temperature and humidity collected from loggers was analyzed to identify trends in indoor environmental conditions. Mahoney’s table was used as a reference for energy efficient optimization of the proposed housing, Design Builder software was used to simulate energy performance inside building. Scenarios were created by altering building features (e.g., materials, insulation, and openings) to evaluate potential improvements in thermal comfort and energy efficiency. Responses from questionnaire survey were processed and analyzed using Kobo Toolbox and MS Excel. The results highlighted on residents' thermal satisfaction, energy usage patterns, and adaptive behaviors. Transcripts from interviews with residents, stakeholders, engineers, architects, and local representatives was coded thematically to identify recurring patterns, insights, and narratives. Themes included housing needs, cultural relevance, material preferences, and thermal comfort perceptions. Analysis of these data was conducted using manual thematic coding. Notes from on-site observations of building designs, spatial arrangements, and material usage was analyzed to identify factors influencing thermal comfort and energy performance. Observational findings complemented interview data, providing a richer understanding of the socio-cultural dimensions of housing design.

### 3.6 Conceptual framework

The conceptual framework of the research explores the interplay between independent variables, intervening variables, processes, and dependent variables, providing a

comprehensive understanding of the factors influencing energy efficiency, thermal comfort, and residential satisfaction in post-disaster shelters.

The independent variables include design parameters, environmental conditions, and community involvement. Design parameters, such as building orientation, window-to-wall ratio (WWR), and building materials, play a critical role in shaping the thermal and energy performance of the shelter. Environmental conditions, such as the local climate, solar radiation, and seasonal temperature variations, determine the external forces that influence indoor comfort. Additionally, community involvement through consultation, active participation in planning, and feedback incorporation ensures that the design reflects the needs and preferences of the residents.

The intervening variables, which mediate the relationship between the independent and dependent variables, include cultural factors and policy frameworks. Cultural factors, such as compatibility with traditional practices and adaptability to social norms, ensure the shelters align with the socio-cultural context of the affected community. Policy frameworks, encompassing housing guidelines and reconstruction policies, provide the necessary regulatory structure to guide the implementation process.

The processes that connect these variables include the integration of passive design strategies, application of policies, and community feedback integration. Passive design strategies involve techniques like the use of thermal mass, shading devices, cross-ventilation, and the application of local materials to enhance energy efficiency and indoor comfort. Policy application ensures compliance with reconstruction standards, guaranteeing the shelters meet the required benchmarks. Community feedback integration involves incorporating residents' input into the design, ensuring that the shelters align with their expectations and functional requirements.

The dependent variables reflect the outcomes of the framework, namely thermal comfort and thermal performance. Thermal comfort is measured by indoor temperature stability, predicted mean vote (PMV), and predicted percentage dissatisfied (PPD). Thermal performance focuses on metrics like discomfort hours and thermal condition inside a building.

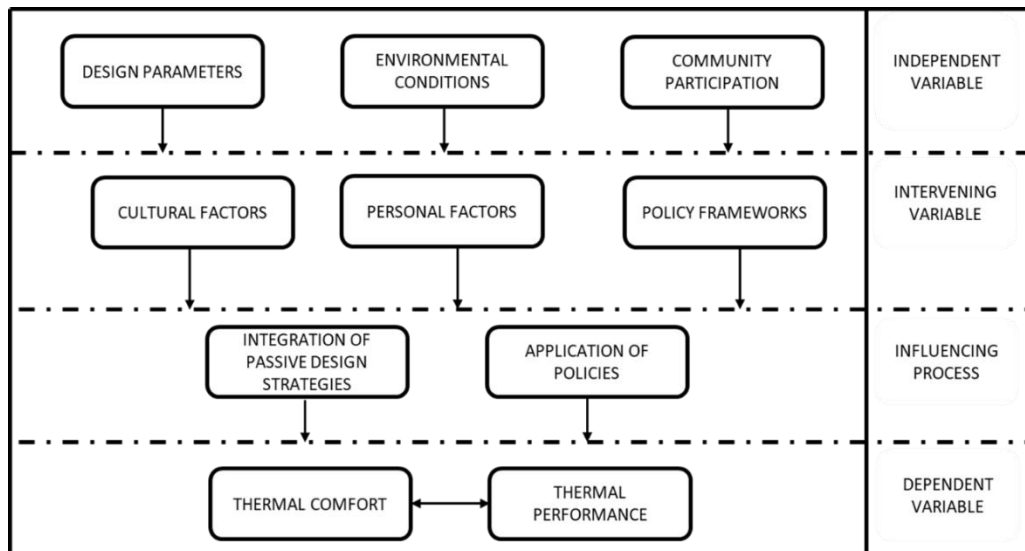


Figure 7 Conceptual framework of the research

## CHAPTER 4: DISASTER CONTEXT

### 4.1 Overview of the 2023 Jajarkot Earthquake

#### 4.1.1 Seismic Overview

On November 3, 2023, at 18:02:54 (UTC), a moderate earthquake struck the Jajarkot district of Nepal. The United States Geological Survey (USGS) reported a moment magnitude ( $M_w$ ) of 5.7 ( $6.4 M_L$ ), with an epicenter at  $28.852^\circ\text{N}$ ,  $82.163^\circ\text{E}$ , and a focal depth of 32.6 km. Despite its moderate magnitude, the earthquake caused substantial loss of life and property, resulting in 153 fatalities and widespread damage to more than 62,000 houses (UNRCO, 2023). Strong shaking was felt as far as the Indo-Gangetic Basin in India (Silwal *et al.*, 2024), which highlights the regional impact of the event.

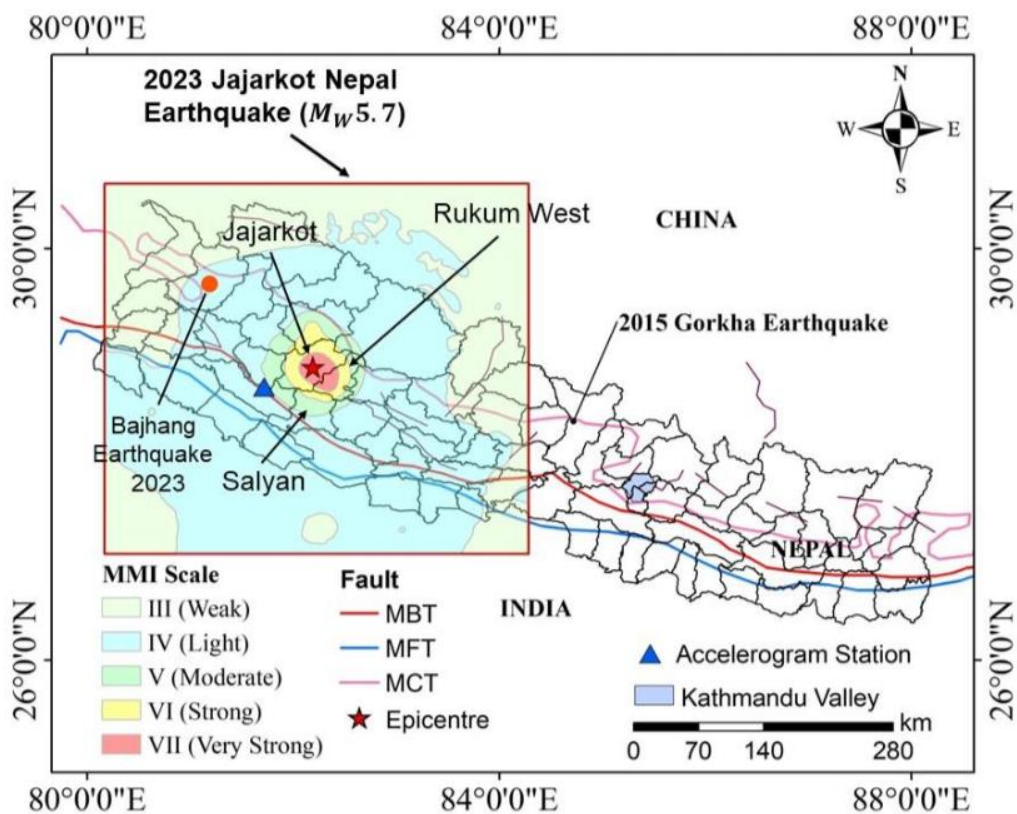


Figure 8 Affected area map of 2023 Jajarkot Earthquake

Source: (USGS, 2023; Subedi *et al.*, 2024)

Western Nepal has experienced multiple significant earthquakes in the past, underscoring its seismic vulnerability. The region lies within the Main Himalayan Thrust (MHT), a major tectonic boundary where the Indian plate subducts beneath the Eurasian plate. This tectonic setting has resulted in numerous destructive earthquakes,

including the 1505 Lo Mustang earthquake, estimated to have been of magnitude 8.0+, and the 1833 Nepal earthquake, which affected large portions of central and western Nepal. More recently, the 1934 Bihar-Nepal earthquake (Mw 8.1) and the 2015 Gorkha earthquake (Mw 7.8) released significant seismic energy but did not fully rupture the western segment of the MHT.

Seismologists have identified the "seismic gap" in western Nepal, an area where accumulated tectonic stress has not been released by a major earthquake in recent history. This unruptured segment, combined with stress loading from previous earthquakes in Nepal and northern India, suggests that western Nepal remains at high risk of a future large-magnitude earthquake. Recent studies indicate that large earthquakes in 1905 (Kangra), 1934 (Bihar-Nepal), and 1950 (Assam-Tibet) have redistributed tectonic stress toward western Nepal, increasing the probability of a major seismic event in the near future (Silwal et al., 2024).

The energy accumulation in this region is further confirmed by Global Positioning System (GPS) measurements, which show continued northward movement of the Indian plate at a rate of approximately 2 cm per year. Without significant energy release, the seismic gap in western Nepal remains a critical concern for disaster preparedness and mitigation strategies. The potential for a magnitude 8.0+ earthquake in this region poses a significant threat to densely populated rural areas with limited infrastructure resilience.

Given this heightened risk, it is imperative that seismic-resistant construction, retrofitting of existing buildings, early warning systems, and community awareness programs are prioritized to minimize the potential devastation of future earthquakes in western Nepal.

#### **4.1.2 Impacts of the Earthquake**

The earthquake caused 153 deaths in Jajarkot and Rukum West district. According to the National Emergency Operation Centre (NEOC), approximately 62,011 households were damaged (completely and partially) and 250,000 people were affected (127,750 females and 122,250 males, including 69,575 children), with Jajarkot and Rukum West districts bearing the brunt of the damage. The disaster severely damaged over 62,000 houses, including 26,557 that were completely destroyed and 35,455 that were partially damaged (NDRRMA, 2023b). Families set up temporary shelters next to damaged

homes facing harsh winters with local materials where old age people, infants, and lactating mothers succumbed to respiratory illnesses (UN, 2024).

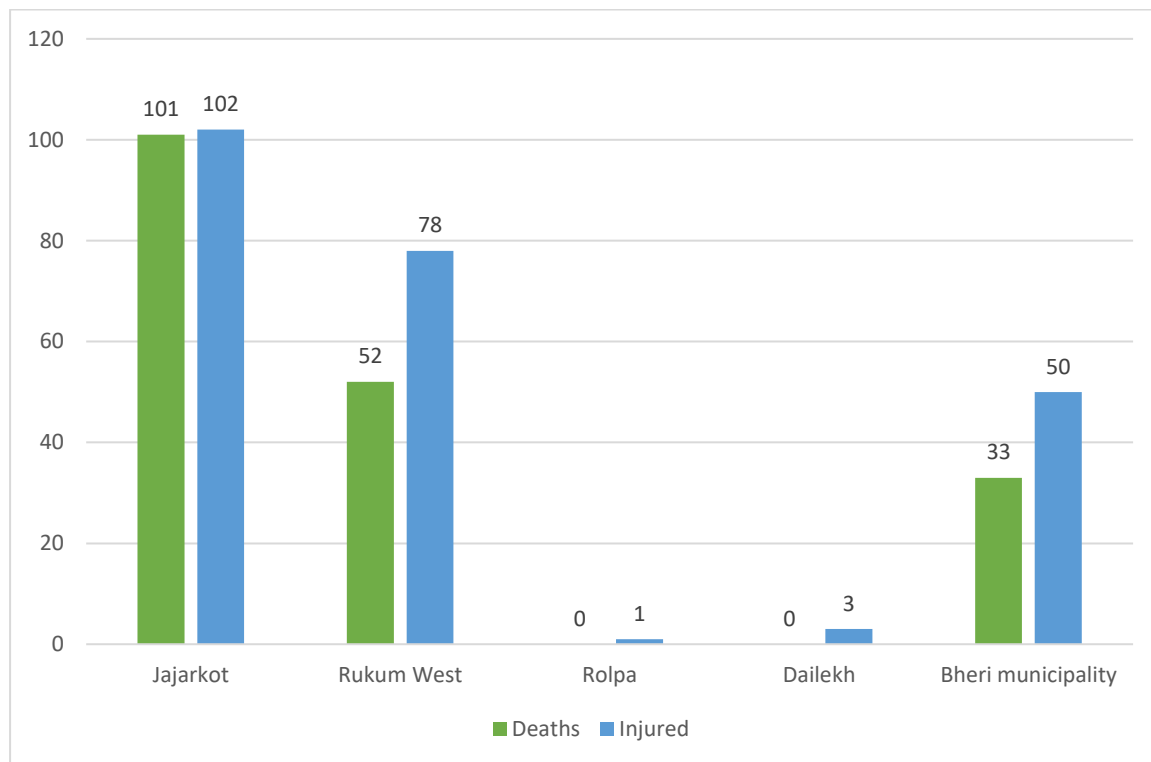


Figure 9 Total injured and deaths of 2023 Jajarkot earthquake

Source: (UNRCO, 2023)

#### 4.1.3 Government and International Response

##### i. Governmental Response

The Nepalese government responded swiftly to the 2023 Jajarkot earthquake, demonstrating a proactive approach to disaster management (NDRRMA, 2023a). Within 48 hours of the disaster, search and rescue operations were concluded, marking an immediate lifesaving response. The government allocated NPR 50,000 for each household with completely damaged homes to aid in the construction of temporary shelters, with disbursements contingent on adherence to minimum construction standards (Republica, 2023). Additionally, NPR 200,000 was provided to families of those killed, and free medical treatment was made available for all injured individuals (THT, 2023).

##### ii. International response

Internationally, the United Nations (UN) and its agencies promptly supported the government's efforts. The International Organization for Migration (IOM), World Food Programme (WFP), World Health Organization (WHO), and UNICEF played significant roles in delivering aid and resources (UN, 2024). The NRCS deployed Emergency Response Teams (ERTs) to conduct Initial Rapid Assessments (IRAs) and detailed assessments, involving over 190 volunteers across Jajarkot and Rukum West (NRCS, 2023). Bilateral donations from neighboring countries, along with contributions from international NGOs and the private sector, supplemented relief operations. Coordination meetings at the provincial level ensured the alignment of national and international efforts to provide effective and targeted assistance (NDRRMA, 2023a).

National Disaster Risk Reduction and Management Authority (NDRRMA) launched the Joint Recovery Action Plan (JRAP) Western Nepal Earthquake to respond to the needs and long-term resilience of vulnerable communities affected by the Jajarkot earthquake. JRAP is being implemented by four UN agencies – IOM, UNFPA, UNICEF, and WFP – under the leadership of the UN Resident Coordinator's Office with the financial support from the UK's Foreign, Commonwealth and Development Office (FCDO). IOM Nepal in collaboration with Nepal Red Cross Society (NRCS), Catholic Relief Services (CRS)/ National Housing and Settlements Resilience Coordination Platform (NHSRP), and Community Impact Nepal (CIN) is working the shelter component of the program (IOM, 2023).

#### **4.1.4 Immediate aid and relief efforts:**

The immediate aid and relief operations focused on providing essential support to the earthquake-affected regions. Temporary shelters were constructed using materials supplied by both the government and humanitarian partners. Relief items, including tarpaulins, blankets, winter clothing, hygiene kits, and temporary toilets, were distributed to mitigate the harsh winter conditions. The provision of food was prioritized, with 85.72 metric tons of nutritious supplementary food supplied to benefit children under five and pregnant or breastfeeding women.

Emergency medical services were enhanced through the establishment of temporary facilities, deployment of health teams, and the provision of medicines and first-aid kits. Psychological support services were also extended to affected individuals. In addition,

water purification tablets, repaired pipelines, and hygiene supplies addressed the urgent need for clean water and sanitation facilities. Multipurpose cash transfers of NPR 15,000 per household were provided to over 3,000 families to purchase essential items.

## **4.2 Reconstruction Efforts in Jajarkot earthquake affected region**

### **4.2.1 Post-Disaster Reconstruction Framework**

#### **i. Temporary Shelter Construction Grant Procedure, 2080**

The "Disaster Risk Reduction and Management Act, 2074" provides the legal foundation for post-disaster reconstruction efforts in Nepal. Under this act, the "Temporary Shelter Construction Grant Procedure, 2080" was introduced to facilitate structured aid distribution and temporary shelter construction. This framework aims to support families whose houses were fully or partially damaged and are deemed uninhabitable, providing them with financial aid to construct temporary shelters. The procedure specifies a total grant of NPR 50,000 per household, distributed in two installments, to help beneficiaries rebuild. The identification process for beneficiaries involves verification through local government recommendations and supporting documents, including photographs of the damaged structures and identity cards.

The policy defines two prototype models for temporary shelters to standardize reconstruction efforts. It recommends rectangular shelter design with dimensions of 2700 mm x 4500 mm, incorporating easily available materials such as UPVC sheets, wood, stone slates, etc. This design prioritizes simplicity, cost-effectiveness, and ease of construction. The models emphasize adaptability with a choice of internal layout providing flexibility for families to choose designs based on their specific requirements while ensuring adherence to safety and thermal comfort standards.

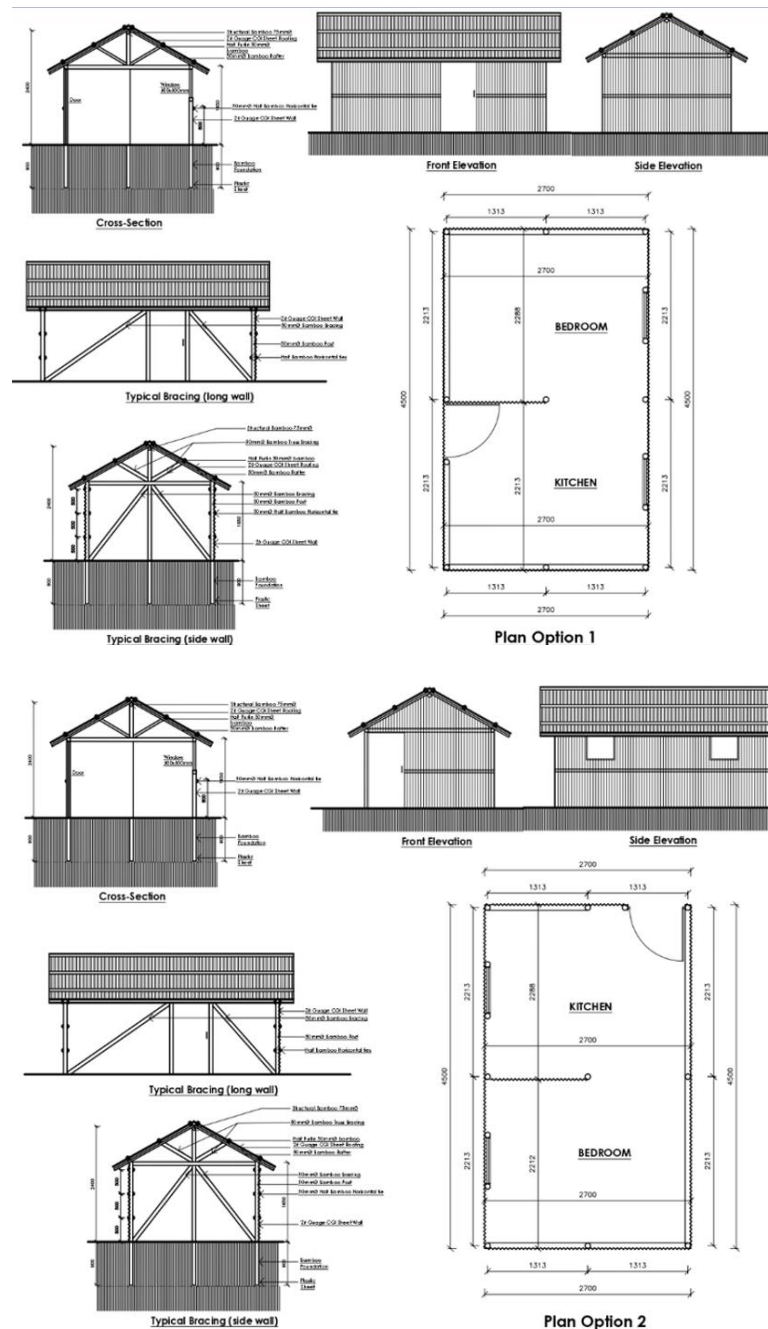


Figure 10 Prototype design of post disaster temporary shelter as proposed by  
 “Temporary Shelter Construction Grant Procedure, 2080”

To promote sustainability and accessibility, the framework emphasizes the use of locally available materials and encourages the reuse of salvaged resources from damaged structures. Local governments play a crucial role in implementing this framework by identifying beneficiaries, facilitating grant distribution, and monitoring construction progress. Provincial and federal governments provide additional technical and financial support, while collaboration with NGOs ensures efficient supply chains for construction materials and technical training for local builders.

Technical assistance is a core aspect of the framework, with engineers and technicians deployed by the Ministry of Urban Development to support beneficiaries during construction. Monitoring mechanisms are in place to ensure adherence to safety standards and design specifications. Despite its strengths, the framework faces challenges, including bureaucratic delays, coordination issues among stakeholders, and limited access to construction materials in remote areas. However, its emphasis on local materials, community involvement, and standardized prototype models presents an opportunity to foster resilience and align with sustainable reconstruction principles. Recommendations to enhance the framework include simplifying bureaucratic processes, strengthening coordination among local and provincial bodies, and providing extensive training on disaster-resilient construction techniques to local builders and stakeholders.

## **ii. Procedure for Grant Assistance on Strengthening, Reconstruction, and Restoration of Disaster-Affected Private Housing, 2081 (First Amendment)**

The "Procedure for Grant Assistance on Strengthening, Reconstruction, and Restoration of Disaster-Affected Private Housing, 2081 (First Amendment)" provides a legal framework for post-disaster housing reconstruction efforts in Nepal. This procedure outlines the responsibilities of local, provincial, and federal governments in assessing damage, categorizing affected districts, and distributing financial aid to eligible beneficiaries.

