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Study on the Winter Thermal Environment and Thermal Satisfaction of the Post-Disaster Prototype and Vernacular Houses in Nepal

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Abstract: Post-disaster housing, constructed on a massive scale, often overlooks the indoor thermal environment, despite being a crucial design factor for residential satisfaction. This study examined the indoor thermal environment in post-Gorkha earthquake-reconstructed prototype and traditional vernacular houses in the Dolakha district of Nepal. It employed a questionnaire survey and measurement of indoor and outdoor temperature in both house types across two study locations: Panipokhari and Jillu, during the coldest winter month. Despite the indoor temperature in both house types falling below the ASHRAE comfort standard, the study found that prototype houses' nighttime indoor temperatures were 2.1 °C lower in Panipokhari and 1 °C lower in Jillu compared to vernacular houses. This difference is attributed to the use of local building materials with low U-values, substantial thermal mass in vernacular houses, and a low window-to-wall ratio. Occupants expressed dissatisfaction with the thermal environment in prototype houses compared to vernacular ones. By incorporating climate-responsive features seen in vernacular houses, heating energy could have been reduced by approximately 21% in Panipokhari and 10% in Jillu, easing the economic burden on vulnerable households. These findings hold significance for policy-makers, implementers, designers, and other stakeholders involved in post-disaster resettlement housing programs, offering insights for enhancing long-term satisfaction and sustainability in such programs.

Keywords: indoor thermal environment; post-disaster resettlement; prototype house; resident satisfaction; vernacular house

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1. Introduction

1.1. Overview

The past decades have witnessed an increasing number of disasters worldwide that resulted in significant loss of lives and properties. In 2022, the disasters resulted in the loss of 30,704 lives and affected 185 million individuals, with an economic loss of around USD 223.8 billion [1]. Developing countries, in particular, were hardest hit, with the greater number of deaths and people affected [2] due to poor governance, poverty, and low-quality housing [3]. Out of the total 5.9 million people displaced by the disaster worldwide in the year 2021, about 22.2% of the internal displacement was from South Asia [4]. Nepal, an underdeveloped country, is ranked 11th in seismic risk, 30th in flood risks, and 4th in climate change vulnerability [5]. The massive 2015 Gorkha earthquake of magnitude 7.6 Richter scale caused massive human losses and physical damage across 32 hilly districts of Nepal. The National Planning Commission [6] reported that the earthquake destroyed about 498,852 houses and partially damaged approximately 256,697 houses, requiring significant settlement planning and reconstruction efforts. In response, the government of

Nepal developed “Integrated Settlements” to reconstruct permanent housing for displaced households and provide planned infrastructure provision.

Post-disaster housing is typically constructed within limited time and resource constraints, often overlooking important design considerations [7]. Several studies [8–10] have highlighted the low priority given to the thermal environment in permanent houses, and the climate adaptability [11] resulting in low thermal satisfaction among households [12,13]. Despite significant policy provisions and financial investment, displaced households in Nepal have not fully resettled in the prototype houses provided to them. The use of a “one size fits all” approach for all prototype houses in the Integrated Settlements (IS) has been criticized for poor indoor thermal environments compared to vernacular houses.

The sense of urgency to complete the reconstruction of houses within a limited time frame leads to the use of modern materials readily available in the market. The new prototype houses in these IS have been constructed using modern materials and technologies, neglecting the principles of vernacular architecture and local climate. Vernacular architecture represents the culmination of traditional knowledge and a long trial and error process, making it best suited to local climate and culture. As only a limited number of heating and cooling technologies are available to achieve thermal comfort, vernacular houses are generally designed to optimize the use of natural resources, such as the sun and wind [14,15]. Several researchers [16,17] have claimed that vernacular buildings exhibit superior thermal performance due to their climate-responsive design features. In particular, Bodach et al. [14] conducted a qualitative investigation of Nepalese vernacular architecture and revealed that it was well adapted to local climate conditions. As a result, it is important to compare the newly constructed prototype houses to vernacular houses to determine their efficacy.

1.2. Thermal Environment

Indoor thermal environment investigation is an emerging research area that is closely related to building energy consumption and plays a significant role in creating a comfortable, healthy, and efficient built environment [18]. Over the past decade, a growing trend of studies [19,20] has focused on the thermal environment of housing in temperate regions. For example, Lin et al. [18] conducted research on China’s cold winter climate and found that the average internal temperature in the bedroom was 12.7 °C, with the lowest acceptable internal temperature without heating at 10 °C. Similarly, Singh et al. [21] demonstrated that vernacular buildings in India were significantly uncomfortable in the winter months. In Nepal, Rijal [19] investigated the vernacular house in the temperate region and revealed the daily mean indoor air temperature of Bhaktapur as 11.5 °C; Dhading as 14.8 °C, and Kaski as 15.3 °C in the winter season. Moreover, Rijal et al. [22] investigated traditional houses in the temperate region during the winter season and reported daily mean indoor air temperature of 11.5 °C for Bhaktapur; 14.8 °C for Dhading, and 15.3 °C for the Kaski district of Nepal. Shahi et al. [20] evaluated the thermal performance of modern houses in the temperate region during winter and found an average measured indoor air temperature of 18 °C. The study suggested enhancing the thermal insulation and reducing the infiltration to improve the indoor air temperature during nighttime. Additionally, Pokharel et al. [23] conducted a survey in vernacular houses during the winter season, and their findings revealed an average measured indoor air temperature of 13.9 °C, which is below the ASHRAE comfort standard.

While the past post-disaster literature has largely focused on structural safety, sociocultural, and livelihood aspects, the examination of thermal environment has been largely neglected. Cheng et al. [24] examined post-disaster housing in the Sichuan Province of China and found that the average winter indoor temperature in the new house was 7.8 °C, showing better performance than the vernacular house (6.6 °C) due to significant improvements like replacing brick masonry with wood and bamboo. Similarly, Kim et al. [25] studied a post-disaster temporary shelter in South Korea during winter, revealing an average indoor temperature of 16.0–20.6 °C when the outdoor temperature dropped to −11.3 °C with the use of a heating system. Wang et al. [26] found that the air temperature inside the temporary prefabricated houses constructed after the disaster was 7.9 °C higher than outside in the daytime, but nearly the same as the outdoor air temperature at nighttime, suggesting an insignificant thermal mass of envelope to store heat gain. Some studies have also attempted to assess the thermal performance of the post-disaster houses constructed after the Gorkha earthquake. For instance, Uprety and Shrestha [27] conducted an investigation of post-disaster houses constructed in Dolakha and found that the utilization of vernacular materials in the prototype houses can reduce discomfort by 35%. Another study by Thapa et al. [28] examined the winter indoor thermal environment in five makeshift shelters constructed after the Gorkha earthquake in Lalitpur, Nepal and found that the mean indoor and outdoor air temperatures were 10.3 °C and 7.6 °C, respectively, during the measured nighttime. However, the study found that the nocturnal indoor air temperature was lower than the lowest acceptable temperature of 11 °C, largely attributed to the use of the materials with a high heat loss coefficient per floor area (U-value).

The lack of a comfortable thermal sleep environment affects daytime activities, impacts health, and also deteriorates the quality of life [29]. Okamoto-Mizuno and Mizuno [29] emphasized that the thermal environment is one of the most important factors affecting human sleep and found that cold exposure might have a greater impact on sleep than heat exposure. According to the ANSI/ASHRAE Standard 55 [30], temperature fluctuations of 2.2 °C or more per hour significantly contribute to thermal discomfort in indoor environments [31]. Scant attention has been paid to studying the indoor thermal environment of permanent prototype houses constructed after the Gorkha earthquake, 2015 and comparing them with the vernacular houses. Hence, it is essential to fill this knowledge gap by investigating the indoor thermal environment of the prototype houses and the vernacular houses during the winter season in Nepal's temperate region. Such research can provide valuable insights for improving indoor comfort and designing energy-efficient houses for post-disaster settings.

1.3. Thermal Satisfaction

Indoor thermal comfort is a critical yet often neglected aspect influencing the residential satisfaction of displaced households. According to the ASHRAE Standard [30], thermal comfort is defined as the state of "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation. Fluctuations in air temperature significantly affect occupants' thermal comfort [30]. Post-disaster permanent housing has faced criticism for its uniform, one-size-fits-all design, employing similar materials and technology, often without considering local conditions [32]. Rather than the physical environmental features, user satisfaction is influenced by personal, social, and cultural issues [33]. Tharim et al. [13] found that respondents were dissatisfied with their post-disaster permanent houses' indoor air temperature, with mean satisfaction values of 2.1 during the daytime and 2.9 at night (measured on a 5-point Likert scale from '1 highly unsatisfied' to '5 highly satisfied'). Kurum Varolgunes [34] in Turkey revealed that the failure to consider climate and topography in post-disaster permanent housing design led to occupants' dissatisfaction with thermal comfort. Dikmen and Elias-Ozkan [32] highlighted complaints about damp and cold conditions in concrete permanent houses constructed after the 1970 Gediz earthquake. Miculax and Schramm [35] reported poorer housing due to improper use of technology in new roofs compared to traditional straw roofs, which proved unsuitable for local climatic conditions.

The choice of appropriate building materials is another crucial factor that has not received sufficient attention, impacting the long-term satisfaction of residents in post-disaster housing reconstruction [36]. Research has emphasized the use of unsuitable materials as a major contributor to poor indoor thermal comfort. For instance, Enginoz [37] found households living in hollow brick masonry houses constructed after the 1995 Dinar earthquake complaining that their houses were "cold in winter and hot in summer, unlike the vernacular mud-brick house". Similarly, Carrasco et al. [8] reported the lowest satisfaction of the residents concerning thermal comfort, with an average mean satisfaction score of only 0.32 (measured on a 5-point Likert scale from '1 highly unsatisfied' to '5 highly satisfied'), attributed to poor ventilation and thermal insulation of building materials. Dias et al. [36] also found dissatisfaction among residents with their permanent housing constructed after the disaster due to the use of the building materials without considering the local climatic conditions. Bang and Few [38] disclosed that respondents were more thermally satisfied with their pre-disaster houses made of mud bricks and grass roofs than the newly constructed houses made of cement bricks and aluminum zinc roofs. Ozden [39] highlighted climate-responsive houses as a major problem faced by post-disaster reconstructed households. Additionally, Tas et al. [12] revealed nearly 43% of households living on the top floor of the reconstructed houses were dissatisfied with roof insulation during both the summer and winter seasons.

Figure 1 presents the conceptual model of this study to investigate the indoor thermal environment of the prototype house constructed after the Gorkha earthquake and the vernacular house. The prototype house utilized modern materials with a high U-value, while the vernacular house was constructed with materials claimed to have a low U-value. However, due to the poor economic conditions and lack of electricity supply, the households did not use any mechanical devices for heating. Instead, occupants relied on behaviors such as closing windows, adding layers of clothes, and staying inside quilts to keep warm during winter. The existing literature [35,37] has identified that occupants of vernacular houses expressed higher satisfaction compared to occupants of the prototype houses concerning the thermal environment. Despite recognizing the significance of the thermal environment for the satisfaction of resettled households in the literature, national policies in Nepal remain silent on the minimum requirements for housing thermal performance. Consequently, there exists a significant knowledge gap regarding the thermal performance of the prototype houses constructed after the Gorkha earthquake, which were expected to be more resilient and sustainable, following the "build back better" approach.

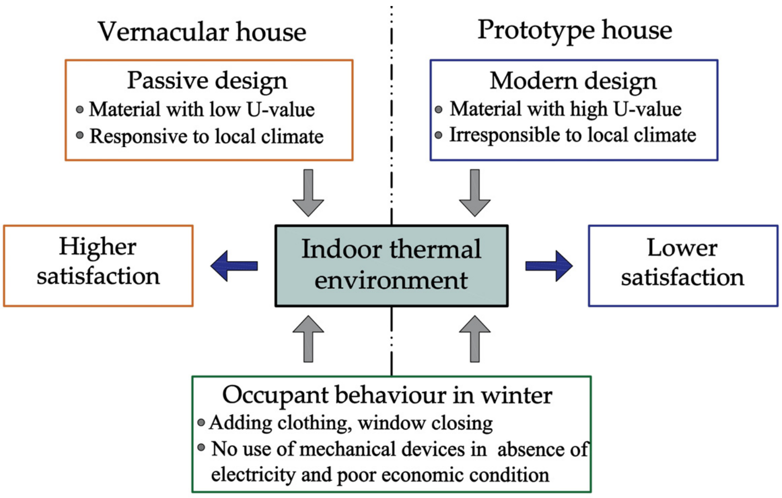


Figure 1. Conceptual model of the study.

1.4. Objectives

The primary aim of this research is twofold: (i) to evaluate the thermal performance of the prototype houses constructed after the 2015 Gorkha earthquake compared to the remaining vernacular houses in the area, and (ii) to investigate the thermal sensation and residential satisfaction of the disaster-displaced households currently residing in the prototype houses. With the escalating scale, frequency, and severity of disasters worldwide, the study's outcomes are expected to hold significant practical implications in policymaking, planning, designing, and reconstructing houses in the aftermath of disasters. The results will be valuable for various stakeholders involved in resettlement planning, including policymakers, implementers, academia, and others, facilitating the design and planning of more thermally comfortable housing, leading to reduced energy costs and contributing to sustainable resettlement outcomes.

2. Methodology

The research involved three distinct methods: (i) building measurement and observation; (ii) data logging of indoor and outdoor air temperature and relative humidity data; and (iii) questionnaire surveys conducted with residents residing in the prototype houses.

