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THERMAL COMFORT PERFORMANCE IN A RESIDENTIAL BUILDING OF SUBTROPICAL CLIMATE OF NEPAL –A CASE STUDY OF HETAUDA

by

Sujata Nepal

A THESIS

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DEPARTMENT OF ARCHITECTURE

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DECLARATION

I hereby declare that the thesis entitled “**Thermal comfort performance in a residential building of subtropical climate of Nepal –a case study of Hetauda**” which is submitted to the Department of Architecture, Pulchowk Campus, Institute of Engineering, Tribhuvan University. in partial fulfillment of the requirements for the degree of Masters in Architecture (M.Arch.) is a research work carried out by me, under the supervision of **Prof. Dr. Sushil Bahadur Bajracharya**, between April to September. I declare that the work is my own and has not been submitted for a degree of another University.

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ABSTRACT

Our temperature sense of our environment is referred to as thermal comfort. Thermal comfort is influenced by two main environmental variables, including air temperature and relative humidity. Up to 90% of people's time is spent inside of homes. Buildings should therefore take the local environment into account while designing them in order to enhance the quality of life for those who inhabit them. Today's Modern residential buildings in the country are designed and built without considering climatic factors .The study area is carried out in Hetauda Padam pokhari a sub-metropolitan area in central Nepal's Bagmati Province's Makwanpur District. .The main objective is to measure thermal performance for thermal comfort of modern residential houses of Hetauda incorporating its improvement in design polices for thermal comfort with comparison with modern residential houses with other types of house in terms of U-value, materials, temperature etc. to incorporate design strategies for the improvement of thermal comfort performance in upcoming modern residential buildings. This research adopts the post positivism paradigm. The objective set lead towards quantitative research as well as a qualitative research method. The outdoor and indoor temperature of the different nine types of the residential house like modern, hybrid &traditional residential building of Padampokhari for 7 days winter and 15 days summer has been collected in the field, which has been compared with each other investigated residential building of case area The summer comfort temperature of padampokhari, Hetauda has been calculated using Nicol's adaptive thermal comfort model, which has been also compared with the assessed temperature of investigated residential house. The findings based on calculations and regression analysis shows that the investigated traditional residential house maintains 1-2.2°C indoor temperature in summer. The findings based on calculations and regression analysis shows that the investigated traditional residential house maintains 1-1.4°C indoor more temperature in winter Finally proposed design strategies for the newly constructed modern residential building has been suggested according bioclimatic chart and Mahoney table and recommendations at different levels has been provided for future study.

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Chapter 1: INTRODUCTION

1.1 Background

The thermal performances of a building are ruled by the factors like climatic condition, geographical location, material availability, lifestyle, and socio-cultural activities. Usually, as seen traditional houses are performing well in this context than modern houses. There were many types of research speak about building performs better thermal environment than contemporary buildings (Rijal, et al., 2010). Building thermal comfort and performance frequently overlap as the first defines the context of the latter. The ability of a building to maintain a comfortable inside climate with little energy demand, regardless of the outdoor weather condition, is referred to as thermal performance, and thermal comfort is a statement of approval with the thermal. (Chaulagain, et al., 2019). Worldwide around 40 % of energy is consumed in buildings. The reduction of energy resources and climate change is demanding for an energy efficient based on renewable energies and energy efficiency (Bodach, et al., 2014). People stay maximum of the time inside the building like residences so it is always important to know about the thermal comfort inside the building. When designing metropolitan areas and estimating how much energy is used to cool and heat buildings, thermal comfort is crucial. The definition of thermal comfort is "that state of consciousness that conveys happiness with the thermal environment” (Persily, 2012). According to ASHRAE (America society of heating, refrigerating and air conditioning engineers) it mainly focused in the 4 point for inner thermal comfort in a building 4 points are visual comfort, air quantity, noise level and thermal comfort which is mainly studied in this area, This is the most well studied factor, and it depends on a number of other factors, such as humidity, air conditioning temperature, outside temperature, and air speed, rather than just one.. The British Standard Institute ISO 7730 – the grid: 1994 According to the definition of thermal comfort, "that frame of mind that conveys satisfaction with the thermal environment," an individual's satisfaction is influenced by both physiological and psychological elements. (Cheng & Givoni, 2005). Since people can live and thrive in a variety of climatic circumstances, from extremely hot places to freezing ones, there is no definitive norm for it. (Darby & White, 2005).There are several a set of criteria for creating a comfortable interior climate in Most European and western countries have specific. However, Nepal lacks such practice (Mishra & Ramgopal, 2013).

The quality of people's indoor settings has a significant impact on their quality of life because people spend up to 90% of their time in isolated structures (Arif, et al., 2016). Bioclimatic condition like geographical location, climatic condition of the location buildings should be consider where they are built in order to raise the level of living for every occupant (Gaitani, et al., 2007). The word "bioclimatic" refers to the architecture of buildings based on the context of the local climate in order to achieve good thermal performance and the place's desired thermal comfort, per a study (Akande & Adebamowo, 2010). A person's sense of physical and emotional well-being in an indoor and outdoor built environment is referred to as comfort (Lamsal, et al., 2021). There are various ways like active use of energy, passive design strategies with good thermal performance to realize thermal comfort inside buildings. One of the best way is Climate responsive design strategy performance good to reach thermal comfort as it consumes less energy and proves economical in long run. Sustainable development of building sector can also achieve, climate responsive design is very essential. Climate responsive design uses climatic elements like wind air temperature, relative humidity and rainfall to reduce heating and cooling energy within the building and provide good thermal performance to achieve good thermal comfort inside building. The thermal performance of environments, individual variables, and other contributing factors all determine thermal comfort. Air temperature, air velocity, humidity, and radiation are examples of environmental elements (Simion, et al., 2016), while clothing and activity (metabolic rate) are categorized as personal factors. The fact that the functioning of HVAC (heating, ventilation, and air conditioning) systems popular buildings is mostly driven by thermal comfort is another reason why thermal performance for thermal comfort considered principally. HVAC systems typically account for 50% of building energy use in developed nations (Pérez-Lombard, et al., n.d.). Lack of the necessary temperature conditions has frequently led to discomfort, illness, and decreased productivity (Dili & Varghese, 2010).

Modern residential buildings within the country are designed and built without considering the climatic factors like air temperature, humidity, geography, etc. the variation of In most areas of Hetauda, decisions about building materials, variety of architectural forms, and orientation are frequently taken without taking geographic zone into account (Tharu, et al., 2019). The phenomenon is particularly noticeable in Hetauda City, where many new homes are being built and distributed to residents, but due to the comfort of the inside, people are not interested in relocating there. When those residential buildings were being planned and constructed, indoor thermal comfort issues weren't taken into account. Therefore, it is crucial to check on these individuals' comfort levels, level of comfort, and the range of acceptable settings.Within the present scenario, the normal houses are seen replicated by modern houses which has caused loss within the thermal comfort of the house (Tharu, et al., 2019). An essential component of maintainable architecture, indoor thermal comfort is essential to ensuring a secure indoor environment. Regarding thermal comfort, modern and traditional expectations, preferences, and acceptance differ.

Hetauda The study will be distributed throughout central Nepal's Padam Pokhari, Hetauda Sub-metropolitan within the Makwanpur District of Bagmati Province. According to the majority of Provincial Assembly Members, it is the executive headquarters of the Makwanpur District and, as a result, the capital of Bagmati Province, as of January 12, 2020. Hetauda City is 76 kilometers (km) away from the capital city by car, 132 kilometers (km) by Daman, and 224 kilometers (km) via Narayanghat. It is situated in the state's central development region, in the middle of the Makwanpur district (Sapkota, et al. 2020).It is developing rapidly in building construction and in land use planning. Many new constructions of building are adopted with modern HVAC system (heating, ventilation, air condition) for thermal comfort. No any passive measurement is allotted for thermal comfort performance. As a result, the sector's energy consumption has significantly increased. Nepal has been suffering from an influence crisis of historic severity for more than seven years as a result of an expanding electricity shortfall. (WECS, 2010).

Subtropical climate is commonly characterized by hot summer and mild winter with infrequent frost. Hetauda region have subtropical monsoon climate. The average temperature of Hetauda is around 15 degrees Celsius in the winter and is widely known to exceed 30 degrees Celsius in the summer. The monthly average for precipitation during the dry summer months ranges from 4 to 72 millimeters. The amount of rain climbs to 550 mm per month after the monsoon season begins in June (Sapkota, et al. 2020). There are several readings on the thermal performance of homes within the subtropical climate in Nepal but not in Hetauda city. In line with Chaulagain, N., et al., (2019), the old structural architecture of Nepal which is also known as vernacular architecture are done in step with geographical location, the difference is seen in terms of fabric availability and construction technology. The utilization of indigenous materials and construction technology makes the building thermally comfortable to measure. But within the present scenario, the standard houses are seen replicated by modern houses which has caused loss in the thermal comfort of the house (Tharu, et al., 2019).

1.2 Statement of the Problem

The level of urbanization has been rapidly increasing in Nepal. This rapid climb is principally contributed by migration from the agricultural area to urban areas, thanks to the changes in administrative boundaries. Urbanization and migration directly increase the population and increase the number of residential buildings. Buildings are becoming more active players in the energy system as a result of the rapid urbanization process, the digitization of daily life, and their capacity to supply renewable energy and change demand over time. Nepal is rated 124th out of 135 nations in the world for energy consumption per capita, coming in at 382.64 kg, and is ranked 173 out of 191 countries for CO2 emissions, coming in at 0.14 metric tons per capita in 2010. (Global economy). In line with (UNDESA, 2012), approximately 40% of worldwide energy has been employed in the development and maintenance of buildings. The high demand for building construction results in the shortage of local resources and high demand for contemporary materials. Many modern materials are utilized in residential buildings. The employment of recent materials directly affects the thermal performance of recent residential buildings (Chapagain, 2018). Thermal performance for thermal comfort is important for the human level thermal comfort inside the built space. People think that traditional materials can't be employed in a contemporary building. But there are several samples of a contemporary building that's done by using traditional materials like Matoghar which perform the most effective thermal comfort. In Nepal, electricity is the most common source of energy for cooling, whereas firewood is used primarily for residential heating and cooking (Regmi, et al., 2019). This maximizes the employment of excessive energy in cooling and heating. Thermal performance affect in thermal comfort then thermal comfort directly influences the efficiency and contentment of building occupants indoors. Working in a hot environment can be uncomfortable for employees and reduce productivity (Ismail, et al., 2009). According to Ismail M. Budaiwi (2007) Many freshly built structures come with cutting-edge HVAC systems by electricity and other people betting on clothing and food habits to thermally adjust (Rijal, et al., 2010), during bad atmospheric condition, the utilization of HVAC systems is crucial for achieving acceptable thermal-comfort conditions in present days (Finance, 2018).

Human factor and other factors associated with the operation and maintenance of the HVAC system, dissatisfaction with the thermal environment direct impact on the comfort. Therefore, the focus should not be on reducing energy use but rather on improving efficiency and preventing unnecessary increases in consumption (WECS-Nepal, 2014). Nepal is currently undergoing an electrical crisis of unparalleled severity that has lasted for over seven years because to an expanding gap between electricity demand and supply (WECS, 2010). There have been several research done on luxury and energy use in Nepali buildings. Toffin gathered information on a variety of Nepalese traditional homes, demonstrating how the use of local resources and clever space-planning produced cozy abodes (Toffin, 1991). One in every of the most reasons for the rise within the power consumption of buildings relies on the socio-economic increase of the users, yet this cannot be prevented through various measures will be taken. The buildings consume the largest a part of the ability energy during the employment stage within the lifecycle (Esin & Yuksek).