The procedure empowers local governments to conduct primary assessments of disaster damage with support from locally active organizations, police, volunteers, and other stakeholders. A more detailed damage assessment must be carried out with the assistance of expert technicians, incorporating economic, social, and technical data to classify private housing damage. If large-scale assessments are required, the Nepal Reconstruction Authority (NRA) or the provincial government will conduct the evaluations upon request and share the findings with the respective local governments and District Disaster Management Committees (DDMCs).

Grant assistance is provided jointly by the Nepal Government, provincial government, and local governments. Districts are categorized based on the level of disaster impact, with financial aid varying accordingly. Jajarkot district, classified under Category B, is eligible for a total grant of NPR 400,000, distributed in three installments: NPR 50,000

as the first installment, NPR 200,000 after completion of the plinth level, and NPR 150,000 as the final installment upon full completion of the house. Before receiving the final installment, the damaged structure must be fully removed in a manner that does not impose financial hardship on the beneficiary.

To facilitate reconstruction, eligible beneficiaries are entitled to subsidized construction materials:

- Up to 40 cubic feet of timber at 90% discounted rate of the government sale price, provided upon recommendation by the DDMC and approved by the Division Forest Officer.
- Permission to use Sal tree timber from private forests upon submission of an application to the Division Forest Office.
- Supervision of timber utilization by the Division Forest Office, with monitoring reports submitted to the Ministry of Forests and Environment. Any misuse of provided timber will be subject to legal action.
- Access to stone, gravel, and sand at subsidized rates through local government provisions.

For settlements deemed at risk due to disaster-induced instability, a structured relocation process is established:

- Local governments must conduct technical studies to determine settlement vulnerability and submit requests to the NRA for additional geological assessments.
- The NRA, in coordination with federal or provincial agencies, will conduct further geological evaluations of both the high-risk settlement and potential relocation sites.
- If a settlement is deemed uninhabitable, the NRA will present relocation proposals to the Executive Committee for approval.
- Relocation beneficiaries will be formally registered and provided grants according to the approved scheme.
- If relocation within the same district is not feasible, the Provincial Disaster Management Committee may authorize resettlement within other districts of the province.
- Inter-district or inter-local government relocations must follow the procedural framework outlined in the procedure.

- Infrastructure development at relocation sites will be coordinated by local, provincial, and federal government agencies to ensure necessary facilities and services.

In disaster-affected areas with historical, religious, or cultural significance, the reconstruction and restoration process must align with heritage conservation guidelines:

- Beneficiaries reconstructing private homes within heritage zones must ensure adherence to traditional architectural styles and cultural preservation standards.
- If additional restoration measures are required, local governments must compile and submit detailed reports to the DDMC, which will forward them to the NRA for further action.
- The Executive Committee will review and determine necessary interventions for cultural preservation.

This procedure establishes clear roles for local governments, DDMCs, provincial authorities, and the NRA in implementing and overseeing disaster recovery efforts. Regular monitoring, technical assistance, and inter-agency collaboration are essential to ensuring effective grant utilization and sustainable reconstruction. Challenges such as bureaucratic delays, coordination gaps, and material shortages in remote areas must be addressed through streamlined administrative processes and enhanced stakeholder cooperation.

By integrating financial assistance, technical expertise, and heritage preservation into a comprehensive reconstruction framework, this procedure aims to promote resilience and sustainable rebuilding in disaster-affected communities.

### **iii. Integrated Settlement Development Program Implementation Directive, 2078**

The "Integrated Settlement Development Program Implementation Directive, 2078" formulated by the Karnali Province provides a structured framework for addressing the challenges faced by dispersed and vulnerable settlements. This directive aims to integrate physical, social, economic, and cultural aspects to create sustainable and resilient settlements. Under this framework, settlements are identified based on their high disaster risk, geographic remoteness, and lack of basic infrastructure. Emphasizing equitable relocation, the program mandates local governments to ensure essential services such as roads, drinking water, electricity, and healthcare in the selected settlement areas.

The directive highlights a multi-stakeholder approach, with local governments responsible for identifying safe land, preparing settlement development plans, and managing resource allocation. Technical and financial support is provided by provincial and federal agencies, with NGOs playing a supportive role in capacity-building activities. A key aspect of the program is its focus on utilizing locally available materials and traditional construction practices while integrating disaster-resilient and energy-efficient designs. This not only preserves the cultural identity of the region but also promotes sustainability.

#### **iv. Local and national stakeholders involved in the process.**

Governmental structures such as National Emergency Operations Center (NEOC), District Disaster Management Committee (DDMC) and Local Disaster Management Committees (LDMC) are actively involved in post disaster activity. Similarly, non-governmental organizations (NGO) are also locally focused in post disaster relief activities. NGO actively involved includes Youth Awareness Raising Center Nepal (YARCN), Social Service Centre (SOSEC), Rural Reconstruction Nepal, Welt Hunger Hilfe (WHH), HRRP Nepal, etc.

#### **4.2.2 Challenges in Reconstruction**

The structure of bureaucracy, political instability, corruption, and lack of coordination are major challenges in reconstruction. Similarly, socio-economic vulnerabilities of displaced populations pose as another challenge in reconstruction. The earthquake-affected areas are among the poorest in Nepal (WHH 05/11/2023). Nationally, Karnali Province has the highest Multidimensional Poverty Index rate of 39.5% compared to the national MPI of 17.4% (NPC, 2021). Karnali Province is known for its food scarcity and lack of basic infrastructure, such as roads, electricity, health care, and education (ACAPS, 2023).

#### **4.2.3 Current Status of Reconstruction**

Altogether 68,326 temporary shelters have been constructed with the governmental aid of Rs. 50,000 each in Jajarkot, Rukum (west) and Salyan district (NDRRMA, 2024). Table 3 shows the overall progress of temporary shelter reconstruction in 2015 Jajarkot earthquake affected areas. Currently, NDRRMA in collaboration with Centre for Disaster Studies, Institute of Engineering (IOE) is conducting Detail Damage Assessment (DDA) in the region.

Table 3 Temporary shelters constructed with governmental aid in 2023 Jajarkot earthquake affected region

S.N.	District	Amount disbursed (in billion)	No. of temporary shelter	
			Under construction	Construction completed
1.	Jajarkot	1.54	0	34700
2.	Rukum (west)	1.24	0	32276
3.	Salyan	0.07	0	1350

Source: (NDRRMA, 2024)

#### 4.3 Case study area

Rimna is a village located in Bheri Municipality-1, Jajarkot, predominantly inhabited by the Magar community. It was one of the most affected areas during the 2023 Jajarkot earthquake. While RCC buildings remained intact, it was nearly impossible to find a vernacular house without physical damage during survey. The village is situated at the confluence of the Sanibheri and Thulibheri rivers, which provide economic opportunities for the locals. The river serves as a source of sand and fish, both of which have played a crucial role in helping the community recover after the devastating earthquake.

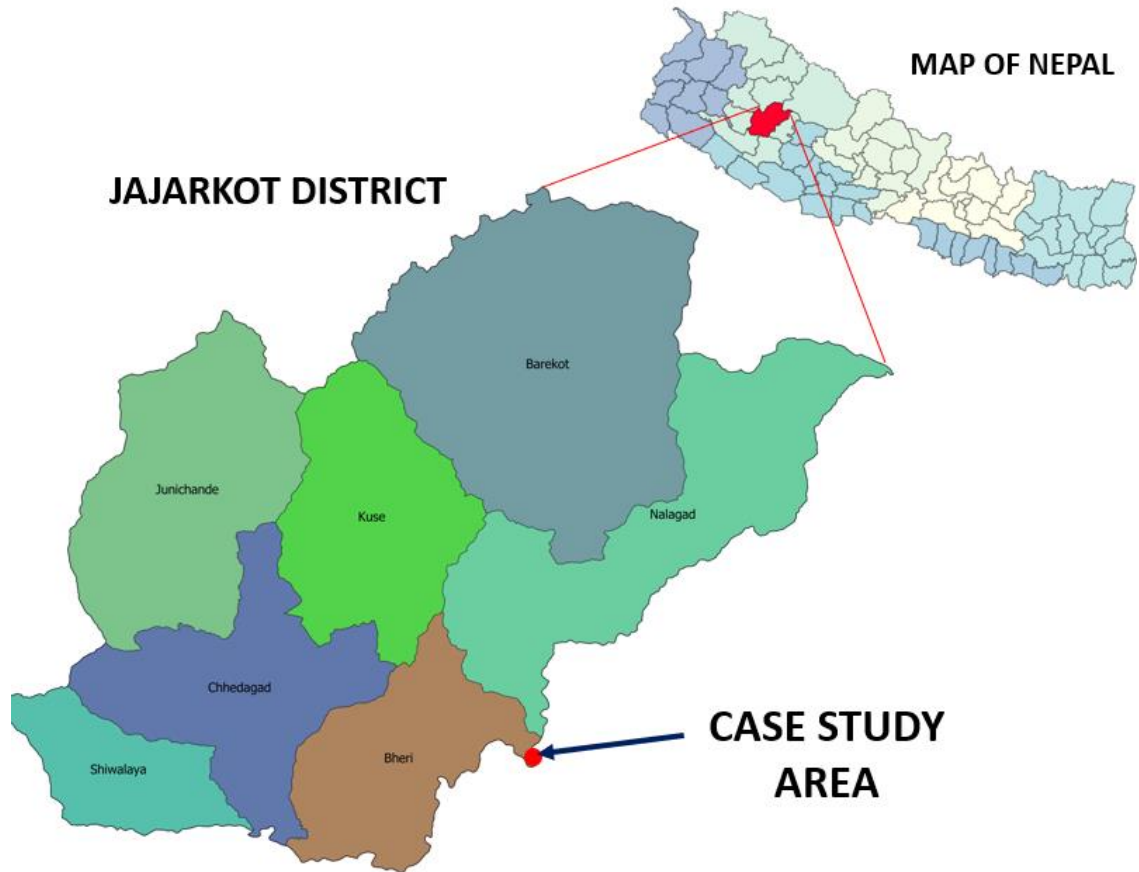


Figure 11 Location map of case study area

The case study area consists of 57 households spread over 0.35 km<sup>2</sup>. In the aftermath of the disaster, financially stable residents have started reconstructing new RCC houses, either within Rimna or in nearby urban centers such as Khalanga, Surkhet, and Nepalgunj. However, the majority of the population is still waiting for governmental aid while residing in temporary shelters.



Figure 12 Typical vernacular house in the case study area



Figure 13 (a) male and (b) female working in reconstruction in the case study area

## CHAPTER 5: DATA ANALYSIS

### 5.1 Background

This chapter presents the analysis of data collected during the study, focusing on both quantitative and qualitative aspects. It examines socio-demographic characteristics, energy consumption patterns, and the thermal performance of different housing types in Rimna. The findings provide insights into the living conditions of residents in post-disaster shelters, highlighting key trends in temperature variations, humidity levels, and energy usage. The analysis aims to identify factors influencing indoor comfort and sustainability, supporting informed decision-making for future housing solutions.

### 5.2 Quantitative Data Analysis

#### 5.2.1 Analysis of Questionnaire Survey Data

Questionnaire survey was conducted in Rimna village as a part of quantitative data collection. The following map shows the locations of houses where questionnaire survey was done. The questionnaire survey covered all types of houses in the case study area.



Figure 14 Satellite image of Rimna showing surveyed households

### **i. Socio-demographic details**

The study surveyed 50 households in Rimna to understand the socio-demographic characteristics of residents living in post-disaster temporary shelters (Table 4). The population was composed of 60% male and 40% female respondents. The age distribution showed that 28% of respondents were between 18-30 years old, 44% were aged 31-45, 26% were between 46-60 years old, and only 2% were above 60 years old. The average household size was 4.88 members per household.

Education levels varied, with 34% of respondents having no formal education, while 28% had completed primary education. A smaller proportion had higher secondary education (18%) and bachelor's degrees or higher (6%). The majority of respondents were engaged in agriculture (24%), while 20% were housewives, 16% worked as laborers or self-employed, 10% were students, and 4% were employed in the service sector. The monthly household income averaged NPR 20,000, while monthly expenditures averaged NPR 15,000.

A small proportion of households, 8%, had at least one family member working in foreign employment, contributing to household income. These socio-demographic insights highlight the economic challenges and employment conditions faced by residents in temporary shelters, further influencing their energy consumption patterns and affordability.

Table 4 Demographic information of the residents in case study area

S.N.	Personal Factor		Proportion
1	Gender	Male	60
		Female	40
2	Age	18-30	28
		31-45	44
		46-60	26
		60+	2

3	Marital status	Married	70
		Unmarried	10
		Widowed	20
4	Family size	4.88	
5	Education Level	Bachelor's degree or higher	6
		Higher secondary education	18
		No formal education	34
		Primary education	28
		Secondary education	14
6	Occupation	Agriculture	24
		Housewife	20
		Labor	16
		Retired	2
		Self-employed	22
		Service	4
		Student	10
		Unemployed	2
7	Household expenditure per month	Rs. 15000	

8	Household income per month	Rs. 20000	
9	Foreign employment	Yes	8

### ii. Types of temporary shelter

The temporary shelters in Rimna were primarily constructed using Corrugated Galvanized Iron (CGI) sheets, which were constructed by the Nepal Red Cross Society and other humanitarian organizations as the response to the earthquake. Approximately 93.2% of households resided in fully CGI-sheet shelters, while a small proportion, 6.8%, lived in shelters made of wooden planks with CGI sheet roofing. These shelters were built as an emergency response to the disaster but remain the primary housing solution due to delays in permanent reconstruction efforts. The lack of insulation and proper ventilation in these shelters has led to thermal discomfort, with extreme temperatures in both summer and winter exacerbating energy consumption challenges.



Figure 15 Temporary shelter constructed using CGI and reused materials from destroyed house in Rimna, Jajarkot

### iii. Types of permanent housing constructed post disaster

Only a few houses are built post-earthquake due to delays in reconstruction efforts. The delays are due to policy shortcomings and financial condition of the residents in the case study area. A few houses are constructed in the case study area by international organizations and private efforts. International organizations have built houses as a

model demonstrative house for target class residents. Similarly, residents with good financial status have started building their houses on their own.



Figure 16 CSEB brick house constructed post disaster by IOM



Figure 17 RCC building with stone cement wall under construction post disaster in Rimna



Figure 18 RCC building with CSEB brick under construction post disaster scenario



Figure 19 RCC building with cement block wall under construction post disaster scenario

#### iv. Energy consumption pattern

##### Electrical energy consumption

Most households in Rimna rely on grid electricity provided by the Nepal Electricity Authority. However, frequent power outages and voltage fluctuations affect its reliability. Among the surveyed households, 97.6% had national grid electricity access, while 2.4% relied solely on solar power due to issues with land ownership in post-earthquake relocated place. The average household lighting consumption was 7.92 kWh per month, with LED bulbs being the predominant lighting source. 14.28% of

households used solar panels as a secondary energy source for lighting, indicating an emerging trend towards renewable energy solutions.

Table 5 Monthly cost of electricity

S.N.	Cost per month	Season	
		Summer (in %)	Winter (in %)
1	Less than Rs 50	4.76	4.76
2	Rs 151- 300	11.90	16.67
3	Rs 51 - 150	83.33	78.57

### Cooking energy consumption

Cooking energy in temporary shelters was primarily derived from firewood, with 85.7% of households depending entirely on it. The remaining households used LPG partially or fully, with 4.76% relying solely on LPG and 9.52% combining LPG with firewood. The average firewood consumption was 8-12 bhari per month, with variations based on household size and livestock ownership.



Figure 20 Firewood stored and dried simultaneously

Firewood collection was done from nearby forests, raising concerns on indoor air pollution. While firewood collection requires no monetary purchases, the LPG cylinder costs Rs. 2200 to 2300 on the roadside stores. The price of LPG rises as we move further from Jajarkot Khalanga.

Table 6 Energy consumption for cooking

S.N.	User type	LPG replacement	Firewood consumption	Proportion
1	Firewood only	0	8-12 bhari	85.71
2	LPG only	1-2 month	0	4.76
3	LPG mostly, Firewood often	2-3 month	2-6 bhari	2.38
4	LPG often, Firewood mostly	6-8 month	6-10 bhari	7.14



Figure 21 Gas cylinders for sale in the case study area



Figure 22 Kitchen with LPG stove provision in case study area



Figure 23 Outdoor cooking specially adopted when cooking for more people



Figure 24 Kitchen of a local tea shop

### Electrical appliances used

The most commonly used electrical appliances were mobile phones and LED lights, present in 100% of households. Other appliances included televisions (16.67%), Wi-Fi routers (11.9%), radios (7.14%), and fans (2.38%) (Table 7). The average monthly electricity load varied based on appliance ownership, with LED lights and mobile chargers contributing the most to consumption. The limited presence of high-power appliances suggests that energy use in these shelters remains minimal and focused on basic necessities.

Table 7 Electrical appliances used by households

S.N.	Appliance	Proportion
1	Mobile	100
2	LED Light	100
3	Television	16.67
4	Wifi Router	11.9
5	Radio	7.14
6	Fan	2.38



Figure 25 Electric meter in temporary shelter

Table 8 Typical energy consumption pattern in case study area

S.N.	Equipment	Nos.	Rating (W)	Average usage (hrs)	Monthly load (kWh)
1	LED light	3	6	6	3.24
2	LED	1	12	10	3.6
3	Mobile charger	3	15	4	5.4
	Total				12.24

### 5.2.2 Temperature and Humidity Analysis

For this study, two houses- one vernacular and one modern- were selected in Rimna. Only few vernacular houses survived the 2023 Jajarkot earthquake. However, a two-storey vernacular house with residents living in it was found near to a modern house (Fig. 27). Data loggers were installed in order to collect temperature and relative humidity variations inside the rooms of those houses.

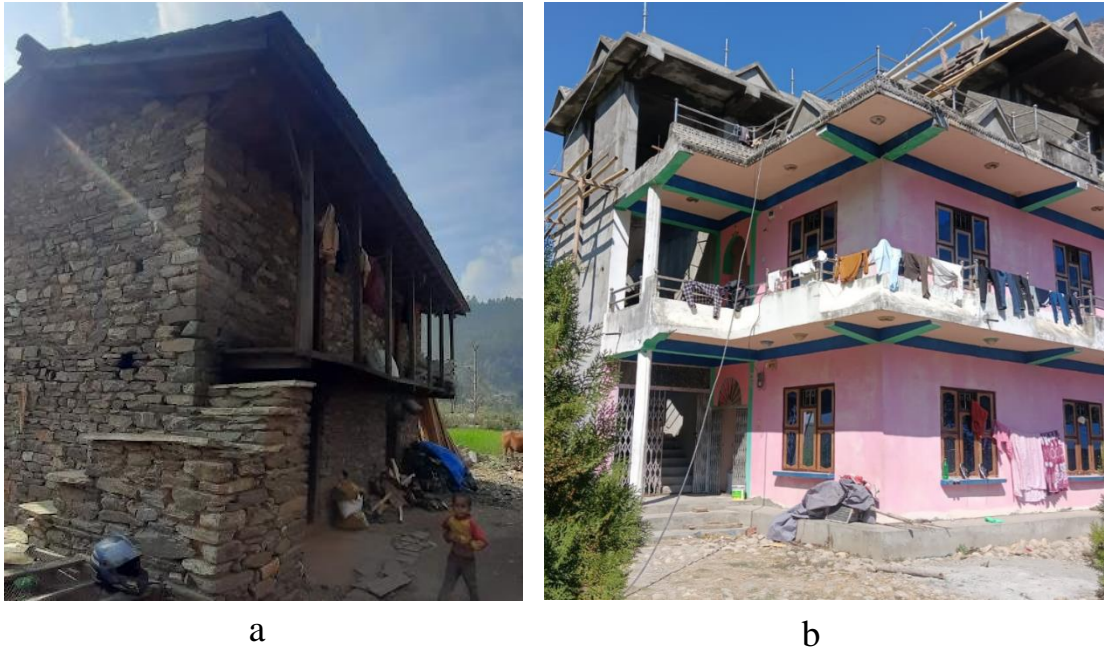


Figure 26 Building where datalogger was installed (a) Vernacular house, (b) RCC

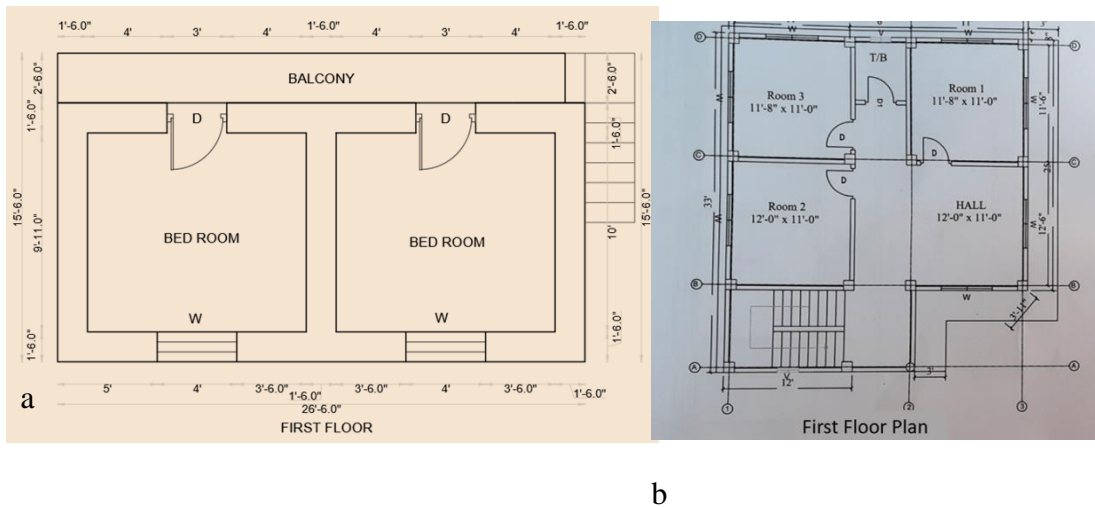
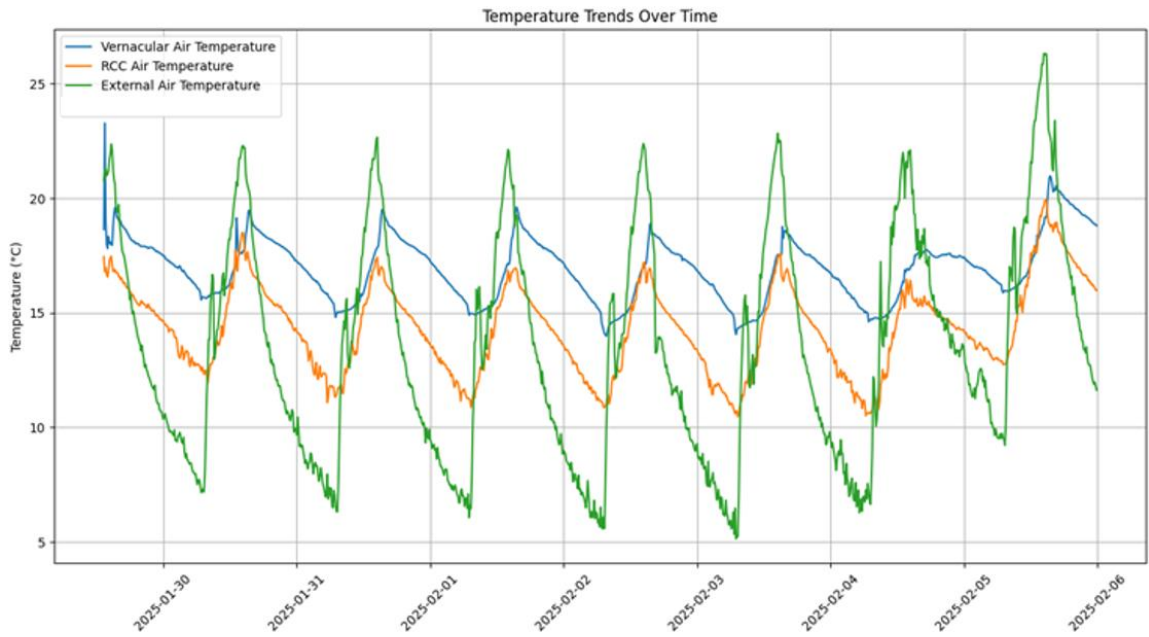