2.1. Study Area and Climate

A case study methodology was used to investigate the thermal performance of prototype houses constructed after the 2015 Gorkha earthquake in both the Panipokhari Integrated Settlement and Jillu Integrated Settlement. These settlements are situated within the Bhimeshwor municipality of the Dolakha district in Nepal (Figure 2). The Dolakha district was selected due to its severe impact during the 2015 Gorkha earthquake, which resulted in around 170 fatalities, the complete destruction of 56,293 houses, and partial damage to 4346 houses [40]. The earthquake displaced the Thami community, traditionally living in the rural villages of Bhimeshwor municipality, forcing them to relocate to temporary shelters [41] (Figure 3a), compromising their safety, security, and quality of life. The Panipokhari Integrated Settlement (Figure 3b) was developed by the Nepalese government to relocate 56 households from the vulnerable Buma and Boshimpa villages. The relocation brought the households situated from the old village at a higher altitude (1845 m) to Panipokhari, situated at 27°42′43.3″ latitude and 86°03′16.6″ longitude, at a lower altitude of 1765 m above sea level, roughly at an hour's walking distance. Similarly, the Jillu Integrated Settlement (Figure 3c,d) was initiated by the community to resettle 70 households in Fasmi village, located between 27°38′52.8″ latitude and 86°04′40.8″ longitude at an altitude of about 1170 m.

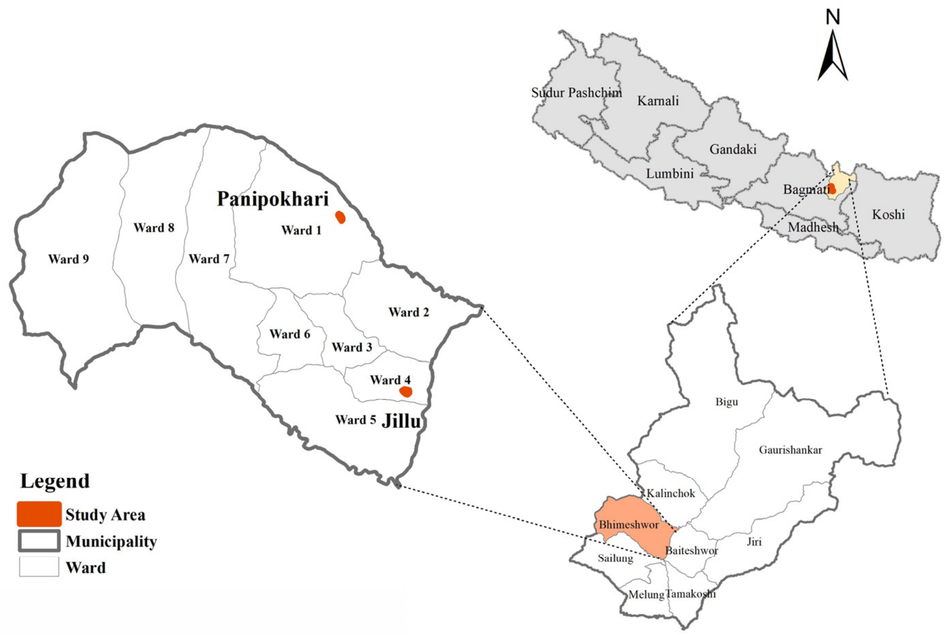
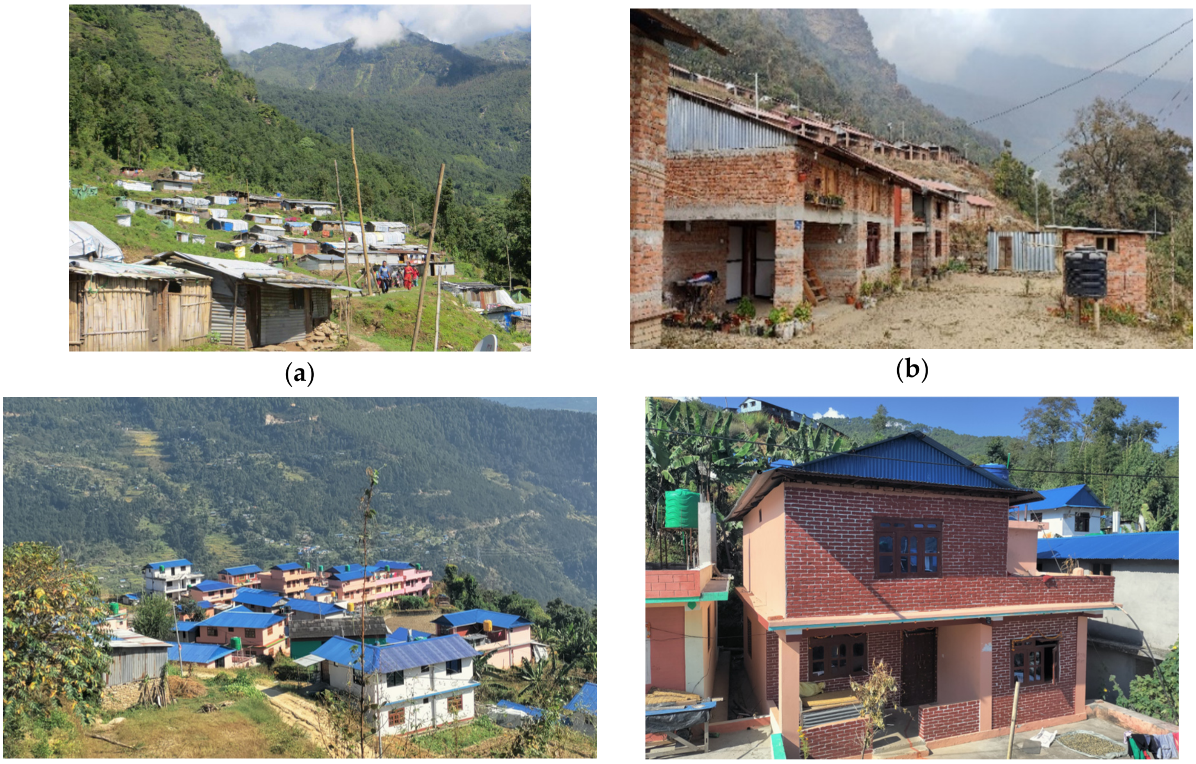


Figure 2. Location map of Panipokhari and Jillu Integrated Settlements in Nepal.



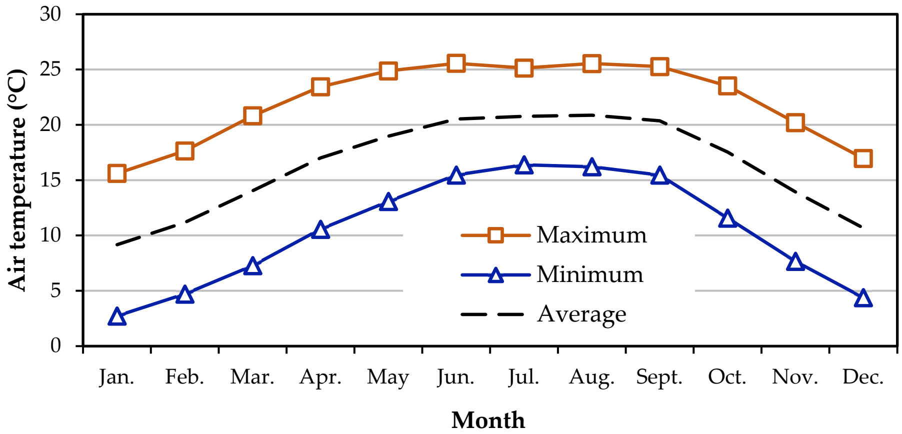
(**a**) (**b**) (**c**) (**d**)

Figure 3. Integrated Settlement in Dolakha: (**a**) Temporary shelter in Panipokhari, source: Mr. Yekraj Adhikari; (**b**) Integrated Settlement in Panipokhari; (**c**) Aerial view of Jillu Integrated Settlement; (**d**) Jillu Integrated Settlement.

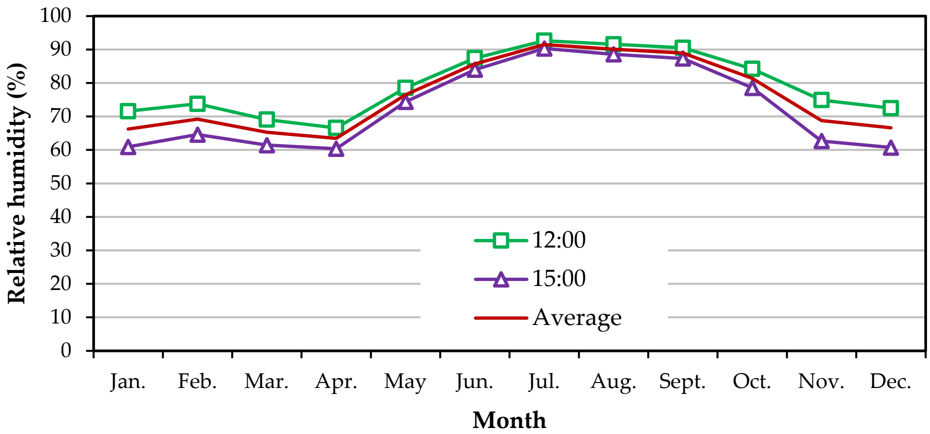
Both study areas are located in the hilly region of Nepal and have a warm temperate climate with cold winters and warm summers [14]. The average monthly temperature ranges from a maximum of 20.9 °C in August to a minimum of 9.2 °C in January (Figure 4a). The highest average monthly maximum temperature occurs in June at 25.6 °C, and the average monthly minimum temperature drops to 2.7 °C in January. The annual average relative humidity is 76%. Figure 4b shows the monthly average relative humidity along with average relative humidity at 12:00 and 15:00. Additionally, the average annual precipitation is 2157 mm, with the maximum occurring in July at 579 mm and a minimum of 5 mm in December (Figure 4c).

2.2. Selection of Houses

For this study, two houses—one vernacular and one prototype—were selected in each of the Panipokhari and Jillu Integrated Settlements. The decision to choose houses in two different locations stemmed from the presence of only one surviving vernacular house in Panipokhari, which limited the possibility of a direct comparison within the same settlement. Given that most vernacular houses in the district and the broader hilly region of Nepal share similar architectural characters—such as a long axis facing south, a rectangular floor plan, and walls constructed using mud mortar—two vernacular houses were selected. One was selected within Jillu itself (Figure 5c), while the other was in the nearby Buma area (Figure 5a), located at a 5-minute walk from Panipokhari. Likewise, two prototype houses—one in Panipokhari (Figure 5b) and the other in Jillu (Figure 5c)—were selected for the investigation. The distinction between these two locations lies in their genesis; Panipokhari was initiated by the government, leading to the construction of 56 prototype houses, while Jillu's construction was driven by the community, resulting in 70 houses. The prototype houses in Panipokhari are similar, while those in Jillu exhibit variations in terms of design and construction. Concerning the vernacular buildings, they remained consistent in both locations, with the exception of roofing materials; corrugated iron sheets were used in Panipokhari in contrast to slate roofs in Jillu.



(**a**)



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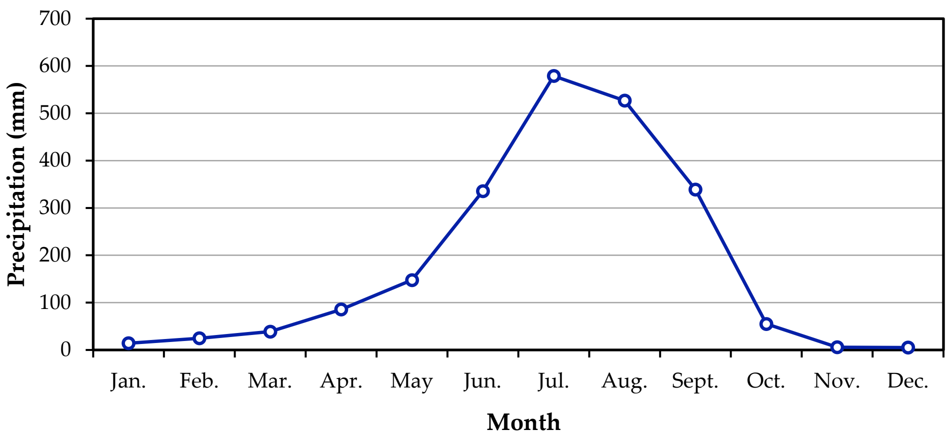


(**c**)

Figure 4. Monthly climatic data of the study area (Charikot meteorological station): (**a**) Outdoor air temperature; (**b**) Relative humidity; (**c**) Precipitation.

