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ENERGY RETROFITTING CONSIDERATION WHEN RENOVATING RESIDENTIAL BUILDINGS FOR THERMAL COMFORT

by

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A THESIS

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Abstract

Though largely overlooked when it comes to renovation, thermal comfort is a well-known terminology in architecture. In order to attain comfort in terms of indoor quality and functionality, building maintenance is done throughout its existence. People refurbish their homes during every festive season all across the world, perpetuating a trend that has existed for years. The study area is chosen inside the Kathmandu valley which is known to have the most comfortable weather conditions but poor building envelope systems. The paper highlights the importance of climate responsive design with respect to thermal insulation in residential buildings. It has been addressed that, cold homes are a contributing factor to health issues and can also be psychologically unproductive.

In order to examine the existing level of comfort that building residents are experiencing, the research uses a case study of a residential building. Additionally, recommendations for achieving consistent thermal comfort are made. This article compares the existing state of residential buildings, analyzes it, and offers additional ways to address the problems that its residents may be experiencing. Since energy consumption in residential structures is rising quickly, efficient energy use in the residential sector is a major challenge. Consideration should be given to three fundamental factors: thermal comfort, air quality comfort, and visual comfort. Consequently, it is noted that one of the key variables is thermal comfort.

Keywords: *thermal comfort, building envelope, insulation ,openings, orientation, renovation, strategy*

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Acronyms and Abbreviations

CBS	Central Bureau of Statistics
AEC	Architecture, Engineering, And Construction
BIM	Building information modeling
HVAC	Heating, Ventilation and Air Conditioning
IT	Information Technology
SPSS	Software Package for Social Science
ASHRAE	American Society of Heating Refrigerating and Air-conditioning Engineers
PPD	Predicted Percentage Discomfort
WHO	World Health Organization
GHG	Green House Gas Emission
PHPP	Passive House Planning Package
CFD	Computational Fluid Dynamics

CHAPTER 1. INTRODUCTION

1.1 Background

Since the residential sector consumes the most of the total energy produced by various energy sources during the past several years, energy management in residential buildings has attracted the attention of many scientists, (Muhammad Fayaz, 2018). The world's population is estimated to reach 8.3 billion by 2030, implying that an additional 1.3 billion people would require energy, while global GDP in 2030 is expected to be approximately double that in 2011, (Energy Outlook 2030, 2013). Per capita energy consumption is one-third the average for Asia as a whole and less than one-fifth the worldwide average, only 53% of Nepal's population was electrified in 2010; 76 percent relied on wood for cooking, (Nepal Energy Situation Energy Consumption). An effective energy control system that can reduce overall energy consumption without compromising the user-preferred environment inside the building is needed to manage energy in residential buildings effectively. According to research, European projects aim to save 160 GWH of energy during renovations, which is great and doable provided we take thermal comfort into account. The study seeks to recommend a user-preference environment while reducing energy utilization. The current state of residential buildings will be compared in this article through analysis of their existing condition and recommendations for additional ways to address tenant problems.

The architecture, engineering, and construction (AEC) business is known for combining distinct entities into a project today. Architects, engineers, and contractors collaborate to bring the project to fruition and accomplish a shared objective. Delivering high-quality work on time while also tying in pertinent data from various teams engaged is the main issue projects encounter. Building information modeling (BIM), Technical information is linked to a schedule that tracks time from crane deliveries through handover dates using the model. Though it is still in its infancy in the bulk of Asia's developing nations, BIM has unquestionably increased in popularity globally in recent years. BIM is a practical technology for forecasting a building's thermal comfort and occupant satisfaction. BIM appears to hold promise for resolving execution-related issues and maximizing time savings because the best solutions may be recommended in advance. Over time, buildings need upkeep and repair; today, there is a culture of renovation to attain aesthetics on the inside and the outside. Numerous built structures can also be suggested for adaptive reuse.

In residential buildings, energy consumption is rising quickly. The efficient use of energy in the home sector is therefore a major challenge. There are three fundamental factors that should be considered: thermal comfort, air quality comfort, and visual comfort. Thermal comfort and visual comfort are two of the elements that are taken into account in the study. The main goal of this research is to put forth an optimization technique that will reduce energy consumption in residential buildings while enhancing user comfort. By examining the dwelling building's current condition, I have suggested a renovation strategy in this study. Therefore, as a project concept, I would like to propose the idea of renovating a residence building with design solution strategies for more thermal comfort, analyzing the thermal comfort in its present stage and predicting the quality of the indoor environment after the transformation.

1.2 Statement of the Problem

People living in discomfort, not analyzing the best possible orientation and investing in a cheaper building envelope, results in discomfort and loss of energy. Therefore, we lack proper design solutions along with analysis that prevents failure in achieving indoor thermal comfort, causing problems of discomfort in residential buildings. Home maintenance and renovation are unavoidable processes. On average, people update some rooms as their needs change. Residents in Nepal are observed to be more concerned about functional requirements than visualizing spaces, which further lack supportive lighting and ventilation requirements for thermal comfort. Later, many interventions are followed to accommodate these requirements.

The residential sector is known to be the biggest consumer of energy. The sector consumed almost 89% of the total energy consumption in 2008/09. The energy consumption has increased due to the poor thermal construction of residential buildings, (Bajracharya, Shakya, & Bajracharya, 2020). There are building codes that represent interests in building safety, but the terms of energy and efficiency are neglected. The concept in foreign countries has taken to the next level of visualization and implementation, which reduces the cost for comfort. The need for understanding climatic conditions to implement passive strategies also aids thermal comfort. Design strategies with consideration to functional needs should also include prioritization of indoor thermal quality, which is neglected in Nepal.

Nepal has almost 95% of construction cast in situ, which means all the work is executed on site and there is more risk of material as well as manpower wastage and coordination failure if the visualization process is misconceived. Therefore, understanding the need as per the climate of a place is significant.

1.3 Need of Research

The research aims to understand the current scenario of comfort in residences and problems regarding thermal comfort. The technical guidance in Nepal gives more emphasis on functional needs, neglecting thermal comfort, which later becomes a main problem. There is a gap between concepts and practicality. Predicting user comfort for occupants with respect to the site’s climatic condition is a useful tool to achieve a successful design. Thermal comfort in buildings is influenced by a wide range of environmental and socioeconomic factors, which can both protect and exacerbate risks to the occupant's health. As a result, the primary goal of this research is to achieve user comfort through building renovation analysis.

According to the research conducted in the AEC industry in the USA, the surveys conducted by McGraw-Hill Construction published a market report in 2008 projecting the usage of BIM. The practice of these tools predicts indoor comfort, determining future problems. The finding denotes architects as one of the heavy users of the software, that is, 43% and in more than 60% of their projects, which is understood to be more solution-oriented. Moreover, building design and operation relating to thermal comfort are influenced by a broad spectrum of environmental and socio-economic factors, which can both protect and heighten risks to the health of the occupant. Hence, the principal motive of this research focuses on achieving thermal comfort through proper analysis for renovating buildings for better indoor quality.

1.4 Research Objective

The main objective of this research is to boost the building's thermal performance through renovations by using better envelope components and design strategies. Through proper analysis of the existing scenarios, the research can find design strategies that can be applicable for the Kathmandu valley.

1.5 Nature of Research

Analysis through software tends to deliver potential remedies for construction projects in terms of time and quality; as these elements denote the productivity of the project. Though BIM comes under natural science as software, the study of the practice falls under the boundary of social science to predict clarity of resource availability and possible project execution; hence, BIM is an analytical system where social science plays a vital role in determining the operation of occupants. Social sciences encompass a vast number of disciplines; economy, sociology, education, history, geography, psychology, anthropology, science and technology studies (STS) as well as subject areas; behavior, markets, organizations, strategy, environment, technology, public policy and regulation etc. (Winch1990). Therefore, the nature of research is interdisciplinary and connects both natural as well as social science, which indeed reviews the practice in the construction industry, problems in productivity, and improvements required for a holistic approach.

1.6 Research Paradigms

1.6.1 ONTOLOGY

User comfort strategies are very important to achieve consistent thermal comfort and visual comfort as per the occupant’s needs. Research focuses on thermal comfort mainly as the basic parameter. Thermal comfort affects people’s moods, performance, and productivity, with research showing a correlation between perceived comfort and productivity. Heating and cooling in buildings to gain thermal or user comfort might result in more carbon emissions and energy consumption. Designing shading devices, airtightness in ventilation, passive heating and cooling, and insulation in buildings is important to be implemented in the correct way. The rapid development of IT fields in the architecture, engineering, and construction industries has resulted in a wide range of products and systems that require the use of BIM for envelope analysis. Accordingly, I claim that "the research on the case-study gives clarity to the aimed results and, in fact, makes the whole process effective for renovating buildings."

In the case of a construction site, there are various products with different features that complement the building experience for heating and cooling purposes. I would like to analyze the heating and cooling demand before and after the renovation with a suggestion of a suitable HVAC system. However, the pragmatic paradigm of research will be followed using mixed methods to understand the drawbacks as well as limits of our cultural practice, focusing on how to renovate buildings for improvised user comfort.

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1.6.2 EPISTIMOLOGY

The research follows the concept of knowledge that should be examined via the best tools suited. Thus, the research tries to explain what is lacking in current architectural practice that fails to achieve a good thermal envelope. Standard residence of up to 3000 sq ft has been selected in this research with reasonably more discomfort levels compared to standards required for indoor thermal comfort. In the research, the embedded approach to research is taken to identify and focus on core problems and their solutions.

1.6.3 VALIDITY OF RESEARCH

The research emphasizes on thermal comfort; which importantly measure quality that is aimed at and in a justified time frame. Not only is the motive to understand the quality intended, but also if the time frame consumed is regarded as productive. The research represents a case study of a residence building to analyze the current state of comfort experienced by occupants and, furthermore, to obtain a consistent thermal comfort. A local climate analysis and perspective are important to strike a balance of health and comfort. Hence, the data collected in the field is analyzed carefully with comparative process on Ecotect and field measurement.

1.7 Research Methodology

The research was conducted with a case study on a residential building located in Kathmandu. The building was constructed in the year-and since it is on the outer skirts of a valley, the site experiences cold wind waves from autumn to winter. The rooms of the residential buildings are considered and analyzed.

The research emphasizes two main aspects; thermal comfort in the present context and energy consumption, which importantly measures the quality of house interiors. Therefore, the data is to be collected through quantitative and qualitative approaches and measured through qualitative and quantitative analysis.

1.7.1 DATA COLLECTION

Firstly, the study of thermal comfort will be done through software along with HVAC consumption by the housing unit. Thereafter, the household members will be interviewed to understand their energy consumption needs and indoor user comfort.

The study consists of data analysis using BIM software "ECOTECT", field measurement, and interviews. To measure the thermal comfort, field measurement consists of a measurement of the room temperature during winter as well as summer. As the research focuses on perception and usage of buildings, it is important to conduct the study during the coldest period where the users find the weather conditions to be thermally most uncomfortable. At least 2 case scenarios are taken to underrate the present scenario and demand for envelope standards. And the results will be implemented on a new construction site via software for verification.

1.7.2 DATA ANALYSIS

The analysis of the obtained data was done based on the research questionnaire. The relationship between various variables was analyzed to derive the conclusion from the questionnaire survey. Below is the list of variables that are inter-related to obtain the answer to the research question.

All the raw data was collected in the KOBO TOOLBOX software instantly after the questionnaire survey was conducted. Further, the statistical analysis was done using the SPSS statistical tool such that direct graphical comparisons could be made with the obtained results. The results are represented in percentages to compare the entire sample with the population. SPSS refers to Software Package for Social Science, which is used for complex statistical data analysis to analyze survey data and provides a plethora of basic statistical functions which include frequencies, cross-tabulation, and bivariate statistics (Foley, 2018). This technique is used to understand the relationship between dependent and interdependent variables that are stored in a data file and to compare events and groups.

a. Field Measurement

The field measurement focuses on measuring four thermal comfort parameters: air temperature, wind velocity, humidity, and radiant temperature. The air temperature was recorded using a thermostat inside each room. All the readings were taken at a height of 1.8 m above floor level, which represents the height of an occupant at standing level. The maximum occupancy is considered to be from 10 am in the morning until after 11 pm in the night.

b. Questionnaire Survey

The case study scenarios include residences with families including members such as 2 grandparents, 2 middle-aged occupants, and 1 child. The occupants were approached with a questionnaire in advance to inform them of the study, and their consent was obtained to be approached and participate in the survey. All the questions were answered by 3 family members. The research questions for open-ended answers are such as:

- What kind of discomfort do you feel in the house?

- Which of the rooms feels more comfortable in winter or summer and why?
- Were any of the family members ill due to a cold last year?
- In which season do you use HVAC appliances more frequently when you are inside the room?

1.7.3 RESEARCH LOGIC

In research, there are broadly four types of logic, namely inductive, deductive, reproductive, and abductive (Uprety, 2020). The logic determines the strategical procedures that the researchers follow. This research considers the inductive strategy as it answers the "what" questions. This research aims at gathering data, looking for patterns, and developing a generalized theory from it. A deductive approach was difficult to consider as no initial data was available. Therefore, inductive research logic was considered.

1.7.4 RESEARCH ETHICS

This research abides by the ethical considerations that research needs to consider. Therefore, discriminatory questions according to caste, gender, culture, the community were avoided as far as possible. The participation of the respondents is considered voluntary.

1.7.5 EXPECTED OUTPUT

The research focuses on outcome for building envelope elements like standard wall thickness and openings suitable for Kathmandu valley. The residential development in the valley has reached to all possible extensions. There exists a conflict on suitable standards for the core area of Nepal, hence, the research probably will produce outputs that might be reliable for standard wall thickness and openings for Kathmandu.

1.8 Scope and Limitations

As per the given time frame for the research, following limitations is faced:

- One of the research scenarios is done for summer season only.
- Weather data is taken as relevant site data.
- Used tools for analysis have their limitations.
- Input data is as per site visit on June/July and February.

CHAPTER 2. LITERATURE REVIEW

2.1 Thermal comfort

The consequence of a considered arrangement of building systems that has been adapted to the local climate and the nature of the activities being done is thermal comfort. The materials and kind of structure employed in the design play a significant role in determining thermal inertia, but rather how gradually a building's temperature rises to that of its surroundings. As a result, the inside stays cooler — or warmer, depending on the area and necessity — for a longer period of time. These components interact with the outer environment. The u-value defines the thermal resistance provided by different materials such as bricks, glass, timber, stones and other insulating materials. Envelope consists of factors such as air ventilation, air exchange and air tightness which contributes to maintain thermal comfort. Our comfort requirements will probably not change in the future. However, the environment in which those requirements are met is drastically and quickly changing. Hot locations are bearing even more heat and will do so for years to come while cold places are getting warmer. But if we believe that using artificial techniques to create thermal comfort is the answer, we haven't been paying close attention to what brought us to this point in the first place.

"That state of mind that conveys satisfaction with the thermal environment is referred to as thermal comfort", (standard, 2022). According to Olygay, thermal comfort is defined as "condition where an average person does not have a feeling of discomfort". The level of discomfort may differ from person to person depending on personal experience. Givoni (1998) defines thermal comfort as absence of irritation and discomfort due to heat and cold. As per theories by Szoklay (2008), the parameters affecting thermal comfort can be categorized to environmental, personal and other contributing factors. One of the important model from Fanger, represents comfort equation into six thermal comfort variables, which is based on heat balance equation with respect to the skin temperature of human body and surrounding environment. The equation states that the skin temperature and sweat evaporation rate gives values of predicted mode vote and predicted percentage of dissatisfaction. The PMV ranges from +3 to to 3 where +3 denotes hot, +2 denotes warm +1 demotes slightly warm, 0 denotes neutral, 1 denotes slightly cool, 2 denotes cold and 3 denotes very cold. Whereas PPD (Predicted percentage dissatisfaction) expresses percentage of thermally dissatisfied people. The model indicates that people with +2/-2 and +3/-3 are in discomfort level.

2.2 The factors of Climate

Altitude- Typically, as altitude rises, the climate gets cooler. High mountains have "life zones" that represent these changes; the plants at the foot are identical to those in the nearby countryside, but no trees can grow beyond the timberline. The highest elevations are covered in snow.

Land and water distribution- The climate of an area is influenced by the water. In comparison to inland locations, coastal environments are cooler and wetter. When warm air from interior regions and chilly air from the sea collide, clouds are created. A wide range of temperatures can be found in the heart of continents. As rainwater from the sea evaporates before it reaches the core of the land mass, summertime temperatures can be extremely scorching and dry.

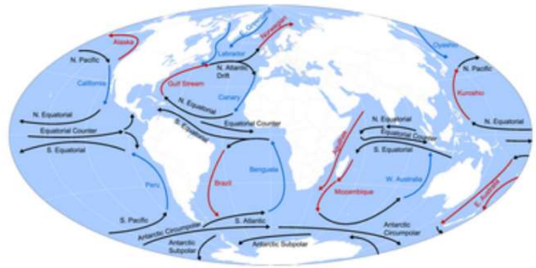


Figure 1: Global Ocean Currents

Ocean Currents- Temperatures can rise or fall due to ocean currents. The world's ocean currents are depicted in the diagram below. The Gulf Stream is the principal ocean stream that has an impact on the UK.

Topography- Our climate can be significantly influenced by an area's topography. Mountains act as natural airflow obstructions. For example, winds off the Pacific Ocean in California blow moist air toward the coast. Some condensation and light precipitation are permitted by the Coastal Range. The taller Sierra Nevada range in the interior produces more considerable precipitation. The Sierra Nevada's western slopes are dry and have sinking air that warms from compression and evaporation.

Vegetation- The Earth's surface is another significant component that affects climate, as can be seen by looking at any globe or world map that shows land cover. The quantity of atmospheric heating depends on how much sunlight is either reflected or absorbed by the surface. Darker areas—like those that are extensively covered in vegetation—tend to be good absorbers, while lighter areas—like those that are coated in snow and ice—tend to be good reflectors. Compared to land, the water absorbs and releases heat more slowly. Heat is gradually released from its waters into the atmosphere, which subsequently spreads heat throughout the world.

Prevailing Winds- Sea breezes frequently bring rain to the shore and dry weather to the interior. Warm, dry winds will blow to Britain from warm interior regions like Africa. In the winter, cold, dry winds from inland regions like central Europe will blow toward Britain.

1.1.1 The Classification of climate

The five major types of terrestrial climates that compose Köppen's classification—A, B, C, D, and E—are denoted by capital letters. Except for B, temperature requirements are used to categorize each of these climatic groups. Type B describes regions where dryness is the primary element influencing vegetation (rather than coldness). Aridity is not solely determined by precipitation; rather, it is determined by the interaction between precipitation input into the soil, where plants grow, and evaporative losses. A second letter, f (no dry season), w (winter dry), or s (summer dry), and a third symbol (a, b, c, or d [the last category exists only for D climates]), designating the warmth of the summer or the harshness of the winter, are assigned to the mid-latitude C and D climates. Although the highland climate category, or H climate, is occasionally added to climate classification systems to account for altitudes above 1,500 meters, Köppen's classification did not take into account the distinctiveness of highland climate zones (about 4,900 feet).

The other four main climate categories are determined by temperature, as was mentioned above. These are further separated, and different subtypes are again identified by additional letters. Based on the seasonality of precipitation, Type A climates (the warmest) can be classified as Af (no dry season), Am (short dry season), or Aw (winter dry season). Traditional classifications of Type E climates (the coldest) include tundra (ET) and snow/ice climates (EF).

The mid-latitude C and D climates are given a second letter, f (no dry season), w (winter dry), or s (summer dry), and a third symbol (a, b, c, or d [the last subclass exists only for D climates]), indicating the warmth of the summer or the coldness of the winter. Although Köppen’s classification did not consider the uniqueness of highland climate regions, the highland climate category, or H climate, is sometimes added to climate classification systems to account for elevations above 1,500 metres (about 4,900 feet).