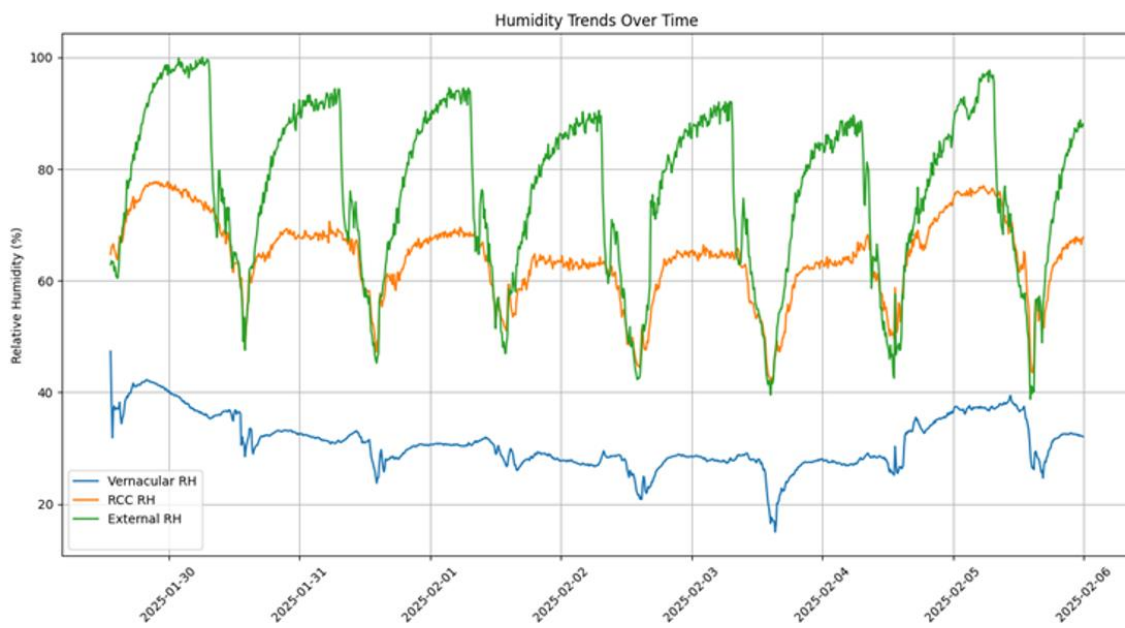
Figure 27 Floor plan of house studied (a) vernacular and (b) modern

### i. Temperature and Humidity Variation in the Case Study Area

The graph illustrates the fluctuations in air temperature and relative humidity over time (Fig. 29) in the study area. Internal and external temperature and humidity data was logged for 21 days (presented in Annex-IV) using various sensors mentioned in Table 2. It highlights daily variations, showing how external factors such as sunlight exposure and weather conditions influence temperature changes.



(a)



(b)

Figure 28 Weekly variation of (a) Air temperature and (b) Relative humidity in various setting in Rimna

### 5.2.3 Thermal sensation Vote

#### i. Estimation of mean radiant temperature

The mean radiant temperature ( $T_{mr}$ ) was estimated from a formula given by (Thorsson *et al.*, 2007).

$$T_{mr} = \left\{ (T_g + 273)^4 + \frac{1.1 \times 10^8 v^{0.6}}{\epsilon d^{0.4}} \times (T_g - T_i) \right\}^{0.25} - 273$$

where,  $T_g$  is the globe temperature [ $^{\circ}\text{C}$ ],  $v$  is the air velocity [m/s],

$T_i$  is indoor air temperature [ $^{\circ}\text{C}$ ],  $d$  is the diameter of globe (= 0.075m),

$\epsilon$  is the emissivity of globe surface (= 0.95).

Velocity of air = 0.10m/s adopted from (Thapa *et al.*, 2018)

#### ii. Estimation of comfort temperature

The comfort temperature can be estimated either by the regression method or Griffiths' method (Thapa, Rijal and Shukuya, 2018). In the regression method, the comfort temperature is estimated by substituting “4. Neutral” to the linear regression equation obtained from the relationship between the measured indoor globe temperature and the thermal sensation vote. Studies (Thapa *et al.*, 2018) recommends investigation of the thermal comfort temperature by the Griffiths' method ( $\alpha=0.50$ ) over regression method in the field survey based studies.

$$T_c = T_g + (4 - C) / \alpha$$

where,  $T_c$  = Comfort temperature

$T_g$  = Indoor globe temperature at the time of survey

$C$  = Thermal sensation vote (TSV) given by the respondent

$\alpha$  = Regression coefficient (0.25, 0.33, or 0.50) (Griffiths, 1991; Humphreys *et al.*, 2013; Thapa *et al.*, 2018)

Table 9 Thermal comfort temperature by Griffith's method

S.N.	Regression coefficient ( $\alpha$ )	Comfort temperature ( $T_c$ )
1.	0.25	21.48
2.	0.33	20.13
3.	0.50	18.7

The graph (Fig.30) shows the distribution of the comfort temperature.

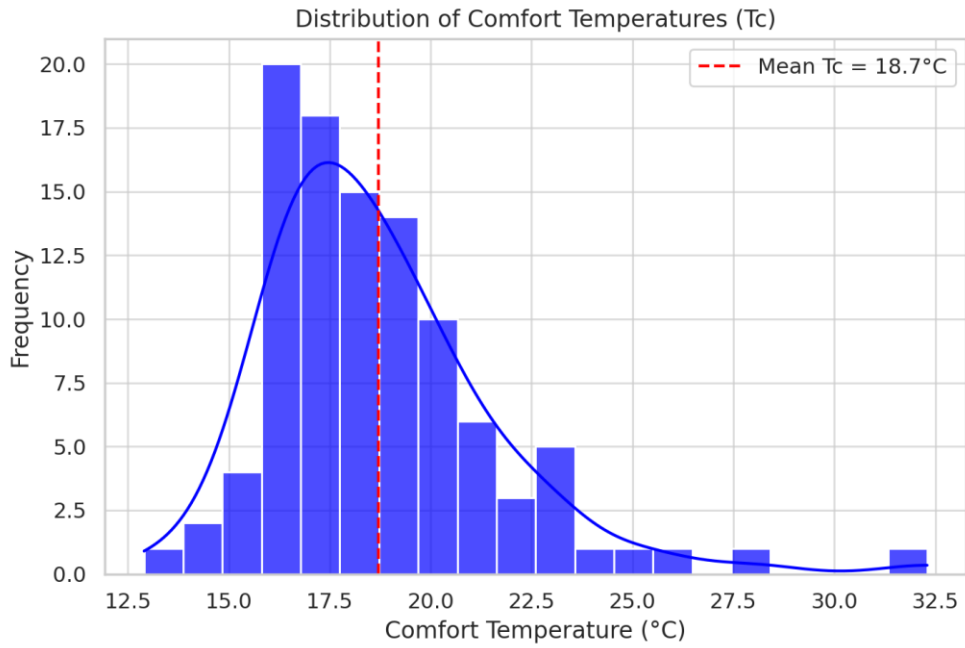


Figure 29 Distribution of comfort temperature

### iii. Estimation of thermal acceptability

The logistic regression was applied to predict the thermal acceptability, which is calculated from the binary data: “1. Acceptance” and “0. Unacceptance”, as a function of the indoor globe temperature.

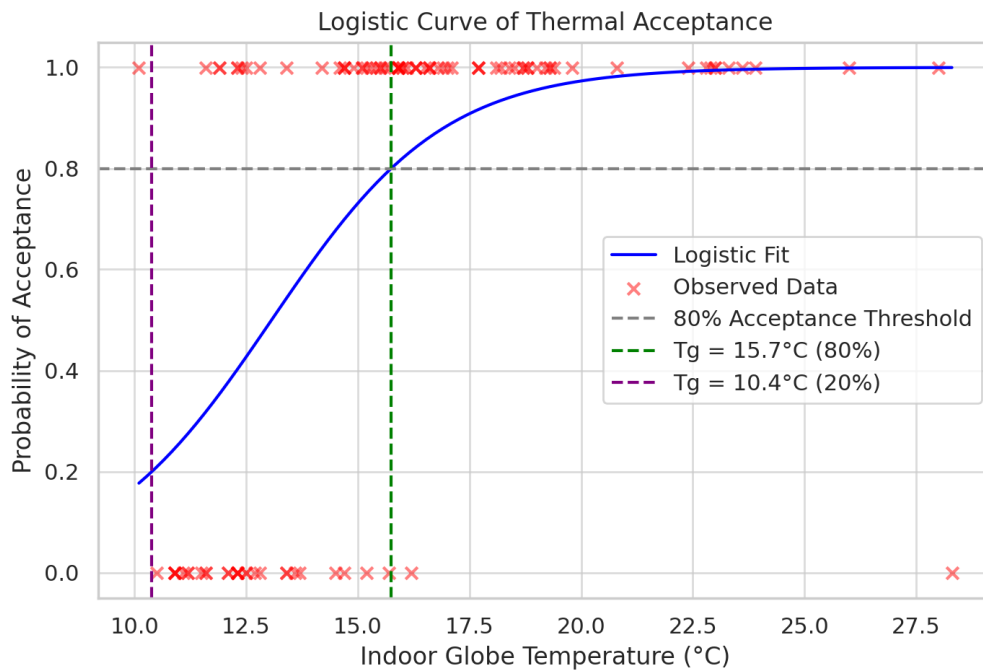


Figure 30 Logistic curve of thermal acceptance

The relationship between the thermal acceptability and indoor globe temperature is expressed below.

$$\text{Logit}(p) = \ln\{p/(1-p)\} = bT_g + c$$

Where,  $p$  is the probability of thermal acceptance,  $b$  and  $c$  are the constants obtained from the regression analysis on the values of probability of acceptability as the linear function of globe temperature.

Using an 80% acceptability threshold, the acceptable temperature was determined as 15.7 °C. However, for 20% acceptability, the acceptable temperature was determined as 10.4°C.

### **5.3 Qualitative Data Analysis**

#### **5.3.1 Interview Data**

The interviews with affected residents, local experts, and construction workers in the Jajarkot region reveal critical insights into the experiences of individuals living in post-disaster reconstructed shelters. While the provision of permanent housing has been met with appreciation, there are notable concerns regarding thermal comfort that need to be addressed.

One of the beneficiaries of Caritas Nepal's housing project, wife of a disabled male, expressed gratitude for receiving a new home but admitted that her family continues to live in the temporary shelter because the new house is too cold. Stone masonry house with lime and mud plaster on the outside and cement plaster on the inside was built as a model house by Caritas Nepal. She noted that raw wooden beams in the house have started developing mold, and while applying enamel paint could prevent it, the associated costs are beyond their financial capacity. The cement plaster on the interior walls contributes to the cold indoor environment, making the house less comfortable than traditional mud houses. Reflecting on this, she remarked,

*"Had the organization used mud plaster on the inside, the home would have felt much warmer."*

Apart from Caritas Nepal, IOM had built a CSEB based model house in the case study area. The beneficiary of IOM's CSEB Model house project mentioned his new house being colder than the stone mud masonry house he had before the earthquake. He told,

*“This house (CSEB) is warmer than CGI sheet temporary shelter, but couldn’t meet the thermal comfort of stone mud masonry house.”*

A local school teacher, recognizing the emotional and cultural connection people have with mud-based housing, explained that the community strongly believes in the superior warmth and health benefits of mud houses compared to modern materials. While newly constructed houses come with cement-plastered walls, these are perceived to be colder, and many people are struggling to adjust to this change. He further clarified,

*“In homes constructed with mud, it typically takes one to one and a half years for the structure to completely dry, meaning that the initial two winters are bound to feel colder. The more percentage of the mud used, the more indoor thermal comfort will be achieved and drying time also increases. The lack of seasoned wood in reconstruction projects has exacerbated this issue, as the unseasoned wood is prone to mold and dampness.”*

Local engineers and construction workers have acknowledged the challenges of post-disaster reconstruction, highlighting the need to balance earthquake resistance with thermal comfort, especially in the high-altitude regions of Jajarkot. They noted that the urgency of rebuilding meant that unseasoned wood had to be used, leading to mold growth and durability concerns. Additionally, delays in reconstruction efforts resulted in prolonged hardships, particularly for vulnerable populations such as children, the elderly, and pregnant women. As winter set in, many families were left without adequate shelter, forcing them to prioritize food and survival over home modifications that could improve warmth.

Residents have adopted various adaptive strategies to cope with the harsh winter conditions. Many families layer their clothing and use thick blankets to mitigate cold indoor temperatures. Sleeping arrangements have also changed, with multiple family members sharing a single room at night to retain warmth. Traditional wood-fired stoves remain the primary source of heat, as electric heaters are not affordable or practical due to inconsistent power supply. The agriculture-based family considers thermal comfort more important to livestock than humans who can cope the thermal environment with various strategies. A local involved primarily in agriculture mentioned,

*"People can adapt to the cold by layering clothes, sitting by the fire, and using blankets, but livestock struggle in the winter. They need warm shelters just as much as people do. That is why I am first building a stable for my animals, using stone and mud walls for better insulation."*

He further added on the community driven reconstruction efforts,

*"I am doing most of the work myself, and when needed, I call upon neighbors and relatives to help, as we do not need to spend money this way. When they need help with their houses, I will return the favor."*

Economic constraints have significantly influenced reconstruction efforts, with most residents unable to afford reinforced concrete structures. Instead, they opt for cheaper materials. A local supplier explained,

*"The cost of bricks, timber, and cement has increased post-earthquake, making it difficult for families to build homes that are both safe and warm. Government support and NGO assistance have been crucial in helping residents access materials, but financial limitations remain a significant barrier."*

Newly built houses generally follow standardized designs, which do not always align with local preferences and climatic needs. Local construction workers mentioned that rather than strictly adhering to engineered blueprints, most people prefer to customize their homes based on neighboring structures. In rural areas, government enforcement of building regulations is minimal, allowing residents to make modifications as they see fit. However, without expert guidance, some modifications may inadvertently reduce thermal efficiency. A local construction worker remarked,

*"Rather than relying on engineered designs, many homeowners base their house structure on nearby houses. Standardized designs do not always match what the community needs, and minor adjustments based on familiarity feel more reliable."*

Looking ahead, local engineers and experts suggest integrating passive solar heating techniques into future reconstruction efforts. This includes improving building orientation and window placement to maximize sunlight exposure. Hybrid construction methods that combine cement-based structures with traditional *Babiyo*-mud mixture plastering could also enhance insulation. Additionally, allowing greater community

involvement in the design process would ensure that houses meet both safety and comfort needs. One local engineer suggested,

*"Elderly residents could have their homes internally plastered with Babiyo (Eulaliopsis binate) and mud mixture while still maintaining structural safety with RCC frameworks. This would significantly improve warmth and comfort."*

The ward chairman from the case study area had attended numerous seminars and discussion sessions with experts, stakeholders, governmental authorities, and local residents on post disaster reconstructions. Chairman's knowledge on the local context as well as understanding of concerned stakeholders would be useful in drawing a conclusion of this study. He reflected on the shifting family structures and future housing needs, stating,

*"Before the earthquake, many families lived in joint households. The earthquake relief and support distribution process has somehow pushed our community to a nuclear family. Over time, each family will require at least five rooms, but at present, most people have no money and are relying on the government's grant of NPR 400,000 per household. This amount is sufficient to build traditional-style houses but not necessarily earthquake-resistant structures, which are crucial given the seismic activity in our region."*

He further elaborated on the need for earthquake-resistant designs and sustainable materials,

*"We cannot rely on non-pillar structures anymore. Our primary priority is seismic safety, and ensuring thermal comfort comes next. The choice of construction materials can significantly influence indoor thermal conditions. I lost three homes during the earthquake and am currently living in a temporary shelter while building a new one using compressed stabilized earth blocks (CSEB). These bricks, produced locally, are more affordable than the red bricks transported from Dang."*

Discussing community-wide reconstruction efforts, he noted,

*"There are currently two CSEB brick factories in Rimna, each with a production capacity of 800 bricks per day. If demand increases, they plan to expand their capacity. As a representative, I am actively promoting the use of environmentally friendly CSEB bricks in new constructions."*

Looking ahead, he shared his thoughts on future-proof housing strategies,

*"For now, a three-room house, with two bedrooms and a storage room, would be sufficient for most families. Many people still use temporary kitchen structures, and a phased construction approach—starting with a ground floor and later expanding—would be more feasible. Earthquake-resistant structures should take priority, followed by thermal comfort improvements."*

Reflecting on past reconstruction efforts, he mentioned,

*"Government and NGOs have helped build temporary shelters, but long-term housing needs must be considered. The preference for concrete structures is rising, yet we must be cautious about their impact on health and comfort. Cement buildings can be too cold in winter and too hot in summer, making alternative materials like CSEB bricks a more viable option."*

These findings indicate that while post-disaster reconstruction has successfully provided shelter, thermal comfort remains a pressing issue. Residents continue to value traditional materials and techniques for warmth but face economic and structural limitations in implementing them. Future interventions should prioritize hybrid construction methods, community-driven design processes, and passive heating strategies to create homes that are both resilient and comfortable for the affected populations.

### **5.3.2 Observation data:**

Even though thermally, residents prefer stone mud constructed buildings, post 2023 Jajarkot earthquake and multiple aftershocks, residents are inclined towards RCC structure. The residents who are financially able have either moved to bigger cities are already reconstructing their new homes. But the residents with financial difficulties in reconstructing, are waiting for governmental aid for the reconstruction. Materials like stone, sand, mud, slate are either locally available in cheaper rates, or are already with the residents from the debris of houses destructed in 2023 earthquake. Also, all the residents have CGI sheet based temporary shelter, either completely or as a roofing material only, whose materials can be reused in new construction. After the earthquake, several INGOs, NGOs and governmental agencies has provided trainings and awareness campaign in the region, which provided a certain amount of knowledge thermally performing materials. Also, the non-governmental organizations have

financially and technically helped in establishing eco-friendly construction materials such as interlock CSEB bricks, eco-blocks, etc. Residents with higher level of education and opportunities to attend on trainings and awareness campaign have developed their interest towards sustainable and thermally comfortable materials.

One of the residents in IOM constructed CSEB based building mentioned CSEB building better than CGI building, still underperforming that his old stone mud masonry building. I found similar perceptions of other residents of similar project funded buildings. Upon discussing why residents are preferring stone mud buildings to their new buildings, I found out cement plastered interior being less preferred by the residents. The residents in this area never take shoes and slippers inside the house, leaving them barefooted. The barefoot on cement plastered floor will certainly make one feel cold as compared to mud-based floor. This might be related with relative humidity inside the building too. As we found a low relative humidity inside stone mud masonry building at all times of our 22 days long data logging. Another factor why residents felt cold in new building could be room size, as new houses have bigger room sizes compared to vernacular houses.

At present condition, in my opinion after conducting data collections in the case study area, kiln burnt bricks are not viable option for reconstruction. The major factor is the cost of these bricks. There are no local brick kilns and transporting them from Dang(170km) and Nepalgunj(130km) make its cost almost double to that in the factory. However, there was a cement block factory before the disaster, and post 2015 earthquake, two CSEB block factory are established in the area with technical and financial aid from a NGO. So, I think one alternative of wall envelope material for reconstruction is CSEB brick.

Since, stones are locally available and can be recycled from the debris of destructed houses, they stand out as most viable alternative for majority of the residents. The residents with no money for purchasing expensive bricks, will choose stone and mud as the wall materials. If stones, slates, wooden frames from house destroyed by the earthquake are not reused, their disposal is going to create another problem. One of the residents, whose three small vernacular houses were destroyed, mentioned owning a lot of stones and woods, and is planning to build RCC building and sell woods that won't be reused in his new house at cheaper rates.

### 5.3.3 Data from cognitive drawing

Selected respondents, stakeholders, technicians, engineers and elected local representative were asked to sketch their ideal house. Findings from these sketches has been incorporated in building design input for simulation study.

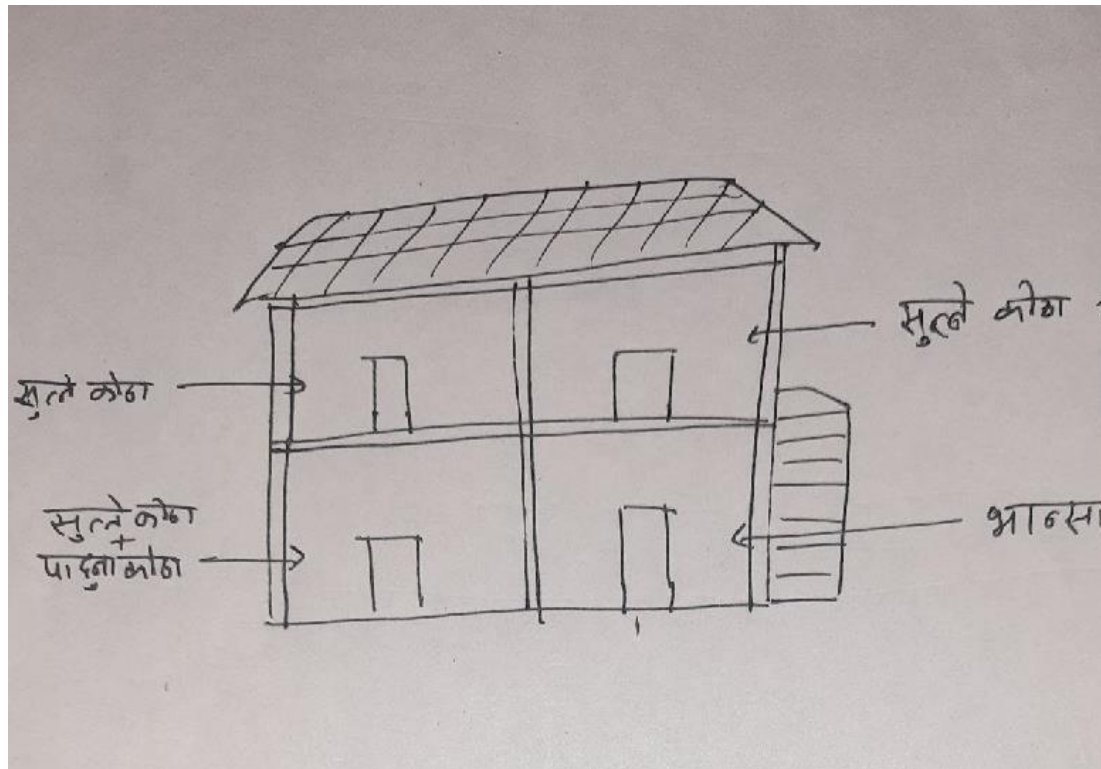


Figure 31 Example of cognitive drawings of ideal house collected during survey

The key elements to be considered during house design that was collected from sketches includes preferred number of room (2-5) and storey (1/2), material preferences (stone, cement block and CSEB for wall, wood for door and window), room size preferences (more than 10ft\*10ft), layout (bed rooms on first floor, use of temporary shelter as separated kitchen) and orientation choices (either aligned to road or east west elongated). All the cognitive sketches collected has been presented in Annex.