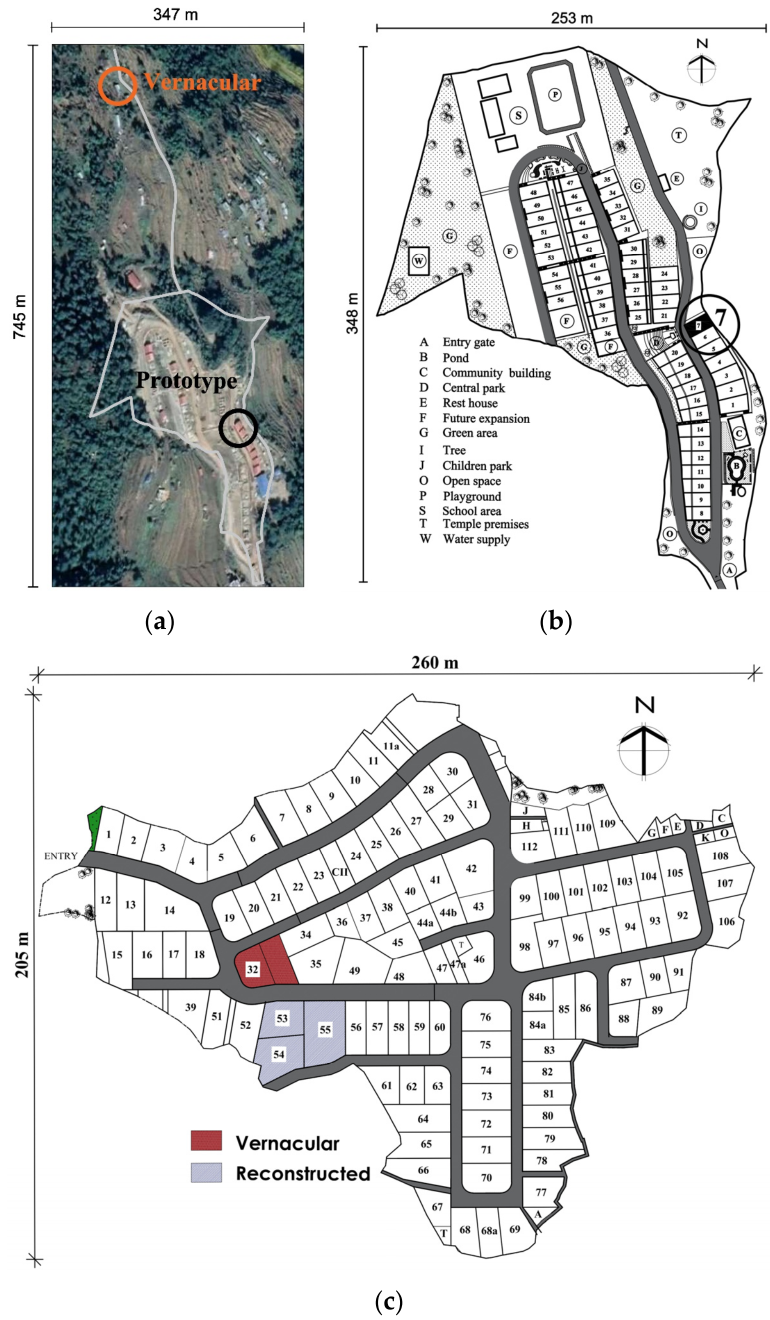


Figure 5. Master plan of Panipokhari and Jillu: (**a**) Aerial view in Panipokhari; (**b**) Master plan of Panipokhari Integrated Settlement; (**c**) Master Plan of Jillu Integrated Settlement.

Table 1 presents a comparison of the characteristics of the vernacular and prototype houses. The selected vernacular houses in Panipokhari (Figure 6a) and Jillu (Figure 7a) represent a typical two-story design with a rectangular plan. In Panipokhari, the ground floor is a single large room without partitions, serving as a kitchen, living, and bedroom (Figure 6c), while in Jillu, the rooms are partitioned (Figure 7c). An open hearth is located in the left corner of the room, providing warmth to both floors through the open staircase at the center and inside the house. The staircase leads to the first floor, which serves as a sleeping area with a wooden plank flat ceiling and storage space for food grains (Figure 6b,d) in Panipokhari, and solely as a bedroom in Jillu (Figure 7b,d). The semi-open space in front of the house, covered by the roof, serves multiple functions depending on the time and season, including sun basking, rest, and entertaining guests. The vernacular house is constructed using a 450 mm-thick random rubble stone masonry wall in mud mortar in

Panipokhari, and a 350 mm-thick wall in Jillu. Inside the house, a 25 mm-thick mud plaster is applied. Medium-sized wooden windows and doors are used. While the vernacular house in Jillu retains the traditional slate roofing, the slate roofing in Panipokhari was replaced with a corrugated galvanized iron (CGI) roof about five years ago.

Table 1. Characteristics of vernacular and prototype houses.

Description	Vernacular House	Prototype House
Building form	Rectangular elongated	Nearly square floor plan
Building orientation	Longer walls with openings towards the south	Building with openings towards the east in Panipokhari and south in Jillu
Story	Two	Two
Walls	350–450 mm stone with 25 mm mud plaster inside	230 mm brick with 12 mm cement plaster inside
Roof	Pitched roof; 0.26 mm corrugated galvanized iron (CGI) roof with a wide overhang in Panipokhari, slate roof in Jillu	Pitched roof; narrow overhang 0.26 mm corrugated galvanized iron (CGI) sheet in Panipokhar; RCC roof in Jillu
Openings	Medium-sized wooden windows with wooden frames About 16% Glazing/wall ratio	5 mm single-glazed, medium-sized wooden framed windows About 12% Glazing/wall ratio

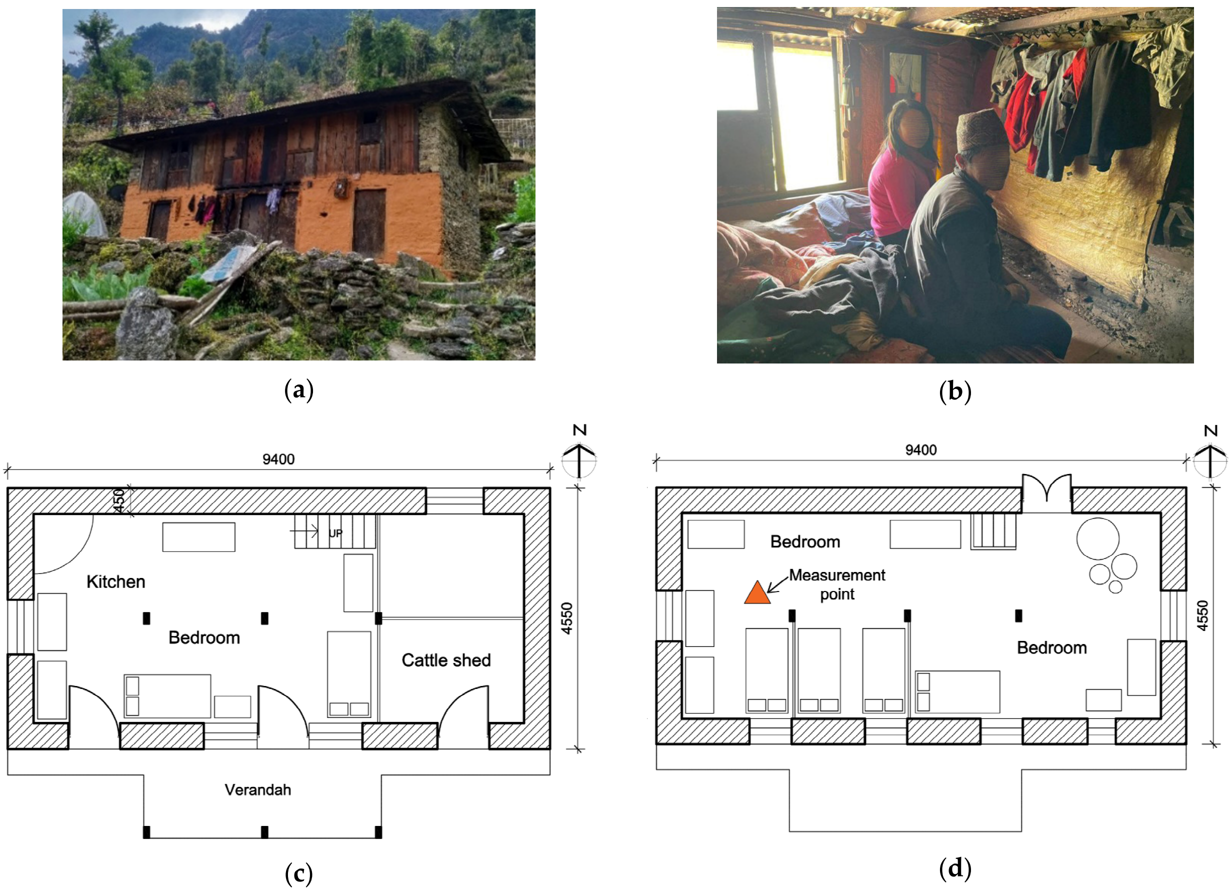


Figure 6. Exterior view, interior space of vernacular house in Panipokhari: (**a**) Exterior view; (**b**) interior view; (**c**) Ground floor plan; (**d**) First-floor plan.

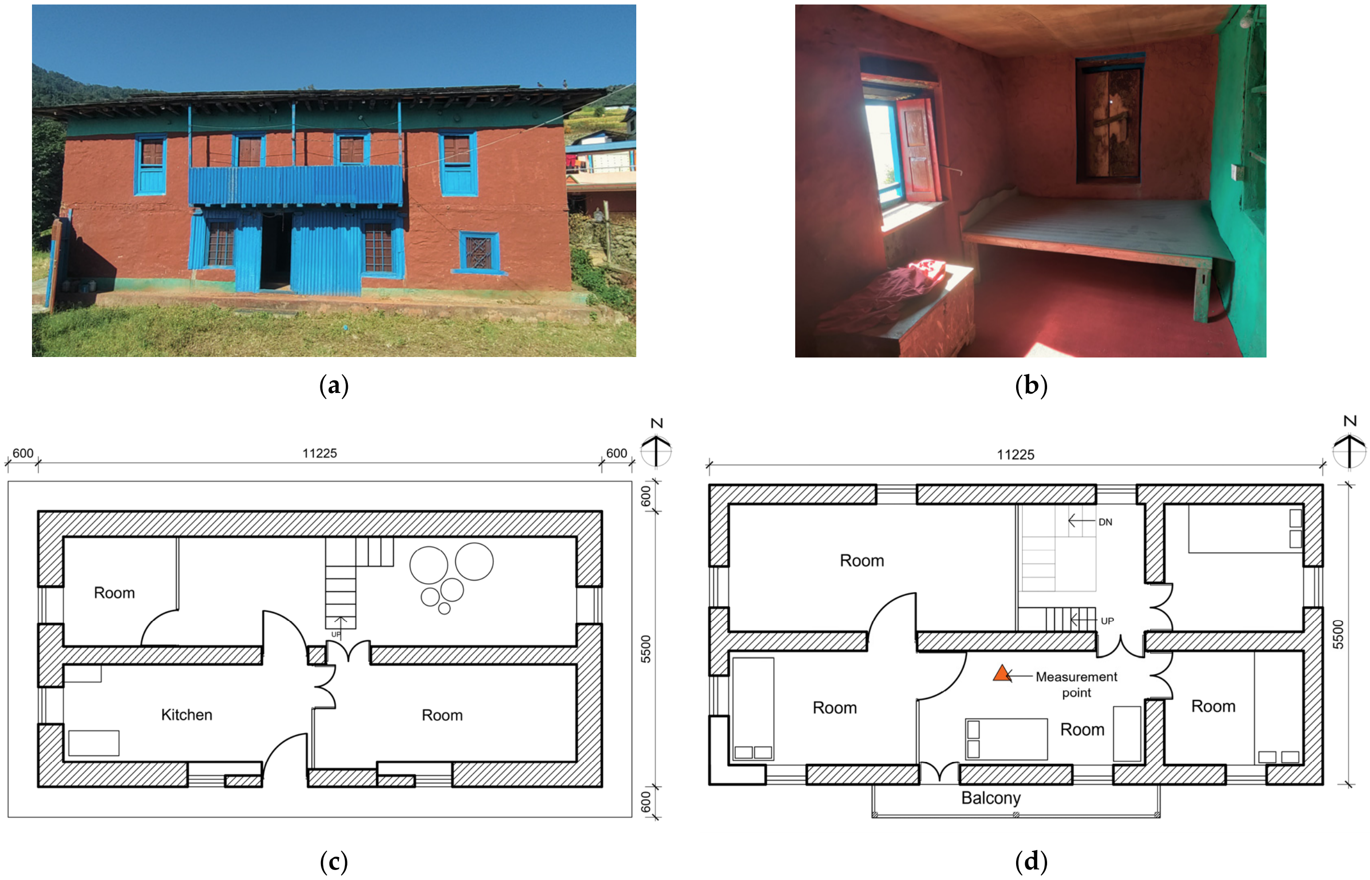


Figure 7. Exterior view, interior space of the vernacular house in Jillu: (**a**) Exterior view; (**b**) Interior spaces; (**c**) Ground floor plan; (**d**) First-floor plan.

Regarding the prototype house, a typical prototype house (house number 7) (Figure 8a,b) was selected for the investigation among the 56 uniform houses constructed in Panipokhari. This house, oriented eastward on a sloped site terrace, features a two-story design and is built on a square-shaped plan. The ground floor consists of three rooms with a veranda (Figure 8c), while a single-flight staircase leads to the first floor, utilized as a bedroom and for storage (Figure 8d). Similarly, a typical house (plot numbers 53, 54, and 55) facing south (Figure 9a,b) was selected in Jillu. This house features bedrooms and a kitchen on the ground floor (Figure 9c), with a staircase leading to the first floor containing three bedrooms and an open terrace (Figure 9d). Both houses were constructed using 230 mm-thick brick masonry in cement mortar and have 12 mm cement plaster on the inside. The roofing in Panipokhari is made of 0.26 mm CGI, while Jillu has a 127 mm-thick RCC roof. However, the overhang of both houses is narrower compared to the vernacular houses. The windows have a wooden frame with 5 mm single-paneled glass. The floor plans resemble the space layout planned for urban community life, such as space provided for liquefied petroleum gas (LPG) in the kitchen instead of space for a fireplace provided in a vernacular house. Consequently, households in Panipokhari have constructed a separate kitchen for cooking with firewood and LPG outside the house. It is worth noting that, due to the absence of a house ownership certificate, the houses in Panipokhari have not been connected to the national electricity grid. Therefore, houses there are utilizing electricity from the host communities' houses.