1.1.2 Climate Change

Due to its disproportionate impact on those who bear the least responsibility for its causes and who are least able to adapt, climate change is a significant cause of injustice. They are particularly at risk in many nations because they lack access to resources and decision-making authority. (Amendment 2001) Although there are natural causes for climate change, the increased consumption of fossil fuels and other changes to the natural ecosystem have sped up the process, raising the average temperature of the earth. It is an evaluation of how the Greenhouse Effect, which may be the biggest global environmental concern facing humanity, may be modifying the Earth's climate as a result of human activity. (1991 Jenkins).

Classification of major climatic types according to the modified Köppen-Geiger scheme

letter symbol			
1st	2nd	3rd	criterion
A			temperature of coolest month 18 °C or higher
	f		precipitation in driest month at least 60 mm
	m		precipitation in driest month less than 60 mm but equal to or greater than 100 – (r/25)[1]
	w		precipitation in driest month less than 60 mm and less than 100 – (r/25)
B[2]			70% or more of annual precipitation falls in the summer half of the year and r less than 20t + 280, or 70% or more of annual precipitation falls in the winter half of the year and r less than 20t, or neither half of the year has 70% or more of annual precipitation and r less than 20t + 140[3]
	W		r is less than one-half of the upper limit for classification as a B type (see above)
	S		r is less than the upper limit for classification as a B type but is more than one-half of that amount
		h	t equal to or greater than 18 °C
		k	t less than 18 °C
C			temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month less than 18 °C but greater than −3 °C
	s		precipitation in driest month of summer half of the year is less than 30 mm and less than one-third of the wettest month of the winter half
	w		precipitation in driest month of the winter half of the year less than one-tenth of the amount in the wettest month of the summer half
	f		precipitation more evenly distributed throughout year; criteria for neither s nor w satisfied
		a	temperature of warmest month 22 °C or above
		b	temperature of each of four warmest months 10 °C or above but warmest month less than 22 °C
		c	temperature of one to three months 10 °C or above but warmest month less than 22 °C
D			temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month −3 °C or lower
	s		same as for type C
	w		same as for type C
	f		same as for type C
		a	same as for type C
		b	same as for type C
		c	same as for type C
		d	temperature of coldest month less than −38 °C (d designation then used instead of a, b, or c)
E			temperature of warmest month less than 10 °C
	T		temperature of warmest month greater than 0 °C but less than 10 °C
	F		temperature of warmest month 0 °C or below
H[4]			temperature and precipitation characteristics highly dependent on traits of adjacent zones and overall elevation—highland climates may occur at any latitude

Figure 3: Koppen Climate Classification Table

2.3 Thermal comfort in residential buildings

The building structure that creates the space, the material used or installations and the boundary condition of the building constructs the thermal quality. The main concept is to maintain the level of comfort with no respect to the outdoor temperature value. While in case of residential building envelope the activities with different zones are not as predictable which might affect the satisfaction. Therefore, proper study of the base case scenario considering the occupant and their activities is important, which helps the resemblance to the reality. As psychological response is equally important, thermal comfort becomes the condition of mind that expresses satisfaction. When people are not satisfied with the thermal environment the causes are not only potential health hazard but also affect in efficiency. An environment is said to achieve "reasonable comfort" when at least 80% of its occupants are thermally comfortable. (executive, 2021). The factors can be categorized into environmental factors that include, air velocity, Temperature, relative humidity and personal factors such as clothing, metabolic rate and wellbeing. Separating occupants from sources of discomfort can make a difference to achieve the thermal comfort. There existed a period when people valued self-contained architecture, where the building envelope acted as an inert, independent barrier rather than as a moderator between the temperature outside and the internal environment. The connection between architecture and the environment in which it is placed is a growing issue for architects today. As a result, they are taking on more responsibility for the thermal comfort of interior spaces and adopting design techniques for natural climate control, (Ghisleni, 2021). The most individuals should be comfortable with thermal comfort conditions because it is difficult to select temperatures that accommodate everyone's preferences. Individually programmable thermostats that let users control their own temperature independently of other zones should be utilized when zoning permits. However, it's crucial to choose energy-efficient equipment and to train staff members on how to use it safely and effectively. In various settings, such as homes and schools, similar strategies can be used. The ability to manage and modify their surroundings to preserve a desired state is a significant benefit for users.

The requirement as well as the human body's skin temperature are important factors. Thermal comfort, according to Fanger's model, is described as the estimation of an occupant's skin temperature, metabolic rate, clothing, and the environment's air circulation condition. The residential space is divided into four thermal zones in this paper: living room, bedroom, kitchen, and bedroom 1, which is the most commonly used. Theories related to temperature characterization suggests that adaptation to the climate takes up to a week for any individual. (Leen peters, 2008). As per the theory by Fanger, the parameters therefore is different according the space, for example the bedroom as a thermal zone consist of input parameters like Metabolic rate of 0.7met, Clothing index 0.8 clo, relative humidity 55% and air speed range of 0.05 to 0.1 m/s. (Leen peters, 2008). The temperature value considered adequate for sleeping as per by Collins and Hartley with reference to World health organization indicates a limit to 16 degrees, temperature below 16 degrees in bedrooms can cause respiratory diseases. The metabolic rate consideration for bedroom can be considered similar to the living room as activities such as watching tv, seating , homework etc represents a strong correlation during winters. The rooms such as Kitchen and living room have physical activity as compared to offices which is more intensive which represents metabolic rates from 0.8 to 1.4 met. The reason of fact that people might feel living room with uncomfortably high temperatures in summer also relates to the metabolic rate. (Maeyens J., 2001)

Thermal comfort as per American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 55-2017 notes that for thermal comfort purposes, indoor temperatures could range from between approximately 67 and 82 °F, or 19 and 28°c. The standards recommend that relative humidity in occupied spaces be controlled to less than 65% to reduce the likelihood of conditions that can lead to microbial growth. The Hong Kong government recommends 25.5°C as the ideal indoor temperature for air-conditioned spaces, striking a balance between comfort and energy conservation, whereas The WHO's "Housing and Health Guidelines" (2018) recommend indoor housing temperatures of 18°C (and over) for countries with temperate or cold climates to protect occupant health during cold periods. Higher temperatures are acceptable for buildings in tropical climates. The use of the building affects the laws and regulations governing temperature. According to UK law, workplaces that need more sedentary work should have temperatures above 13°C and at least 16°C. UK law states work environments should be at least 16°C in more sedentary workplaces, and above 13°C where work requires physical effort. Hence, climatic condition of a place is affected by the various factors as follows:

Temperature- The amount of kinetic energy in the air, which physically emerges as sensations of heat or cold, is measured by the concept of temperature. Celsius, Fahrenheit, and Kelvin scales are frequently used to measure temperature. The thermometer is the name of the instrument used to measure temperature.

Humidity- The amount of water vapor in the air at any particular time is known as humidity. Only water in a gaseous condition can be called water vapor (after the liquid has evaporated).

Precipitation- Precipitation is made up of water in all its various stages, which developed after condensation transformed water vapor into its solid form. After becoming too heavy to remain suspended in the air, precipitation falls to the ground. Rain, snow, or hail are all examples of precipitation. Evaporation and condensation are the main causes of precipitation.

Atmospheric Pressure- The weight of the air in the Earth's atmosphere exerts pressure, which results in air pressure. In honor of the device used to measure air pressure, it is also known as a barometric pressure. Air has weight because it is not empty even if it may not be apparent. Small particles of nitrogen, oxygen, argon, carbon dioxide, and a few additional gases are present inside.

Wind- The large-scale flow of air through the atmosphere from a region of high pressure to one of low pressure is known as wind. The distance between low and high pressure areas, as well as the air pressure differential, both affect the wind's speed and strength.

Sunshine Duration- The amount of time the Earth's surface is directly exposed to solar radiation is known as the sunshine duration. It also goes by the name "sunlight hours" and measures how much exposure there is over a specific amount of time, usually expressed in hours per day or year.

Second, reducing heat loss in the winter and conduction heat gains in the summer by insulating the building envelope and using thermally efficient windows. Retaining trees therefore serves as a natural air conditioner that can aid in lowering the heat island effect. A single tree's evaporation can equal the cooling power of 10 room-sized, household air conditioners running twenty hours a day. Residential heating expenditures can be cut by 10-15% with tree windbreaks, while air conditioning costs can be reduced by 20–50% with tree shading and evaporative cooling.

In relation to Nepal, the north experiences cool summers and cold winters, whereas the south experiences hot summers and mild to cold winters. Nepal has five seasons, namely, Spring, summer, monsoon, autumn, and winter. Winter temperatures in the Terai (southern Nepal) range from 7°C to 23°C, with summer temperatures exceeding 40° C and even 45° C in some places. Summers are moderate in mountainous areas with hills and valleys, while winters can get extremely cold. The average summer and winter temperatures in the Kathmandu Valley range from 20° to 35°C and 2° to 12°C, respectively. As a result, the average temperature in Nepal decreases by 6°C for every 1,000 m of elevation gain. In winter, the Himalayas block chilly winds from Central Asia and serve as the monsoon rains' northern limit. Some areas, like Manang and Mustang, are typically dry because they are in the rain shadow cast by the mountains. The monsoon season in Nepal accounts for 80% of total rainfall (June-September). In the western slopes, winter showers are more noticeable. The annual rainfall is 1,600 mm on average, but it varies by eco-climatic zone, with Pokhara receiving 3,345 mm and Mustang receiving less than 300 mm.

Table 1: Climate details - different cities of Nepal

Place	Summer (May, June, July)			Winter (Dec, Jan, Feb)		
	Max (°C)	Min (°C)	Rain (mm)	Max (°C)	Min (°C)	Rain (mm)
Kathmandu	28.1	19.5	312	19.3	3.0	15.4
Pokhara	29.7	21.3	829.7	20.3	7.7	26.3
Chitwan	33.0	25.3	404.0	24.1	8.3	13.8

In context to Kathmandu, climatic conditions for cool and moderate climates can be considered for implementing passive strategies. Practical findings prove that passive heating standards works well in various range of climates such as both hot and cold mild and extreme. Thus the design of passive strategies can be adopted to a particular climate.

2.4 Energy Demands and Performance gaps

As per world building council, it is important to ensure consistent user comfort to enhance wellbeing. Generally, Comfort should be a primary indicator for all building users as it is a fundamental element of its purpose of shelter. Design at both community and building level can substantially impact both the feasibility and energy requirements for achieving thermal comfort in a building (council, 2020). Environmental and social factors can be influential for building design and operations, which influences the health of the occupant. Furthermore, Climate change is increasing population susceptibility; increasing exposure to both heat and cold temperature events around the world. Thus, extreme temperature events are increasing in frequency and this trend is expected to continue. Between 2000 and 2016, the number of people exposed to heat waves has increased by millions; additionally people were exposed to heat waves in the current years compared to average years, which results to heat illness (dehydration, heat cramps, heat stroke), and accelerated death from respiratory disease, cardiovascular disease and other chronic diseases (WHO, 2022). Continual exposure to frigid temperatures (particularly within the home) also raises the risk of pneumatic, cardiovascular, and respiratory diseases, as well as having a bad effect on mental health. Cold homes are a significant contributor to the level of excess winter deaths in temperate climates (Guertler, feb,2018). According to Energy consumption on Household Level Percentage of energy types used for cooking in rural and urban areas (WHO, 2010). Almost 40% of global energy use relates to buildings, and buildings are often said to offer great potential for reductions in greenhouse gas (GHG) emissions. Industrial sector accounts for 54% global energy usage, followed by transportation sector responsible for 26% while residential and commercial sector exhaust 13% (UNEP, 2017). Building energy performance is regulated, and this has had some positive effect in the sense that new buildings are more energy efficient than older ones (Gram-Hanssen & Georg , 2018).

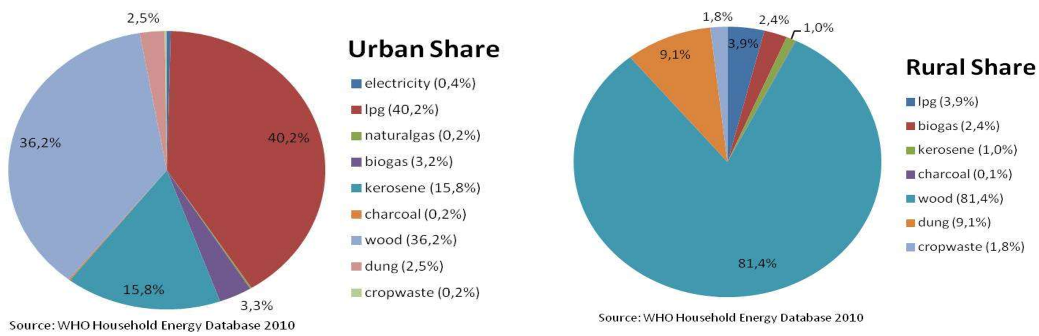


Figure 4: Household energy data base from WHO

Nearly 89 percent of the nation's energy was used for residential purposes in Nepal in 2008–09. The main fuel utilized in this industry is derived from biomass resources. Recently, traditional fuels for cooking and lighting have been replaced with renewable sources including biogas and energy from micro hydro and solar household systems. The modern lifestyle and growing urbanization have increased energy consumption in the building sectors even more. The energy consumption is increased due to the poor thermal construction of the residential buildings (Bajracharya, Shakya, & Bajracharya, 2020). This is a vital sign for the change in our consumption pattern via building energy efficient buildings. The use of energy efficient buildings accounts for a large share of the total end use energy. Energy efficiency helps control rising energy costs, reduce environmental footprints and increase the value and competitiveness of buildings. Sustainability is all about using the resources of today efficiently so that they meet our needs in the future. Thermal comfort can impact people's mood, performance, and productivity outside of weather extremes, with research demonstrating a link between perceived comfort and productivity. This is particularly true of overheating; however, creating the necessity for mechanical cooling interventions can lead to an increase in carbon emissions from energy expenditure.

Buildings used for business and institutions are the cornerstone of a nation's socioeconomic progress. The total amount of energy consumed increased on average by 2.4% year between 2001 and 2009. It is crucial to analyze how much energy is used in buildings and make the appropriate design and construction changes (Ruparathna, Hewage, & Sadiq, 2016). Building owners and designers can assess a facility's energy performance and improve its energy efficiency by making the necessary design changes before the building is built by using energy simulation, a computer-based analytical procedure. This study seeks to investigate the Housing building from the standpoint of energy use and recommend necessary actions to enhance the building's energy performance by finding energy performance gaps.

2.5 Comfort in buildings

The degree to which a building provides a comfortable environment for its residents is one of the most crucial factors to take into account while constructing it. Many various aspects that affect comfort in the built environment can, if not addressed effectively, result in low levels of comfort, discomfort, or even harm and ill health for occupants. User comfort can be impacted by individual aspects such as age, gender, health status, type of activity, psychological state, etc. Due to the intimate connection between comfort and health as well as allergies and illnesses caused by the structure. Thermal comfort is linked to symptoms of sick building syndrome and other disorders that reduce productivity, whereas building users who are comfortable with their thermal environment are more productive with their respective activity. The symptoms of itchy eyes, headaches, and throat irritation are linked to unfavorable heat, humidity, and ventilation in building occupants.

One of the main requirements that buildings must satisfy is the provision of a secure and comfortable indoor environment. In fact, the quality of the indoor environment, as defined by its three main axes—thermal, acoustic, and visual comfort—as well as the quality of the indoor air, is a crucial factor for reasons related not only to health issues but also to the well-being and productivity of building occupants. One of the most popular passive design strategies is natural ventilation, which uses fluctuations in air pressure to circulate fresh air throughout the interior spaces. For instance, with cross ventilation, the pressure differential encourages airflow by positioning the apertures on opposite ends of the space.

According to Skelton, building a better structure can lead to future energy and operating cost savings. For a country's energy planning and strategy, a thorough understanding of the energy demands of various sectors is crucial. Numerous socioeconomic variables, including population, urbanization, industrialization, net capital income, and technological advancement, among others, influence energy consumption. Prior to predicting future energy demand, policymakers must have a thorough understanding of the increase and distribution of energy demand across all sectors, which necessitates energy demand analysis, (M.Hasanuzzaman, 2020).

2.5.1 Improvising indoor thermal comfort

Air temperature, thermal radiation, humidity, airspeed, as well as individual factors like physical activity and the level of clothing insulation, can all be used in conjunction to estimate indoor thermal comfort. The six basic thermal comfort characteristics in every given setting must be controlled to some extent in order to achieve optimal thermal comfort are as follows air temperature, humidity, air movement, mean radiant temperature of surrounding surfaces, metabolic rate and clothing insulation. At an early point of the design process, numerical approaches became a regular tool for the prediction of comfort levels, which depend on the aforementioned environment and individual variables. Virtual simulation has also been shown to be a useful tool for designers at any stage of a new building or space's development, but particularly in the early stages. The layout and design of spaces and HVAC systems can still benefit greatly from general best practices and personal experience, but modeling now makes it feasible to anticipate thermal comfort conditions more precisely than ever before, (R.J., 1998). Thermal comfort surveys assist projects prioritize the actions required to increase occupant thermal comfort satisfaction by allowing them to objectively assess whether building services and design components are or are not performing well. If survey results show that the percentage of building occupants who are dissatisfied with the building's thermal conditions is higher than the desired thresholds, a clear action plan and commitment are required to resolve tenant discontent with thermal conditions.

2.5.2 Compact buildings with good thermal protection

The building envelope's constituent parts must all be properly insulated. Thermal bridges must be avoided by carefully planning edges, corners, connections, and penetrations. The heat transfer coefficients (U-values) of all opaque building components should be sufficiently well-insulated that they do not exceed 0.15W/(m2K), which means that no more than 0.15 watts of heat energy are lost via the external envelope per degree Kelvin and square meter. These U-values for freestanding, single-family dwellings are frequently less than 0.10 W/(m2K). Reaching the Passive House Standard is simpler and more affordable the smaller the building envelope is.

A superiorly airtight building will ensure favorable ventilation and temperatures while preventing moisture damage. A pressure test that limits the permissible air change to 0.6 times a room's volume per hour and the pressure differential to 50 Pascals must be used to prove the airtightness of a Passive House.

2.5.3 Building materials

Each material used to build together a structure is a building material. In the construction sector, there are numerous types of building materials suitable for projects of any size. Every material used in construction has qualities that is ideal for a range of uses. These fundamental building supplies could be helpful for your project, whether you're building a new structure or undertaking home remodeling work.

A. Brick

   Bricks are rectangular blocks that are mortared together. Bricks can be created from a number of materials, despite the fact that they are typically made from dried clay. Bricks can withstand severe heat and have a very high compressive strength, yet they are very fragile when dropped. Bricks are frequently used for paving, walls, and fireplaces. Due to its propensity to collapse during earthquakes, the building of new brick walls has decreased since the turn of the twentieth century. If you prefer the appearance of brick, though, you can still use it in contemporary structures as long as you strengthen it with steel rods.

B. Stone

   Compared to other natural building materials, stone is a more lasting and necessary building element. Depending on the type, stones can be employed in construction for flooring, roofing, brickwork, paving roads, and as concrete aggregates. Quarrying is a method used to get stones for construction projects from solid, huge rocks. The stones used in masonry building should be strong, resilient, and devoid of weathered soft spots of material, fissures, and other flaws that would reduce its longevity and strength. Limestone, granite, marble, slate, kota stones etc. are example for stones often used in buildings.

C. AAC blocks (Autoclaved Aerated concrete blocks)
   Precast foam concrete AAC blocks are an environmentally friendly building material manufactured from quartz sand, calcined gypsum, lime, portland cement, water, and aluminum powder. The concrete is autoclaved under heat and pressure after mixing and molding, giving it its particular qualities. Due to their excellent strength, load-bearing, and thermal insulating qualities, AAC bricks are in high demand. In India, the advantages of AAC blocks as a cost-effective and environmentally friendly replacement for conventional building materials are becoming increasingly well known. We describe AAC blocks in this post, along with its benefits and drawbacks for building homes.

