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Energy Consumption Behavior in Informal Settlements: A Case Study of Squatter Settlements of Kathmandu Valley

by

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DECLARATION

I hereby declare that the thesis entitled **"Energy Consumption Behavior in Informal Settlements: A Case Study of Squatter Settlements of Kathmandu Valley"** 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, 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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Regards

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ABSTRACT

The research aims to analyze energy consumption behavior in informal settlements, specifically squatter settlements in the Kathmandu Valley, and to explore economically viable and thermally efficient housing solutions. Informal settlements face significant challenges due to inadequate infrastructure, unreliable electricity access, and dependence on traditional biomass for energy needs. These factors contribute to inefficient energy use, increased environmental impact, and poor thermal comfort. A mixed-method approach, including household surveys, field observations, and energy simulations in DesignBuilder, is used to assess current energy usage patterns and identify optimal solutions. Various building design scenarios are simulated to evaluate the impact of construction materials, insulation, window-to-wall ratios, and other passive design strategies on thermal performance and cost efficiency. The results indicate that optimizing window placement, improving façade material, and incorporating cost-effective alternative materials can significantly enhance energy efficiency and indoor comfort. Findings suggest that specific design modifications, such as using hollow concrete block and GI roofing, WWR of 30% which can improve thermal comfort by a measurable percentage, while the use of alternative wall materials can further optimize energy performance. The study concludes that implementing affordable, thermally efficient construction techniques can help enhance living conditions in informal settlements while promoting sustainable urban development. The findings offer valuable insights for policymakers, urban planners, and researchers working to improve energy access and efficiency in low-income housing.

Keywords: Squatter settlements, Informal Housing, Low-Income, Energy efficiency

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ABBREVIATION

CGI	Corrugated Galvanized Iron
CSEB	Compressed Stabilized Earth Blocks
DUDBC	Department of Urban Development and Building Construction
MoUD	Minisity of Urban Development
KVDA	Kathmandu Valley Development Authority
IFRC	International Federation of Red Cross and Red Crescent Societies
MoHA	Ministry of Home Affairs
NRA	Nepal Reconstruction Authority
RCC	Reinforced Cement Concrete
SDG	Sustainable Development Goals
UNDP	United Nations Develpoment Programme
UNRCO	United Nations Resident Coordinator's Office

CHAPTER 1: INTRODUCTION

1.1 Background

Energy consumption behavior refers to the patterns and practices through which individuals and households use energy resources. In informal settlements, where access to formal energy infrastructure has numerous barriers (Butera *et al.*, 2016), understanding these behaviors is crucial for addressing energy-related challenges. These settlements, characterized by makeshift housing and a lack of basic services, present unique energy consumption patterns influenced by socioeconomic constraints, environmental conditions, and cultural practices (Moreno et al., 2020). Residents often rely on traditional biomass, kerosene, or informal electricity connections, which can lead to high costs, health hazards, and environmental degradation (Butera et al., 2016).

UN-Habitat (2015) defines informal settlements as suburban areas where the inhabitants often have no security of tenure of the land or dwellings they occupy or the neighborhoods, that are usually lacking essential services to city infrastructure, and where housing does not comply with planning and building regulations. The term "informal settlements" encompasses a range of descriptions, including slums, squats, shantytowns, spontaneous settlements, and uncontrolled or unplanned areas (Gilbert, 2007; Nuissl and Heinrichs, 2014).

Informal settlements are a common occurrence in developing countries, and are becoming the only viable alternative for individuals with limited financial capabilities to meet their housing needs (Awad, Bartlett and Conaldi, 2021). In developing regions, including Nepal, informal settlements are prevalent due to rapid urbanization, poverty, and inadequate housing policies (Singh and Dhakal, 2024). These areas often lack access to clean and affordable energy, impacting the residents' quality of life and contributing to broader issues such as air pollution and deforestation. Addressing the energy needs of these communities is essential for improving living standards, health outcomes, and environmental sustainability (IEA, 2021).

The case area informal settlement in Balkhu is a locality in Jagriti Nagar, Ward No 14, Western Kathmandu, covering 18 acres of land situated along the Bagmati river. It is a dwelling place for a large number of low-income, urban squatters, some even multigenerational, comprising individuals from varying places of origin, socio-economic statuses, political affiliations, and age group (Rumba, 2014). This diversity makes Jagriti Nagar an ideal sample for studying energy consumption behavior in informal settlement. As of 2010, the informal settlements in Jagriti Nagar comprised 296 households with a population density of 1,300 persons per hectare(NEST (P), 2010).

The Banisghat Squatter Settlement is an informal residential area located in Ward No. 12 of central Kathmandu, spanning approximately 15 acres along the banks of the Bagmati River. It serves as a habitat for a significant number of low-income urban squatters, including both first-generation migrants and multigenerational families. The settlement consists of individuals from diverse geographic backgrounds, socio-economic conditions, and political orientations, reflecting a wide demographic mix. This diversity makes Banisghat an important site for studying urban informality and energy consumption patterns. As of 2010, the settlement comprised around 280 households, with a population density of approximately 1,250 persons per hectare (NEST (P), 2010).

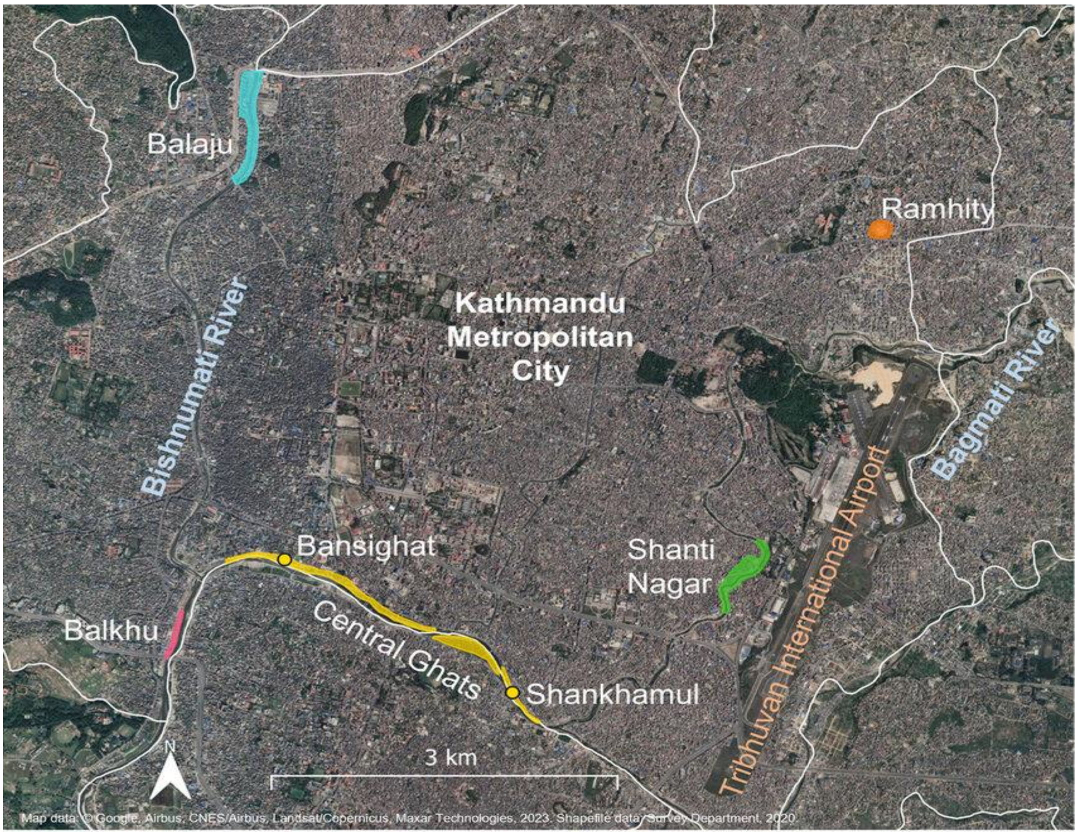


Figure 1 Location of Informal Settlements in Kathmandu (Source: Gill J.C., 2025)

1.2 Importance of Research

Energy consumption behavior in informal settlements is a critical area of study due to its profound implications on public health, household economics, and broader environmental sustainability. In marginalized urban areas like Jagriti Nagar in the Kathmandu Valley, where infrastructure is limited and socio-economic vulnerabilities are high, gaining a comprehensive understanding of household energy use patterns becomes essential. These communities often experience energy poverty—characterized by limited access to reliable, safe, and affordable energy—which perpetuates cycles of poverty and social exclusion. Understanding how households in such contexts consume energy, the choices they make regarding energy sources, and the constraints they face can enable the development of targeted, evidence-based policies and interventions.

In the specific context of squatter settlements, energy consumption behavior is shaped by a combination of factors, including income level, housing structure, education, availability of resources, and awareness of energy-efficient practices. By closely analyzing these variables, this study seeks to identify practical and cost-effective energy solutions tailored to the needs of the community. These solutions must be adaptable to the informal nature of the settlements and sensitive to the socio-economic and cultural realities of the residents. The goal is not only to reduce energy poverty but also to create co-benefits such as improved indoor air quality, enhanced safety, and better resilience to climate variability.

Improving energy access and efficiency in such contexts can significantly transform the quality of life for residents. By reducing dependency on hazardous traditional fuels—such as firewood, kerosene, or low-efficiency stoves—and encouraging the adoption of cleaner and more efficient alternatives like LPG, solar technologies, and improved insulation techniques, communities can experience lower health risks, reduced energy expenditures, and a diminished environmental footprint. Moreover, this research aims to support long-term planning by recommending sustainable building materials and construction methods suitable for the resettlement of squatter communities, ensuring thermal comfort and affordability.

Importantly, this study directly contributes to the achievement of multiple Sustainable Development Goals (SDGs), most notably SDG 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all. It also aligns with SDG 3 (Good Health and Well-being), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) by addressing interlinked challenges in energy, health, urban development, and environmental protection. The insights generated through this research can inform inclusive policy frameworks and practical interventions that bridge the gap between informal urban development and sustainable energy transitions.

1.3 Problem Statement

The informal settlements in Kathmandu Valley, such as Jagriti Nagar and Bansighat, are complex urban environments characterized by high population density, diverse socio-economic profiles, and a wide spectrum of housing typologies, ranging from temporary shelters to semi-permanent structures. These settlements have emerged largely due to rapid urbanization, rural-to-urban migration, and a lack of affordable housing, leading to unregulated and often unplanned residential clusters. The living conditions are typically marked by inadequate access to basic services such as electricity, clean water, sanitation, and waste management, which directly influence the overall quality of life.

Despite their growing prevalence, the energy consumption behavior of households in these informal settlements remains significantly under-researched in the context of Nepal. There is limited empirical data on how residents access and utilize energy, what types of fuels and technologies they rely on, and how their socio-economic status shapes their energy choices. Understanding these dynamics is vital for designing inclusive and context-sensitive energy policies, especially in areas where the formal energy grid may be unreliable, inaccessible, or unaffordable.

In many cases, households rely on a mix of traditional biomass fuels (such as firewood and charcoal), kerosene, LPG, and electricity—often in inefficient and unsafe ways. Such practices not only contribute to indoor air pollution and associated health issues but also increase the financial burden on low-income families. Furthermore, poor insulation and thermally inefficient housing materials lead to excessive energy use for heating and cooling, exacerbating the economic strain and environmental impact.

The existing body of literature often generalizes energy use patterns across urban or rural populations without adequately addressing the unique challenges of informal settlements, where infrastructure deficits, tenure insecurity, and economic vulnerability are dominant factors. These gaps in understanding hinder the development of targeted interventions that can enhance energy efficiency, promote the use of cleaner alternatives, and improve thermal comfort in a financially feasible manner.

This study seeks to address these gaps by thoroughly examining the energy consumption behavior of households in Jagriti Nagar and Bansighat. It aims to identify key drivers of energy usage, assess the relationship between socio-economic variables and energy choices, and explore opportunities for introducing energy-efficient technologies and behavior change strategies. Additionally, the research will focus on proposing cost-effective and thermally efficient building materials suitable for future housing projects targeted at resettling squatter populations. The findings are expected to inform policy recommendations and guide stakeholders—including government agencies, NGOs, and urban planners—towards more sustainable, inclusive, and resilient urban development solutions.

1.4 Research Gap

Research on energy consumption behavior in informal settlements of Kathmandu Valley is crucial, particularly given the rapid urbanization and challenges in providing adequate energy access to these communities. These informal settlements, such as those in Sankhamul, Thapathali, and Manohara, face significant socio-environmental hurdles due to inadequate infrastructure, high poverty rates, and limited access to modern energy systems. Rumba (2014) highlighted the heavy dependence on traditional fuels in informal settlements like Sankhamul, where socio-economic conditions force households to rely on 4 inefficient and expensive energy sources. This foundational study reveals how the lack of affordable, modern energy systems impacts the overall energy consumption behavior of these communities. Building on this, Rajbhandari et al. (2019) found that many informal households in the Kathmandu Valley rely on firewood and biomass for cooking, exacerbating energy poverty and contributing to environmental degradation. Their research emphasizes that poor access to reliable energy infrastructure results in negative health and environmental outcomes, a pattern consistent with global findings in informal settlements. Shrestha et al. (2020) further explored these challenges, emphasizing that the socio economic constraints such as income levels and household size prevent the widespread adoption of energy efficient technologies in informal settlements. Their study indicates that, while informal households use electricity for lighting, many still rely on biomass fuels for cooking due to the high cost of modern energy services like LPG and solar power. Shrestha et al. (2021) expanded on these findings by identifying the unreliable electricity supply and socio-economic barriers that exacerbate the energy access gap in settlements such as Thapathali. This research shows that lower-income households in these areas tend to consume more energy for basic needs, similar to trends observed globally (Butera et al., 2018). Rumba (2014) highlighted the heavy dependence on traditional fuels in informal settlements like Sankhamul, where socio-economic conditions force households to rely on inefficient and expensive energy sources. This foundational study reveals how the lack of affordable, modern energy systems impacts the overall energy consumption behavior of these communities. Muzzini et al. (2013) addressed the broader socio-environmental challenges faced by informal settlers along the Bagmati riverbanks, including energy insecurity and health risks due to nonrenewable fuel reliance. Previous research in the field of energy-efficient housing has predominantly centered around the reconstruction and retrofitting of large residential buildings and apartment complexes. These studies have explored various active and passive energy efficiency measures—such as advanced insulation systems, high-performance glazing, solar energy integration, and smart home technologies—that are often applicable in planned urban developments or high-income residential areas. While these approaches offer valuable insights into sustainable architecture and energy management, they are often financially and technically unfeasible for implementation in informal settlements, where resources, expertise, and space are limited.

However, a significant gap remains in the existing body of literature when it comes to the application of energy efficiency principles within the context of low-income, informal, or squatter housing. Very few studies have examined the specific construction techniques, building materials, and design strategies that can be employed to create thermally comfortable and energy-efficient homes for people living in squatter settlements. This omission is particularly critical, as these communities often face harsh climatic conditions, inadequate infrastructure, and severe financial constraints that directly impact their energy usage and thermal comfort.

Affordable housing solutions in such settings require a fundamentally different approach—one that prioritizes low-cost, locally available, and environmentally sustainable materials, while also taking into account cultural preferences and space limitations. Without context-specific research, policy recommendations and technical solutions risk being inaccessible or ineffective for the populations most in need.

This study addresses this gap by focusing specifically on the energy and thermal performance of building materials and construction features suited for squatter settlements in Kathmandu Valley. It aims to identify low-cost, replicable strategies for constructing affordable homes that are not only structurally sound but also thermally efficient and adaptable to local climatic conditions. By doing so, the research contributes to a more inclusive understanding of sustainable housing and supports the development of realistic, community-oriented solutions that can enhance energy resilience and living standards in marginalized urban areas.

This study underscores the need for integrating climate adaptation strategies with energy access initiatives to enhance resilience and maximize the benefits of energy-efficient technologies through community driven interventions.

1.5 Rationale of the Study

Kathmandu's informal settlements, such as those in Jagriti Nagar, Balkhu and Bansighat of Thapathali, present a unique context for studying energy consumption behavior. The diverse demographic composition, varying climatic conditions, and economic challenges of these areas require targeted interventions to address energy-related issues effectively. This study aims to fill a research gap by providing a detailed analysis of energy use patterns, efficiency levels, and barriers to energy access in squatter communities. The findings can inform policy recommendations and practical solutions that improve energy access and efficiency in informal settlements.

Pradhan and Shrestha (2022) emphasized that socio cultural factors, such as household energy practices and community dynamics, play a pivotal role in determining energy consumption behaviors. Their research in the Sankhamul area noted that community-led interventions, such as cooperative energy projects, could significantly enhance energy efficiency if tailored to the unique socio 5 economic context of informal settlers. Enel Foundation (2021) emphasized that informal settlements globally suffer from an "energy poverty trap," where residents are unable to access modern energy due to high costs and infrastructural barriers. They recommend decentralized, community-driven renewable energy systems to bridge this gap, which could be adapted to the Kathmandu Valley context. Ranjitkar et al. (2021) explored the implications of thermal comfort in low-income housing, noting that informal structures lack proper insulation, leading to increased energy consumption for heating and cooling. Their findings suggest that passive design strategies and localized renewable solutions could mitigate energy poverty and improve living conditions, aligning with global sustainability goals.

A policy review by the Nepal Energy Commission (2021) revealed that while renewable energy installations, such as solar panels, are increasing, informal settlements are still excluded from these programs due to technical and financial barriers. The review stresses that energy policies in the Kathmandu Valley must be more inclusive, addressing the affordability and accessibility of modern energy services for low-income households. This research contributes to the existing body of knowledge by filling key gaps, particularly in understanding how socio-cultural and economic factors influence energy consumption patterns in Kathmandu's squatter settlements. The findings will provide essential data for policymakers to design targeted interventions, contributing to Sustainable Development Goals 7 (Affordable and Clean Energy) and 11 (Sustainable Cities and Communities). The insights gained will inform sustainable energy policies, not only for Kathmandu Valley but also for other rapidly urbanizing regions facing similar challenges (Rajbhandari et al., 2019; Shrestha et al., 2020).

1.6 Research Objective

The objectives of the study are:

• To analyze the energy consumption patterns and socio-economic factors influencing energy consumption behavior in households within informal settlements.

- To evaluate different building materials for building thermally efficient and financially viable housing solutions for relocation of people in such Informal Settlements.

1.7 Theoretical Framework

This research is grounded in theories related to energy poverty, fuel choice behavior, socio-economic constraints, informal urbanism, and energy justice, which collectively guide the study of energy consumption behavior in informal settlements of Kathmandu Valley.

The Energy Poverty Theory provides a foundation for understanding the multidimensional deprivation in energy access faced by informal settlers. According to Bouzarovski and Petrova (2015), energy poverty is not just a lack of access to electricity or clean cooking fuels but also includes affordability constraints, unreliable supply, and social inequalities. These factors shape the adaptive strategies of squatter households, forcing them to rely on multiple energy sources in a fragmented and often inefficient manner.

The Theory of Planned Behavior (Ajzen, 1991) frames the decision-making processes behind energy consumption in informal settlements. It suggests that attitudes, social norms, and perceived behavioral control influence household choices regarding energy sources and efficiency measures. This framework helps analyze how informal governance, community-level energy sharing, and policy barriers shape energy behavior.

Furthermore, the Energy Justice Framework (Sovacool & Dworkin, 2015) is central to this study, addressing the ethical and equity-related dimensions of energy access. It highlights how marginalized communities often face discriminatory energy policies, higher costs, and exclusion from formal energy infrastructure. The study integrates this perspective to evaluate whether existing policies and interventions support or hinder equitable energy access in squatter settlements.

Building on the work of Gurung et al. (2021) and Bhattarai et al. (2020), this framework also explores the intersection of urban informality and energy vulnerability. It considers how land tenure insecurity, infrastructure deficits, and governance challenges shape energy consumption patterns in squatter settlements. The study emphasizes the need for inclusive, context-specific energy policies that recognize the realities of informal urbanism in Nepal

1.8 Conceptual Framework

The independent variables include socioeconomic factors, energy sources, and infrastructure availability. Socioeconomic factors such as income levels, household size, education, and occupation determine energy affordability and consumption patterns. Energy sources, including grid electricity, LPG, biomass, and alternative energy options, shape household energy choices based on availability, cost, and reliability. Infrastructure availability, such as access to formal energy grids, cooking technologies, and distribution networks, directly influences the ease and efficiency of energy use in informal settlements.

The intervening variables mediate the relationship between independent and dependent variables and include policy frameworks, informal governance, and cultural practices. Policy frameworks, including government regulations, subsidies, and electrification programs, determine the extent of formal energy access and affordability. Informal governance structures, such as community-led energy sharing and unauthorized connections, play a significant role in shaping access to electricity and fuel. Cultural practices, including traditional cooking methods, fuel preferences, and social norms, further influence household energy choices and adaptation strategies.

The processes that connect these variables include energy access mechanisms, decision-making patterns, and adaptation strategies. Energy access mechanisms involve both formal and informal supply chains, where households may rely on a combination of legally connected power grids and unauthorized energy sources. Decision-making patterns refer to how households prioritize energy use based on economic constraints, availability, and cultural preferences. Adaptation strategies include fuel stacking, energy rationing, and reliance on community-based solutions to cope with supply shortages or affordability issues.

The dependent variables represent the outcomes of the framework, including energy consumption behavior, affordability, and sustainability. Energy consumption behavior is assessed through fuel choices, daily energy use patterns, and reliance on multiple energy sources. Affordability is measured by the proportion of household income spent on energy and the ability to transition to cleaner energy sources. Sustainability considers environmental impacts, efficiency improvements, and long-term viability of energy solutions in informal settlements.

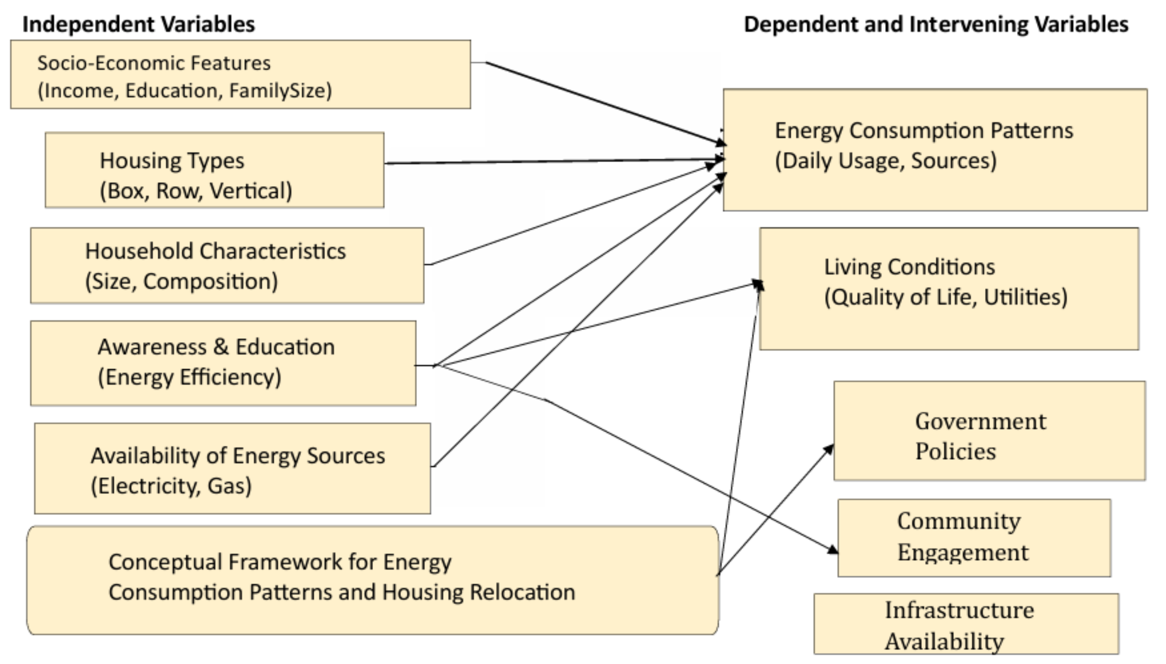


Figure 2 Conceptual Framework

1.9 Limitations of the study

This study was conducted with the following limitations:

i. The research was completed within a limited timeframe, thereby constraining the duration available for data collection and analysis.

ii. The sample size was relatively small, which may limit the generalizability of the findings to a larger population.

iii. The study was geographically restricted to two specific Informal settlement area, which may not fully represent the energy consumption behavior in other regions or settings.

iv. Data collection relied on self-reported information from participants, which may introduce biases or inaccuracies in the data due to the subjective nature of the responses.

CHAPTER 2: LITERATURE REVIEW

2.1 Informal Settlements

Informal settlements, also known as slums, squatter settlements, or shanty towns, are characterized by unauthorized land occupation and the absence of formal planning and services. These settlements emerge due to rapid urbanization, poverty, and inadequate housing policies (Moreno et al., 2020). They are often located on marginal lands with limited access to essential services such as clean water, sanitation, and electricity. Globally, an estimated 1 billion people live in informal settlements, with numbers expected to rise as urban populations grow (Davis, 2006). India and Bangladesh have the highest urban population among Asian countries living in slum area (UN-Habitat, 2018).

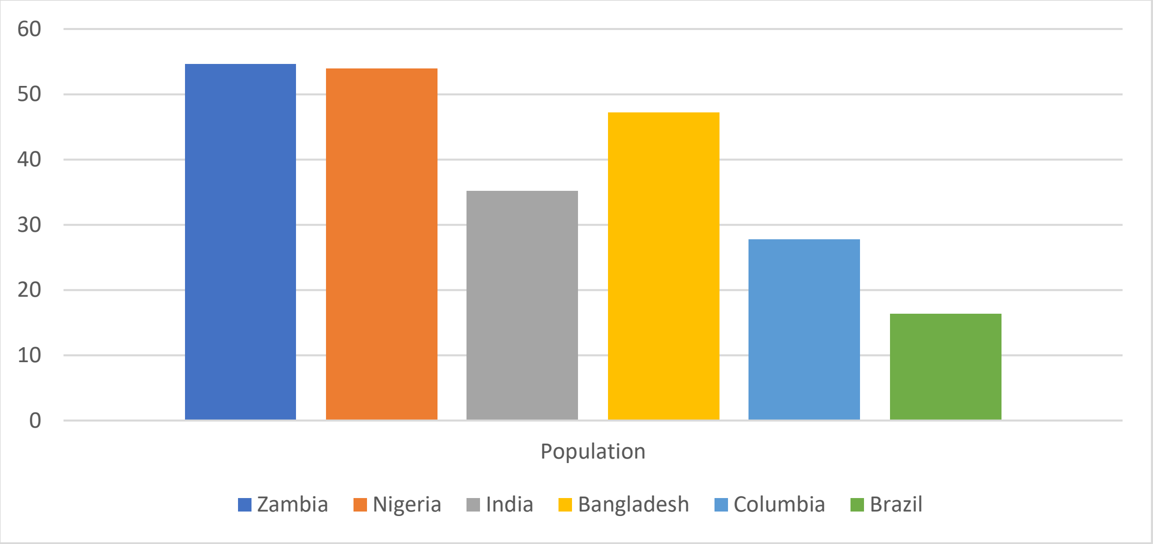


Figure 3 Urban Population Living in Slum

Welisiejko and Cáceres (2022) adopted from UN Human Settlements Programme (2018)

Urban population has been rapidly increasing all over the world. 7 out of 10 people are expected to live in cities by 2050s. This is increasing issues of availability and affordability of urban land, resulting in increase of informal settlements (UN-Habitat, 2014). Historically, informal settlements began to proliferate during the industrial revolution in the 19th century when cities experienced massive population inflows that outpaced the development of formal housing and infrastructure (Davis, 2006).

In Latin America, for example, the rapid urbanization post-World War II led to the widespread development of informal settlements or "favelas", particularly in countries like Brazil. Similarly, in sub-Saharan Africa, informal settlements grew exponentially as people migrated to cities seeking better economic opportunities amidst limited formal housing options (UN-Habitat, 2003).

South Asia has seen a significant rise in informal settlements due to factors such as population growth, economic disparities, and natural disasters. Cities like Mumbai, Karachi, and Dhaka have large informal settlements that house millions of people. In India, informal settlements, or "slums," have been documented since the British colonial period when urban areas expanded rapidly without corresponding infrastructure development(Bhan, 2009).

The political and economic turmoil in Pakistan and Bangladesh has also contributed to the growth of informal settlements, with rural migrants flocking to urban centers in search of better livelihoods. The lack of affordable housing and weak urban planning policies have further exacerbated this issue (Hasan, 2006).

Kathmandu, the capital of Nepal, has witnessed the development of informal settlements due to a combination of socio-economic and environmental factors. Kathmandu's urbanization has been driven by rural-urban migration, political instability, and economic opportunities in the city. Informal settlements in Kathmandu, locally known as "squatter settlements" or "*sukumbasi basti*", have grown particularly along the riverbanks and peri-urban areas(Khanal and Khanal, 2022).

In Kathmandu, almost 1% of the total population is residing as *Sukumbasi*. *Sukumbasi* in legal term is referred to those who can prove that in the last three generations, nobody in his/her family held and land ownership. However, Kathmandu has a proportion of *Hukumbasi* – one pretending to be *Sukumbasi* to obtain land title; and *Swabasi* – poor people, mainly belonging to *Dalit*, who lived in Kathmandu for long time (Khanal and Khanal, 2022). This also seems to fit with many recent news and studies were many of the inhabitants are actually enforcing government to hand over them land even though they hold land in their respective villages.

Table 1 Population and households of informal settlers in Kathmandu

S.N.	Region	Number of informal settlements	Total male population	Total female population	Total population	No. of households
1	Kathmandu Valley	65	14829	13583	28412	4696
2	Kathmandu	48	9377	8825	18202	3177
3	Jagriti Nagar		928	872	1800	361

Source: Khanal and Khanal (2022)

The fear of eviction, health risks and disaster risks in riverside settlements has not stopped the expansion of informal settlements. The squatter settlements in Kathmandu started in the early 1950s when rural migrants moved into cities looking for employment (Toffin, 2010). The first informal settlements in Kathmandu valley reports back to 1969 in Kimal Phant, ward number 3 of Kathmandu metropolitan city. There were only 17 squatter settlements in the valley in 1985. By 2000, there were 61 squatter settlements with 2,031 households and 11,851 people which increased to 64 by 2003, increasing the squatter households to 2,134 and population to 14,500 (Lumanti, 2013).