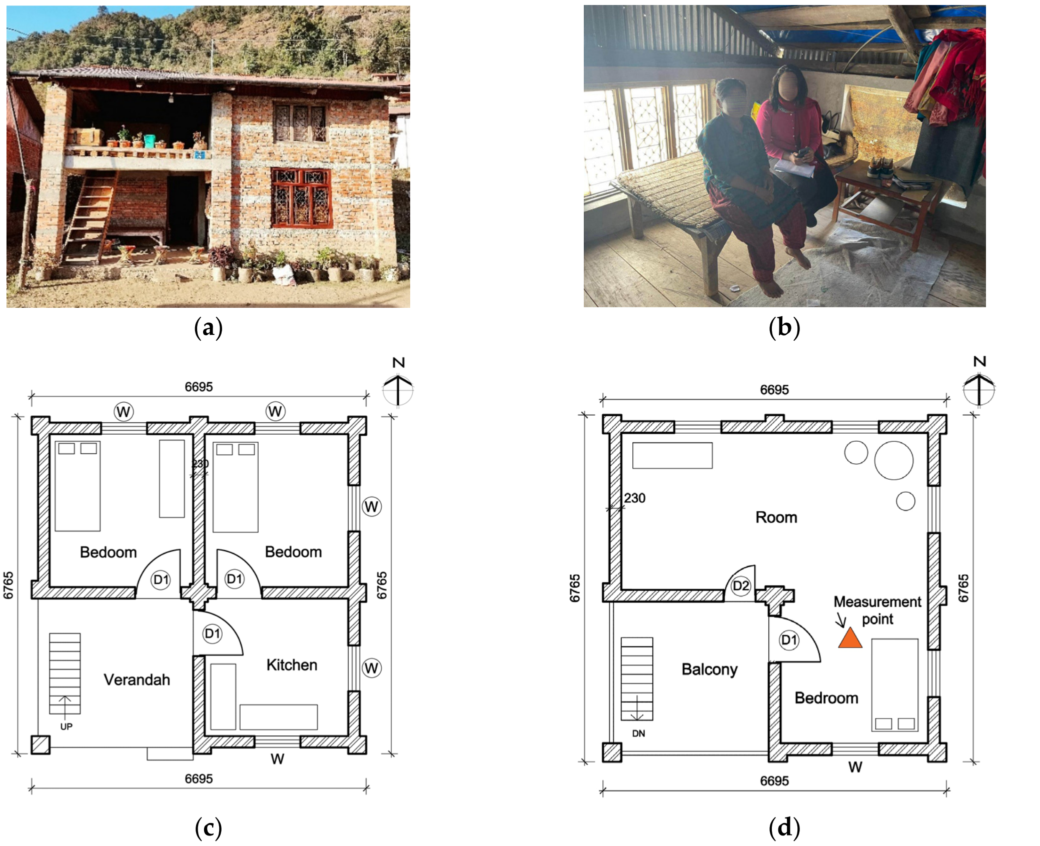


Figure 8. Exterior view, interior space of prototype house in Panipokhari: (**a**) Exterior view; (**b**) Interior spaces; (**c**) Ground floor plan; (**d**) First-floor plan.

Figure 9. Exterior view, interior space of prototype house in Jillu: (**a**) Exterior view; (**b**) Interior spaces; (**c**) Ground floor plan; (**d**) First-floor plan.

2.3. Occupant Behavior

The resettled households in Panipokhari mainly comprise members of the poor indigenous Thami community (about 95%) and the remaining 5% are from the Dalit community, which is considered the lowest caste in Nepal (Figure 10a). Conversely, Jillu is predominantly occupied by the high-class Brahmin (Chaulagain) community (Figure 10b). The average household size is four and five people in Panipokhari and Jillu, respectively, with approximately 15% of households having family members working abroad. Over 50% of the households rely on subsistence agriculture and livestock, followed by 13% of the households involved in labor work in Panipokhari and 26% earning livelihood from service and business in Jillu. The households in Panipokhari have a very low monthly income of nearly USD 155, and monthly expenditures of around USD 117, while the residents of Jillu have better conditions with an average income and expenditure of nearly USD 260 and 166, respectively.

(**a**) (**b**)

Figure 10. Occupants of the study area: (**a**) Male in Panipokhari; (**b**) Female in Jillu.

The occupants of both Panipokhari and Jillu follow a similar daily routine, starting their day by leaving their bedrooms at 6:00 to engage in morning activities. In Panipokhari, they usually depart for daily farming activities around 21:00 and return at around 16:00 before finally going to their bedrooms at 21:00. The occupants usually sleep for an average of nine hours each night. In Jillu, the households go to their farm and return home for meals due to the closer proximity to the farm. Due to financial constraints, occupants in Panipokhari do not use active heating or cooling systems, while a few households in Jillu use heaters. In all four houses, the bedrooms are occupant-controlled and naturally conditioned spaces, where occupants regulate thermal environments primarily by opening and closing windows. To shield themselves from the cold winter air, occupants reported keeping windows closed, which also reduced air movement during the study period. These observations emphasize the need to consider these variations in housing design and construction, utilizing local materials and techniques, both in vernacular houses and reconstructed houses, when assessing the energy efficiency of these dwellings.

2.4. Thermal Environment Survey

The survey was conducted in a total of four houses, two each in Panipokhari and Jillu, during the coldest winter months of January and February. This period was chosen as winter presented a significant challenge for the settlement situated in the hilly region of Nepal. For the study, a representative prototype reconstructed house was selected in both Panipokhari and Jillu. This choice was made because all the other prototype houses had similar floor plans oriented towards the east and were constructed using similar building materials and technology. Similarly, the examined vernacular houses were the only standing ones in Panipokhari and Jillu. The measurement duration spanned from 9 January to 18 February 2023, totaling 41 days. To ensure accurate measurements, data loggers were positioned at a height of 1 m in the center of the bedrooms on the first floor of all four houses. These bedrooms were equipped with openable windows facing east in Panipokhari (Figures 6d and 8d) and south in Jillu (Figures 7d and 9d) to minimize the direct effect of solar radiation. This installation approach was based on the findings of a study by Rodriguez et al. [31], which identified the worst thermal environments on the top floor. To record outdoor air temperature, measurements were taken outside the houses on the east side to avoid the effect of direct solar radiation on the sensors. Throughout the measurement period, data loggers recorded indoor and outdoor air temperature as well as relative humidity every hour. Detailed information about the devices used for the recordings is provided in Table 2.

Table 2. Instruments used in the field survey.

Parameter Measured	Name of Instrument	Range	Accuracy
Indoor air temperature and relative humidity (RH)	Onset HOBO UX100-003	−20 to 70 °C, 15–95% RH	±0.21 °C, ±5% RH
Outdoor air temperature and relative humidity (RH)	Onset HOBO MX2302A	−40 to 70 °C, 15–95% RH	±0.2 °C, ±2.5% RH

2.5. Thermal Sensation and Satisfaction Survey

In addition to the thermal measurements, a questionnaire survey was conducted to assess the thermal satisfaction experienced by occupants of both prototype and previous vernacular houses (Table A1). As indicated by Bennet and O'Brien [42], capturing occupants' ratings is crucial for evaluating their thermal comfort. The thermal satisfaction survey included a total of 102 households, 46 households (out of a total of 56) in the Panipokhari Integrated Settlement and 56 households in Jillu (out of a total of 70) in Jillu Integrated Settlement. It is worth noting that not all households could be included due to their absence—many homes were unoccupied and locked during seasonal migration for labor jobs in larger cities. While all the vernacular houses, except for one standing house in Panipokhari and two houses in Jillu, had collapsed in the earthquake, the thermal satisfaction survey encompassed respondents from the remaining vernacular house, 46 prototype houses (comprising 71% male and 29% of female respondents, aged between 15 and 75 years) in Panipokhari and 56 reconstructed houses (with 67% male and 33% female respondents, aged between 15 and 75 years) in Jillu. The survey was conducted in the local Nepalese language. Households who had lost their vernacular houses in the earthquake were also queried about their satisfaction with their previous vernacular housing before the earthquake. During the winter season, respondents were attired in thick clothing to keep warm.

The thermal sensation of the households in both prototype and vernacular houses was evaluated using a seven-point thermal sensation scale, ranging from '−3 very cold' to '+3 very hot' (Table A1). To prevent disruption during working hours, the survey was conducted from 6:30 to 9:00 and 16:00 to 19:00. During these times, respondents were queried about the thermal sensation of their sleeping rooms at nighttime. To account for language nuances, the modified thermal sensation scale (mTSV) was used, wherein the terms 'cool' and 'warm' were substituted with 'cold' and 'hot' to align better with comfort perception in the Nepali language as previously adopted by other researchers [20]. Additionally, a 5-point Likert scale was used to evaluate respondents' satisfaction perception, ranging from '1. highly unsatisfied' to '5. highly satisfied'.

3. Result and Discussion

3.1. Variation of Indoor and Outdoor Air Temperature

In free-running buildings, the indoor air temperature is influenced by the outdoor air temperature. This section discusses the variation in indoor air temperature within both the prototype and vernacular houses, considering their relationship with the outdoor air temperature. Figure 11a presents the indoor and outdoor air temperature profiles of the vernacular house and prototype house for a week in both Panipokhari and Jillu. Notably, the indoor air temperature has shown less fluctuation in the vernacular houses compared to the prototype house, both during morning and nighttime. Similarly, Figure 11b displays the 24-h temperature profile of a typical day on 13 January 2023. This day was selected as it displayed no significant deviation in the temperature profile. The indoor air temperature tends to be higher in the prototype house during the daytime, as solar radiation gets trapped in the CGI sheets and RCC roofs, leading to a phenomenon similar to the greenhouse gas effects.

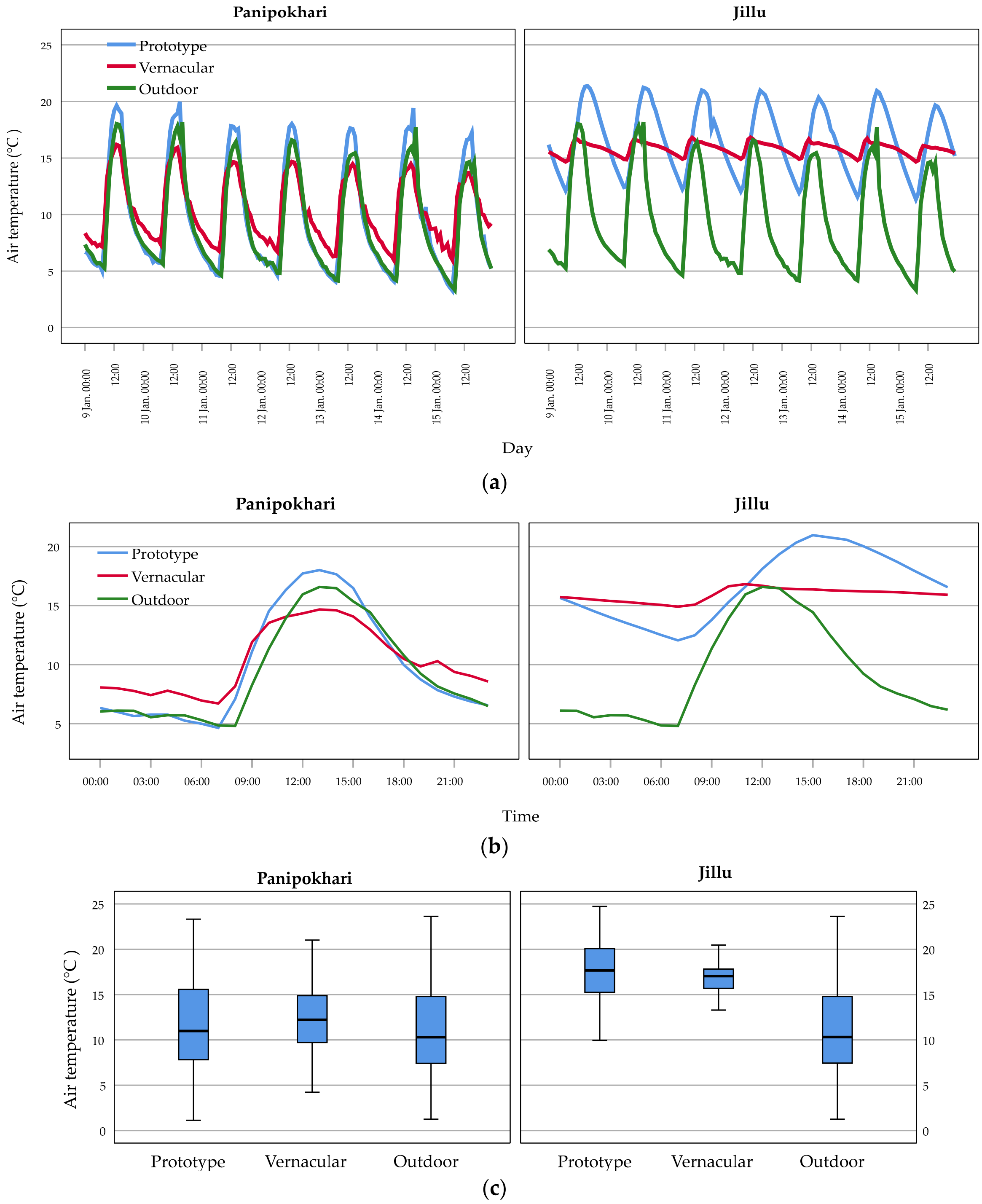


Figure 11. Indoor and outdoor air temperature in prototype and vernacular houses: (**a**) Weekly variation; (**b**) Daily variation (13 January 2023); (**c**) Box plot.