### 5.4 Simulation

For computer simulation, Designbuilder software was used. The energy plus weather file for nearest available weather station (Surkhet 64km) was used as weather input. Iterative simulation was done for varying parameters of window wall ratio (WWR), orientation and building materials.

### 5.4.1 Model for simulation

The RCC structure house whose detailed study was done has been used as a base model (Fig. 33) for computer simulation. Various parameters were varied in order to find out optimized orientation, window wall ratio and construction materials.

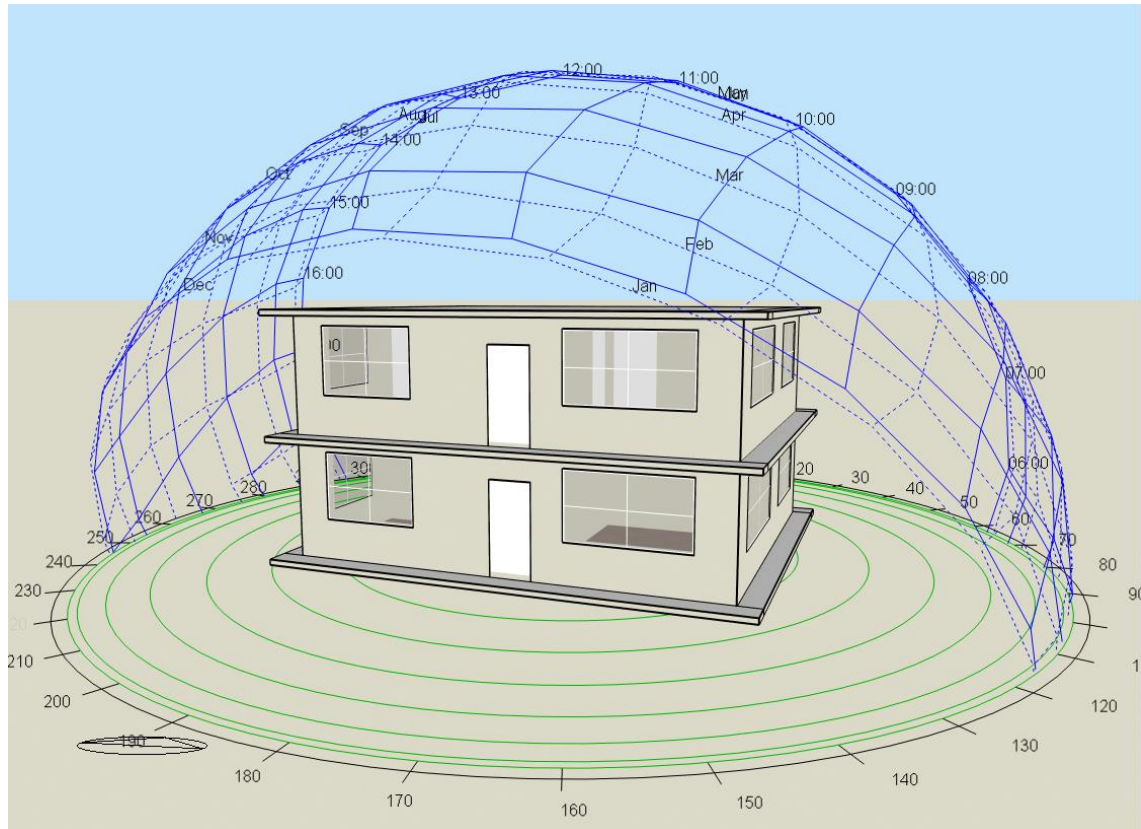


Figure 32 Model used for simulation in Designbuilder with Sun-path diagram

### 5.4.2 Parameters of simulation

The variation was done in wall material, roof type, orientation and WWR.

#### i. Wall material

8 different types of wall masonry were considered during simulation. Table 10 shows the detailed properties of these variations.

#### ii. Orientation and WWR

Orientation analysis was done for  $0^{\circ}$  -  $360^{\circ}$  for an interval of  $5^{\circ}$ . By  $0^{\circ}$ , it meant base case of west facing building. Similarly, WWR variation was studied from 10% to 80%, with interval of 5%. Altogether 1380 iterations were carried out by varying these parameters of orientation and WWR for 7 different wall materials.

iii. Roof material

For roofing materials, pitched CGI Sheet, flat 100 mm RCC Slab and pitched slate stone roof were studied for base model.

Table 10 U-value of wall masonry used for simulation

S.N.	Wall materials	U-value (W/m <sup>2</sup> -K)
1.	9’’CSEB Wall with mud plaster	2.071
2.	8’’ AAC block wall with cement plaster on both sides	0.438
3.	9’’ CSEB cavity wall with cement plaster on both sides	1.021
4.	12’’ Stone wall with cement plaster (exterior) mud plaster (interior)	3.338
5.	9’’ Ecobrick Wall with mud plaster	1.064
6.	9’’ Brick cavity wall with cement plaster on both sides	2.050
7.	9’’ Brick wall with cement plaster on both sides	2.119

Source: DesignBuilder

## **CHAPTER 6: FINDING AND DISCUSSION**

### **6.1 Background**

This chapter presents the findings of the study and discusses their implications in the context of post-disaster reconstruction, thermal comfort, and energy efficiency. The findings are based on both quantitative and qualitative data collected from the field, including household surveys, temperature and humidity measurements, and stakeholder interviews. The discussion interprets these findings in relation to existing literature, highlighting key themes such as housing design, energy consumption, cultural relevance, and policy challenges.

### **6.2 Socio-demographic characteristics**

The demographic profile of the respondents provides insights into the socio-economic background of the affected population in the study area. As per the census, Bheri-1 constitutes 48% male and 52% female, average household size 4.36 (NHPC,2021). However, respondents of our study constituted 60% male population. The support and relief programs run by various agencies required legal house owner for enumeration purpose. Due to which, a patriarchal community in Rimna had more males responding to survey team. Females when approached for questionnaire survey, redirected the survey team to male member of the household. Bheri municipality has literacy rate of 75.1%, which is higher than that of our respondents (66%). The age group of respondents played vital role in this deviation of literacy rate as only 28% of the respondents were of 18-30 age group which constitutes of more literate population. The monthly income and expenditure of the respondents is Rs. 20000 and Rs. 15000 respectively.

### **6.3 Finding and Discussion in relation to objectives of the study**

The primary objective of this study was to examine the thermal comfort of shelters reconstructed after the 2023 Jajarkot earthquake, focusing on indoor thermal environments during winter. For this data loggers were installed in case study buildings. Similarly, computer simulations were carried to find the optimized design of the buildings. The findings of the computer simulations aligned with widely accepted passive design strategies. Cavity wall and stone wall with high thermal mass performed well in building material. Summarized finding of computer simulations has been presented in Table 15.

The temperature variations in the three types of buildings—vernacular, RCC, and CGI sheet temporary shelters—show distinct thermal performance characteristics. Regression analysis of the indoor and outdoor air temperature was carried out to find the relationship between the indoor air temperature of these types of buildings.

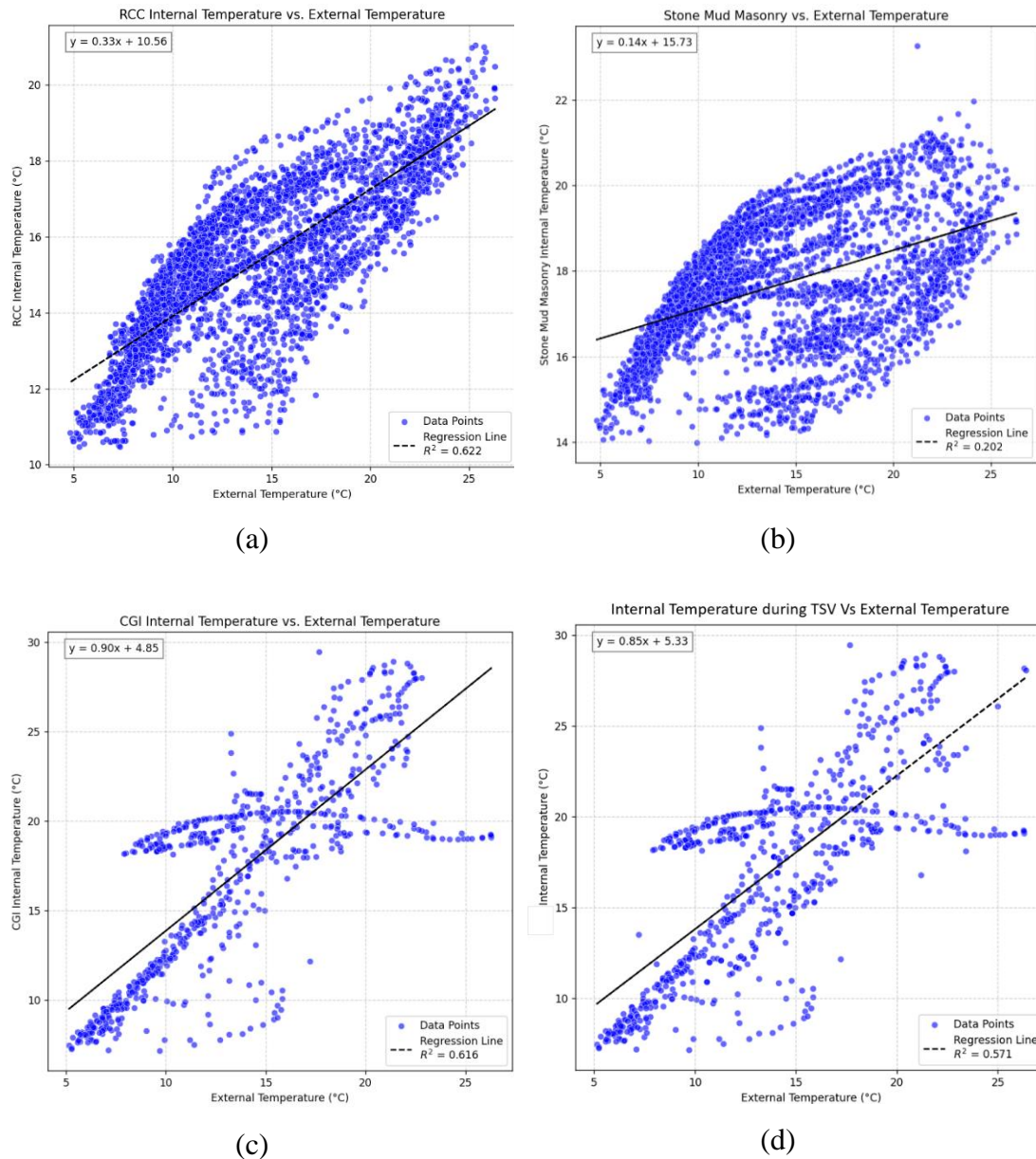


Figure 33 Relationship between external and internal air temperature (a) Modern, (b) Vernacular, (c) Temporary house and (d) during TSV collection

Based on the regression analysis, the following relationships were obtained:

Modern house:  $T_i = 0.33T_o + 10.56$  (N=3455,  $R^2=0.622$ , S.E.=0.004,  $p<0.001$ )

Vernacular house:  $T_i = 0.14T_o + 15.73$  (N=3455,  $R^2=0.202$ , S.E.=0.005,  $p<0.001$ )

Temporary (CGI) shelter:  $T_i = 0.90T_o + 4.85$  (N=709,  $R^2=0.616$ , S.E.=0.027,  $p<0.001$ )

During TSV collection:  $T_i = 0.86 T_o + 2.96$  (N=103,  $R^2=0.880$ , S.E.=0.028,  $p<0.0001$ )

where, N: number of sample, R<sup>2</sup>: coefficient of determination, p: significance level of the regression coefficient

The vernacular building maintains a relatively stable indoor temperature, with smoother fluctuations compared to both the RCC structure and the external environment. This suggests that vernacular construction materials and techniques provide better thermal insulation, reducing the impact of external temperature extremes. In contrast, the RCC building exhibits greater temperature variation than the vernacular structure, though it still moderates fluctuations compared to the external environment. The RCC air temperature follows a trend similar to the external temperature but with reduced amplitude, indicating some level of thermal mass effect.

On the other hand, the CGI sheet temporary shelters show the least thermal regulation, closely following the external temperature pattern with slightly higher peak values. This suggests that CGI sheets have poor insulation properties, allowing rapid heat gain during the day and quick cooling at night. As a result, these temporary shelters experience more extreme temperature variations, making them less thermally comfortable compared to vernacular and RCC buildings. Overall, the vernacular building demonstrates superior thermal performance by minimizing temperature swings, while the RCC structure provides moderate insulation, and CGI shelters offer minimal protection from external temperature fluctuations.

i.

The material used for external walls significantly influences indoor thermal conditions. Stone walls, cavity walls, and compressed stabilized earth blocks (CSEB) with mud plastering show the best performance. These materials provide thermal mass, slowing heat transfer and maintaining stable indoor temperatures. Cavity walls, especially, help in reducing heat gain by trapping air, which acts as an insulating layer. The dataset suggested that orientations between 160° and 185° results in the least discomfort hours. This orientation likely reduces direct exposure to intense solar radiation while optimizing cross-ventilation. Similarly, a lower WWR consistently results in fewer discomfort hours. This is because a smaller window area reduces direct solar heat gain, minimizing overheating during the daytime. However, daylighting is another factor to

be considered for WWR. Mahoney table suggests WWR to be in between 20-40% for the case study area. In post-disaster shelters, where passive cooling strategies are crucial, a low WWR is beneficial for thermal comfort.

Before the 2023 Jajarkot earthquake, most houses in the region followed vernacular construction practices, featuring thick stone-mud masonry walls, small openings, and predominantly south-facing orientations. These architectural elements were well-suited to the local climate, providing passive solar heating and maintaining stable indoor temperatures throughout different seasons. Load-bearing structures were commonly built as two-story houses, with the upper floor serving as the main living space, while the ground floor was often used for storage or as cattle sheds. These sheds housed livestock on the lower level, while the upper level was used to store agricultural equipment, harvested crops, and firewood. The construction of these houses generally did not adhere to municipal regulations, as most were built using traditional techniques passed down through generations.

In contrast, pre-earthquake reinforced cement concrete (RCC) structures were typically one to two stories, with provisions for future vertical expansion up to three stories. These buildings primarily used kiln-burnt bricks and cement blocks as construction materials, with stone-cement masonry serving as a secondary option. Notably, compressed stabilized earth blocks (CSEB) were not used in construction before the earthquake, as traditional or cement-based materials dominated the housing sector.

Post-earthquake reconstruction introduced significant changes in housing design, materials, and construction techniques. The use of RCC increased considerably due to its perceived durability, while alternative materials such as kiln-burnt bricks, CSEB, stone-mud masonry, and stone-cement masonry gained popularity. CGI sheets became a widely used roofing material because of their affordability, availability, and ease of installation. A key shift in construction practice was the reduction in the height of load-bearing structures, which were commonly rebuilt as single-story homes, whereas RCC structures continued to be constructed as two-story buildings. This shift in load-bearing structures likely reflected safety concerns and resource limitations in the reconstruction phase.

Beyond material and structural changes, architectural preferences also evolved. Many homeowners chose to relocate closer to roads and urbanized areas, prioritizing

accessibility over traditional orientation practices that had previously optimized passive heating. Additionally, reconstructed houses featured larger rooms than their pre-disaster counterparts, reflecting changing lifestyle preferences and aspirations for more spacious living conditions. Despite the increased use of modern materials, many residents still favored mud plaster for interior finishes, citing its better thermal properties compared to cement-based surfaces, which were described as cold and uncomfortable, especially in winter.

ii.

The study found that energy consumption patterns in Rimna's post-disaster shelters are largely influenced by economic conditions, infrastructure availability, and traditional practices. Despite policies promoting renewable energy, implementation remains minimal, and reliance on conventional sources continues.

The per capita energy consumption of Nepal is 380 units as per NEA reports. However, in the study area, it is only 37 units. Limited reach to electrical appliance, unreliable supply and use non-commercial traditional fuel are the major reason behind this. The average household size is 4.88 members, influencing overall energy consumption. Bases on family size, 8-12 bhari of firewood are required per month. One bhari weighs around 25 kg. This aligns with the findings of similar studies in Nepal (Rijal and Yoshida, 2002).

For lighting, 97.6% of households use grid electricity, though frequent power outages and voltage fluctuations have led 14.28% to adopt solar panels as a secondary source. LED lights are the primary lighting option, with no reported use of incandescent bulbs, reflecting an awareness of energy efficiency. Cooking energy is primarily sourced from firewood (85.7%), with only 4.76% using LPG exclusively and 9.52% using both LPG and firewood. In similar study (Shrestha, 2022) conducted in Dolakha town, LPG gas was predominantly used for cooking. This reflects the difference in energy sources in village and town areas. The heavy reliance on firewood raises concerns about deforestation and indoor air pollution, while limited LPG use is linked to affordability and supply constraints. Heating methods remain traditional, with households relying on firewood, and layered clothing for warmth. The lack of insulation in CGI sheet shelters exacerbates thermal discomfort, increasing reliance on firewood. Electrical appliances are used sparingly, with 100% of households owning mobile phones and LED lights.

Other appliances, such as televisions (16.67%), Wi-Fi routers (11.9%), radios (7.14%), and fans (2.38%), are found in fewer homes, indicating restricted electricity use due to financial constraints. Electricity bills vary, with most households spending Rs 51-150 per month, while 16.67% spend Rs 151-300. A study in Dolakha town found more than 50% of the respondents spending monthly Rs. 300 or higher in electricity charge (Shrestha, 2022). This difference is mainly due to unavailability of electrical appliances in remote setting. A small number of households report bills under Rs 50, showing that while electricity is accessible, consumption remains low due to economic limitations.

The reliance on firewood highlights both environmental and health concerns, as indoor air pollution remains a significant issue in poorly ventilated shelters. Energy-efficient alternatives, such as improved biomass stoves, solar heating, and better insulation, could reduce energy demand while maintaining comfort. Policies promoting sustainable energy sources should be integrated into post-disaster reconstruction efforts to mitigate long-term economic burdens on affected households.

iii.

Thermal environment in the case study area has been evaluated in this section. Thermal environment was measured (i) by installing datalogger for 22 days, and (ii) by measuring at the instant of collecting thermal sensation vote to find the actual conditions of thermal environment of the houses in which respondents were residing. Table 11 and Table 12 shows relationship and comparison between indoor and outdoor temperature in various locations in Nepal.

Table 11 Relationship between indoor and outdoor air temperatures

S.N.	Reference	Equation	Location	House Type
1.	This study	$T_i = 0.90T_o + 4.85$ $T_i = 0.14T_o + 15.73$ $T_i = 0.33T_o + 10.56$	Jajarkot	Temporary Vernacular Modern
2.	Shrestha <i>et al.</i> , (2023)	$T_i = 0.99T_o + 0.5$ $T_i = 0.67T_o + 4.9$ $T_i = 0.43T_o + 12.7$ $T_i = 0.18T_o + 14.7$	Panipokhari Jillu	Prototype Vernacular Prototype Vernacular

3.	Thapa <i>et al.</i> , (2019)	$T_i = 0.894T_o + 3.27$	Lalitpur	Temporary
4.	Thapa <i>et al.</i> , (2018)	$T_i = 0.920T_o + 2.7$	Central Nepal	Temporary
5.	Thapa <i>et al.</i> , (2019)	$T_i = 1.156T_o - 0.15$	Sindhupalchowk	Temporary
6.	Thapa <i>et al.</i> , (2019)	$T_i = 1.22T_o - 0.87$	Gorkha	Temporary
7.	Bajracharya, (2014)	$T_i = 0.939T_o + 1.34$	Kathmandu	Modern
8.	Bajracharya, (2014)	$T_i = 0.890T_o + 1.61$	Kathmandu	Traditional
9.	Nepal and Bajracharya, (2022)	$T_i = 0.386T_o + 17.36$	Makwanpur	Modern
10.	(Nepal and Bajracharya, 2022)	$T_i = 0.937T_o + 3.48$	Makwanpur	Traditional

Table 12 Comparison of indoor and outdoor air temperature with previous research

Reference	Season	Location	Altitude	House type	To (°C)	Ti (°C)
This study	Winter (Jan-Feb)	Rimna	750 m	Vernacular	14.3	17.7
				Modern		15.6
	Winter (Feb)	Rimna (Night only)	750 m	Vernacular	10.45	16.9
				Modern		13.6
				Temporary		11.1
Shrestha <i>et al.</i> , (2023)	Winter (Jan)	Panipokhari	1765	Vernacular	10.2	12.3
			1170	Prototype		11.6
		Jillu		Vernacular	10.0	16.7
				Prototype		17.5
Thapa <i>et al.</i> , (2018)	Winter (Jan-Feb)	Lalitpur (Night only)	1329	Temporary	7.6	10.3

Rijal <i>et al.</i> , (2010)	Winter (Dec)	Bhaktapur	1350	Vernacular	10.1	11.45
		Dhading	1500		11.9	14.8
		Kaski	1700		11.8	15.3
Pokharel <i>et al.</i> , (2020)	Winter (Dec-Jan)	Panchthar		Traditional, modern	4.1 to 22.1	13.9
Shahi <i>et al.</i> , (2021)	Winter (Jan-Feb)	Kathmandu		Modern	11.3- 18	18

Adopted from (Shrestha *et al.*, 2023)

Figure 35 shows the relationship between mean indoor air temperature ( $T_i$ ) and mean radiant temperature ( $T_{mr}$ ). Mean radiant temperature tends to be higher than indoor air temperature. The maximum and mean values of the differences between  $T_{mr}$  and  $T_i$  are approximately 2.68 °C and 0.25 °C, respectively. This is likely due to the effects of solar radiation absorbed by external surfaces such as walls and roofs.