Although the modern methods of building dwellings are widely acknowledged in the area, Hetauda's modern architecture has not yet been given a definite definition. Due to a lack of information regarding thermal comfort, the majority of building facades are exposed to solar radiations that collect heat during the day. This heat is transferred creating thermal discomfort for the building occupants to inner spaces. Buildings become more and more aesthetically pleasing but not thermal comfortable (Lal, 2017, pp. 99-107). Thanks to the energy crisis in Nepal, it's better to own designs that may be independent of mechanical intervention for comfort. So, it's important to style strategies supported the passive cooling design for the warm and humid region of Nepal. (Manandhar & Yoon, 2015). The Nepali government has guidelines for the countries architectural design code, although the planning is lacking when considering the buildings' thermal comfort (DUDBC, 2018). There is no clear image of this situation regarding the thermal performance of Nepalese structures because studies on the thermal comfort performance of residential buildings are uncommon. (Chaulagain, et al., 2019).

1.3 Need of the Research

Residential buildings are essential to society since most human activities take place inside of them, having a direct impact on occupant health and energy use. The fabric used in modern structures does not provide good thermal comfort. (Al-Yasiri & Szabó, 2021). In today’s context modern residential building thermal performance less thermal comfort. As a result, legislation has raised the requirements for thermal comfort and energy efficiency in contemporary residential buildings and has encouraged rehabilitation efforts to raise building standards. Building spaces with adequate thermal comfort raises people's quality of life. According to studies done in 1987 by Altman and Stokol, when a room's temperature and humidity are high, a worker's productivity at a factory or office consistently drops. Despite the acknowledged links between worker productivity and thermal comfort, building owners frequently reduce the value of investments made to achieve thermal comfort. However, in accordance with Edward in 1989, investment and running expenditures to achieve thermal comfort are significantly less expensive than the value of staff pay and company growth. So always put the client's comfort first for your own good health and a longer career as an architect. Numerous research have been done on the thermal performance of homes in Nepal's subtropical environment, but none have been done in Hetauda city.

The influence of modern building materials and construction technology is declining the thermal comfort performance of modern residential buildings. The use of less efficient modern materials and construction technology in comparison to traditional materials and construction technology resulted in the loss of thermal comfort performance of the modern residential building as well as declining the vernacular architecture of any place. So the research is needed to measure the thermal performance of all types of building in the site area to compare and analyze the effectiveness of materials that contribute to maintaining the thermal comfort inside the residential building. The research is required to know how the local building materials help to respond to the climate of the subtropical climate of Nepal. According to Chaulagain, N., et al., (2019), to attain interior thermal comfort, the majority of European and western countries have a specific set of indoor environment rules. However, this practice is absent in Nepal. So such research is needed to improve health of the building and the health of people who lives inside built surface.

1.4 Importance of research

The research has provided the current situation of construction, materials which has been used in the modern residential houses in the case area. Research also helps to know about that how people are using modern materials for construction and the drawback and goodness of materials. The research also links thermal comfort performance of the modern residential building with other types of residential building in case areas which help to strengthen the importance of the use of local materials which help to make building climate-responsive and more ecological in the society. Design strategies for spatial thermal comfort is one of the important qualities of good architecture to achieve thermal comfort performance of buildings.

1.5 Research objectives

1. To assess the thermal performance of residential houses of Hetauda.
2. To compare the thermal performance of the modern building with other types of houses like the hybrid, traditional residential house in the case area.
3. To incorporate design strategies for the improvement of thermal comfort performance in upcoming modern residential buildings.

1.6 Research validity

Around the world, various research is conducted on the evaluation of thermal performance to maintain warm air comfort in cold and dry climates as well as hot climates. "Singapore has a hot and muggy climate all year round. To help promote thermal comfort and lower the energy use of air conditioning", many passive temperature management techniques are used in naturally ventilated residential structures (Wong,N. H., & Li,S., 2007).

Likewise in globally, during a neighboring country in India: Scientific investigation on thermal performance for thermal comfort traditional architecture of india in sate like kerela are using natural and passive strategies methods for comfort indoor environment, which is the best result present days. A field study was undertaken concurrently in an extremely chosen conventional and a contemporary residential building during the most uncomfortable summer period as a next step to better understand the performance of the standard building in comparison to a contemporary structure. The findings show that Kerala traditional architecture has an effective passive and natural system in place to provide a comfortable indoor environment independent of the outer weather.

Likewise in globally, in an exceedingly neighboring country in India: Scientific investigation on thermal performance for thermal comfort traditional architecture of India in numerous states like Kerala, which is renowned for using passive and natural approaches to create comfortable interior environments, has recently shown amazing achievements. A study of the passive techniques used in conventional structures and a thorough quantitative research conducted in all seasons to assess thermal comfort have already been published. As a next phase, a field research was carried out concurrently in a chosen traditional and a contemporary residential during the summer in order to learn how well the normal construction performed in comparison to the latter. The outcome demonstrates that traditional buildings can effectively use passive techniques and natural systems to directly give the greatest indoor environment within the built area.

"Toffin collected evidence on varied thermal comfort performances in vernacular buildings in Nepal to show how they produced comfortable living spaces using indigenous materials, in the context of few research done addressing building energy usage and luxury in Nepal. Bodach et al. investigated the climate-responsive characteristics of several types of vernacular structures throughout Nepal. In the Kathmandu Valley, a study on the vernacular houses' thermal comfort performance aspects was conducted by Upadhyaya et al." (Manandhar, R., & Yoon,J., 2014).

Many studies are tired of vernacular design so, the identical process and style is drained the fashionable built building for passive heating cooling systems in situ like Janakpur, Dang. So by many examples globally, neighborhoods and a few examples with associated with thermal comfort performance studies of national context validate this research proposal.

1.7 Scope & limitations

Scope of the researcher is to find out the air temperature, the humidity of the different types of a residential buildings in the case area. It also helps to know about the thermal performance of different types of a residential buildings in the case area. It helps to provide the different design strategies which can be used in upcoming modern residential buildings.

The study has been conducted at the community level so that study of different residential types presents in the case area. Assessed thermal performance mainly based on measurement of air temperature, materials properties of the residential houses. The findings and results are limited to the investigated residential building which really does not generalize all the settlement residential buildings in the case area. Compare the thermal performance of the modern building with other types of houses like the hybrid, traditional residential house in the case area among investigated buildings. Indoor and outdoor air temperature for summer and the rainy season is taken using a room thermometer. Previous winter climatic data with minimum mean temperature will be used in this research.

1.8 Time schedule

Following the time schedule is the upcoming proposal plan to complete my research proposal on the topic "Thermal comfort performance in a modern residential building of subtropical climate-incase of Heatuda".

Table 1-1 Time schedule of thesis

	Proposed activities	Months & weeks																															
	Month	Feb				March				April				May				June				July				Aug				Sept			
S.N	week number	1	2	3	4				4	1	2	3	4	1	2	3	4		2	3	4	1	2		4	1	2	3		1	2		
1	Field visit and collection of data for winter data																																
2	Proposal submission and presentation for thesis																																
3	Literature review																																
4	Prelimary thesis submission and presentation																																
5	Field visit and collection of data																																
6	Data entry, graphs ,findings																																
7	Analysis/ discussion																																
8	Mid term thesis submisssion and presentation																																
9	Finalizing recommendation and report																																
10	Final thesis presentaion and submission																																

Chapter 2: LITERATURE REVIEW

Thermal performance for Thermal comfort is a thermal balance for human body. For thermal balance, the deep body temperature is 37°C/98°F, and body skin temperature is 31°C –34° C. When heat exchange in human body is equal to zero i.e. 37°C/98°F (deep body temperature) then, it is called as thermal balance. Similarly, thermal comfort in a room is heat gain equal to heat loss. According to ASHRAE the comfort or standard room temperature is 20°c ±2°c (Rijal, et al., 2010). There are lots of factors those effects on the thermal performance of the buildings.

2.1 Modern residential building architecture of Hetauda

Here in Hetauda, the Traditional system of construction has also been influenced by modernism. Traditional building has begun to supplant the RCC construction's beauty and elegance. Here at the highway axis, aluminum composite panels (ACP) are preferred. The modern reinforce concrete residential building normally built in the Hetauda city according to building byelaw of Nepal is two and half story building or more than 2,3 storey built with RCC structure, bricks and cement mortar. (Bajracharya, 2013)

2.1.1 Settlement pattern

Isolated sensing of human settlement patterns has practiced an upward trend in volume especially during the present 21st urban century. Many of the normal houses are replaced by more modern structures. Compact settlement is seen in site area. Settlements is which sizable amount of buildings are built near one another. Settlements in past era develop along river valleys or in periphery in fertile plains. Communities are close-knit and share common occupations.

2.1.2 Typical house and functional planning

Modern residential house run throughout the road with street orientation. The house is linear in different geometrical in pattern with entry always toward any direction according to land orientation. The modern residential house is very much identical in concept with flat roof and a short overhang. The house is usually multi storied. The size of the house varies according to the size of the land/plot area.

2.1.3 Building form and orientation

The modern residential building of Hetauda consist of an elongated rectangular space. Modern residential have a larger floor plan. The building form or orientation or longer facade is typically oriented according to the land orientation. (Nematchoua, et al., 2015)

Figure 2-1 Modern residential building of padampokhari,Hetauda

2.1.4 Walls

The building is rectangular in form with sun-dried brick at both interior and exterior walls. The walls are usually 9" thick at the exterior of the house and 4" thick at the inner partition. Both exterior and interior walls have cement plaster with two coats of paints. (Nematchoua, et al., 2015).

Similarly, the laboratory experiments done for modern building by Sushil B. Bajracharya.; a wall of 230 mm thick using only burnt brick in cement mortar constructed in a LAB and graph of temperature gradient after heating effect recorded as follows (Bajracharya, 2013): Initially, Tout = 21°C & Tin = 21°C Heating effect after 5 hours blowing hot air @ 36°C Finally, Tout = 36°C & Tin = 25°C The figure 3 shows that the inside thermal environment directly changes when outdoor temperature rises up in modern brick wall. The graph shows that outdoor temperature directly effects indoor environment. This shows that rate of flow of heat very fast in modern wall of burnt brickwork. The temperature rises in inside proportionately when temperature increases in outside. This proved that the outdoor environment has direct effect on indoor environment with 230mm burnt brick wall.

2.1.5 Roof

Most Modern roofs types in Hetauda are made of concrete in form of a flat roof. Thatch used to be used as roof elements present it is replaced by tile or by CCI sheet. The cantilevered roof overhangs edge concealing the slope have a gravel stop metal flashing. The main roof beyond has a coping cap flashing piece over the parapet wall. Over the parapet wall, the main roof has a coping cap flashing piece. Recently, there have been some fantastic examples of how architects, designers, and homeowners have modernized various roof types. (Nematchoua, et al., 2015)

2.1.6 Foundation, floor and ceiling

Foundation seem to be less in compare with traditional building. Traditional building used to have 2 floor but in modern building have more than 2 floor. The ceiling height of the modern building have low ceiling height which block the flow of the air inside the room space. Modern homes have open floor plans for their internal areas, denying their occupants any sense of seclusion. A house with an open floor plan has no walls dividing the various rooms. Take the kitchen, for instance. The dining area, living room, and kitchen are all connected. Therefore, open floor plans do not give kitchen cooks any privacy.

2.1.7 Opening and shading

In cases where there is unchecked solar gain from huge windows, the cooling energy may rise. Thus, shading devices are crucial for regulating solar gain through transparent building envelope apertures, yet contemporary buildings exhibit less projection. Buildings feature very large windows that, when combined with a roof opening, not only improve air circulation but also achieve a high level of solar radiation within the building, which can be uncomfortable during the hot and muggy summer months. There is no roof overhang and no provision for window shading. The windows have a wooden or aluminum frame and single-glazed glass that is 6 mm thick. Windows make up almost 8% of the total floor space in modern buildings (Bajracharya, 2013).

2.2 Vernacular residential architecture of Hetauda

The design, planning, and materials of vernacular architecture are influenced by the socioeconomic, cultural, and climatic factors of various geographic areas. Different construction techniques and materials availability in the region Thermal comfort performance in modern residential building of subtropical climate- case of Hetauda affect the energy performance of vernacular architecture. Architectural features of sub-tropical climatic zones in terms of materials and technologies used are considered here. "People from Hetauda city later came here for various reasons after the east-west highway project entered the heart of the Nijgadh" Making a settlement dense along the highway axis is (Baniya, 2015). Here at Hetauda, the vernacular and traditional architecture has its own unique antique components and exterior geometry detail. Due to the 2015 earthquake, about 30 traditional homes were destroyed in these localities. (Baniya, 2015).