However, the figure indicates that the indoor air temperature of the vernacular house is higher at nighttime, creating thermal comfort for occupants who primarily use the rooms at night, after their daytime farmwork. In Panipokhari, the indoor air temperature of the prototype house experiences notable fluctuations throughout the day, ranging from 2.5 °C at 7:00 to 17.5 °C at 13:00, with a diurnal range of 10 °C (Figure 11c). In contrast, the vernacular houses demonstrate only a 6 °C diurnal range of the air temperature, indicating reduced indoor temperature fluctuations. High fluctuations during the daytime coincide with solar radiation exposure. It is important to recognize that in free-running buildings, the outdoor air temperature significantly impacts indoor air temperature. In Jillu, despite similar fluctuation patterns, indoor temperature variation remains lower compared to the vernacular houses. This study's findings underscore the importance of designing buildings that provide occupants with thermal comfort while minimizing indoor air temperature fluctuations.

3.2. Thermal Environment Assessment of Prototype and Vernacular House

According to the literature, vernacular houses tend to exhibit a warmer thermal environment than prototype houses constructed after disasters [34,36]. In this section, we examine the thermal environment of the prototype and vernacular houses reconstructed for displaced households in the Panipokhari Integrated Settlement and Jillu Integrated Settlement for a period of 41 days. Figure 12 illustrates that the average mean indoor temperature of the prototype house is 0.7 °C lower than that of the vernacular house in Panipokhari, but in Jillu, it is 0.8 °C higher. Furthermore, Figure 13 shows the wider standard deviation of indoor temperature in prototype houses (4.8 °C in Panipokhari and 3.0 °C in Jillu) compared to vernacular houses (3.3 °C in Panipokhari and 1.4 °C in Jillu). This higher indoor temperature variation within prototype houses might stem from factors such as low insulation levels [21], materials with higher U-values, and poor air tightness [43].

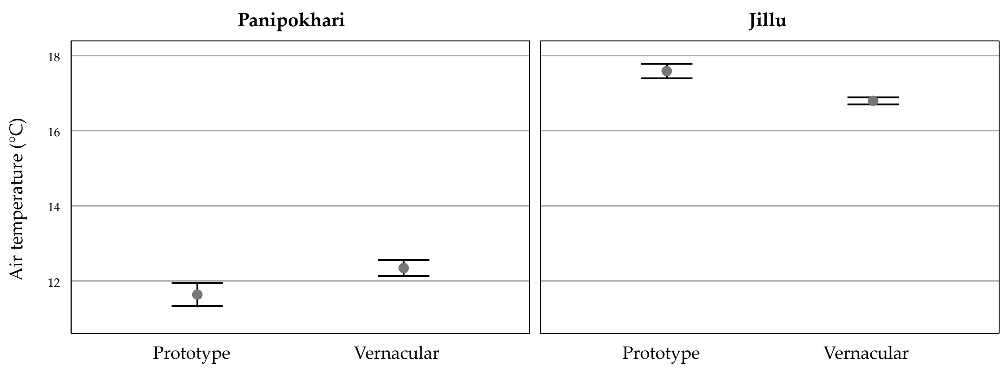


Figure 12. Mean air temperature in prototype and vernacular houses with 95% confidence interval (mean ± 2 S.E.).

Table 3 presents the comparison of the indoor and outdoor air temperatures of this study with the previous research carried out in the temperate region in the international and national context. In the context of China, Juan et al. [43] revealed that the traditional earth dwelling, although well adapted to the local climate in summer, was not quite so during the winter. The study found that on the coldest day of winter, the average indoor temperature of the bedrooms of earth dwellings and brick dwellings was 6.3 °C and 4.2 °C, respectively, when the outdoor air temperature was 0.8 °C. In India, Singh et al. [21] measured the indoor air temperature of 15 °C in vernacular houses when the outdoor air temperature was 13.7 °C. Likewise, in the Nepalese context, Rijal et al. [22] also revealed that the indoor air temperature of the traditional houses in the temperate climate in the winter month is 11.5 °C in Bhaktapur, 14.8 °C in Dhading, and 15.3 °C in Kaski districts, which are also the 2015 earthquake-affected districts of Nepal. This study found that the indoor air temperature was similar to the outdoor air temperature in the post-disaster house with a difference of only 1.4 °C in prototype house of Panipokhari, which is similar to the findings of Thapa et al. [28] with the difference of only 2.7 °C in the study of the earthquake-affected districts of Nepal. The result of this study is similar to other studies, which revealed that although the indoor air temperature of the vernacular house was higher than the prototype house, both were as low as the outdoor air temperature.

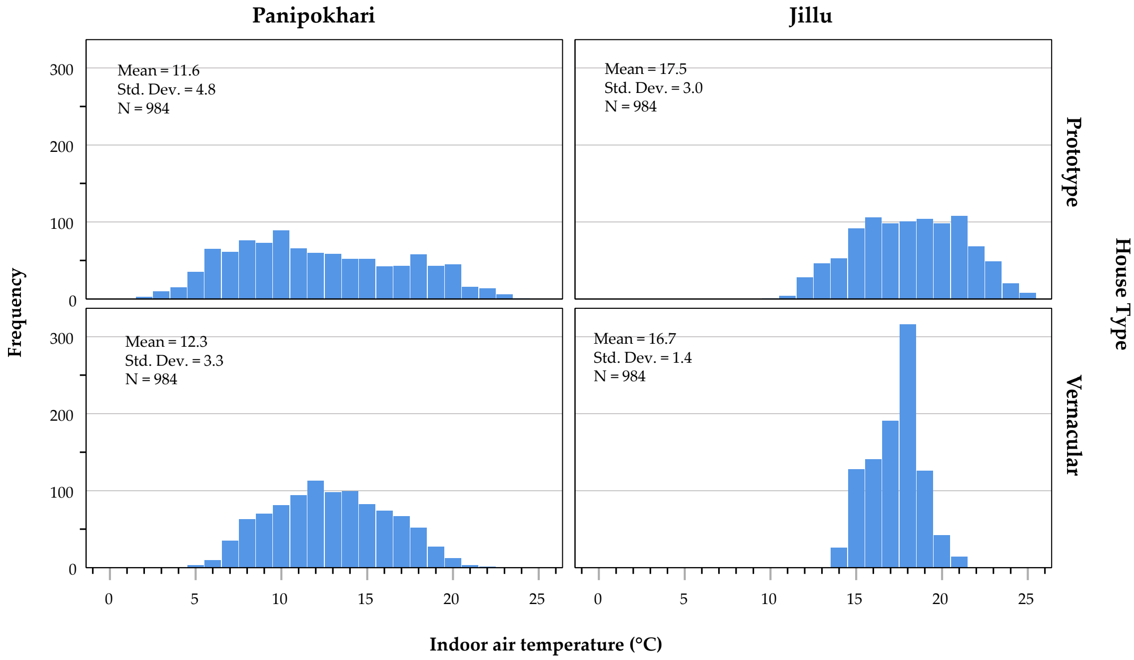


Figure 13. Indoor air temperature in prototype and vernacular houses.

Table 3. Comparison of indoor and outdoor air temperature with previous research.

Reference	Season	Country	Place	House Type	Material	Altitude (m)	T_o (°C)	T_i (°C)
This study	Winter (January)	Nepal	Panipokhari Jillu	Vernacular, Prototype Vernacular, Prototype	Stone, CGI Brick, CGI Stone, Slate Brick, RCC	1765 1170	10.2 10.0	12.3 11.6 16.7 17.5
Rijal [44]	Winter (January)	Nepal	Mustang	Vernacular	Sun-dried brick, small opening	3705	−3.1	−0.4~2.3 (Non-heated room) 4.1 (Heated room)
Juan et al. [43]	Winter (January)	China	Qinba mountainous area	Vernacular Modern	Earth Brick	1200	0.8 (coldest day)	6.3 (Earth dwelling) 4.2 (Brick dwelling)
Singh et al. [21]	Winter (January)	India	North India, Cherrapunjee	Vernacular	Rock slab, brick, small opening	1400	13.7	15.0
Thapa et al. [45]	Winter	India	Kurseong	Modern	Brick in cement mortar, CGI roof with wooden plank	1420	14.2	16.6
Rijal et al. [22]	Winter (December)	Nepal	Bhaktapur Dhading Kaski	Traditional	Brick, CGI roof Stone, slate roof Stone, thatch, slate	1350 1500 1700	10.1 11.9 11.8	11.5 14.8 15.3
Pokharel et al. [23]	Winter (December–January)	Nepal	Panchthar	Traditional, Modern	Stone in mud mortar, CGI		4.1~22.1	13.9
Shahi et al. [20]	Winter (January–February)	Nepal	Kathmandu	Modern	Brick, concrete		11.3–18	18
Gautam et al. [16]	Winter (December–January)	Nepal	Kavrepalan-chok	Traditional	Stone in mud, medium-sized opening		10~16	16.9 *
Thapa et al. [28]	Winter (January–February)	Nepal	Lalitpur	Temporary shelters	CGI sheet	1329	7.6 (Nighttime)	10.3 (Nighttime)

T_o: Outdoor air temperature, T_i: Indoor air temperature; CGI: Corrugated Galvanized Iron, *: Mean indoor globe temperature.

3.2.1. Mean Thermal Environment of the Nighttime

The study also investigated the nighttime mean indoor temperature of both the vernacular and prototype houses and subsequently compared it with outdoor air temperature. Based on the mapping of everyday activities, it was observed that the households used the bedroom exclusively for a period of 9 h each day, specifically between 21:00 and 6:00. This leaves the remaining 15 h to be divided into daytime (6:00 to 21:00) and nighttime (21:00 to 6:00). As outlined in Table 4, the average mean indoor air temperature during nighttime in Panipokhari was found to be 8.3 °C for the prototype house and 10.4 °C for the vernacular house. These values are, respectively, 0.5 °C and 2.6 °C higher than the outdoor air temperature. Notably, the standard deviation of the prototype house (2.6 °C) exceeded that of vernacular houses (2.4 °C), indicating a wider fluctuation in indoor air temperature. Similarly, in Jillu, the indoor air temperatures of both prototype and vernacular houses are 4.5 °C and 5.5 °C higher than the outdoor air temperature, respectively. These results suggest that vernacular houses were better suited to the local climate conditions. Consistent with the findings of Thapa et al. [28], the study observed that the indoor air temperature of the prototype house in Panipokhari closely aligned with the outdoor air temperature during nighttime. Meanwhile, the indoor relative humidity of vernacular houses remained relatively stable, fluctuating between 37% and 77%. A separate study has indicated that maintaining indoor relative humidity levels within the range of 40% to 60% could reduce adverse health effects [35].

Table 4. Nighttime thermal environment of prototype and vernacular houses.

Study Area	Description	Air Temperature (°C)			Relative Humidity (%)		
		Outdoor	Prototype	Vernacular	Outdoor	Prototype	Vernacular
Panipokhari	Mean	7.8	8.3	10.4	77	68	63
	Std. Deviation	2.3	2.6	2.4	10	10	8
Jillu	Mean	7.9	12.4	13.4	77	58	54
	Std. Deviation	2.3	4.8	3.6	10	12	10

3.2.2. Relationship between Indoor and Outdoor Air Temperature

Regression analysis of the indoor and outdoor air temperature was carried out to estimate the indoor air temperature of the prototype house and vernacular house. Figure 14 shows the relationship between the indoor air temperature of the prototype house and the vernacular house with the 80% and 90% limits of the ASHRAE standard. It asserts that the indoor air temperature of the prototype houses and the vernacular house has a strong positive correlation with the outdoor air temperature. Based on the regression analysis, the following regression equations were obtained.