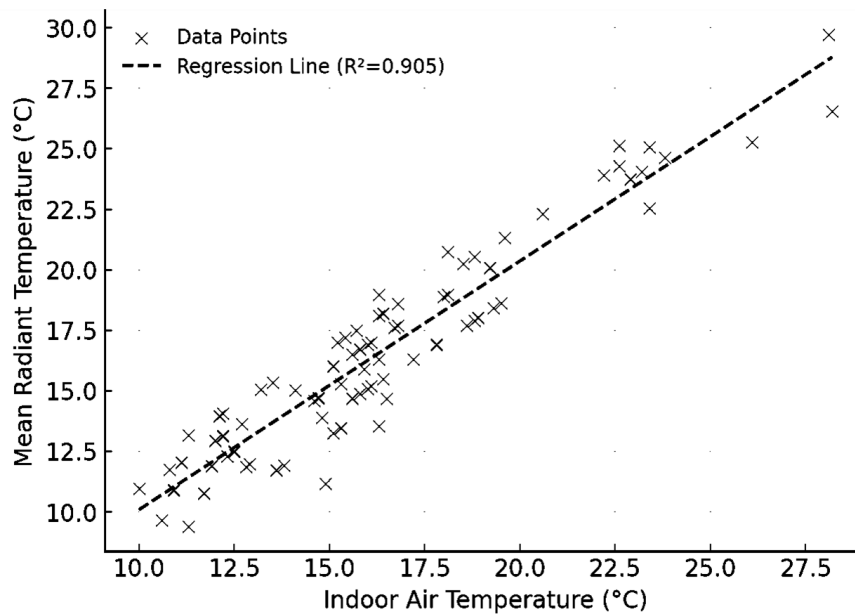


Figure 34 Relationship between MRT and indoor air temperature

Here, we have obtained the following regression equation:

$$T_{mr}=1.027T_i-0.186 \quad (N=103, R^2=0.905, P<0.0001)$$

The coefficient of determination ( $R^2$ ) is 0.905, indicating a strong correlation between mean radiant temperature and indoor air temperature.

Fig. 36 shows the relationship between the measured indoor comfort temperature ( $T_c$ ) and indoor globe temperature ( $T_g$ ). The comfort temperatures ( $T_c$ ) were generally higher than indoor globe temperature ( $T_g$ ), indicating that occupants tend to prefer slightly warmer conditions than the actual globe temperature.

Relationship Between Indoor Globe Temperature and Comfort Temperature

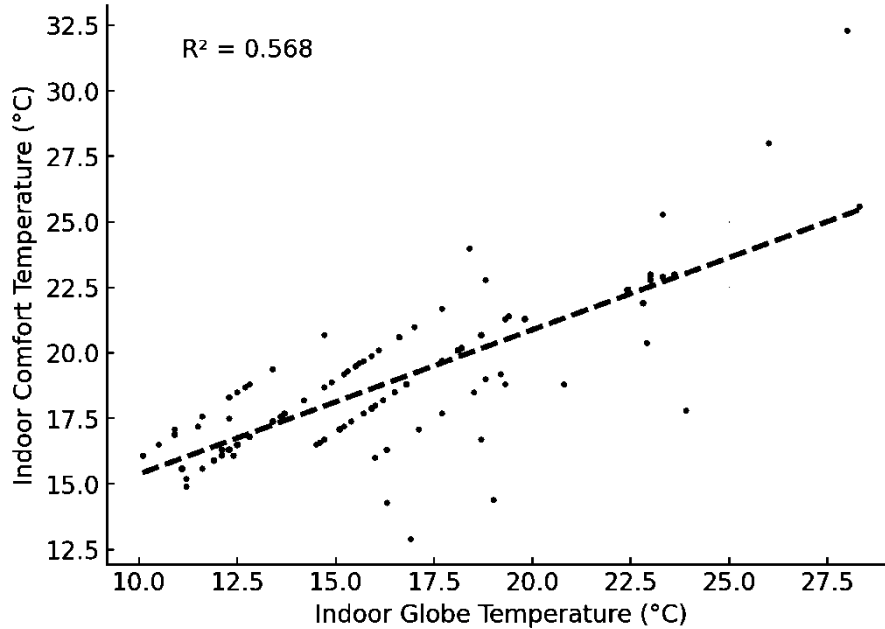


Figure 35 Relationship between indoor globe temperature and indoor comfort temperature

The results suggest that people perceive comfort differently based on indoor thermal conditions, likely influenced by factors such as heat absorption from surrounding surfaces. The comfort temperature changes according to variations in globe temperature, demonstrating an adaptive thermal response. Here, we have obtained the following regression equation:

$$T_c = 0.551T_g + 9.867$$

The coefficient of determination ( $R^2$ ) is 0.568, indicating a moderate correlation between indoor globe temperature and indoor comfort temperature.

In a study conducted in temporary shelters in central region of Nepal, the relation was found to be:

$$T_c = 0.606T_g + 9.2 \text{ (Thapa et al., 2019)}$$

The estimated comfort temperature by Griffiths' method obtained in this research has been compared with those of in previous research (Table 13). Since this study was

conducted during winter, the comfort temperature for winter season has only been discussed.

Table 13 Comfort temperature in Nepal

S.N.	Area	References	House type	Comfort temperature (°C)
1.	Jajarkot	This study	Temporary	18.7
2.	Lalitpur, Kathmandu, Shindhupalchowk, Gorkha	Thapa <i>et al.</i> , (2019)	Temporary	15.0-20.8
3.	Banke, Bhaktapur, Dhading, Kaski, Solukhumbu	Rijal <i>et al.</i> , (2010)	Traditional	13.4-24.2

The similar value of comfort temperature of this study with previous study suggests that no matter the regional variations, building type or clothing pattern, human beings prefer to maintain core temperature at nearly constant level.

The study has found that indoor air temperature was highly correlated with the outdoor air temperature (Fig. 34). Thapa *et al.*, (2018) has come up with adaptive comfort model specifically for temporary shelters. Following this approach, Fig. 37 depicts the relationship between comfort temperature ( $T_c$ ) and outdoor air temperature.

We have obtained the following equation from the regression analysis.

$$T_c = 0.4602T_o + 11.68 \text{ (N=103, } R^2=0.46, P<0.0001)$$

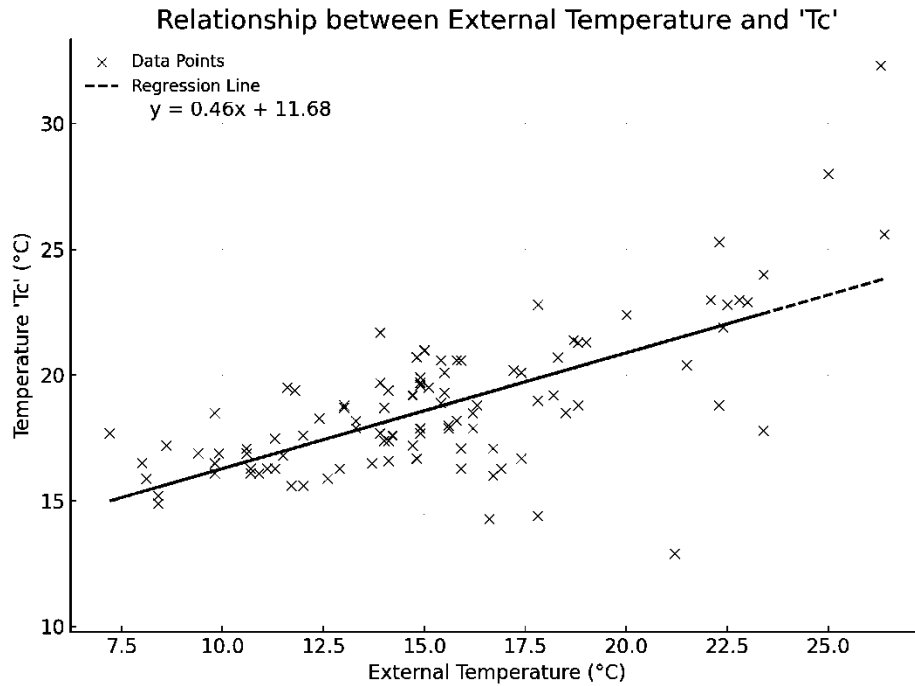


Figure 36 Relationship between comfort temperature and external air temperature

This equation suggests moderate relationship between comfort temperature and external air temperature. Along with external air temperature, there are other factors that affects comfort temperature. However, the results are similar to other studies conducted in the similar domain. Table 14 compares the adaptive model of this study with those from the previous research.

Table 14 Comparison of adaptive model of various studies

S.N.	Reference	Regression equation	Mode
1.	This study	$T_c = 0.4602T_o + 11.68$	Natural Ventilated
2.	Thapa <i>et al.</i> , (2018)	$T_c = 0.556T_o + 10.9$	Free Running
3.	Humphreys <i>et al.</i> , (2013)	$T_c = 0.531T_o + 12.5$	Free Running
4.	Nicol and Roaf, (1996)	$T_c = 0.38T_o + 17.0$	Natural Ventilated
5.	de sDear and Brager, (2002)	$T_c = 0.31T_o + 17.8$	Natural Ventilated

The average clothing insulation was 0.89clo, ranging in 0.5clo and 1.2clo. During the day time, respondents wore light clothes due to their constant involvement in physical activities. However, during morning and evening hours, the respondent wore warm clothes. Along with other factors affecting thermal comfort, clothing preference was dependent on physical activity. Clo value as reported in Kathmandu (1.11), Lalitpur (1.29) and Gorkha (1.26) were higher, and in Sindhupalchowk (0.93) was similar during winter season (Thapa, Rijal and Shukuya, 2018) as compared with the case study area. The detail analysis of the material choice for selected house design has been performed in simulation study to reach to a conclusion on material recommendation. Table 15 presents the simulation-based recommendations on window wall ratio, orientation and wall materials for enhancing thermal comfort inside the building.

Table 15 Optimized value for parameters under study

S.N.	Parameter	Optimized value
1.	Orientation	160° and 185°
2.	WWR	20% to 40%
3.	Wall material	CSEB block cavity wall
4.	Roof material	RCC Slab or Slate stone

In our study, the orientation 180° refers to south facing building. So, from simulation, it is found that the building should be south oriented with flexibility of 5° towards west and 20° towards east. The lower WWR corresponds to higher energy efficiency, however, considering daylighting factor, a WWR of 20% to 40% has been accepted as optimized range. The CSEB block cavity wall displayed a better performance, and it is cost friendly and locally available too. The workability of CSEB has been praised by local masons. Similarly, various organizations working in post disaster reconstruction in the case study area are promoting environment friendly CSEB blocks. As a roofing material, in case of multistorey RCC building, RCC slab is the sole alternative. However, for low-cost housing, slate stone or even CGI sheet roofing with storage space partitioned by wooden planks or reef mud mixture can also be used. These



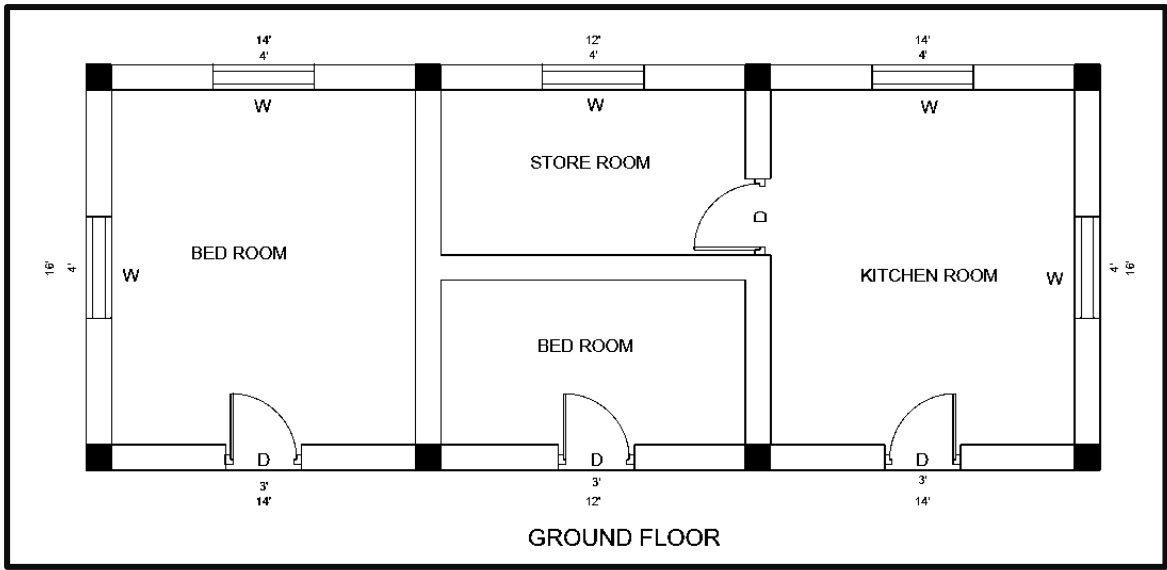


Figure 38 Basic layout of the proposed single-bay house

## CHAPTER 7: CONCLUSION

### 7.1 Summary of Research

This study examined thermal comfort in post-disaster reconstruction shelters in the context of the 2023 Jajarkot earthquake. The research aimed to assess the effectiveness of various cost-effective materials in enhancing thermal performance and energy efficiency in these shelters. By integrating qualitative and quantitative data collection methods, material analysis, cognitive drawings, and energy modeling using DesignBuilder software, the study provided insights into optimal design strategies for improving post-disaster housing.

The research findings indicate that many post-disaster temporary shelters exhibit poor thermal performance because of inadequate insulation, high heat loss in winter, and overheating in summer. The indoor temperature variation across house type during night time shows the difference in thermal performance. While outdoor average temperature was 10.45°C, indoor temperatures were 16.9°C (vernacular), 13.6°C (modern), 11.1°C (temporary). The external and indoor temperature showed strong correlation inside the modern RCC house ( $R^2=0.622$ ) and temporary shelters ( $R^2=0.616$ ), and a weak correlation in stone mud masonry vernacular house ( $R^2=0.202$ ).

Thermal sensation vote revealed the average comfort temperature inside temporary shelters as 18.7°C. Below 10.4°C, most people rejected the thermal conditions, while at around 15.7°C, 80% find the environment comfortable. Locally available and cost-effective materials, such as stone, mud, ecoblocks, CSEB blocks, etc. provide superior thermal properties compared to commercially trending materials. Findings reveal that affected households prioritize materials that balance cost, availability, and comfort. The preference is influenced by their cultural and traditional norms and values. Simulations conducted in DesignBuilder software demonstrate that shelters constructed with thermally efficient materials and optimized design modifications significantly improve indoor comfort levels and reduce energy consumption. The optimized parameters include WWR 20-40%, south oriented buildings with cavity walls of CSEB or Ecobricks.

The energy consumption analysis in the case study area reveals that 97.6% of households rely on the national grid, while 2.4% depend on solar power due to relocation challenges after the earthquake. Households use an average of 7.92 kWh per

month for lighting, primarily with LED bulbs, and 14.28% also incorporate solar panels as a secondary energy source. Cooking is predominantly powered by firewood, with 85.7% of households relying solely on it, leading to concerns over deforestation and indoor air pollution. Only 4.76% of households use LPG exclusively, but high costs (Rs. 2200-2300 per cylinder) and limited access restrict its widespread adoption. Electrical appliance usage is minimal, with mobile phones and LED lights being universally present, while televisions (16.67%), Wi-Fi routers (11.9%), and fans (2.38%) are less common. Overall, the per capita energy consumption is low at 37 kWh, reflecting a lifestyle focused primarily on essential needs.

## **7.2 Implications for Post-Disaster Reconstruction**

The study highlights the need of policy interventions that prioritize local materials and community participation in shelter reconstruction. Government agencies, non-governmental organizations, and local stakeholders should incorporate energy-efficient strategies to enhance the resilience of post-disaster housing. Future post-disaster housing policies must ensure a balance between immediate relief and long-term sustainability, emphasizing thermal comfort as a critical factor in rebuilding efforts.

## **7.3 Limitations and Future Research**

While this study provides valuable insights, certain limitations exist:

- The research primarily focused on Rimna, Bheri-1, Jajarkot, and findings may not be directly generalizable to other earthquake-affected regions.
- The study relied on simulation models that, while useful, require real-world validation through long-term monitoring.
- The scope was limited to thermal comfort and did not extensively cover structural resilience.
- The study was done during winter season only, which misses out on seasonal variations.

Future research should explore:

- The long-term performance of different materials in diverse climatic conditions.
- The integration of renewable energy technologies in post-disaster shelters.
- Broader policy frameworks that incorporate thermal comfort as a standard in reconstruction guidelines.

## **7.4 Conclusion**

The study comprehensively analyzed the envelope of the shelters reconstructed after the disaster in Rimna village, focusing on construction materials, architectural techniques, and design elements. The findings reveal that while the materials used ensure structural stability, the lack of thermally efficient designs—such as improper orientation, poor building layout, and insufficient insulation—compromises interior comfort. The location and size of openings, along with surface color and texture, significantly influence heat retention and ventilation; however, these factors have not been adequately optimized in most shelters.

The analysis of energy consumption highlights the increasing reliance on inefficient heating methods, which exacerbates the financial burden on households. The high energy demand for heating, coupled with limited financial resources, makes it difficult to maintain comfortable indoor temperatures. The study also assessed the actual thermal conditions of the reconstructed shelters, revealing significant temperature fluctuations and inadequate insulation, leading to discomfort in extreme weather conditions.

To address these challenges, the study recommends integrating energy-efficient building materials, improving insulation, and adopting passive solar design principles for future post-disaster housing. Optimizing orientation, optimizing window placement, and better utilization of thermal mass can improve indoor comfort and reduce heating costs. Furthermore, policy interventions and financial support mechanisms should be considered to facilitate the adoption of low-cost, sustainable heating solutions. By implementing these strategies, post-disaster housing can be more thermally comfortable and economically sustainable for affected communities.

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## APPENDIX– A: QUESTIONNAIRE – I

This questionnaire has been designed to gather information on demographic, socio-economic, housing and infrastructure, residential satisfaction, energy consumption pattern, energy efficiency and awareness, challenges and perceptions of the residents of the case study area for the purpose of aiding in the thesis entitled “Thermal Comfort in Post-Disaster Reconstructed Shelters: A Case Study of the 2023 Jajarkot Earthquake”.

### Section 1: Demographic Information

Name of the respondent: .....

1.1. What is your age?

- Under 18
- 18-30
- 31-45
- 46-60
- Over 60

1.2. What is your gender?

- Male
- Female
- Other

1.3. What is your marital status?

- Single
- Married
- Widowed
- Divorced

1.4. How many people live in your household?

.....

1.5. What is your employment status?

- Agriculture
- Service
- Labour
- Self-employed
- Retired

- Housewife
- Student
- Unemployed
- Others .....

1.6. What is your highest level of education?

- No formal education
- Primary education
- Secondary education
- Higher secondary education
- Bachelor's degree or higher

1.7. Is any member of your family out for foreign employment?

Yes/No (If yes, country.....)

1.8. What is the total monthly expenditure in your household?

- 10,000-20,000
- 20,001-30,000
- 30,001-40,000
- 40,001-50,000
- More than 1,00,000

1.9. What is the total monthly earning in your household?

- 10,000-20,000
- 20,001-30,000
- 30,001-40,000
- 40,001-50,000
- More than 1,00,000

1.10. How long have you been living in this house?

- Less than 6 months
- Less than 1 year
- 1-3 years
- 4-6 years
- 7-10 years
- More than 10 years

1.12. If less than 3 years, where was your house before earthquake?

.....

1.13. What is the full address of this place?

District..... Municipality..... Ward..... Tole.....

## **Section 2: Housing and Infrastructure**

2.1. What type of dwelling do you live in?

- Temporary structure
- Semi-permanent structure
- Permanent structure

2.2. What materials were used to build your house? (Select all that apply)

- Mud
- Brick
- Wood
- Metal
- Plastic
- Other (please specify): \_\_\_\_\_

2.3. What is the roofing material in your house?

.....

2.4. What is the orientation of your house?

.....

2.5 Who designed your current house, and did you participate in design and selection of construction materials for your house?

.....

2.6. Do you like the design of the house?

Yes/No

2.7. Can you draw the basic plan of a house that you desire to build for yourself?

Include building materials, orientation, layout, provision of various activities to be performed inside and nearby the house, room size, number of floors, number of rooms for various purposes, etc.

2.8. What is the cost of construction of your house?

.....

2.6. Did you take any loans while building this house?

Yes/No (If yes, from which financial institution and is it already paid or how much remaining).....

2.7. Did you receive grants from Nepal Government for reconstruction of temporary shelter?

First Installment..... Second Installment..... No.....

2.8. Does your house have access to the following services? (Select all that apply)

- Electricity
- Water supply (Specify source)
- Drainage
- Sanitation facilities (septic tank, sewage)
- Cooking gas
- Telephone, Internet

2.9. What is the total number of rooms in your house?

.....

2.10. What is the total number of floors in your house?

.....

2.10. Are you planning to make any modifications on this house in near future?

.....

2.11. Are you satisfied living here?

Yes/No

2.12. Do you think the factors are important?

1- Not Important, 2- Slightly Important, 3- Moderately Important, 4- Very Important 5- Very Important

- Road
- Water supply
- Sanitation and Drainage

- Electricity
- Health facility
- Religious place
- Education facilities
- Provision of kitchen garden
- Provision of open space
- Location if the house in the site
- Livelihood opportunities
- Neighborhood relations

2.13. Do you think the factors are important?

1- Not Important, 2- Slightly Important, 3- Moderately Important, 4- Very Important 5- Very Important Layout of the house

- Size of the rooms
- Number of rooms
- Thermal comfort in summer
- Thermal comfort in winter
- Daylight
- Ventilation
- Feeling for privacy
- Interior for cultural and religious activities
- Interior for life cycle activities
- Interior space for everyday activities
- Interior space for family interaction
- Using space outside of house

2.13. On the scale of 1-5 how much satisfied are you with your current house?

1- Very unsatisfied, 2- Unsatisfied, 3- Neutral, 4- Satisfied, 5- Very satisfied

2.14. How do you feel inside your house?

1- Very cold, 2- Cold, 3- Slightly cold, 4- Neutral, 5- Slightly hot, 6- Hot, 7- Very hot

- Summer Morning
- Summer Day

- Summer Night
- Winter Morning
- Winter Day
- Winter Night

2.14. Rate your overall thermal satisfaction

1- Extremely dissatisfied 2- Dissatisfied 3- Somewhat dissatisfied 4- Neutral 5- Somewhat satisfied 6- Satisfied 7- Highly satisfied

2.15 Once you feel uncomfortable in the room, what do you do to provide comfort?

- Open windows
- Open doors
- Use hand fans
- Take off layer of clothes
- Turn on electric fans
- Use heaters
- Use firewood heating
- Others

### **Section 3: Energy Sources and Usage**

3.1. What is your primary source of energy for cooking?

- Firewood
- Charcoal
- Kerosene
- Liquefied Petroleum Gas (LPG)
- Electricity
- Other (please specify): \_\_\_\_\_

3.2. What is your primary source of energy for heating?

- Firewood
- Charcoal
- Kerosene
- Electricity
- Other (please specify): \_\_\_\_\_

3.3. What is your primary source of energy for lighting?

- Kerosene
- Candles
- Solar lanterns
- Electricity
- Other (please specify): \_\_\_\_\_

3.4. How much do you spend on energy per month (in NPR) during winter season?  
(Ask separately on electricity and cooking fuel.)