2.2.1 Settlement pattern

From ancient period, Terai people have been selecting plain land at the forest and river side for the construction of house. They usually built house with close proximity of forest and have been utilizing the locally available materials like bamboo, reed and thatch for the construction of house. They usually settle in group of their community members, forming a dense settlement. The houses lie very close to each other with houses on the both sides of the village lane. The reason for the dense settlement may Thermal performance of Traditional house and its improvement techniques-A case of padampokhari Hetauda be for the sense of security and whenever they need help people could gather. (Shrestha K., 2001). The volume of remote sensing of human settlement patterns has increased, particularly in the current 21st century metropolitan environment.Rural communities are most closely and immediately linked to their surrounding lands. Primary industries including agriculture, fishing, and others predominate there. The settlements are rather tiny in size.

Whatever may be the orientation of the roads, the house is always built with north south orientation with the entry always towards east. If the house in the village lane faces west direction, the entry is always made towards east. The reason for this is that there is deity present at the eastern courtyard of the ever houses and people have rite of worshipping their deity early in the morning facing east. Terai belt of Neal where the temperature is usually high, so the biological reason for facing the main facade of the house towards east is that the people need to sit in early morning sun which warms the building also and at evening the sun is low and the eastern courtyard is cooled.(Shrestha K., 2001)

2.2.2 Typical house and functional planning

Usually Traditional house run throughout the village lane with north-south orientation. Generally the house is linear rectangular in pattern with entry always toward east. The traditional house is very much identical in concept with two way slope roof and a deep overhang. The house is usually single storied and some are seen two storied as well. The size of the house varies according to the number of family members. Every male members of the family is given with the individual room. Hence the size of the house is defined. (Shrestha K., 2001)

The length and width of the house is defined by the number of posts used lengthwise and width wise. The length varies according to the number of post called "Kothari" and width varies according to the number of posts called "Bala" With regard to the space layout of the house, the house mainly consists of the following spaces:

Figure 2-2 plan of Traditional Building

Source: Baniya, 2015

2.2.3 Building form and orientation

In the subtropical climate of Hetauda, dwellings are made of an extended rectangular space enclosed by low walls. (Gansach & Meir, 2004). Traditional houses have a more compact floor plan. The longer facade is typically oriented north-south which reduces the exposure to the sun(Bodach, Lang, et al., 2014a). The analysis of the building's best orientation for minimizing the heating and cooling load through simulation demonstrates that the energy requirement is lower when the building is oriented toward the north and south (Manandhar & Yoon, 2015).

Figure 2-3 Traditional house

Source: Baniya, 2015

2.2.4 Walls

Traditional homes in this Hetauda have thin, light, non-massive walls built of wood, bark, or bamboo. There are bamboo strips loosely woven into an open mesh at the top of the outer wall, which allows for continuous day illumination and ventilation. Wood or reed walls without plaster contain sporadic gaps. Additionally, external walls could be constructed from thin, mud-plastered cane mats connected to a timber frame and painted white.(Bodach, Lang, et al., 2014a). Additionally, the Rat-Trap Bond (RTB) Masonry Technique can serve as an excellent starting point for constructing thermally comfortable homes in subtropical climates where brick is a common building material (Bhattarai, Uperety, & Lamsal, 2020).

2.2.5 Roof

In subtropical climates, thatch is used to make the majority of traditional pitched roof styles. The low windows or the triangular openings ensure the continuous inflow of air from the shaded area beneath the eaves, which results in interior temperatures that are typically substantially lower than exterior temperatures (Bodach, Lang, et al., 2014a). T Previously, thatch was employed as a roof component; today, tile has taken its place. Dried grass or reeds are applied in a layer on top of a wooden or bamboo frame, creating a thatch. Dryed grass or reeds are woven together and stacked on top of a wooden or bamboo frame to form thatch. Modern traditional buildings in Europe have thatched roofs, just like in Nepal. It is suitable for conditions ranging from cold to hot, humid to dry, and thatch is a great insulator that can quickly cover almost any shape (Zhai & Previtali, 2010) .

2.2.6 Foundation, floor and ceiling

Most of the traditional homes found in tropical areas are above ground, with many of those in humid climates elevated above the ground because this provides for cooling ventilation through the floor. Vaulted ceilings appear to play a significant role in cooling in hot and humid conditions by allowing stratification of air through resilience. allowing cool air to rest close to the floor and hot air to collect above inhabitants (Zhai & Previtali, 2010). In hetauda the residential builings found that plinth with stone or earth so that can protect the indoor with flooding during rainy season. Also some residential building are constructed for the same purpose, from 90 to 300 cm of timber piling. High ceilings and pilings that raise the building off the ground improve airflow inside the structure. Compacted soil, clay tiles, or locally sourced stones that may be covered with cement plaster serve as floors (Bodach, Lang, et al., 2014a).

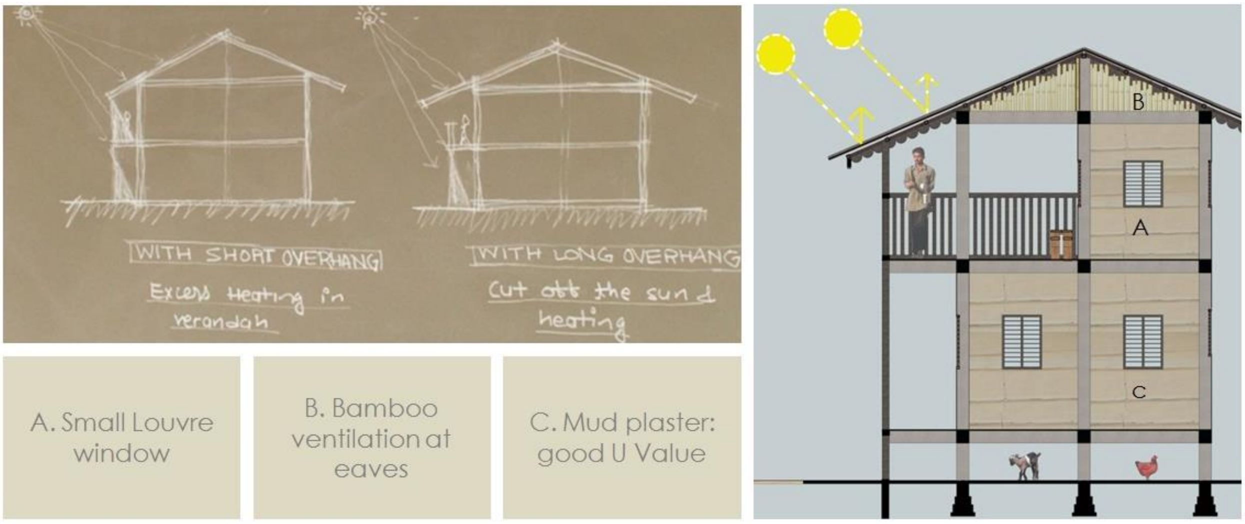


Figure 2-2 Traditional house

Source: Baniya, 2015

2.2.7 Opening and shading

In cases where there is unchecked solar gain from huge windows, the cooling energy may rise. Thus, it is crucial to use shading mechanisms to reduce solar gain through transparent openings in the building exterior.

Buildings contain openings in the roof that allow air to enter inside spaces, and these openings, together with the few, low windows that they have, help to improve air circulation and keep people comfortable throughout the hot, humid summer months. Roof overhangs help provide the shading to the windows and the planting of trees around the buildings(Bodach, Lang, et al., 2014a). Eaves were installed on houses with thin walls in hot climes, indicating that they are utilized to cool the building (Zhai & Previtali, 2010). The amount of energy used varies substantially when there is a window. For a subtropical environment, a northern window is preferable to reduce cooling energy (Manandhar & Yoon, 2015).

2.2.8 Building occupancy and operations

Design variables

Buildings are thought to be primarily to blame for indoor temperature conditions since they serve as the primary point of contact between the indoor and external environments. When designing and erecting the structure, many factors need to be taken into account (Yao, 2014).

The form of building

Both the solar and wind variables are impacted by the building's shape, spacing, and design in relation to its surroundings. Since the building's surface is the part that is exposed to the outside environment and has a low ratio of building surface to volume, which is the primary characteristic of compact forms, they have a significant impact on how much solar radiation the building's surface receives as well as the airflow around it (Gupta, 2017).

The size and orientation of the outside envelope that is exposed to the outside environment are both determined by the building shape, which can have an impact on thermal performance. Additionally, the building's design always has an impact on price and appearance. By choosing the best shape, orientation, and envelope arrangement, energy consumption can be decreased by roughly 40%.Another component which affect the cost that is roof form of building form. Curved roofs, including cylinder and dome shapes, have greater convective heat transfer areas and coefficients than flat roofs with the same base. The ceiling height, which impacts the volume of the building, is a further concern associated with roof form (Gupta, 2017).

Building orientation

By reducing direct solar radiation entering the building envelope through building openings or opaque walls, the building orientation can affect the building's thermal performance. When choosing a building's orientation, many aspects must be taken into account. They consist of the anticipated shade effect and solar movements based on latitude, time of day, and season (Gupta, 2017).

The envelope of the building

The condition of both indoor and outdoor spaces is significantly influenced by the building envelope. It is a significant factor in the overall heat gain and heat transfer coefficient. For buildings to operate adequately in terms of energy and thermal comfort, the building envelope is a crucial component. The important factor for thermal performance for thermal comfort of any building is the material and technology that use in its building envelope. Building envelope is One of the most vulnerable elements for high amounts of energy loss, which cooperates with both indoor and outdoor environments (Habibi, 2019). The interior and exterior of buildings is physically separated by building envelope. It is comprised of series of components like roofs, walls, floors, foundation, doors, and windows. These elements shield the inner space from environmental factors like UV rays, wind, precipitation, temperature, and humidity. Utilizing the right building materials for the building envelope can result in significant energy savings.

(Saffari, et al., 2017) . Recent studies that concentrate on novel strategies and methodologies have incorporated improvement solutions in this area. (Al-Yasiri & Szabó, 2021).

In Hong Kong, Singapore, and Saudi Arabia, the building envelope is found to be responsible for 36%, 25%, and 43% of the peak cooling loads, respectively. As a result, it's critical that building envelopes have a certain level of thermal resistance and a limited number of thermal bridges in order to prevent the entry of water vapor into the structures. (Gupta, 2017).

Shading devices

In Mediterranean and semi-arid climates, shading devices are extremely beneficial. The time of year and the relative transparency of the materials can both have an impact on shading. Additionally, according to a study by Al-Tamimi and Fadzil (2011), choosing the optimum shade options can increase the number of comfortable hours in tropical climates by roughly 26% and 4.7% in ventilated and unventilated environments, respectively. (Gupta, 2017).

Material properties

The material characteristics of a building's components are essential for controlling the heat transmission process. We'll go through the four most crucial thermal properties: thermal conductivity, thermal resistance, thermal transmittance, and density (Gupta, 2017). The modern buildings of present era use the modern materials in reinforce concrete residential building built with RCC structure, bricks and cement mortar (Best Building Materials in Hetauda, 2013). The traditional building are made of the materials like wood, bamboo, thatch, and further biogenic material as well as mud and sand are locally available for house construction (Bodach, Lang, Hamhaber, et al., 2014) . The tropical and subtropical parts of the world have an abundance of bamboo as a common building material. It is lightweight, highly durable, and adaptable. It is a typical material for wall construction in the Hetauda. It gains its strength from its hollow tubular construction. Due to its rates of growth, harvesting, and transportation, it has been categorized as a very economical construction material. Although it has several benefits in terms of its characteristics, it is prone to buckling. However, research indicates that this flaw is easily remedied (Kofi Agyekum & Danku, 2020). Earth is another important vernacular material that has been used for centuries. One of the most innovative technologies in the current hunt for housing that is both economically and environmentally sustainable is the use of earthen construction materials (Kofi Agyekum & Danku, 2020). Clay blocks (also known as adobe), clay soil, and rammed earth are examples of earthen building materials (Kofi Agyekum & Danku, 2020).