D. Steel
   Steel is an iron-based metal alloy with a negligible amount of carbon. Structural steel is the material of choice for the framework of skyscrapers and other massive constructions like stadiums and bridges due to its high strength-to-weight ratio. Nails, screws, bolts, and other fasteners used in construction also contain steel as an element.

E. Cellular light weight concrete(CLC)
   Cellular Lightweight Concrete Blocks, commonly known as Fly Ash Bricks, are referred to as CLC blocks. Fly ash, water, sand, cement, and foaming agents are the materials used to create these lightweight blocks. These modern concrete blocks are superior to traditional red bricks in that they provide additional advantages. There are two types of CLC blocks: protein-based and synthetic. Strength, durability, and heat conductivity are among the differences between the two varieties. By altering the ratio of raw elements in their composition, you can increase their strength and durability.

   For the frame structure house construction approach, CLC blocks are mostly employed as partition blocks. Although these blocks aren't known for being used in load-bearing structures, their strength can be improved by increasing their thickness. CLC blocks can thus be used for border, exterior, and interior walls.

F. Hollow concrete blocks
   Using a mold and the appropriate addition for your area and project, hollow blocks are manufactured. Concrete blocks are thought to be among the most widely utilized building materials in the construction sector worldwide. Parts are fastened together using cement to create sturdy, long-lasting blocks. According to the "Indian Standard - IS 2185 (Part 1) 2005," hollow concrete blocks are defined as those that have one or more large holes, between 50 and 75 percent of the block's total volume, measured

in terms of its total size. These cracks or holes lessen the block's overall surface area, which is why the weight of total structure is reduced.

Table 2: U value of various materials

BRICK	U value for : 8 inch – 0.38 : 12 inches- 0.31 : 16 inches – 0.25
STONE	U value for : 8 inch – 0.38 : 12 inches- 0.31 : 16 inches – 0.25
WOOD	U value for : 1inch – 0.4
GLASS	Double glaze- 1.8 DOUBLE glaze with low E argon gas-0.8
GLASS FIBRE	U value for : 1inch – 0.22 : 2 inches- 0.12 : 3 inches – 0.09
STYROFOAM	U value for : 1inch – 0.001

2.5.4 Window glazing and frames

According to research, any zone of the envelope must have an opening of at least 30%. If natural ventilation is used, the envelope must have 70% operable windows, but the minimum operable opening when using active systems is 30%. Multiple opening window styles may offer thermal comfort in a range of weather conditions. Large openings close to the inhabitants' level can offer high air exchange rates, possibly faster airflow, and a cooling effect as a result.

The entire window, i.e.: glazing and frame, should have a U-value of 0.80W/(m²K) or less (this value may have to be more stringent in more extreme climates, whereas milder climates may manage to meet the criteria with higher U-values) and the installed window should have a total U-value of no more than 0.85 W/(m²K). Therefore, it is crucial to employ window frames with numerous lip packing that are well-insulated. For the winter to allow for a net heat gain, glazings should have a high total solar transmittance (g-value) of at least 50%. (although lower g-values may be appropriate for extremely warm, sunny climates). The spacers in the glass seal edge must be thermically separated, that is, they cannot be made of aluminum, and the windows themselves must be airtight. Windows should be fitted in the insulation layer without creating any thermal bridges.

2.5.5 Window orientation and shading

For Passive Houses, proper window alignment and shading are crucial. The largest window surfaces should, if at all possible, face the equator in order to capture as much of the sun's energy when it is most needed. In order to minimize unintended heat losses, it is crucial to keep the window framing to a minimum while designing the windows (or gains). Windows facing East and West should have blinds installed to minimize overheating. Shades are also advised for windows facing the equator, particularly in hotter areas. Every room that faces the outside must have windows that may be opened in order to provide appropriate cross ventilation on warmer day

2.5.6 Ground heat exchangers

Throughout the year, subsurface temperatures are normally very stable. This can be used as a practical technique to passively pre-heat or pre-cool fresh, incoming air: fresh air can be directed through a ground heat exchange system, consisting of air ducts put underground, before entering the structure (such ground heat exchangers must also be equipped with a drain). This is a possibility to consider even if it's not required and might not always be viable.

2.5.7 Ventilation with heat recovery for efficiency

Heat-recovery ventilation systems are essential for maximizing energy savings because they make sure that the warmth carried by exhaust air is not lost but instead transferred to the incoming fresh air before the two air streams physically interact. Heat exchangers can also function in reverse under excessively hot situations, transferring heat from the incoming air to the exhaust air and pre-cooling the air before it enters the rooms. These systems ought to have automatically controlled bypasses as well, allowing incoming air to avoid heat exchange during periods when it is cool at night and the day is warm.

As ventilation systems without heat recovery waste much more energy annually than a Passive House does for heating (at the same rate of air exchange, a ventilation unit without heat recovery may lose about 24kWh/(m2yr) whereas a Passive House's maximum space heating demand is only 15kWh/(m2yr)), a Passive House can only function with a highly efficient heat recovery system. In order to comply with this requirement, ventilation systems used in Passive Houses must have heat recovery efficiency of at least 75% and an electricity consumption limit of 0.45 Wh/m3 of transport air volume. Additionally, the ventilation systems used in Passive Houses should not have an acoustic burden greater than 25dB. Utilizing silencers, pipes and values should be planned correctly. (IPHA, n.d.)

2.5.8 Ventilation with heat recovery for comfort

A ventilation system with heat recovery makes sure that plenty of fresh air enters the building in a controlled manner at temperatures close to room temperature. Residents no longer need to actively air out their rooms because draughts are avoided. In order to prevent too dry air, it is crucial that the fresh air entering the building not exceed 30m3 per hour per person. Such ventilation systems should not be mistaken with air conditioners, and it is unhygienic to humidify the air inside the ventilation system. By employing a premium F7 filter at the suction point, the ventilation systems utilized in Passive Houses deliver unrivaled interior air quality (the unit must also be equipped with a drain), (IPHA, n.d.). Due to reasons of hygiene, a humidifier within the ventilation unit is not possible. It is important to remember that Passive Houses utilize ventilation systems, not air necessarily conditioning systems.

2.5.9 Protection against mould

Continuous aeration with a mechanical ventilation system, strong thermal protection, and a thermal bridge-free structure—all features of the Passive House Standard—are essential to prevent the buildup of moisture and mold. Frames for windows and doors need to be effectively insulated. Although double glazing might be adequate in hotter climates, triple low-e glass window panes with noble gas filling are recommended. At the glass edge seal, thermally isolated, non-aluminum spacers are also crucial.

2.5.10 Domestic hot water

Domestic hot water usage has a higher heating demand in passive homes than does space heating. Therefore, it is crucial that the system be effective and that seamless insulation is used to reduce any heat losses that occur during the production, storage, and distribution of domestic water. Solar thermal, biomass, and/or heat pumps can supply all or part of a building's domestic hot water requirements while consuming less fossil fuel.

2.5.11 Efficient household appliances and lighting

Reduced internal heat loads lower internal heat loads, which decreases the likelihood that rooms may overheat during the warmer months, which is beneficial for the environment and your money. The little amounts of heat produced by personal appliances, lighting, and even humans (each person produces about 80 watts of heat) matter in Passive Houses, in contrast to conventional buildings. As a result, energy-efficient lighting, household appliances (such as refrigerators, ovens, lights, washing machines, dishwashers, etc.), and domestic water heating systems are necessary for Passive Houses. A drying cabinet connected to an extract air valve, as opposed to a dyer, can offer quick, cost-effective drying in a Passive House. Such methods enhance passive solar heating by lowering domestic heating loads.

2.5.12 Optimizing the whole concept and saving

In order to reach the Passive House Standard, all components must be optimised and checked for compatibility. The Passive House Institute developed the Passive House Planning Package (PHPP) to help designers in just this regard. An extremely accurate, Excel-based energy balance tool, the PHPP not only determines the space heating and primary energy demands of a design, but also calculates aspects such as window U-values, the influence of orientation and shading, heating loads and overheating frequencies. With PHPP, designers can optimize the components to be used and their construction plans to come up with the most cost-effective solution. The PHPP thus forms the basis of good Passive House design

2.6 Energy Consumption Pattern of Residential Building in Nepal

The commercial sector of Nepal consumed only about 4% of the total consumed energy. The residential sector consumed the highest percentage of energy 80% followed by industrial sector 8% and transport sector 7% (MOF, 2018). The consumption of commercial sector increased from 1% to 4%.

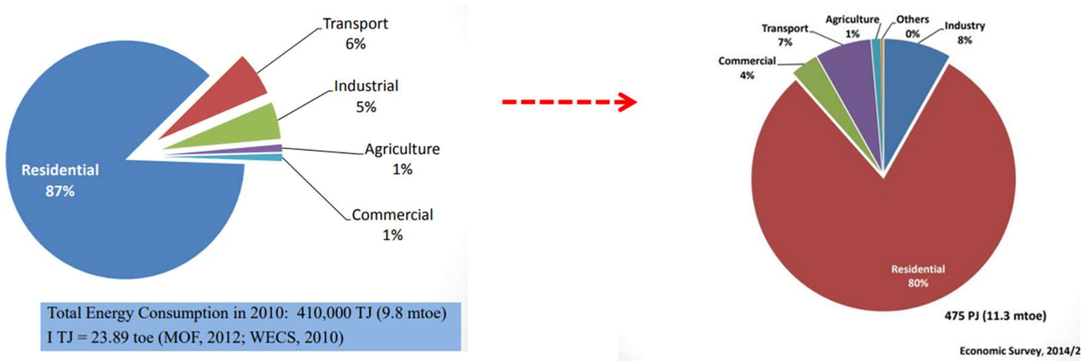


Figure Sectoral consumption of energy 2010

Figure Sectoral consumption of energy 2014/15 (MOF, 2018)

Figure 5: Sectoral Consumption of Energy

Energy resources in Nepal are broadly classified into three categories;

- Traditional- biomass (i.e., fuel wood, agriculture resides and animal dung),
- Commercial- fossil fuels and electricity, and
- Alternative- new and renewable.

Nepal has no significant reserves of fossil-fuel resources.

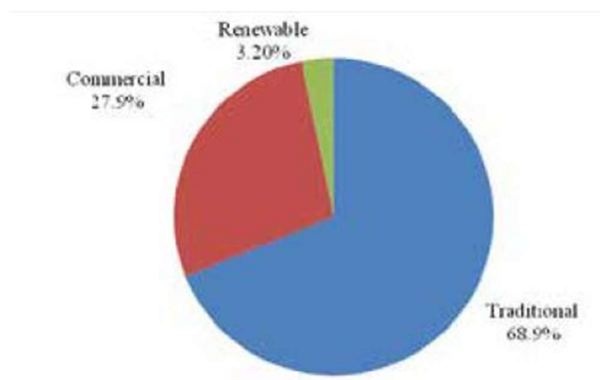


Figure 6:Status of Energy Consumption

As per the data of first eight months of the FY 2017/18,

- Business/trade (commercial) sector consumed 7.4% of the total consumed electricity.

- Households, industrial and other sectors have consumed 44 %, 37.2 % and 11.4% of
- electricity respectively.

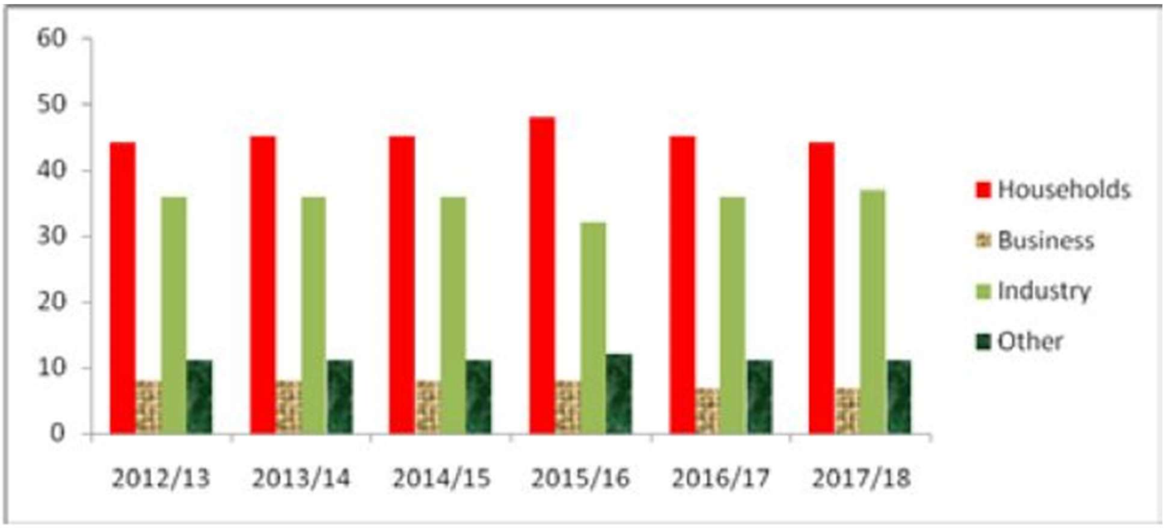


Figure 7:Graph showing sectoral consumption of electricity 2017/18

2.7 Built environment and user comfort

Numerous factors that affect human health and comfort but fall outside the purview of "conventional" building design can be directly attributed to the built environment. Olfactory, ergonomic, and visual comfort are some broader comfort indicators. Unpleasant scents can cause headaches, nausea, and eye, nose, and throat irritation in addition to olfactory discomfort. Muscle and ligament strain from repetitive jobs and uncomfortable visual conditions might lower occupant health and wellbeing. Development replaces the natural landscape elements as communities grow. The urban heat island phenomenon has emerged in the urban landscape as buildings made of materials that trap heat have taken the place of open spaces and flora. When compared to the nearby suburban or undeveloped areas, an urban heat island's most noticeable characteristic is a consistently higher temperature. This may result in harmful health effects like weariness, heart disease, respiratory problems, and illnesses brought on by the heat. High-rise structures can also accelerate the prevailing winds, causing discomfort for pedestrians and hazardous circumstances.

Additional comfort indicators may go beyond the "conventional" design parameters for health, happiness, and quality of life; "Comfort alone is not enough. In order to create more flourishing, stimulating, creative, and productive environments for individuals, we need to continue to expand our understanding of how the environment affects human health and welfare. (BCO, 2018). Interior design and aesthetics, color, character, layout and functionality, space, access to views, nature, and vegetation are some of the design and operational elements that can create the extra "flourish" factor. Consequently, a built environment that actively reduces risks to people's overall wellness while incorporating measures to enhance occupant visual, olfactory, and ergonomic comfort. Visual comfort and interior design for aesthetics should be designed in accordance with guidance on hazardous chemicals.

The strategies for designing buildings with respect to the built environment includes:

- Design of interiors and outdoors for visual stimulation, aesthetic pleasure and comfort
- Olfactory: Limiting the spread of odours by separating source (sources may include restrooms, kitchens and cleaning products) using pressurisation, self-closing doors and design strategies (such as hallways)
- Ergonomics: strategies which incorporates techniques to build furniture interventions can include adjustable workspaces; example, sit to stand desks, adjustable chairs etc.

2.7.1 Ensure inclusive design of the built environment

'Inclusive Design is the design of an environment so that it can be accessed and used by as many people as possible, regardless of age, gender and disability'; The Inclusive Design Hub. Recent World Health Organization publications estimate that 15% of people worldwide have a disability, of whom 2-4% experience significant difficulties in functioning. Blindness and vision impairment are particularly prevalent, estimated to affect at least 2.2 billion people around the world[30]. This proportion of disability in the global population is increasing, due partially to improvements in measurement capabilities to assess disabilities, but also the ageing global population. Since 1980, the number of people in the world who are 60 or older has doubled. By 2050, when the population is predicted to be close to 2.1 billion, the number of elderly people would have more than doubled once more.

Therefore, Inclusive design must keep the diversity and uniqueness of each individual building occupant in mind, considering all people utilizing a built environment, including those with mental and physical disabilities as well as vulnerable and ageing populations. An environment that is designed inclusively must apply to buildings, their surrounding open spaces, and local urban infrastructure and services.

<u>Strategies:</u>

- Universal design for inclusion, conscious of diversity and accessibility, increases usability, safety, health, and social participation: follow principles of inclusive design for the built environment published by the Commission for Architecture and the Built Environment.

- Design strategies for dedicated populations, ranging from accessibility measures to enhanced social engagement interventions for ageing groups: Age-friendly environments should include particular measures to increase safety and security of older people and ensure continued engagement with community; Design to cater for partially sighted people should ensure clear differences between color of pillars and floors, between steps and change in levels
- During every stage of the design process, from the design brief and detailed design to construction and completion, built environment specialists should involve potential users. Inclusion obstacles should be identified as early in the design process as possible because effective design may remove them.

Operation

- • Promote an inclusive culture. Enabling settings can be physical, social, or mental. Environments that are accessible are very important for people with various degrees of ability and are also advantageous to the general public.
- Supportive company policies to support diversity in the workforce, including flexible scheduling, child and elder care support, diversity and inclusion and wage equity policies, paid parental leave and civic engagement and gathering input and feedback from employees.

2.8 Ecotect as a tool for analysis

Numerous analyses can be performed with Ecotect. The majority of the evaluations focus on energy efficiency because it was intended for architects. Only extremely intricate models can be used for these studies. They go beyond a city planner's design possibilities, who typically simply creates the framework for an architect's building design. In this study, only the analytical tools with a minimal requirement for building detail were investigated. These include sunlight, shadows, reflection, insolation, and prevailing winds. In 2009, Autodesk released the building analysis program Ecotect Analysis. Based on complex weather data it can be used to evaluate how much the building-design is adapted to the climate. The goal of the simulation tool is to aid the designer at every stage of the creative process. It is intended to be used in conjunction with Revit for architectural design as an Autodesk software family product. Revit has been substituted by Sketch Up in the working process because no highly detailed models or additional architectural features were needed.

In the insolation analysis, the proportion on diffuse and direct insolation can be estimated on every surface in the model. The Ecotect software supports exploring the insolation on an hourly, daily monthly or yearly basis. The result of the analysis is the number of total sunlight hours

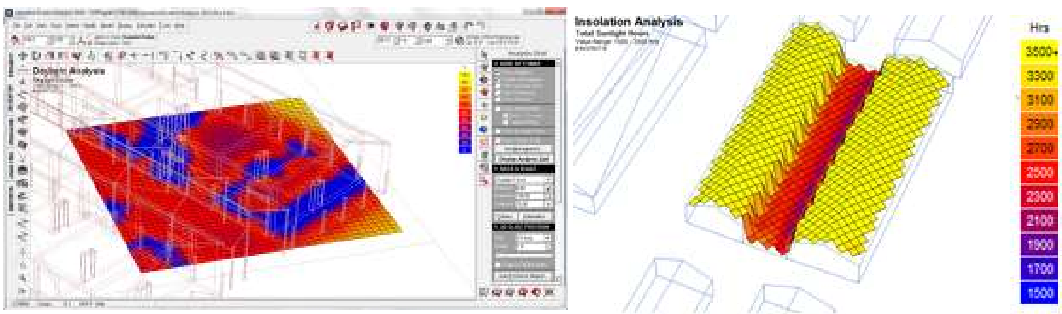


Figure 8: Ecotect as tool for analysis

An essential planning consideration is whether there is daylight on interior or exterior surfaces. The percentage of daylight access to a surface can be determined using Ecotect. In a detailed 3D-Building Model, the position of doors and windows can be checked and optimized. In city planning, it is useful to adjust the use-structure of a site, based on the quantity of daylight on every season. In the picture, an example for an interior daylight analysis is shown.