Table 2 Informal settlements in Kathmandu Valley

S.N.	Nearby river	Informal Settlement
1.	Bagmati river	Shanti Nagar, Bijaya Nagar, **Jagriti Nagar**, Gairigaun Tole, Chadani Tole,Pragati Tole, Kalimati Dole, **Bansighat**, Kuriyagaun, Shankhamul, PaurakhiBasti

2.	Bishnumati river	Dhikure Chouki, Kumaristhan Buddhajyoti Marg, Balaju Jagriti Tole, Sangam Tole, Ranibari, Inyatole, Ramghat, Hyumat, Dhaukhel and Bhimmukteshwor
3.	Hanumante river	Manohara Bhaktapur, Manohara Bhaktapur-2, Manohara-Bhaktapur-3 (Lokanthali
4.	Dhobikhola	Shanti Binayak, Devi Nagar, Bishal Nagar, Kalopul and Pathivara
5.	Tukucha	Narayantole Maharajgung and Khadipakha Maharajgunj
6.	Other location	Palpakot, Anam Nagar, Maijubahal, Kumarigal, Radhakrishna Chowk, Mulpani, Kapan Dhungen, Subigaun, Ramhiti, Mahankal, Sukedhara and Mandikatar

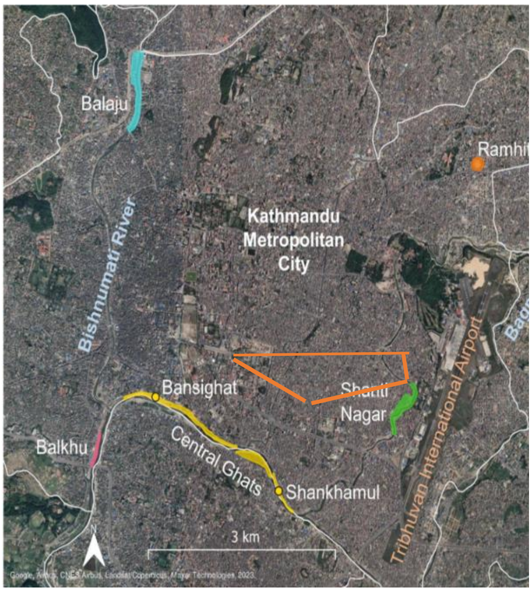
Adopted from Phuyal et al. (2019)

The vacant public land in Kathmandu valley alongside river banks gave shelter to domestic migrants lacking affordability to available rental housing. Reports has documented origin of Balkhu settlement as 2008. Similarly, satellite imagery shows Balkhu informal settlement area vacant till 2007. Balkhu informal settlement can be considered one of the newest additions of informal settlement for Kathmandu.

Moving forward to 2009 AD, the google satellite imagery reveals the area densely occupied. Nepal Basobas Basti Samrakhshan Samaj, an organization of informal settlers in Nepal, claims some of the older informal settlements in Kathmandu valley being socially and developmentally integrated into the city. The electricity connection in Balkhu settlement is a sign of developmental integration; however, the road condition and the persistent flood risk of the Bagmati River have not been adequately addressed. Additionally, with no water supply from Kathmandu Upatyaka Khanepani Limited (KUKL), residents are forced to choose expensive options, adding to their financial burden.

Jagriti Nagar Case study area in 2007 AD

Case study area in 2009 AD (Source :Google Earth)



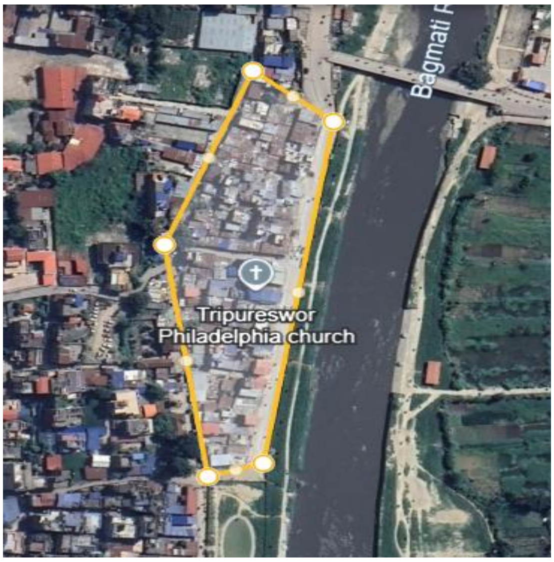


Figure 4 Google Earth Map of Study Site   Source: Study Team

2.2 Energy Consumption Patterns

Energy consumption patterns in informal settlements are influenced by various factors, including income levels, household size, and cultural practices. Studies have shown that low-income households in urban slums typically spend a higher proportion of their income on energy compared to wealthier households, despite using less energy overall (Sovacool, 2012). This paradox highlights the inefficiencies and high costs associated with the energy sources available to these communities.

In Kathmandu, like many other developing cities, informal settlements such as Jagriti Nagar exhibit unique energy consumption behaviors due to the socio-economic and environmental context. Residents often adopt a mix of energy sources, including firewood, charcoal, kerosene, and, where available, electricity. These practices are shaped by factors such as availability, cost, and cultural preferences (Shrestha, 2019).

2.3 Energy Efficiency and Access

Improving energy efficiency and access in informal settlements is crucial for enhancing living conditions as well as achieving SDGs. 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.

Several interventions have been proposed to address energy challenges in informal settlements. These include the distribution of energy-efficient cookstoves, the installation of solar home systems, and the regularization of informal electricity connections. Such initiatives aim to reduce the health risks associated with traditional energy sources, lower energy costs, and promote environmental sustainability.

2.4 Energy poverty

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, Mishra and Maruta, 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).

The challenge of energy poverty is particularly acute in informal settlements, where the lack of access to modern energy services exacerbates existing vulnerabilities. The concept can be measured using various indicators, including the percentage of household income spent on energy, the accessibility and reliability of energy services, and the quality of energy supply. For instance, a household is typically considered energy poor if it spends more than 10% of its income on energy needs (Boardman, 1991).

Several factors contribute to energy poverty in informal settlements. Socio-economic factors such as low income, unemployment, and lack of education significantly hinder access to affordable and reliable energy. The absence of formal planning and legal recognition restricts residents' access to government energy schemes and subsidies. Additionally, the high cost of energy services and inefficient energy usage due to outdated appliances and lack of awareness contribute to the persistence of energy poverty in these communities (Bhattacharyya, 2012).

2.5 Global and Regional Contexts

Case studies from various parts of the world including Nepal provide valuable insights into the effectiveness of different approaches to improving energy access and efficiency in informal settlements. In Kenya, the adoption of solar home systems has significantly improved energy access in off-grid communities, reducing reliance on kerosene and other polluting fuels (Ondraczek, 2013). Similarly, in India, the introduction of energy-efficient cookstoves has led to substantial reductions in indoor air pollution and fuel consumption (Sagar *et al.*, 2016).

Lloyd (2020) examined the energy profile of a low-income urban community, highlighting that kerosene was the primary source of energy for cooking and space heating. Firewood also played a significant role, particularly in water heating and lighting. The study noted health issues associated with the use of firewood for space heating in certain informal settlements.

(Niyongabo and Makonese, 2016) found that firewood was the primary energy source for low-income households in the Mubuga informal settlement. They observed that longer firewood collection times often hindered women and children from engaging in other empowerment activities, such as education and running informal businesses.

Makonese, Ifegbesan and Rampedi (2018) identified several factors influencing energy consumption in Johannesburg's informal dwellings, including seasonality, fuel availability and price, and socio-cultural aspects. Their study revealed that coal and wood were commonly used for space heating and cooking in winter, whereas kerosene dominated in summer for cooking and lighting.

(Gyawali *et al.*, 2020) examined household energy consumption in Kathmandu and identified several factors affecting energy consumption behaviors. These factors included physical and structural, social and cultural, economic, communication and information, and psychological aspects. The study found that households with less than 1000 sq. ft. spent approximately Rs 2437 monthly on energy. Additionally, households with a monthly income of less than Rs 50,000 spent about 5% of their income on energy. However, the study did not specify whether informal settlements were studied, indicating a gap in the research.

Desta (2022) studied households in Addis Ababa's informal settlements and found that only 51% had legal access to electricity. The remaining 49% primarily used electricity for illumination and charging mobile phones. The high connection fees and unreliable power supply posed significant challenges. Moreover, 61% of residents were reluctant to adopt new energy sources or energy-efficient technologies.

Bhattacharjee and Reichard (2011) systematically reviewed over 200 research papers and identified several socio-economic factors influencing energy consumption behaviors. These factors included household size, age structure, economic condition, education, and knowledge.

Maniragaba, Manirafasha and Karemera (2020) focused on socioeconomic factors and cooking energy in Kigali's informal settlements and found that family size and monthly income significantly influenced energy choices. Higher-income families were more likely to use clean energy sources like LP gas.

Several research has derived the relationship between the level of income and the type of energy sources used by households, categorized by their cleanliness and efficiency. At the low-income end, households predominantly use traditional solid fuels such as cow dung and crop residues, followed by fuelwood. As income levels increase, there is a shift to intermediate sources like charcoal and kerosene, which are still less clean and efficient compared to modern energy sources. In the high-income bracket, households tend to use non-solid fuels such as ethanol and biogas, ultimately progressing to modern sources like electricity and natural gas (LPG), which are the cleanest and most efficient. This progression highlights the impact of economic status on energy choices, with wealthier households having better access to cleaner and more efficient energy options. This framework helps in understanding the energy consumption patterns in informal settlements, where economic constraints often limit access to modern energy sources, forcing residents to rely on less efficient and more polluting fuels.

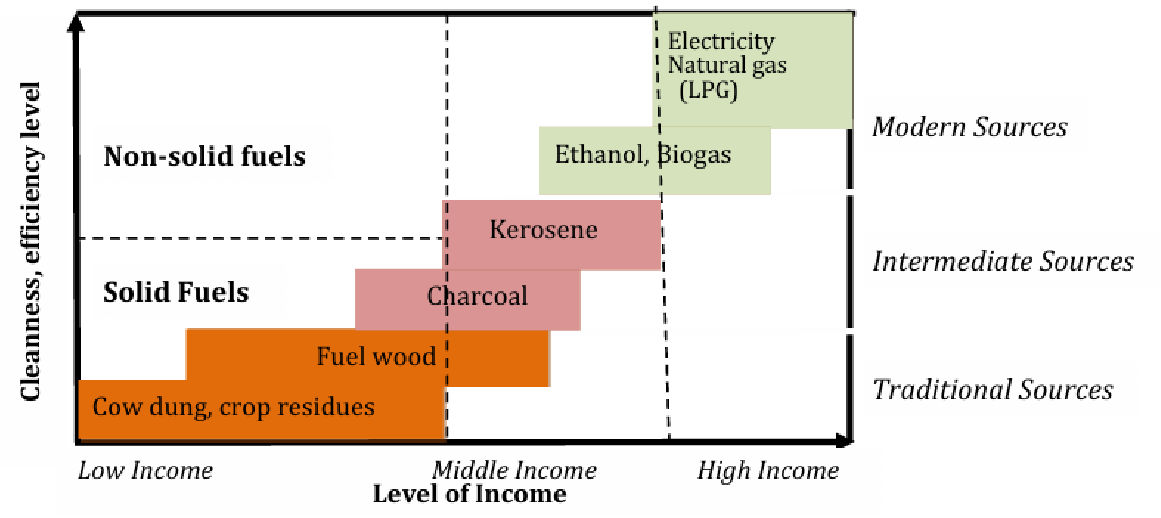


Figure 5 Household's income level and energy ladders

Adopted from (Butera *et al.*, 2016; Dongzagla and Adams, 2022)

The government and non-governmental organizations have implemented various programs to enhance energy access in informal settlements in Nepal. Governmental bodies and policies in the recent years have tried to address the issues of informal settlers. Service provides like KUKL and NEA are providing their services to informal settlements in Kathmandu. (Karki and Singh, 2022). The coverage map of multiple internet service providers includes these areas.

The study on energy consumption behavior in informal settlement at Jagriti Nagar, Balkhu will fill the research gap prevailing in the topic as well as provide a benchmark for future studies on energy behavior and informal settlements in Nepal.

2.6 Passive Design Strategies:

The key passive design strategies for improving energy efficiency and thermal comfort in buildings has been summarized in Table 1.

Table 3 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 & 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 & 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 & 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. (Bureau of Energy Efficiency, 2021; Stauffer & Hooper, 2000)
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 & 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. (Bureau of Energy Efficiency, 2021; Stauffer & Hooper, 2000)
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 $m^3/hr/m^2$. (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. (Chaulagain et al., 2019; Gut & Fislisbach, 1993)
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 & 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)

2.6 Design Builder and EnergyPlus :

DesignBuilder is a widely used building performance simulation software that enables architects, engineers, and researchers to analyze energy efficiency, thermal comfort, and indoor environmental quality in buildings. It provides an intuitive graphical interface for modeling building geometry, materials, and HVAC systems, facilitating rapid performance assessments. DesignBuilder utilizes the EnergyPlus simulation engine, which is a robust, physics-based tool developed by the U.S. Department of Energy (DOE) for dynamic energy modeling (Crawley et al., 2001). This integration allows users to evaluate multiple design alternatives by simulating factors such as heating and cooling loads, daylighting performance, and ventilation strategies, making it particularly useful in assessing low-cost, energy-efficient housing solutions for informal settlements.

At the core of DesignBuilder's capabilities is EnergyPlus, which employs a heat balance approach to simulate transient thermal performance and energy consumption in buildings. EnergyPlus models energy flows by accounting for external climate conditions, material properties, and occupant behavior, providing detailed insights into thermal dynamics and energy use (DOE, 2022). Its extensive material database and customizable input options allow for the evaluation of various construction materials and insulation techniques, making it an ideal tool for assessing cost-effective housing designs in resource-constrained environments (Attia, 2012). For informal settlements, where thermal comfort is often compromised due to poor-quality materials and inadequate passive design strategies, EnergyPlus-based simulations in DesignBuilder help identify optimal building envelopes that balance affordability with performance.

DesignBuilder’s application extends beyond thermal comfort analysis, encompassing life-cycle energy assessments, carbon footprint evaluations, and renewable energy integration. The software supports parametric studies, enabling researchers to compare different materials, window-to-wall ratios, and ventilation strategies to determine the most efficient configurations (Hensen & Lamberts, 2011). By simulating real-world conditions specific to Kathmandu Valley, this study leverages DesignBuilder to assess the thermal and energy performance of alternative building materials, ultimately guiding sustainable and contextually appropriate housing solutions for informal settlers. The ability to integrate empirical climate data and run optimization algorithms enhances the reliability of simulation results, ensuring that proposed interventions are both environmentally and socially viable.

2.7 Policy Frameworks and Institutional Challenges

Policy frameworks governing informal settlements in Kathmandu Valley often lack provisions for sustainable energy solutions, focusing primarily on short-term housing provisions rather than long-term energy efficiency and thermal comfort (Shrestha et al., 2023). Government-led initiatives, influenced by political and economic constraints, often fail to incorporate passive design principles and local community needs in housing projects. Standardized housing solutions, which emphasize cost-efficiency over climatic responsiveness, result in dwellings that perform poorly in terms of energy efficiency, increasing dependence on artificial heating and cooling (Bhattarai & Conway, 2020). Furthermore, the limited integration of energy-efficient technologies in informal housing policies exacerbates energy poverty, restricting access to reliable and affordable energy for marginalized communities (Certomà et al., 2023).

Institutional challenges further hinder the implementation of sustainable housing solutions. Inconsistencies in regulatory frameworks, lack of inter-agency coordination, and weak enforcement mechanisms create significant barriers to energy-efficient housing development (Dev & Das, 2020). The absence of a cohesive policy linking urban planning, energy efficiency, and informal housing regulations results in fragmented interventions that fail to address the root causes of inefficient energy use. Studies have shown that international humanitarian frameworks, such as the Sphere Handbook, advocate for minimum energy efficiency and thermal comfort standards in post-disaster and informal housing scenarios, yet these guidelines are rarely translated into enforceable local policies (Sphere Project, 2011). Additionally, donor-driven housing reconstruction projects often prioritize rapid implementation over long-term sustainability, overlooking key aspects such as material selection, solar orientation, and ventilation strategies that could significantly improve energy performance (Montalbano & Santi, 2023).

A major challenge in improving energy efficiency in informal settlements is the lack of community participation in policy-making and housing design processes. Top-down approaches to housing development have historically ignored local knowledge and social dynamics, leading to housing solutions that are incompatible with residents' lifestyles (Alshawawreh et al., 2020). Conversely, bottom-up strategies that emphasize participatory design, where residents contribute to decisions regarding material selection and passive design interventions, have shown greater success in improving energy efficiency and residential satisfaction (Jabeen, Johnson, & Allen, 2010). Addressing these institutional gaps requires a shift towards integrative policy-making, where energy efficiency standards are embedded within informal housing policies, and local communities are actively engaged in designing and implementing sustainable housing solutions.

2.8 Resident Satisfaction in Relocation Settlements

Residential satisfaction in informal settlements is a key measure of housing adequacy, reflecting how well a dwelling meets the functional, psychological, and socio-cultural needs of its residents. It is influenced by factors such as housing design, construction quality, thermal comfort, and opportunities for livelihood integration (Danquah et al., 2014). Informal settlements, particularly in rapidly urbanizing regions like Kathmandu Valley, face unique challenges, including inadequate infrastructure, overcrowding, and vulnerability to environmental hazards. Studies indicate that standardized housing solutions often fail to align with residents' cultural and social preferences, leading to dissatisfaction and frequent modifications to dwelling structures (Shrestha, Uprety, & Pokharel, 2023).

Housing materials and thermal performance significantly impact residential satisfaction in informal settlements. In many cases, low-cost construction materials such as CGI roofing and uninsulated walls contribute to poor thermal comfort, exacerbating seasonal discomfort (Shrestha et al., 2022). DesignBuilder simulations provide a valuable tool for assessing the thermal efficiency of various materials, enabling the identification of cost-effective, energy-efficient housing solutions. By optimizing material selection and passive design strategies, it is possible to enhance comfort levels while maintaining affordability—key concerns in informal housing development.

Community engagement and adaptability are crucial in achieving higher residential satisfaction in informal settlements. Research highlights the importance of participatory planning approaches that incorporate local knowledge and preferences into housing design (Shrestha, Uprety, & Pokharel, 2023). Providing flexibility for household modifications and ensuring adequate space for social and economic activities, such as home-based businesses and communal interactions, can further enhance satisfaction. Ultimately, integrating climate-responsive designs, culturally sensitive layouts, and energy-efficient materials is essential to creating sustainable and resilient housing solutions for informal settlers.

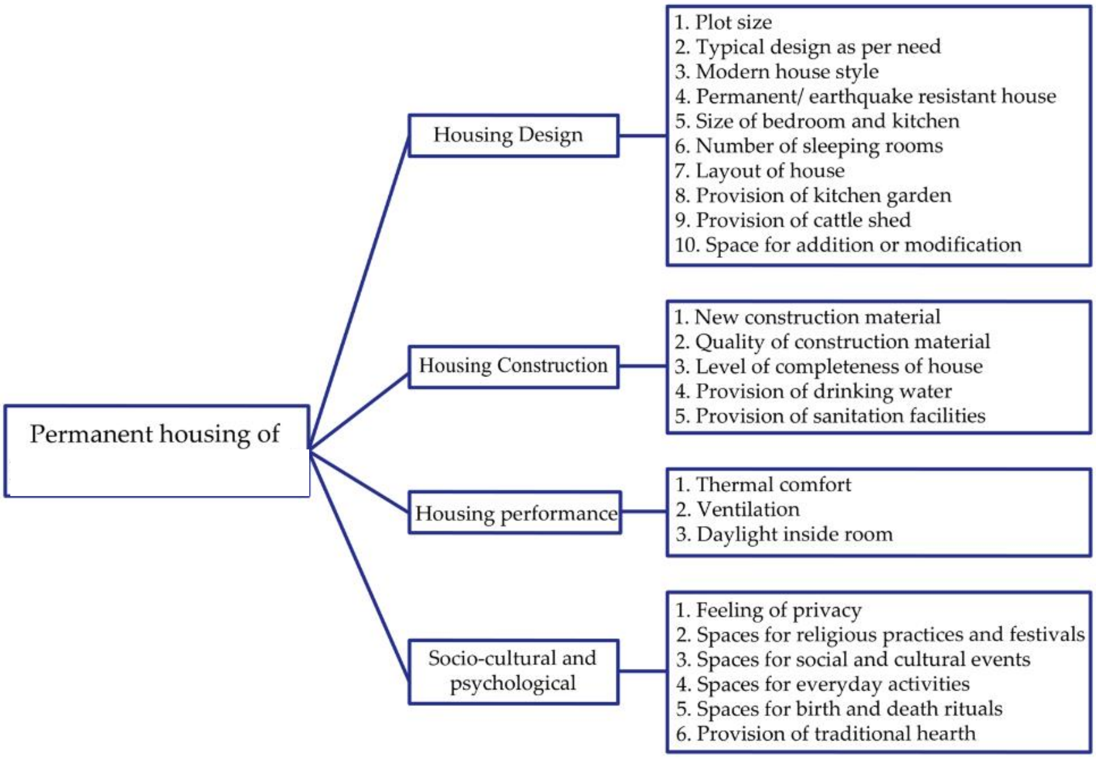


Figure 6 Factors influencing Resident Satisfaction Source: (Shrestha, Uprety, Pokharel, 2024

The figure above presents a comprehensive framework for understanding the essential aspects of housing for resettlement or rebuilding of houses of squatter settlers**.** It identifies four major categories that contribute to successful resettlement: Housing Design, Housing Construction, Housing Performance, and Socio-cultural and Psychological considerations.

The housing design aspect emphasizes the importance of creating homes that are not only functional but also adaptable to the specific needs of resettled families. Key considerations include adequate plot size, room dimensions, and the number of sleeping rooms to accommodate family members. Design should follow modern yet practical styles while ensuring earthquake resistance, especially in disaster-prone regions like Nepal. The layout must support efficient living and allow for additions or modifications as families grow. Additionally, provisions such as kitchen gardens and cattle sheds are important for livelihoods and self-sufficiency.

Housing construction focuses on the materials and infrastructure that form the foundation of safe and durable housing. This includes the use of new and high-quality construction materials, the structural completeness of houses, and access to basic services such as drinking water and sanitation. These elements are crucial to ensure the physical safety and health of the residents.

The housing performance dimension highlights the need for houses to provide a comfortable and livable environment. It includes ensuring thermal comfort to adapt to seasonal temperature variations, proper ventilation for air quality, and adequate daylighting to reduce energy needs and improve mental well-being. Homes should offer privacy and spaces for religious practices, festivals, and everyday cultural rituals. The inclusion of areas for birth and death ceremonies and the preservation of traditional elements like the hearth are vital for maintaining a sense of identity, continuity, and community cohesion.

Together, these four dimensions ensure that permanent housing for post-disaster resettlement is holistic, sustainable, and culturally sensitive, ultimately contributing to the resilience and dignity of displaced communities.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research Design

A methodology refers to the philosophy and overarching framework that guides the entire research process. According to Mackenzie and Knipe (2006), the method encompasses the systematic techniques, tools, and processes employed for data collection and analysis. In contrast, methodology refers to the broader approach and theoretical framework applied to the research. It links the proposed research to a specific scientific paradigm, which provides the foundational beliefs, conventions, and guidelines that dictate how the research should be conducted and interpreted (Mackenzie, 2006). A scientific paradigm is essentially the lens through which research is approached, encompassing established norms and practices within a given field. The importance of aligning research with an appropriate methodology is supported by Creswell (2014), who emphasizes that methodological consistency ensures that the findings are credible and relevant within the context of the chosen research paradigm.

This study adopts a mixed-methods approach, integrating both quantitative and qualitative research techniques to offer a comprehensive and nuanced understanding of energy consumption behavior in the informal settlements of Jagriti Nagar and Bansighat. By combining numerical data with personal insights, the mixed-methods approach allows for a more holistic examination of the factors influencing energy use in these communities. This dual approach ensures that the study captures both the measurable aspects of energy consumption and the underlying social and behavioral dynamics. Tashakkori and Teddlie (2010) argue that the mixed-methods approach is particularly valuable when addressing complex social issues, as it enables the triangulation of data and improves the depth and reliability of the research outcomes.

The quantitative component of this research focuses on analyzing energy consumption patterns, assessing the socio-economic factors influencing energy behavior, and evaluating the awareness and adoption of energy-efficient practices and technologies among residents of Jagriti Nagar. Data collection through structured questionnaire surveys, interviews, and case studies within the case area will provide valuable insights into these aspects. Statistical analysis of the data will be conducted to identify patterns and correlations, contributing to a clearer understanding of energy consumption behaviors. According to Liddell et al. (2012), quantitative surveys are effective in capturing the breadth of energy consumption behaviors across large populations, offering insights into the factors that influence energy choices and access.

On the other hand, the qualitative method draws upon the interpretation of a wide range of literature, including articles, reports, and documents relevant to energy consumption behavior, socio-economic influences on energy use, and informal settlements. In addition to the literature review, the study incorporates field observations of the case area and focus group discussions (FGD) with local residents. These qualitative techniques provide deeper insights into the motivations, perceptions, and social contexts influencing energy consumption decisions. The qualitative analysis serves to complement the quantitative data by capturing subjective experiences, social norms, and community dynamics that cannot be fully quantified. As noted by Braun and Clarke (2006), qualitative research techniques such as FGDs are valuable for exploring participants' perspectives and understanding the contextual factors that shape behaviors and decisions. Together, both methods will enhance the overall research process and contribute to a more robust understanding of the energy consumption behaviors in these informal settlements.

3.1.2 Research Paradigm

This research adopts a pragmatic paradigm, integrating both qualitative and quantitative approaches to analyze energy consumption patterns in informal settlements of Kathmandu Valley. The study initially employs positivist principles, focusing on objective data collection through surveys, energy audits, and observational studies (Ryan, 2006). However, given the socio-economic complexities of informal settlements, the paradigm shifts towards pragmatism, incorporating qualitative methods such as semi-structured interviews and participatory observations.

Interpretation of findings may vary among stakeholders, but this research prioritizes the researcher's perspective while also considering insights from local residents and key informants. The primary objective is to examine the socio-economic influences on energy consumption and access in informal settlements and to propose strategic interventions for improving energy efficiency and accessibility. Knowledge is derived from both empirical data and the lived experiences of residents in study areas such as Jagriti Nagar, Balkhu, and the Thapathali squatter settlement.

Ontologically, this research recognizes that informal settlements exhibit a dynamic mix of traditional and modern energy usage patterns. The gradual shift from traditional biomass-based energy sources to more modern alternatives—often driven by affordability, access, and government policies—significantly influences energy consumption behaviors. However, challenges such as inconsistent grid access, reliance on inefficient appliances, and socio-economic constraints contribute to energy inefficiencies and disparities. Addressing these issues requires a holistic research approach that captures both quantitative energy usage metrics and qualitative socio-economic insights.

The study methodology aligns with its research objectives, epistemological concerns, and best practices in energy research. Previous studies on energy consumption in urban informal settlements, as documented in articles, journals, and policy reports (Buchanan & Bryman, 2007), serve as a foundation for validating the study's claims. By bridging the research gap on energy consumption behaviors and access in informal settlements, this study aims to inform sustainable energy interventions that enhance efficiency and equity in these communities.

3.1.3 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.

Ontology

The research assumes that poverty, lack of education and lacking governmental policies lead to formation of informal settlements. 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.

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.

Axiology

This research adopts a value-driven approach, recognizing the importance of inclusivity, human interaction. It seeks to ensure that the proposed solutions not only enhance thermal comfort and energy efficiency but also be financially viable for both parties.

3.2 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.

3.2.1 Qualitative Method

The qualitative method focuses on understanding the social, cultural, and behavioral aspects of post-disaster housing reconstruction and the lived experiences of those directly involved. This approach seeks to go beyond the physical and technical dimensions of reconstruction to uncover the deeper, often overlooked, social dynamics, which are crucial to the success of recovery efforts. According to Jones et al. (2015), qualitative methods, such as interviews and focus groups, provide a rich, contextualized understanding of people's experiences, attitudes, and perceptions, especially in disaster-affected communities, where emotional and psychological factors significantly influence rebuilding efforts.

Literature Review:

A detailed and comprehensive review of existing literature, reports, and documents was conducted, focusing on the causes of informal settlements, energy access, energy poverty, and the materials used for housing construction. This review also included an analysis of studies on passive design strategies, sustainable building practices, and the socio-cultural factors that influence the decisions made during reconstruction efforts. Previous research by Gough et al. (2016) highlighted how housing materials and design choices can either facilitate or hinder energy efficiency and sustainable living in post-disaster housing. The review also covered the intersection of social, economic, and cultural factors that influence housing reconstruction, emphasizing the role of community participation in ensuring that reconstruction efforts meet the real needs of residents.

Semi-Structured Interviews:

Semi-structured interviews were conducted with a diverse group of participants, including residents, stakeholders, technicians, and elected representatives directly involved in reconstruction activities. These interviews were designed to capture both objective data and subjective experiences, allowing for the exploration of a range of perspectives. The interviews aimed at obtaining:

i. **Resident Experiences of Thermal Comfort and Energy Usage:** Understanding how residents perceive the thermal comfort of their homes, how they use energy, and their challenges related to energy access and efficiency. This aligns with findings from several studies (e.g., Allen et al., 2015) that highlight the importance of thermal comfort in post-disaster housing as a critical factor affecting residents' health and well-being.

ii. ii. **Perceptions of Housing Needs and Preferences:** Gaining insights into the specific needs, preferences, and priorities of residents in terms of house design, location, and functionality. This addresses the gap identified by Dovey (2012), who suggested that housing reconstruction efforts often overlook the preferences of local communities, leading to a mismatch between the built environment and residents' expectations.

iii. **Stakeholder Insights on Design Priorities, Material Choices, and Reconstruction Challenges:** Exploring the viewpoints of stakeholders involved in the reconstruction process, such as architects, engineers, and policymakers, to understand their design priorities, challenges in material selection, and the overall difficulties faced during the reconstruction process. This aligns with the research of Talen and Whelan (2017), who argued that stakeholder involvement is essential to ensure that designs are both feasible and culturally appropriate.