- Less than 500
- 500-1000
- 1001-1500
- 1501-2000
- More than 2000

3.5. How much.....

- Monthly units of electricity consumer.....
- Monthly electricity bill.....
- Monthly firewood usage.....
- Gas cylinder refill time.....
- Kerosene use per month.....
- Water bill per month.....

3.6. How many hours per day do you use lighting?

.....

3.7. How often do you experience power outages?

- Never
- Occasionally (1-2 times per week)
- Frequently (3-4 times per week)
- Daily

3.9. Do you use any alternative energy sources? (Select all that apply)

- Solar panels
- Biogas
- None
- Other (please specify): \_\_\_\_\_

3.10. List of electrical appliances and its usage in the household:

S.N.	Name of Appliance (with Model No.)	Purpose of the appliance	Power rating (in Watts)	Energy star rating (if available)	Daily average usage

3.11. Which electrical equipment do you think consumes most energy?

.....

3.12. Do you use solar energy ?

Yes/No

#### Section 4: Energy Efficiency and Awareness

4.1. Are you aware of energy-efficient appliances?

- Yes
- No

4.2. Do you use energy-efficient appliances? (e.g., LED bulbs, energy-efficient stoves)

- Yes
- No

4.3. If yes, what types of energy-efficient appliances do you use? (Select all that apply)

- LED bulbs
- Energy-efficient stoves
- Solar water heaters
- Other (please specify): \_\_\_\_\_

4.4. How did you learn about energy-efficient appliances?

- Government programs
- NGO initiatives
- Media (TV, radio, newspapers)
- Word of mouth
- Other (please specify): \_\_\_\_\_

4.5. Have you received any training or information on energy conservation practices?

Yes..... No.....

4.6. Are you interested in learning more about energy conservation?

Yes..... No.....

4.7. How do you act in the following?

1- Always, 2- Often, 3- Occasionally, 4- Rarely, 5- Never

- Do you regularly switch off the lights while leaving room?
- Do you use natural light in the day to minimize use of artificial lighting?

## **Section 5: Challenges and Perceptions**

5.1. What challenges do you face in accessing reliable energy? (Select all that apply)

- High cost of energy
- Unreliable supply
- Poor infrastructure
- Lack of information
- Other (please specify): \_\_\_\_\_

5.2. In your opinion, what are the most effective ways to improve energy access and efficiency in your community? (Select all that apply)

- Government intervention and policies
- Community awareness programs
- Subsidies for energy-efficient appliances
- Improved infrastructure
- Other (please specify): \_\_\_\_\_

5.3. How satisfied are you with your current energy situation?

- Very satisfied
- Satisfied
- Neutral

- Dissatisfied
- Very dissatisfied

5.4. What changes would you like to see in your energy supply and usage?

.....

...

Surveyors Use

Sky condition during survey?

- Clear
- Mixed (Sun and clouds)
- Overcast

Air temperature (°C) .....

Relative humidity (%) .....

Occupant's location in a surveyed area

- Inside room
- Outside
- Others

State of person while being surveyed (Generalize)

- Reclining
- Seated Relaxed
- Standing Relaxed
- Standing with Light Activity
- Standing with Medium Activity
- High Activity

What cloth is occupant wearing? (Multiple answer is allowed)

- Half-sleeve or sleeve less vest
- Half pant with light upper clothing
- Jacket Coat- pant
- Kurtha-surwal
- Sari
- Kamij-surwal
- Daura-surwal
- T-shirt /shirt and pant
- Others

Remarks

## APPENDIX – B: QUESTIONNAIRE – II

### Thermal Sensation Vote:

<b>Name</b>		<b>Date/Time</b>	
<b>Gender</b>		<b>Building type</b>	

### 1. How hot or cold do you feel right now?

1	2	3	4	5	6	7
Very Cold	Cold	Slightly Cold	Neutral <small>neither hot nor cold</small>	Slightly hot	Hot	Very hot

### 2. How you prefer now?

1	2	3	4	5
Much warmer	A bit warmer	No change	A bit cooler	Much cooler

### 3. Can you accept the present thermal environment?

1	2
Acceptable	Unacceptable

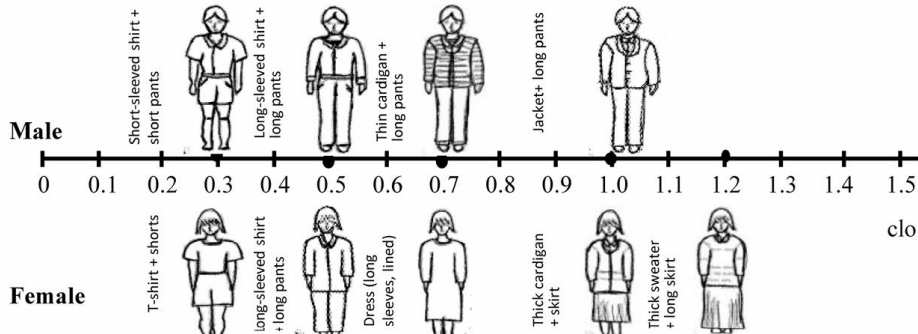
### 4. Overall thermal satisfaction

1	2	3	4	5	6
Very Uncomfortable	Moderately Uncomfortable	Slightly Uncomfortable	Slightly Comfortable	Comfortable	Very Comfortable

### 5. What are you currently doing?

1	2	3	4	5
Lying down	Sitting and resting	Sitting and working	Standing	Moving around

### 6. Clothing insulation right now: (Can choose between the numbers too)



### To be filled by surveyor:

	Internal	External
Temp. (Celsius)		
RH %		
Globe temp.		
Sky condition		

## APPENDIX – C: RESULTS FROM MAHONEY TABLE

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(range)
<b>Relative humidity %</b>														
Monthly mean max am		80	72	68	59	71	81	91	90	86	68	68	72	1 <30% 2 30–50% 3 50–70% 4 >70%
Monthly mean min pm		80	72	68	59	71	81	91	90	86	68	68	72	
Average		80	72	68	59	71	81	91	90	86	68	68	72	
Humidity group		4	4	3	3	4	4	4	4	4	3	3	4	

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
<b>Rain and wind</b>														
Rainfall mm		41	48	33	36	90	316	579	459	242	61	12	17	1934
Wind, prevailing		NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	N, NE, E, SE, S, SW, W, NW
Wind, secondary		E	NE	NE	NE	NE	NE	E	NE	NE	NE	NE	NE	

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AMT
<b>Diagnosis °C</b>														
Monthly mean max		16	19	24	29	29	29	27	27	27	25	22	18	25
Day comfort, upper		27	27	29	29	27	27	27	27	27	29	29	27	
Day comfort, lower		22	22	23	23	22	22	22	22	22	23	23	22	
Thermal stress, day		C	C	O	O	H	H	O	O	O	O	C	C	
Monthly mean min		4	6	9	14	17	20	21	21	20	14	9	5	
Night comfort, upper		21	21	23	23	21	21	21	21	21	23	23	21	
Night comfort, lower		17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress, night		C	C	C	C	O	O	O	O	O	C	C	C	

H = Hot  
 O = Comfort  
 C = Cold

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

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

Indicator totals from data sheet					
H1	H2	H3	A1	A2	A3
2	3	4	4	0	4

**Rimna, Jajarkot, Nepal**  
Latitude 28°N

#### Layout

			0-10			<input checked="" type="checkbox"/>	Orientation north and south (long axis east-west)
			11-12				Compact courtyard planning

#### Spacing

11-12							Open spacing for breeze penetration
2-10						<input checked="" type="checkbox"/>	As above, but protection from hot and cold wind
0-1							Compact layout of estates

#### Air movement

3-12						<input checked="" type="checkbox"/>	Rooms single banked, permanent provision for air movement
1-2			0-5				Rooms double banked, temporary provision for air movement
			6-12				
0	2-12						No air movement requirement
	0-1						

#### Openings

			0-1		0		Large openings, 40-80%	
			11-12		0-1		Very small openings, 10-20%	
Any other conditions							<input checked="" type="checkbox"/>	Medium openings, 20-40%

#### Walls

			0-2				Light walls, short time-lag
			3-12			<input checked="" type="checkbox"/>	Heavy external and internal walls

#### Roofs

			0-5			<input checked="" type="checkbox"/>	Light, insulated roofs
			6-12				Heavy roofs, over 8h time-lag

#### Outdoor sleeping

				2-12			Space for outdoor sleeping required
--	--	--	--	------	--	--	-------------------------------------

#### Rain protection

		3-12				<input checked="" type="checkbox"/>	Protection from heavy rain necessary
--	--	------	--	--	--	-------------------------------------	--------------------------------------

#### Size of opening

			0-1		0		Large openings, 40-80%
					1-12	<input checked="" type="checkbox"/>	Medium openings, 25-40%
			2-5				
			6-10				Small openings, 15-25%
					0-3		Very small openings, 10-20%
			11-12		4-12		Medium openings, 25-40%

#### Position of openings

3-12						<input checked="" type="checkbox"/>	In north and south walls at body height on windward side
1-2			0-5				
			6-12				
0	2-12						As above, openings also in internal walls

#### Protection of openings

					0-2		Exclude direct sunlight
		2-12				<input checked="" type="checkbox"/>	Provide protection from rain

#### Walls and floors

			0-2				Light, low thermal capacity
			3-12			<input checked="" type="checkbox"/>	Heavy, over 8h time-lag

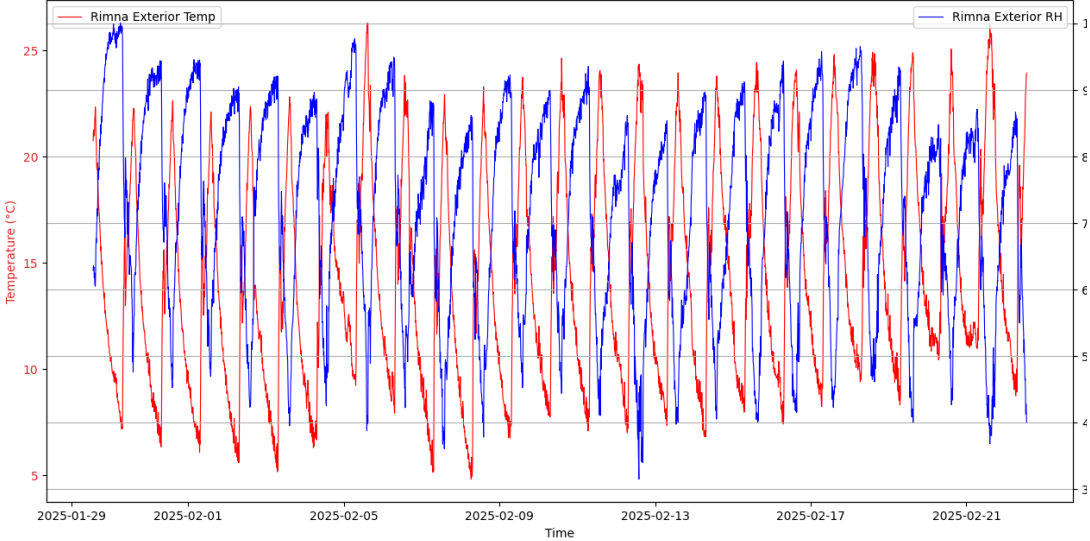
#### Roofs

10-12			0-2				Light, reflective surface, cavity
			3-12			<input checked="" type="checkbox"/>	Light, well insulated
0-9			0-5				
			6-12				Heavy, over 8h time-lag

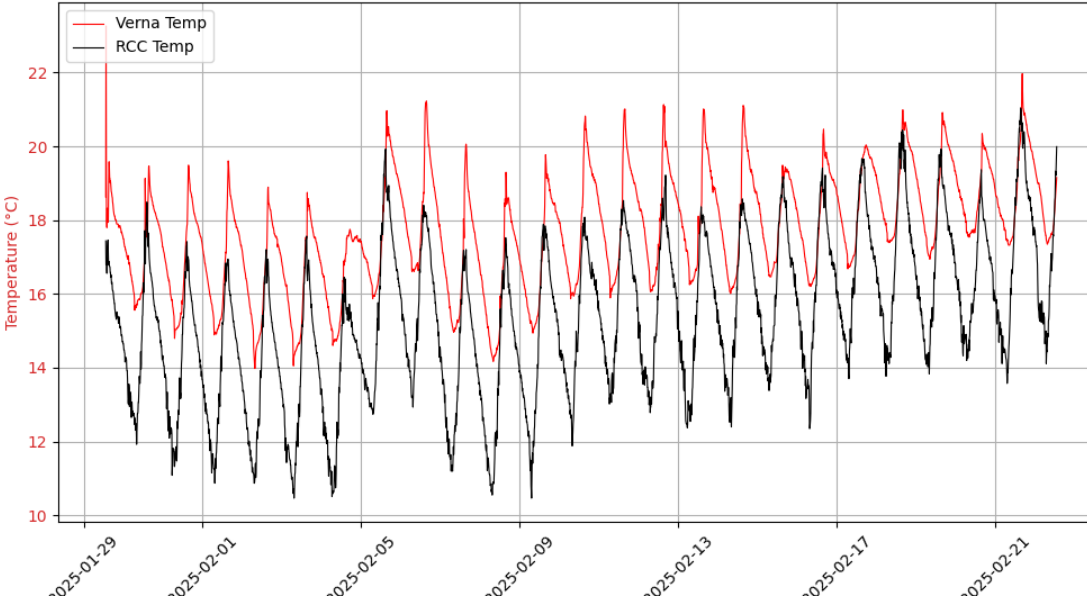
#### External features

				1-12			Space for outdoor sleeping
		1-12				<input checked="" type="checkbox"/>	Adequate rainwater drainage

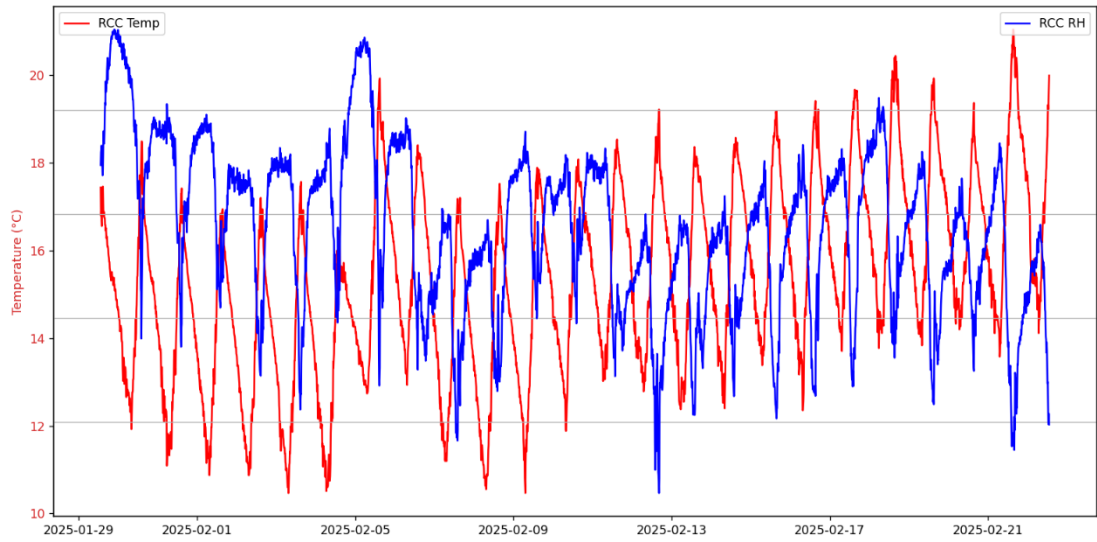
# APPENDIX – D: TEMPERATURE AND HUMIDITY DATA



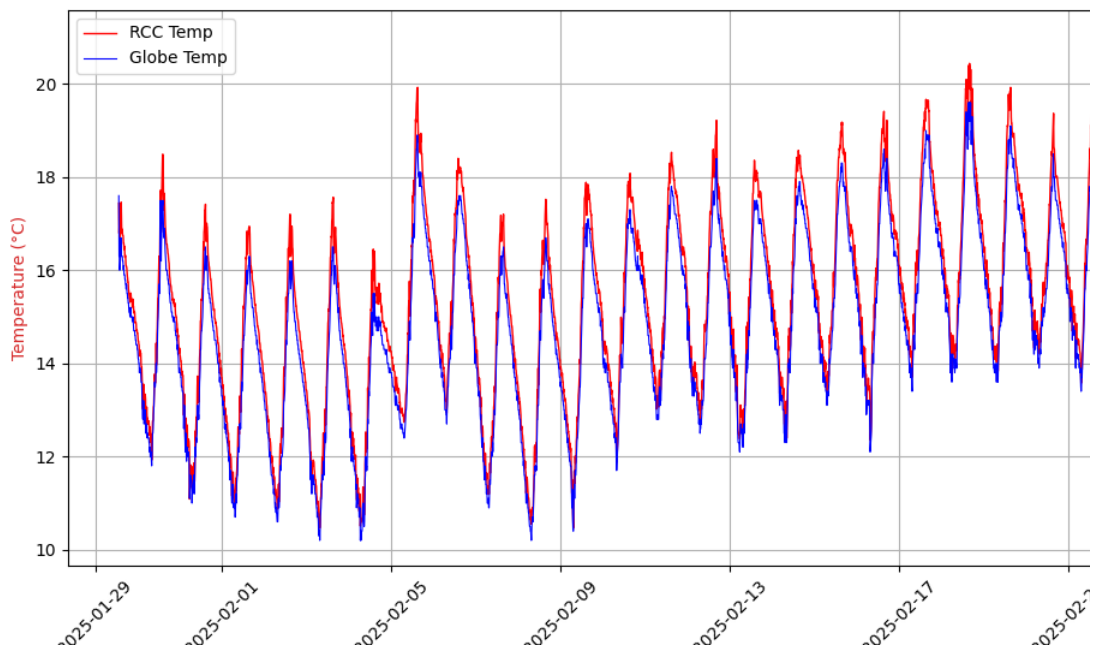
External air temperature and relative humidity variation over time in case study area



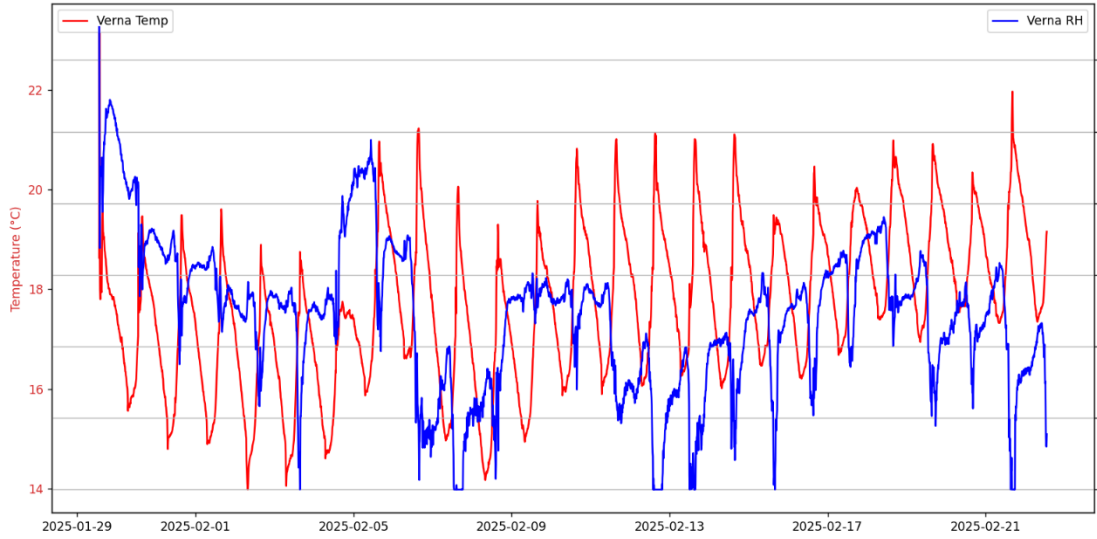
Air temperature variation over time inside vernacular and modern house



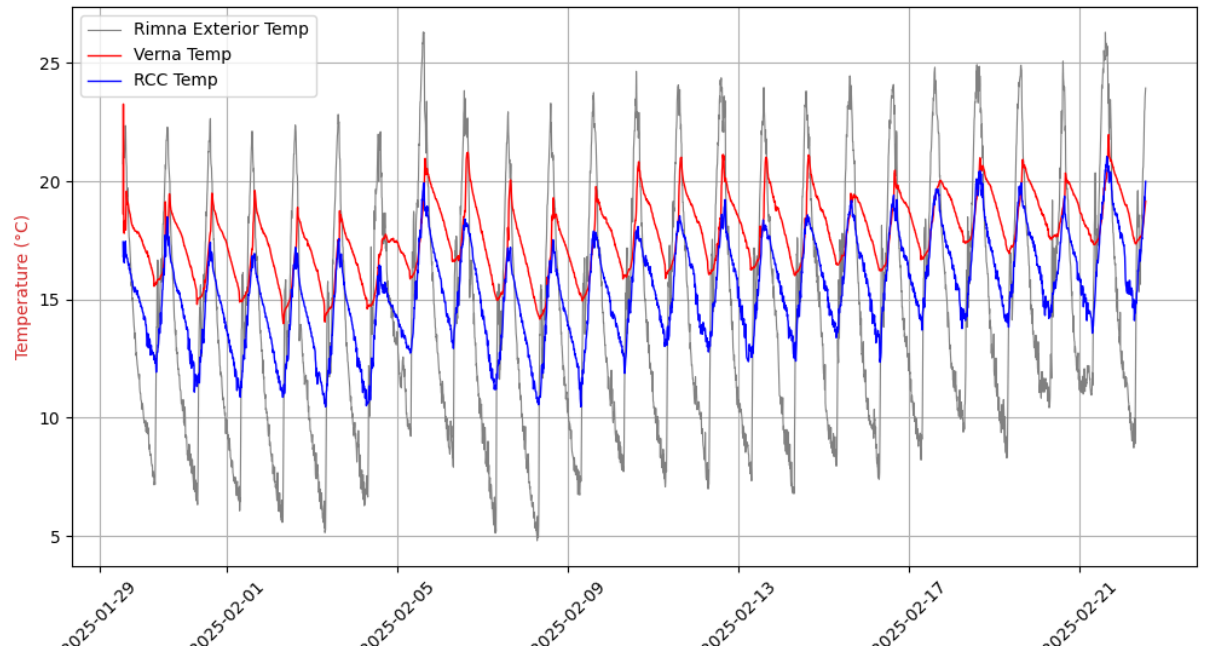
Air temperature and relative humidity variation over time inside RCC building