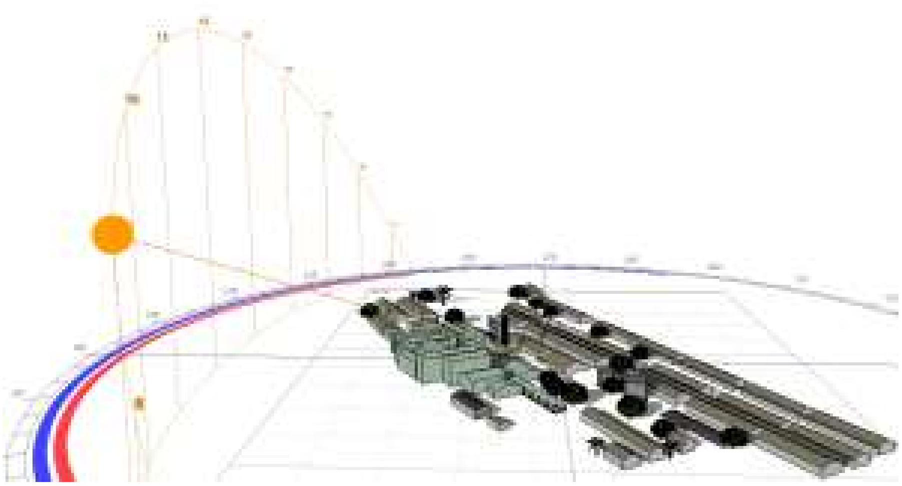


Figure 9: Example of Sunpath diagram from Ecotect

Based on latitude and longitude, it is possible to display the sun's location in the simulation model. In the sun path diagram that is provided, the user can change the sun's position to a certain day and time. This makes it possible to examine the position of the sun throughout the year. Additionally, the position of the sun can be shown in respect to the shadows. In the first instance, it may be essential to alter the reflective properties of the building surfaces. Before beginning a design concept, it's helpful to verify whether there are too many buildings in stock by using the tool that shows shadow range on a certain day.

Simulation models By using ECOTECT software for analysis and simulation gives new strategies that inspire from a human skin were applied to the existing building to enhance the sustainability and efficiency of the building. shows the monthly heating/cooling load. For example, before applying the double glazed window the amount of cooling load was around 35,488,444 MWh/year. The cooling load will decrease with the installation of Low E double-glazed windows with a timber frame, making the structure more pleasant and effective. Analyzing the monthly heating and cooling load after improving the building envelope with double glazing shows that energy consumption used for the cooling load reduced to around (40%). By analyzing the hourly gains in July, heat gain that enters the existing building will reduce and the building will become more sustainable and more thermally comfortable for occupants by reducing the heat gains. Ecotect puts something in the hands of architects that empowers better building design, so long as you can understand the concepts. The performance of any structure and system will become absolutely important in obtaining planning approval and compliance for potential tax credits as the trend toward naturally ventilated, low power, low emission designs continues. With the weather data loaded, and orientation defined, Ecotect can provide a very visual display of the prevailing winds around the building all year. This information assists in designing cooling and natural ventilation systems of the buildings. This also expands to average max and min temperature, humidity and rainfall. There are links out to Computational Fluid Dynamics (CFD) engines too, so you can really Ùse Ý the airflow and forces that your building is likely to undergo. The software shows visual feedback on the natural light penetrating a structure. Using this, the architecture can be improved to let more natural light into the building's interior, cutting down on the requirement for artificial lighting systems.

On the basis of changing the glazing to pass, the software can even build a complying reference module. The Ecotect Solar components are quite beneficial since they produce the shadows that the model casts at specific times or on a specific day of the year. The Sun's path may be adjusted in real time using an extremely realistic model, which results in shadows. You may evaluate the amount of light entering your building at any given time and compare it to building compliance. The placement of windows or the design of the ceiling lighting will both benefit from this feedback. The program used to design building envelopes uses the opposite approach; it is feasible to determine the maximum building enclosure on-site that would provide proper light to the adjacent building.

CHAPTER 3. CASE STUDY OF RESIDENCE

3.1 INTRODUCTION

Figure 10: SUN PATH DIAGRAM OF SITE

The site is located at Hepali heights, latitude 27.75, longitude 85.34. The building is on the north-to-south axis and was constructed in 2017. The total site area is 222.53 sqm(2395.29 sq.ft) and the total built-up area of the building is 2273 sq ft. The ground coverage of the building is 913 sq.ft., keeping openings at a north to west solar angle as the building's orientation. As per the literature review, it is found that more than 80% of energy consumption is by residences, which is mostly due to thermal discomfort. The case of this residence also indicates a lack of comfort as people living in this house are reportedly sick with fever during the winter due to cold. As the current building envelope fails to perform well in terms of thermal comfort during the winters and also in the summer in Kathmandu, the house owner is looking for renovation strategies to achieve more thermal comfort. The envelope design has façade openings on the north, east, and south. The longest façade faces east with fewer openings, whereas the south opening is also not much, which results in less solar gain. Therefore, as per feedback from respondents' requirements, the building needs interventions that would access more sunlight from the east.

Figure 11: EAST/SOUTH/NORTH EXTERIOR VIEW

Figure 12 : 3D rendered image of design before construction

The current building envelope in north, east and south is shown in the given pictures. The balcony covering in east is done with toughen glass on the balcony

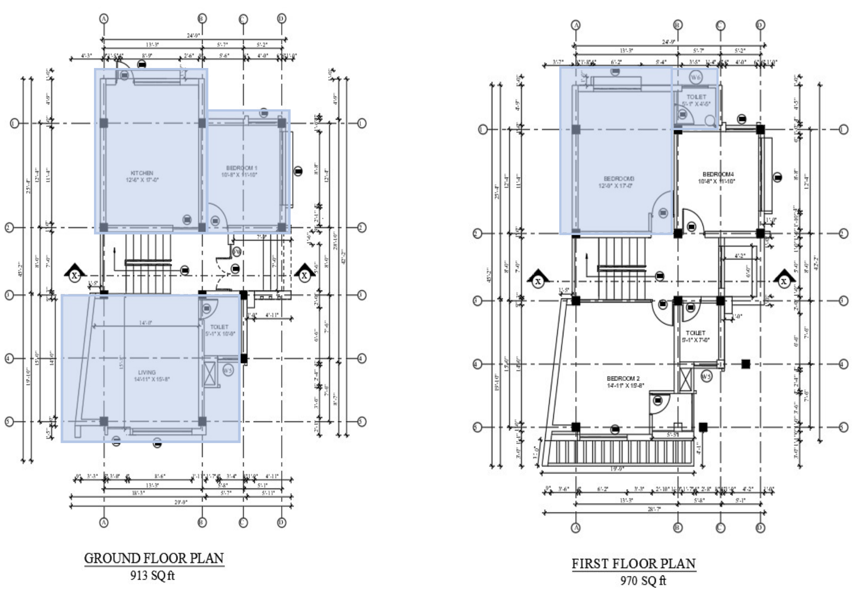


Figure 13: Residence plans as per site

Most occupied rooms are marked in the plans, which are the living room, kitchen, and guestroom on the ground floor, and Bedroom 2 on the first floor. The respondents were interviewed with an open-ended question along with analyzing the current envelope in Ecotect to understand the comfort level of the envelope. The kitchen is in the north and only gets north light, while the other rooms are in the north-east and the living room is in the south-east. The most occupied rooms are on the ground floor for all occupants except one of the members.

For field measurement, a thermometer is used to measure the room temperatures of 4 rooms, which means that the outdoor temperature and indoor temperature do not have much difference. Hence, it is considered that the building did not work well as a thermal envelope. The room temperature measured for the living room is 20 degrees in the living room and guest room on the ground floor. The room temperature in the kitchen while cooking was measured to be 24 degrees.

3.2 Field measurement:

The site visit of 14 days was done for the study of indoor temperature with respect to outdoor temperature. From the site visit on June 31st, 2022, it is observed that the envelope has sunlight from the south façade till 5:30 pm, but due to negligible openings on the south, the interior has no solar exposure during the day till 1:30 pm. The research is based on a limited consideration of temperature for measurement at the site.

The data collected is from the metrological station at Panipokhari, which is at a distance of 4 km from the current site. As per the data given by the meteorological department, the following is the data achieved for Panipokhari. The following is the calculated average:

SNO	MONTH	T MAX (°c)	TMIN (°c)	AVG TEMPERATURE (°c)	RAINFALL(mm)
1	JAN	20.12	4.487	12.30	9.53
2	FEB	21.91	6.63	14.28	23.93
3	MAR	25.74	10.19	17.97	30.43
4	APR	28.58	13.52	21.05	57.61
5	MAY	29.06	16.66	22.87	125.01
6	JUN	30.16	19.81	24.98	230.76
7	JUL	29.53	20.91	25.23	430.35
8	AUG	29.74	20.46	25.09	371.99
9	SEP	28.97	19.45	24.21	231.25
10	OCT	27.89	16.20	22.04	34.15
11	NOV	24.77	9.83	17.30	5.85
12	DEC	21.93	6.45	14.19	7.40

Table 3: Average data results from DHM (2000 to 2022)

The data shows the minimum temperature in the month of January, whereas the maximum temperature in the month of July. The average temperature given by these variables is 18.76 °C. Temperature is the main variable measured in this research. The measured temperature over 14 days is shown in the table below:

DATE	OUTDOOR TEMP. AT 11:30AM	OUTDOOR TEMP. AT 1:30AM	LIVING ROOM TEMP AT 1.5 M	KICTHEN ROOM TEMP AT 1.5 M	KICTHEN ROOM TEMP. While cooking AT 1.5 M	MASTER BEDROOM TEMP. AT 1.8 M	GUEST BEDROOM TEMP. AT 1.8 M
31st june	30 °c	30 °c	29°c	28°c	31°c	29°c	28°c
1st july	30 °c	30 °c	29°c	28°c	31°c	29°c	28°c
2nd july	30 °c	30 °c	29°c	28°c	31°c	29°c	28°c
3rd july	31°c	31°c	30°c	29°c	32°c	30°c	29°c
4th july	31°c	31°c	30°c	29°c	32°c	30°c	29°c
5th july	31°c	31°c	30°c	29°c	32°c	30°c	29°c
6th july	31°c	31°c	30°c	29°c	32°c	30°c	29°c
7th july	32°c	32°c	31°c	30°c	33°c	31°c	30°c
8th july	32°c	32°c	31°c	30°c	33°c	31°c	30°c
9th july	32 °c	32 °c	31°c	30°c	33°c	31°c	30°c
10th july	32 °c	32 °c	31°c	30°c	33°c	31°c	30°c
11th july	32 °c	32 °c	31°c	30°c	33°c	31°c	30°c

Table 4: Data measured at site for 14 days

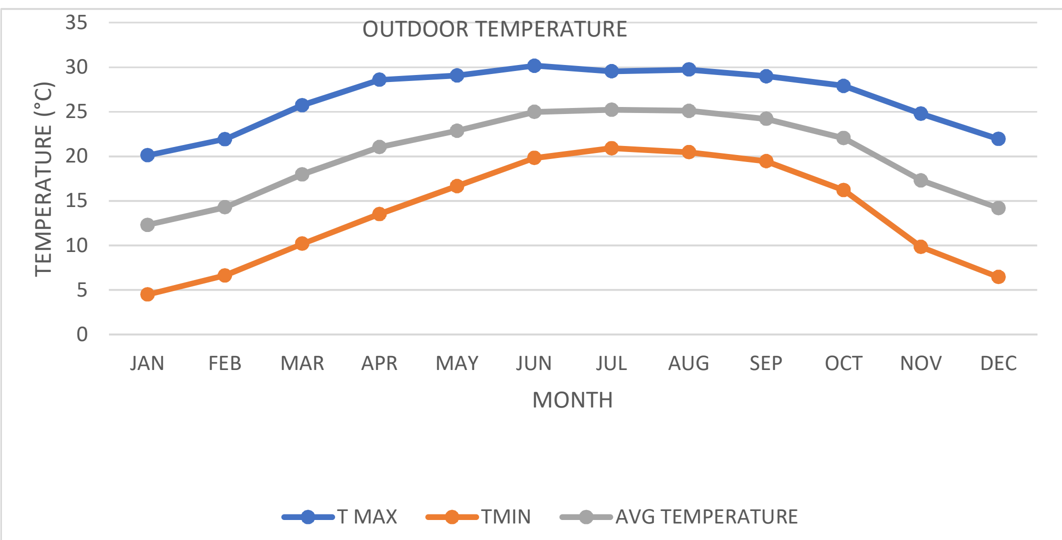


Table 5: Line-graph presentation on temperature for panipokari(2000-2022)

Compared to the table, the data is seen to be relevant and a slight increase in temperature is seen this year. The DHM data gives a probable prediction for each month throughout the year, while the data measured at site shows the building envelope performance, which shifts along with each room. The literature highlights various factors like the occupant's skin temperature, metabolic rate, clothing, and the environment's air circulation condition that affect the thermal comfort in the rooms. The data from DHM acts as a basis to understand the weather of the given place for the purpose of creating thermal comfort, which aids our lifestyle. The study of temperatures in the month of June-July falls under the highest temperatures of the year. The rise of 2 degrees is seen from the recorded average value of the highest temperature given in table 2.

Figure 14: Temperature measurements taken at site for living room/kitchen/bedroom(feb 28 2022)

Figure 15: Field measurement by thermometer for June 5 2022

Figure 16: Indoor temperature measurement July5, 2022

It is understood that a building envelope with proper insulation offers thermal comfort in spite of the outdoor temperature. While we observe the current state of indoor temperature, the envelope offers insulation of a maximum of 2 degrees on the ground floor and reduced to 1 degree on the first floor. The envelope has poor insulation and a lack of strategic solar exposure and ventilation in the rooms. Therefore, strategic conduction and insulation are needed to gain thermal comfort in all seasons.

As per the measured data, February has the most comfortable temperature compared to other months. The goal of the research is to optimize comfortable insulation throughout the year, decreasing discomfort in winter as well as summer.

3.3 Parameters considered in Ecotect

The observed clothing value and activity of respondents in various days with respect to the temperature reading is as follows:

DATE	OUTDOOR TEMPERATURE	CLOTHING VALUE	DESCRIPTION	ACTIVITY
28TH FEB	20 °c	1.5	THERMAL /SWEATERS	RESTING/ READING
5TH JUNE	30 °c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
31ST JUNE	30 °c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
1st JULY	30 °c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
2nd JULY	30 °c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
3rd JULY	31°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
4th JULY	31°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
5th JULY	31°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
6TH JULY	31°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
7TH JULY	32°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
8TH JULY	32°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
9th JULY	32°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING
10th JULY	32°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING

11th JULY	32°c	0.6	T-SHIRT/ TROUSER	RESTING/ READING

Table 6: Data collected /field measurement of site

The above table shows the parameters observed in the respective site visits on the respective dates. With interaction among the household members, it is known that the thermal comfort on February 28th is understood to be satisfactory when the outdoor temperature recorded is 20 degrees. Other data collected from June-july with the relevant clothing factor and activity observation is of summer. With respect to the data on table 1, the DHM data of Panipokhari gives an average temperature of 18.76 °C. As per theories by Schoklay, the established mean temperature helps in finding the neutrality temperature. From the equation, Tn = 17.6+0.31 x Tav. The study of data from 2000 to 2022 yielded a comfort band of 20.9 °C to 25.9 °C.

The other collected data, such as relative humidity and rainfall for the weather data file, are also the basic input in Ecotect. The average relative humidity and average rainfall from 2000 to 2022 are calculated and modelled as the parameters that give the thermal comfort results.

MONTH	Relative Humidity(max)	Relative Humidity(min)	Relative Humidity(avg)
JAN	80	73	76.5
FEB	74	70	72
MAR	70	74	72
APR	69	66	67.5
MAY	72	68	70
JUN	78	72	75
JUL	86	84	85
AUG	82	78	80
SEP	80	81	80.5
OCT	81	79	80
NOV	81	78	79.5
DEC	81	79	80

Table 7: Data collected from DHM for weather tool

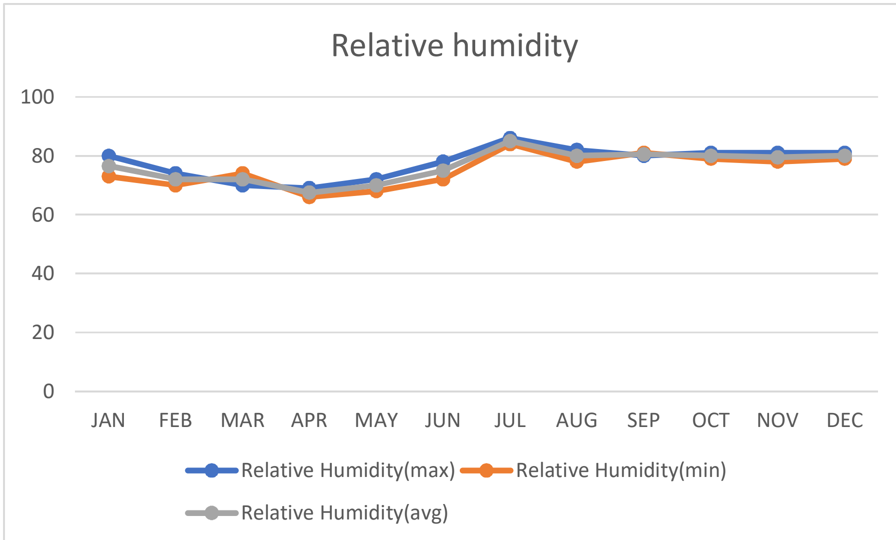


Table 8: Line gragh for avg. Relative humidity (2000-2022)

The humidity in hot weather and cold weather both increase the discomfort level. A humidity range of 25 to 60 percent is considered comfortable.As the humidity rises, there is a probability of rainfall. High humidity in summer results in a failure in evaporation, whereas the higher humidity levels in winter cause a lack of warm air. Even warm clothes might not be able to provide comfort due to cool water vapor. Thus, high humidity in summer or winter results in a hotter or colder environment. As per the scatter plot presentation, months like January have the highest humidity, and June ends with the first 2 weeks of July being hotter due to high humidity.

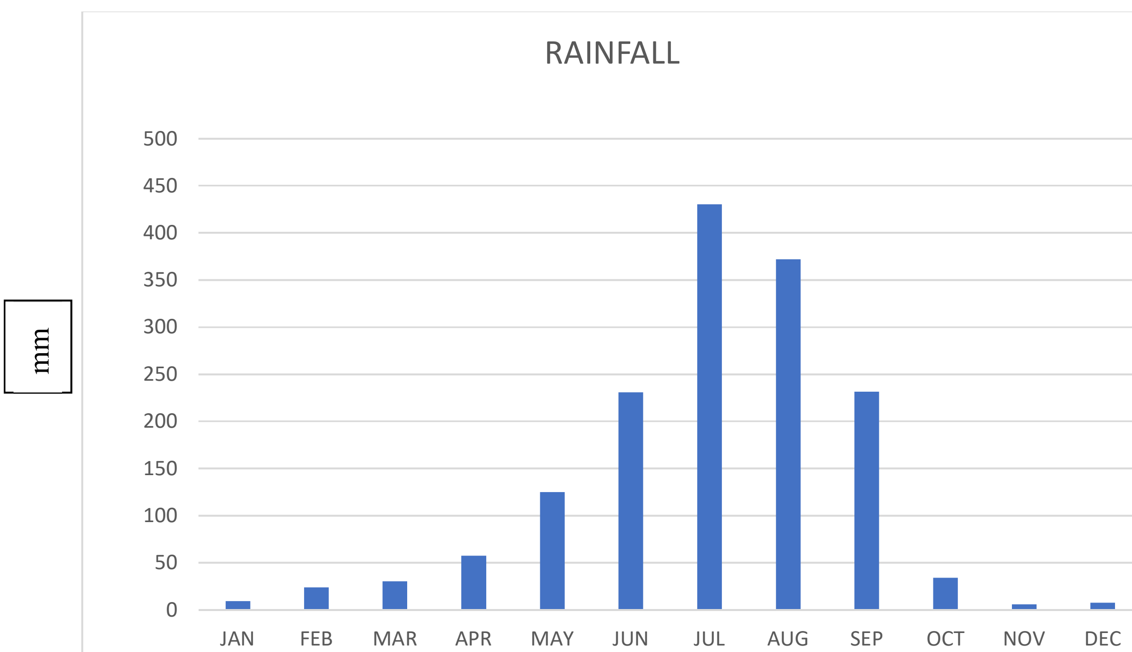


Table 9: Bar diagram showing avg. rainfall (2000-2022)

As per the data from Table 7, it is observed that the month of July has the highest humidity levels. The precipitation level in July also seems to be higher than in other months throughout the year, as the lowest humidity level is 84% on average throughout the year. Chances of rainfall during January are observed as the humidity level is at its maximum, which results in one of the coldest months of the year.