Community-Driven Design:

In a participatory effort, key informants and a select group of respondents were invited to draw or describe their ideal house designs, providing valuable insights into preferred floor plans, sizes, orientation, and material choices. This approach not only empowered the community but also allowed for a deeper understanding of the cultural and social values that influence housing decisions. The results from this participatory design process were critical in deducing a widely accepted building design that aligns with both community needs and cultural practices, contributing to the literature on community-driven design in disaster reconstruction (e.g., Parnell et al., 2018). By incorporating local knowledge and preferences, the study promotes the idea that housing reconstruction must be culturally sensitive and adaptable to local contexts.

This qualitative approach aims to provide a nuanced understanding of the social and cultural challenges faced in post-disaster reconstruction. As emphasized by Satterthwaite (2013), the success of housing reconstruction is not solely dependent on technical and economic considerations but must also integrate local social dynamics, cultural values, and community participation to achieve long-term sustainability and resilience.

3.3.2 Quantitative Method

The quantitative method focuses on the measurable aspects of thermal performance, energy consumption, and resident satisfaction, providing objective data to complement the qualitative insights and enhance the robustness of the study. This approach is essential for understanding how the physical aspects of housing, such as thermal comfort and energy efficiency, align with the needs and preferences of the residents.

Thermal Satisfaction Assessment:

A structured questionnaire survey, adapted from the work of B. Shrestha, Uprety, Pokharel (2023), was conducted with residents of the case study area. The survey gathered comprehensive data on occupant perceptions of thermal comfort, their satisfaction levels, and adaptive behaviors during the winter months. This survey aimed to assess how effectively the housing responds to seasonal temperature fluctuations and whether residents' expectations of thermal comfort are met. According to Mahdavi et al. (2015), understanding thermal satisfaction is critical in post-disaster housing, as it directly impacts the health and well-being of residents and can inform the design of more responsive and comfortable homes.

Energy Consumption Analysis:

An energy consumption survey was conducted to analyze the energy usage patterns within the case study area. Data on the power ratings of electrical equipment, as well as monthly consumption of other energy sources used for cooking, heating, lighting, and other household activities, were gathered. This survey helped identify the energy consumption profile of the region and provided insight into the dependency on different energy sources. Studies by Gough et al. (2016) have highlighted how post-disaster settlements often face energy poverty, and understanding consumption patterns is crucial to addressing these issues through the adoption of more efficient energy practices and technologies. The survey data will also help evaluate the effectiveness of energy-saving interventions that may be implemented in future reconstruction efforts.

Thermal Performance Evaluation:

To assess the actual thermal performance of the homes, temperature and relative humidity data loggers were installed in selected houses between January 29, 2025, and February 22, 2025. These included one vernacular (stone mud masonry) house and one modern (RCC structure) house, which represent the typical housing types in the region. The data loggers were installed at a height of 1.5 meters from the floor level on the first floor of each house, ensuring they captured conditions at the level where residents experience the indoor environment most. Additionally, an external thermal environment datalogger was installed on the northern face of the house, ensuring no direct solar radiation interfered with the sensor. These devices collected continuous data on temperature variations and relative humidity levels, offering precise measurements of thermal performance. The collected data served as primary data for evaluating the thermal efficiency of the two different house types. According to Arundel et al. (2017), such data-driven evaluations are critical to determining the real-world performance of building materials and designs in maintaining thermal comfort, especially in the context of varying climatic conditions.

This quantitative approach allows for a detailed and precise assessment of the physical conditions in the case study area, providing valuable insights into how housing designs perform in terms of energy consumption and thermal comfort. The results of these assessments will be used to guide recommendations for improving thermal performance and energy efficiency in post-disaster reconstruction efforts.

3.3 Selection of Case Area

To fulfill the research objective, the study areas have been carefully selected based on their diverse residential structures, energy usage patterns, and socio-economic conditions. The case study areas, Bansighat and Jagriti Nagar Informal Settlements, have been chosen for their representation of a range of housing types, from traditional to hybrid and modern, making them ideal for analyzing energy consumption patterns, energy efficiency challenges, and the socio-cultural factors that influence energy use in these communities.

Bansighat and Jagriti Nagar are among the most prominent informal settlements in the Kathmandu Valley, housing a significant portion of the population that relies on a variety of energy sources. These sources include grid electricity, biomass (such as wood and agricultural waste), and alternative energy solutions like solar power and biogas. The settlements are characterized by a high level of energy poverty, with many households struggling to access reliable energy. In addition to limited access, inefficient energy appliances and socio-economic constraints further shape the energy consumption behaviors of the residents. According to Malla and Shrestha (2019), informal settlements often face complex energy challenges, where limited infrastructure, coupled with a reliance on traditional energy sources, exacerbates the difficulties of achieving sustainable energy solutions.

Rather than covering the entire settlement, small clusters with diverse building types will be selected for field visits and case study analysis. These clusters will serve as representative samples of the broader settlement, providing valuable insights into energy consumption trends, challenges, and potential interventions aimed at improving energy efficiency and access in informal settlements. The approach of selecting specific clusters is supported by the work of Davis and Rojas (2016), who argue that targeted case studies allow for a more in-depth understanding of local energy dynamics and help identify actionable interventions that can be scaled to larger areas.

The primary reason for selecting Bansighat and Jagriti Nagar is their heterogeneous energy landscape, where modern technology, traditional energy practices, and hybrid energy solutions coexist. This diversity provides an opportunity to study the intersection of different energy systems and explore how these systems interact with each other and with residents' energy consumption behaviors. Such an approach has been suggested by Ahsan and Rashed (2018), who emphasize the importance of examining the coexistence of various energy systems in informal settlements to identify strategies that can effectively address the energy needs of these communities while promoting sustainability. This heterogeneity makes the settlements ideal for studying energy consumption behavior and proposing sustainable energy interventions that can be applied to similar informal settlements across Kathmandu Valley and beyond.\

Figure 7 Banisghat Squatter (Adapted from Sovacool et al 2021)

3.4 Research Methodology

First Stage: The first step of the research began with a comprehensive literature review aimed at developing the research objectives and generating ideas related to the research topic. This involved interpreting various related documents, articles, research papers, and reports. The literature review focused on the energy consumption behavior in informal settlements, factors influencing these behaviors, and the challenges associated with energy access and efficiency. This stage also involved identifying gaps in the existing literature to ensure the study's relevance and contribution to the field.

Second Stage: The second step involved identifying the case area and conducting on-site field measurements. The informal settlement in Jagriti Nagar, was selected as the case area due to its diverse demographic composition and significant representation of informal settlements in Kathmandu. The data collection process included conducting a detailed survey using structured questionnaires to gather quantitative data on household demographics, energy sources and usage, monthly energy expenditures, and awareness of energy-efficient practices and technologies. Semi-structured interviews with key informants such as community leaders, local NGO representatives, and knowledgeable residents provided qualitative insights into the socio-economic factors influencing energy consumption behavior and community attitudes towards energy use as well as identification of collective challenges and potential solutions. Direct observations documented the physical conditions of the settlement, types of energy infrastructure in place, and visible energy consumption behaviors.

Third Stage: In the third stage, data collection and analysis were conducted to draw findings and conclusions. The survey data were analyzed using statistical software (SPSS) to produce descriptive statistics and explore relationships between variables such as income levels and types of energy sources used. Interview and FGD transcripts were analyzed using thematic analysis, identifying and coding key themes and patterns to understand the socio-economic and cultural factors influencing energy consumption. The quantitative and qualitative findings were integrated to provide a comprehensive understanding of energy consumption behavior in Jagriti Nagar and Bansighat. The triangulation of data sources enhanced the validity and reliability of the research findings, leading to conclusive insights and recommendations for improving energy access and efficiency in informal settlements.

3.5 Data Collection Methods

3.5.1 Sampling:

In order to collect the field data for this research, a questionnaire survey was conducted with 20 respondents of Jagriti Nagar and 20 residents from Bansighat of Thapathali. The respondents were selected using a stratified random sampling method to ensure a representative sample that reflects the diverse socio-economic backgrounds and energy consumption behaviors of the community.

3.5.2 Surveys:

Structured questionnaires were administered to a representative sample of respondents to gather quantitative data on energy consumption patterns, types of energy sources used, monthly energy expenditures, and awareness of energy-efficient practices and technologies. The questionnaire will include sections on:

- Household demographics
- Energy sources and usage
- Monthly energy expenditure
- Awareness and adoption of energy-efficient technologies
- Challenges and barriers to energy access

Questionnaire survey was conducted using Kobo toolbox. Kobo toolbox is a software which is used as data collection, management, and visualization platform globally for research and social good (KoboToolBox, 2024).

3.5.3 Interviews:

Semi-structured interviews were conducted with key informants, including community leaders, representatives from local NGOs, and residents with in-depth knowledge of the community's energy practices. These interviews provided qualitative insights into the socio-economic factors influencing energy consumption behavior and the community's perception of energy efficiency interventions.

3.5.4 Observations:

Direct observations were conducted to document the physical conditions of the settlement, types of energy infrastructure in place, and visible energy consumption behaviors. This method helps corroborate data from surveys and interviews, providing a contextual understanding of the living conditions and energy usage patterns.

3.6 Data Analysis

3.6.1 Quantitative Data Analysis:

Survey data were analyzed and presented using statistical tools in software like SPSS and Microsoft Excel.

3.6.2 Qualitative Data Analysis:

Interview transcripts were analyzed using thematic analysis. Key themes and patterns are identified, coded, and categorized to understand the socio-economic and cultural factors influencing energy consumption.

3.6.3 Integration of Data:

Quantitative and qualitative findings have been integrated to provide a comprehensive understanding of energy consumption behavior in Jagriti Nagar, Balkhu. Triangulation of data sources enhances the validity and reliability of the research findings.

3.7 Methodological Framework

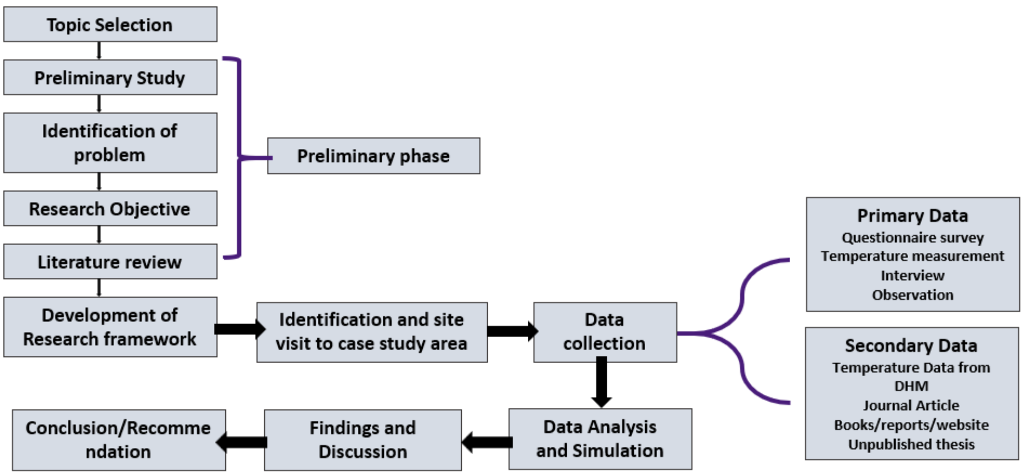


Figure 8 Methodological framework

The presented figure illustrates the systematic research methodology adopted in this study. The entire process is divided into sequential phases to ensure a comprehensive and logical progression from topic identification to final conclusions and recommendations. The methodology is structured into three primary phases: the Preliminary Phase, the Fieldwork and Data Phase, and the Analysis and Interpretation Phase.

Preliminary Phase

The research process begins with the Topic Selection, followed by a Preliminary Study to explore the existing knowledge base and identify critical gaps in the current literature. This is succeeded by the Identification of the Problem, which narrows down the research focus based on the observations and preliminary findings. Following this, the Research Objective is formulated to define the aim and scope of the study clearly. A Literature Review is then conducted to understand the theoretical framework, methodologies employed by previous researchers, and relevant case studies. These initial steps collectively form the Preliminary Phase, which lays the foundation for the research framework.

Fieldwork and Data Collection Phase

Once the preliminary phase is completed, the next step involves the Development of the Research Framework, which includes outlining the methodological approach, research questions, and tools for data collection and analysis. This is followed by the Identification and Site Visit to the Case Study Area, where the research context is examined in its real-world setting.

The Data Collection process then commences, drawing from both Primary and Secondary data sources.

- Primary Data includes direct observations and firsthand information gathered through questionnaire surveys, temperature measurements, interviews, and on-site observations.
- Secondary Data involves the use of existing resources such as temperature datasets from the Department of Hydrology and Meteorology (DHM), journal articles, published reports, websites, and unpublished theses. The combination of these two types of data ensures both empirical depth and contextual breadth in the study.

Analysis and Interpretation Phase

Following data collection, the research proceeds to Data Analysis and Simulation, where the gathered data is processed using appropriate analytical tools and software platforms. This may involve statistical analysis, simulation modeling (e.g., using DesignBuilder), and interpretation of results in the context of the defined research objectives.

Subsequently, the Findings and Discussion section presents the interpreted results, linking them with the existing literature and highlighting key insights and patterns. The final step in the research process is the Conclusion and Recommendations, where the overall findings are synthesized, and practical or policy-oriented recommendations are proposed. This section also identifies potential areas for further research.

3.8 Ethical Considerations

Informed Consent: All participants were informed about the purpose of the study, their right to withdraw at any time, and how their data will be used.

Confidentiality: Participants' identities and responses are kept confidential. Data has been anonymized during analysis and reporting to protect participants' privacy.

Non-maleficence: The study ensures that no harm comes to participants as a result of their involvement in the research. Sensitive topics were handled with care, and support will be provided if participants experience distress.

3.9 Study Area

The research has been conducted in the informal settlement located in Jagriti Nagar, Ward No 14, Western Kathmandu. The settlement covers about 15 *ropanis* of land and is situated along the Bagmati river (Nepal Bashobash Tatha Samrakchan Samaj, 2013). It has a large vegetable market and the Vayodhya hospital next to the bridge. Jagriti Nagar is a dwelling place for a large number of low-income, urban squatters, some even multigenerational, comprising individuals from varying places of origin, socio-economic statuses, political affiliations, and age groups (Rumba, 2014). This diversity makes Jagriti Nagar an ideal sample for studying energy consumption behavior in informal settlement.

The research has also been conducted in the informal settlement located in Bansighat, Ward No. 11, Central Kathmandu. This settlement is situated along the banks of the Bagmati River, covering a densely populated urban area with limited access to infrastructure and basic services. Bansighat is home to a significant number of low-income households, many of whom have resided in the area for generations. The settlement consists of a mix of makeshift dwellings, semi-permanent houses, and some modern structures, reflecting diverse housing and energy consumption patterns.

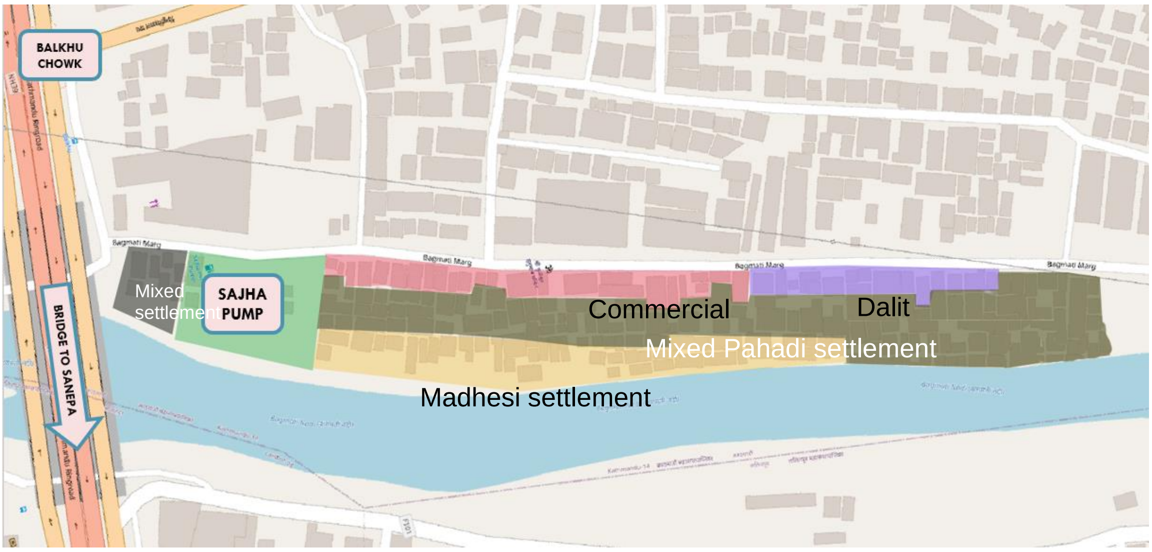


Figure 9 Jagriti Nagar Social Context

Source: Study Team, Adopted from Kivela, Sami (2013)

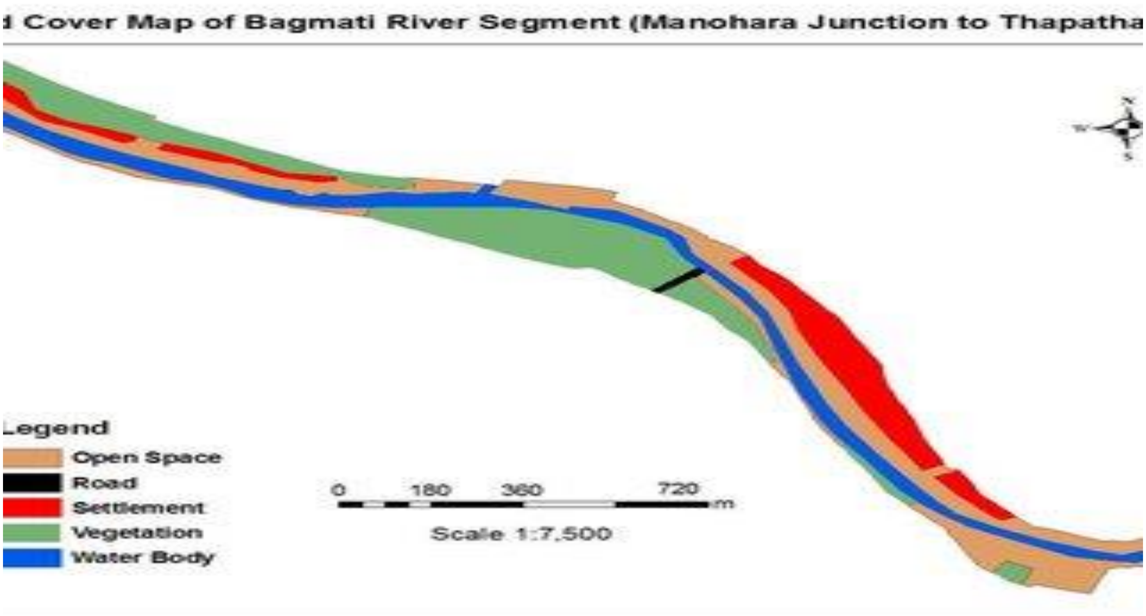


Figure 10 Banisghat Squatter Land Use (Adopted from Shradha Shrestha, 2016)

Informal settlement in Jagriti Nagar and Banisghat consists of people from different socio-economic, ethnic, cultural, religious, and political backgrounds. The residents range from the poorest to those with modest levels of infrastructure. Key reasons for migration to this area include displacement due to natural disasters, fleeing from villages during the Maoist insurgency, and seeking employment opportunities and better prospects for their children.

Figure 11 Typical Houses in Squatter settlement

The images presented depict the physical conditions and construction typologies commonly observed in squatter settlements within the Kathmandu Valley. These structures reflect a highly informal and resource-dependent construction approach, shaped largely by economic constraints, land insecurity, and the lack of access to formal planning or engineering services. The variation in materials and techniques across the settlements reveals a layered and adaptive form of urban development, where households modify and expand their homes incrementally as resources permit.

A wide range of building materials is evident in these settlements, including fired bricks, cement blocks, timber, corrugated galvanized iron (CGI) sheets, plastic coverings, and recycled components. In some cases, the use of cement blocks or bricks for walls indicates attempts at permanence and durability. These materials, when properly laid and plastered, offer better structural integrity and thermal mass, although many of the houses remain unplastered, leaving the walls vulnerable to moisture ingress and rapid degradation. In contrast, timber and CGI sheets are widely used in both wall and roof construction, especially in vertically extended or rear portions of the houses. While cost-effective and easy to work with, such materials contribute to poor insulation and thermal discomfort, particularly during the region's extreme seasonal variations.

The construction techniques employed are mostly incremental in nature. Many of the buildings have been constructed in phases over time, resulting in a visible mix of materials within a single structure. This incremental growth often lacks structural coherence, with little to no professional oversight in the design and execution stages. The spatial organization within the settlements is typically congested, with houses built in close proximity and narrow passageways separating them. This dense arrangement significantly limits natural ventilation and daylight access, leading to poor indoor air quality and exacerbating thermal discomfort.

These construction practices have direct implications for the thermal performance of dwellings and energy consumption behavior. Houses with CGI roofing and uninsulated walls are especially prone to overheating in summer and excessive heat loss during winter, compelling residents to rely on inefficient heating or cooling strategies where available. Even in structures with more durable materials, the lack of thermal insulation, proper ventilation, and regulated design standards contributes to indoor discomfort. As a result, these households exhibit highly adaptive behaviors in their daily energy use, balancing between necessity, affordability, and available infrastructure.

Furthermore, many of the homes display makeshift attachments and temporary sheds made from salvaged materials, reflecting the ingenuity of occupants in addressing evolving spatial needs. Water storage tanks, cooking spaces, and utility areas are often external and exposed, impacting not only hygiene and safety but also energy and water use patterns. Electrical wiring is often seen to be unmanaged and exposed, posing safety risks and further contributing to energy inefficiency. The use of dark-colored materials and poor roof insulation amplifies the heat gain during daytime, especially in summer, thus intensifying thermal stress.

In some dwellings, modifications such as shaded verandas or fabric screens indicate efforts to regulate solar exposure, though these are rarely optimized for energy efficiency. The orientation of structures, largely dictated by space constraints rather than climate-conscious planning, further limits passive design opportunities. In the absence of any formal intervention, these dwellings continue to evolve in a spontaneous and organic manner, often perpetuating cycles of vulnerability and inefficiency. This makes it imperative to understand and model these material and spatial characteristics accurately during energy simulations to ensure that proposed interventions—whether in the form of retrofits, new material choices, or passive strategies—are context-sensitive and technically feasible.

CHAPTER 4: DATA ANALYSIS AND RESULT

The result and discussion include data on the energy consumption patterns, socio-economic factors influencing energy behavior, and the awareness and adoption of energy-efficient practices among the residents.

4.1 Demographic and socioeconomic information

The residents of Jagriti Nagar and Banisghat included people from various caste and origin. *Tamang*, *Rai*, *Limbu*, *Mahaut*, *Dalit*, *Newar*, Muslims were the major caste that we observed during our survey. However, *Chhetri* and *Bhramin* were not found during our survey. Abundance of *Janajatis* specially *Tamang* and *Limbu* was observed. An interview with key respondents revealed the fact that there were 40 households of *Mahaut* caste, among which 25 families had their own house and 15 households were residing on rent. *Mahaut* caste was originally from Nepalgunj and resided along the bank side of Bagmati river in houses built by an NGO named Center for Dalit Women Nepal. *Mahaut* claim themselves as *Dalit*, however government has listed them as *Janajati*.

4.1.1 Gender of the respondents

The survey revealed a balanced representation of genders among the respondents, with a slight majority being male. Out of 40 respondents, 55% of the respondents were male and 45% were female. Khanal and Khanal (2022) found out the percentage of male and female population in Jagriti Nagar as 52% male and 48% female. The variation in the data is due to smaller sample size of this research.

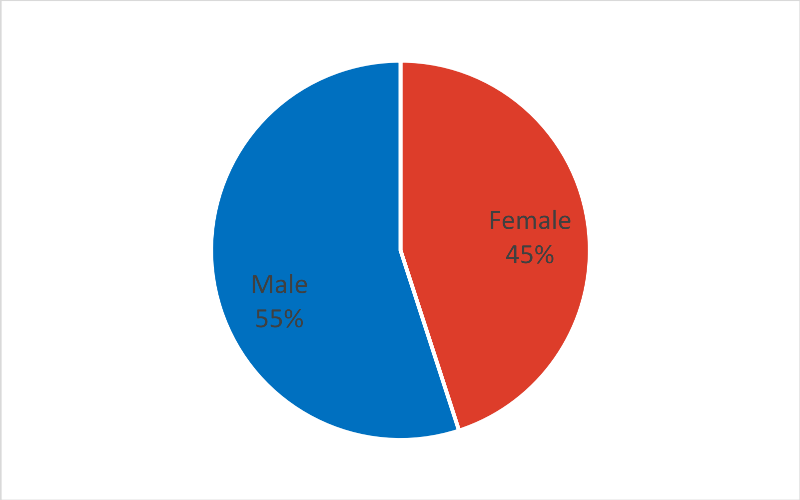


Figure 12 Gender of the respondents

4.1.2 Caste of the respondents

The caste composition of the informal settlement in showed a mix of diverse culture in the region. The majority being Madhesi 39% was followed by Dalit and Mahaut with one fifth population each in the community. Communities like Limbu, Newar, Thami, etc representing various district of origin were also living in the area. The research found no Bhramin and Chhetri in the study area whereas Mishra and Shah (2018) found the caste composition of Thapathali informal settlement as Bhramin, Chhetri, Dalit, Rai, Limbu, Gurung, Lama, Madhesi, Magar, Newar, Tamang indicating variation in caste composition across different informal settlements.

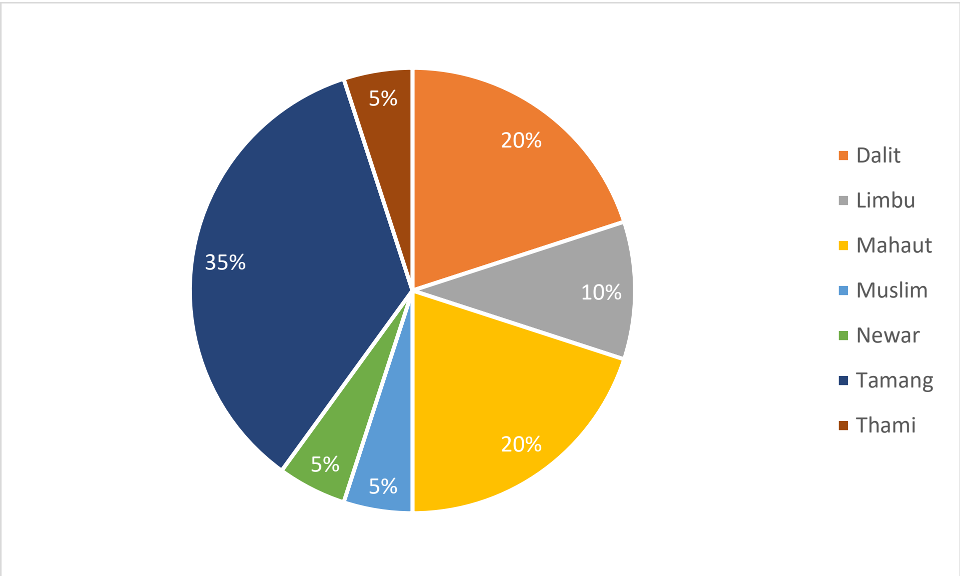


Figure 13 Caste of the respondents

The majority of respondents were originally from Nepalgunj, Banke followed by Jhapa District. The people from eastern, central and western region of Nepal were living in the informal settlement. The survey found out few multi-generational residents of informal settlement with no concrete idea on their ancestral place.

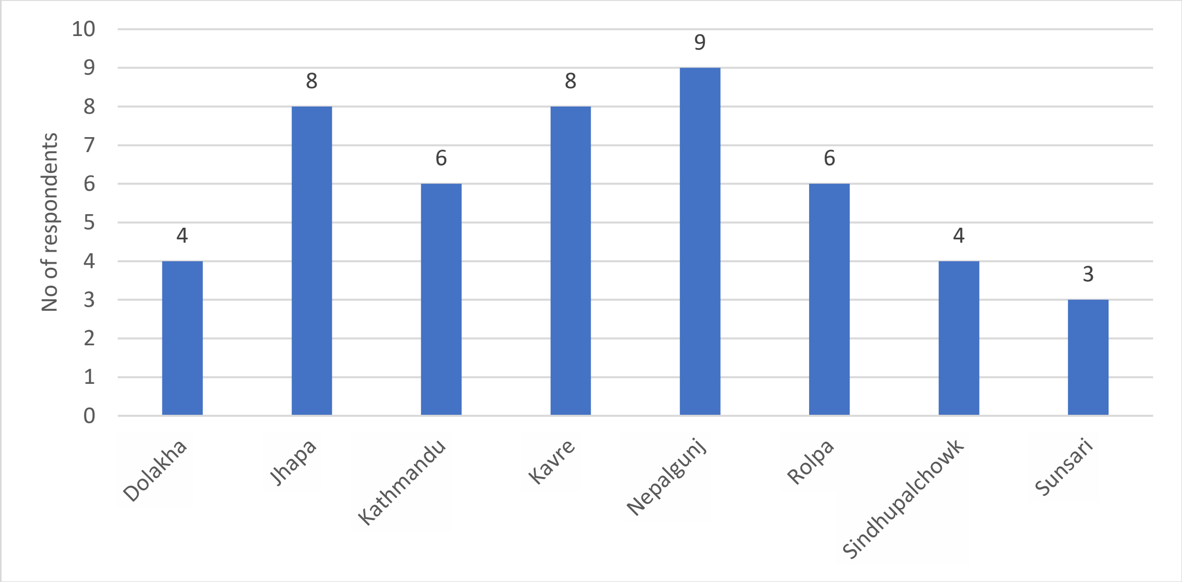


Figure 14 Ancestral place of the respondents

According to the chart, the highest number of respondents came from Nepalgunj, with a total of 9 participants. This is closely followed by Jhapa and Kavre, each contributing 8 respondents to the study. These districts thus form the core sample base, likely due to their relatively larger or more accessible squatter settlements.