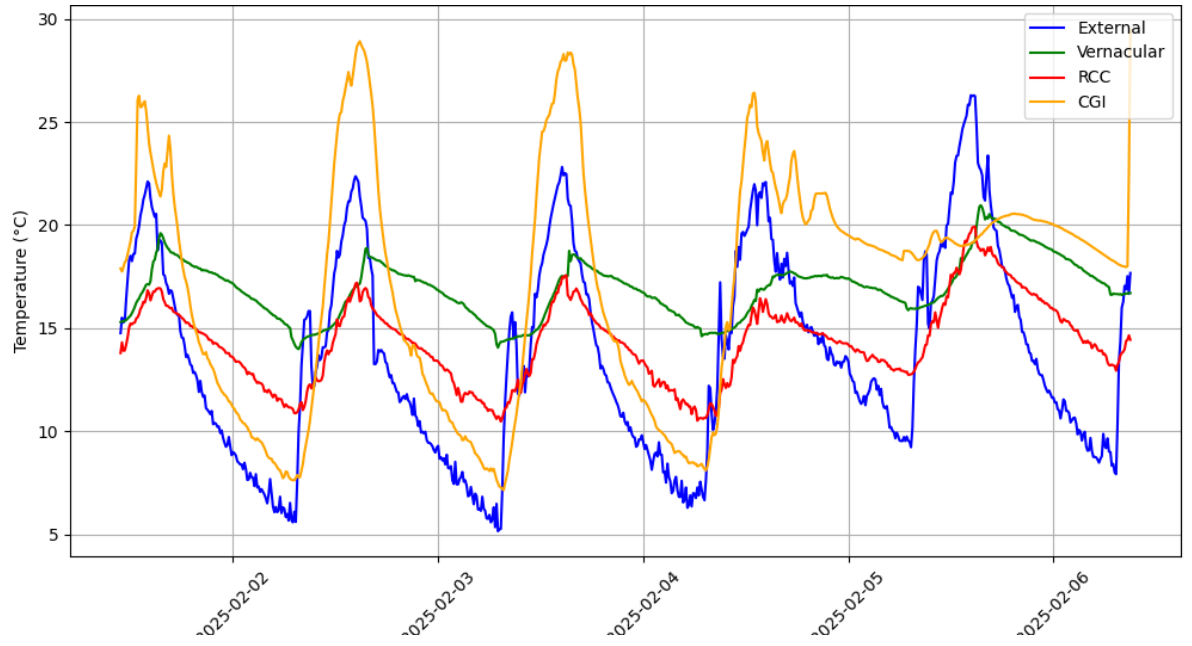
Air temperature and globe temperature variation over time inside RCC building



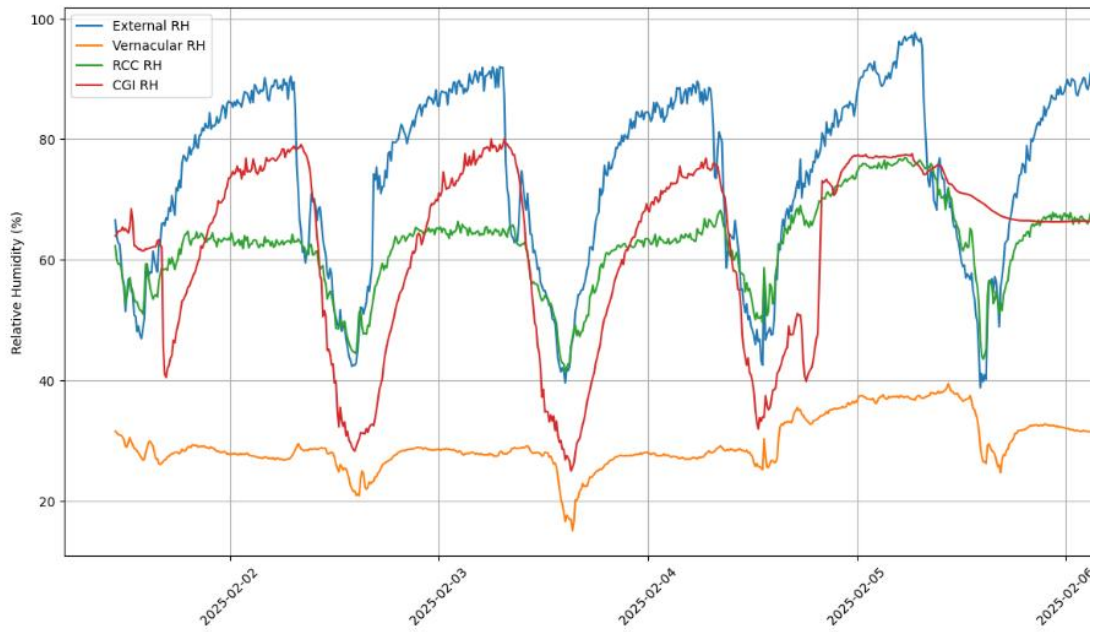
Air temperature and relative humidity variation over time inside vernacular house



Air temperature variation over time in case study area



Air temperature variation over time in case study area



Relative humidity variation over time in case study area

## APPENDIX – E: THERMAL SENSATION VOTE

A	i	ii	iii	iv	1	2	3	4	5	6	INTERNAL			EXTERNAL		
											7	8	9	10	11	12
1	NAREN RANA <sup>me</sup>	M	CGI	1128 8:30	2	2	1	2	2	0.9	15.6	51	15.1	16.1	69	Clear
2	SHIM BIR RANA <sup>me</sup>	M	CGI	1128 9:00	3	2	1	3	3	0.9	16.3	55	16.5	16.2	65	Clear
3	ONAMPATHA PUN <sup>me</sup>	F	STONE	1128 9:30	2	2	1	3	2	1	15.7	35	15.9	13.3	75	Clear
4	KALPANA RANA <sup>me</sup>	F	WOOD	1128 9:30	2	2	1	3	2	0.7	15.2	55	15.2	14.0	71	Clear
5	BHUMILAL RANA <sup>me</sup>	M	CGI	1128 10:10	2	2	1	2	2	0.7	15.8	51	15.9	14.9	72	Clear
6	LILA RANA <sup>me</sup>	F	CGI	1128 10:10	3	2	1	3	3	0.9	15.8	51	15.7	14.9	72	Clear
7	BIRMALA RANA <sup>me</sup>	F	ACC	1128 18:10	3	2	1	3	3	1.0	15.9	75	15.9	15.6	82	Clear
8	JANGITA RANA <sup>me</sup>	F	CGI	1128 18:20	3	2	1	2	2	0.9	15.4	59	15.6	14.9	85	Clear
9	BIPANA RANA <sup>me</sup>	F	CGI	1128 18:30	3	2	1	3	3	0.8	15.8	60	15.9	14.9	85	Clear
10	SASHIRAM RANA <sup>me</sup>	M	CGI	1130 18:30	3	1	1	2	2	0.7	16.4	51	16.8	15.9	71	Clear
11	CHANDRABIR THAKUR <sup>me</sup>	M	CGI	1130 12:30	4	2	1	3	2	0.7	19.5	48	19.4	18.7	65	Clear

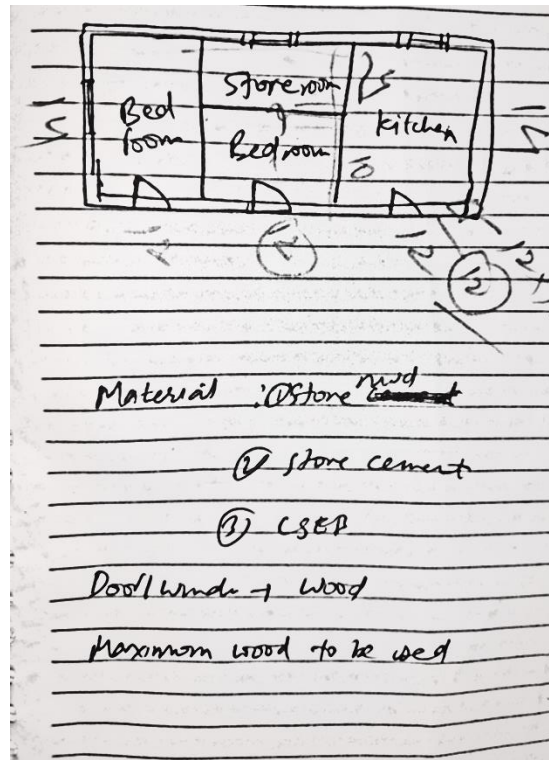
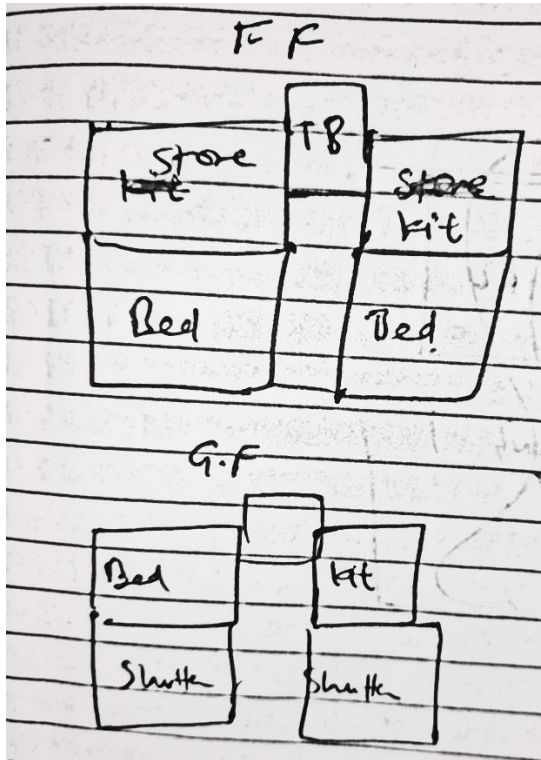
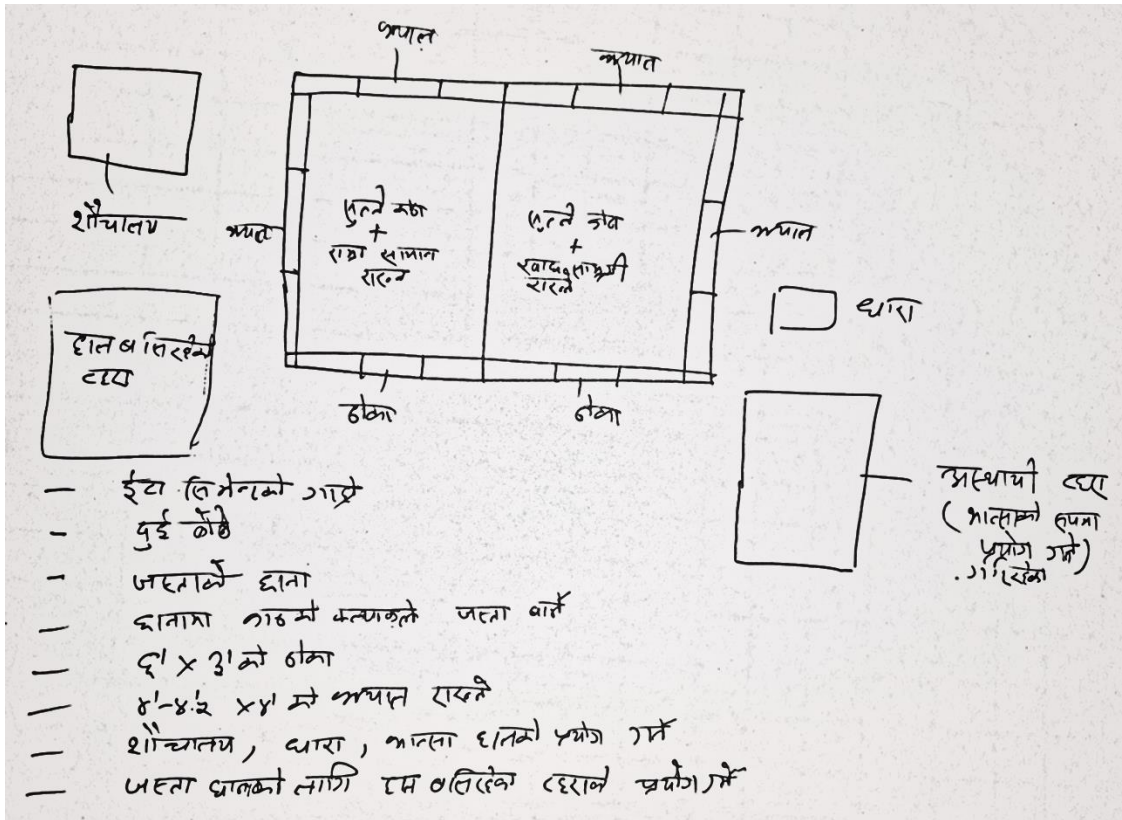
B	i	ii	iii	iv	1	2	3	4	5	6	INTERNAL			EXTERNAL		
											7	8	9	10	11	12
1	BALJIT RANA <sup>me</sup>	M	CGI	1128 9:00	1	1	2	2	2	1.1	15.6	40	15.7	14.7	73	Clear
2	GANGARAM PUN <sup>me</sup>	M	CGI	1128 10:00	2	2	2	2	2	0.9	15.1	42	15.2	14.7	73	Clear
3	NISHA PUN <sup>me</sup>	F	CGI	1128 10:00	2	2	1	3	3	0.7	15.1	42	15.2	14.7	73	Clear
4	KHUMBA RANA <sup>me</sup>	M	CGI	1128 10:20	3	2	1	2	3	0.69	15.3	45	15.3	15.5	68	Clear
5	BIBASH RANA <sup>me</sup>	M	CGI	1128 10:50	3	3	1	5	3	0.9	16.4	50	16.3	16.6	71	Clear
6	NARESH K RANA <sup>me</sup>	M	CGI	1128 11:10	4	2	1	3	2	0.7	16.7	41	16.8	16.3	70	Clear
7	PARIMALE RANA <sup>me</sup>	M	CEB	1128 12:20	5	3	1	5	4	0.5	20.6	52	20.8	22.7	52	Clear
8	NIMA RANA <sup>me</sup>	M	CGI	1128 5:00	4	3	1	4	2	0.8	17.2	45	17.1	16.7	71	Clear
9	LALITA RANA <sup>me</sup>	F	CGI	1128 5:10	3	2	1	3	3	0.9	16.0	47	15.9	16.2	74	Clear
10	RAMB. PUN <sup>me</sup>	M	CGI	1128 5:30	3	2	1	3	2	0.9	16.1	64	16.2	15.8	75	Clear
11	NARATERANA <sup>me</sup>	M	CGI	1128 18:30	2	1	2	2	2	0.8	14.8	65	14.7	15.0	78	Clear
12	BHASHI RAM RANA <sup>me</sup>	M	CGI	1128 18:00	2	1	1	3	3	1.0	15.9	69	14.5	13.7	80	Clear
13	CHANDLABIR THAKUR <sup>me</sup>	M	CGI	1129 7:30	1	1	2	1	1	0.9	8.4	72	8.5	8	99	Clear
14	KHIM BIR RANA <sup>me</sup>	M	CGI	1129 7:40	2	1	1	1	3	1.0	10	70	10.1	9.8	97	Clear
15	MANA RANA <sup>me</sup>	F	STONE	1129 7:50	2	1	1	2	2	0.9	15.6	55	15.5	11.6	96	Clear
16	NARESH RANA <sup>me</sup>	M	CGI	1129 18:00	3	2	1	3	2	1	16.1	61	16.0	15.6	85	Clear
17	BHUMILAL RANA <sup>me</sup>	M	CGI	1130 8:30	3	2	1	2	2	1	16.0	62	16.1	15.5	75	Clear
18	LILA RANA <sup>me</sup>	F	CGI	1130 16:20	3	3	1	5	3	0.8	18.5	65	18.7	17.4	72	Clear
19	KAVI PUN <sup>me</sup>	M	CGI	214 18:30	3	2	1	2	2	0.9	16.4	62	16.0	15.8	73	Clear
20	SHIV BIR RANA <sup>me</sup>	M	CGI	214 18:40	2	2	1	2	3	0.9	16.3	60	16.0	15.4	75	Clear
21	BALMATEERANA <sup>me</sup>	F	WOOD	214 18:50	2	2	1	2	3	1.0	16.8	45	17.0	15.0	77	Clear

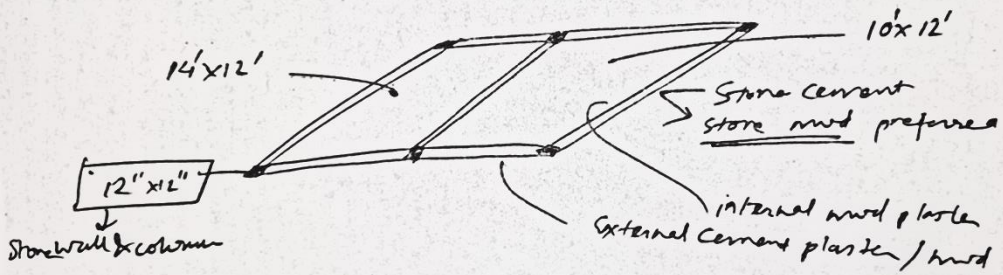
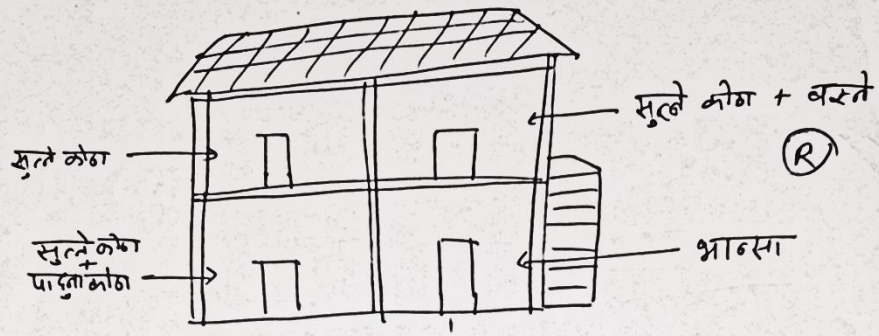
C	i	ii	iii	iv	1	2	3	4	5	6	7	8	9	10	11	12
1	Tilsara Ram Md	F	CGI	212 11:40	3	2	1	3	2	0.8	18.0	40	18.1	17.9	57	Clear
2	Gaurari Ram	F	CGI	212 12:00	4	3	1	4	2	0.9	18.6	41	18.5	18.5	51	Clear
3	Lalita Ram	F	STONE	211 11:30	4	3	1	6	3	0.8	16.8	28	16.9	21.2	49	Clear
4	Ram Bdr Md	M	CGI	212 10:40	3	2	1	3	2	0.9	14.6	55	14.6	14.1	62	Clear
5	Nar Bdr Ram Md	M	CGI	212 11:20	4	3	1	4	2	0.8	16.3	40	16.3	15.9	57	Clear
6	Parbati Ram Md	F	CGI	212 11:00	5	3	1	4	2	0.6	22.2	38	22.9	20	50	Clear
7	Gopani Ram Md	F	CGI	212 11:30	5	4	1	3	2	0.8	23.2	36	23.3	22.7	42	Clear
8	Amata Ram Md	F	CGI	212 16:40	2	2	1	2	2	0.7	14.1	55	14.2	13.3	74	Clear
9	Balmati Ram Md	F	WOOD	214 16:40	4	3	1	4	3	0.7	19.3	45	19.2	18.2	68	Clear
10	Kalu Ram Md	M	CGI	214 16:30	3	2	1	3	3	0.8	18.8	48	18.7	18.3	68	Clear
11	Dinesh Ram Md	M	CGI	214 17:00	3	2	1	3	2	0.9	18.1	54	18.2	17.2	73	Clear
12	Bashanti Ram Md	M	CGI	215 12:30	4	3	1	4	2	0.6	21.9	40	23.0	22.1	60	Clear
13	Bahadur Ram Md	M	CGI	215 12:30	4	3	1	4	2	0.5	23.4	41	23.3	23	58	Clear

Name (i)	G	iii	Time	1	2	3	4	5	6	7	8	9	10	11	12
B7			1/30 7:20	1	1	2	2	1	0.9	13.5	42	13.7	7.2	99	Clear
B11			1/30 7:30	2	1	1	2	2	1.1	11.9	72	11.9	8.1	95	Clear
A7			1/30 7:40	2	1	2	2	1	1.1	12.5	71	12.5	7.8	88	Clear
Krishnakant	M	RIC	" "	1	1	2	1	2	0.9	12.5	71	12.5	7.8	88	Clear
Tika Ram	F	"	" "	1	1	1	2	3	1.2	12.5	71	12.5	7.8	88	Clear
B12			1/30 8:10	2	1	2	2	2	1.0	12.9	62	12.8	7.5	71	Clear
B8			1/30 8:20	1	1	2	1	2	0.9	13.2	58	13.4	11.8	77	Clear
B6			1/30 8:40	2	1	2	1	3	1.1	12.7	68	12.7	12.4	71	Clear
B9			1/30 8:40	2	1	2	1	2	1.0	12.2	68	12.7	12.4	71	Clear
B5			1/30 8:50	1	1	2	2	3	1.1	12.7	56	12.3	12.9	67	Clear
B8			1/30 9:00	1	1	2	1	2	1.0	12.8	71	12.7	13.0	79	Clear
B10			1/30 9:10	1	1	1	1	2	1.2	12.7	69	12.8	13.0	80	Clear
B6			1/30 16:50	3	2	1	4	2	0.7	16.5	65	16.3	16.9	73	Clear
B9			1/30 17:00	3	2	1	4	3	0.7	16.7	70	16.0	16.7	72	Clear
B1			1/30 17:20	2	2	1	3	2	0.8	15.3	68	15.1	15.9	75	Clear
B17			1/30 17:20	3	2	1	3	2	0.8	15.3	68	15.1	15.9	75	Clear
B5			1/30 17:40	2	2	1	2	2	0.8	15.1	71	14.9	15.4	76	Clear
B19			1/30 18:00	2	2	1	3	3	1.0	14.7	67	14.3	14.8	76	Clear
B2			1/30 18:00	2	2	1	3	2	1.1	14.7	67	14.3	14.8	76	Clear
B13			1/30 18:00	1	1	2	1	2	1.2	14.7	67	14.3	14.8	76	Clear
B2			1/30 18:10	1	1	2	2	3	1.2	13.8	69	13.6	14.2	78	Clear
B3			1/30 18:30	1	1	2	1	3	1.1	12.6	70	13.4	14.1	79	Clear
A5			1/30 18:30	2	2	1	2	3	1.2	12.6	70	13.4	14.1	79	Clear
B7			1/30 18:40	3	2	1	3	2	0.9	17.8	45	17.7	17.9	80	Clear
Kabir Ram	F		1/30 18:40	2	2	1	2	2	1.0	17.8	45	17.7	17.9	80	Clear
Pratik Ram	F		1/30 18:40	3	3	1	4	3	1.1	17.9	45	17.7	17.9	80	Clear