3.4 Base case scenario (Model in Normal condition)

With collected data from DHM, weather data file is created and loaded in Ecotect. The comfort temperature of 20.9 to 25.9 degrees is adjusted in the zone settings. The model in Ecotect represents the current envelope for base case scenario with out any intervention.

The home is subdivided into a total of 12 zones, including the circulation zone. The indoor thermal range for the software was from 18 to 26 degrees. The comfort range is changed as per the neutrality temperature found through Ecotect. Out of all zones, three rooms on the ground floor and one room on the first floor are among the five zones that are thought to be the most populated. Three people lived in the residence on the day of the site visit; their apparel, as observed in the field visit, is taken into account in the software as a light jacket.

The rooms are observed to have 9 inches thick wall with single glazed windows; depending on the plan position they have different orientation openings which is seen to have some affect in indoor thermal comfort.

The kitchen located on the north east side at ground floor is considered more colder than other rooms in the house. The two other rooms that are living room and guest room at ground floor that functions for sitting and chatting or watching tv and as a study area for kids are known to be hotter to the respondents.

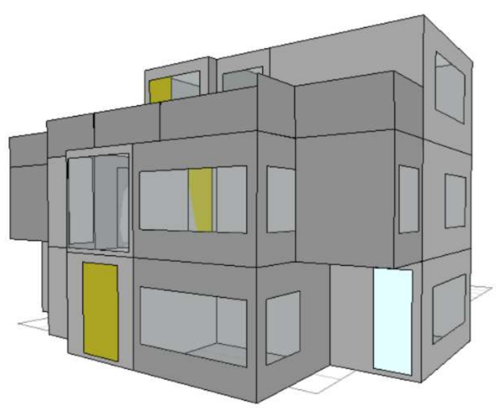


Figure 17: Ecotect modelling of site at hepali height(normal condition)

Each room is analyzed in Ecotect to figure out the discomfort level and discomfort hours. The result analysed for current situation is shown below.

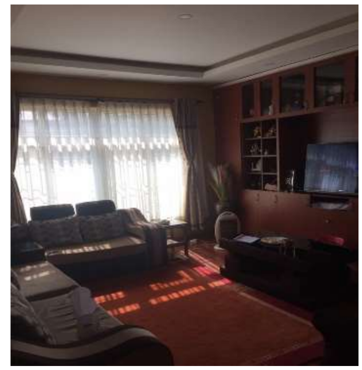


Figure 18: LIVING ROOM

Considered values:

Clothing value = 0.6 (t-shirt and trouser)

Occupancy=3

Activity = Reading/sitting watching tv

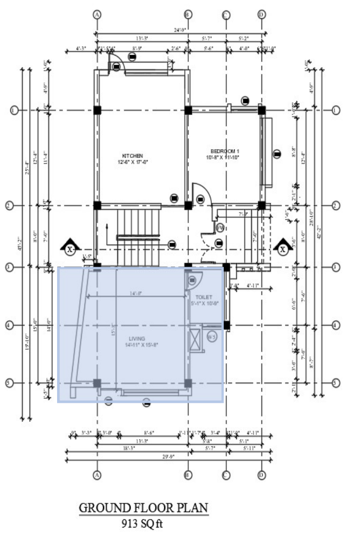


Figure 19: Key plan reference

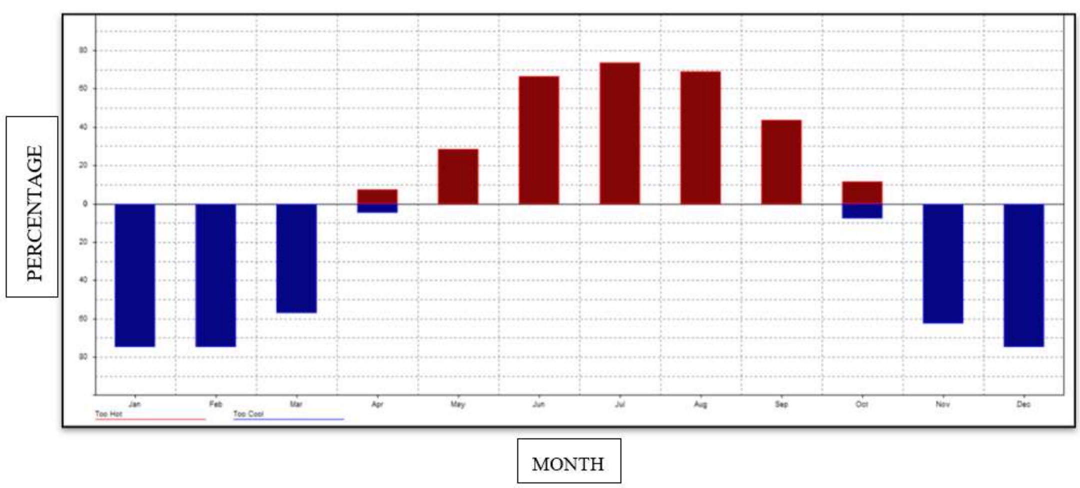


Figure 20:Graph showing the discomfort level in percentage for Living room

The bar graph represents the discomfort level of living rooms in percentage. The discomfort in the winter season is seen to be about 78% in natural ventilation mode with an opening at the south wall. The result shows that the discomfort in summer also reaches up to 73 percent. The room requires constant heating during the winter and constant cooling during the months of June, July, August and September. With natural ventilation mode, the total discomfort hours is 17864 deg hrs, in which discomfort due to cold was 15094 deg hrs, which results in 84% heating demand.

Figure 21: Graph showing the discomfort hours in living room

Considered values:

Clothing value = 0.6 (t-shirt and trouser)

Occupancy=3

Activity = Reading/sitting watching tv

Figure 22:Kitchen

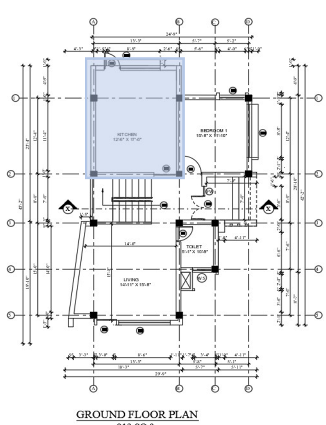


Figure 23: Key reference plan -kitchen

DISCOMFORT FROM HEAT

DISCOMFORT FROM COLD

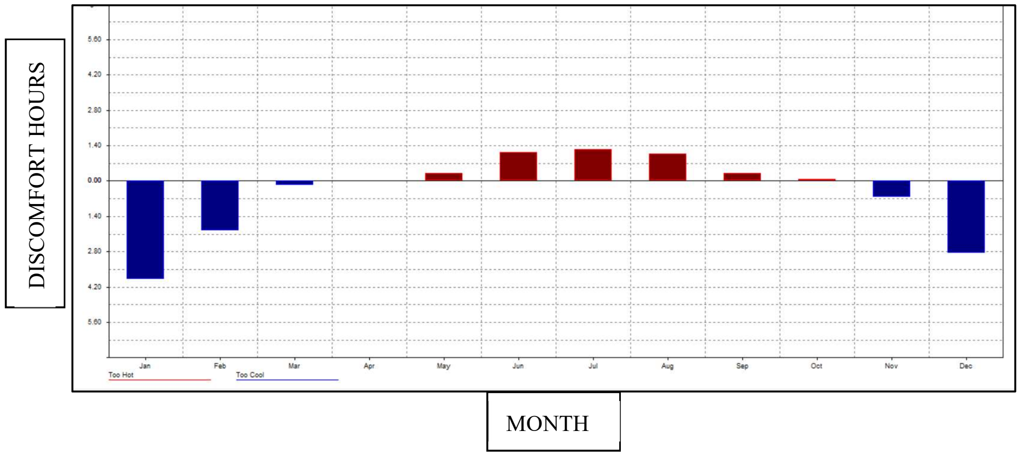


Figure 24:Graph showing the discomfort hours in Kitchen (not cooking)

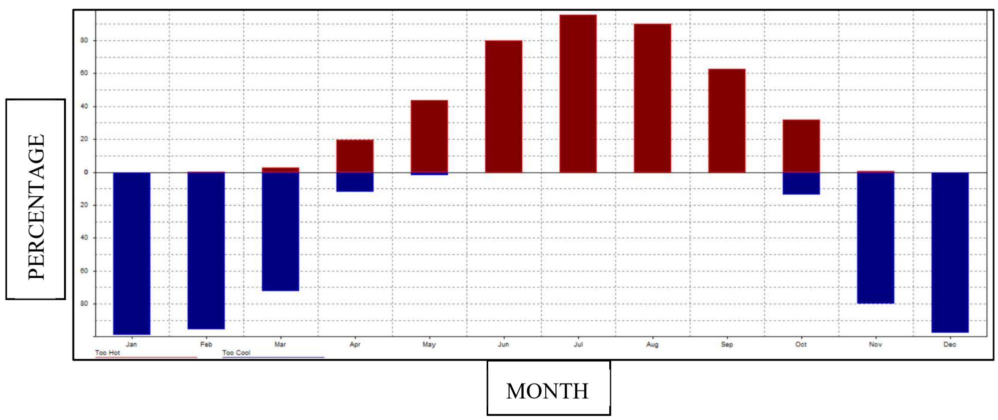


Figure 25:Graph showing the discomfort hours in Kitchen (while cooking)

The bar graph represents the discomfort of the kitchen in percentage. The discomfort in the winter season is seen to be about 99% in natural ventilation mode with an opening at the north wall. The result shows that the discomfort in summer also reaches up to 95 % due to cooking as an activity. The room requires constant heating during the winter and constant cooling during the months of June, July, August and September. With natural ventilation mode, the total discomfort hours is 17954 deg hrs, in which discomfort due to cold was 12694 deg hrs, which results in 76% heating demand. The room is dedicated to cooking and eating activities as dining is also accommodated in the room.

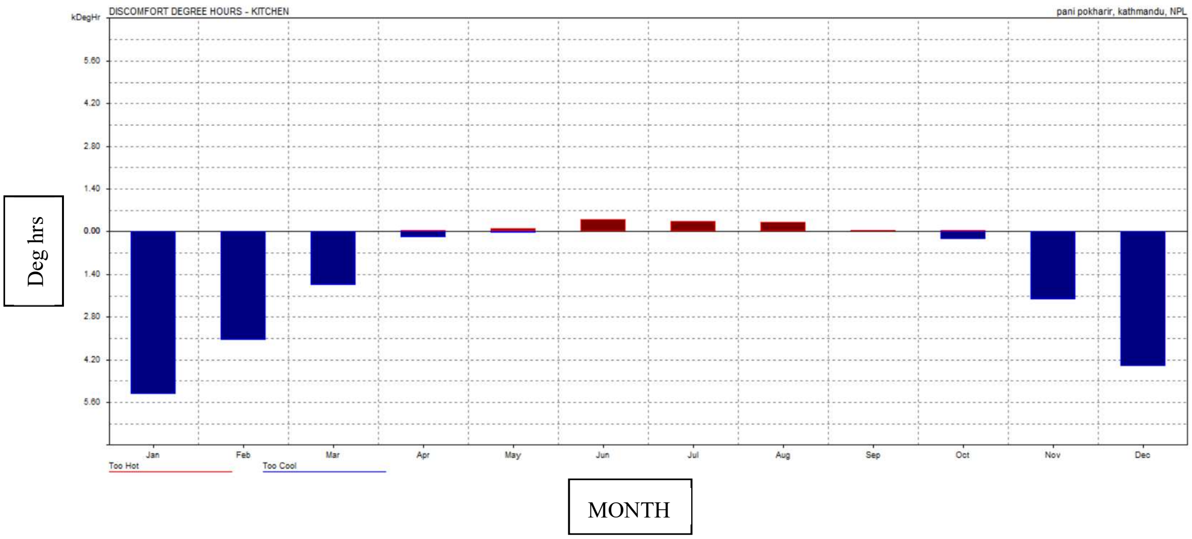


Figure 26:Graph showing the discomfort hours in Kitchen (cooking)

Considered values:

Clothing value = 1 (thermals)

Occupancy=3

Activity = Reading/sitting watching Tv

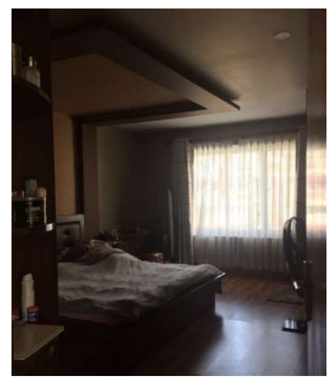


Figure 27:Master Bedroom

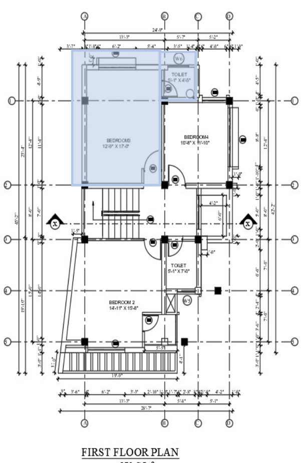


Figure 28: Master Bedroom

The master bedroom is used mainly for reading or sleeping purposes. The discomfort in the winter season is seen to be about 85% in natural ventilation mode with an opening at the south wall. The result shows that the discomfort in summer also reaches up to 44%.

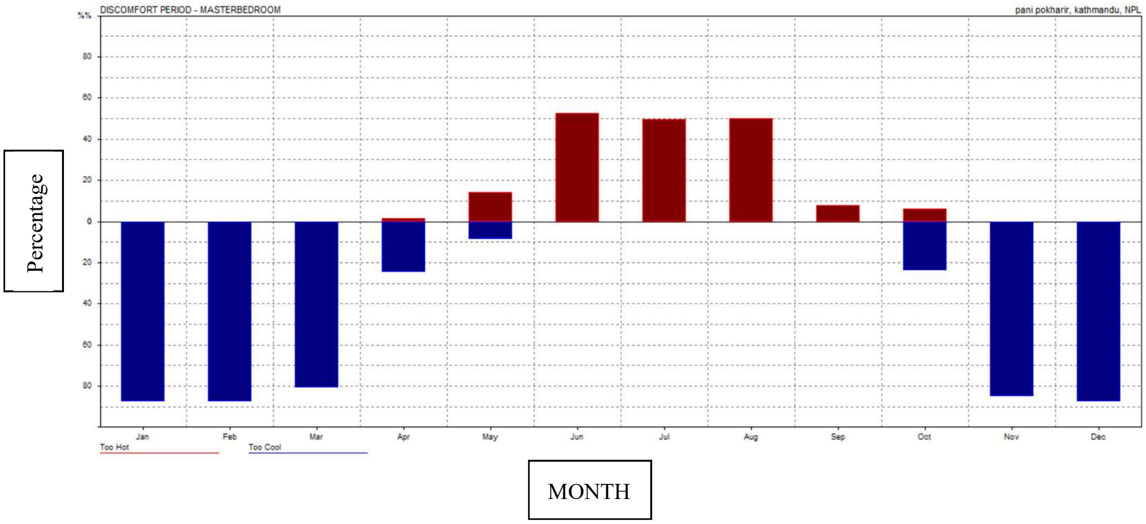


Figure 29:Graph showing the discomfort hours in Master bedroom

With natural ventilation mode, the total discomfort hours is 16015 deg hrs, in which discomfort due to cold was 14011 deg hrs, which resulted in heating deg hrs. The room is understood to be very cold for sleeping. A child sleeping in this room suffers from fever every winter.

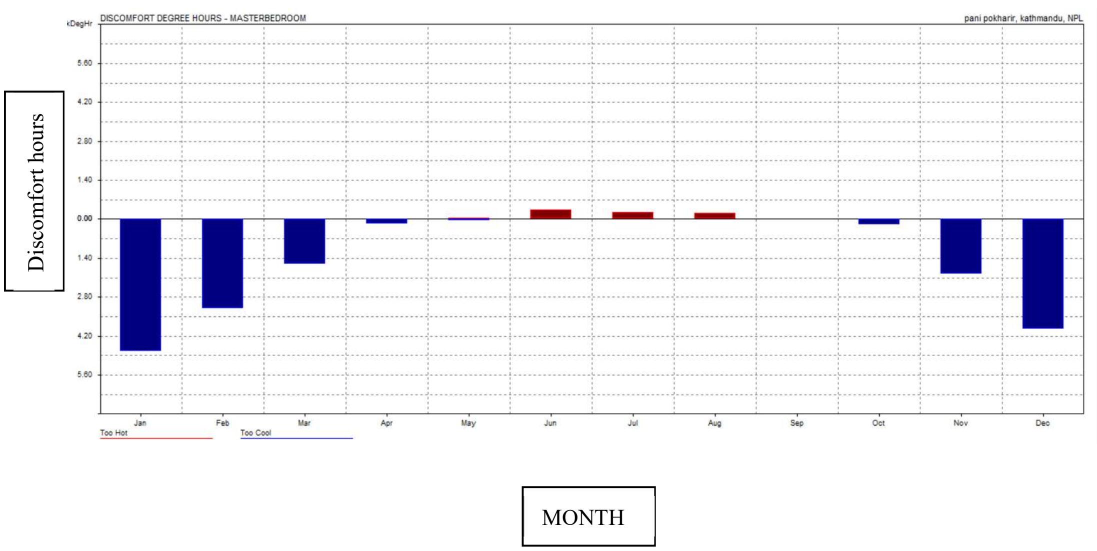


Figure 30:Graph showing the discomfort hours in Master bedroom

DISCOMFORT FROM HEAT
DISCOMFORT FROM COLD

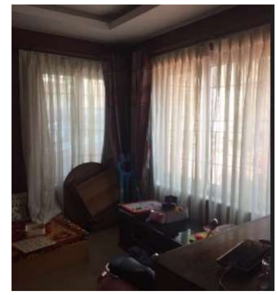


Figure 31: Guestroom

Considered values:

Clothing value = 0.6 (t-shirt and trousers)

Occupancy=3

Activity = Reading/sitting watching tv

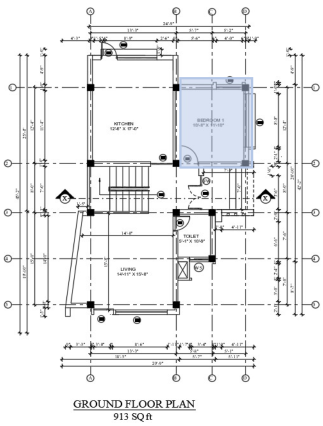


Figure 32: Key reference plan- Guest room

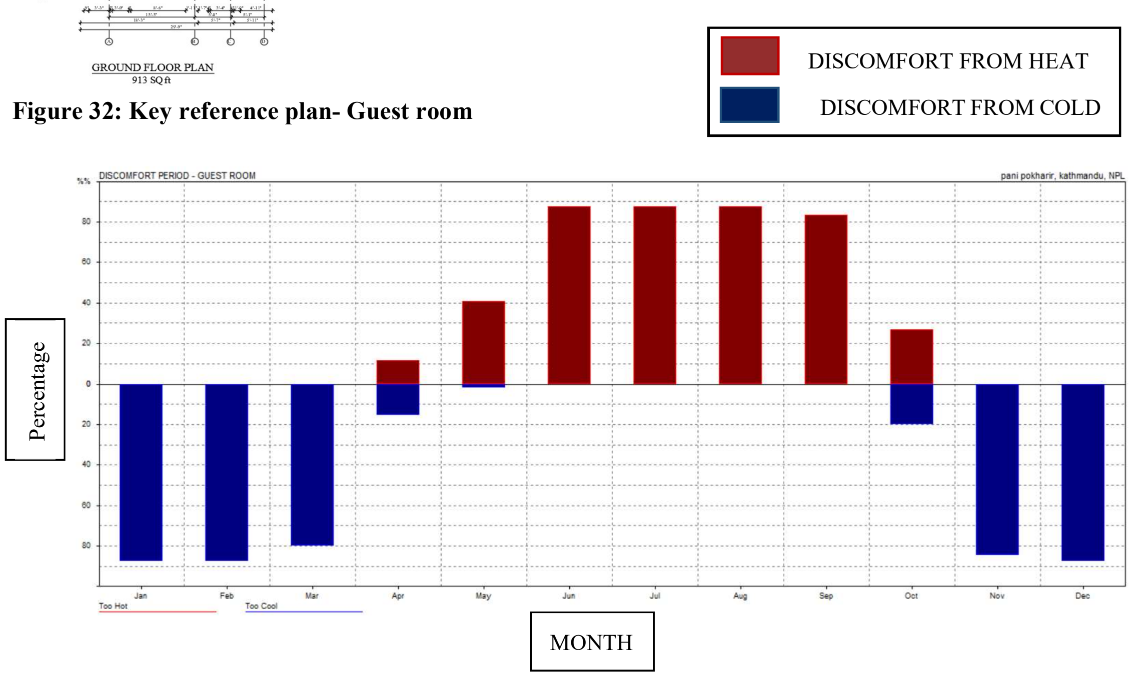


Figure 33:Graph showing the discomfort hours in Guestroom

The master bedroom is primarily used for reading or playing/extra-curricular activities for children, and the discomfort in the winter season is approximately 84% in natural ventilation mode with an opening on the east wall, which is also observed in the summer.Discomfort levels in the room are observed to be in 9 out of 12 months, which is 29394 total discomfort hours with 13950 deg hrs in winter.