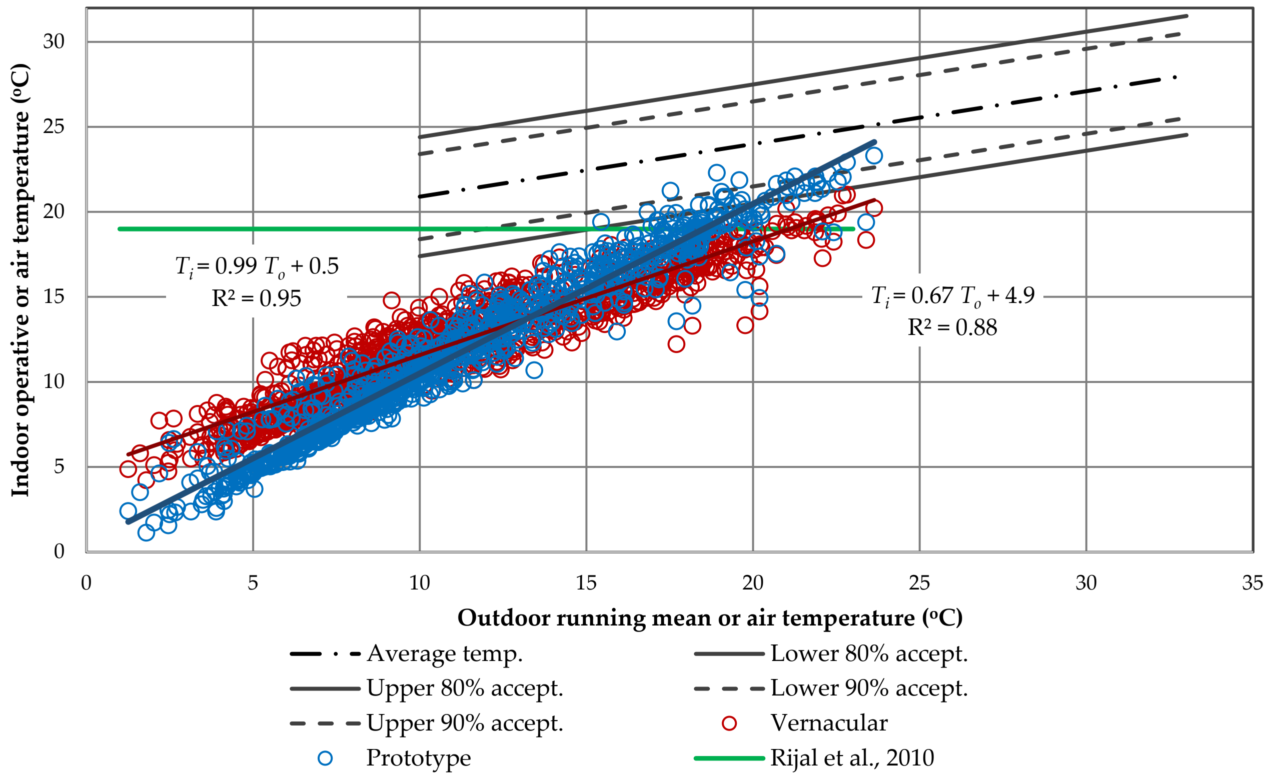
$$\text{Prototype house in Panipokhari: } T_i = 0.99\ T_o + 0.5\ (\text{n} = 984,\ \text{R}^2 = 0.95,\ \text{S.E.} = 0.008,\ p < 0.001) \quad (1)$$

$$\text{Vernacular house in Panipokhari: } T_i = 0.67\ T_o + 4.9\ (\text{n} = 984,\ \text{R}^2 = 0.88,\ \text{S.E.} = 0.008,\ p < 0.001) \quad (2)$$

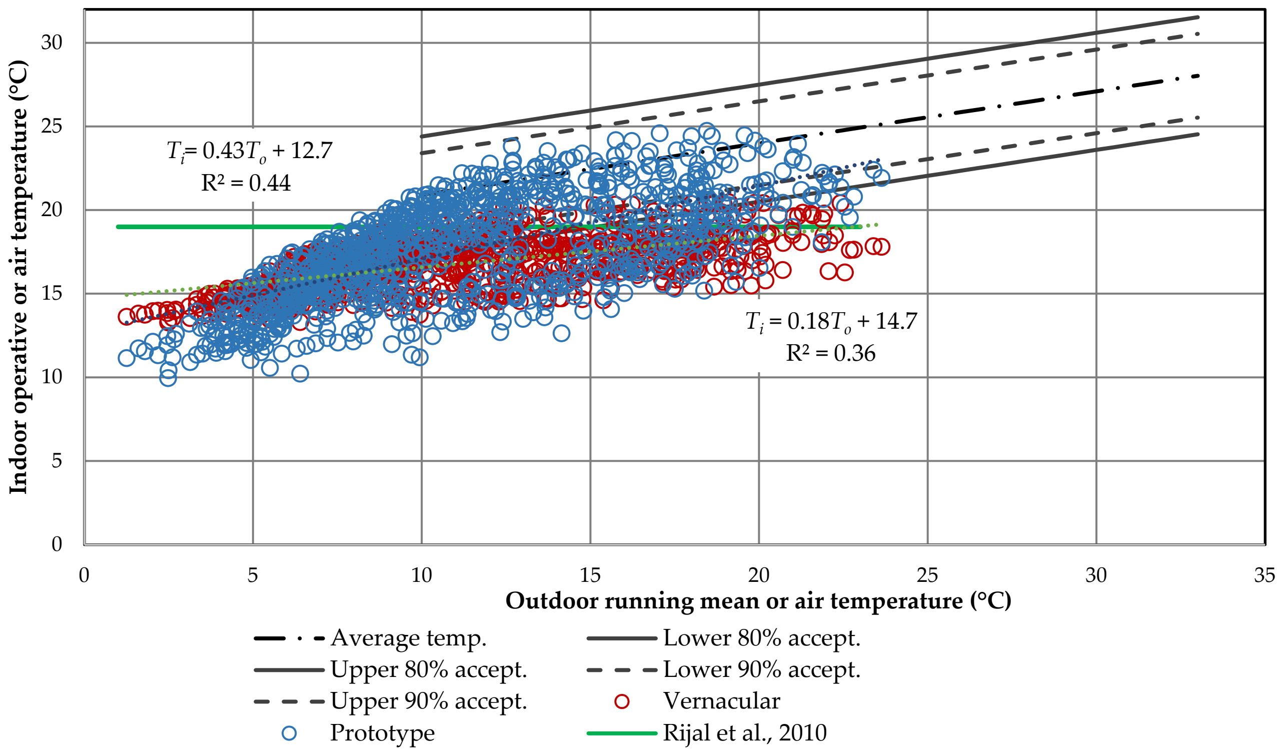
$$\text{Prototype house in Jillu: } T_i = 0.43\ T_o + 12.7\ (\text{n} = 984,\ \text{R}^2 = 0.44,\ \text{S.E.} = 0.008,\ p < 0.001) \quad (3)$$

$$\text{Vernacular house in Jillu: } T_i = 0.18\ T_o + 14.7\ (\text{n} = 984,\ \text{R}^2 = 0.36,\ \text{S.E.} = 0.008,\ p < 0.001) \quad (4)$$

where T_i is the indoor air temperature (°C), T_o is the outdoor air temperature (°C), n is the number of data samples, R^2 is the coefficient of determination, S.E. is the standard error of the regression coefficient, and p is the significance level of the regression coefficient.



(**a**)



(**b**)

Figure 14. Relationship between indoor and outdoor air temperature: (**a**) Panipokhari; (**b**) Jillu. Rijal et al. [22] is the winter comfort temperature for the Kaski district.

The vernacular houses exhibited a lower regression coefficient compared to the prototype houses, attributable to their higher thermal mass. As illustrated in Figure 14, the indoor air temperatures in both the prototype and vernacular houses fell below the ASHRAE standard in Jillu and were significantly lower than the ASHRAE standard in Panipokhari, suggesting a need for active heating systems. This observation is consistent with previous studies. For instance, Pokharel et al. [23] found that indoor air temperatures in temperate regions were as low as 10.5 °C, falling below the ASHRAE comfort standard. Similarly, Rodriguez et al. [31] affirmed that indoor temperatures were below the acceptable comfort zone, leading to reduced occupant satisfaction. Yoshino et al. [46] also documented that the winter indoor thermal environment of residential buildings in Shanghai was notably colder than the ASHRAE standard, but they speculated that the improvements could occur with higher household income levels.

However, the impoverished indigenous Thami community has encountered limited income-generating prospects, a situation further exacerbated by the earthquake's aftermath, which has driven them into deeper economic hardship and substantial debt. Consequently, their precarious financial situation and inability to afford electricity bills have compelled them to endure the cold conditions of their living spaces, with just one among the surveyed households being equipped with a heater. This situation is particularly challenging for vulnerable populations, such as the elderly, children, and the sick, who are compelled to endure cold environments. To cope with these conditions, households resorted to adopting various measures, such as adding extra layers of clothing, shutting windows, and using blankets to stay warm during cold winter nights.

3.2.3. Explanation of Thermal Performance by U-Value

This study also examined the U-value of the prototype and vernacular houses in both resettlement sites. The calculation of the U-value revealed that vernacular houses with a stone wall and wooden window have lower U-values compared to prototype houses with a brick wall, and glass window (Figure 15). Specifically, the U-value of the roof in the prototype house with CGI sheet was 3.34 W/(m^2·K), while for the vernacular house with CGI sheet and 1.5 mm bamboo beneath was 3.26 W/(m^2·K). In Jillu, the roofing material had a lower U-value of 2.73 W/(m^2·K) in the case of a slate roof and 2.38 W/(m^2·K) in the case of an RCC roof. The wooden windows in the vernacular houses have less infiltration and thus less heat loss compared to the glass windows in the prototype houses. The prototype houses, built using high U-value building materials compared to vernacular buildings, exhibited a temperature fluctuation of 12.8 °C, indicating poor thermal performance and lack of significant thermal mass to store solar heat gain. As indicated by Rodriguez et al. [31] and, Sarkar and Bose [47], the study confirms that the building envelope, thermal mass, infiltration, and roof leakage contribute to poor thermal performance. The use of CGI roofs in both house types could be attributed as one of the main reasons for the low indoor temperature. Additionally, the study found that the infiltration and leakage increased heat loss, resulting in the indoor air temperature being similar to the outdoor air temperature during the nighttime. The findings of Yoshino et al. [46] align with this study, emphasizing the importance of thermal insulation and air tightness for energy conservation and better performance of residential buildings. Enhancing the thermal performance of windows, walls, roofs, and floors is crucial for enhancing the indoor thermal environment [20]. The findings of this study are consistent with Yoshino et al. [46], which emphasize the importance of better thermal insulation and air tightness for energy conservation and improving residential building performance.

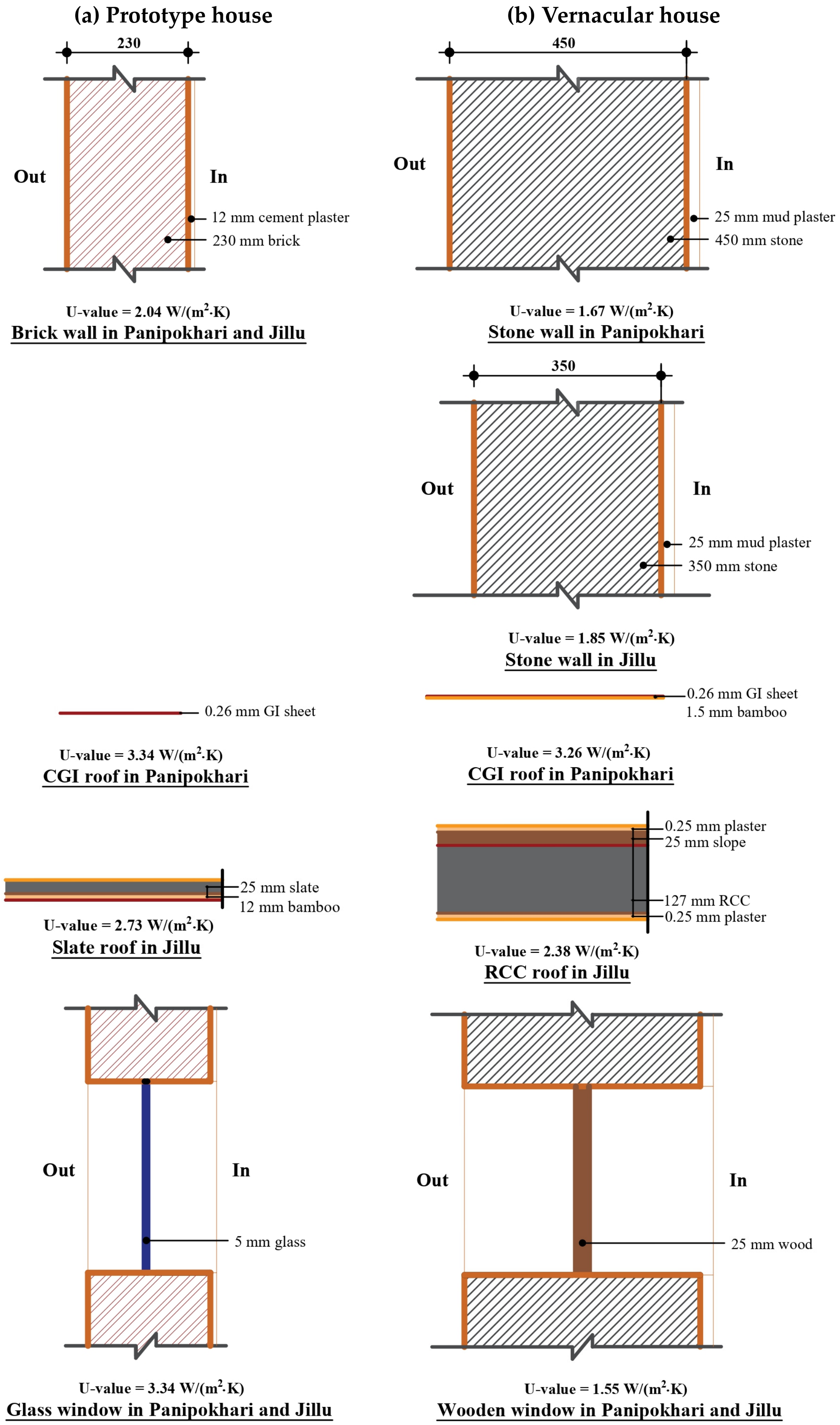


Figure 15. U-value of wall, roof, and window of prototype and vernacular house.

3.3. Resident Satisfaction Survey

In the context of post-disaster resettlement, resident satisfaction does not solely hinge on physical environmental factors but also intertwines with personal, social, and cultural factors [33]. The resident satisfaction survey, encompassing eight distinct factors that influence housing satisfaction, was conducted in both study sites. Using a questionnaire survey with a 5-point Likert scale ('1. highly unsatisfied' to '5. highly satisfied'), the survey was administered among the 46 households in Panipokhari and 56 households in Jillu with the aim of evaluating the difference between actual and desired housing outcomes from the households' perspective. The results showed a consistent trend: residents were least satisfied with the thermal comfort of their homes, as evidenced by low mean satisfaction scores of only 1.9 in Panipokhari and 2.5 in Jillu (Figure 16).