Kathmandu and Rolpa each had 6 respondents, indicating moderate representation from both an urban hub and a more remote hill district. Meanwhile, Dolakha and Sindhupalchowk each contributed 4 respondents, and Sunsari had the least number, with only 3 participants.

The variation in respondent numbers across districts may reflect differences in the size, accessibility, or willingness of squatter communities to participate in the survey. It also suggests that while the study aims to be representative, certain areas had stronger engagement, which may influence the overall trends observed in the data. This distribution is important to consider when analyzing results, especially in terms of regional differences in construction practices, climate conditions, and energy use patterns.

4.1.3 Occupation and education level of the respondents

Two charts cross tabulating occupation of the respondents with their education level and gender is presented below. The first charts depict housewife as the major occupation however, the second chart relating occupation and gender clarifies the phenomenon. Males are working as a labor or are self-employed. The respondents mentioning self-employed as their occupation were mostly street food vendors or fruit sellers.

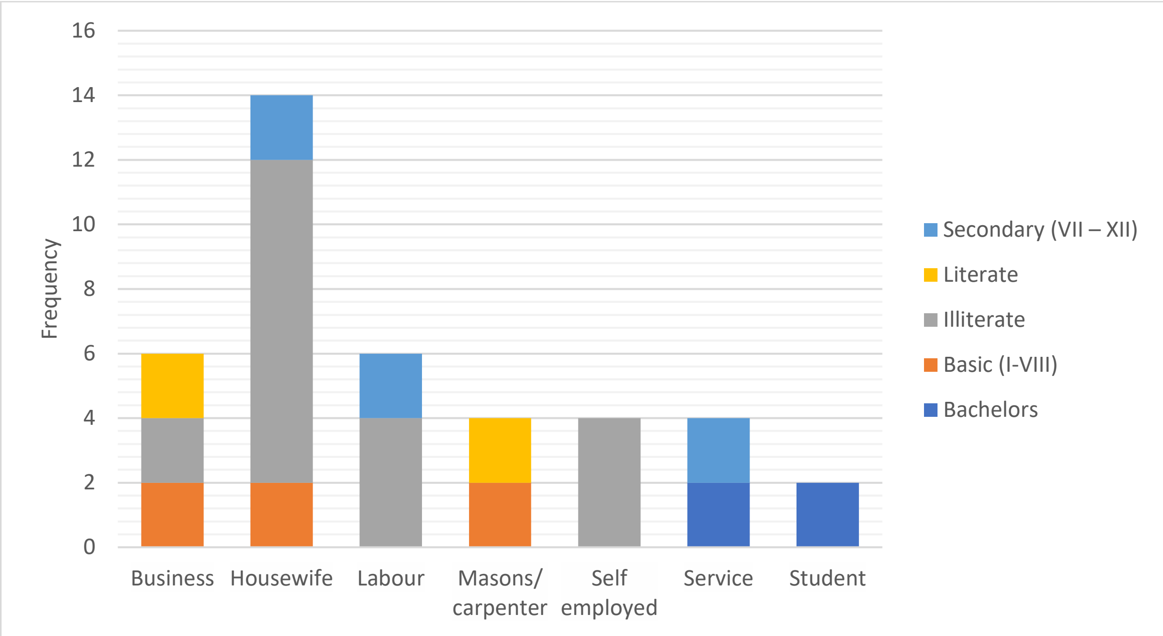


Figure 15 Occupation and education of the respondents

The survey found that 50% of the respondents were illiterate, 20% were either literate or had basic level of education completed and 15% had completed secondary level of education. 10% of the respondents were pursuing or completed the undergraduate studies. Compared to findings of Shrestha and Shrestha (2020) in Sankhamul informal settlement of Kathmandu, where 80% of the respondents were illiterate, Jagriti Nagar has less percentage of illiterate residents. Acharya (2024) found 71% illiteracy in Jagriti Nagar while Mishra and Shah (2018) found 70.77% illiteracy in Thapathali settlement and 64% illiteracy in Sinamangal settlement, reflecting a need of study with larger sample size.

The questionnaire survey was deployed among residents above the age of 18 and kids going school were not accounted. Only 5% of the participants of the survey mentioned as student. Similarly, no women mentioned themselves as a student. Similar occupation pattern was seen in research done in Thapathali settlement and Sinamangal settlement, however account of housewife and student was not given in previous research.

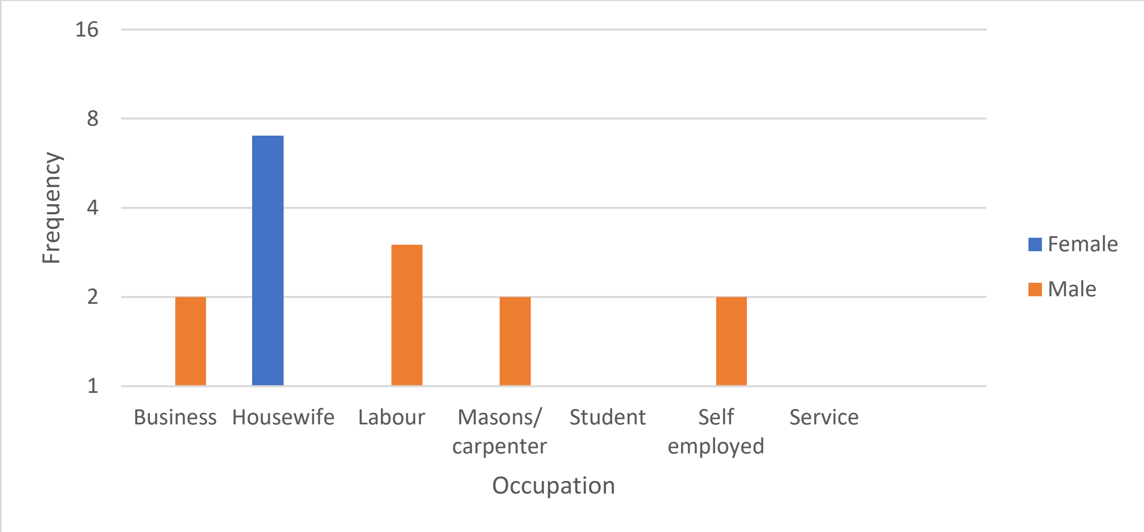


Figure 16 Occupation and gender of the respondents

The bar chart above presents the occupational distribution of male and female respondents in a surveyed population. Occupations are categorized into seven types: Business, Housewife, Labour, Masons/Carpenter, Student, Self-employed, and Service. The data is visually represented using two bars for each category—blue for females and orange for males—allowing for a comparative view of gender-based participation in different occupational sectors.

A key observation from the chart is the dominance of females in the "Housewife" category, with a frequency of 7. This indicates that a significant portion of the female respondents are engaged in domestic responsibilities rather than formal employment. In contrast, this category is not represented at all among males, as expected.

On the other hand, males are distributed across a wider range of occupations. The "Labour" category has the highest number of male participants (3), followed by equal representation (2 each) in "Business," "Masons/Carpenter," and "Self-employed." These findings suggest that males in the surveyed group are more likely to be engaged in economically productive or skilled labor-intensive work.

Interestingly, there is no representation in the "Student" and "Service" categories for either gender in this sample. This absence could be indicative of the demographic or socio-economic profile of the respondents, possibly pointing toward limited access to education or formal employment opportunities.

Overall, the bar chart highlights a clear gender-based occupational pattern, with females predominantly involved in household responsibilities, while males are more involved in various forms of labor and income-generating activities. This insight can be crucial for analyzing gender roles and economic participation within the community under study.

Table 4 School going chindren and household size of the respondents

		School going children			
		Zero	One	Two	Three
Household size	0-3	12	2	0	0
	4-6	4	12	6	0
	6+	2	0	0	2

The table above illustrates the relationship between household size and the number of school-going children within those households. Households are grouped into three size categories: 0–3 members, 4–6 members, and more than 6 members (6+), with data showing how many of these households have zero, one, two, or three school-going children.

Among the smallest households (0–3 members), the majority—12 out of 14—do not have any school-going children. Only 2 households in this group have one child attending school, while none have two or more. This trend suggests that smaller households are less likely to have children of school-going age, possibly due to younger couples without children or older adults with grown-up children.

The mid-sized households (4–6 members) show a more varied distribution. Here, 4 households have no school-going children, while 12 have one child in school, and 6 have two children. This indicates that families of this size are more likely to have school-age children, typically one or two, which reflects a common family structure.

In contrast, larger households with more than six members display a different pattern. While two households have no school-going children, another two have as many as three. Interestingly, none in this group fall into the categories with one or two school-going children. This may imply that such households either include extended family members or have several children of school-going age.

The data suggests a general trend where larger households are more likely to have multiple school-going children, whereas smaller ones often have none. This relationship between household size and the number of children attending school provides meaningful insight into the demographic composition and educational demands of the surveyed population.

4.1.5 Respondent's duration of stay in Jagriti Nagar

Out of 40 respondents, 45% were residing in these squatters for more than 10 years. Majority had lived there for more than 4 years. However, 20% of the respondents mentioned living there for less than 3 years. Upon unstructured interview with those respondents, it was found that few of them 75% of them were living as a tenant while 25% bought their space in the area recently.

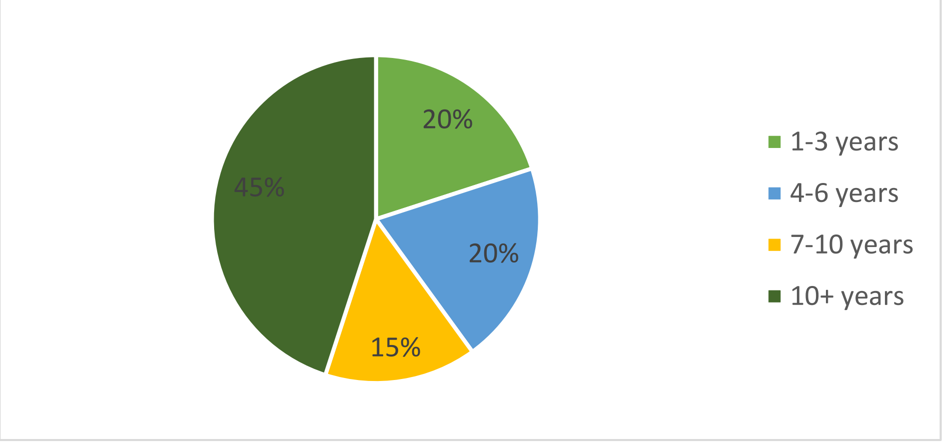


Figure 17 Years of stay in Jagriti Nagar of the respondents

4.1.6 Age and Marital status of the respondents

Out of 40 respondents, 80% of them were married, 10% were unmarried and 10% were widowed. Similarly, 80% of the respondents were below the age of 40. The simple scatter with fit line below illustrates the age and marital status of the respondents.

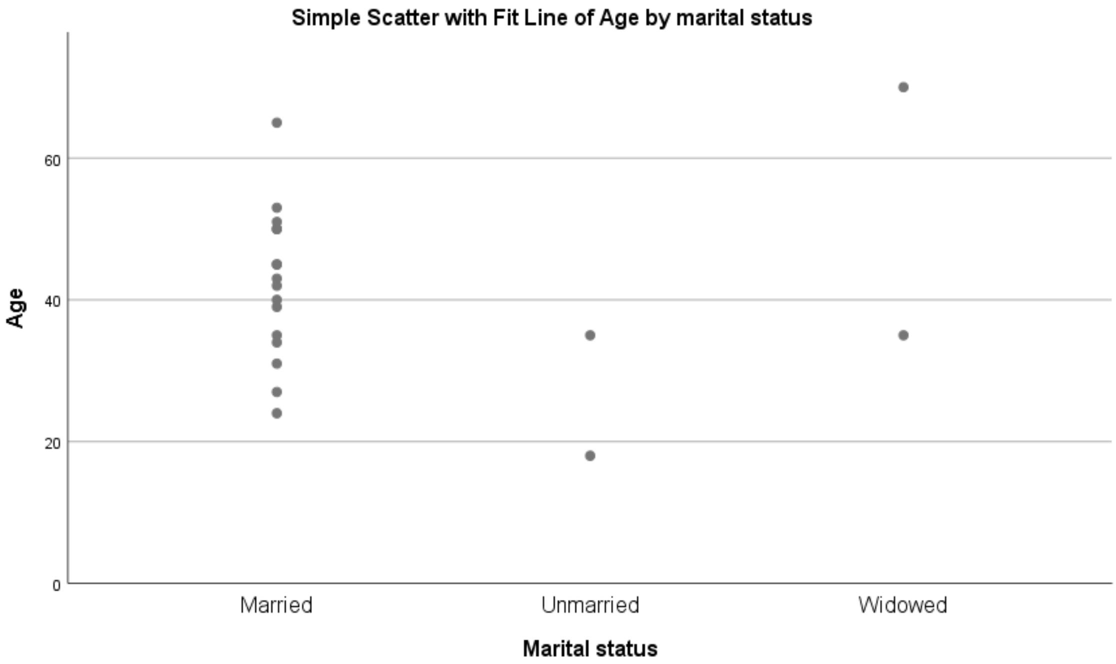


Figure 18 Marital status and age of the respondents

4.1.7 Monthly household income and expenditure of the respondents

The household income of the respondents varied from as less as Rs. 10,000 per month to more than Rs. 1,00,000 too. However, most of the respondents had lower ranges of income. 25% of the respondents had monthly household income between Rs. 10,000 to Rs. 20,000. Similar percentage of respondents was seen in income range of Rs. 20,000 to Rs. 30,000 and Rs. 30,000 to Rs. 40,000. Similarly, the monthly household expenditure of the respondents ranged between Rs. 10,000 to Rs. 40,000. Only 10% respondents spent Rs. 30,000 to Rs. 40,000 monthly, while 55% respondents spent Rs. 20,000 to Rs. 30,000 monthly. About 35% of the respondents had only Rs. 10,000 to Rs. 20,000 to spend on household expenses. A relationship between household size, energy consumption and monthly household income was observed, which aligns with the research findings of Dongzagla and Adams (2022), Desta (2022) and Niyongabo and Makonese (2016) suggesting similar patterns in informal settlements in other regions too.

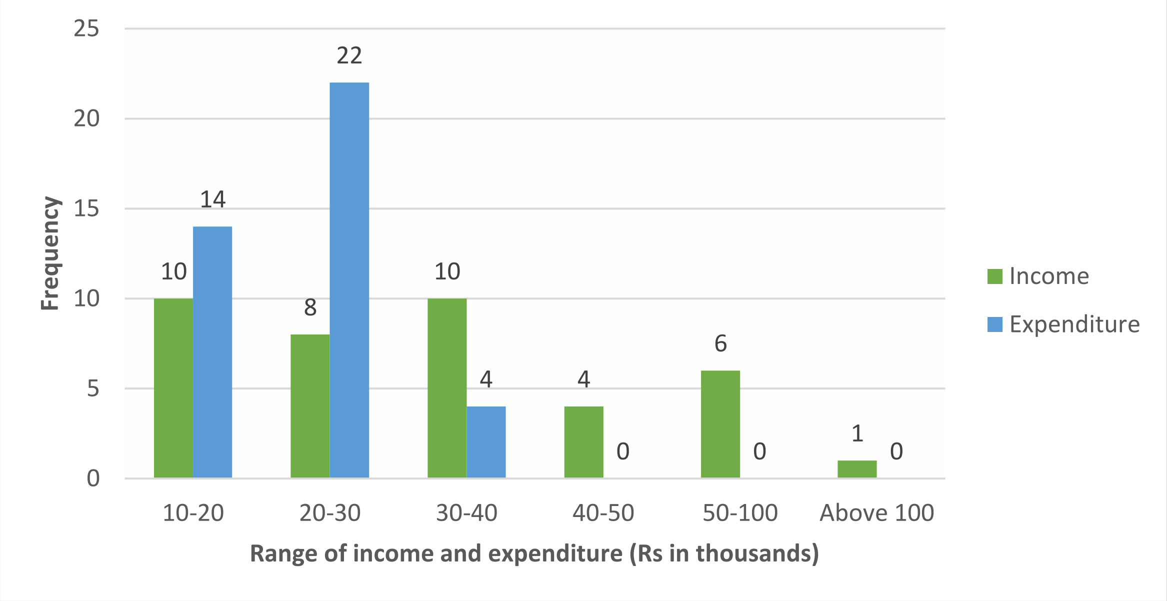


Figure 19 Monthly household income and expenditure of the respondents

4.2 Housing and infrastructure information

4.2.1 Type of structure and no. of storey of house of respondents

20% of the houses in Jagriti Nagar were temporary structure whereas only 5-7% of houses were temporary structures in Bansighat. The permanent and semi-permanent structure shared equal percentages of 45% each. Similarly, 60% of the respondents lived in one storey house while 40% of the respondents lived in two storey houses. In study conducted by Mishra and Shah (2018), 100% houses in Thapathali were temporary and 52% houses in Sinamangal were temporary. A comparative study in same time frame is required to find out whether settlers have adopted CGI sheet with the passage of time or housing conditions in Jagriti Nagar are better than other informal settlements.

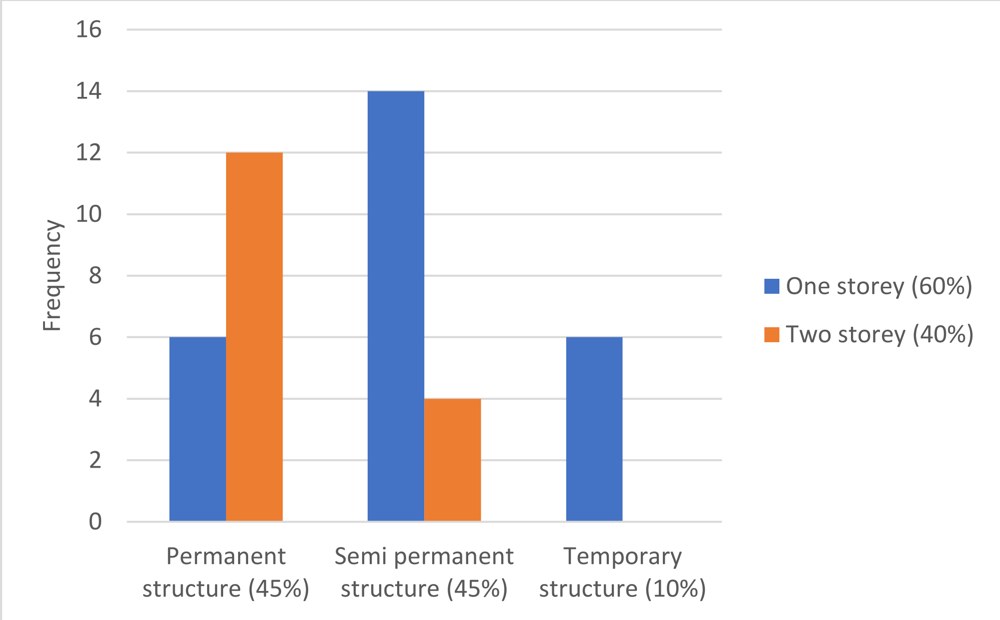


Figure 20 Type of structure and no. of storey of house of the respondents

4.2.2 Material used and the type of structure of house of respondents

Various materials are used as building construction material in Jagriti Nagar. The table below tabulated the percentage of the construction material and types of structures in which the materials are used. The adaptation of newer technologies like prefabricated truss structure is growing as Toffin (2010) the use of CGI sheets, bamboo, mud, bricks and plastic tarpaulins in informal settlements of Kathmandu.Mishra and Shah (2018) found out that in Thapathali informal settlement, only 4% of the houses had CGI roof and in Sinamangal informal settlement, 46% of the houses were covered with CGI roofing.

Table 5 Construction material used and type of structure of the house of the respondents

S.N.	Material	Permanent structure	Semi-permanent structure	Temporary structure	Total	
					Frequency	Percent
1.	Concrete Block	4	0	0	4	10%

2.	Brick	2	10	2	14	35%
3.	Wood	6	10	4	20	50%
4.	Prefabricated Truss	8	0	0	8	20%
5.	Mud	0	2	2	4	10%
6.	CGI	18	18	4	40	100%

The table above presents data on the use of various construction materials across different types of building structures—permanent, semi-permanent, and temporary. The materials listed include Concrete Block, Brick, Wood, Prefabricated Truss, Mud, and CGI (Corrugated Galvanized Iron). For each material, the table provides the frequency of usage in each type of structure, along with the total count and its corresponding percentage of the overall sample.

From the data, CGI stands out as the most commonly used material, with a total of 40 instances spread evenly across all structure types—18 in permanent, 18 in semi-permanent, and 4 in temporary. This material alone accounts for 100% coverage, indicating it is used in combination with other materials in every recorded structure, highlighting its widespread utility and versatility, likely due to its affordability and ease of installation.

Wood is the next most frequently used material, with 20 instances (50%), showing balanced usage in all three structure types. Its application in both permanent and non-permanent structures suggests that it is a flexible material that suits a range of construction needs, possibly in rural or low-cost housing settings.

Brick is another widely used material with 14 instances (35%), predominantly in semi-permanent structures (10), which suggests it is preferred where durability is required but cost constraints may prevent the use of more permanent materials like concrete. Prefabricated trusses, used exclusively in permanent structures (8 instances, 20%), imply a more modern or industrial construction approach, possibly in public or institutional buildings.

Concrete blocks are used solely in permanent structures, though only in 4 instances (10%), suggesting limited but specialized use, likely due to their durability and higher cost. In contrast, mud, an entirely traditional and low-cost material, is only used in semi-permanent and temporary structures (4 instances), emphasizing its declining role in modern or long-lasting construction.

Figure 21 A resident in front of her house in Balkhu

4.2.3 Ownership status and cost of ownership of the respondents

Out of 40 respondents, 25% of the respondents were residing as a tenant in these informal settlements. 18% of the respondents had their house built by an NGO. 25% of the respondents didn't have information on cost of construction of their house. 5% of the respondents bought the structure recently for less than One Lakh rupees. Among remaining respondents, construction cost of semi-permanent housing was about Rs. 50,000 while permanent houses costed from Rs. 3,00,000 to Rs. 15,00,000 depending on storey, floor area and materials used.

4.2.4 Facilities and amenities in house of the respondents

During the survey, all the respondents mentioned having a kitchen and a toilet in their houses. The number of bedrooms varied from 1 to 4. The average number of bedrooms in a house was between 2 to 3. The houses had rooms as per the requirement and land area. No respondents had living room in their house. However, in two-storey houses, ground floor was used for self-run business or was rented. The respondents mentioned rent for residential units' costing from Rs. 3000 to Rs 5000 per month. As per our key informant, rent for commercial rooms on road side costs Rs. 5000 to Rs. 8000 per month. During unstructured interview with respondents who were living on rent, they mentioned their poverty as the main reason behind their stay at disaster prone area. Also, their willingness to purchase structures on the same area at after being financially able was reflected. Mahaseth (2017) in a study conducted in Manohara informal settlement found that people are living as a tenant in informal settlement after being unable to afford the rent in the city.

The water supply system in the whole settlement area was dependent in tankers and 20 litre plastic jars. For basic utility, Jagriti Nagar and Banisghat had various *chowks* with 5000 to 7000 litres water tanks for households nearby. The users raised fund to buy the tankers, and refills tanker on equal cost sharing basis. For drinking purpose, 95% of the respondents mentioned using plastic jars, while 5% of the respondents mentioned using tanker refilled water for drinking purpose too.

Figure 22 Water storage tank in Jagriti Nagar and Bansighat

4.3 Energy consumption patterns

The energy consumption pattern in Jagriti Nagar has been categorized based on the types of electrical appliances used in households and the monthly electricity charges paid by each household. The study revealed a noticeable increase in both energy consumption and the number of electrical appliances in informal settlements, indicating a shift toward modern living standards even in low-income areas. This rising trend reflects growing access to electricity, improved economic conditions, and changing lifestyle preferences among residents.

Toffin (2010) noted that while most informal settlements in Kathmandu had access to electricity, very few households owned televisions at the time, highlighting limited appliance use in the past. However, the current findings in Jagriti Nagar show a significant departure from this pattern. More than 50% of the households in informal settlements now own and use LED televisions, demonstrating not only greater access to electronic goods but also a cultural and social shift towards media consumption and digital inclusion. This trend is further supported by the presence of other appliances such as electric fans, rice cookers, and mobile charging devices, contributing to higher monthly electricity bills. These changes suggest that informal settlements are gradually bridging the technological and energy-use gap with formal urban areas, and they emphasize the importance of sustainable energy planning in these rapidly evolving communities.

Category I: High Energy Consumption

This category includes households that utilize comparatively higher units of electricity per month. The electricity charge in these households ranges from Rs. 1700 to Rs. 3500. These households are located next to the road and often have restaurants, shops, small businesses, etc. For a house with hotel, the cooking gas refill per month is at least 2, while other business has heavy electrical equipment increasing the total expense on energy. The average monthly expense on energy in these households is Rs. 2500 to Rs. 8000.

Table 6 Energy consumption pattern in high energy consuming households

S. N.	Name of Electrical Appliance	Number	Power rating	Average Daily usage	LPG refills per month

1	LED Light	2	6	5	2
2	LED Light	1	12	4	
3	LED Light	1	3	1	
4	Tube Light	3	40	12	
5	Electric Fan	2	60	5	
6	Electric Heater	1	800	2	
7	Refrigerator	1	130	24	
8	Electric Kettle	1	1500	0.5	
9	Electric Iron	1	750	0.1	
10	TV	1	100	4	
11	Router	1	10	24	

The table provides detailed information on the types and usage of electrical appliances found in a household or group of households. Each row represents a different appliance, including data on the number of units, power rating (in watts), average daily usage (in hours), and the number of LPG refills per month (where applicable).

Lighting appliances such as LED lights and tube lights are used extensively. There are a total of 4 LED lights with varying power ratings (3W, 6W, and 12W), used for an average of 1 to 5 hours daily. Three tube lights, each rated at 40W, are used for around 12 hours a day, indicating heavy use, likely for general household illumination.

Among cooling and heating appliances, electric fans (2 units of 60W) are used for about 5 hours daily, which is common in warmer conditions. A single electric heater with a high power rating of 800W is used for 2 hours a day, likely for winter comfort. This contributes significantly to electricity consumption. The electric kettle (1500W) and electric iron (750W) have short usage durations—0.5 hours and 0.1 hours per day, respectively—yet their high-power ratings still add to energy load.

The refrigerator, running continuously (24 hours/day) at 130W, and the router, also operating 24 hours a day at 10W, are among the few devices with constant usage, contributing to the base load of the household.

A TV (100W) is used for 4 hours daily, highlighting media consumption as a regular part of daily life. The LPG refill information is only filled in for the first LED light entry (2 refills/month), likely referencing cooking energy use, although LPG usage is not directly tied to electrical appliance data here.

Category II: Moderate Energy Consumption

This category includes households with moderate energy consumption. They typically have fewer appliances compared to Category I, and the energy usage is primarily for household purposes without any business operations. The monthly energy expense on this category of households ranges from Rs. 1200 to Rs. 2500.

The respondents in this category had electrical equipment such as fan, heater and kettle. Not all respondents in this category had their own TV and router. Some respondents reported that they had internet access via shared router.

Table 7 Energy consumption pattern in moderate energy consuming households

S.N.	Name of Appliance	Number	Power rating	Average Daily usage	Gas
1	LED Light	2	6	5	0.5
2	LED Light	1	12	4	
3	LED Light	1	3	1	
4	Electric Fan	1	60	6	
5	Electric Heater	1	800	2	
6	Electric Kettle	1	1500	0.5	

7	TV	1	100	2	
8	Router	1	10	24	

This table provides an overview of various electrical appliances used in a household, highlighting key details such as the number of units, power rating (in watts), average daily usage (in hours), and an additional column labeled "Gas," which likely refers to the household's monthly LPG (cooking gas) consumption in refills, indirectly connected to appliance use.

Starting with lighting, there are a total of 4 LED lights (two 6W, one 12W, and one 3W), used between 1 to 5 hours daily. LED lights are energy-efficient and commonly used for general illumination, contributing minimally to overall power consumption due to their low wattage.

The electric fan (1 unit, 60W) is used for 6 hours daily, suggesting a moderate need for cooling. The electric heater, at 800W and used for 2 hours daily, adds a significant load to the energy consumption, especially during colder periods. Similarly, the electric kettle (1500W) is used for 0.5 hours per day. Despite short usage, high-wattage appliances like the kettle and heater significantly influence the total energy bill.

The TV (1 unit, 100W) is used for 2 hours daily, indicating regular but limited media usage. The router, running continuously at 10W, is among the appliances with 24-hour usage, contributing to the household's base load despite its low power rating.

The gas column shows only one entry (0.5 refills), linked with the first LED light row. While this may be a data entry overlap or format issue, it hints that gas usage is minimal or not the primary focus for these particular households, possibly due to increased reliance on electric appliances like the kettle or heater for cooking and heating needs.