Thermal conductivity

The amount of heat per unit of time in watts that passes through a layer of material that is 1 m thick and even with an area of Im2 and a temperature gradient of 1 K (Kelvin) in the direction of the heat flow is known as the material's thermal conductivity" (Gupta, 2017).

Thermal resistance of a material, R

The resistance to heat transfer between two surfaces at various temperatures is known as a material's thermal resistance. It can be stated as the R-value, which depends on both the material's heat conductivity and thickness. It is "the time needed for one unit of heat to travel through one unit area of a material of one unit thickness when there is one unit temperature differential between opposite faces," according to one definition" (Gupta, 2017).

Thermal transmittance, U

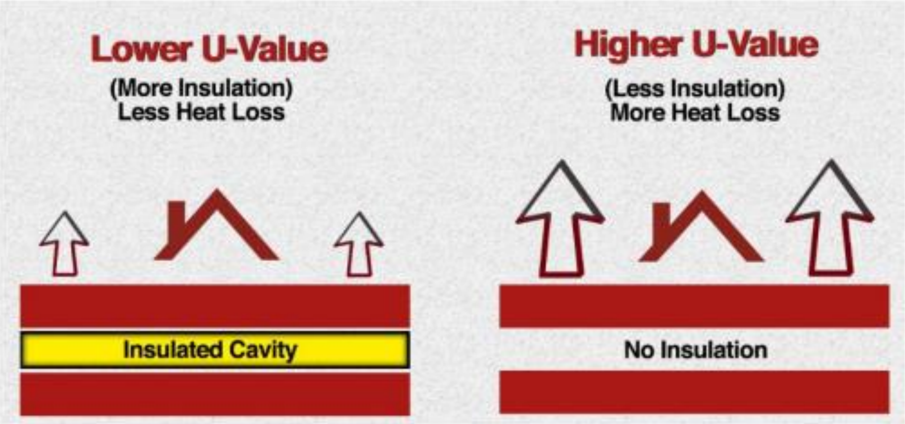


Figure 2-3 Relationship between U-value & Heat

Source: Source: burtonroofing.co.uk

The thermal z of the thermal insulating ability of a given building component air to air. It is obtained by reciprocating the total thermal resistance of the building component, R (i.e., U = 1/ R). It is described as "the amount of heat that flows through a unit area of a building section in a unit time per unit temperature difference of the air on either side of the section" under steady-state conditions (Gupta, 2017).

U Value, or thermal transmittance, is the amount of heat that is transported through a building's envelope as a result of temperature differences. W/m2K, or watts per square meter for each degree of temperature difference between two sides, is the unit used to measure u-value. From fig we can see that; higher the U-value, lower the insulating property and quicker the transmission of heat and lower the U-value better-insulated property and lesser transmission of heat. Thermal resistance or Thermal transmittance's opposite, or R-value, is a material's capacity to resist heat flow. The unit of measurement for R-value is m^2K/W. (Rye, 2012)

Table 2-1 calculation of U-value of modern building

Modern Building	U-Value (W/m² °K)
Brick wall (230 mm thick burnt brick)	1.93
Concrete Roof (110mm)	2.87
Window (Single Glazed)	5.00
Energy Consumption per year (kwh/year)	1337.48

Source:Bajracharya T., et al., (2020)

Here the table 1 gives a u-value calculation of different building envelopes components of modern building (Bajracharya, et al., 2020). From table we can see that the u-value of window is highest compare to other components. Therefore, window has lower insulating property and quicker transmission of heat or cold in modern reinforces concrete building. (Bajracharya, 2013). The less insulating materials more heat is lost from the building so, less insulating materials should be used in sub-tropical climatic region.

Density/Porosity

The mass of a unit volume of the material, consisting of the solid itself plus the gas-filled pores, is the density, or p (kg/m3). The thermal qualities of a substance are greatly influenced by its density: the denser a material is, the more heat it can store, and the more insulating it is. (Gupta, 2017).

2.2.9 Design strategies for spatial thermal comfort

Architecture with good thermal comfort plays vital role in important qualities of architect. Among many parameters affecting human comfort with in the built space. Poor thermal comfort of the building effects on the efficiency of work people live inside. There is no any fixed standard or recommended ranges for thermal comfort inside the built surface. But some designing help to achieve balance with local climate. Here is some designing strategies to achieve the thermal comfort inside the building (Gupta, 2017).

Insulation

Building envelope plays important role in achieving indoor thermal environment to a great extent. Efficient insulation is one of the primary requirements to achieve a comfortable inside condition. It helps to reduce the amount of heat gained during the warm season and conserves heat during the cold month. To achieve maximum insulation both opaque and glazed area the envelope should be taken in consideration. Any building needs good insulation, but construction in subtropical regions need it much more. "High levels of humidity and moisture can cause rot and mold, which weaken the wall structure, if the building is not properly insulated. Additionally, thermal bridging might happen because of the higher subtropical temperatures. Heat conduction is made possible by the expansion of studs and the materials around them as a result of intense heat. Continuous insulation acts as a further barrier to moisture and prevents this thermal bridging. (Gupta, 2017).

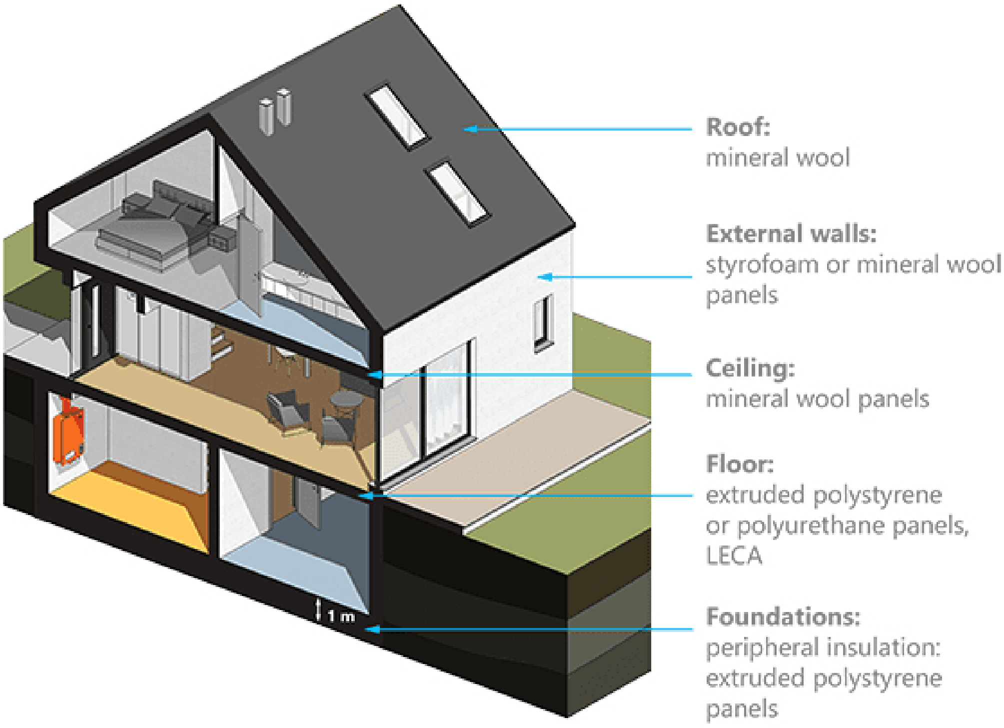


Figure 2-4 Thermal insulation in wall

Source: google.com

Roofing

Overheat can be seen in roof of subtropical region. There are the lot of solution to reduce the roof heat from the roof. There are many ways to minimize the heat generated by the roof. Utilizing roofing materials of lighter hues, such as terracotta shingles, which won't heat up as quickly as conventional black asphalt shingles, is one remedy. Additionally crucial in this area is the presence of vented attics in structures. By doing so, the heat is removed from the building and the interior and external temperatures are kept at comfortable levels. The final option is metal roofing, which will offer additional protection during hurricanes and other storms with strong winds, which occur more frequently in subtropical areas. (Gupta, 2017).

Siding

Metal siding offers excellent protection from wind and moisture damage, much like metal roofing does. Brick or stucco, on the other hand, are more aesthetically pleasant choices. Both brick and stucco are appropriate building materials for hot areas because they resist deterioration from moisture, also offer good insulation, and have incredibly lasting (Gupta, 2017).

Walls and window

The walls and windows of a building can sustain significant damage from the sun. Because they offer a layer of shade that shields walls and windows from direct sunlight, porches are popular in the south. Subtropical storms with high winds can also harm windows. When big storms hit, installing high impact rated windows and doors can assist prevent wind and moisture damage. The selection of material and structure should be done concerning the location, climate and function. Materials such as brick and stone are used in hot environments for their high thermal inertia to keep the interior cool for a longer period (Gupta, 2017).

Air-flow and ventilation

Managing the exchange of air and circulation with the outdoors is critical to achieving a comfortable indoor climate. This can be achieved by providing either mechanical or natural ventilation. Natural ventilation is most commonly used as a passive design solution for the flow of fresh air. Cross ventilation or stack effect promotes airflow due to the pressure difference. To release humidity and provide an in-filtered airflow stable air currents is required. Apart from these larger strategies, there are many design interventions. Creating interior courtyard which provision of sunscreen, use of water-bodies, vegetation, use of verandas and large eaves, and green roofs (Gupta, 2017).

Climatic factors

In order to provide comfort and conserve energy, climatic elements might have an impact on the design and operation of a building's envelope. It's critical to comprehend both the region's macroclimate and its microclimate (Gupta, 2017).

Nepal has diversity in geography which is because of altitude range from 60m- 8848m. This led to variety of climatic and vegetation zones. This geographic variation causes diversity in socio-economic, cultural patterns and architectural expressions as well. Nepal offers a range of climates, from a subtropical one to a chilly tundra climate. Latitude, altitude, slope orientation, prevailing wind as well as local wind and vegetation are geographical elements that affect the nation climate (Bodach, et al., 2014).

The subtropical climate of Nepal is represented by the city of Hetauda. The Indo Gangetic plain, which stretches over 800 km from east to west and 30 to 40 km north to south with elevations varying from 60 to 200 m, has its northernmost point at Hetauda in Nepal. (Government of Nepal, 2015). Hetauda's average monthly temperature in the summertime exceeds 30 C, and the city's mean temperature in the wintertime is roughly 15 C. The average monthly precipitation ranges from 4 to 72 millimeters during the winter and the dry summer. Rainfall climbs to 550 mm per month after the monsoon season begins in June (Sapkota, et al. 2020).

Solar radiation

According to the definition of solar radiation, it is "the amount of sunlight falling over a certain region and period, usually expressed in Watts per square meter." (Nayak, 2006) They discovered that the location (latitude and longitude of the site), direction, season, time of day, and atmospheric conditions are some of the variables that affect the radiation incident on a surface. The most significant weather factor that affects air temperatures is solar radiation. Direct radiation (ID) and diffuse radiation (Id), which fluctuate depending on the sky conditions, make up this radiation. Reflections from the ground and surrounding structures, shade from those structures, and vegetation are additional factors that alter the total solar energy. (Gupta, 2017).

Humidity

Air humidity refers to the amount of vapor present in the atmosphere. The relative humidity RH is defined as "the ratio of the partial pressure (or density) of the water vapor in the air to the saturation pressure (or density) of water vapor at the same temperature and same total pressure" in ASHRAE Standard SSP (2003). According to the climate, different levels of humidity are appropriate. While low humidity levels are favorable in dry settings, they are uncomfortable in tropical climates (Gupta, 2017).

Pressure and winds

The design and thermal performance of buildings are significantly influenced by wind. It has an impact on the air infiltration and convective heat exchanges of a building envelope (Nayak, 2006). Avoiding the impact of winter wind, which increases infiltration heat loss, and making use of summer breeze to promote ventilation

Building occupancy and operations

Building consumption, including occupants, lighting, and equipment, generates heat. The total heat gain is influenced by activity kinds and occupation density. In a crowded area, it might matter. People release heat from their metabolism to keep their bodies at a steady temperature. Building heat is produced in proportion to the electrical energy used by electric lighting and equipment. (Gupta, 2017).