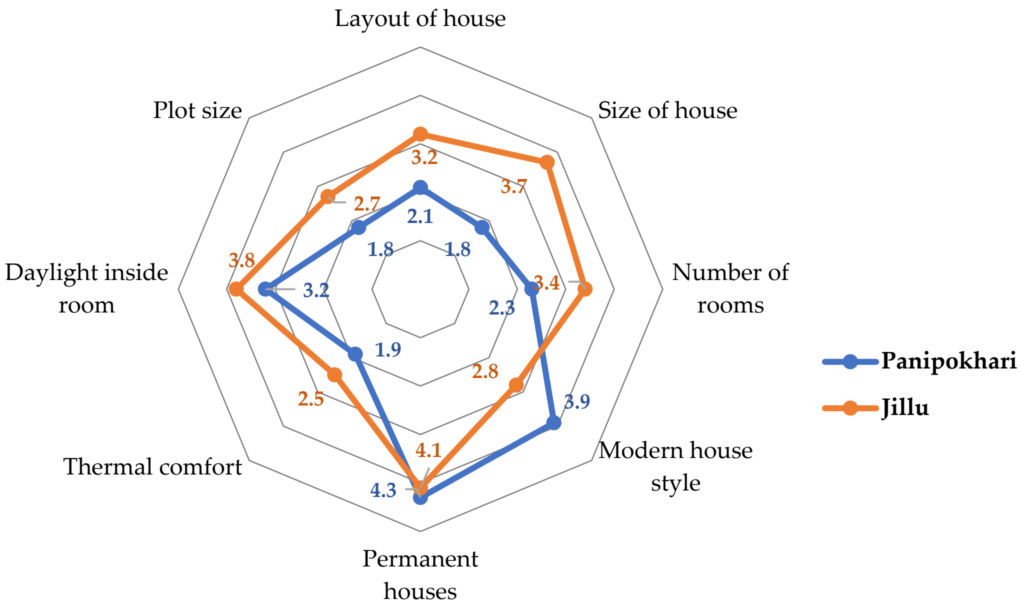


Figure 16. Mean satisfaction score of eight factors influencing housing satisfaction.

Consequently, this study proceeded to carry out a thermal sensitivity survey among the 102 earthquake-displaced households, currently residing in the prototype houses in both study sites. The focus was on assessing their perceptions of thermal sensation in their newly constructed post-earthquake houses and comparing them with their experiences in the vernacular house before the earthquake.

The result of the thermal sensation survey in Panipokhari indicated that a significant 70% of occupants characterized their houses as "very cold", while another 30% described their rooms as "cold" in the morning (Figure 17). Similarly, in the same setting, 7% of the occupants found their houses to be "very cold", while 61% deemed their rooms "cold", and 33% felt them to be "slightly cold". During nighttime hours, more than half of the occupants reported that the indoor environment of the house was very cold, with 35% indicating "cold" and 2% opting for "slightly cold" in the afternoon. In Jillu, the prevailing perception among respondents was that their houses were "slightly cold" (45% in the morning, 55% in the afternoon, and 45% at night), followed by a neutral feeling in thermal comfort (11% in the morning, 36% in the afternoon, and 11% at night). These results were consistent with the temperature measured by data loggers, which demonstrated that morning and night temperatures were akin to the outside temperature. These findings correspond with a previous thermal sensation survey by Thapa et al. [28], wherein 58% of respondents reported a "cold" thermal sensation in winter. Similarly, the occupants' reports of experiencing "cold" sensations in their homes during winter align with the findings of Rodriguez et al. [31] and Shahi et al. [20].

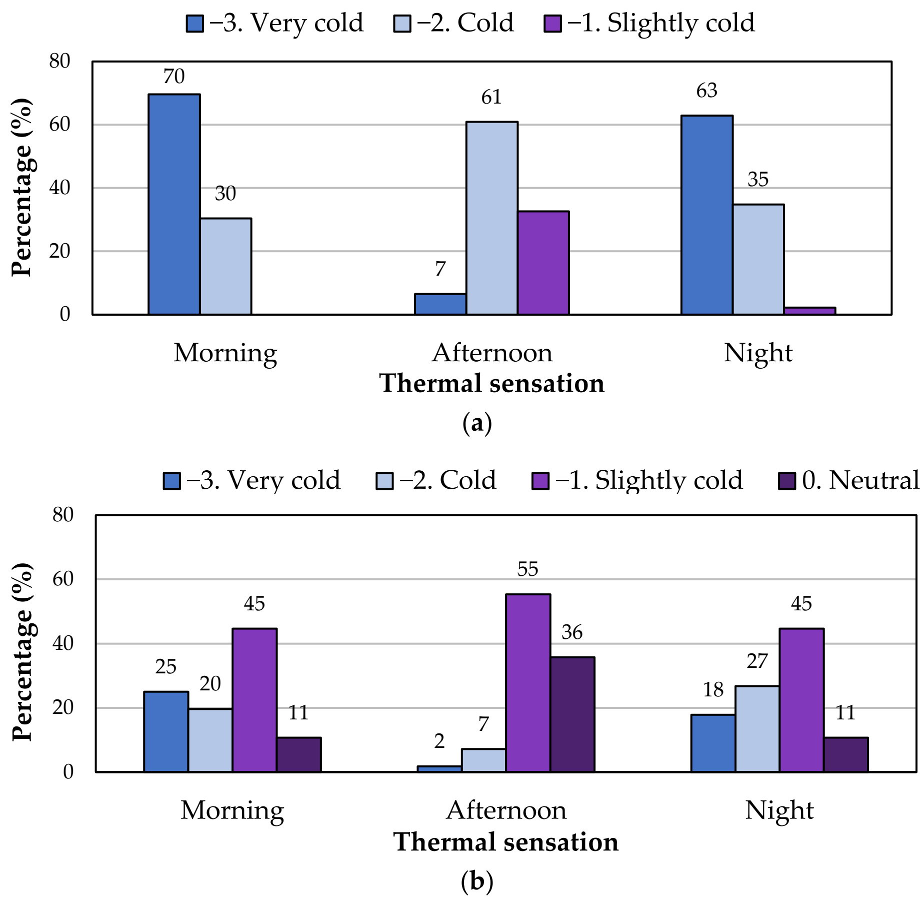


Figure 17. Thermal sensation of the occupants of the prototype houses: (**a**) Panipokhari; (**b**) Jillu.

The thermal environment satisfaction survey, as presented in Figure 18, indicates a clear disparity in occupants' satisfaction levels between the prototype houses and the vernacular houses. In Panipokhari (Figure 18a), approximately 80% of the occupants expressed their dissatisfaction with the thermal environment in the prototype houses, while another 13% and 7% stated that they were "neutral" and "satisfied" with these houses' thermal environment. In contrast, about 69% of the occupants were satisfied with the vernacular houses, and 7% had a "neutral" perception. Only 24% were "unsatisfied" with the bedrooms in their previous vernacular houses. In Jillu (Figure 18b), about 55% of the households were neutral in their assessment of prototype houses, followed by 38% unsatisfied and 7% very unsatisfied. The household's satisfaction with their previous vernacular houses was notably higher, with 59% expressing satisfaction, while those who were neutral and very satisfied accounted for 18%. These findings are in contrast to the results reported by Rodriguez et al. [31], where they found that slightly over half of the occupants surveyed were satisfied with the indoor temperature of their prototype houses. This indicates a strong preference for the thermal environment and overall comfort provided by vernacular houses compared to the newly constructed prototype houses.

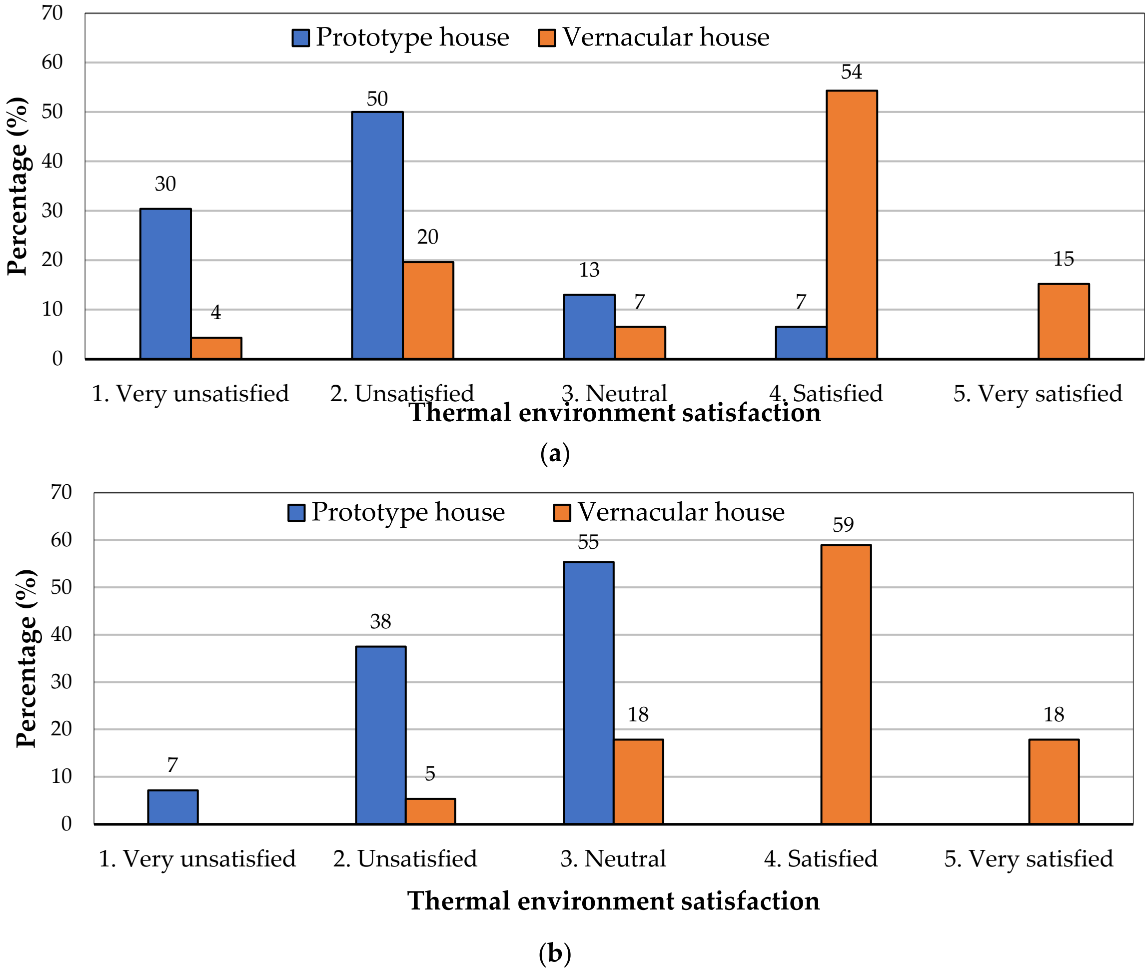


Figure 18. Housing satisfaction score of prototype and vernacular houses: (**a**) Panipokhari; (**b**) Jillu.

This analysis shows that the occupants living in the prototype houses were very dissatisfied with the indoor thermal environment and considered their rooms to be cold. The majority of the households expressed that the cement and CGI sheets used in the house made the house cold and difficult to live in. The residents also expressed that their former vernacular houses before the earthquake were very warm. Similar to several studies [8,34], this study also confirms that the residents were dissatisfied with the post-disaster permanent housing constructed after the earthquake. Additionally, this study also supports the findings of studies [38,48] that the residents were unsatisfied with the prototype houses compared to the pre-disaster vernacular houses constructed to suit the local climate. Furthermore, the households also complained about their degraded health condition in the prototype houses, such as headaches, colds, coughs, body aches, swelling in legs, etc. However, the respondent of the vernacular house, who also has a prototype house in Panipokhari, expressed high satisfaction with the thermal comfort of his vernacular house. He further stated that the thermal environment was one of the reasons for staying in the vernacular house in the winter season.

4. Overall Discussion

The investigation into the indoor thermal environment and resident satisfaction with newly constructed prototype houses and standing vernacular houses following earthquakes has revealed critical insights that can greatly inform post-disaster resettlement programs. Despite the intentions behind resettlement as an opportunity for development [49], it has inadvertently exacerbated thermal discomfort to vulnerable households. This discrepancy highlights the need for a more holistic approach in the design and construction of the prototype housing within resettlement efforts, which should encompass a thorough understanding of thermal dynamics, local context, and climate, rather than merely focusing on structural aspects [50].

The comparison of daily average indoor air temperatures highlights the thermal superiority of vernacular houses. For instance, in Panipokhari, the vernacular house maintained an average indoor temperature of 12.3 °C, whereas the prototype house had a slightly lower average of 11.6 °C. Similarly, in Jillu, the vernacular houses registered an average indoor temperature of 16.7 °C, contrasting with prototype houses' 17.5 °C. This finding challenges the previous findings made in China by Cheng et al. [24] that the indoor air temperature of post-disaster permanent houses exceeded that of vernacular houses. Our study found the opposite trend: lower indoor air temperatures in prototype houses compared to vernacular buildings at night. The prototype house exhibited notable temperature fluctuations throughout the day, unlike the more stable conditions in vernacular houses, showcasing the latter's inherent thermal resilience. Moreover, vernacular houses consistently maintained indoor air temperatures higher than the prototype houses, further affirming their superior thermal performance.