Category III: Low Energy Consumption

This category includes households with minimal energy usage. The households primarily use basic appliances like lights and fans, and their energy consumption is the lowest among the categories. This category includes households with only LED lights as electrical equipment, households who completely rely on firewood for cooking, households with LED lights and a TV to households with electric heater and fan in their house. In this category of respondents, the electric heater was reported by respondents with infants. The monthly cost of energy in this category ranges from Rs 500 to Rs 1200. This category can further be subcategorized as follows:

Type A:

Table 8 Energy consumption pattern in low (type A) energy consuming households

S.N.	Name of Electrical Appliance	Number	Power rating	Average Daily usage	Gas refills per month
1	LED Light	2	6	5	0.5 or 0
2	LED Light	1	3	1	
3	TV	1	80	4	

Type B:

Table 9 Energy consumption pattern in low (type B) energy consuming households

S.N.	Name of Electrical Appliance	Number	Power rating	Average Daily usage	Gas refills per month
1	LED Light	2	6	5	0.5
2	LED Light	1	12	4	
3	LED Light	1	3	1	
4	Electric Fan	1	60	5	
5	Electric Heater	1	800	2	

The energy consumption chart shows that all the respondents used LED lights as the source of lighting. Few households who ran business used tube lights too. During informal discussion with respondents, they mentioned the electrical appliance shop recommending of LED bulbs and lights as energy efficient technology. It shows that the awareness of energy efficient technology among electrical store owners will be effective in promoting energy efficient systems to the desired population.

Majority of the households had LED television in their house. It was considered necessary as the source of entertainment, especially among elderly members of the house. One respondent mentioned of owning a LED television while had rented LPG cooking stove because she couldn't afford it.

Refrigerator is not considered basic amenity in Jagriti Nagar as only households with its commercial use owns it. Majority of the two-storey house were observed having a restaurant or tea shop or retail store in ground floors. It was observed that a lot of two-storey houses in inner areas of the settlement also had small restaurants and retail stores, reflecting the attraction of residents to running small business of their own.

Most of the households mentioned LPG gas refills at every second month. However, they reported it varying due to factors like season and festivals. The average household size of our sample is 4.5 with standard deviation of 1.6.

Overall, the energy consumption in Jagriti Nagar has been limited due to several factors. Most of the households are living under energy poverty as the percentage of energy costs in overall expenditure is higher and availability of appliances that consumes energy is lacking. The findings of this research align with the research findings of Dongzagla and Adams (2022), Desta (2022) and Niyongabo and Makonese (2016) suggesting global interventions to enhance energy efficiency and address energy poverty in low-income households of informal settlements.

4.4 Simulation Output

4.4.1 Introduction to Modelling Parameters

In this study, Design Builder software was utilized to simulate the thermal performance of three distinct building configurations, each employing different construction materials. The first model featured a structure entirely clad in galvanized iron (GI) sheets for both walls and roofing. The second configuration incorporated concrete block walls combined with a GI sheet roof. The third design comprised concrete block walls with a roofing system that included GI sheets supplemented by plywood panels.

To accurately represent these constructions, custom materials and assemblies were defined within Design Builder, specifying thermal properties such as conductivity, density, and specific heat. Each building model was subjected to identical environmental conditions and occupancy patterns to ensure a consistent basis for comparison. Simulation outputs were analyzed to assess key performance indicators, including indoor temperature stability, energy consumption, and occupant comfort levels, thereby determining the most effective material combination for enhancing thermal comfort and energy efficiency in residential structures.

4.4.2 Physical Characteristics of Simulated Materials

Table 10 Thermal Properties of Building Materials Used in Simulations *(Source: Ashrae Handbook - Fundamentals, 2017)*

Property	**Concrete Block**	**GI Sheet**	**Plywood**
Thermal Conductivity (W/mK)	2.2	60	0.13
Density (kg/m³)	1440	7850	480
Specific Heat Capacity (J/kgK)	1120	350	1260
Thermal Diffusivity (m²/s)	0.8×10^{-6}	2×10^{-5}	1.5×10^{-7}
R-Value (m²K/W)	0.125	0.0006	0.35
U-Value (W/m²K)	8	1666.66	3

Emissivity (ε)	0.85	0.45	0.9
Solar Absorptance (α)	0.75	0.22	0.63
Moisture Content (% mass)	7-1	0.05-1	12%

The table compares three common construction materials—Concrete Block, GI Sheet, and Plywood—based on their thermal and physical properties. These characteristics play a significant role in determining how a building responds to heat transfer, thermal storage, and insulation, especially in designs with a **window-to-wall ratio of 30**% and a floor slab thickness of 90 mm. Each material presents unique advantages and limitations depending on its application within a structure.

Thermal conductivity is a key indicator of a material's insulation quality. GI Sheet has the highest thermal conductivity at 60 W/mK, making it a poor insulator as it rapidly conducts heat. Concrete Block, with a conductivity of 2.2 W/mK, performs moderately, while Plywood, at only 0.13 W/mK, provides excellent thermal insulation, minimizing heat transfer through walls or partitions.

The density and specific heat capacity of each material reveal their ability to store and retain heat. GI Sheet is the densest at 7850 kg/m³ but has a low specific heat capacity of 350 J/kgK, which means it heats up quickly and does not retain heat well. On the other hand, Plywood, the lightest material at 480 kg/m³, has the highest specific heat capacity at 1260 J/kgK, allowing it to buffer temperature changes effectively. Concrete Block, with intermediate values, offers a balanced combination of mass and thermal storage.

Thermal diffusivity further illustrates how fast a material responds to temperature changes. GI Sheet has the highest thermal diffusivity, reacting quickly to heat gain or loss, which can result in interior discomfort. Plywood has the lowest diffusivity, contributing to thermal stability inside the building by slowing down temperature fluctuations. Concrete Block once again sits in the middle, offering moderate performance.

The R-value and U-value of the materials represent their resistance and transmission of heat, respectively. Plywood shows the best insulation properties with an R-value of

0.35 and a corresponding U-value of 3 W/m²K. Concrete Block, while structurally robust, has a lower R-value of 0.125 and a U-value of 8, indicating moderate insulation. GI Sheet performs poorly in this regard, with an extremely low R-value of 0.0006 and a very high U-value of 1666.66, emphasizing its unsuitability as a standalone wall material in thermally efficient buildings.

Emissivity and solar absorptance are essential when considering the material's surface behavior in response to solar radiation. Plywood and Concrete Block have high emissivity values, meaning they release absorbed heat efficiently, which can help reduce overheating. GI Sheet, with its lower emissivity of 0.45, tends to retain more heat. In terms of solar absorptance, Concrete Block absorbs the most sunlight at 0.75, followed by Plywood at 0.63, while GI Sheet reflects most solar energy with a value of 0.22.

Moisture content varies across the materials, influencing durability and thermal performance. Plywood shows the highest moisture content at around 12%, which may require treatment or protection against humidity. Concrete Block has moderate moisture retention between 7–1%, while GI Sheet, being non-porous, absorbs minimal moisture, enhancing its durability but not compensating for its poor thermal properties.

4.4.3 Different Cases studied in Simulation

In the first case, a building with GI sheets for both walls and roofing was simulated to analyze its thermal performance. The high thermal conductivity (60 W/mK) and low R-value (0.0006 m²K/W) of GI sheets result in rapid heat transfer, leading to extreme indoor temperature fluctuations. Due to its low thermal mass and high U-value (1666.66 W/m²K), the structure exhibits poor insulation, making it highly susceptible to external temperature variations. The simulation results highlighted excessive heat gain during the day and rapid cooling at night, demonstrating significant thermal discomfort for occupants.

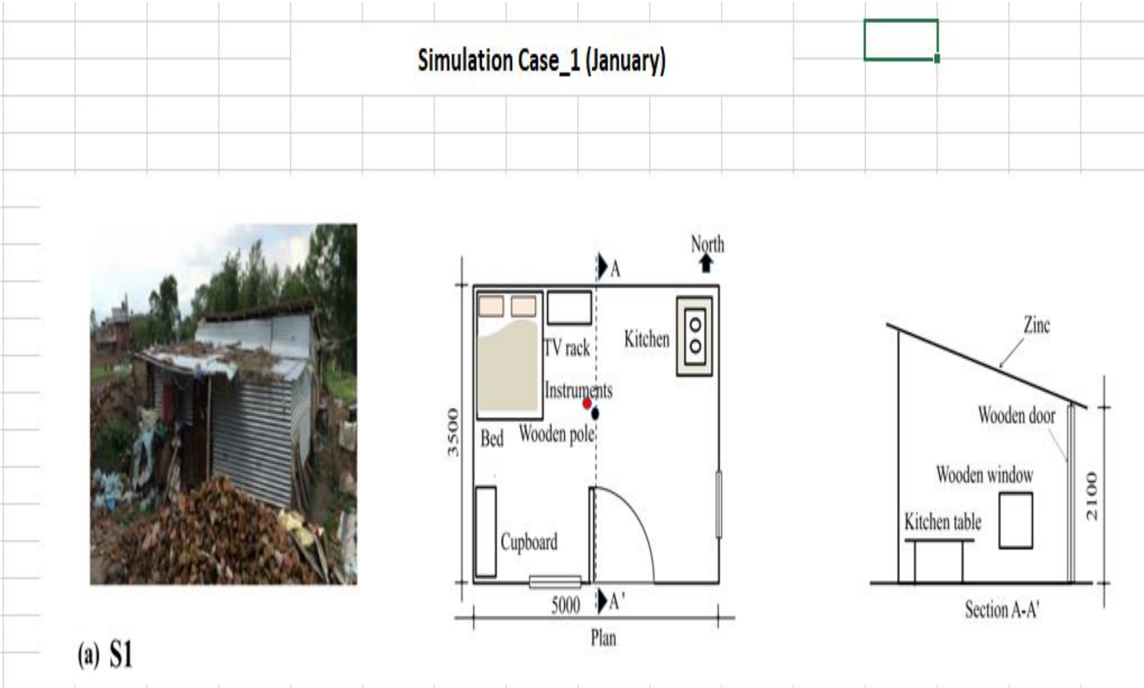
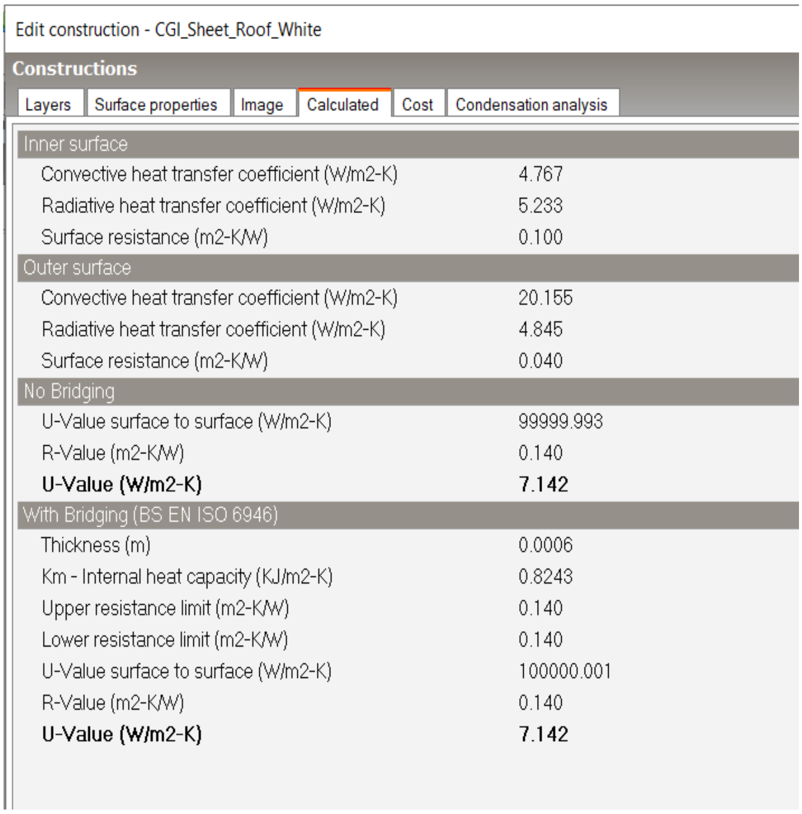


Figure 23 Typical Building Plan for Simulation Case 1



Edit construction - CGI_Sheet_Roof_White

Constructions

Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

Inner surface	
Convective heat transfer coefficient (W/m2-K)	4.767
Radiative heat transfer coefficient (W/m2-K)	5.233
Surface resistance (m2-K/W)	0.100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	20.155
Radiative heat transfer coefficient (W/m2-K)	4.845
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	99999.993
R-Value (m2-K/W)	0.140
U-Value (W/m2-K)	**7.142**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.0006
Km - Internal heat capacity (KJ/m2-K)	0.8243
Upper resistance limit (m2-K/W)	0.140
Lower resistance limit (m2-K/W)	0.140
U-Value surface to surface (W/m2-K)	100000.001
R-Value (m2-K/W)	0.140
U-Value (W/m2-K)	**7.142**

Figure 24 Material Properties in Design Builder for Case 1

In the second case, a building constructed with concrete block walls and a GI sheet roof was simulated to assess thermal efficiency. Concrete blocks, with a lower thermal conductivity (2.2 W/mK) and higher specific heat capacity (1120 J/kgK), provide better thermal mass, reducing temperature fluctuations. However, the GI sheet roof, with its high U-value, allowed significant heat gain and loss. The results indicated that while the concrete walls stabilized internal temperatures to some extent, the metal roof contributed to overheating during the daytime and heat loss at night. This scenario highlighted the need for insulation strategies for the roofing system.

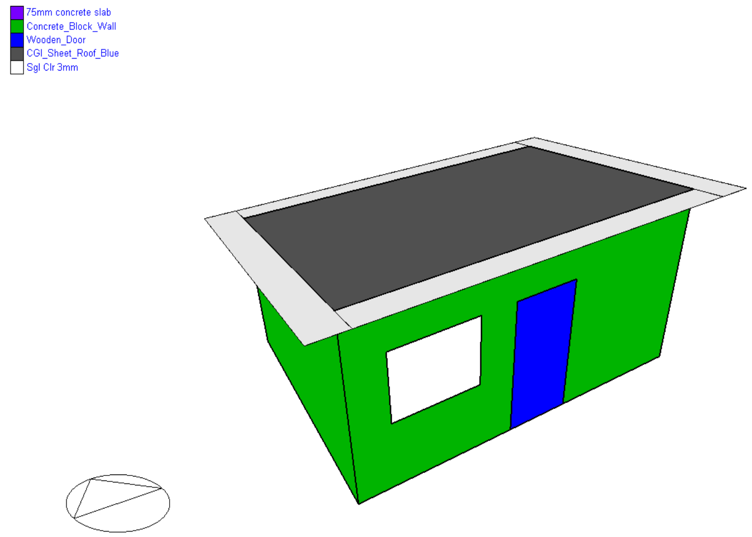
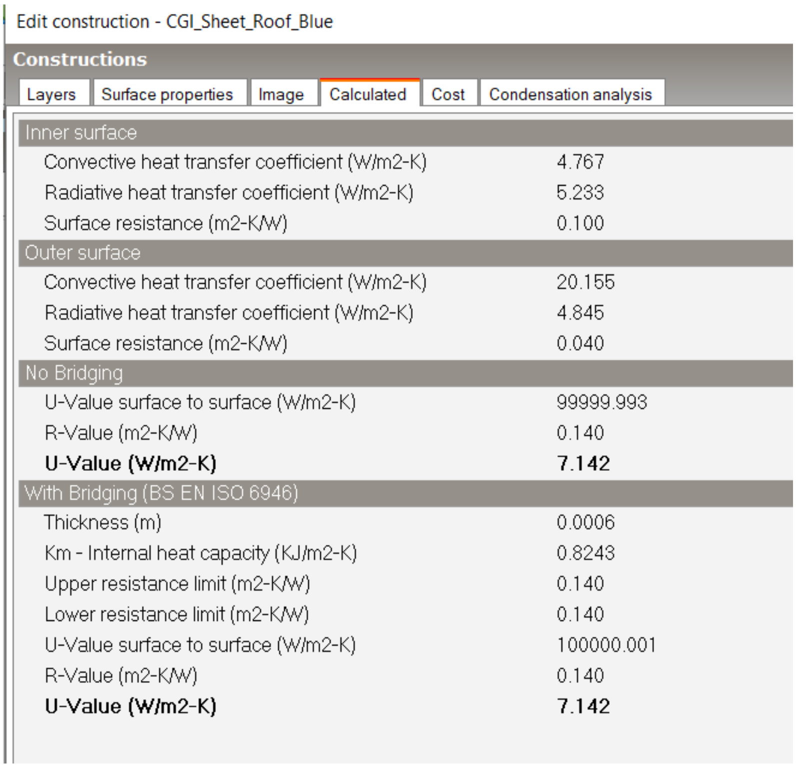


Figure 25 Building Model for Case 2



Edit construction - CGI_Sheet_Roof_Blue

Constructions

Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

Inner surface	
Convective heat transfer coefficient (W/m2-K)	4.767
Radiative heat transfer coefficient (W/m2-K)	5.233
Surface resistance (m2-K/W)	0.100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	20.155
Radiative heat transfer coefficient (W/m2-K)	4.845
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	99999.993
R-Value (m2-K/W)	0.140
U-Value (W/m2-K)	**7.142**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.0006
Km - Internal heat capacity (KJ/m2-K)	0.8243
Upper resistance limit (m2-K/W)	0.140
Lower resistance limit (m2-K/W)	0.140
U-Value surface to surface (W/m2-K)	100000.001
R-Value (m2-K/W)	0.140
U-Value (W/m2-K)	**7.142**

Figure 26 Building Material Properties for Case 2

In the third case, a building with concrete block walls and a composite roofing system of GI sheets with plywood paneling was simulated to analyze improvements in thermal comfort. The addition of plywood, with its lower thermal conductivity (0.13 W/mK) and moderate specific heat capacity (1260 J/kgK), acted as an insulating layer, reducing the impact of external temperature changes. The results demonstrated that this configuration improved indoor thermal stability by mitigating the extreme heat gain and loss observed in the GI-only roofing system. The combination of materials provided a balance between thermal mass and insulation, making it the most effective solution among the three cases for maintaining indoor comfort.

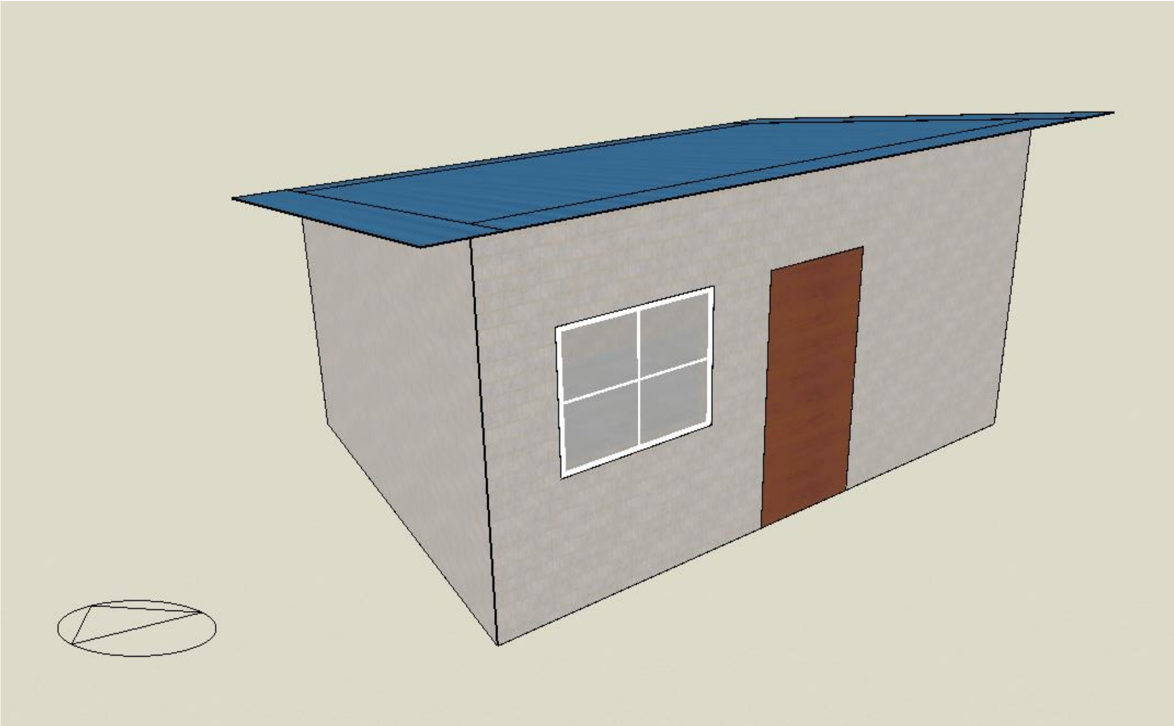


Figure 27 Building Model for Case 3

Edit construction - Concrete_Block_Wall

Constructions

Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	14.667
R-Value (m2-K/W)	0.238
U-Value (W/m2-K)	**4.198**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.1500
Km - Internal heat capacity (KJ/m2-K)	161.2800
Upper resistance limit (m2-K/W)	0.238
Lower resistance limit (m2-K/W)	0.238
U-Value surface to surface (W/m2-K)	14.667
R-Value (m2-K/W)	0.238
U-Value (W/m2-K)	**4.198**

Figure 28 Material properties for Case 3

4.4.4 Output of Simulation

The simulation is run from 1st January to 31st January of year 2024 using climate data obtained from Department of Hydrology and Meteorology (DHM) and material parameters obtained from different relevant research articles and material property websites. The software used for Simulation was Design Builder 7.3.3 on EnergyPlus engine. All 3 cases were created first in the design module of DesignBuilder itself and then prominent physical properties of building materials were entered in the Design Builder character module. Finally, all 3 models were simulated to obtain various data related to internal gain, façade gain, discomfort hours etc.

Case 1:

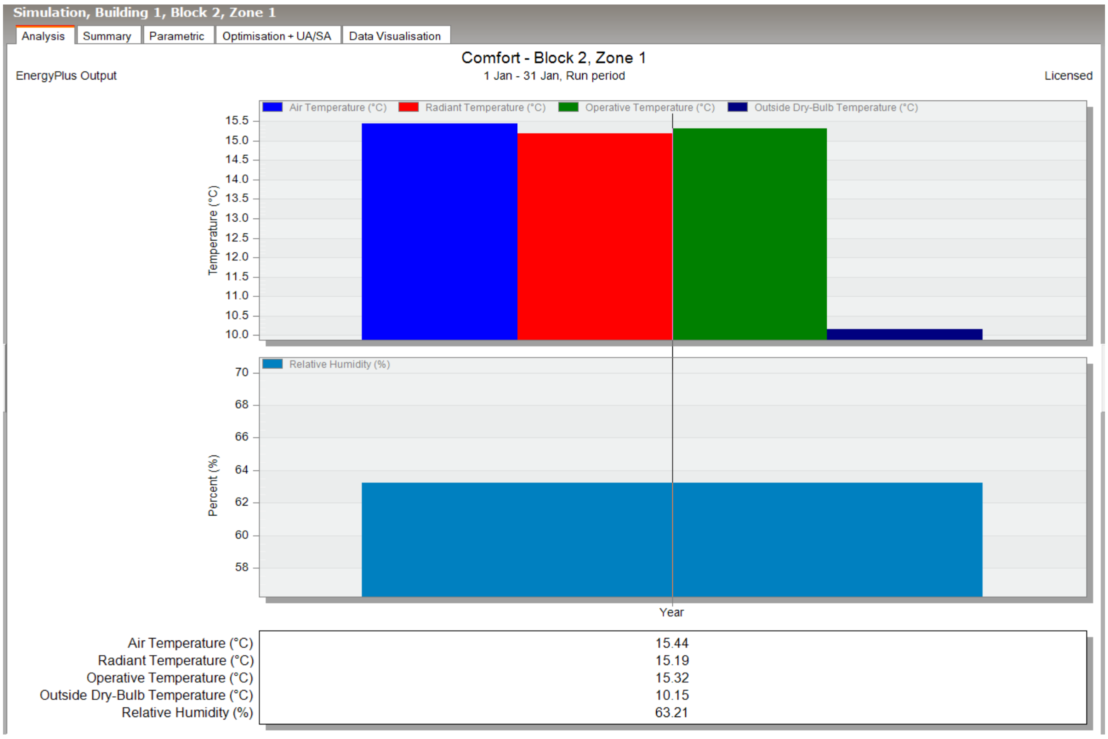


Figure 29 Internal Gain in Case 1

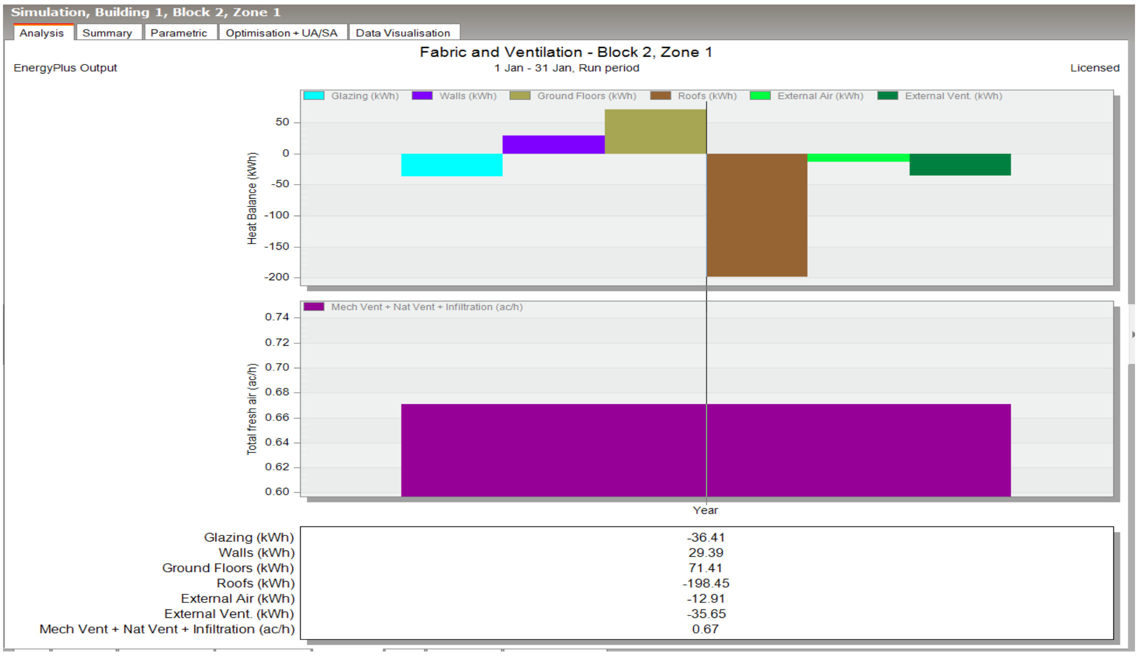


Figure 30 Façade Heat gain in Case 1

Case 2:

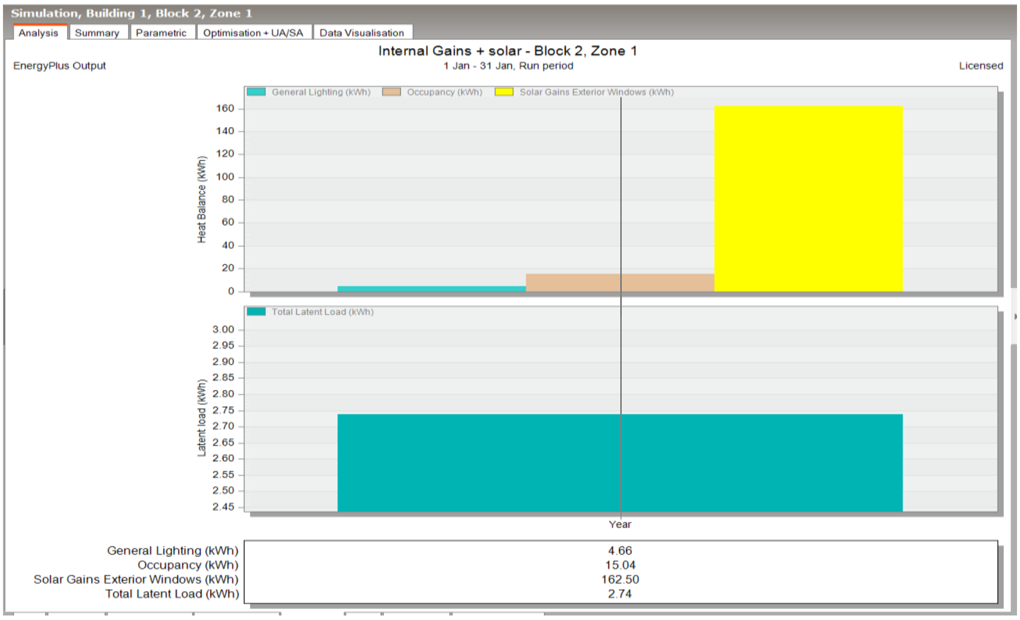


Figure 31 Internal gain in case 2

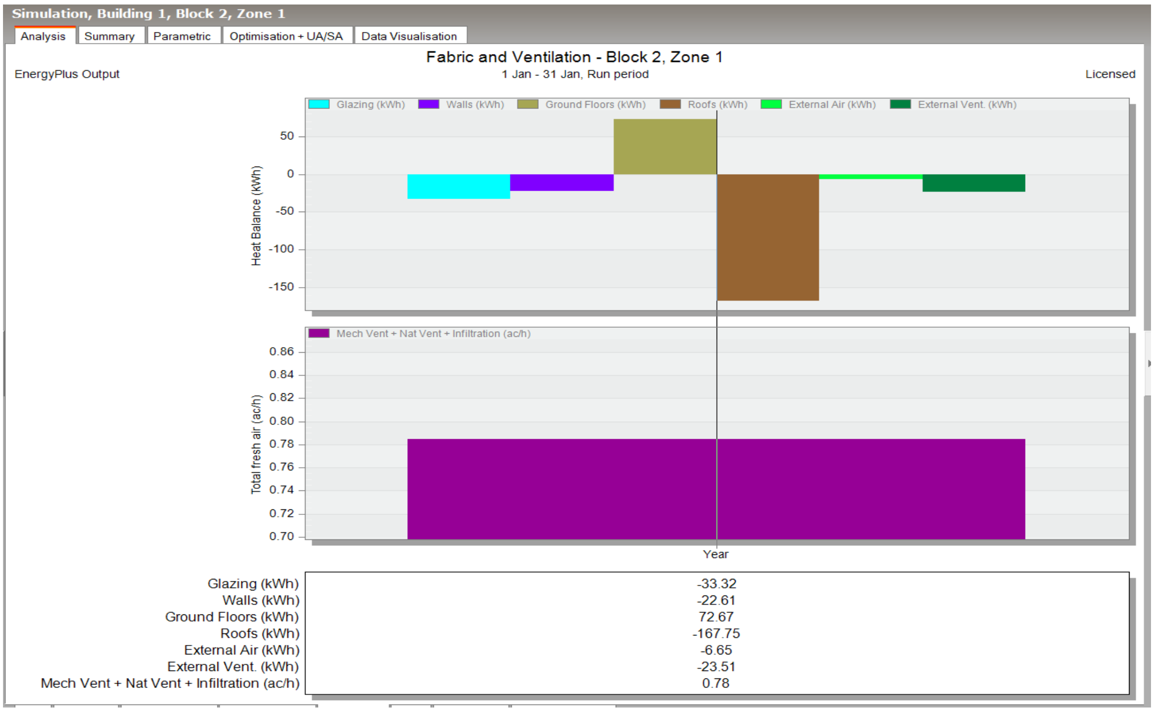


Figure 32 Façade gain in case 2

Case 3:

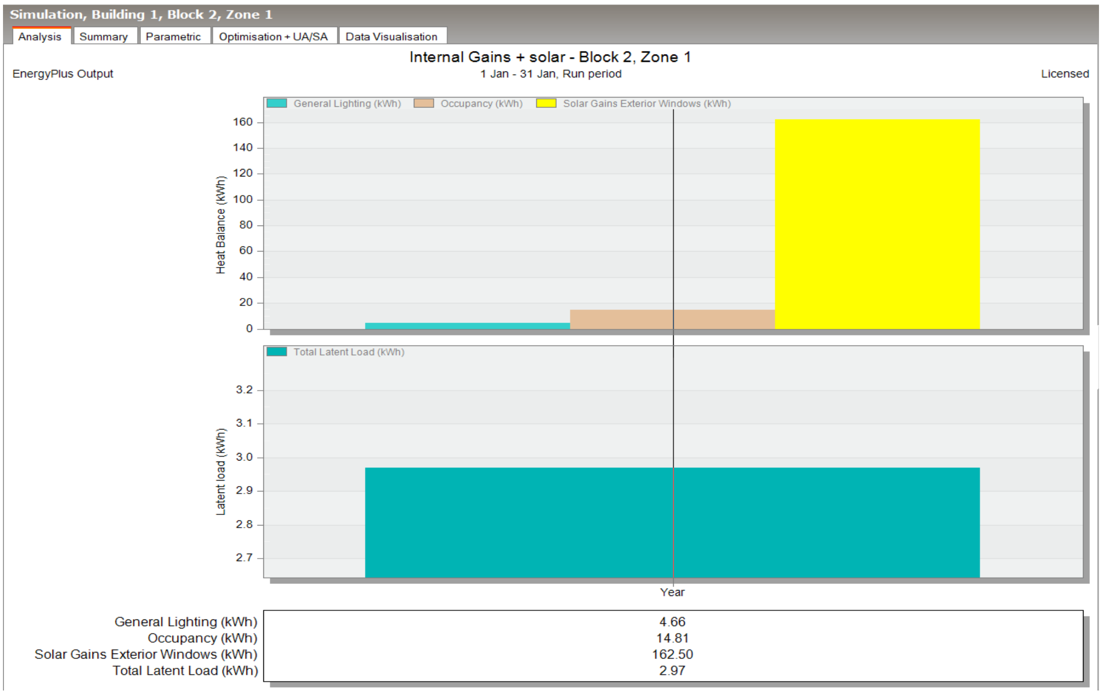


Figure 33 Internal gain in case 3

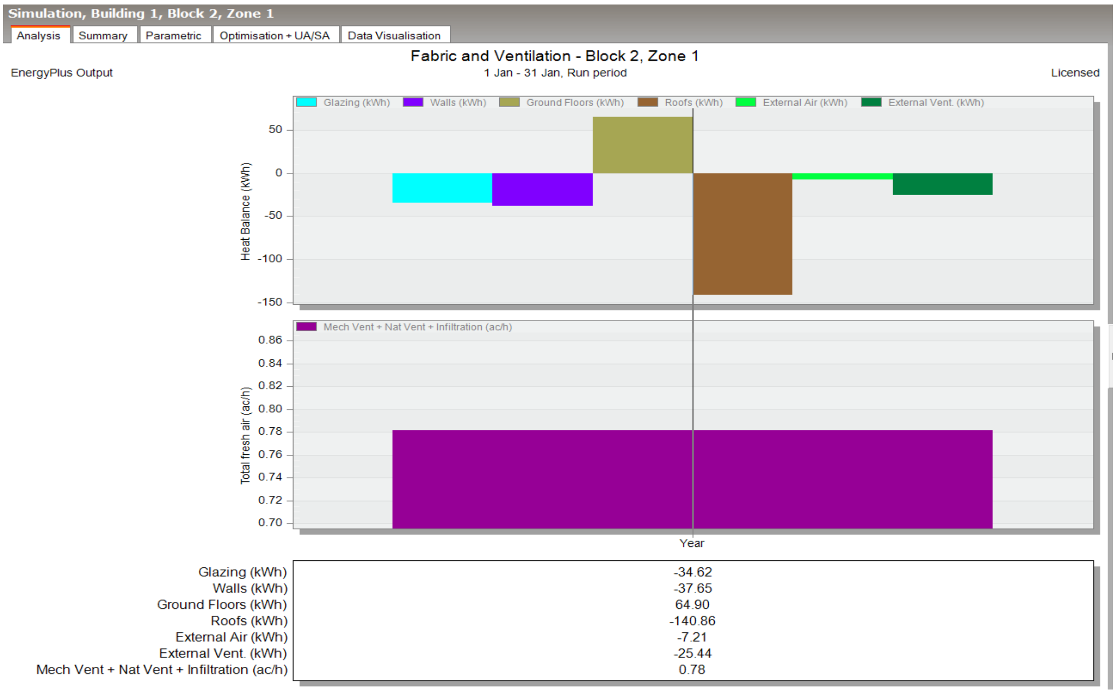


Figure 34 Façade gain in case 3

Timestamp: **2025-03-23 22:10:40**

Case 1:

	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]
PEOPLE BLOCK2:ZONE1	338.65	330.17

Timestamp: **2025-03-23 23:20:49**

Case 2:

	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]
PEOPLE BLOCK2:ZONE1	271.13	239.25

Timestamp: **2025-03-23 23:00:05**

Case 3 :

	ASHRAE55 90% Acceptability Limits [Hours]	ASHRAE55 80% Acceptability Limits [Hours]
PEOPLE BLOCK2:ZONE1	258.87	228.85

Figure 35 Comparative Discomfort Hour in Case 1, 2 and 3

The image compares three cases based on thermal comfort metrics following ASHRAE55 Acceptability Limits, which are internationally recognized standards for determining thermal comfort in buildings. These limits are categorized into two thresholds: 90% and 80% acceptability levels, representing the percentage of occupants expected to find the environment thermally comfortable. The analysis evaluates the total hours within each threshold across the three cases, highlighting differences in comfort levels due to varying environmental or design factors.

In Case 1, the highest thermal acceptability is achieved, with 338.65 hours within the 90% acceptability limit and 330.17 hours within the 80% limit. This indicates that Case 1 provides the most favorable thermal environment among the three. Meanwhile, Case 2 shows a noticeable drop in comfort hours, with 271.13 hours meeting the 90% limit and 239.25 hours falling under the 80% limit. Similarly, Case 3 has the lowest comfort hours, registering 258.87 hours for the 90% threshold and 228.85 hours for the 80% threshold, suggesting less efficient design or environmental conditions compared to Case 1.

4.5 Rate Analysis of Different Building Scenarios

4.5.1 Rate Analysis of Individual Materials

Actual rates for the GI sheet(4mm thickness), plywood(3cm) and Hollow concrete blocks(6inch) was used for the rate calculation. The rate for GI sheet(/m^2) , Concrete Blocks(/m^3) and plywood(/m^2) was calculated according to District Rate and Norms of Kathmandu (2080/81 amendment):

18	इटा	गोटा			2.21			0.0650			0.1730			3.05			19.00	19.00	चिम्नी भट्टाको
19	६" x ८" x ८" होलो कङ्क्रिट ब्लक	गोटा			8.18			0.0650			0.1730			3.05			60.00	60.00	
20	स्क्रिन हलो ब्लक (१२" x ४" x १२")	गोटा			10.38			0.0650			0.1730			3.05			90.00	90.00	
21	रङ्गीन जस्ता पाता ०.४५ मिमि	व.मि.	हो		4.04			0.0650			0.1730			3.60			894.06	894.06	0.45 मि.मि.
22	रङ्गीन जस्ता पाता ०.50 मिमि	व.मि.	हो		4.04			0.0650			0.1730			3.60			955.72	955.72	0.50 मि.मि.
23	रङ्गीन जस्ता पाता ०.३५ मिमि	व.मि.	हो		4.04			0.0650			0.1730			3.60			709.08	709.08	0.35 मि.मि.
24	सादा जस्ता पाता ०.४१ मिमि	व.मि.	हो		4.04			0.0650			0.1730			3.60			536.43	536.43	0.४१ मि.मि.
25	सादा जस्ता पाता ०.५० मिमि	व.मि.	हो		4.04			0.0650			0.1730			3.60			594.17	594.17	0.50 मि.मि.
26	सादा जस्ता पाता ०.45 मिमि	व.मि.	हो		4.04			0.0650			0.1730			3.60			536.43	536.43	0.45 मि.मि.

Figure 36 District Rate for Material as 2080/81 of Kathmandu Valley

दर प्रति घ.मी.को

रु. 4363.59 पै.

१५% ठेकेदार ओभरहेड 569.16

जम्मा दर रेट 4363.59

45

C13

कंक्रिट होलो ब्लकको गारो सिमेन्ट, बालुवा (१:४) मा लगाउने काम
३० मी. सम्म ढुवानी समेत

दर विश्लेषणको लागि १ घ.मि. लिइएको

स्रोत साधन	तह/किसिम	परिमाण	एकाई	दर प्रति एकाई	रकम	प्रत्येक स्रोत साधनको जम्मा
श्रमिक	क) सिपालु	0.25	जना	1030.00	257.50	
	ख) ज्यामी	0.25	जना	750.00	187.50	445.00
निर्माण सामग्री	१५०X२००X४०० एमएम को होलो ब्लक	13.00	गोटा	60.00	780.00	
	सिमेन्ट	0.014	मे.ट.	16700.00	233.80	
	बालुवा	0.044	घ.मी.	3107.28	136.72	
	पानी	12.00	लीटर	0.31	3.72	1154.24

वास्तविक दररेट 1599.24

दर प्रति घ.मी.को

१५% ठेकेदार ओभरहेड 239.88

?= 1839.12 पै.

जम्मा दर रेट 1839.12

Block Size 40*15*20cm For 1 sqm=13no

Figure 37 Rate Analysis for Concrete Block

From Rate Analysis:

Per m^3 rate for Concrete Block Masonry= Rs 1839/m^3

Per m^2 rate for GI sheet= Rs 700/m^2

Per m^2 rate for plywood= 3800/m^2

4.5.2 Actual Costing and LCA of Housing Solutions

The total cost of construction is obtained by providing Design Builder with standard rate (obtained after applying material, labor, machinery and taxes), whose summary is listed below.

Table 11 Cost Comparison Between Different Housing Solutions

Category	Floor/Construction Area (m²)	Cost (NPR) - Building 1	Cost (NPR) - Building 2	Cost (NPR) - Building 3
Structure Costs	15.8 / 15.0	3,326	3,158	3,158
HVAC Costs	15.8 / 15.0	0	0	0
Lighting Costs	15.8 / 15.0	950	902	902
Sub-Structure Costs	17.5	1,925	1,925	1,925
Super Structure Costs	73.7	60,441	78,496	135,965
- CGI Sheet Roof	17.8	12,428	12,428	79,897

- Wooden Door + Glazing	1.8	72	-	-
- Wooden Door	1.8	-	72	72
- CGI Sheet Wall	36.6	25,628	-	-
- Concrete Block Wall	36.6	-	33,683	33,683
- 75mm Concrete Slab	17.5	22,313	22,313	22,313
Total Cost	-	66,642	84,481	131,950

The table presents a detailed comparison of the construction costs for three buildings (Building 1, Building 2, and Building 3) across various categories, including structure, HVAC, lighting, sub-structure, and superstructure, with specific attention to materials used for each. The cost breakdown helps to assess how different elements of construction contribute to the overall cost of each building.

In the structure costs category, the floor or construction area is 15.8 m² for Building 1 and 15.0 m² for Buildings 2 and 3. The costs for structure construction are relatively consistent, with Building 1 having a cost of NPR 3,326 and Buildings 2 and 3 each having a cost of NPR 3,158. This indicates that the structural design and materials used in all three buildings are very similar, with only minor cost variations.

In terms of lighting costs, all three buildings have a similar floor area for lighting, at 15.8 m² for Building 1 and 15.0 m² for the other two. The lighting costs are also quite comparable, with Building 1 incurring a cost of NPR 950, while Buildings 2 and 3 both have lighting costs of NPR 902. The minor cost differences likely reflect variations in the type or number of light fixtures used, though the overall lighting design remains relatively similar.

The sub-structure costs, which account for foundational elements like the foundation and lower parts of the building, are consistent across all three buildings at NPR 1,925 each. This suggests that the foundation work or similar sub-structural components are identical for all buildings.

The **superstructure costs**, which include the primary structural components above the foundation, vary significantly across the three buildings. Building 1 incurs NPR 60,441 for the superstructure, while Building 2 costs NPR 78,496, and Building 3 is the most expensive at NPR 135,965. These costs likely reflect different materials, structural designs, or additional features incorporated into the buildings. Specifically, the sub-items under the superstructure category show where the differences lie: for example, Building 1 and Building 2 both use CGI sheet roofing and concrete slab walls, but Building 3 has higher costs due to different materials, such as concrete block walls and additional CGI sheet walls. Building 3 also includes a more expensive CGI sheet roof.

Finally, the **total cost** of each building is calculated by adding all the individual costs in each category. Building 1 has a total cost of NPR 66,642, Building 2 totals NPR 84,481, and Building 3, with the highest costs across several categories, totals NPR 131,950. This breakdown illustrates that Building 3 has the most complex or costly design and materials, while Building 1 offers the most cost-effective solution.

Table 12 LCA Analysis of Different Buildings

Category	Embodied Carbon ($kgCO_2$) - Building 1	Equivalent CO_2 ($kgCO_2$) - Building 1	Embodied Carbon ($kgCO_2$) - Building 2	Equivalent CO_2 ($kgCO_2$) - Building 2	Embodied Carbon ($kgCO_2$) - Building 3	Equivalent CO_2 ($kgCO_2$) - Building 3
Materials Embodied Carbon						

- Textured Door	0.0	0.0	0.0	0.0	0.0	0.0
- Plywood	0.0	0.0	0.0	0.0	0.0	0.0
- CGI Sheet (Blue)	276.8	297.7	276.8	297.7	276.8	297.7
- CGI Sheet (White)	570.8	613.9	-	-	-	-
- Concrete Block	-	-	0.0	0.0	0.0	0.0
- Earth Common	115.0	115.0	115.0	115.0	115.0	115.0
- Cast Concrete (Dense)	220.5	220.5	220.5	220.5	220.5	220.5
Materials Sub Total	1183.1	1247.1	612.3	633.2	612.3	633.2
Constructions Embodied Carbon						
- CGI Sheet Roof (Blue Plywood)	276.8	297.7	276.8	297.7	276.8	297.7
- Wooden Door	0.0	0.0	0.0	0.0	0.0	0.0

- CGI Sheet Wall	570.8	613.9	-	-	-	-
- Concrete Block Wall	-	-	0.0	0.0	0.0	0.0
- 75mm Concrete Slab	335.5	335.5	335.5	335.5	335.5	335.5
Constructions Sub Total	1183.06	1247.08	612.28	633.18	612.28	633.18
Glazing Embodied Carbon						
- Single Clear 3mm Glass	21.6	21.6	21.6	21.6	21.6	21.6
- Local Shading	0.0	0.0	0.0	0.0	0.0	0.0
- Window Shading	0.0	0.0	0.0	0.0	0.0	0.0
Glazing Sub Total	21.6	21.6	21.6	21.6	21.6	21.6
Renewables Embodied Carbon						
- PV Panels	0.0	0.0	0.0	0.0	0.0	0.0
Renewables Sub Total	0.0	0.0	0.0	0.0	0.0	0.0

Building Total	1204.7	1268.7	633.9	654.8	633.9	654.8

Above table compares the embodied carbon and equivalent CO_2 emissions of three buildings (Building 1, Building 2, and Building 3), focusing on the materials, construction, glazing, and renewables involved. Embodied carbon refers to the CO_2 emissions generated throughout the lifecycle of materials and construction, while equivalent CO_2 quantifies the total impact in terms of CO_2 emissions.

For materials embodied carbon, Building 1 has the highest total at 1183.1 kg, with an equivalent CO_2 of 1247.1 kg. The major contributors to this figure are the CGI sheets (both blue and white), earth common, and cast concrete (dense). The use of white CGI sheet materials in Building 1 significantly increases its embodied carbon. Building 2, on the other hand, has much lower embodied carbon at 612.3 kg, with an equivalent CO_2 of 633.2 kg. This reduction is largely due to the absence of white CGI sheets and concrete block materials in Building 2's design. Building 3 has the same embodied carbon and equivalent CO_2 as Building 2, both totaling 612.3 kg and 633.2 kg, respectively, indicating similar material choices between these two buildings.

In the construction embodied carbon category, which includes materials like CGI sheet roofs, concrete slabs, and walls, the figures follow a similar trend. Building 1 again has the highest embodied carbon at 1183.06 kg, with an equivalent CO_2 of 1247.08 kg. This includes contributions from CGI sheet roofing and walls, as well as the 75mm concrete slab. Building 2's total construction embodied carbon is 612.28 kg, with an equivalent CO_2 of 633.18 kg, while Building 3 shares the same values as Building 2, demonstrating similar construction methods and materials between the two.

Overall, Building 1 has the highest total embodied carbon at 1204.7 kg and an equivalent CO_2 of 1268.7 kg, largely due to its use of white CGI sheets and extensive use of concrete. Both Building 2 and Building 3 have the same total embodied carbon and equivalent CO_2, at 633.9 kg and 654.8 kg, respectively, indicating more sustainable material and construction choices compared to Building 1.

4.5.3 Benefit/Cost Analysis of Evaluated Building Solutions

A brief analysis comparing LCA, cost and comfort hours/discomfort hours, thermal gain was conducted to evaluated best fit options amongst all building solutions.

Table 13 Discomfort Hours using ASHRAE Standards

Building	ASHRAE 90% Acceptability Limit (Hours)	ASHRAE 80% Acceptability Limit (Hours)
Building 1	338.65	330.17
Building 2	258.87	228.85
Building 3	271.13	239.25

Table 14 Benefit vs Cost Analysis

Criteria	Building 1	Building 2	Building 3	Best Choice
Embodied Carbon	High (1204.7 $kgCO_2$)	Low (633.9 $kgCO_2$)	Low (633.9 $kgCO_2$)	Building 2/3
Cost (Nrs)	Rs. 67,000	Rs. 85,000	Rs. 1,32,000	1st
Thermal Comfort (Discomfort Hours)	338.65 (worst)	258.87 (better than B1)	241.13 (better than B1, and B2)	Building 3

Building 2 emerged as the best option based on a holistic evaluation of environmental impact, thermal comfort, and cost-effectiveness. It had the lowest embodied carbon footprint (633.9 $kgCO_2$), which is nearly 50% lower than Building 1 (1204.7 $kgCO_2$). This significant reduction in embodied carbon highlights its superior sustainability, making it a more environmentally responsible choice. Additionally, while Building 3 had a similar carbon footprint, Building 2 outperformed it in thermal comfort.

Table 15 Weightage Criteria for Best fit Model Selection

Criteria	Weight (%)	Justification	Source
Affordability	45%	Housing affordability is a primary factor in cost-benefit analysis, often assessed based on income expenditure. Studies indicate that affordability should hold the highest weight in decision-making.	Ali et al., 2024
Thermal Comfort	30%	Ensuring comfortable indoor conditions improves well-being and reduces energy costs. Research highlights that thermal performance is critical in affordable housing design.	Wang et al., 2021
Environmental Sustainability	25%	Sustainable housing design reduces long-term carbon footprints and enhances energy efficiency. Studies emphasize sustainability's role in affordability assessments.	Jones & Smith, 2019

Benefit-Cost Analysis for Building Selection

In order to select the most optimal building design, a Benefit-Cost Analysis (BCA) was conducted based on three key criteria: Affordability, Thermal Comfort, and Environmental Sustainability. The weightage assigned to each criterion is as follows:

- Affordability: 45%
- Thermal Comfort: 30%
- Environmental Sustainability: 25%

Step 1: Normalization of Scores

The following normalization process was applied to each criterion:

1. Affordability (Cost): The costs for each building were normalized by dividing each building's cost by the lowest cost (Building 1).
    - Normalized Cost for Building 1 = 1.0
    - Normalized Cost for Building 2 = 1.27

- Normalized Cost for Building 3 = 1.97

2. Thermal Comfort (Discomfort Hours): The discomfort hours for each building were normalized by dividing each building's discomfort hours by the lowest discomfort hours (Building 2).
   - Normalized Thermal Comfort for Building 1 = 1.31
   - Normalized Thermal Comfort for Building 2 = 1.0
   - Normalized Thermal Comfort for Building 3 = 1.05
3. Environmental Sustainability (Embodied Carbon): The embodied carbon for each building was normalized by dividing each building's embodied carbon by the lowest value (Building 2 or Building 3).
   - Normalized Embodied Carbon for Building 1 = 1.9
   - Normalized Embodied Carbon for Building 2 = 1.0
   - Normalized Embodied Carbon for Building 3 = 1.0

Step 2: Calculation of Weighted Scores

The weighted scores for each building were then calculated using the following formula:

$$\text{Score}=(W_{\text{Affordability}}\times\text{Normalized Cost})+(W_{\text{Thermal Comfort}}\times\text{Normalized Thermal Comfort})+(W_{\text{Environmental Sustainability}}\times\text{Normalized Embodied Carbon})$$

Step 3: Calculating the Scores

Using the normalization values, the following weighted scores were calculated:

1. Building 1:

$$\text{Score1}=(0.45\times1.0)+(0.30\times1.31)+(0.25\times1.9)=0.45+0.393+0.475= 1.318$$

2. Building 2:

$$\text{Score2}=(0.45\times1.27)+(0.30\times1.0)+(0.25\times1.0)=0.5715+0.30+0.25=1.1215$$

3. Building 3:

$$\text{Score3}=(0.45\times1.97)+(0.30\times1.05)+(0.25\times1.0)=0.8865+0.315+0.25= 1.4515$$

Step 4: Conclusion

Based on the calculated scores, Building 2 emerges as the best choice with the lowest score of 1.1215, indicating it is the most balanced option in terms of affordability, thermal comfort, and environmental sustainability.

- Building 1: Score = 1.318
- **Building 2: Score = 1.1215 (Best Choice)**
- Building 3: Score = 1.4515

From the thermal performance perspective, Building 3 recorded the lowest discomfort hours, with 258.87 hours at the ASHRAE 90% acceptability limit and 228.85 hours at the ASHRAE 80% acceptability limit. In contrast, Building 1 had the worst thermal comfort, with discomfort hours reaching 338.65 hours (90% limit) and 330.17 hours (80% limit). Although Building 2 performed better than Building 1, with 271.13 and 239.25 discomfort hours, it still did not match the comfort level of Building 2. The decision-making was driven by sustainability and comfort. Therefore**, building 2 was the optimal choice**, balancing all theree factors most effectively.

Validation with relevant research articles:

Table 16 Research Articles Backing GI Roof+ Concrete Block Façade for Thermally Comfortable and Affordable Houses

Aspect	Findings	Reference
Economic Sustainability	- **Affordability**: Concrete blocks and GI sheets are cost-effective materials, reducing initial construction expenses. Their durability minimizes maintenance costs, making them suitable for low-income housing.- **Cost-Effectiveness**: Utilizing local materials like concrete blocks and GI sheets can significantly lower construction costs, enhancing affordability for low-income populations.	IIE (2022)

Environmental Impact	- **Sustainability**: Concrete blocks can incorporate recycled materials, reducing environmental impact. GI roofing materials are recyclable, supporting sustainable building practices.- **Reduced Environmental Footprint**: Alternative construction technologies, such as using concrete blocks, have shown potential in reducing environmental impacts compared to conventional methods.	Salzer, C., et al. (2017)
Thermal Performance	- **Heat Mitigation**: Implementing low-cost thermal upgrades to GI roofs can significantly reduce indoor temperatures, mitigating overheating in slum housing.- **Thermal Comfort**: Concrete block walls provide thermal mass that helps in stabilizing indoor temperatures, enhancing occupant comfort.	Hashemi, A., & Cruickshank, H. (2022)
Occupant Comfort	- **Improved Living Conditions**: Combining concrete block walls with GI roofs, especially when incorporating passive design strategies and thermal upgrades, enhances indoor environmental quality, contributing to better health and well-being of occupants in informal settlements.	Hashemi, A., & Cruickshank, H. (2022)

4.5.4 Pay Back Period Analysis

Building 2 (costing NPR 84,481) for squatter families in Nepal, considering a revised loan structure under specific loan conditions. The analysis includes calculations for loan repayment, the effect of interest, and the percentage of monthly income that would go towards loan repayment.

Loan Details:

- Loan Amount: NPR 84,481
- Interest Rate: 8% per annum (compound interest)
- Loan Term: 12 years
- Monthly Income of Squatter Families: NPR 9,687.50 (as per the study team)

Step-by-Step Calculations:

a) Annual Interest Payment: To determine the annual interest payment, we apply the formula for compound interest. For the first year, the interest is calculated as follows:

Annual Interest Payment=Loan Amount × Interest Rate

Annual Interest Payment=84,481×0.08=6,758.48NPR

b) Annual Principal Repayment: The principal repayment is calculated by dividing the total loan amount by the loan term (12 years):

Annual Principal Repayment=Loan Amount/Loan Term

Annual Principal Repayment=84,481/12=7,040.08NPR

c) Total Annual Payment: The total annual payment is the sum of the annual interest payment and the annual principal repayment:

Total Annual Payment

=Annual Interest Payment + Annual Principal Repayment

Total Annual Payment=6,758.48+7,040.08=13,798.56NPR

d) Monthly Payment: Monthly Payment=Total Annual Payment/12

Monthly Payment=13,798.56/12≈1,149.88NPR

e) Percentage of Monthly Income: To assess the impact of the monthly payment on the squatter families' finances, we calculate the percentage of their monthly income that would be used to repay the loan:

Percentage of Monthly Income= (Monthly Payment /Monthly Income) ×100

Percentage of Monthly Income= (1,149.88/9,687.50) ×100≈11.87%

Providing housing loans for Building 2 at an 8% interest rate with a 12-year term appears to be a feasible and affordable solution for squatter families in Nepal. The monthly loan repayment is approximately NPR 1,149.88, which constitutes about 11.87% of the families' monthly income. This indicates that the loan repayment is relatively manageable, given the average monthly income of NPR 9,687.50. The lower percentage of income required for repayment ensures that the housing loan is an affordable option for these families, making it a viable solution to improve their living conditions.

4.6 Energy efficiency awareness

Awareness and use of energy efficient appliances: All respondents were unaware of energy-efficient appliances, and many lacked detailed knowledge regarding the specific benefits of these devices. However, despite this lack of awareness, it became clear that due to the widespread availability of energy-efficient products in the market, many residents were unknowingly using energy-efficient appliances. This was particularly evident in the homes, where all the bulbs were LED, and a few shops still had tube lights installed. Additionally, many of the refrigerators in the homes were star-rated, indicating that they met specific energy efficiency standards. Similarly, the televisions in the households were all LED, contributing to lower energy consumption compared to older, more energy-intensive models. Furthermore, the increasing awareness of rising energy costs and the influence of manufacturers and retailers promoting energy-efficient products could have also played a role in the adoption of these more sustainable appliances. Despite the lack of formal knowledge, the residents seemed to be adopting energy-efficient technologies in response to market trends and the growing availability of energy-saving alternatives.

Training or information on energy conservation: None of the respondents had received any formal training or information on energy conservation, which highlights a significant gap in awareness and knowledge on this important topic. Despite this, a small portion of the respondents, about 20%, expressed interest in attending training sessions or seminars aimed at educating them on energy conservation techniques. These individuals recognized the potential benefits of learning how to reduce energy consumption and were open to improving their energy efficiency practices. On the other hand, a majority, around 80%, showed no interest in such learning opportunities. This lack of interest could be attributed to a variety of factors, such as a general lack of awareness about the importance of energy conservation, perceived inconvenience, or a belief that the current energy usage practices were already sufficient. It also reflects a potential challenge in encouraging widespread participation in energy conservation programs, even though such initiatives could have significant benefits both in terms of cost savings and environmental sustainability.

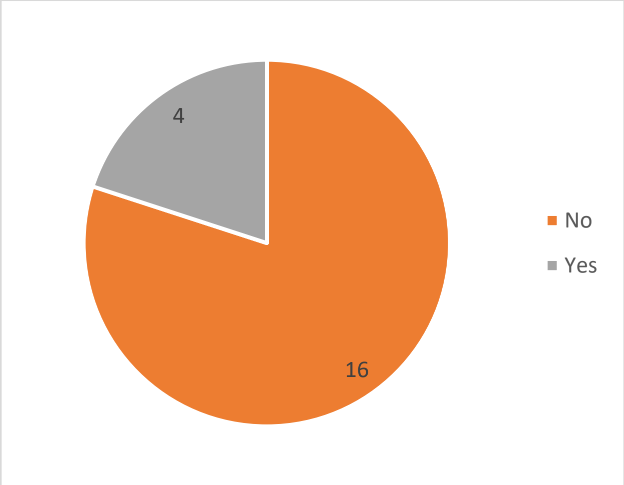


Figure 38 Respondents interested in learning about energy conservation

Similarly, 60% of the respondents mentioned to regularly switching off the lights and to utilizing natural light in the day time. It reflects that proper awareness regarding energy efficiency and passive strategies is required in the case area.