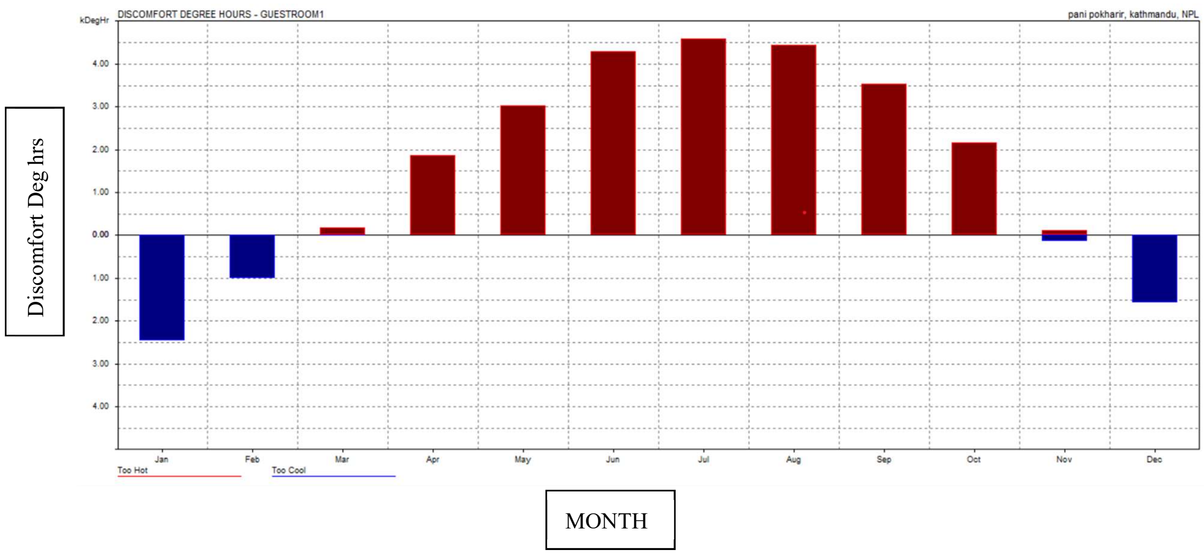


Figure 34:Graph showing the discomfort hours in Guestroom

The above bar graph represents the discomfort of guest rooms in percentage. The discomfort in the winter season is seen to be about 98% in natural ventilation mode with an opening at the north wall. The result shows that the discomfort in summer also reaches up to 83 % due to poor insulation. The room requires constant heating during the winter months from November to March and constant cooling during June, July, August and September. With natural ventilation mode, the total discomfort hours is 26356 deg hrs, in which discomfort due to cold is 19304.6 deg hrs . The room is usually occupied by kids for study or playing activities.

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
------------	--------	--------	--------
Jan	1482914	0	1482914
Feb	941248	0	941248
Mar	472355	12474	484828
Apr	94445	308257	402702
May	21867	630937	652804
Jun	0	997557	997557
Jul	0	868078	868078
Aug	0	826566	826566
Sep	0	652395	652395
Oct	79662	443100	522762
Nov	570148	6638	576787
Dec	1203110	0	1203110

------------	--------	--------	--------
TOTAL	4865748	4746002	9611750
------------	--------	--------	--------
PER M²	94474	92149	186622
Floor	51.504		
Area:	m2		

Table 10: Simulation result for overall heating/cooling demand

The results show that the most heating is required in January, with a heating load of 1482914 Wh, while the cooling load is comparatively low in summer, at around 997557 Wh.From the results, considering the discomfort that might be affecting health in winter, renovation strategies prioritizing 4 zones are suggested to the respondents. The model with intervention is evaluated in Ecotect for comparative analysis with several scenarios.

3.5 Data validation

Comparing temperature data from field visit and DHM Data, the average data findings are relevant. The data input to Ecotect shows result of discomfort corresponding to the response of occupants seems reliable. Following is the response recorded in the site visit from home owners:

As per the research questions asked to the respondents at site :

QUESTION – HOW COMFORTABLE IS THE INDOOR TEMPERATURE IN SUMMER AND WINTER IN ROOMS THAT YOU USE MORE OFTEN?

RESPODANT 1: *"We usually are in the ground floor. In winter the living area is very cold; starting from November. So we usually use heaters. Also in summer the temperature in living room is very high for me. So use of fan is also maximum in the day time."*

RESPODANT 2: *"Most of the time we are in the ground floor. Winters are very uncomfortable. But summer is Comparatively comfortable in the house."*

RESPODANT 3: "*I use my own room at first floor, the room is very cold comparing all other rooms, so I*

use heater in winters. The kitchen area seems comfortable while cooking but in summer

it is uncomfortable some times."

Question 2: Was any of the family member ill due to cold last year?

Respondent 3: The kid went ill most of times this year due to flu and we avoid cold products from her. Even we all got common cold and had to quarantine for a week.

As per the research questions asked to the respondents at site in 5TH June:

1. QUESTION1: What kind of discomfort do you feel in the house?
   Respondent 1: "*I feel the house is very uncomfortable due to heat. I cannot sit without the fan on*."

RESPODANT 2: *"Kitchen feels extremely uncomfortable while cooking otherwise we use fan most of times."*

RESPODANT 3: *"I feel comfortable usually but these days its extremely hot"*

2. Which of the rooms feel more comfortable in winter/summer and why?
   Respondent 1: *"Winters feel uncomfortable in almost all the rooms and even in summer I don't feel comfortable as my rooms has sunlight after3 it is usually hot till 5 pm."*
   Respondent 2: *"I feel my room is more comfortable, but not during the day.*
3. Which season do you use HVAC appliances more frequently when you are inside the room?
   Respondent 1: *" I use heater almost all the time during winter whereas in summer too its about 8 pm, we use fan at least for most of the time."*
   Respondent 2: *" I use heater almost all the time during winter whereas in summer iam more comfortable after in mornings and evenings."*
   Respondent 3: *" I use heater almost all the time during winter whereas in summer I usually donot use any appliances"*

With respect to observations from Table 2,3,5 and base case scenario results from Ecotect, it is understood that the weather file input in Ecotect has similarity to field data taken in summer 2022. The results obtained from Ecotect have marked relevant information from house occupants. Hence, the data input to Ecotect that is mentioned as parameters input in the research is valid. The current state of envelope results from Ecotect when compared to the occupants' response is thus valid. Therefore, the occupant's wish to renovate the house requires inspection for thermal comfort. From the given study in chapter 3, the data shows failure in the thermal envelope through a lack of insulating property in the envelope.

Particulars	28th February (spring)	5th June (summer)	5th July (summer)	Expected data for winter as per DHM
Occupancy	1	0.6	0.6	1.5
Outdoor Temperature	19° C	30° C	32° C	12.3° C
Comfort range	20.9° to 25.9° C	20.9° to 25.9° C	20.9° to 25.9° C	20.9° to 25.9° C
Living room	20° C	28° C	31° C	13° C
Kitchen(while cooking)	24° C	31° C	34° C	16 ° C

Guestroom	21° C	29° C	30° C	13° C
Master Bedroom	21° C	29° C		13° C
Clothing	T/TROUSER	T/TROUSER	T/TROUSER	Double layer clothing

Table 11: Temperature comparison with respect to DHM data

The information above compares the interior temperatures in different rooms. The temperature recorded on-site during the spring and summer is contrasted with the anticipated values during the winter. According to the study's literature analysis, a room temperature of 15 degrees or less can lead to lung illnesses in the future. The information provided shows that the winter room temperature should be as low as 14 to 15 degrees. Open-ended interviews conducted on-site revealed that the owners' health issues have gotten worse in the wintertime since moving into their new home, which is aggravating the situation.

All zones are known to have high degrees of summer discomfort due to poor ventilation. A toughened glass partition in the corridor area rapidly transfers heat from the summer to the winter. These particular locations require care. In order to understand the effects and function of passive methods, the research seeks to introduce modest modifications in the envelope. In the first two optimization kinds, the envelope materials are altered, and in the third optimization type, design techniques are included with different envelope options. The data shows comfortable indoor temperature during spring when outdoor temperature is around 19 to 20 degrees. As a result, methods for home envelope optimization are needed to improve indoor thermal comfort.

CHAPTER 4. OPTIMIZATION THROUGH SIMULATION TOOL

4.1 Optimized Model 1

For the first optimization scenario, the model was introduced with 18 inches wall. The scenario explores the contribution of wall thickness keeping all other factors fixed.

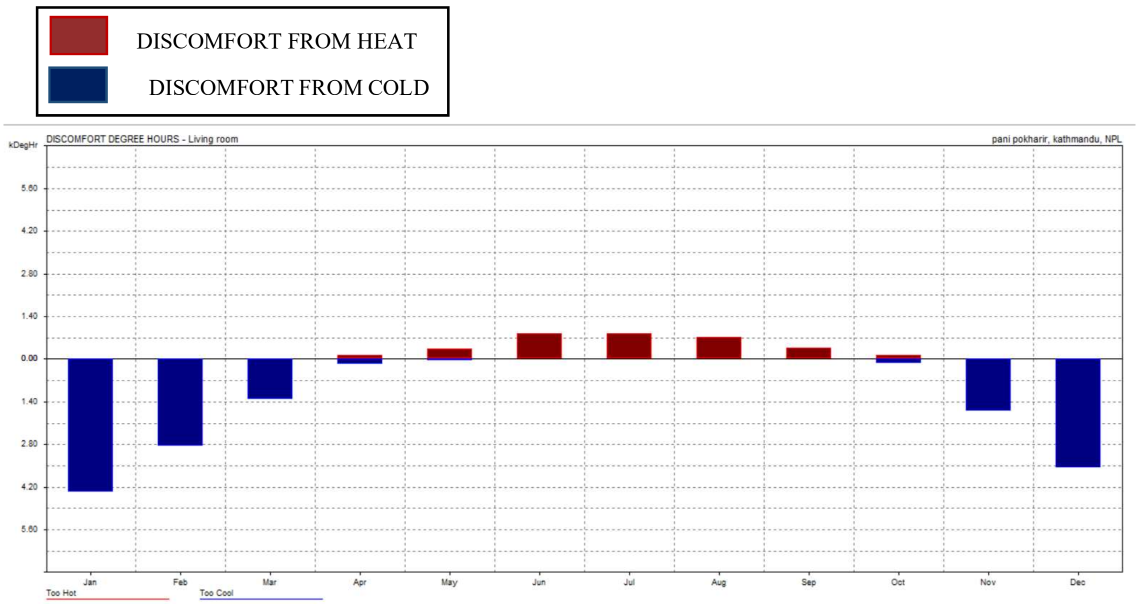


Figure 35:Graph showing optimization with increase in wall thickness(living room)

- The increase in wall thickness showed a slight change to heating and cooling demand, decreasing the demand for living room 17864 deg hrs to 17514 deg hrs.

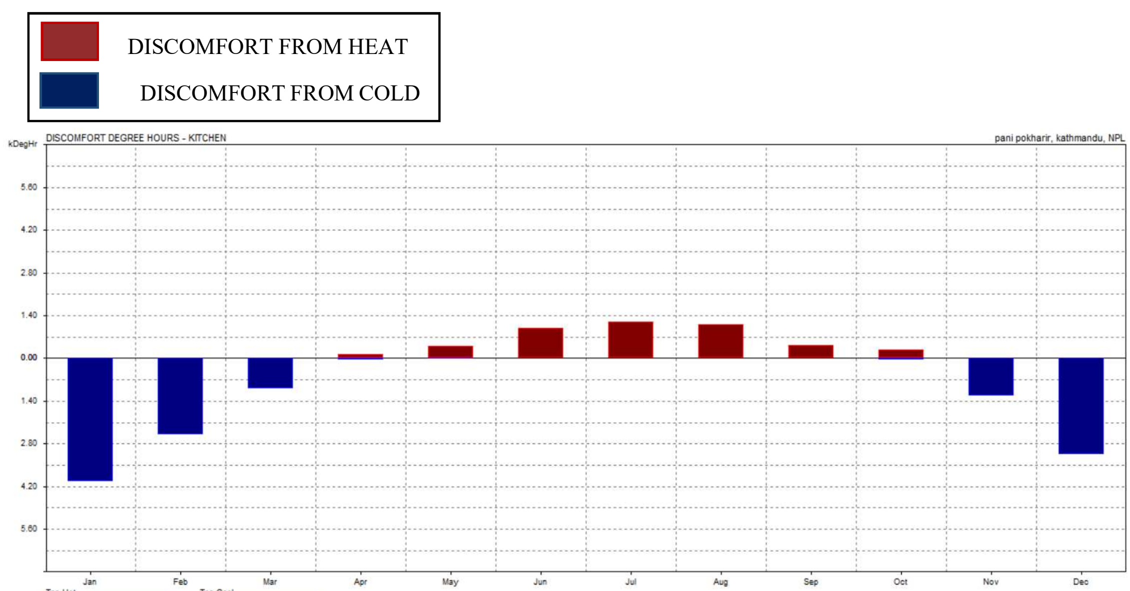


Figure 36:Graph showing optimization with increase in wall thickness(Kitchen)

- The increase in wall thickness showed a slight change to heating and cooling demand, decreasing the demand for Kitchen 17549 deg hrs to 16552 deg hrs, while cooking.(light food, value – 115w)

DISCOMFORT FROM HEAT

DISCOMFORT FROM COLD

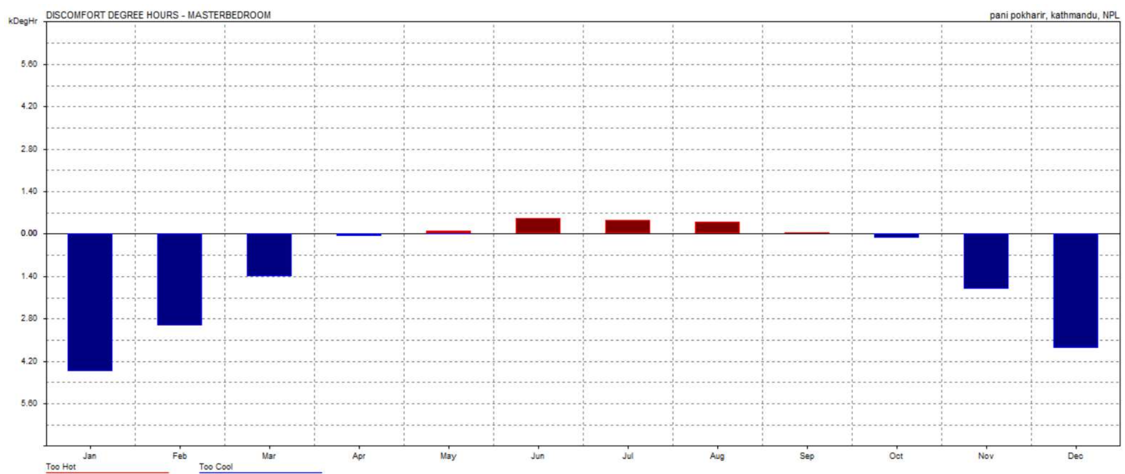


Figure 37:Graph showing optimization with increase in wall thickness(Master Bedroom)

- The increase in wall thickness showed a slight change to heating and cooling demand, decreasing the demand for Master bedroom 16015 deg hrs to 15856 deg hrs, while cooking.

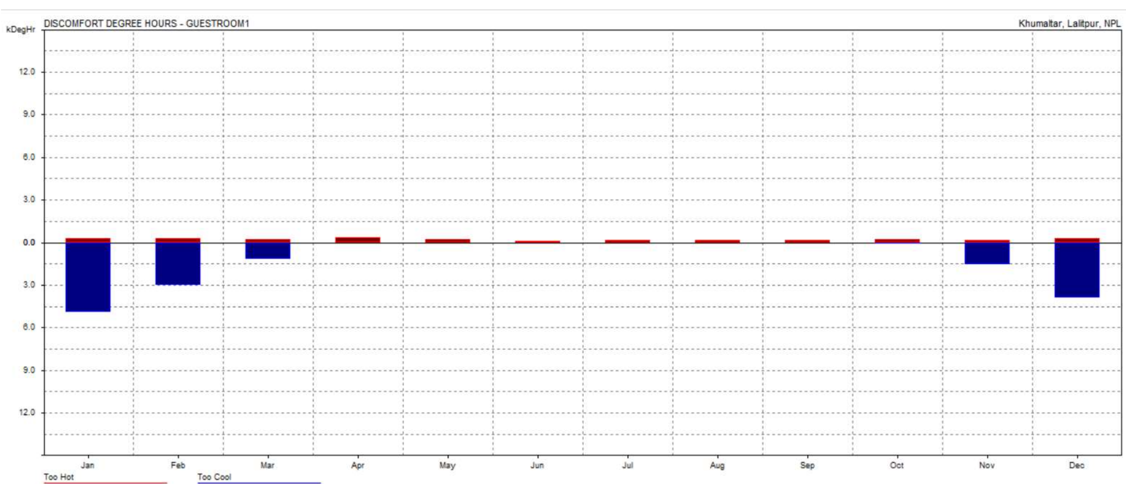


Figure 38: Graph showing optimization with increase in wall thickness(Guest room)

- The increase in wall thickness showed a slight change to heating and cooling demand, decreasing the demand for Guestroom 26536 deg hrs to 16042 deg hrs.

From the optimizing strategy increasing wall thickness of all the external wall, the heating and cooling load decreases in all rooms. When the model is analysed in mixed mode system the heating and cooling load is observed to be decreased from 1,05,92,006 wh to 58,68006 watt hrs.