The indoor air temperature of the vernacular house was found to be 2.1 °C higher than that of the prototype house and 2.6 °C higher than the outdoor air temperature in Panipokhari. Similarly, the indoor air temperature of both prototype and vernacular houses in Jillu were 4.5 °C and 5.5 °C higher than the outdoor air temperature, respectively. These findings, align with Juan et al.'s [43] study, confirming that the indoor temperature in the bedroom of vernacular houses is 2.1 °C and 5.5 °C higher than the prototype houses when auxiliary thermal sources are absent. Similarly, our study in the case of Panipokhari supports Thapa et al.'s [28] findings that the indoor and outdoor air temperatures of the prototype houses closely match outdoor air temperatures, resulting in occupants' discomfort due to the lack of differentiation. Displaced households are compelled to live in indoor air temperatures similar to outdoor air temperatures. This concurs with prior research [23,46] indicating that indoor air temperatures often fall far below the lower limit of the acceptable comfort temperature range specified by ASHRAE standard. Our study also aligns with Singh et al.'s [21] conclusions that vernacular buildings tend to also be uncomfortable during winter months. Additionally, other studies [22] have similarly found that the mean comfort temperature in vernacular houses during winter is below the ASHRAE standard. However, in Jillu's prototype case, the result showed higher indoor temperature with respect to outdoor air temperature, suggesting the paramount importance of the choice of material and construction techniques used in determining the thermal condition.

The observed temperature patterns in both case locations, with high daytime temperatures and low nighttime temperatures, indicate a potential issue with the construction of the prototype houses, likely involving high U-value materials. Further field observations and examination into the thermal transmittance of building components (e.g., wall, window, and roof) revealed a significant difference in U-values between vernacular and prototype houses. The vernacular house has notably lower U-Values, attributed to the minimal heat gain or loss through the stone wall, wooden window, and slate roofing in the case of Jillu, while Panipokhari showed slightly higher U-values due to the use of CGI roofing. This suggests that CGI sheets, given their thinness and high thermal conductivity, provide poor insulation, allowing heat to escape easily. Slate, though thicker and with better insulation than CGI sheets, is still not highly insulating. In contrast, Reinforced Concrete (RCC) roofs, with their significant thickness and lower thermal conductivity, offer much better insulation, making them more energy-efficient for maintaining indoor temperatures. In contrast to Juan et al.'s [43] findings that the air tightness of brick houses is better than that of the vernacular house, field observations showed issues with the prototype house in Panipokhari, including air infiltration and thermal leakage through the uninsulated roof construction with gaps at eve levels, warping of unseasoned woods used for doors and windows, poor fittings, and irregular operation schedules of doors and windows. These factors collectively increased heat loss in the prototype house in Panipokhari, leading to the indoor air temperature being similar to the outdoor air temperature at night.

Such a close resemblance of indoor and outdoor air temperatures at night and increased fluctuations in indoor air temperature within the prototype house in Panipokhari can be attributed to factors such as inadequate insulation levels [21], the usage of materials with higher U-values [20], and suboptimal air tightness [43]. This finding aligns with the results of Tas et al. [12], who found that occupants living on the top floor were unsatisfied with the roof insulation. The poor thermal performance of the CGI sheets was one of the major reasons for the low indoor temperature in the winter. In the case of the prototype in Jillu, where a higher indoor temperature was observed compared to Panipokhari, the insulation provided by a concrete roof with a lower U-Value can be attributed as one of the key reasons for the warmer environment, especially considering the prototypes in both locations shared similar problems discussed in the preceding paragraph. Some of these problems also existed in vernacular houses, but to a lesser degree than in the prototypes.

Moreover, the survey analyzing occupant perceptions also revealed that 70%, 7%, and 63% of respondents deemed prototype houses to be "very cold" during the morning, afternoon, and evening, respectively in Panipokhari. Conversely, in Jillu, a majority of the respondents characterized their houses as only slightly cold, followed by a neutral rating. The occupants indicated greater satisfaction with the thermal environment of vernacular houses [17] compared to prototype houses. In the vernacular house, central hearths provided heating, whereas the prohibition of firewood-based room heating in prototype houses, due to concerns about interior aesthetics, left occupants without this option. With limited financial means, households could not afford active heating systems. The absence of auxiliary heater compelled households to endure the cold, exacerbating the health-related vulnerability of already loan-burdened, economically disadvantaged, displaced households. Juan et al.'s [43] study similarly recommended auxiliary heating systems, underscoring that both vernacular and modern brick houses faced unsatisfactory indoor thermal environments. However, the Thami community's constrained economic circumstances, compounded by earthquake-induced hardships and an inability to cover electricity costs, left many with no choice but to occupy cold rooms. The predicament especially affected the elderly, children, and the sick. While only one household reported having an electrical heating system to warm their room, others have adopted various strategies, such as adding a layer of clothing, closing the windows, and staying under blankets to keep warm during the cold winter nights to cope with the low indoor temperature. The unsatisfactory living conditions and dissatisfaction with housing may eventually prompt households to consider abandoning the houses or returning to their original locations [50,51], seeking better options.

Furthermore, while post-disaster reconstruction is typically expected to result in housing improvements, our study reveals that the constructed prototype houses actually performed less effectively in comparison with their vernacular counterparts. This discrepancy could potentially lead to decreased satisfaction and acceptance of these prototype houses, thereby affecting the overall success of the reconstruction initiative. The study suggests that constructing post-disaster prototype houses should carefully consider the local climate conditions and available materials to ensure their effectiveness and alignment with the thermal and energy needs of the community. Research by Fuller et al. [52] indicates high infiltration rates due to poor levels of construction. Shahi et al. [20] emphasize that augmenting thermal insulation and reducing infiltration can effectively raise nighttime indoor air temperature by 1.1–1.8 °C. Furthermore, they propose that enhancing building envelope systems can contribute to increased indoor air temperatures without a corresponding rise in energy consumption for heating. Shahi et al. [20] have also reviewed energy savings achieved through adjustments in temperature settings. In the context of this discussion, Juan et al. [43] found that the brick house required 19% more energy for heating compared to vernacular houses. Furthermore, insights from Hoyt et al. [53] suggest that a mere one degree Celsius change in the setpoint can result in an energy savings of 10%. Similarly, Nicol et al. [54] found that a 1 °C increase in indoor air temperature could lead to a 10% reduction in heating energy usage during winter. Building upon these insights, a shift towards the indoor air temperature similar to the vernacular building's 2.1 °C and 1 °C advantages could potentially lead to a substantial 21% and 10% reductions in heating energy requirements for prototype houses in Panipokhari and Jillu Integrated Settlements respectively. This becomes particularly significant when considering the socio-economic challenges faced by the disadvantaged Thami community. In light of these circumstances, adopting passive design strategies akin to those observed in vernacular houses could have resulted in notable energy savings for winter heating.

In the context of the preceding discussion, it is evident that despite comparable outdoor air temperatures at both case locations, variations are observed in indoor temperatures, contingent on the selection of materials and construction techniques. This phenomenon becomes a significant concern in post-disaster resettlement initiatives not only in Nepal but also in other locations. The existing policies in Nepal have primarily focused on reducing seismic vulnerability, while paying limited attention to the indoor thermal environment and energy efficiency. Government policies and initiatives from development partners have widely promoted the use of lightweight CGI sheets in roofing and gables, overlooking the varying thermal properties of these sheets across different climatic regions and altitudes. Consequently, this practice has contributed to the inadequate thermal performance of the prototype houses. Despite the availability of locally sourced stone in Panipokhari, implementers opted for bricks in construction, disregarding the material's thermal properties and high U-values. A comparison of materials and their U-values used in the prototype and the vernacular house indicated that the latter was constructed over time with careful material selection, resulting in low U-values due to accumulated knowledge. In contrast, the prototype houses were designed and constructed by technical experts, who prioritized seismic safety without adequately considering material properties. Alternative material selection could not only have improved the indoor thermal environment, but also reduced the need for energy to increase room temperature. Thus, the judicious choice of building materials in housing construction can enhance thermal comfort, reduce energy consumption, and contribute to the overall sustainability of the resettlement projects.

As indicated by Sarkar and Bose [55] or policymakers, planners, and implementers, a deliberate emphasis on building materials that account for thermal comfort and long-term energy cost is crucial for the sustainability of post-disaster resettlement programs. The study recommends that reconstructed prototype houses following disasters prioritize the indoor thermal environment by meticulously selecting building materials with better U-values, surpassing those used in vernacular houses. However, it is important to note that vernacular houses have better aesthetic appeal, generate local employment, and use locally available materials, making it cost-effective and thus, offering a sustainable solution. Learning from the design principles of vernacular houses, adapted to the local climate and context, can pave the way for an improved indoor thermal environment, reduced energy expenses, and overall program sustainability. Integrating these findings holds practical significance for policy-formulation, planning, design, and construction of houses, particularly in the context of increasing climate and disaster-induced displacements.

This study acknowledges two main limitations. Firstly, it did not extensively investigate health problems associated with poor thermal performance in houses. Addressing this aspect in future research would enhance our understanding of the study's implications and occupants' well-being. Secondly, for a more comprehensive understanding, further research on surface temperature, along with a longitudinal study during the summer months is needed. This should also include a larger sample of houses to ensure robust results, which could not be done due to the limited availability of only one or two remaining traditional buildings following the earthquake. Additionally, this study does not include a detailed analysis of the glazing and window wall ratio's impact on indoor thermal environments, which also plays a role in determining indoor comfort. Including this analysis in future research would enable the development of improved design strategies for energy-efficient and comfortable living spaces.

5. Conclusions

In this study, we investigated the indoor thermal environment and resident satisfaction of the prototype house constructed for displaced households in Nepal's Dolkaha district, a region frequently affected by disasters. This study utilized the primary data collected in two case locations through fieldwork, including measurements of air temperature and relative humidity, a structured questionnaire survey, and direct observations. This's study findings highlight several key points:

1. Nighttime Temperature Variations: The nighttime indoor air temperature of the prototype house was 8.3 °C, which was 2.1 °C lower than the vernacular house reconstructed before the Gorkha earthquake of 2015 during the coldest month of January and February in Panipokhari. In Jillu, the nighttime temperature in the prototype house was recorded at 12.4 °C, which is 4.5 °C higher than the outdoor air temperature. This suggests that the vernacular houses were able to provide a warmer indoor environment compared to the prototype houses.
2. Non-Compliance with Comfort Standard: Both the prototype houses and the vernacular houses had indoor air temperatures that fell short of meeting ASHRAE comfort standard, particularly during nighttime hours. This indicates a need for an improved thermal environment, especially for occupants engaged in farmwork and who cannot afford auxiliary heating systems.
3. Material Properties: The U-value of the building construction materials in the vernacular house was found to have a lower value than the prototype house, indicating that the materials used in the prototype house have poor thermal insulation properties. Despite reconstruction being an opportunity to build back better, the prototype houses exhibited poor thermal performance attributed to the mismatch in the selection of material according to the local climate and context. If the indoor air temperature in the prototype could be increased to an indoor air temperature similar to the vernacular building of 2.1 °C and 1 °C higher in both study locations, the heating energy could be saved by 21% and 10%, respectively. This suggests that selecting building materials aligned with local climate conditions could result in an improved indoor thermal environment and substantial energy savings.
4. Resident Dissatisfaction: Residents of prototype houses expressed high dissatisfaction with their thermal environment, underlining the importance of considering thermal comfort in design and construction. Drawing from lessons in vernacular architecture, which utilizes local materials with higher U-values suitable for the climate, can guide future resettlement programs.

Overall, this research emphasizes the critical need to address indoor thermal comfort in post-disaster resettlement efforts, particularly for the well-being of vulnerable communities. Despite the opportunity to enhance the living conditions of over 5,000 displaced households, insufficient attention has been given to the indoor thermal environment. Integrating considerations of indoor thermal comfort in the design and construction of post-disaster prototype houses not only holds the potential to elevate occupants' well-being and satisfaction, but also contributes to the long-term success and sustainability of resettlement initiatives. This study's recommendation to select construction materials based on the local context and climate, drawing insights from vernacular architecture, offers a practical pathway for improvement. Moreover, for economically disadvantaged communities like the Thami community in Panipokhari, implementing passive design strategies and utilizing locally appropriate building materials akin to those in vernacular houses can yield substantial energy savings and improved thermal comfort for occupants. These measures can significantly enhance the sustainability and overall success of post-disaster resettlement programs.

It is evident that prototype houses in earthquake-affected regions often employed similar materials and technologies, designed without considering local climate nuances and material availability. This highlights the broader relevance of the findings of this research on indoor thermal comfort, energy efficiency, and material selection. Insights from this study may benefit not only the specific study area, but also similar contexts undergoing post-disaster reconstruction and resettlement efforts, providing valuable insights for policymakers, implementers, and researchers working towards thermally comfortable and environmentally sustainable resettlement solutions

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Appendix A

Table A1. Questionnaire used in the thermal sensation and thermal satisfaction survey.

Thermal Comfort Parameter	English	Nepalese Translation
Thermal sensation	−3 Very cold	जाडो
	−2 Cold	चिसो
	−1 Slightly cold	अलिकति चिसो
	0 Neutral	ठिक्क
	+1 Slightly hot	अलिकति तातो
	+2 Hot	तातो
	+3 Very hot	गर्मी
Resident satisfaction survey	1. Highly unsatisfied	एकदम असन्तुष्ट
	2. Unsatisfied	असन्तुष्ट
	3. Neutral	ठिक्क
	4. Satisfied	सन्तुष्ट
	5. Highly satisfied	एकदम सन्तुष्ट

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