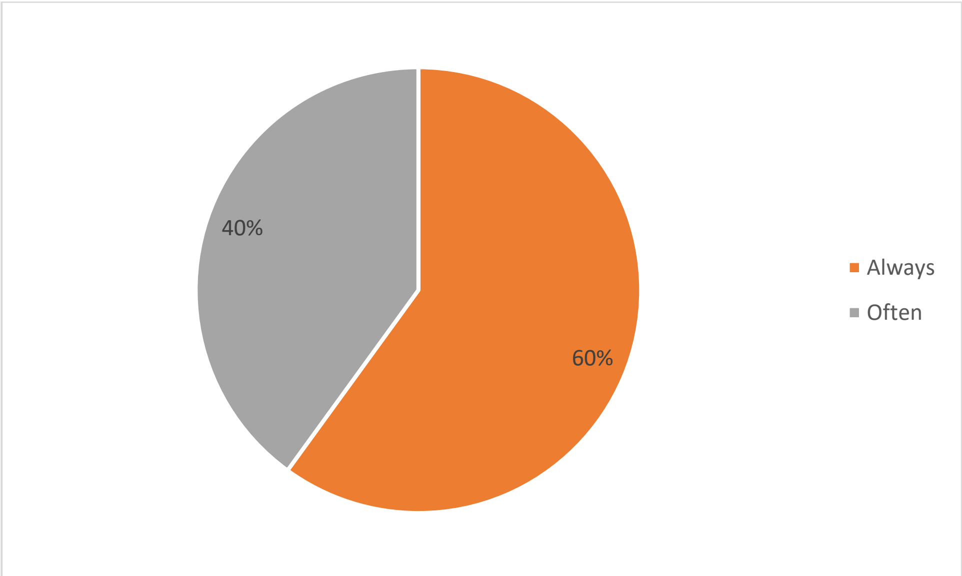


Figure 39 Respondents who regularly switch off lights

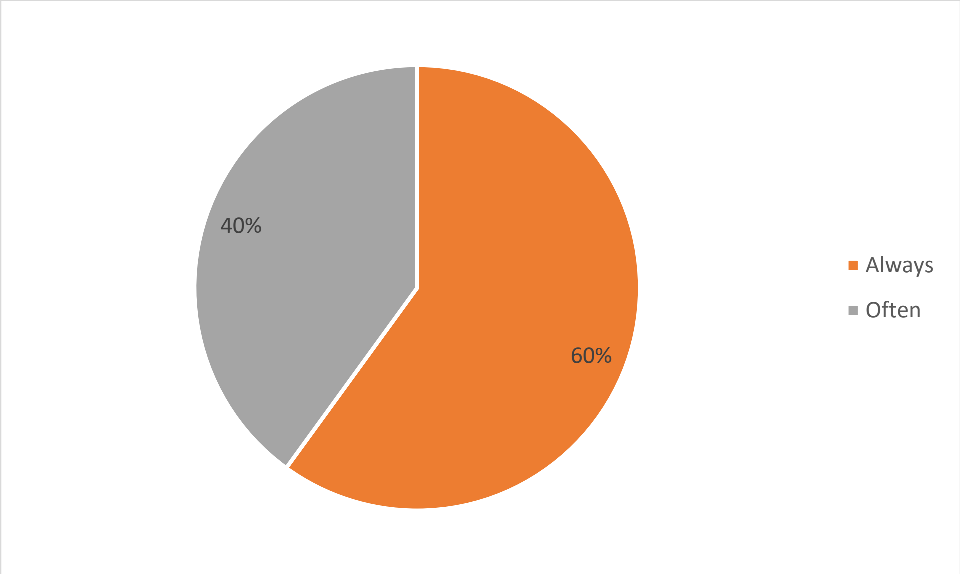


Figure 40 Respondents utilizing natural light in day

4.7 Challenges and perceptions

The respondents identified several significant challenges in accessing reliable energy in the informal settlement. These challenges included a lack of information, an unreliable energy supply, the high cost of energy, and poor infrastructure. Notably, 75% of the respondents believed that the lack of information was the primary issue they faced. This highlights an urgent need for awareness and informative programs within the case study area to bridge the knowledge gap. Without access to accurate and timely information about energy conservation and available technologies, residents remain unaware of more efficient alternatives and solutions. This lack of knowledge contributes to the persistence of inefficient energy usage and missed opportunities for energy savings.

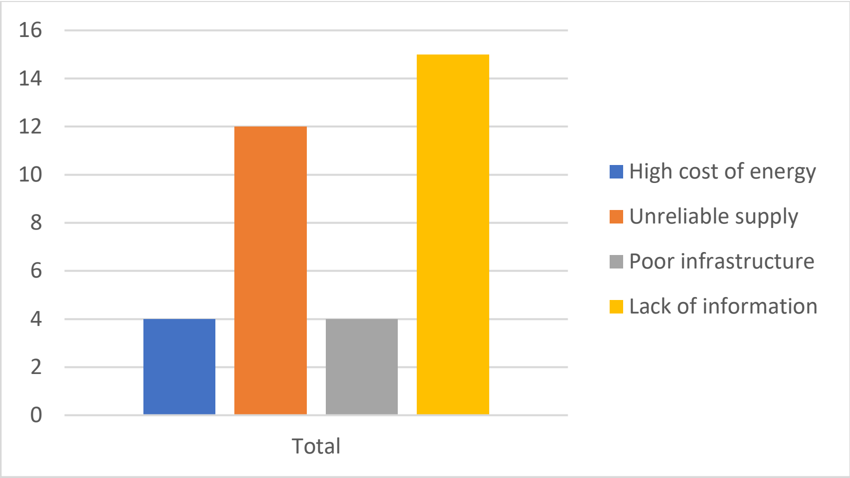


Figure 41 Challenges faced by the respondents in accessing reliable energy

In addition to identifying the challenges, the respondents also suggested several effective ways to improve energy access and efficiency in informal settlement sites. The majority of the respondents emphasized that providing subsidies for energy-efficient appliances would be a key strategy. Such financial support could make energy-efficient technologies more affordable and accessible to low-income households. Following this, community awareness programs were identified as another crucial approach. These programs could help educate residents about the benefits of energy-efficient appliances, proper usage techniques, and simple behavioral changes to reduce energy consumption.

Moreover, the respondents recognized that the economic status of the residents, their willingness to invest in advanced technology, and their level of awareness all play significant roles in shaping the energy efficiency in informal settlement households. The residents' financial constraints may limit their ability to invest in energy-efficient technologies, but by offering subsidies or financial incentives, their willingness to adopt these solutions could increase. Additionally, the overall level of awareness regarding the importance of energy efficiency and the available solutions directly influences the degree of implementation of these technologies in the settlement. This underscores the need for a multi-faceted approach that addresses both the financial and informational barriers to improving energy efficiency in these communities.

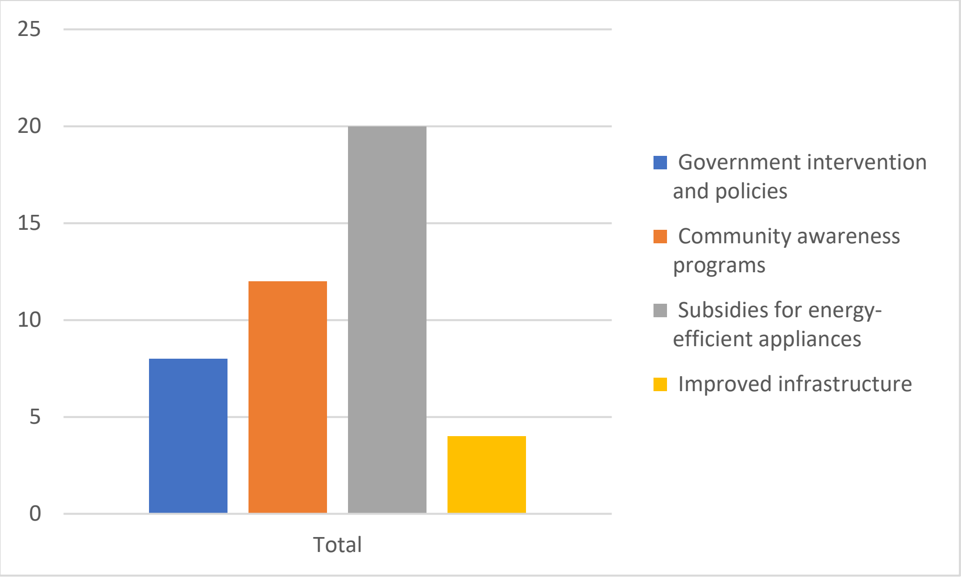


Figure 42 Effective ways to improve energy access and efficiency

CHAPTER 5: Findings and Discussions

5.1 Introduction

The study conducted in Jagriti Nagar and Bansighat has provided valuable insights into the complex interplay between energy consumption behavior, socio-economic factors, and energy efficiency awareness and perception among households. The findings offer a detailed understanding of how energy consumption varies among different households in informal settlements and highlight the need for targeted interventions to address energy inefficiencies.

Energy consumption patterns in these informal settlements are influenced significantly by household characteristics such as income, education level, and household size. Higher-income and more educated households tend to consume more energy due to their greater access to a variety of electrical appliances, such as air conditioners, refrigerators, and other modern household technologies. These households are more likely to have multiple appliances running simultaneously, leading to higher overall energy consumption. On the other hand, lower-income households restrict their energy use to essential appliances like lighting and cooking equipment, which results in comparatively lower energy consumption. However, this restriction often means that these households are unable to benefit from modern energy-efficient appliances that could reduce their overall energy expenditure.

Socio-economic factors also play a crucial role in determining household energy use. Income levels, education, and the presence of special household members such as single women, elderly people, or individuals with disabilities significantly influence energy consumption patterns. Higher-income and educated households are more likely to adopt energy-efficient practices due to their greater access to information and resources. In contrast, vulnerable households may face unique energy needs and barriers to adopting energy-saving technologies. For instance, households with special needs may require tailored energy solutions that account for the specific challenges they face, such as the need for more consistent or regulated heating and cooling.

Awareness and perception of energy efficiency are key determinants of energy-saving behaviors. A majority of the households in the study were found to be unaware of energy-efficient technologies, and there was little interest in participating in energy conservation programs. This lack of awareness and engagement suggests that educational initiatives and economic incentives are essential for promoting energy efficiency. By raising awareness about the benefits of energy-efficient appliances and how they can reduce both energy consumption and costs, residents can be encouraged to adopt energy-saving practices. Furthermore, offering economic incentives such as subsidies or financing options for energy-efficient appliances could make them more accessible to lower-income households.

The study's findings underline the need for targeted policies to promote energy efficiency, particularly for vulnerable households. Policymakers could consider income-based subsidies that reduce the upfront costs of energy-efficient appliances, making them more affordable for households in informal settlements. Educational campaigns that focus on the benefits of energy efficiency, as well as tailored support programs that address the specific energy needs of vulnerable populations, could significantly improve energy conservation practices. By focusing on increasing awareness and making energy-efficient appliances more accessible, these policies could help drive sustainable energy consumption practices across the settlement.

This study provides a foundation for future comprehensive studies on energy usage in informal settlements. It highlights the importance of considering socio-economic factors, such as income and education, alongside energy efficiency awareness in order to design effective interventions that meet the diverse energy needs of households. With a focus on tailored solutions and targeted support, energy efficiency in informal settlements can be significantly improved, leading to more sustainable and equitable energy practices in the long term.

5.2 Finding and Discussion related to objectives of the study

Findings which explain and answer the objectives of thesis are:

5.2.1 Analyzing the energy consumption behavior of informal settlements

The first research objective of this study was to analyze the energy consumption behavior of informal settlements in the Kathmandu Valley. This thesis successfully addresses this objective by providing a comprehensive assessment of the multiple factors influencing energy use in these settlements, with a particular focus on socio-economic conditions, access to energy infrastructure, and household consumption patterns. Through the collection of primary data, including surveys and field observations, the study explores how residents in these informal settlements rely on various energy sources, such as traditional biomass (wood, agricultural residues), liquefied petroleum gas (LPG), and grid electricity. The study reveals significant disparities in energy consumption patterns across different income groups, shedding light on the complex relationship between socio-economic status and energy use in these areas. For instance, higher-income households have greater access to grid electricity and are more likely to invest in energy-efficient appliances, while lower-income households often rely on more costly and less efficient alternatives like LPG or biomass, due to limited access to reliable electricity.

One of the key findings of this study is how affordability, reliability, and efficiency are intertwined in shaping the energy consumption behavior of informal settlement residents. Low-income households face immense challenges in affording the high costs of energy, which often forces them to use inefficient and costly energy sources, further exacerbating their financial burden. Meanwhile, socio-economic factors such as education and occupation influence how energy is consumed, with educated households more likely to adopt energy-efficient practices, while households with lower educational levels may be unaware of the long-term savings associated with such measures. The study clearly demonstrates that socio-economic conditions, in combination with limited access to formal energy infrastructure, result in an energy consumption pattern that is unsustainable and inefficient, especially in informal housing areas.

In addition to income and infrastructure, other socio-economic factors such as marital status, family size, caste, and education level also have a significant impact on energy consumption patterns in informal settlements. Marital couples, particularly those with children, tend to have higher energy demands due to the increased household activities that require more energy-consuming appliances, such as larger refrigerators, water heaters, and fans. Larger family sizes often lead to higher energy consumption, as more people contribute to the use of household appliances and lighting. Furthermore, the study found that education level plays a crucial role in shaping energy consumption behavior. Households with higher educational attainment are generally more aware of the importance of energy efficiency and are more likely to adopt energy-saving practices. They tend to invest in energy-efficient appliances and seek ways to reduce energy use through behavioral changes, such as using energy-efficient lighting or regulating the use of air conditioning. In contrast, households with lower educational levels may lack awareness about energy-saving opportunities, which leads to inefficient energy use despite lower overall consumption. Caste, as a socio-cultural factor, also influences household energy consumption to a certain extent, with certain caste groups in Nepal traditionally occupying areas with less access to reliable energy infrastructure. These socio-cultural dynamics often exacerbate the already existing challenges of affordability and access, creating a complex web of factors that influence energy use patterns. Understanding these interlinkages between marital status, family size, caste, and education level is essential for designing targeted interventions that can effectively promote energy efficiency and reduce consumption in these communities.

Additionally, the research broadened its scope by incorporating comparative case studies from informal settlements in other global contexts. By examining best practices from cities with similar socio-economic, climatic, and infrastructural conditions, the study identifies effective strategies for improving energy efficiency in low-income urban housing. These case studies illustrate how other cities have successfully implemented energy-efficient housing solutions, such as subsidized energy-efficient materials, incentives for renewable energy adoption, and community-driven approaches to sustainable housing development. These insights not only provide valuable lessons for improving energy efficiency in Kathmandu's informal settlements but also emphasize the potential for applying similar policy interventions in other low-income urban settings. By integrating these global best practices, the study strengthens its findings and underscores the importance of targeted, context-specific interventions to promote sustainable housing and energy practices.

This research not only evaluates the energy consumption behaviors of informal settlement residents but also highlights the significant interlinkages between socio-economic factors and energy use in these communities. The findings underscore the need for targeted energy interventions that consider the specific challenges faced by low-income families. By addressing issues related to affordability, efficiency, and energy access, the study contributes to the development of a more sustainable energy framework for informal settlements in Kathmandu and similar urban areas worldwide.

The insights provided by this study lay a strong foundation for policy recommendations and future research aimed at improving energy access, reducing energy costs, and enhancing the overall quality of life for residents of informal settlements.

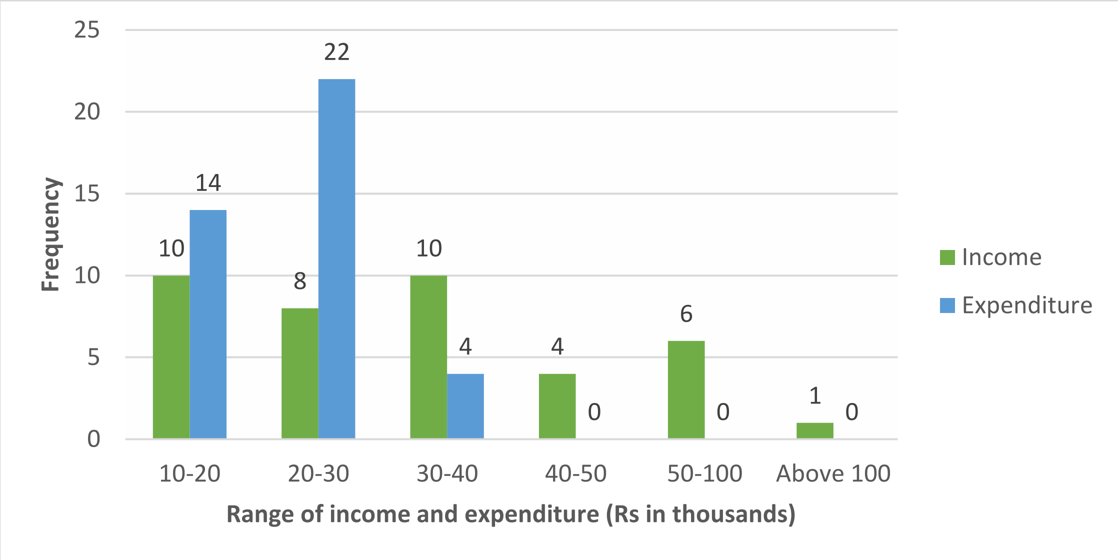


Figure 43 Income vs Expenditure of People in Squatters

Paradox of Energy Use vs Income in Informal Settlements

Squatter households, particularly those in informal settlements, often rely on more expensive and less reliable alternatives for their energy needs. These include sources such as LPG cylinders, kerosene, and illegally purchased electricity, which cost more per unit than grid electricity. The reliance on such energy sources further exacerbates the financial strain on these households. Additionally, many of these families use inefficient stoves, lighting systems, and household appliances, which leads to higher energy consumption and costs. Despite using less energy overall, the inefficiency of these systems causes their energy bills to remain disproportionately high. This is compounded by the fact that the appliances and energy systems used in these informal settlements are often outdated and poorly maintained, further amplifying the wasteful consumption of energy.

The financial burden of energy costs is especially acute for low-income families in squatter settlements. According to the study, low-income households spend a significant portion of their income—approximately **40%**—on energy, equating to about **3,000 NPR per month**. In contrast, higher-income families earning **60,000–70,000 NPR per month** spend only about **10-12%** of their income on energy, which amounts to approximately **7,000–8,000 NPR**. This stark difference in energy expenditure underscores the disproportionate financial pressure that low-income households face. Despite earning much less, these families allocate a much higher percentage of their income to cover the costs of their energy needs. This reality highlights the unsustainable nature of the current energy consumption patterns in informal settlements and reinforces the need for affordable, efficient energy solutions tailored to the specific challenges of these communities.

Moreover, this situation calls attention to the broader implications for the well-being of families living in informal settlements. The high energy costs, coupled with the inefficiency of the appliances and systems they rely on, contribute to a cycle of poverty that is difficult to break. Households in these areas often cannot afford to invest in more energy-efficient appliances, which perpetuates the reliance on costly and inefficient energy sources. The financial strain on these families not only affects their standard of living but also limits their ability to invest in other critical areas, such as education, health, and housing improvements.

This study, emphasizes the urgent need to raise awareness about energy efficiency and promote energy-efficient housing solutions in informal settlements. Educating residents about energy-saving practices, as well as providing access to affordable energy-efficient technologies, can significantly reduce their energy expenditure and improve their quality of life. Additionally, introducing policies that make energy-efficient appliances and alternative energy solutions more accessible to low-income households could help alleviate the financial burden and promote sustainable energy use.

This study successfully addresses the first research objective by providing a comprehensive evaluation of energy consumption patterns in informal settlements. It identifies the key challenges faced by these households, including high energy costs, inefficient appliances, and limited access to reliable energy sources. Furthermore, the thesis proposes practical solutions aimed at enhancing energy efficiency in these communities, such as promoting affordable energy-efficient technologies and developing targeted interventions to improve energy access. By integrating field data, computational simulations, and global case studies, the study offers a well-rounded analysis that informs future urban policies and housing strategies. The findings underline the critical need for targeted interventions that improve energy access and efficiency, ultimately ensuring that informal settlement dwellers can achieve a more sustainable and affordable energy future.

5.2.2 Material Selection Justification (2nd Objective)

Comparative tabular discussion of the three different scenarios based on the simulation results:

Table 17 Material Properties

Scenario	**Average Indoor Air Temperature (°C)**	**Average Operative Temperature (°C)**	**Average Outdoor Temperature (°C)**	**Thermal Stability (Fluctuation Reduction)**	**Economic Feasibility**
GI Sheet Roof & Walls	14.10	13.80	10.15	Low	High (Low Cost)
GI Sheet Roof + Concrete Block Facade	14.90	14.50	10.15	Moderate	Moderate

GI Sheet Roof + Plywood Panel Ceiling + Concrete Block Facade	15.44	15.32	10.15	High	Optimal (Balance Cost & Efficiency)

Table 18 Simulation Output

Scenario	**Thermal Stability**	**Internal Heat Gain (kWh/m²)**	**Facade Heat Gain (kWh/m²)**	**Discomfort Hours (Hrs/month)**	**Economic Feasibility**
GI Sheet Roof & Walls	Low	8.5	3.2	339	High (Low Cost)
GI Sheet Roof + Concrete Block Facade	Moderate	9.8	4.7	280	Moderate
GI Sheet Roof + Plywood	High	11.2	5.9	237	Optimal (Balance

Panel Ceiling + Concrete Block Facade					Cost & Efficiency)

The second research objective aimed to identify the best-fit materials for constructing thermally and economically efficient housing for the relocation of informal settlers. The simulation results provide a clear justification for this objective by evaluating different material configurations and their impact on thermal performance, energy efficiency, and economic feasibility.

The analysis compared three different building envelope scenarios:

1. GI Sheet Roof & Walls (basic setup),
2. GI Sheet Roof + Concrete Block Facade, and
3. GI Sheet Roof + Plywood Panel Ceiling + Concrete Block Facade (enhanced insulation).

The simulation demonstrated that the GI sheet-only structure had the highest discomfort hours (339 hours/month) due to poor thermal stability and excessive heat loss. Adding concrete block facades improved insulation, reducing discomfort hours to 280hours/month, while the plywood panel ceiling + concrete block facade setup achieved the lowest discomfort hours (239 hours/month). This shows that increased thermal mass and better insulation significantly enhance indoor comfort levels.

Furthermore, the internal heat gain and facade heat gain values confirmed that materials with higher thermal mass (such as concrete blocks and plywood panel ceilings) improve energy retention. The plywood-ceiling configuration had the highest internal heat gain (11.2 kWh/m²) and facade heat gain (5.9 kWh/m²), ensuring better heat conservation and thermal stability. This highlights that combining plywood ceilings and concrete block facades provides the most effective insulation for informal settlement housing.

Finally, the economic feasibility assessment showed that while GI sheet-only structures are the cheapest, they lack thermal efficiency, leading to higher long-term heating costs. The plywood-ceiling + concrete block facade configuration offers the best balance between cost and thermal performance, making it the most suitable solution for energy-efficient, low-cost housing for relocated informal settlers.

Thus, the simulation successfully validates the research objective by identifying a material configuration that optimizes thermal performance, reduces discomfort hours, and remains cost-effective, providing a scientific basis for selecting appropriate building materials for informal settlement relocation.

5.2.3 Cost/Benefit Analysis and LCA of different Materials

Building 2 emerged as the best option based on a holistic evaluation of environmental impact, thermal comfort, and cost-effectiveness. It had the lowest embodied carbon footprint (633.9 $kgCO_2$), which is nearly 50% lower than Building 1 (1204.7 $kgCO_2$). This significant reduction in embodied carbon highlights its superior sustainability, making it a more environmentally responsible choice. Additionally, while Building 3 had a similar carbon footprint, building 2 outperformed it in affordability criteria.

From the thermal performance perspective, Building 3 recorded the lowest discomfort hours, with 258.87 hours at the ASHRAE 90% acceptability limit and 228.85 hours at the ASHRAE 80% acceptability limit. In contrast, building 1 had the worst thermal comfort, with discomfort hours reaching 338.65 hours (90% limit) and 330.17 hours (80% limit). Although Building 3 performed better than Building 1, with 271.13 and 239.25 discomfort hours, it still did not trump over Building 2 in affordability and sustainability criteria. Therefore, **building 2 was the optimal choice**, balancing all three factors most effectively.

Recommendation for future study:

- Conduct the research in larger sample size to reach significant conclusion on each factor identified by the research.
- Conduct comprehensive research on energy consumption patterns in different many more informal settlements to gain comparative information.
- Find out suitable building materials for houses in informal settlements using energy modelling.

- Integrate Geographic information system (GIS) to analyze energy distribution and identify high-consumption areas.
- Explore successful interventions in other informal settlements in other regions and identify the scalability and adaptability of those interventions in informal settlements in the research area.

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APPENDIX-A QUESTIONNAIRE

Questionnaire:

Energy Consumption Behavior in Informal Settlement - A Case Study of Jagriti Nagar, Balkhu, Nepal

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?

- Unemployed
- Service
- Labour
- Self-employed

- Retired
- Housewife
- Student
- 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. Where is your house of origin?

…………………………………….

1.11. How long have you been living in this settlement?

- Less than 1 year
- 1-3 years

- 4-6 years
- 7-10 years
- More than 10 years

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 is your land plot size?

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. Do you own or rent your dwelling?

- Own
- Rent
- Other (please specify): ________________

2.5.1 If you rent your dwelling.

2.5.1.1 How much is the rent of your dwelling?

2.5.2 If you own your dwelling.

2.5.2.1 What is the cost of construction of your house?

2.5.2.2 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)

2.6. 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

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

…………………………………

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

…………………………………

2.9. Are you planning on relocating from this place in recent 6 months?

…………………………………

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

…………………………………

2.11. Satisfaction to the following?

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

2.12. Satisfaction to the following?

1- Very unsatisfied, 2- Unsatisfied, 3- Ok , 4- Satisfied 5- Very Satisfied

- 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

2.12. 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

2.13. 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- Very unsatisfied, 2- Unsatisfied, 3- Ok , 4- Satisfied 5- Very Satisfied

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

Summer

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

Winter

- Heater
- Firewood
- Put on warm clothes
- Stay close to kitchen
- 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 summer season?

(Ask separately on electricity and cooking fuel.)

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

3.5. 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

3.6. How much…………………..

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

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

……………………..