Name (i)	G	iii	Time	Run												Globe	Key	Run	Key
				1	2	3	4	5	6	7	8	9	10	11	12				
B 1			215 12:10	4	3	1	3	3	6	7	8	9	10	11	12				
BIS			215 12:50	4	3	1	5	2	0.7	22.6	45	22.9	22.5	60	Clear				
B 16			215 12:30	5	3	1	4	2	0.7	18.1	98	18.4	23.4	58	Clear				
B 19			215 14:20	6	4	2	2	3	0.5	26.1	40	26.0	25.0	55	Clear				
B 21			215 14:40	5	4	1	3	2	0.5	28.2	40	28.0	26.3	41	Clear				
B 11			215 15:20	4	3	1	4	2	0.5	28.1	35	28.3	26.4	39	Clear				
B 9			215 15:30	4	3	1	4	2	0.7	23.4	41	23.6	22.8	56	Clear				
A 1			215 16:10	4	3	1	5	2	0.6	22.9	45	23.0	22.5	56	Clear				
C 11			215 16:20	3	2	1	5	2	0.7	22.6	42	22.8	22.4	55	Clear				
C 5			215 17:30	3	2	1	3	2	0.7	23.8	34.7	23.9	23.4	49	Clear				
C 9			215 17:40	4	3	1	3	2	0.8	19.6	54	19.8	19	67	Clear				
C 13			215 17:40	4	2	1	3	2	0.8	19.2	52	19.3	18.8	68	Clear				
C 2			215 18:00	3	2	1	2	2	0.7	19.2	52	19.7	18.8	69	Clear				
C 8			215 18:00	3	2	1	4	3	0.8	18.9	61	18.8	17.8	71	Clear				
A 10			215 18:20	3	2	1	3	2	0.9	18.9	61	18.8	17.8	71	Clear				
C 11			216 8:30	1	1	2	2	1	0.9	12.2	55	12.4	10.9	70	Clear				
C 8			216 8:50	2	1	2	2	3	1.0	12.0	58	12.1	10.7	68	Clear				
C 10			216 9:00	1	1	1	2	3	1.0	12.0	58	12.1	10.7	65	Clear				
C 12			216 9:20	2	1	2	2	2	1.0	12.2	45	12.3	10.7	78	Clear				
C 13			216 9:30	2	2	1	2	3	1.0	12.1	51	12.3	10.3	72	Clear				
C 4			216 9:30	1	1	2	2	2	0.9	12.1	51	12.2	10.3	72	Clear				
C 6			217 8:00	1	1	2	1	2	1.2	11.3	61	11.5	10.6	65	Clear				
C 2			217 8:10	1	1	2	2	3	1.1	11.1	59	11.2	10.4	60	Clear				
A 11			217 8:10	1	1	2	2	2	1.0	11.1	59	11.2	10.4	60	Clear				
A 6			217 8:20	2	1	2	1	2	1.1	10.8	61	10.9	10.4	68	Clear				
C 5			217 8:30	1	1	2	1	2	1.1	10.9	62	10.9	10.9	69	Clear				
A 9			217 8:50	2	1	2	1	2	1.0	10.9	55	10.9	10.6	60	Clear				
C 10			217 8:50	1	1	2	1	2	1.0	10.9	55	10.9	10.6	60	Clear				
B 4			217 9:10	1	1	2	2	3	1.1	11.3	60	11.1	11.7	68	Clear				
B 8			217 9:20	1	1	2	1	2	1.0	11.7	54	11.6	12	68	Clear				
B 19			217 9:20	2	2	1	2	3	1.0	11.3	54	11.6	12	68	Clear				
C 7			217 9:30	2	1	1	2	2	1.1	11.9	55	11.9	12.6	68	Clear				

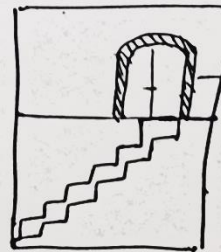
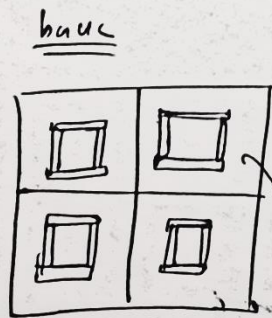






→ Wooden floor on first floor

- External staircase
- External balcony



wooden bifold door

4' x 4' to 5' x 5'

# APPENDIX – G: CONFERENCE PAPER

## Energy consumption pattern in post disaster constructed temporary shelter: A case study of Rimna, Jajarkot

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### Abstract

Post-disaster temporary shelters play a crucial role in providing immediate housing solutions for displaced populations. However, energy consumption patterns in these shelters are often overlooked, impacting sustainability, affordability, and environmental consequences. This study investigates energy use trends in post-disaster temporary shelters in Rimna, Jajarkot, following the 2023 Jajarkot earthquake. The research findings indicate that firewood remains the dominant energy source for cooking and heating, with 85.7% of households relying on it, raising concerns about deforestation and indoor air pollution. Although 97.6% of households have access to grid electricity, frequent power outages and voltage fluctuations force 14.28% of households to rely on solar panels as an alternative. The use of LPG for cooking is minimal, largely due to economic constraints and supply chain limitations. Furthermore, poor insulation in CGI sheet shelters exacerbates energy inefficiency, leading to increased firewood consumption for heating during winter. The study concludes that sustainable energy interventions are necessary to reduce reliance on biomass fuels and improve energy security in post-disaster shelters. Recommendations include promoting solar power systems, enhancing insulation techniques, subsidizing LPG and clean cooking technologies, strengthening energy infrastructure, and increasing community awareness on energy efficiency. These measures are essential for ensuring affordable, sustainable, and resilient energy access in post-disaster temporary settlements.

### Keywords

temporary shelter, energy consumption, post disaster reconstruction

## 1. Introduction

Energy consumption is a crucial factor in post-disaster recovery, especially in temporary shelters constructed for displaced populations. The pattern of energy consumption includes both commercial sources like crude oil and petroleum products, as well as non-commercial sources such as firewood, cow dung, and agricultural residues [1]. Following natural disasters, such as earthquakes, floods, or landslides, affected communities rely on temporary shelters to provide immediate housing solutions.

In Nepal, earthquakes have historically led to large-scale destruction, displacing thousands of people and necessitating rapid reconstruction efforts. The 2023 Jajarkot earthquake was a recent disaster that caused significant infrastructural damage, leading to the construction of temporary shelters across affected areas, including Rimna, Jajarkot. These shelters, built primarily to provide short-term housing, have different energy consumption patterns compared to regular residential buildings, directly impacting the daily lives and well-being of residents. Reducing energy dependency has to be the prime focus of post disaster reconstruction [2].

Energy access in temporary shelters is often unreliable due to infrastructure limitations, forcing residents to depend on biomass fuels and inefficient heating methods. In rural areas like Rimna, firewood remains the dominant cooking fuel, with limited adoption of LPG and solar energy solutions. Such energy reliance poses environmental and health concerns, including deforestation and indoor air pollution.

## 2. Methodology

The research follows a mixed-methods approach, combining both quantitative and qualitative methods to analyze energy consumption patterns in post-disaster shelters. The study was conducted in Rimna, Jajarkot, a region heavily affected by the 2023 Jajarkot earthquake. The study area, located in Bheri Municipality Ward No. 1, is situated approximately 14 km east of Jajarkot Khalanga. The region experiences a subtropical and temperate climate, with a total district population of 189,360.



Figure 1: Temporary shelter in Rimna, Jajarkot

Data for the study were collected through household surveys, field observations, and semi-structured interviews. A structured questionnaire was administered to 50 households

in temporary shelters to gather information regarding lighting energy sources and consumption levels, cooking fuel usage, heating energy sources, and household expenditures on energy. Additionally, on-site observations were conducted to assess the construction materials, insulation quality, and ventilation systems of the shelters. Semi-structured interviews with residents, local government officials, and energy experts provided qualitative insights into the challenges related to energy access and policy gaps.

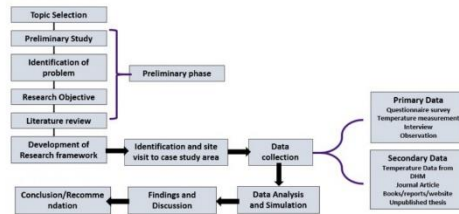


Figure 2: Methodological framework of the research

The collected data were analyzed using descriptive statistics to summarize energy consumption trends, while thematic analysis was applied to qualitative data obtained from interviews and observations. This methodological approach ensures a comprehensive understanding of energy consumption in Rimna's post-disaster shelters, providing data-driven insights for future policy recommendations.

### 3. Limitations of the study

The study is limited to the post-disaster reconstructed temporary shelters in Rimna village of Bheri municipality, Jajarkot. Due to unavailability of residents in a few households, the data interpretation will not contain the entire population but will instead reflect the energy consumption pattern of the settlement.

### 4. Case study area

Rimna, a rural settlement within Bheri Municipality Ward No. 1, is among the most affected areas of Jajarkot. Situated approximately 14 km east of Jajarkot Khalanga, Rimna lies at the confluence of the Sanibheri and Thulibheri rivers. The settlement is predominantly inhabited by the Magar community. The geographical location and rugged terrain contribute to limited access to modern infrastructure, further exacerbating the challenges faced by residents.

On November 3, 2023, at 18:02:54 (UTC), a moderate earthquake struck the Jajarkot district of Nepal. The United States Geological Survey (USGS) reported a moment magnitude (MW) of 5.7 (6.4 ML), with an epicenter at 28.852°N, 82.163°E, and a focal depth of 32.6 km. Despite its moderate magnitude, the earthquake caused substantial loss of life and property, resulting in 153 fatalities and widespread damage to more than 62,000 houses [3]. Strong shaking was felt as far as the Indo-Gangetic Basin in India [4], which highlights the regional impact of the event.



Figure 3: Map of case study area

The earthquake caused 153 deaths in Jajarkot and Rukum West district. According to the National Emergency Operation Centre (NEOC), approximately 62,011 households were damaged (completely and partially) and 250,000 people were affected (127,750 females and 122,250 males, including 69,575 children), with Jajarkot and Rukum West districts bearing the brunt of the damage. The disaster severely damaged over 62,000 houses, including 26,557 that were completely destroyed and 35,455 that were partially damaged [5]. Families set up temporary shelters next to damaged homes facing harsh winters with local materials where old age people, infants, and lactating mothers succumbed to respiratory illnesses [6].

The Nepalese government responded swiftly to the 2023 Jajarkot earthquake, demonstrating a proactive approach to disaster management [7]. However, the reconstruction of permanent housing has not begun. The "Procedure for Grant Assistance on Strengthening, Reconstruction, and Restoration of Disaster-Affected Private Housing, 2081 (First Amendment)" provides a legal framework for post-disaster housing reconstruction efforts in Nepal. NDRRMA and Centre for disaster management studies has just begun post disaster damage survey in Nalgad and Bheri municipalities of Jajarkot as a pilot project [8].

Due to its remote location and lack of adequate infrastructure, energy access in Rimna remains a major concern. The majority of households rely on firewood as their primary cooking fuel, which they collect from nearby forests. While electricity is available, frequent power outages force many families to depend on solar energy as an alternative lighting source.

### 5. Data sets and Analysis

The results of the household survey conducted in Rimna village are as follows:

#### 5.1 Socio-demographic data

The study surveyed 50 households in Rimna to understand the socio-demographic characteristics Table[1] of residents

living in post-disaster temporary shelters. The population was composed of 60% male and 40% female respondents. The age distribution showed that 28% of respondents were between 18-30 years old, 44% were aged 31-45, 26% were between 46-60 years old, and only 2% were above 60 years old. The average household size was 4.88 members per household.

**Table 1: Personal Factors of Respondents**

Personal Factor		Proportion (%)
Gender	Male	60
	Female	40
Age	18-30	28
	31-45	44
	46-60	26
	60+	2
Marital Status	Married	70
	Unmarried	10
	Widowed	20
Family Size	Average	4.88
Education Level	Bachelor's degree or higher	6
	Higher secondary education	18
	No formal education	34
	Primary education	28
	Secondary education	14
Occupation	Agriculture	24
	Housewife	20
	Labor	16
	Retired	2
	Self-employed	22
	Service	4
	Student	10
	Unemployed	2
Household Expenditure per Month	Average	15000
Household Income per Month	Average	20000
Foreign Employment	Yes	8

Education levels varied, with 34% of respondents having no formal education, while 28% had completed primary education. A smaller proportion had higher secondary education (18%) and bachelor's degrees or higher (6%). The majority of respondents were engaged in agriculture (24%), while 20% were housewives, 16% worked as laborers or self-employed, 10% were students, and 4% were employed in the service sector. The monthly household income averaged NPR 20,000, while monthly expenditures averaged NPR 15,000.

A small proportion of households, 8%, had at least one family member working in foreign employment, contributing to household income. These socio-demographic insights highlight the economic challenges and employment conditions faced by residents in temporary shelters, further influencing their energy consumption patterns and affordability.

## 6. Types of temporary shelter

The temporary shelters in Rimna were primarily constructed using Corrugated Galvanized Iron (CGI) sheets, which were constructed by the Nepal Red Cross Society and other humanitarian organizations as the response to the earthquake. Approximately 93.2% of households resided in fully CGI-sheet shelters, while a small proportion, 6.8%, lived in shelters made of wooden planks with CGI sheet roofing. These shelters were built as an emergency response to the disaster but remain the primary housing solution due to delays in permanent reconstruction efforts. The lack of insulation and proper ventilation in these shelters has led to thermal discomfort,

with extreme temperatures in both summer and winter exacerbating energy consumption challenges.

## 7. Energy consumption pattern

### 7.1 Electrical energy consumption

Most households in Rimna rely on grid electricity provided by the Nepal Electricity Authority. However, frequent power outages and voltage fluctuations affect its reliability. Among the surveyed households, 97.6% had electricity access, while 2.4% relied solely on solar power due to issues with land ownership in post-earthquake relocated place. The average household lighting consumption was 7.92 kWh per month, with LED bulbs being the predominant lighting source. 14.28% of households used solar panels as a secondary energy source for lighting, indicating an emerging trend towards renewable energy solutions.

**Table 2: Seasonal variation in monthly electricity bill**

Cost per Month	Summer (%)	Winter (%)
Less than Rs 50	4.76	4.76
Rs 51 - 150	83.33	78.57
Rs 151 - 300	11.90	16.67

### 7.2 Cooking energy consumption

Cooking energy in temporary shelters was primarily derived from firewood, with 85.7% of households depending entirely on it. The remaining households used LPG partially or fully, with 4.76% relying solely on LPG and 9.52% combining LPG with firewood. The average firewood consumption was 8-12 bhari per month, with variations based on household size and livestock ownership. Firewood collection was done from nearby forests, raising concerns on indoor air pollution. While firewood collection requires no monetary purchases, the LPG cylinder costs Rs. 2200 to 2300 on the roadside stores. The price of LPG rises as we move further from Jajarkot Khalanga.

### 7.3 Electrical appliances in use

The most commonly used electrical appliances were mobile phones and LED lights, present in 100% of households. Other appliances included televisions (16.67%), Wi-Fi routers (11.9%), radios (7.14%), and fans (2.38%). The average monthly electricity load varied based on appliance ownership, with LED lights and mobile chargers contributing the most to consumption. The limited presence of high-power appliances suggests that energy use in these shelters remains minimal and focused on basic necessities.

**Table 4: Household Appliance Usage**

Appliance	Proportion (%)
Mobile	100.00
LED Light	100.00
TV	16.67
Radio	7.14
Fan	2.38
Wifi Router	11.90

**Table 3:** Fuel Consumption by User Type

User Type	LPG Replacement	Firewood Consumption	Proportion (%)
Firewood only	0	8-12 bhari	85.71
LPG only	1-2 month	0	4.76
LPG mostly, Firewood often	2-3 month	2-6 bhari	2.38
LPG often, Firewood mostly	6-8 month	6-10 bhari	7.14

The typical energy usage pattern in temporary shelters of Rimna can be presented as in Table[5]

**Table 5:** Electric Equipment Usage and Monthly Load

Equipment	No	Rating (W)	Avg. Usage (hrs)	Monthly Load (kWh)
LED Light	3	6	6	3.24
LED Light	1	12	10	3.60
Mobile Charger	3	15	4	5.40
<b>Total</b>				<b>12.24</b>

## 8. Findings and Discussion

The study found that energy consumption patterns in Rimna's post-disaster temporary shelters are largely influenced by economic conditions, infrastructure availability, and traditional practices. Despite policies promoting renewable energy, implementation remains minimal, and reliance on conventional sources continues.

The census report shows more female population in the study area (52%), however, due to post disaster relief and aid policy provisions, mostly the legal owner of the house were responding to the study team. This brought significant increase in proportion of the male respondents (60%) in the study. Most residents belong to the 31-45 age group (44%), while 28% are between 18-30 years. Many younger individuals have migrated to urban areas for work or education, leading to lower household energy demand.

The per capita energy consumption of Nepal is 380 units as per NEA reports. However, in the study area, it is only 37 units. Limited reach to electrical appliance, unreliable supply and use non commercial traditional fuel are the major reason behind this. The average household size is 4.88 members, influencing overall energy consumption. Bases on family size, 8-12 bhari of firewood are required per month. One bhari weighs around 25 kg. This aligns with the findings of similar studies in Nepal [9].

For lighting, 97.6% of households use grid electricity, though frequent power outages and voltage fluctuations have led 14.28% to adopt solar panels as a secondary source. LED lights are the primary lighting option, with no reported use of incandescent bulbs, reflecting an awareness of energy efficiency. Cooking energy is primarily sourced from firewood (85.7%), with only 4.76% using LPG exclusively and 9.52% using both LPG and firewood. In similar study [1] conducted in Dolakha town, LPG gas was predominantly used for cooking. This reflects the difference in energy sources in village and town areas. The heavy reliance on firewood raises concerns about deforestation and indoor air pollution, while limited LPG use is linked to affordability and supply constraints. Heating methods remain traditional, with households relying on firewood, and layered clothing for

warmth. The lack of insulation in CGI sheet shelters exacerbates thermal discomfort, increasing reliance on firewood.

Electrical appliances are used sparingly, with 100% of households owning mobile phones and LED lights. Other appliances, such as televisions (16.67%), Wi-Fi routers (11.9%), radios (7.14%), and fans (2.38%), are found in fewer homes, indicating restricted electricity use due to financial constraints. Electricity bills vary, with most households spending Rs 51-150 per month, while 16.67% spend Rs 151-300. A study in Dolakha town found more than 50% of the respondents spending monthly Rs. 300 or higher in electricity charge [1]. This difference is due to unavailability of electrical appliances in remote setting. A small number of households report bills under Rs 50, showing that while electricity is accessible, consumption remains low due to economic limitations.

The differences in energy consumption has been observed as compared to the previous study conducted in other regions of Nepal. This is mainly due to differences in socio-economic and cultural structure among the societies in different parts of Nepal. The findings highlight high dependence on firewood, low adoption of renewable energy, and frequent power outages, all contributing to energy insecurity. Addressing these issues requires policy interventions, investment in renewable energy, and improved infrastructure to enhance energy efficiency and resilience in post-disaster shelters.

## 9. Conclusion

This study examined the energy consumption patterns and efficiency challenges in post-disaster reconstructed residential buildings within the Rimna settlement. Findings indicate a heavy reliance on firewood for cooking and heating, with hydroelectricity serving as the primary source for lighting. Per capita firewood consumption ranged from 235–1130 kg/year, while electricity consumption was measured at 37 units per capita. Frequent power outages and infrastructure limitations hinder reliable electricity access, reinforcing dependence on biomass fuels.

The study further highlights economic constraints, lack of energy-efficient technologies, and traditional construction practices as key barriers to sustainable energy use. Limited appliance usage and inadequate insulation in CGI shelters exacerbate energy inefficiencies. Addressing these issues requires policy-driven interventions, including financial incentives for energy-efficient technologies, awareness programs, and improved infrastructure.

Future research should explore comparative analyses with other settlements to validate these findings. Collaborative

efforts among stakeholders—local governments, NGOs, and community representatives—are essential to enhancing energy security and promoting sustainable energy solutions in post-disaster settlements.

### Acknowledgments

Gratitude is extended to all the respondents who generously shared their time and insights for this research. Sincere appreciation goes to the Ward Chairman of Bheri-1, Jajarkot, for the valuable support and cooperation. The residents of Rimna deserve special acknowledgment for their hospitality and willingness to participate, contributing significantly to the success of this study.

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APPENDIX – H: CONFERENCE CERTIFICATE AND  
LETTER OF ACCEPTANCE



## IOE Graduate Conference Certificate of Participation

THIS CERTIFICATE IS AWARDED TO

**Adhish Kumar Khadka**

in recognition of an invaluable contribution as

**POSTER PRESENTER**


**at the 16<sup>th</sup> IOE Graduate Conference**

Organized by Tribhuvan University, IOE, Thapathali Campus in association  
with IOE, Office of the Dean held from April 18-20, 2025 at  
Thapathali Campus, Kathmandu, Nepal.

  
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Convener  
16<sup>th</sup> IOE Graduate Conference

  
Dr. Khem Gyanwali  
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Date: April 21, 2025

To Whom It May Concern:

This is to certify that the paper titled “Energy consumption pattern in post disaster constructed temporary shelter: A case study of Rimna, Jajarkot” (Submission# 102) submitted by Adhish kumar khadka as the first author, which had been accepted for presentation after the peer-review process, has successfully been presented at the 16<sup>th</sup> IOE Graduate Conference held during April 18 - 20, 2025. Kindly note that the final revision of the papers and publication process of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon timely response to further edits during the publication process.



Dr. Raj Kumar Chaulagain,  
Convener,  
16<sup>th</sup> IOE Graduate Conference



# APPENDIX – I: PLAGIARISM TEST REPORT

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### Document Details

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