2.3 Adaptive thermal comfort model based on Humphrey's theory-Nicol graph

The comfort temperature for free-running buildings (Tcomf) calculated for each month in Tehran, Iran, is used in this Nicol graph. The monthly mean of the daily maximum (To max) and minimum (To min) temperatures from meteorological records is divided by the average outdoor temperature to determine the comfort temperature (Tom). Equation is used to compute the comfort temperature. The comfort temperature is calculated using the equation

$T_{comf} = 0.54\ Tom + 12.9$ ……….. (1)

This equation was derived from Humphreys and Nicol's (2000) examination of comfort survey data. By comparing the desired internal temperature to the mean and range of outdoor temperatures using the Nicol graph, designers can recommend potential passive cooling or heating techniques. Numerous Nicol Graphs show the sun intensity and relative humidity. (Clear, 2018).

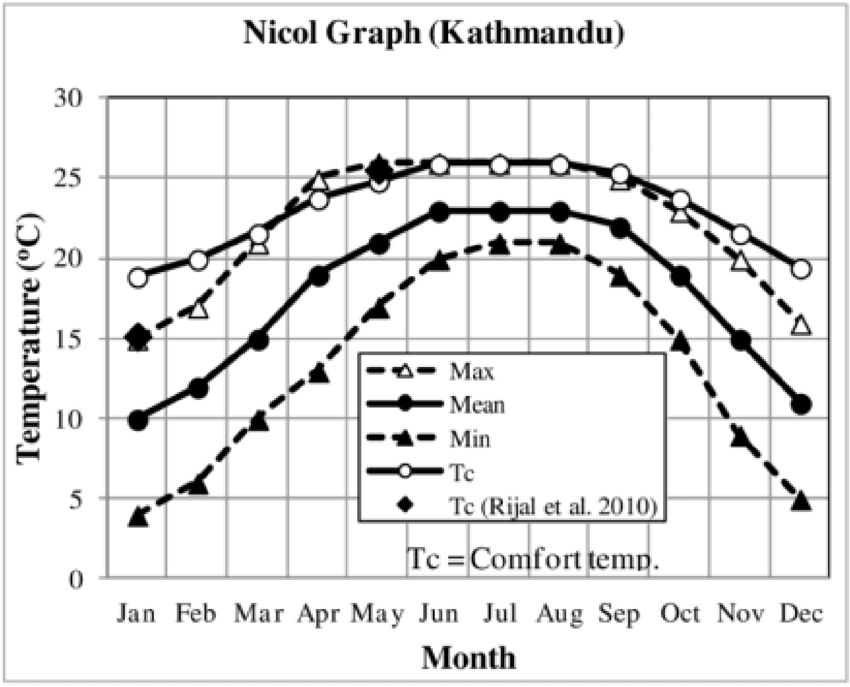


Figure 2-5 Nicol graphs of Kathmandu

Source: (Bajracharya, 2014)

There will be more to comfort standards than just a target temperature if they are based on adaptive assumptions. The formulation of the standard must take into account the relationships between comfort and environment. Predictability, restrictions, variety, adaptive opportunity, and control must all be included in the standard (Clear, 2018).

Let's start with the comfort temperature, which we define as the temperature at which there is the least likelihood that a person will feel uncomfortable or at which a person will most likely be satisfied with their surroundings. Climate and season will, at the very least, have an impact on the value of the comfort temperature. A graph like the one in figure 2-5 can be used to determine the value of the comfort temperature in free-running buildings. Humphreys (1978) discovered that the average of the monthly mean minimum and monthly mean maximum temperatures served as the best external temperature predictor for the comfort temperature. The addition of a term for the yearly maximum temperature considerably improved the forecast; however, we need not know why this is the case, but it suggest a climatic factor is at play. (Clear, 2018).

In a building that isn't free-running, social and economic reasons mostly override climatic ones to determine the comfort temperature. For instance, for populations that really are broadly comparable, Americans and Europeans have differing comfort temperatures. Therefore, study among the local population will be needed to determine the comfort temperature in such situations. These differences exist not just between populations, but also within the same population, between social or economic categories. The need to provide choice and control so that people may make their own judgments can be used to explain these more challenging disparities in comfortable temperature (Clear, 2018).

There are other temperatures that people can feel comfortable besides the comfort level. Obviously, there are acceptable deviations from it that won't be uncomfortable. The permitted degree of fluctuation will vary over time. This is because people may adjust further without experiencing much more discomfort the longer it takes them to do so. Thus, we might discover that +2K was the maximum permitted within-day fluctuation and +5K, for example, the maximum within-week variation.

Dynamic temperature guidelines would alter how a structure is investigated by the designer. The design would take into account both the steady-state and dynamic thermal properties of free-running structures. (Clear, 2018).

The variation in temperature (as well as other elements) within a room is another factor that needs to be clarified. The differences in circumstances within a room and the limitations on how well occupants may utilize this variability must be considered by a model that aims to explain thermal comfort. Many current models of room temperature make the assumption that there is just one "room characteristic temperature" without describing how it could change from one area of the room to another. Variability may play a significant role in user happiness in settings where people can move about (Clear, 2018).

2.4 Better thermal performance from passive cooling strategy for thermal comfort in a subtropical climate

The amount of active energy needed to heat and cool a place can be reduced with passive energy. The greatest way to create a comfortable and energy-efficient interior environment is through passive thermal comfort techniques. (Supic, 1982). The traditional building techniques is the best technique that use limited local resources to achieve maximum thermal comfort while considering non-renewable resources like sun and wind to the maximum. In Nepalese context, from Bajracharya, 2013 research it is conformed that the traditional residential buildings is minimum 1°C to 2°C better thermal comfort in winter & summer than the contemporary residential buildings of Kathmandu valley. However, today's trend shows that the thermal comfortable traditional buildings are fast replacing by the modern reinforce concrete buildings. Advance building technologies, heating and cooling system in modern buildings become easy that result in less concern to nature, climate and environment. Modern structures in Hetauda, Nepal generally adhere to the typical worldwide architectural design without much consideration for the regional environment. (Upadhyay, et al., 2006). ASHRAE Standard 55 provides a smaller relative humidity margin that expands the comfort temperature as of 2004. The recommended comfort range is between 25°C to 28°C when the relative humidity is as low as 10%, and from 24°C to 27°C when the relative humidity is 55%. (Standard 2004). Building design faces challenges and opportunities in providing the appropriate level of thermal comfort and energy efficiency for residential construction in the hot and humid tropics. Passive cooling is aided by direct cooling techniques like shading and natural cooling. The study finds that the thermophysical qualities of building materials have the biggest influence on the building's energy consumption. Different design strategies have varying effects on the cooling energy required (Manandhar & Yoon, 2015).

Many cooling techniques in Darwin comprise minimizing solar heat intake by properly orienting the home, using shading, choosing the right building material, and providing natural ventilation by orienting the structure with apertures to catch prevailing breezes. Darwin designs of today's subtropics must offer a home that is both energy-efficient and thermally comfortable. Numerous research have suggested that the use of passive cooling design strategies results in thermal comfort (Olgyay, 2015), (Baker, 1987) & (Aynsley, 1996). Also, according to several studies, the building solar orientation has a significant influence on energy efficiency (Olgyay, 2015) (Baker, 1987) (Gregory, et al., 2008). The capacity of the construction material and other aspects of the surface's solar radiation orientation affect how much heat a surface can absorb. The ability of "building materials" to reflect, absorb, and store solar radiation is a crucial component of energy efficiency. The thermal mass, a property of material density and specific heat, is used to describe the capacity of construction materials to store heat. (Gregory, et al., 2008)

Experimental findings from a study on the thermal performance of building materials in Hong Kong revealed that while high mass materials enhanced the minimum temperature in free-running homes, light mass materials cooled down more quickly at night. (Cheng & Givoni, 2005) . By delaying the peak internal temperature in the afternoon and saving the cold temperatures from nighttime air conditioning for the following day, high mass building materials perform better in an air-conditioned home. To minimize heat gain, building walls can be oriented with their smaller surfaces toward the sun's direct rays and shaded by large eaves and plants (Baker, 1987). In tropical climates, the part of a building structure most exposed to solar radiation is the roof. In Sri Lankan homes, the amount of heat flowing through various roof and ceiling materials was examined (Emmanuel, 2002). In this study, various roof configurations, including corrugated fiber cement sheet, clay tiles over corrugated fiber cement sheet, and no ceiling, fiber cement, and timber, were used. According to the study, during the daytime under all three configurations of roof and ceiling, the air temperature in the completely closed houses was lower than the outside temperature, but greater at night. Homes without a ceiling and a "tiles on fiber-cement" roof performed better during the day but were warmer at night.(Emmanuel, 2002).

The cooling methods applied in the house are Cross-ventilation in hot and humid climates and sub-tropical climate. Raising the home off the ground is one method for achieving cross-ventilation. Since vegetation restricts wind movement, a building's floor can be raised to a height of 2.5 meters above the ground to enhance cross-ventilation (Aynsley, 1996) . Air flows through a space more quickly because windward openings are smaller than leeward ones in a building. Additionally, internal walls and furniture placement should be considered because they could obstruct airflow; open-plan homes are better suited for cooling by natural ventilation in hot areas (Olgyay, 2015).

A "low thermal mass" dwelling is one where there is a significant heat flow from an uninsulated roof and where the sol-air26 temperature can occasionally rise above 60 C during the day (Szokolay, 2006). Households in temperate regions can benefit from comfortable homes with high thermal mass, highly efficient appliances, and renewable energy systems in addition to significant energy savings and a decline in greenhouse gas emissions (Saman, et al., 2011) In order to provide thermal comfort with traditional air conditioning, homes often need to be airtight and have high thermal mass in order to minimize thermal interaction (exchanges) between indoors and outside.

While a building's design is important for efficiently achieving internal thermal comfort, lot arrangement and building design also have a big impact on this goal. The well-designed buildings are benefit in mitigation of the effects of high temperature in built-up areas. Shaded building structures, breezeways, and open green spaces can all help to mitigate the effects of high temperatures in urban settings.(Johansson & Emmanuel, 2006). The authors came to the conclusion that while metropolitan areas with tall buildings and small streets produce better shading, they may also make natural ventilation more difficult, particularly in residential buildings (Johansson & Emmanuel, 2006).

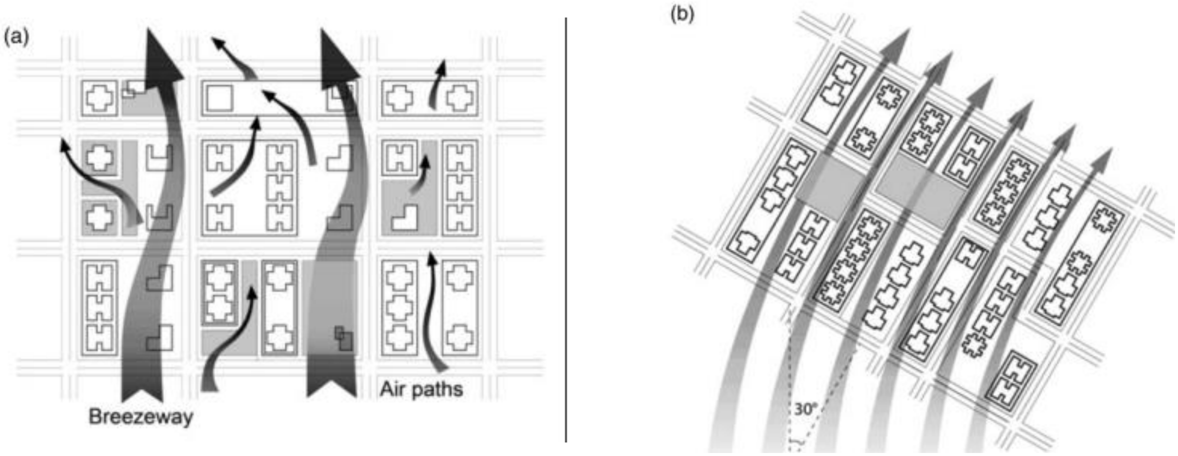


Figure 2-6 study in Colombo, Sri Lanka

Source: (Johansson & Emmanuel, 2006)

The study in Colombo, Sri Lanka (Johansson & Emmanuel, 2006) additionally suggested were wide highways parallel to the ocean, "irregular building placement and producing variances in building height," and spacing high-raised structures farther apart for optimum wind flow. Due to the tiny ratio of lot size to building floor area, it is difficult to provide thermal comfort through passive cooling in homes constructed on short lots without suitable local microclimate considerations. Wider setbacks can improve a house's thermal performance by allowing cooling breezes to enter (Miller & Ambrose, 2005) & (Safarova, et al., 2018). However, from the perspective of thermal comfort, relying on breezes may not always be the greatest option in the hot and humid tropics. Due to the increase in urban density in tropical cities, it is a difficult challenge for architects to take into account the supply of natural ventilation, green spaces, and the best solar orientation for energy efficient structures. The findings demonstrate that people who reside in hot, humid tropical areas can adjust to the temperature conditions in structures made to benefit from mechanical and natural ventilation, such as ceiling fans. In naturally ventilated buildings, occupants can combat the heat and excessive humidity by drinking water, taking showers, changing into fresh clothes, and utilizing fans (Feriadi & Wong, 2004) & (Safarova, et al., 2018).