3.8. 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 MAHONEY TABLE

range)

Relative humidity %	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean max am	80	72	68	59	71	81	91	90	86	68	68	72
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

1 <30%
2 30–50%
3 50–70%
4 >70%

Rain and wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
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	
Wind, secondary	E	NE	NE	NE	NE	NE	E	NE	NE	NE	NE	NE	

N, NE, E, SE,
S, SW, W, NW

Diagnosis °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AMT
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	AMT >20°C				AMT 15–20°C				AMT <15°C			
	Day		Night		Day		Night		Day		Night	
Humidity group	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	26	34	17	25	23	32	14	23	21	30	12	21
2	25	31	17	24	22	30	14	22	20	27	12	20
3	23	29	17	23	21	28	14	21	19	26	12	19
4	22	27	17	21	20	25	14	20	18	24	12	18

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

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

Latitude 28°N

Indicator totals from data sheet							
H1	H2	H3	A1	A2	A3		
2	3	4	4	0	4		
							Layout
			0–10		5–12	X	Orientation north and south (long axis east–west)
			11–12		0–4		Compact courtyard planning
							Spacing
11–12							Open spacing for breeze penetration
2–10						X	As above, but protection from hot and cold wind
0–1							Compact layout of estates
							Air movement
3–12 1–2			 0–5			X	Rooms single banked, permanent provision for air movement
1–2 0	 2–12		6–12				Rooms double banked, temporary provision for air movement
0	0–1						No air movement requirement
							Openings
			0–1		0		Large openings, 40–80%
			11–12		0–1		Very small openings, 10–20%
Any other conditions						X	Medium openings, 20–40%
							Walls
			0–2				Light walls, short time-lag
			3–12			X	Heavy external and internal walls
							Roofs
			0–5			X	Light, insulated roofs
			6–12				Heavy roofs, over 8h time-lag
							Outdoor sleeping
				2–12			Space for outdoor sleeping required
							Rain protection
		3–12				X	Protection from heavy rain necessary
							Size of opening
			0–1		0		Large openings, 40–80%
			0–1 2–5		1–12	X	Medium openings, 25–40%
			6–10				Small openings, 15–25%
			11–12		0–3		Very small openings, 10–20%
			11–12		4–12		Medium openings, 25–40%
							Position of openings
3–12 1–2			 0–5			X	In north and south walls at body height on windward side
1–2 0	 2–12		6–12				As above, openings also in internal walls
							Protection of openings
					0–2		Exclude direct sunlight
		2–12				X	Provide protection from rain
							Walls and floors
			0–2				Light, low thermal capacity
			3–12			X	Heavy, over 8h time-lag
							Roofs
10–12			0–2				Light, reflective surface, cavity
10–12 0–9			3–12 0–5			X	Light, well insulated
0–9			6–12				Heavy, over 8h time-lag
							External features
				1–12			Space for outdoor sleeping
		1–12				X	Adequate rainwater drainage

APPENDIX- C: TEMPRATURE DATA

Daily January Indoor Temperature of Simulated Cases (Used highlighted temperature)

Date/Time	Relative Humidity	Air Temperature	Radiant Temperature	Operative Temperature	Outside Dry-Bulb Temperature
	%	°C	°C	°C	°C
1/1	59.055	16.084	15.739	15.912	11.083
1/2	63.525	15.580	15.233	15.407	10.396
1/3	61.117	15.396	15.152	15.274	8.955
1/4	57.993	16.094	15.840	15.967	9.442
1/5	64.646	14.699	14.460	14.580	9.725
1/6	57.724	15.709	15.439	15.574	9.217
1/7	61.091	14.016	13.729	13.873	8.017
1/8	61.049	14.509	14.294	14.402	7.812
1/9	63.907	13.552	13.380	13.466	8.071
1/10	59.285	15.169	14.876	15.023	8.779
1/11	59.936	13.407	13.203	13.305	9.355
1/12	60.871	15.311	15.063	15.187	9.133
1/13	66.606	14.854	14.590	14.722	9.596
1/14	66.263	15.788	15.551	15.670	10.025
1/15	61.467	16.285	16.061	16.173	10.685

1/16	60.711	16.337	16.065	16.201	9.944
1/17	57.415	17.252	16.997	17.125	10.951
1/18	81.860	10.228	9.903	10.066	9.069
1/19	59.984	15.574	15.282	15.428	8.934
1/20	61.226	16.345	16.024	16.184	10.746
1/21	60.782	16.439	16.246	16.343	10.867
1/22	62.419	16.717	16.540	16.628	12.080
1/23	84.454	11.698	11.323	11.510	12.800
1/24	63.960	16.071	15.899	15.985	11.533
1/25	60.606	16.607	16.329	16.468	11.016
1/26	65.533	15.883	15.601	15.742	10.900
1/27	59.955	17.184	16.941	17.062	11.371
1/28	59.321	16.682	16.490	16.586	11.263
1/29	62.218	16.910	16.724	16.817	11.384
1/30	69.535	15.798	15.633	15.716	10.825
1/31	64.872	16.602	16.350	16.476	10.784

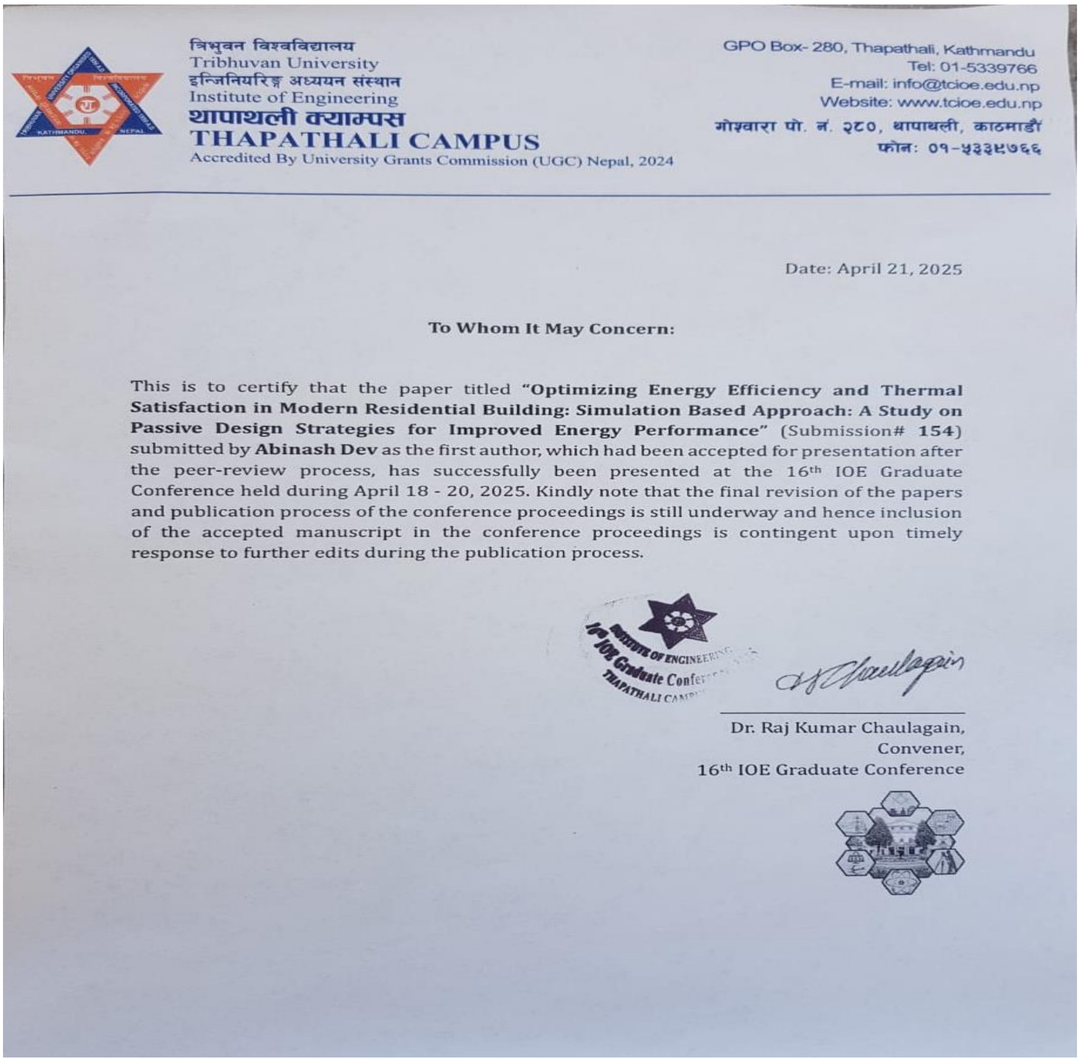
Hourly Indoor Temperature for Case 2(Optimal Case obtained from Simulation)

Hourly Indoor Temperature Cases January

Date/Time	Relative Humidity	Air Temperature	Radiant Temperature	Operative Temperature	Outside Dry-Bulb Temperature
	%	°C	°C	°C	°C
1/1/2024 0:00	54.77713	12.14989	12.81489	12.48239	7.22
1/1/2024 2:00	58.04758	12.13032	12.5222	12.32626	8.196667
1/1/2024 3:00	62.7085	11.54051	11.91229	11.7264	7.491667
1/1/2024 4:00	64.35872	11.08892	11.41999	11.25445	7
1/1/2024 5:00	66.44214	10.50603	10.80294	10.65449	6.491667
1/1/2024 6:00	70.1374	9.515393	9.897128	9.706261	5.491667
1/1/2024 7:00	72.71268	8.62338	9.089284	8.856332	4.898334
1/1/2024 8:00	74.7703	8.356133	8.730567	8.54335	5.511667
1/1/2024 9:00	64.41775	10.73477	10.91504	10.82491	7.115
1/1/2024 10:00	53.76549	13.62073	14.42464	14.02268	7.491667
1/1/2024 11:00	44.22924	17.03759	18.05951	17.54855	10.05
1/1/2024 12:00	34.86564	20.44286	21.17394	20.8084	15.03333
1/1/2024 13:00	29.68778	22.45667	23.09422	22.77545	17.71167
1/1/2024 14:00	29.65413	23.56217	24.01523	23.7887	18.705

1/1/2024 15:00	29.04292	24.01983	24.22389	24.12186	19
1/1/2024 16:00	27.32858	24.24729	24.02677	24.13703	18.89833
1/1/2024 17:00	28.77906	23.198	22.93833	23.06817	17.885
1/1/2024 18:00	37.06186	21.15512	21.38295	21.26904	15.98333
1/1/2024 19:00	44.59199	19.3343	19.78955	19.56192	14.28833
1/1/2024 20:00	48.34485	17.61983	18.22836	17.9241	12.78667
1/1/2024 21:00	50.75224	16.22597	16.86345	16.54471	12.66083
1/1/2024 22:00	54.90993	15.09183	15.73791	15.41487	11.36833
1/1/2024 23:00	56.1053	13.79656	14.56551	14.18104	8.229167
1/1/2024	54.98035	12.59104	13.42606	13.00855	6.491667

APPENDIX D: LETTER OF APPROVAL



त्रिभुवन विश्वविद्यालय
Tribhuvan University
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Institute of Engineering
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गोश्वारा पो. नं. २८०, थापाथली, काठमाडौं
फोन: ०१-५३३९७६६

Date: April 21, 2025

To Whom It May Concern:

This is to certify that the paper titled **"Optimizing Energy Efficiency and Thermal Satisfaction in Modern Residential Building: Simulation Based Approach: A Study on Passive Design Strategies for Improved Energy Performance"** (Submission# **154**) submitted by **Abinash Dev** as the first author, which had been accepted for presentation after the peer-review process, has successfully been presented at the 16th IOE Graduate Conference held during April 18 - 20, 2025. Kindly note that the final revision of the papers and publication process of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon timely response to further edits during the publication process.

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

IOE Graduate Conference
Certificate of Participation
THIS CERTIFICATE IS AWARDED TO
Abinash Dev
in recognition of an invaluable contribution as
POSTER PRESENTER
at the 16th 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.

Dr. Raj Kumar Chaulagain
Convener
16th IOE Graduate Conference

Dr. Khem Gyanwali
Campus Chief
Thapathali Campus

Prof. Dr. Sushil Bahadur Bajracharya
Dean
Institute of Engineering

APPENDIX E: RESEARCH ARTICLE

IOE Graduate Conference
[Placeholder for Publication Information]

Optimizing Energy Efficiency and Thermal Satisfaction in Modern Residential Building: Simulation Based Approach

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Abstract
This study explores the optimization of energy efficiency in modern residential buildings using simulation tools Ecotect and Ladybug. With growing environmental concerns, energy-efficient residential design is crucial for sustainability. The study models and evaluates building performance, ensuring compliance with regulations while promoting eco-friendly and cost-effective solutions. It analyzes the building envelope, HVAC systems, lighting, and appliances, simulating various climate conditions and occupancy patterns. This research also emphasizes integrating renewable energy sources and optimizing daylight and ventilation. Practical recommendations for energy-efficient technologies and materials are provided for architects and engineers. By addressing energy conservation, this study contributes to reducing greenhouse gas emissions and advancing sustainable residential construction.

Keywords
Thermal Satisfcation, Ecotect, modern building

1. INTRODUCTION

The building sector is a major contributor to global energy consumption, accounting for about 40% of total primary energy use[1]. In Nepal, where energy resources are limited, residential buildings consume major portion of the nation's energy. With rapid urbanization and a growing middle class, construction activities have surged, increasing energy demand. Heating, cooling, lighting, and appliance use significantly contribute to energy consumption, raising concerns about sustainability and energy security. The need for energy efficiency is crucial in Nepal, where electricity shortages are common. Beyond cost savings, energy efficiency is essential for environmental conservation and reducing greenhouse gas emissions[2]. It also addresses energy poverty, particularly in rural communities that rely on traditional fuels, thereby bridging social and economic disparities.

This research explores energy efficiency in Nepal's residential buildings through simulation techniques, focusing on tools like Ecotect and Ladybug. These tools allow architects and engineers to model energy performance and optimize building design. Ecotect specializes in energy analysis, helping professionals assess solar radiation, shading, and ventilation to reduce energy consumption.

2. PROBLEM STATEMENT

In the recenet years Kathmandu has experienced high temperatures and significant seasonal variations, making energy efficiency in residential buildings a critical concern. However, the integration of passive design strategies and energy-efficient construction materials remains limited due to a lack of localized research and practical implementation. Existing building practices often rely on conventional materials that may not optimize thermal performance, leading to increased energy consumption for cooling and lighting. Furthermore, daylight utilization and shading strategies are not effectively incorporated into building designs, affecting both energy efficiency and indoor comfort. Despite the growing emphasis on energy efficiency in building design, there is limited research focusing on material-specific energy performance analysis for Kathmandu's unique climate conditions. Most existing studies on energy-efficient buildings in Nepal lack simulation-based comparisons of different material configurations and their impact on heating and cooling loads. Additionally, passive design strategies such as optimal orientation, daylight utilization, and ventilation remain underexplored in the context of Kathmandu's urban residential sector. This research bridges these gaps by using simulation tools to evaluate and compare different building materials, providing data-driven insights and practical recommendations for optimizing energy efficiency in residential buildings.

3. LITERATURE REVIEW

Energy-efficient buildings are designed to minimize energy consumption while maintaining comfort through improved insulation, high-performance mechanical systems, and renewable energy integration [3]. Buildings account for nearly 40% of global energy consumption and one-third of greenhouse gas emissions, making energy efficiency a crucial factor in sustainable development [2]. With the world's reliance on nonrenewable energy sources such as coal and natural gas, the transition to energy-efficient structures is essential for reducing environmental impact [2]. Key strategies include enhancing the building envelope with insulation and high-performance glazing, optimizing mechanical systems, and utilizing energy simulations to identify efficiency opportunities [4]. Performance monitoring through building automation systems ensures energy-efficient operations. Additionally, energy audits and life cycle assessments help in selecting cost-effective energy solutions. By implementing these measures, energy-efficient buildings not only reduce operational costs but also contribute to long-term sustainability and reduced carbon footprints[5].

Passive and active design strategies play a crucial role in maximizing energy efficiency in buildings. Passive strategies leverage natural resources like solar energy, thermal mass, and natural ventilation to maintain indoor comfort without mechanical intervention[6]. Site optimization, passive solar design, green roofs, and rainwater harvesting contribute to sustainability while reducing reliance on nonrenewable energy sources [7]. Active strategies, on the other hand, involve advanced mechanical systems such as high-efficiency HVAC, heat recovery ventilation, and geothermal heat pumps to enhance energy conservation (Council, 2014). Renewable energy technologies, including solar photovoltaics and wind turbines, further improve energy efficiency by reducing dependence on conventional electricity grids. Materials used in construction, such as insulated concrete forms, low-emission interior materials, and permeable paving, also enhance building efficiency [8]. The integration of these strategies results in lower energy consumption, improved indoor air quality, and a significant reduction in greenhouse gas emissions, aligning with global sustainability goals [4].

4. OBJECTIVES

The objectives of this study are:

• Analyze the energy performance of different construction materials for Kathmandu region.

• Compare the proposed model house with possible alterations in building materials concerning energy performance.

• Develop a strategy to enhance the sustainability and habitability of existing building practices with a focus on energy efficiency.

5. LIMITATIONS OF THE STUDY

The limitations of this study are as follows.

Availability and Quality of Data: The study's accuracy heavily relies on the availability and quality of data from DHM and EPW file. Data inaccuracy and data processing techniques could introduce uncertainties in the analysis.

Time limitation: The study is scheduled to its completion in a limited period of time. Due to limitation of time, data collection and data analysis phase has to be done in limited period of time.

6. RESEARCH METHODOLOGY

6.1 Research Paradigm and Methdology

Our research followed a positivist paradigm, emphasizing quantitative analysis and empirical validation through simulation-based assessments. We began by selecting a representative architectural model, ensuring it met the minimum requirement of 2.5 storeys to reflect realistic urban

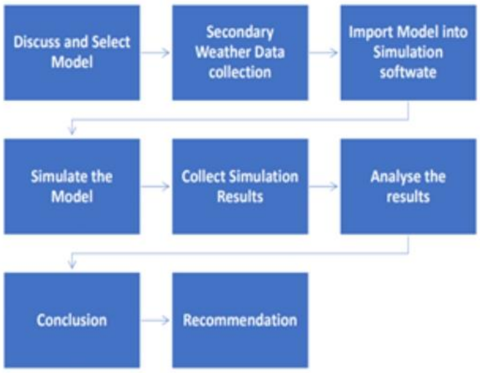

Figure 1: Research Methodology Flowchart

structures. By incorporating secondary weather data, we grounded our study in real-world climatic conditions, enhancing the accuracy and credibility of our findings. The integration of computational tools like Ecotect and Ladybug allowed for detailed simulations, aligning with a scientific approach that prioritizes data-driven insights. To validate our results, we compared simulated outputs with real-world data where possible, reinforcing the reliability of our findings.

6.2 Data sources

Primary Data Sources:

• DHM

Secondary Data Sources:

• Research Articles

• EPW files available on the internet

7. SIMULATION ANALYSIS AND DISCUSSION

7.1 Introduction to residential model

The building is a 2.5 story residential building having mixed HVAC System. One base case and three different modes of silumations were carried out. The second simulation model used mixed ventilation mode (HVAC) whereas all other models used passive natural ventilation. Polystyrene foam was used in the roof of Simulation 4 because it provides superior thermal insulation (low thermal conductivity of 0.03–0.04 W/m·K), minimizing heat transfer and improving indoor thermal stability. Despite its higher cost, Simulation 4 aims to be the best passive energy model, prioritizing materials that enhance energy efficiency and reduce HVAC dependency. Its moisture resistance and durability further support long-term performance in maintaining indoor comfort

7.2 Simulation of a building model

Altogether four simulation models for four cases were prepared and analyzed. First simulation model is considered as a base

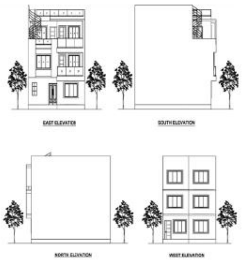

Figure 2: Elevation of Simulated Building

Parameter	Setting
Humidity	70%
Air Speed	0.5 m/s
Lighting level	300 Lux
Occupancy	Bed Room: 3, Kitchen: 1, Living Room: 4
Room Settings	Bed Room: Sedentary (70 W),
	Living Room: Exercising (100 W),
	Kitchen: Cooking Light (95 W),
	Toilet: Resting (45 W),
	Passage/Staircase/Void: Sleeping (40 W)
Sensible Gain	5 W/m^2
Latent Gain	2 W/m^2
Comfort Band	18°C to 26°C

Table 1: Environmental and Room Settings

model. Other three models along with the base model are compared among each other. Various parameter was changed in each case to finally get a best optimization for the building. Variation is brought in Roof, Walls, Windows, Doors, Floorings, Ground Floor Slab and HVAC to get 4 simulation models.

The occupancy and activity levels for different rooms were assigned based on established thermal comfort standards. Bedrooms were set at 70W per person for sedentary activities like reading (ISO 7730). The living room assumed 100W per person due to occasional movement (ASHRAE 55). Kitchens had 95W per person, reflecting high heat generation from cooking (Menezes et al., 2014). Toilets were assigned 45W, considering minimal activity (Haddad et al., 2020). Passages and voids were set at 40W, aligning with nighttime sleeping conditions (ISO 7730). These values ensure realistic internal heat gain estimations for thermal simulations.

8. DATA PRESENTATION

After running the simulation in Ecotect, a wide range of data was generated, covering various aspects of building performance. However, for the purpose of our project, we have selectively extracted and analyzed only the most relevant data that align with our research objectives. The key results are presented below in both tabular and graphical formats, ensuring clarity and ease of interpretation. These selected data points provide insights into critical parameters such as energy consumption, thermal performance, daylight availability, and other environmental factors essential for our study.

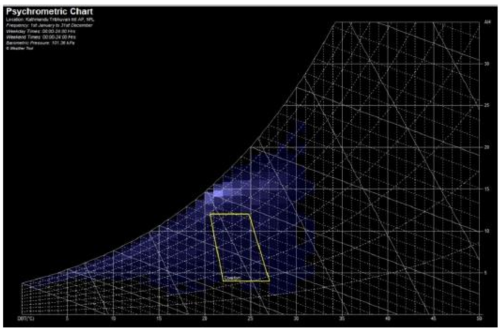

Figure 3: Psychrometric chart for Kathmandu

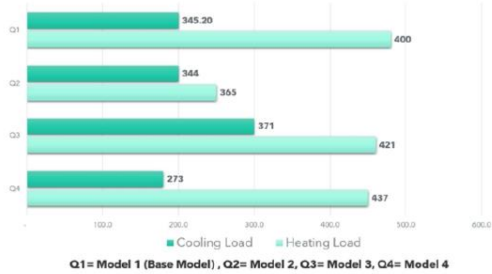

Figure 4: Heating and Cooling Load Comparison for all 4 models

Furthermore, the analysis evaluates variations in heating and cooling loads under different material and design configurations, helping to identify energy-efficient solutions. The simulation also provides an assessment of passive solar gains and losses, which influence indoor thermal comfort and overall energy demand. Additionally, solar exposure patterns have been analyzed to determine the impact of shading and orientation on building performance. These findings contribute to a comprehensive understanding of energy-efficient strategies suitable for informal settlements, aligning with the project's goal of developing cost-effective and sustainable housing solutions.

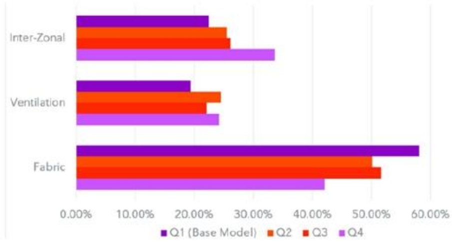

Figure 5: Passive Gain/Loss Comparison

Table 2: Simulation Parameters for Different Configurations

Component	Simulation 1	Simulation 2	Simulation 3	Simulation 4
Roof	125mm RCC Slab	125mm RCC Slab	125mm RCC Slab	125mm RCC Slab + 50mm Polystyrene Foam
Walls	250mm Brick Wall	250mm Brick Cavity Wall	110mm Brick + 50mm Cavity	250mm Cavity Wall with Air Gap
Windows	Single Glazed Aluminum Frame	Single Glazed Aluminum Frame	Double Glazed Aluminum Frame WWR: 0.15 and 0.2	Double Glazed Aluminum Frame WWR: 0.15 and 0.2
Doors	Solid Pine Core Door	Solid Pine Core Door	Solid Pine Core Door	Solid Pine Core Door
Flooring	Tiles on Screed	Tiles on Screed	Tiles on Screed	Tiles on Screed
Ground Floor Slab	Concrete	Concrete	Concrete	Concrete
HVAC	Natural Ventilation	Mixed Mode	Natural Ventilation	Natural Ventilation

Table 3: Thermal Comfort Levels for Different Room Types Across Simulations

Room Type	Simulation 1	Simulation 2	Simulation 3	Simulation 4
GF_RM1	58.1% 5150 hrs	100% 2555 hrs	49.4% 4328 hrs	48.1% 4217 hrs
GF_Kitchen	67.9% 5945 hrs	67.4% 5904 hrs	61.7% 5407 hrs	58% 5078 hrs
GF_RM2	67.8% 5943 hrs	100% 2555 hrs	55.4% 4853 hrs	50.5% 4421 hrs
FF_RM3	59.4% 5206 hrs	100% 2555 hrs	49.6% 4344 hrs	48.5% 4250 hrs
FF_RM4	57.1% 4998 hrs	100% 2555 hrs	49% 4290 hrs	49% 4293 hrs
FF_RM5	55.7% 4881 hrs	100% 2555 hrs	48.8% 4273 hrs	48.1% 4211 hrs
FF_RM6	68.4% 5989 hrs	100% 2555 hrs	70% 6146 hrs	69.5% 6088 hrs
TF_Living	51.7% 4531 hrs	100% 4380 hrs	48.2% 4222 hrs	39.8% 3484 hrs
TF_Kitchen	68% 5956 hrs	70.5% 6174 hrs	71.5% 6261 hrs	67% 5865 hrs
TF_RM7	69.8% 6111 hrs	100% 2555 hrs	70% 6132 hrs	54.1% 4743 hrs

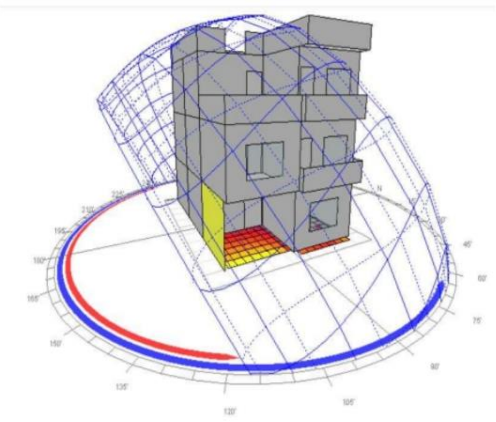

Figure 6: Annual Solar Path of Model Building from Ecotect

9. CONCLUSION

This research successfully analyzed the energy performance of different construction materials in Kathmandu's climate using simulation-based methods. By evaluating four building models with varying material compositions, insulation levels, and HVAC systems, the study demonstrated that high-performance polystyrene insulated walls and AAC blocks can reduce heating loads by 44%, while roof insulation and passive solar design contribute to a 31% reduction in cooling demand. These findings confirm that selecting the right construction materials significantly enhances energy efficiency, addressing the first objective of this research.

The comparative analysis between different building models further highlighted the impact of material alterations on energy consumption. Model 4, which incorporated high-performance insulation, efficient HVAC systems, and optimized daylight utilization, outperformed other models, achieving 39% overall energy savings and 90% compliance with ASHRAE thermal comfort standards. This demonstrates

Table 4: Heat Loss and Gain Percentages Across Different Cases

Category	Case I		Case II		Case III		Case IV	
	Losses (%)	Gain (%)	Losses (%)	Gain (%)	Losses (%)	Gain (%)	Losses (%)	Gain (%)
Fabric	70.7	1.7	62.2	1.6	60.6	0.9	40.0	0.5
Sol-Air	0	17.8	0	13.9	0	10.5	0	2.7
Solar	0	13.0	0	21.5	0	9.0	0	10.4
Ventilation	14.0	0.4	23.5	0.7	23.6	0.5	40.3	0.6
Internal	0	62.0	0	56.9	0	75.8	0	84.7

Table 5: Energy Balance (Wh) Across Different Simulations

SN/Type	Simulation 1	Simulation 2	Simulation 3	Simulation 4
HVAC	0 Wh	-360 Wh	0 Wh	0 Wh
Fabric	-86691 Wh	-45675 Wh	-41335 Wh	-19499 Wh
Solar	17025 Wh	18809 Wh	11870 Wh	12613 Wh
Ventilation	-22818 Wh	-23215 Wh	-23215 Wh	-23215 Wh
Internal	93013 Wh	47607 Wh	93013 Wh	93013 Wh
Zonal	1737 Wh	2007 Wh	1044 Wh	47 Wh

that strategic modifications in building materials and insulation techniques effectively enhance sustainability and reduce energy demand, fulfilling the second research objective. Beyond comparative analysis, this study also developed a strategy to improve sustainability and habitability in residential buildings. Key recommendations include optimizing building orientation (5° east of south), using low U-value materials, implementing passive solar and ventilation strategies, and advocating for policy interventions to promote energy-efficient construction. These insights provide a practical roadmap for sustainable urban housing, meeting the final objective of this research. Future studies could explore renewable energy integration and cost-benefit analysis to further enhance Kathmandu's energy-efficient housing sector.

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Table 6: Heating Energy Requirement (Wh) Across Different Simulations

SN/Type	Simulation 1	Simulation 2	Simulation 3	Simulation 4
HVAC	0	2497	0	0
Fabric	26004	11827	13055	3064
Solar	22786	16595	10038	9947
Ventilation	0	1084	1084	1084
Internal	93013	47607	93013	93013
Zonal	-2384	-2172	-3228	-4323

Table 7: Monthly Heating and Cooling Load (W/hr) Across Simulations

Month	Simulation 1		Simulation 2		Simulation 3		Simulation 4	
	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating
Jan	–	417.77	34490	3247	0	365.09	0	274.14
Feb	–	238.86	4641	1614	0	140.32	1.27	93.50
Mar	5.27	10.50	133	69	12.14	0.73	73.55	0
Apr	89.64	–	1427	38053	204.15	0	277.55	0
May	277.59	–	2452	118521	350.50	0	391.55	0
June	370.41	–	3192	181113	407.09	0	419.73	0
July	400.27	–	3471	144987	432.00	0	439.05	0
Aug	385.41	–	3346	101712	423.91	0	436.55	0
Sep	339.36	–	3019	84507	394.14	0	418.36	0
Oct	99.09	–	1171	19307	168.50	0	246.18	0
Nov	0.05	93.14	364	731	0	49.32	16.60	24
Dec	–	345.00	12697	2524	0	242.18	0	171.00

Table 8: Comparison of Building Mode Performance

Parameter	Model 1 (Base)	Model 2	Model 3	Model 4 (Optimized)
Heating Load Reduction (%)	0% (Baseline)	20%	32%	44% (Best)
Cooling Load Reduction (%)	0% (Baseline)	10%	22%	31% (Best)
Overall Energy Savings (%)	0% (Baseline)	18%	30%	39% (Best)
Wall Material Used	Standard Brick	Insulated Brick	AAC Block	High-performance Insulated Wall
Roof Insulation Level	Basic Concrete	Moderate Insulation	High Insulation	Optimized Insulation
HVAC System Type	Conventional	Mixed	Efficient HVAC	Energy-Efficient HVAC
Passive Solar Gain (%)	Low	Moderate	High	Highest Passive Gain
Daylight Utilization (%)	50%	65%	75%	85% (Best)
ASHRAE Comfort Compliance (%)	60%	70%	80%	90% (Best)

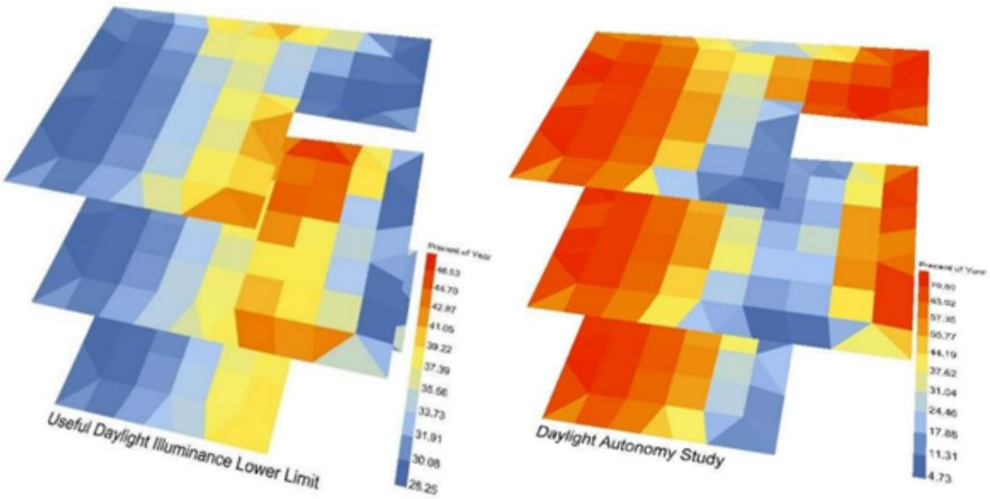

Figure 7: Daylight Autonomous Gain in different floors of Model Building from Ladybug

APPENDIX F: PLAGIARISM TEST

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