4.2 Optimized Model 2

For the second optimization scenario, the model was introduced with double glazed windows. The scenario explores the contribution of window openings to the indoor thermal comfort. In the second scenario test, we have two calculations, one with simple double glaze windows and with u value of 1.8.

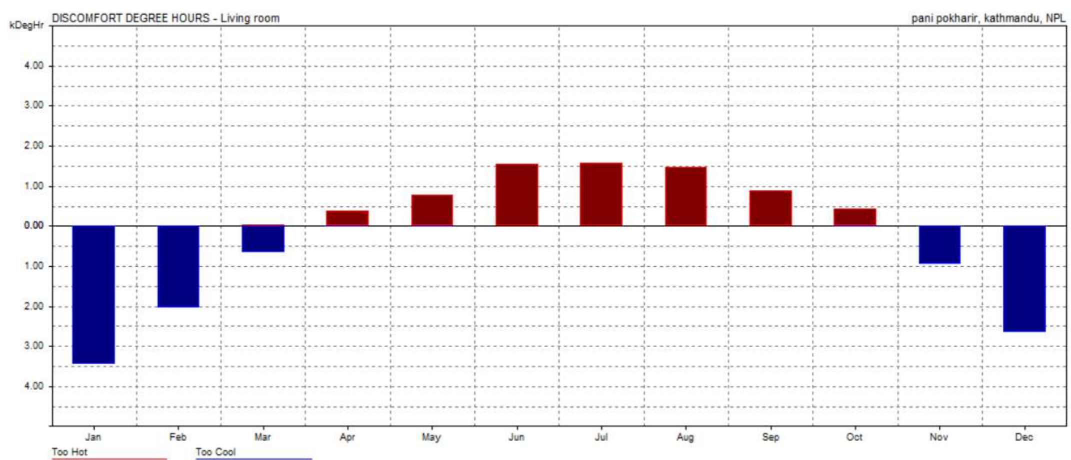


Figure 39:Graph showing optimization with double glazed windows thickness(living room)

The analysis shows that the use of double glaze windows with u value of 1.8 reduces the discomfort load of living room from 17864 deg hrs to 16887 deg hrs.

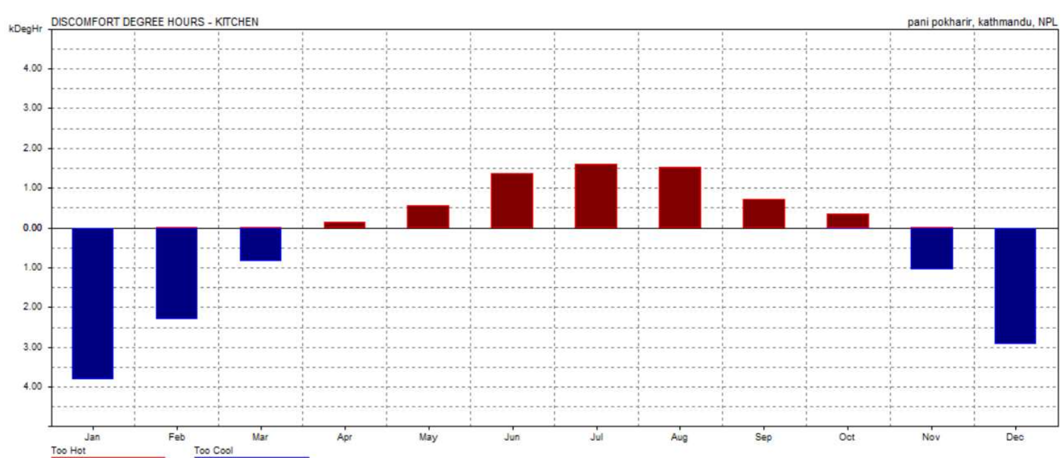


Figure 40:Graph showing optimization with double glazed windows(Kitchen)

The analysis shows that the use of double glaze windows with argon gas with u value of 1.8 reduces the discomfort load of Kitchen from 17549 deg hrs to 17300 deg hrs.

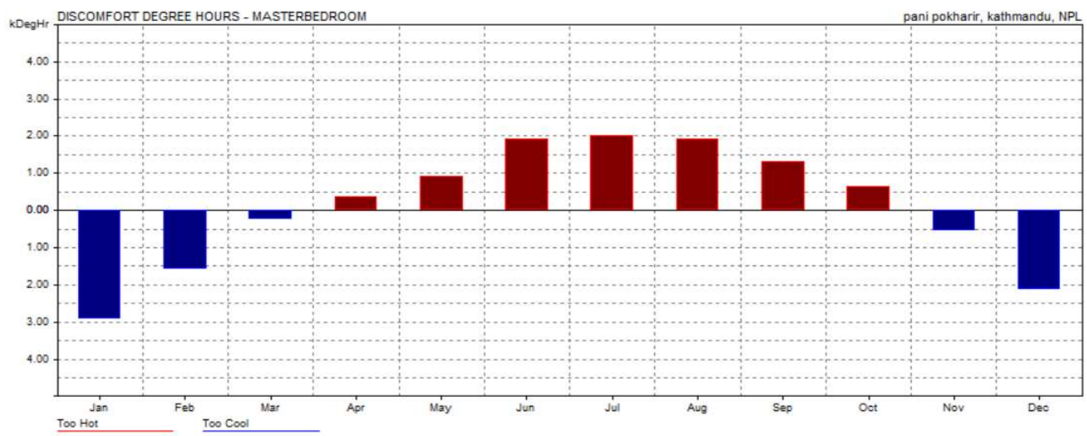


Figure 41:Graph showing optimization with increase in double glazing(Master bedroom)

The analysis shows that the use of double glaze windows with argon gas with u value of 1.8 reduces the discomfort load of Master bedroom from 16379 deg hrs to 16200 deg hrs

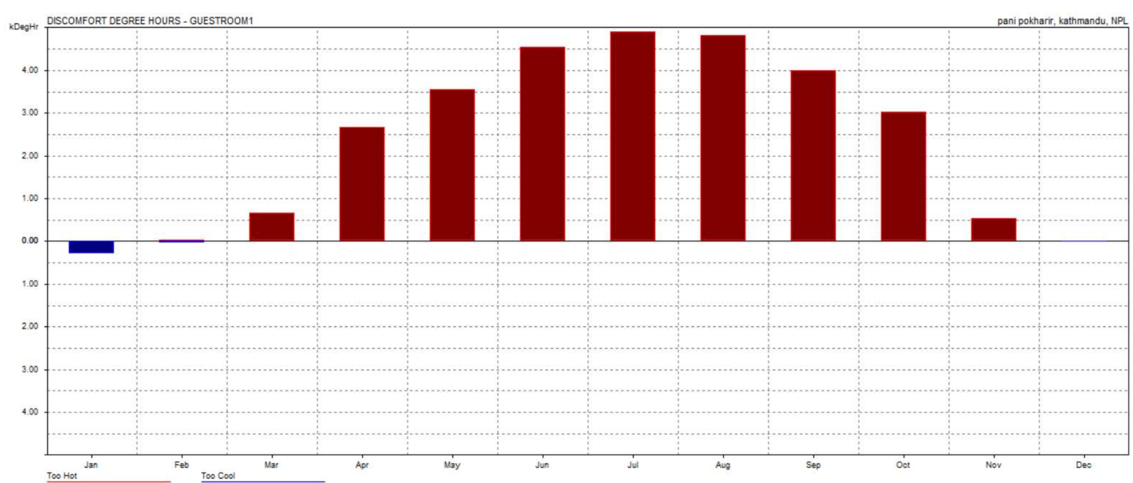


Figure 42:Graph showing optimization with increase in double glazing(Guestroom)

The analysis shows that the use of double glaze windows with argon gas with u value of 1.8 reduces the discomfort load due to cold but the lack of ventilation causes the discomfort due to heat. The south facing window contributes in increasing cooling demand, thus the overall heating/cooling demand increases to 25,330 watt hrs.

Hence, the model suggests the insulation from wall/window and ventilation together has to be considered to reach our goal thermal comfort.

4.3 Intervention Strategies and Requirement

Remodeling and planning the residence seems to be important as per the result shared through Ecotect. Following requirements of the owner is addressed to remodel and suggest strategies for increasing the thermal quality in enevelope:

- keeping structure as it is the house owner want to reshape add or substract element as per required
- openings as per required for ventillation for south east rooms
- bedroom 1 requires more sunlight as the room needs more sunlight
- toilet on the ground floor can be minimized removing shower
- number of rooms cannot be decreased though not usually occupied
- one shower is required on the top floor

Analyzing the current envelope, the discomfort for mostly occupied rooms is addressed. Following changes are done in the building to accommodate the requirements and also to remodel the building as a thermal envelope. Following insulation were done to the envelope:

1. single glazed windows can be replaced by double glazed argon filled windows.
2. External wall can convert to cavity wall, aided with insulation filled with fibre glass and cavity to increase resistance.
3. No insulation added to internal walls.
4. Toilet size on ground floor is not decresed
5. One window is added on the east wall of living room to increase ventilation.
6. One window is added on guestroom to increase cross ventilation.
7. The toughen glass in the corridor area is also replaced by double glazed windows
8. The room on the first floor repositioned to north east from north west, to access sunlight from east.

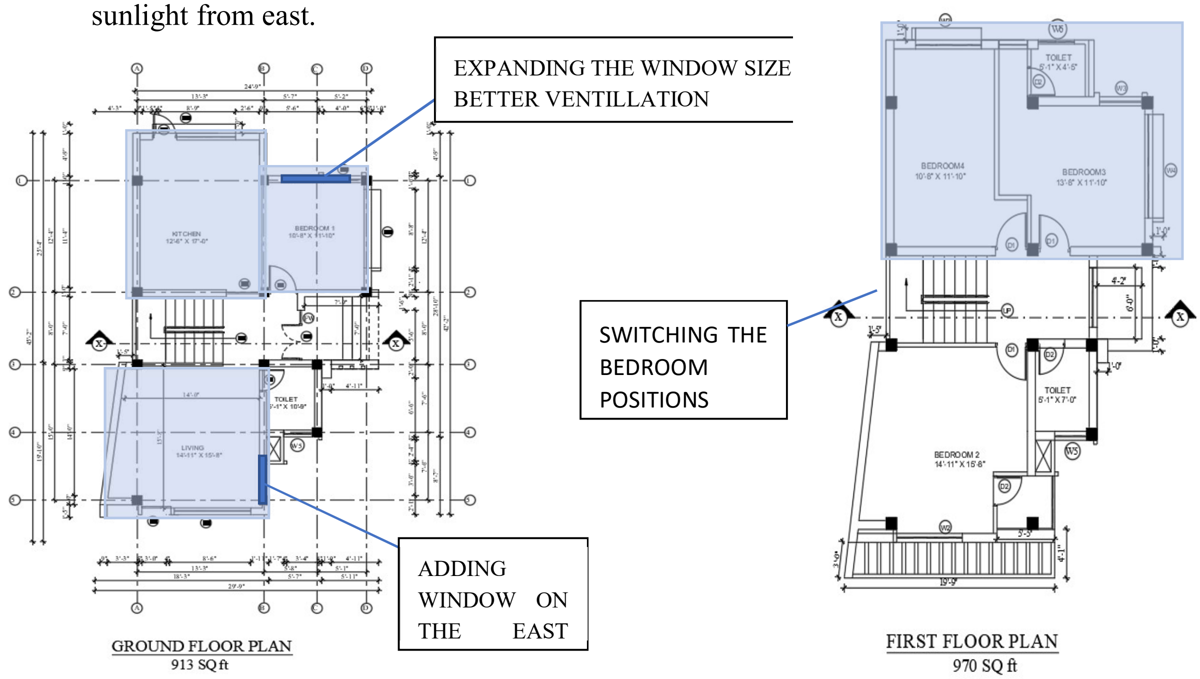


Figure 43: Renovation strategies for current building envelope

4.4 Optimized Model 3

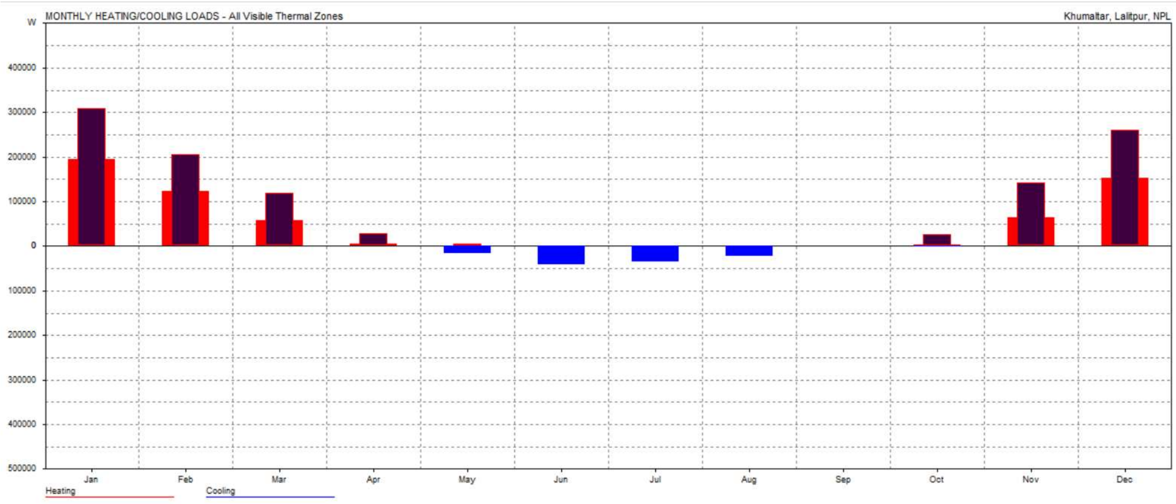


Figure 44:Optimization scenario after Renovation with insulation and double glaze windows

Previous models were analyzed with small changes like wall thickness and window specification whereas this model consists of intervention in the envelope. The figure 45, 46 shows the window openings introduced and change in window sizes.

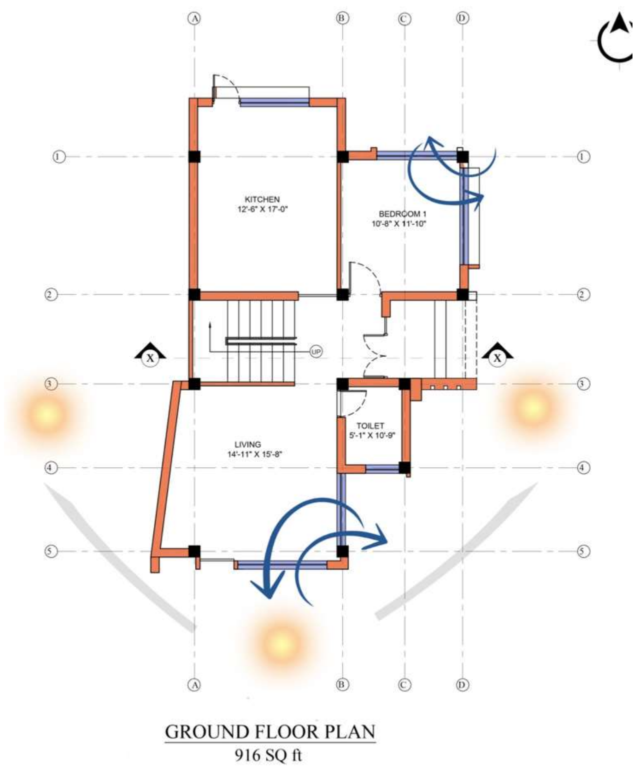


Figure 45: Interventions in building envelope before renovation (ground floor)

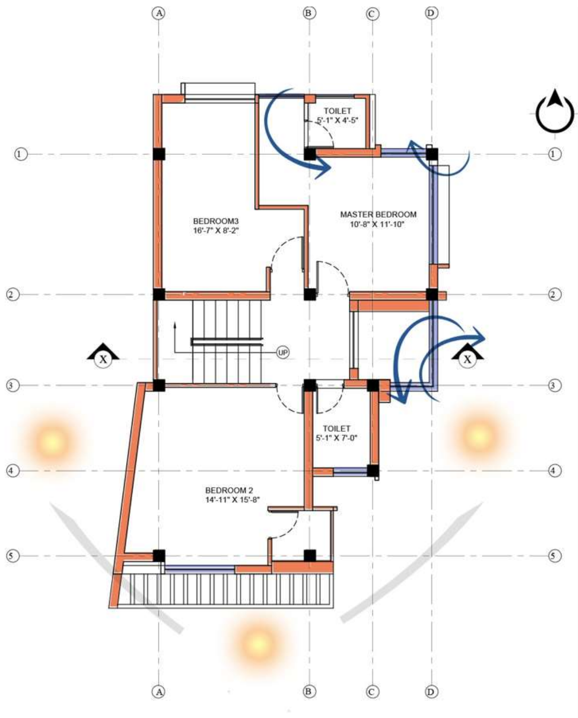


Figure 46: Interventions in building envelope before renovation (first floor)

Optimizing the model with additional insulation from glass fiber installation and cavity wall or cement board cladding in exterior walls. In addition to this double-glazed aluminum windows with argon gas filling is provided in the openings. The 230mm brick wall is further insulated adding a layer of fiber glass installation with cavity and another cladding of 75mm cement board. From the simulation, it is found that while replacing external 230mm brick wall with cavity wall in existing condition of the house with mixed-mode system, results show that heating load needed in January is reduced to 1,95,196 Wh from 27,41345 Wh whereas cooling demand is comparatively lesser that is 45,177 Wh. The data also shows the maximum heating and cooling requirement assumption from simulation as:

Max Heating: 1033 W at 05:00 on 4th January

Max Cooling: 673 W at 14:00 on 30th May

Analyzing individual rooms which are mostly occupied, the simulation results suggests that :

- The simulation results show that adding insulation in external wall and adding double glazed windows will decrease the discomfort hours of living room to 8882 deg hrs FROM 17864 deg hrs. The result shows increase of comfort level in summer and winyer due to solar gain from east and ventilation from openings.
- Similarly, other rooms such as guestroom on the ground floor and living room on the first floor is also seen to decrease the heating demand. The guest room at normal condition has a discomfort hour of 26356 deg hrs where discomfort due to cold is 13950 deg hrs. In

optimized condition the discomfort hours is reduced to 14,735 deg hrs in which discomfort due to cold as well as heat is similar. Also, Bedroom at normal condition has a discomfort hour of 16,015 deg hrs In optimized condition the discomfort hours is reduced to 11050 deg hrs.

- The simulation result in kitchen doesn't show much difference from the previous normal condition. The optimized condition shows total discomfort hours of 17549 hrs which is further reduced to 13093 deg hrs. This room has discomfort from cold as well heat. As the room is located in the north west, cooking as an activity won't be uncomfortable in winters but in summer when 4 degrees adds up the discomfort rises. Aid of active system might reduce the discomfort about 2-3 degrees.