2.4.1 Example of a modern building with good thermal performance for thermal comfort in Nepal –Mato ghar

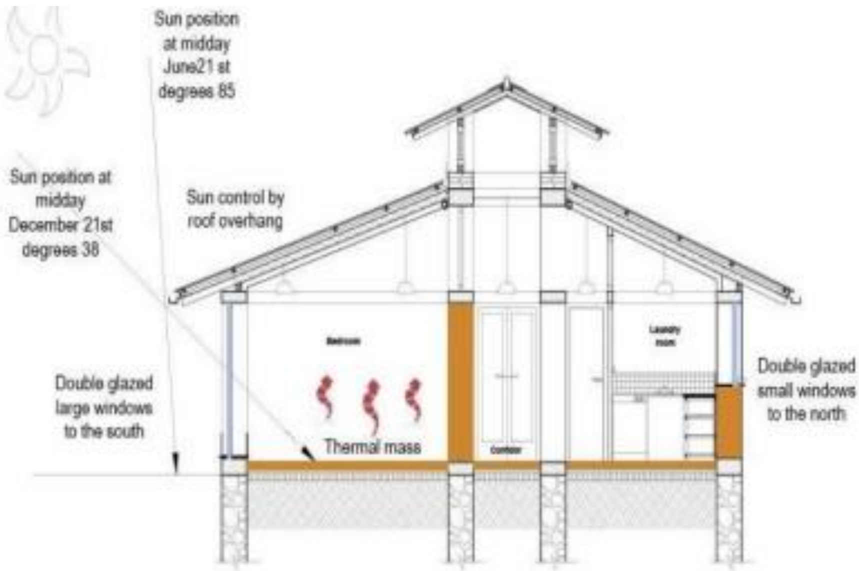


Figure 2-8 Section of MatoGhar

Source: Bajracharya, S.B., 2020, Lecture Notes, Lalitpur, Nepal

One of the best examples to explain the best thermal performance for thermal comfort passive strategies which can be used in a modern building in modern period is Mato ghar which is located at Budanilkantha, Kathmandu can use some same technology in modern building to achieve the thermal comfort inside the built surface. MatoGhar is single storey rectangular shape residential building built in an area of 2000 sq. ft. located at Buddhanilkantha, Kathmandu. It designed and constructed with passive solar techniques. The main component of this building is mud thus named as "MatoGhar". The building also has other passive solar technology integrated like solar photovoltaic panel, floor heating through solar water heating and solar water heater. The rooms arrange linearly along east west direction with all living spaces; living room, bedrooms on the southern side whiles other utility rooms; kitchen, toilets, laundry and study room towards northern side. (Shakya, et al., 2015).

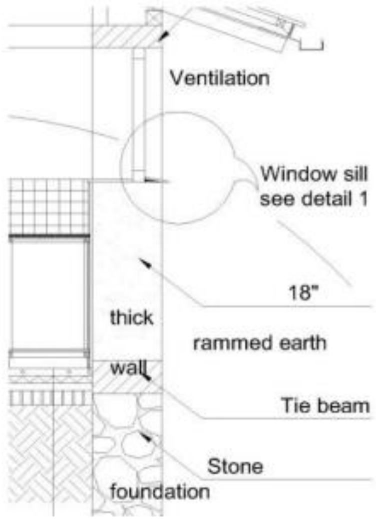


Figure 2-7 Wall section of MatoGhar

Source: Bajracharya, et al., 2020

The exterior and interior wall made of 18" thick rammed earth with mud plastered to make smooth texture inside. Windows made of double glazed aluminum panel with air cavity and cover nearly 10% of total floor area. The windows let in plenty of natural light and somewhat block outside noise inside the building. The big windows at south walls allow sun inside the building for lighting and heating while small windows at north walls resist cold wind. The two-way slope roof has insulation of 2"thick story foam and a gap between external layer and purlin allows heated air to rise above. The roof overhangs provide summer shade, but the chamber is open to the sun in the winter. (Shakya, et al., 2015).

Table 2-2 Calculation of U-Value of Passive Building-MatoGhar

Passive Building – MatoGhar	**U-Value (W/m² °K)**
Rammed earth (18" thick)	0.37
Insulated Roof (110mm)	0.20
Window (Double Glazed)	3.06
Energy Consumption per year (kwh/year)	274.80

Source: Bajracharya, et al., 2020

Here the table 3 gives a u-value calculation of different building envelopes components of passive building; MatoGhar (Bajracharya, et al., 2020). From table we can see that the u-value of window is high but the other components like rammed earth, and insulated roof u-value are very low. Therefore, windows are the only one building envelope that transmits heat or cold quickly in passive building.

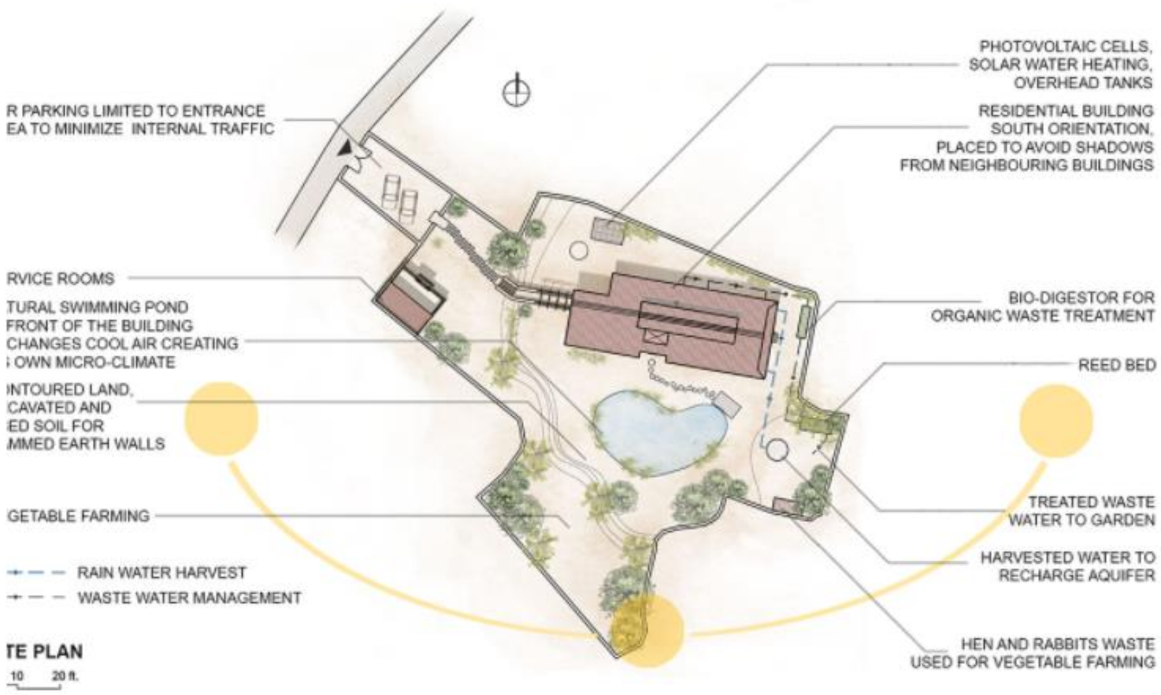


Figure 2-9 matoghar

Source: Bajracharya, S.B., 2020, Lecture Notes, Lalitpur

2.5 Climate parameters analyzing tools

To examine climatic parameters, one can use the Mahoney tables, Building Bioclimatic chart, and Bioclimatic chart. The climatic components of a chart can be combined to create a bioclimatic chart. The center of the graph represents the comfort zone. The bioclimatic approach investigates the possibilities for designing in accordance with the local climate. Givoni used the conventional psychometric chart to create a bioclimatic chart based on indoor circumstances. The Mahoney tables present results of a thermal comfort analysis, which mostly relied on temperature and humidity data, as well as recommendations for design concepts. Mahoney Tablel has a total of four tables (Koenigsberger O., 1973). Another graphical technique based on the psychometric chart (S.V., 2008), that was used to create the bioclimatic chart in this study is the control potential zone. It uses Auliciems' adaptive thermal comfort methodology and is location-dependent.

2.6 Previous studies on thermal performance

Thermal improvements of the traditional houses in Nepal for the Sustainable building design (Rijal et al., 2012)

One of the main problems with sustainable building design for varied climes and societies may be traditional architecture. By utilizing local building materials and construction methods, they are well fitted and adaptable to the climates and cultures. However, modern architecture, artificial materials, and extraterrestrial technology are quickly displacing conventional architectural types. To maintain the principles and applications of conventional architecture, we need robust regulations and reliable research. So, in this study, we will investigate the thermal environment and improvements of traditional homes in Nepal by relating them to thermal comfort, firewood use, and indoor air quality.

The thermal performance of traditional residential buildings in Kathmandu valley (Bajracharya, 2014)

This essay aims to investigate the thermal performance of traditional dwelling structures in Kathmandu valley traditional villages. The goal of this study is to identify the inside thermal environment that is relevant to the outdoor thermal environment during various seasons by analyzing the thorough field data that was gathered. Additionally, this study contrasts the thermal efficiency of old and contemporary residential structures in the valley's historic towns. To learn more about the thermal environment of various classic and contemporary residential structures under varied conditions, multivariate analysis is used. The paper comes to the conclusion that older residential buildings have better thermal performance than modern structures because they have had more time to adjust to changing temperature regimes for thermal comfort.

Seasonal and regional differences in neutral temperatures in Nepalese traditional vernacular houses (Rijal et al., 2010)

In the indoor and semi-open areas of traditional homes, in both the summer and the winter, two assessments of the thermal environment and thermal sensations were carried out in five districts of Nepal: Banke, Bhaktapur, Dhading, Kaski, and Solukhumbu. The questionnaires were conducted over a 40-day period, collecting a total of 7116 thermal sensations from 103 participants. Since they are able to adapt well to the thermal circumstances, the results demonstrate that residents are extremely content with the thermal state of their homes. In semi-open areas like verandas, the residents' neutral temperatures are greater than in enclosed areas. The results show that people in the examined regions adapt well to the natural environment, which is why neutral temperatures vary in different climates. They're lowest within the cool climate, medium within the temperate climate and highest within the sub-tropical climate.'

Thermal performance of Tharu house and its improvement techniques - A case of Dang-Deukhur (Tharu, et al., 2019)

The reason is also thanks to the utilization of indigenous and locally available materials in traditional houses. The goal of the research is to evaluate the thermal performance of traditional Tharu homes in the Gobardiya village of the Dang-Deukhuri region and to recommend ways to make them more energy efficient. For that the research has been initiated by literature on Tharu house and settlement pattern of Dang-Deukhuri district, thermal performance, and adaptive thermal comfort and improvement techniques. In the field, four consecutive days of internal and outdoor temperatures for one Tharu house in Gobardiya village throughout the summer and winter were recorded, which has been compared with the opposite three investigated houses of case area. The assessed temperature of the researched Tharu house was compared with the calculated summer and winter comfort temperatures for Dang using Nicol's adaptive thermal comfort model. The researched traditional Tharu house maintains 3.5°C less temperature than the other investigated buildings in summer and a pair of 1.13°C higher temperature in winter, according to the results of calculations and multivariate analysis. Finally improvement techniques of traditional Tharu house has been suggested on the idea of literature review and suggestions at different levels has been provided for future study.