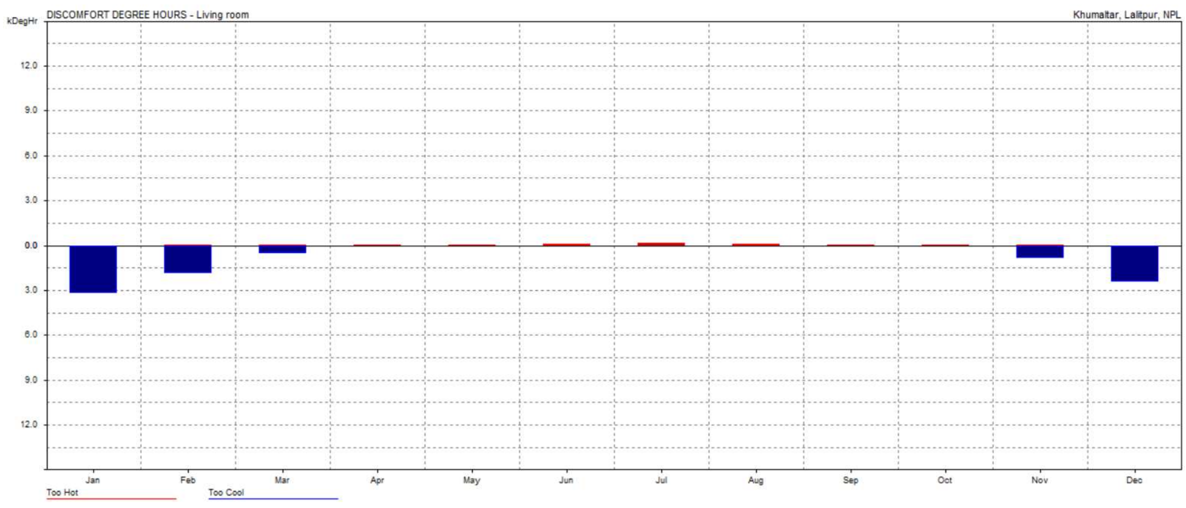
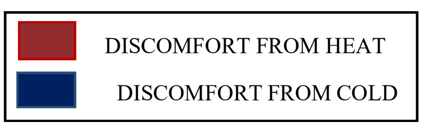
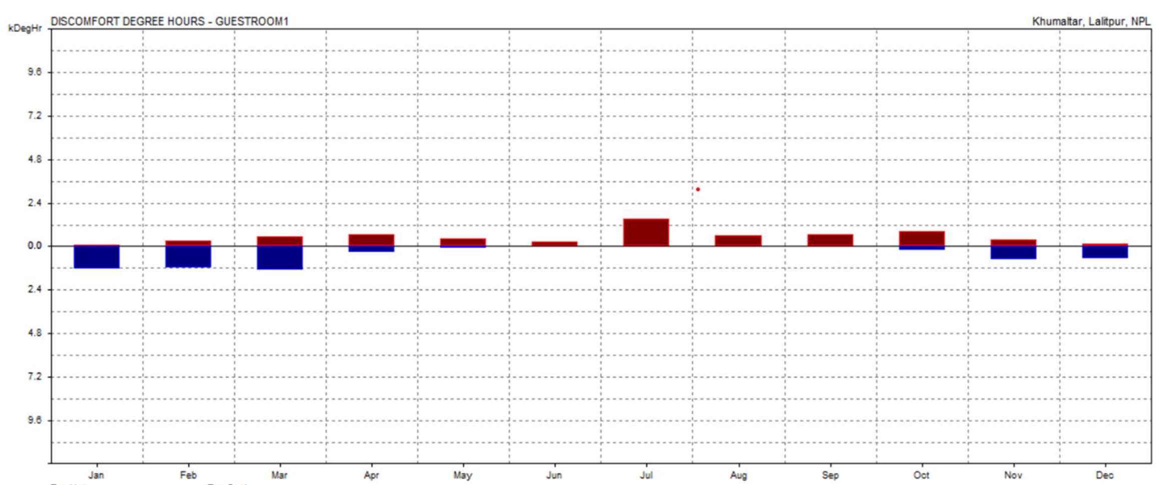


Figure 47: Reduction in Discomfort (Living room)





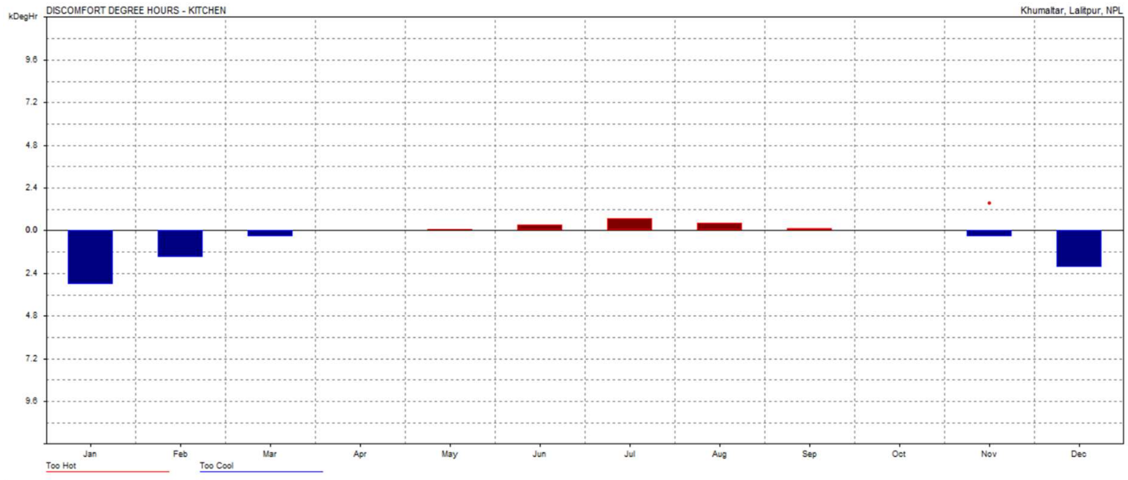


Figure 48:: Reduction in Discomfort (Kitchen)

DISCOMFORT FROM HEAT

DISCOMFORT FROM COLD

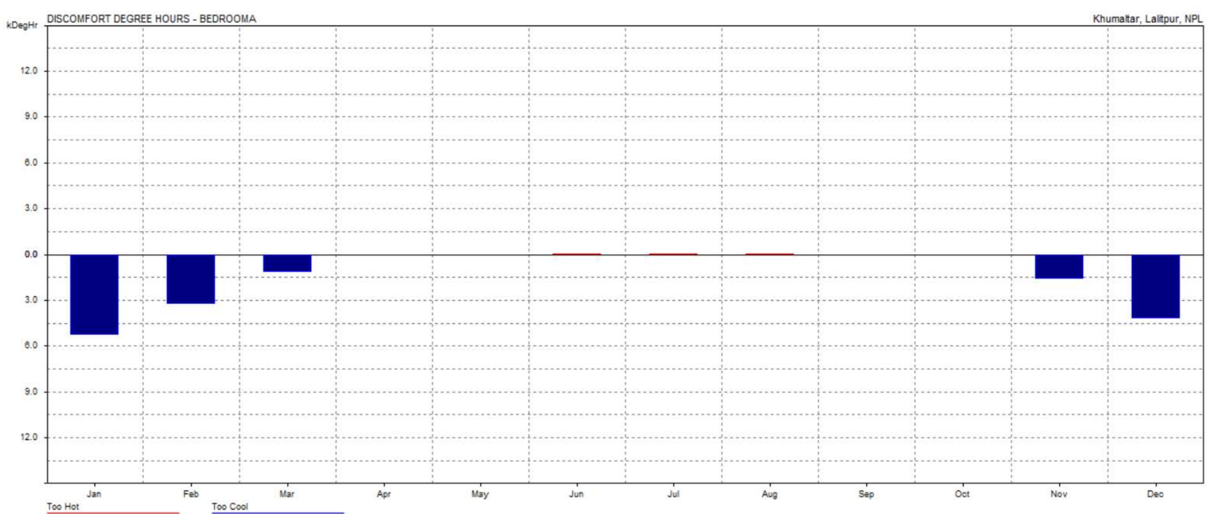


Figure 49:: Reduction in Discomfort (Master bedroom)

DISCOMFORT FROM HEAT

DISCOMFORT FROM COLD

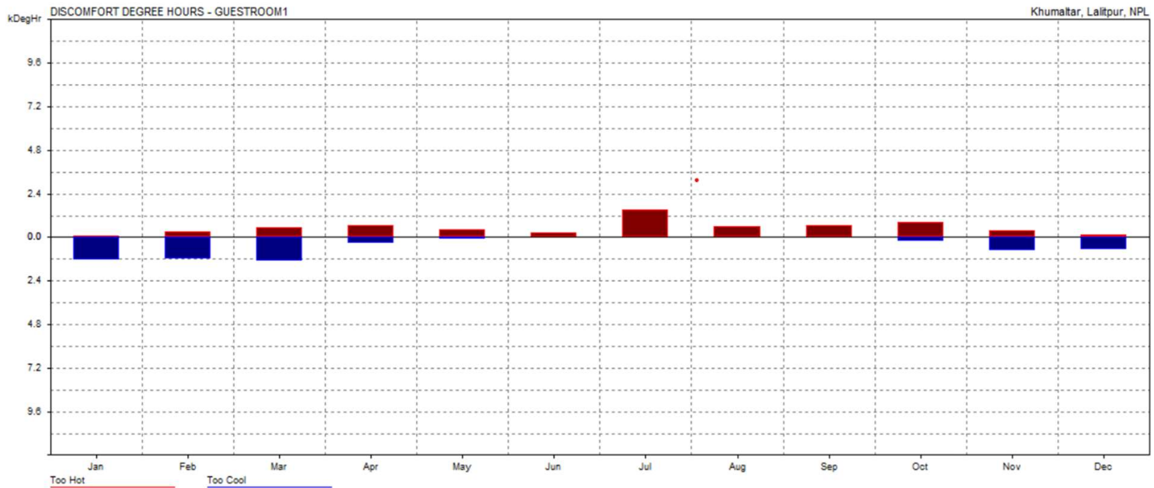


Figure 50:: Reduction in Discomfort (Guest room)

DESCRIPTION	HEATING LOAD (WH)	COOLING LOAD (WH)	COMFORT BAND
NORMAL CONDITION	48,65,748	47,46,002	(20.9°C TO 25.9 °C)
OPTIMISED CONDITION 1	40,01,875	23,24,349	(20.9°C TO 25.9 °C)
OPTIMISED CONDITION 2	20,57,650	38,71,537	(20.9°C TO 25.9 °C)
OPTIMISED CONDITION 3	18,67,993	17,15,346	(20.9°C TO 25.9 °C)

Table 12: showing comparasion of all zone in optimisation types

As we compare all zones in each optimization scenario it is understood that strategical design of building envelope is important to gain the thermal comfort rather than increase in wall thickness or double glazing. Double glazing with argon filling is seen to contribute more than just double glaze windows.

CHAPTER 5. RESEARCH FINDINGS

As per simulation results, it has come to light that most residences designed are not analyzed for thermal comfort. The benchmark energy consumption cost specified by ASHRAE 90.1 is $15.32 per square meter per year. The cost expended per square meter in the current construction reveals a higher value of 108$. This load could be decreased by using renewable energy for heating and lighting. The literature review also emphasizes Nepal's current energy consumption situation, which in 2010 was at 428 kJ. (10,220 k toe).

About 0.7% of the national balance in 2008/09 came from biogas, microhydro, and solar energy. Though a minor portion, it has grown by 40% since 2005.(Nepal Energy Situation Energy Consumption, n.d.). According to (Renewable Energy and Energy Efficiency Partnership (REEEP) Clean Energy Information Portal, Energy Profile Nepal (Vienna: REEEP Secretariat, 2012).

Compared to other nations, Nepal has relatively low CO_2 emissions. The prevalence of renewable energy sources is the cause. Biomass and hydropower as primary energy sources results in 43.6% of Nepalese population able access to electricity; whereas 81.0% depend on traditional fuels (UNDP, 2012).

With changing trends and urbanization, we can predict the consumption demands to rise every year. Energy footprints is impacted majorly from house hold energy demands, the research focuses on highlighting the consumption due to interior discomfort with the help of a simulation analysis considering variety of basic parameters.

5.1 5.1 Building Envelope

The building's envelope, which acts as a structural partition between the inside and external, controls the temperature inside the structure. Walls, roofs, a foundation, doors, and windows all make up the envelope. The materials in the present structure have 229 mm thick brick walls that are covered in 10 mm plaster on the interior surfaces, which when improved with 450 mm of additional brick masonry thickness led to a reduction in discomfort. Therefore, the thickening of the walls indicates less discomfort. Based on the results of the simulation, the cavity walls, which had a 229 mm thickness, performed poorly.

According to research, 32% of the energy used by commercial buildings is absorbed by the envelope, which includes components like the roof, walls, windows, and foundation systems. The envelope performs the roles of an air, vapor, thermal, and noise barrier. Additionally, the fabric layers in the envelope produce better outcomes. To achieve high building performance and to forecast energy performance, BIM software generates life cost analyses.

5.2 5.2 Window to wall ratio

In commercial buildings, recent developments in window technology that reduce conduction losses and solar gains can result in significant energy savings. In the building's typical state, the single-glazed windows are what cause the most leakage and make no contribution as an envelope barrier. The window placements in the north and south, according to the current orientation, appear to be advantageous, as the southern wall has suitable opening sizes, with a window to wall ratio of 19%.

In places where windows contribute to air exchange, the building envelope serves as an air barrier. The air exchange rate depends on the envelope being opened and must be maintained at a specific level. If the building apertures could be created to permit the desired air exchange rate, which is 0.4 ACH, more thermal balance would be attained. Glass with three layers: two layers of soft-coat, two layers of argon gas. One of the greatest options for effective air control is Low-E. The air exchange is further influenced by aspects including construction design, floor-area volume, penetration, installation, and workmanship. Therefore, providing the building with more ventilation than necessary causes the ventilated air to also contain moisture, making moisture control a crucial issue. (IPHA, n.d.)

5.3 Occupancy and building performance

Nowadays, it is commonly acknowledged that one of the main causes of uncertainty in building performance is occupant behavior. A connection is made between occupant behavior and the physical environment through behavioral performance factors. The impact of space size and the number of occupants on a building's occupier as well as the impact of functional distance between spaces on use frequency are examples of typical behavioral performance difficulties. The case study includes 5 residents who occupy the space for 4.5 hours in the kitchen, 8 hours in the bedrooms, and 5 hours in the living room each day. The HVAC requirements, as well as the comfort of the occupants, are determined.

Nowadays, it is commonly acknowledged that one of the main causes of unpredictability in building performance is occupant behavior. **Behavioral performance elements** create a link between occupants’ activities and the physical environment. Typical behavioral performance issues include the effect of area size and number of persons that share it upon a building’s occupant, and the effect of functional distance between spaces upon the frequency of use. The case study consists of 5 occupants with occupancy hours of 4.5 hrs in kitchen, 8 hrs in bedrooms, 5hrs in living room. Occupants determines the HVAC needs, psychological and physical comfort. In general, the living room uses more energy than other rooms in the house due to functional requirements, followed by other rooms. The kitchen has the second-highest energy usage, followed by other rooms. In the winter, heaters appear to use more energy.

Building performance places a focus on work productivity in a variety of situations because occupant happiness improves job performance. An inviting indoor environment is produced as building performance is measured. Consequently, to assess the efficiency of buildings It is possible to conduct a post-occupancy evaluation that offers ways to improve building performance.

Additionally, we can see from the produced optimized models that the thermal environment of the kitchen is different from that of other spaces. While temperature readings at the site were conducted, mild cooking revealed a 3-degree difference when compared to temperature without stove on. As per the literature and other relevant studies highlighted the thermal comfort band considered in the simulation tool is not obtained in any rooms including bedrooms. Perceiving the discomfort due to cold in winters the comfort level needs to maintained to avoid health issues.

CHAPTER 6. Cost Analysis and Owner's Perspective

DESCRIPTION	WALL	DOUBLE GLAZE	DOUBLE GLAZE PREMIUM	GLASS FIBRE INSULATION	PAINT FINISH	TOTAL
OPTIMISATION1	144000				135000	279000
OPTIMISATION2		300000			100000	400000
OPTIMISATION3	36000		640000	450000	135000	1261000

Table 13: General cost estimation as per optimization

Estimated cost as per current market is as follows:

Optimization 1 = Rs 279000 (increase in wall thickness-external wall only)

Optimization2 = Rs 400000 (change in windows from single glaze to simple double glazing)

Optimization 3 = Rs 1261000 (change in windows from single glaze to premium double glazing, Glass fiber insulation on wall with gypsum cladding paint finish – external wall only)

Glass fiber – 14 rolls per roll 4500 with gypsum board installation on top excl.

When comparing the costs of these three kinds of optimization, optimization type 3 is costlier because more material would be used besides just one approach. The anticipated prices are based on market rates, it is expected. It is understood that increasing a wall by 9 inches will cost around the same as installing gypsum board. It costs equally as much to double-glaze the windows. Consequently, more space is needed due to thicker walls.

According to the results of the simulation, optimization type 3 is preferred when comparing these 3 optimization types in terms of thermal quality. The heating and cooling consumption is cut in half compared to the current scenario. According to a review on current operating expenses, it is acknowledged that the monthly bills for the house amounts to 7500. The alleged health problems in the house's young occupants appear to be more severe. In order to increase comfort, the home's owner so wants to add insulation, at the very least, in the bedroom and living room, when the expenses were discussed

However, the average monthly electricity cost is between $6,500 and $7,500, which is double the average monthly family expense. Saving roughly Rs. 4000 each month over the next ten years will equal about Rs. 480,00,000. Also, using insulation solutions is advised if we realize the health risk brought on by the discomfort. The ultimate decision is made in light of ongoing pediatric health difficulties and potential lung disease risks. Every year, the house-born and -raised child goes through a fever during cold, but right now, the focus is on finding a solution rather than making active systems readjust. The findings so show that not all owners may be aware of how temperature influences long-term health difficulties faced in the next 20 years. In light of the comparison, it is clear that Optimization 3 produced the best outcomes, making it a better long-term solution. As per owner's preferences the toilet windows were left single glazed. The owner has decided to ignore intervention in kitchen, making changes especially in bedrooms and living rooms.

CHAPTER 7. Conclusion

This study is aimed to examine how energy efficiency in buildings affects both user and thermal comfort inside a structure. The research emphasizes designing the building envelope while taking optimal insulation into account. The second chapter included a thorough analysis of pertinent ideas and literature and developed the study's framework, while the third chapter includes a case study, site data, and information on the local climate. The data taken on an average of 22 years gives maximum and minimum temperature of the nearest station which helps in predicting the approximate outdoor temperature. Reading the temperatures from past years until now, we can understand that the outdoor environment is drastically and quickly changing with hot locations enduring even more heat and while cooler places are getting warmer.

Domestic energy consumption is the main focus of the literature, which also covers HVAC requirements, energy storage, and management systems. The building envelope is studied in the second chapter as a barrier and a conductor of heat gain and loss. The section also emphasizes the use of climate-oriented design to enhance indoor thermal comfort. The study describes how often energy is needed for residential buildings depending on their use and occupant density. A comprehensive range of research journals are surveyed for the literature in order to fully understand user comfort and analyze post occupancy. The creation of an efficient building exterior is one of the first factors to take into account when designing for thermal comfort. The envelope of a structure serves as a filter between the internal environment and outdoor climate, maintaining the atmosphere within. The study supports simulation's use as a measurement tool for evaluating the level of thermal comfort that can be attained through climate-based building design. Simulation analysis of the residence points the comfort level, if it has met the desirable range as per theoretic concepts at least.

The findings suggest that giving thermal comfort to residents can help create healthy buildings and stop potential disease symptoms. Architecture with correct climatic analysis offer a more efficient design option. As energy consumption habits change, architecture with accurate climatic analysis offers a more efficient design choice. Based on expected expenses and the owner's willingness to pay more, the research paper recommends fitting at least double-glazed windows to address health issues in bedrooms. Toilet ventilation can be selected as a less expensive alternative when considering cost, but for other spaces, such living rooms and bedrooms, a proper passive design approach will be more efficient than the use of particular insulating materials. As a result, using insulating materials should be generalized rather than just for noise or outdoor temperature insulation, as we can observe from the climate extremes compared to prior years. The study makes some recommendations for thermal comfort interventions and stresses the significance of energy efficiency in renovations. Thoughtful architects will always emphasize environmentally friendly thermal comfort strategies, doing so is neither difficult nor implausible. Because of originality and invention, any kind of building will become more regional, habitable, and desirable in the future.

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ANNEX