A Study on Passive Cooling Strategies for Buildings in Hot Humid Region of Nepal (Manandhar & Yoon, 2015)

This is a preliminary analysis of building design tactics that concentrates on internal cooling energy consumption. The study will show that simple passive measures can be implemented in building design to help reduce cooling demand. In this study, various passive cooling techniques such as building size, thermal mass, window design, and two direct cooling techniques are studied. Passive cooling is aided by direct cooling techniques like shading and natural cooling. The study finds that the thermos property of building materials has the biggest impact on the building's energy consumption since different design choices have varying effects on the cooling energy need. The energy consumption is reduced by 20% on average by each design strategy, but the thermal conductivity can reduce it by a maximum of 10 times more than other design methods.

Hot and humid climate: prospect for thermal comfort in residential building (Zain & Baki, 2007)

The human body intelligently adapts to various climatic conditions through acclimatization. The different thermal comfort requirements of individuals in various climate conditions and for various seasons clearly demonstrate that the planning strategy for a building must be appropriate to the project's location. Intelligent system is also used for the aim of compliance to thermal comfort. This essay discusses typical methods for increasing comfort naturally in a hot, muggy area without air conditioning. Except for residential structures, hot and humid nations like Malaysia often need air conditioning; however, this dependence on thermal comfort through air conditioning might be reduced. When a decent design is used, there is a relatively high chance that an area won't need air conditioning.

Thermal Comfort of Residential Building in Malaysia at Different Micro-climates (Jamaludin & Wahab, 2015)

The amount of the thermal environment in Malaysian residential buildings is examined in this study, namely in Kuala Lumpur (KL), Bayan Lepas (BL), and Kuching (K). A simulation model of a domestic building in Malaysia with a typical design was constructed in order to determine the interior temperatures in the indoor living rooms, including the living room (DL), wet kitchen (K), and master bedroom (K) (MB). The results indicate that the best indoor temperature of 32.6 °C was recorded at 1400 hours in the main bedroom (MB) under the KL climate. Temperatures indoors are generally greater.

Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings (Taleb, 2014)

The goal of passive design is to maximize occupant comfort and health while using the least amount of energy possible. It does this by adapting to site and local climate conditions. The secret to creating a passive structure is to take full use of the climate where it is located. Any technology or architectural element used to lower building temperatures without the use of energy is referred to as passive cooling. In particular, Dubai, United Arab Emirates, is the focus of this study to assess the benefits of utilizing a few passive cooling strategies to enhance thermal efficiency and lower energy use in residential buildings in hot, arid climates. One case building received eight passive cooling techniques. IES, a popular piece of energy simulation software, was used to evaluate the building's performance. The effectiveness of solar shade was also evaluated using Sun Cast Analysis, a feature of the IES program. Energy savings were made possible by utilizing natural ventilation as well as good shading mechanisms used in conjunction with windows to reduce heat gain and maximize cooling. Furthermore, green roofing demonstrated its potential by serving as a reliable roof insulator. The study came to numerous important conclusions, one of which was that the use of passive cooling techniques can cut a building's total yearly energy usage in Dubai by up to 23.6%.

Adaptive thermal comfort in Japanese houses during the summer season: Behavioral adaptation and the effect of humidity (Rijal, 2015)

An occupant thermal comfort and behavior survey was carried out over the course of five summers in the living rooms and bedrooms of homes in the Kanto region of Japan to better understand the impact of humidity on the space temperatures that were reported to be comfortable. With the help of over 239 inhabitants in 120 residences, we gathered 13,525 votes on thermal comfort and matching readings of the air's temperature and humidity. The population was typically satisfied with the thermal environment of their homes, whether or not they used air conditioning, making them well-adapted to their thermal conditions. It was discovered that the humidity had little to no direct impact on the comfortable temperature. However, there was a significant correlation between the reported skin wetness and the comfort temperature. Opening windows and using fans are behavioral adaptations that increase air flow and enhance thermal comfort.

Thermal comfort study of Kerala traditional residential buildings based on questionnaire survey among occupants of traditional and modern buildings (Dili & Varghese, 2010)

There have already been published scientific evaluations of the environmental factors affecting thermal comfort. Similar investigations into contemporary homes are in progress. A questionnaire survey was conducted in several seasons, including winter, summer, and monsoon, to compare user feedback from residents of traditional and contemporary residential structures with the findings of the scientific investigation. To understand how factors like temperature, humidity, and air movement affect thermal comfort during the examination of thermal comfort, a very well-prepared questionnaire was created. The compilation of the survey's results is the foundation of this essay. At the end of this document, a comparison of the study results with previously published scientific analyses is also included.This investigation supports the idea that Keralan traditional homes are exceptionally good at creating a comfortable indoor environment throughout the year.

Improving Thermal Comfort of Low-Income Housing in Thailand through Passive Design Strategies (Bhikhoo & Cruickshank, 2017)

Thailand has always struggled to offer adequate low-income housing due to politics, which prioritizes cost and quantity over comfort, quality, and resilience. Buildings must be climate-adaptable in a nation where temperatures are hot and muggy for the majority of the year in order to improve occupant thermal comfort. This study focuses on identifying opportunities to enhance certain home designs' thermal performance. First, the adaptive thermal comfort model CIBSE TM52 was used to execute dynamic thermal simulations on a baseline model for evaluation. The three criteria listed in CIBSE TM52 were used to evaluate the frequency and seriousness of inside-building overheating. It was discovered that the units' interior temperatures were consistently higher than the thermal comfort criterion for these requirements. The apartment's interior operational daily temperatures range from a high of 38.5 °C to a low of 27.3 °C. Supported these findings, five criteria were chosen for sensitivity analysis in order to identify the critical variables that affect thermal performance and to offer potential areas for improvement. Building energy calculations were carried out using Integrated Environmental Solutions—Virtual Environment (IES-VE) computer software. After establishing the baseline circumstances, the sensitivity analysis was carried out using the familiar SimLab2.2 and RStudio software programs. According to these findings, the system is most significantly influenced by the type of roof and the existence of a balcony. The average number of days with excessive heat was decreased by 21.43% by adding insulation to the roof. The frequency of days with extreme heat increased by 19.94% when the balcony was removed because there was a significant drop in interior ventilation.

Performances of traditional houses in dry hot arid climate and the effect of natural ventilation on thermal comfort: a case study in Damascus (Mousli, 2015)

Rooms in traditional Mediterranean residences are placed around a courtyard or courtyards, creating a usually agreeable atmosphere, especially in the sweltering summer. In the Damascus Old City, ancient homes and courtyards are examined to determine how natural ventilation (cross ventilation and single side ventilation) and building structural thermal performance affect indoor thermal comfort. The study offers the results of several monitoring data (air temperature, humidity, and air velocity) collected over the course of a summer in conjunction with an occupancy survey in order to evaluate the comfort levels.

Effect of thermal mass on the thermal performance of various Australian residential constructions systems (Gregory, et al., 2008)

The impact of thermal mass on the thermal performance of several types of Australian residential construction, including: cavity brick (CB), brick veneer (BV), reverse brick veneer (RBV), and lightweight weight (LW) constructions, was numerically examined using the commercial Accurate energy rating tool created by the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO).Four alternative fictitious building envelopes, referred to here as building modules, were used to assess each construction type's performance. The thermal behavior of the modules under study had been found to be significantly impacted by the thermal mass, especially in cases where the thermal mass was enclosed in an insulating protective envelope. In this regard, it was discovered that the RBV and CB structures were the most successful walling systems. Elsevier B.V. is the sole owner in 2007.

Evaluation of energy efficient design strategies for different climatic zones: Comparison of thermal performance of buildings in temperate-humid and hot-dry climate (Yılmaz, 2007)

The majority of governments worldwide have vowed to cut back on greenhouse gas emissions since the Kyoto Protocol was signed in December 1997. As a result, sustainability and the effective use of energy have taken center stage in the most important energy policies. Since buildings are among the largest energy consumers, the terms sustainability and energy conservation are often used in the housing business. It is well recognized that a building's energy usage for heating accounts for a significant portion of its overall energy use. Additionally, the building envelope has lost the majority of the heat. The objective of TS 825, Turkey's Building Energy Conservation Standard, is to minimize heat loss via the building envelope. However, one of the energy demands that are increasing the fastest within buildings is cooling, which is especially true in Turkey's hot, humid, and dry regions where the cooling season lasts much longer than the heating season. Furthermore, for a structure to be energy efficient in a hot, dry region, the capacity of the envelope to store heat becomes a more crucial factor than thermal insulation. Istanbul and Mardin are regarded as being in the same zone because the Turkish standard only takes into account the conservation of heating energy when utilizing the degree-day concept, despite the fact that they are located in the temperate-humid and hot-dry climatic zones, respectively. In this study, energy-efficient design solutions for these climates are presented, and the thermal performance of two buildings built in Mardin and Istanbul in accordance with TS 825 is assessed to show the significance of thermal mass in hot, dry climates.

Influence of environmental variables on thermal comfort and air quality perception in office buildings in the humid subtropical climate zone of Brazil (de Oliveira & Ghisi, 2021)

In the humid subtropical climate of Florianópolis, southern Brazil, this study assesses the impact of environmental variables on users' perceptions of air quality and thermal comfort. A building with a central air conditioning system was also assessed. The evaluation involved three mixed-mode buildings that switched between natural ventilation and air conditioning modes. Statistics were applied to environmental data gathered between 2014 and 2016 utilizing microclimate stations, a carry-on thermometer, and a CO2 analyzer, as well as user comments obtained via an electronic questionnaire. The findings showed a direct correlation between thermal comfort, air temperature and humidity ratio, as well as an indirect correlation between air motions. Additionally, thermal comfort and air quality perception were influenced by temperature, air movement, and humidity sensation, preference, and acceptance, underscoring the significance of concluding a comprehensive assessment of users' perceptions of the thermal environment. This research encourages the use of the ASHRAE 55 adaptive thermal comfort model in mixed-mode buildings with natural ventilation. In accordance with the study's findings, it is generally advised to utilize a hybrid ventilation approach to reduce the need for air conditioning and improve indoor air quality by lowering the quantity of air pollutants. This technique also helps save energy.

Thermal performance of traditional and new concept houses in the ancient village of San Pedro De Atacama and surroundings (Palme, 2014)

Earth, wood et al. traditional materials are still utilized in house constructions in many regions of the planet, especially within the Andes. For instance, San Pedro de Atacama may be a place where rammed earth (tapial) and earth blocks (adobes) are significant building materials and an ancient building technique that has been passed down through the generations. Interesting energy characteristics of the earth include its low thermal conductivity, high heat storage capacity, changing hue, and potential for absorbing light or to reject radiationToday, however, the government's social housing program is recommending a novel type of structure that has little resemblance to the past. In this research, modeling analyses and monitoring of four different San Pedro houses that were built utilizing various methods and materials are presented. Results will be used to analyze the reliability of social housing service buildings that are currently being built in the town as well as the thermal performance required in a desert climate.

S.N	Title	Author/published date	Key findings
1	Thermal improvements of the traditional houses in Nepal for the Sustainable building design	(Rijal, 2012)	By connecting these to thermal comfort, firewood use, and indoor air quality, we can improve the traditional Nepalese home's thermal environment.
2	The thermal performance of traditional residential buildings in Kathmandu valley (Bajracharya, 2011)	(Bajracharya, 2014)	Traditional residential buildings' thermal performance has been modified in a number of ways to account for the

			changing thermal environment for Thermal comfort is superior to that of modern structures. In both hot and chilly seasons, traditional buildings can reduce temperature by at least 1-2°C.
3	Seasonal and regional differences in neutral temperatures in Nepalese traditional vernacular houses (Rijal et al., 2010)	(Rijal & Umemiya, 2010)	-The people of the study area of Nepal Are well adapted to natural environment, neutral climates vary depending on the climate as a result. Lowest in a cool climate, middle in a temperate environment, and highest in a subtropical climate.
4	Thermal performance of Tharu house and its improvement techniques - A case of Dang-Deukhur	(Tharu, et al., 2019)	Investigated traditional Tharu house maintains comfort temperature of Dang traditional Tharu house was seen better since it

			was found to be 3.5°C cooler in summer and 2.13°C warmer in winter.
5	A Study on Passive Cooling Strategies for Buildings in Hot Humid Region of Nepal	(Manandhar & Yoon, 2015)	study regarding building design strategies which focuses on cooling energy consumption within the building design strategy creates and average of 20% decrease in energy consumption
6	Hot and humid climate: prospect for thermal comfort in residential building	(Zain & Baki, 2007)	In an extremely hot and humid region without air conditioning, this study provides a common planning technique for strategies to organically improve comfort.
7	Thermal Comfort of Residential Building in Malaysia at Different Micro-climates	(Jamaludin & Wahab, 2015)	At 1400 hours, the best indoor temperature of 32.6 °C was recorded in the main bedroom (MB) of the KL climate. Temperatures

			indoors are generally greater.
8	Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings	(Taleb, 2014)	In this study, passive cooling techniques were used in residential structures in Dubai, United Arab Emirates, to enhance thermal performance and lower energy usage.
9	Adaptive thermal comfort in Japanese houses during the summer season: Behavioral adaptation and the effect of humidity	(Rijal & Nicol, 2015)	Residents were well adapted to their thermal conditions with or without air condition and the comfort temperature was shown to be very little affected directly by humidity.
10	Thermal comfort study of Kerala traditional residential buildings based on questionnaire survey among occupants of traditional and modern buildings	(Dili & Varghese, 2010)	According to this study, Keralan traditional homes are exceptionally good at creating a comfortable indoor climate throughout the year.
11	Improving Thermal Comfort of Low-Income Housing in	(Bhikhoo & Cruickshank, 2017)	Insulation in the roof decreased the

	Thailand through Passive Design Strategies		average number of days with excessive heat by 21.43%. Because there was a considerable decrease in internal ventilation after the balcony was removed, the number of days with excessive heat increased by 19.94%.
12	Performances of traditional houses in dry hot arid climate and the effect of natural ventilation on thermal comfort: a case study in Damascus	(Mousli & Semprini, 2015)	Internal courtyards, which act as passive cooling systems in hot, arid climates, have an impact on thermal comfort. The thermal performance of buildings and the thermal performance of each individual room can be influenced by various designing variables, materials, and operational situations.
13	Effect of thermal mass on the thermal performance of various	(Gregory, et al., 2008)	The effect of thermal mass on the thermal

	Australian residential constructions systems		performance of several types of Australian residential construction, including cavity brick (CB), brick veneer (BV), reverse brick veneer (RBV), and light weight (LW) constructions, was found to be significant. Particularly in those cases where the thermal mass was enclosed in an insulating envelope, RBV and CB constructions were found to be the most effective.
14	Evaluation of energy efficient design strategies for different climatic zones: Comparison of thermal performance of buildings in temperate-humid and hot-dry climate	(Yılmaz, 2007)	In this study, energy-efficient design solutions for these climate zones have been discussed, and the thermal performance of two buildings built in the cities of Mardin

			and Istanbul in accordance with TS 825 has been assessed to demonstrate the significance of thermal mass in hot, dry climates.
15	Influence of environmental variables on thermal comfort and air quality perception in office buildings in the humid subtropical climate zone of Brazil	(de Oliveira & Ghisi, 2021)	Thermal comfort is directly influenced by air temperature and humidity ratio as well as indirectly by air movement. It is advised to employ a hybrid ventilation strategy to improve indoor air quality and save energy because it uses less air conditioning and uses less energy to remove air contaminants.
16	Thermal performance of traditional and new concept houses in the ancient village of San Pedro De Atacama and surroundings	(Palme, 2014)	Earth, wood and others traditional materials are still used in house constructions for thermal performance

Chapter 3: **RESEARCH METHODOLGY**

A methodology always refers to the philosophy and outline that are basically related to the entire process of the research. According to Mackenzie and Knipe (2006), the method refers to the systematic modes, methods, or tools utilized for data collection and analysis, whereas methodology is the overall method to the proposed research linked to the paradigm or theoretical conceptual framework to be applied (Mackenzie, 2006). Scientific paradigm is a framework that includes all of the widely held beliefs about a topic, conventions for the course that research should take, and guidelines for how it should be conducted.

3.1.1 Research paradigm

This research adopts the pragmatic paradigm. The researcher's involvement in positivism will be confined to gathering data and objectively interpreting it, and is based on full understanding, experiment and observation (Ryan, 2006). Hence the paradigm shifts from positivism to pragmatic paradigm took place. An interpretive approach to social research is qualitative, therefore using unstructured interviews or participant observation methods. Secondly, while interpretation may vary from one stakeholder to another, this research takes into account the interpretation from the researcher’s perspective. The main objective of the research is to measure the thermal performance of modern residential of PadamPokhari in all seasons. And also to suggest the best design strategies for thermal comfort for the future in modern residential buildings. To fulfill this objective the main source of knowledge is obtained through the experience of both the researcher and the local residents or inhabitants who are residing in the case area i.e. Padam pokhari, Hetauda

The ontological claim of this research is that Padam pokhari,Hetauda is a mixed settlement which is the influence of modern technology which is gradually declining the traditional residential building of Hetauda city. This declining process is fast and doesn’t give concern in the traditional residential building directly help to loss of the traditional residential building and accept a lot of modern technology. Accepting the modern technology and modern construction technique in the modern residential building directly affect thermal performance inside the modern residential building. To analyze such a situation and identify such issues in the case area research need to be done in a good way and nicely. Research gap can be easily seen that why modern residential building doesn’t perform well in thermal comfort.

The prime research methodology is based on the goal of the research, epistemological concerns, norms of the practice of the researcher, and other precious work done on that certain topic

(Buchanan &Bryman, 2007). The epistemological claim of based on the thermal performance of the traditional house and modern house, stakeholders, locals, and as well as valid sources like articles, journals books, etc. will be followed which will valid the ontological claim.

3.1.2 Research method

The use of both qualitative and quantitative methodologies is combined in this study. The quantitative methods are used to calculate the air temperature, humidity, regression analysis. Where qualitative research methods used to collection more information like literature study for improvement design strategies of the modern residential building, to collect the perception of the people over the thermal comfort experience with their residential building.). It encourages the combination of quantitative and qualitative approaches to examine the range of facts that may be investigated using different types of investigations, while also accepting and appreciating all results on the crucial factors for the occurrence of information (Clark, 1998).The qualitative research will help to interpret the relationships between the study variables. The quantitative approach, on the other hand, aids in understanding the whole scope of the research issue.

To study the first objective follows a quantitative approach for determining the temperature difference between the environments through the use of the thermometer. In this study, extended surface temperature data are used to characterize the thermal performance of buildings by placing sensors on both interior and external wall surfaces. To conduct this study, quantitative measurement is used. A thermometer is the primary experimental tool used to monitor the temperature of the interior and external wall surfaces of residential buildings that are modern, hybrid, or traditional on an hourly basis. This assessment will be carried out in order to compare the interior room air temperature to the surface temperature of the roof in order to determine the final effect of the building envelope on the indoor and outdoor thermal comfort conditions. The maximum and minimum internal and external surface temperature values of modern, hybrid, and traditional residential will be evaluated and compared.

To study the second objective, both qualitative and quantitative approaches will be taken the second objective involves the review of the thermal performance of modern resident buildings ding with other types of residential houses in the case area. The comparison of residential buildings by use of modern, local materials in the study area is carried out through a questionnaire survey to find this objective both subjective questionnaires survey, perception of respondents, and observation will be involved.

Similarly, the third objective involves. Lastly, the third objective involves design strategies suggestions, or recommendations for upcoming modern residential buildings the different literature reviews, case studies, etc. So it follows both quantitative as well as qualitative methods.

Selection of case area

To fulfill the research objective, the study area has chosen where settlement have all the types of residential building like modern, hybrid and traditional residential building. So the perfect case area will be the Padam Pokhari,Hetauda, In 2073 different families, there were 11,838 people residing in Nepal at the time of the 1991 census (makwanpur, 2022). Not whole padam pokhari is chosen for the filed visit, Small clusters where all the types of residential buildings are available will be chosen for the case study. Where total household may be 45 numbers in total.

The main reason for selecting Padam Pokhari area as a case study is that it is mixed of all types of buildings. So the padam pokhari is adopted for the study of thermal performance.

Figure 3-1 study area

Source: Kathmandu post

Figure 3-2 investigated cluster for case area

Source: google earth (2022)

Sampling

For the field data of this research, the chosen site needed to have buildings constructed with modern, hybrid and traditional technique. Purposive sampling will be used as the sample strategy. The term "purposeful sampling," often known as "judgmental, selective, or subjective sampling", is a type of nonprobability sampling in which researchers choose participants for their study based on their own judgment (Buchanan &Bryman, 2007).

Table 3-1 Total purposive sampling

Total building number in the cluster	45	Total purposive sample number for research
Modern residential building	15	3
Hybrid residential building	20	3
Traditional residential building	10	3

Figure 3-3Selected residential buildings

Data collection

Both primary and secondary data sources were used to gather the data. Utilizing a variety of tools, including questionnaires, interview schedules, checklists, and observation guides, primary data for the study was gathered. Journals, articles, publications, maps, and online sites were some examples of secondary data sources.

Primary source

An account of a recent event or subject written by a first-person or contemporary source. The fact that they were made by individuals or objects present during the time or event makes them the most important proof of that time or event. These sources include unique ideas or brand-new material without any interpretational alterations.

Selection of research indicator

In order to fulfill the objective of the research many indicators should be measured or considered in the field which directly affects the thermal comfort performance of the building. The factor which affects thermal comfort performance includes design variables like the form of building, building orientation, the envelope of the building, shading device, and other from the literature review. Thermal comfort performance affects by climatic factor-like solar radiation, humidity, rainfall, air temperature, building occupancy and operation directly affect in thermal performance of the building. Not only such indicator material properties like thermal resistance, thermal conductivity, thermal transmittance, density & porosity also define the thermal storage capacity of the building. All of these indicators should be look during the case study but due to the limitation of time consideration, it is impossible to fulfill all the indicators some indicators for measurement of thermal comfort performance of investigated houses has given below.

Measurement of air temperature of residential building

In order to fulfill the objective of the research that asses of thermal comfort performance of residential buildings. All the types of houses will be investigated. The total number of a residential building in the cluster is 45 with mixed buildings. 3 modern residential buildings, 3 hybrid residential buildings, and 3 traditional residential buildings will be investigated to obtain a more accurate objective for summer season. 1 modern residential buildings, 2 hybrid residential buildings, and 1 traditional residential buildings will be investigated to obtain a more accurate objective for winter season. Simple room thermometer HTC-2 is used for measuring the temperature of the buildings. Which show the outdoor temperature and indoor temperature with relative humidity. To calculate Minimum air temperature of winter season, four different types of residential building were selected and room thermometer HTC-1was used for continuous 7 days of winter i.e. (13th February- 19th February) at two time a day to calculate the minimum temperature. To calculate maximum air temperature of summer season nine different types of residential building were selected and room thermometer HTC-2 was used for continuous 15 days i.e. (may 16th- june 1st) at center of ground floor of each buildings. The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2 pm, and at night 7pm to calculate the maximum air temperature of summer season .189 number data set air temperature was recorded of summer data where 56 number of winter data were recorded. Before placing these thermometers data will calibrate. One thermometer was placed outside the house to measure the external temperature, while other locations inside the house were used to monitor the internal temperature. For the measurement of indoor air temperature, the thermometer was placed in the internal wall at the height of 1.4m from floor level. The thermometer was mounted on the exterior wall in a manner similar to how it was used to measure the outdoor temperature.

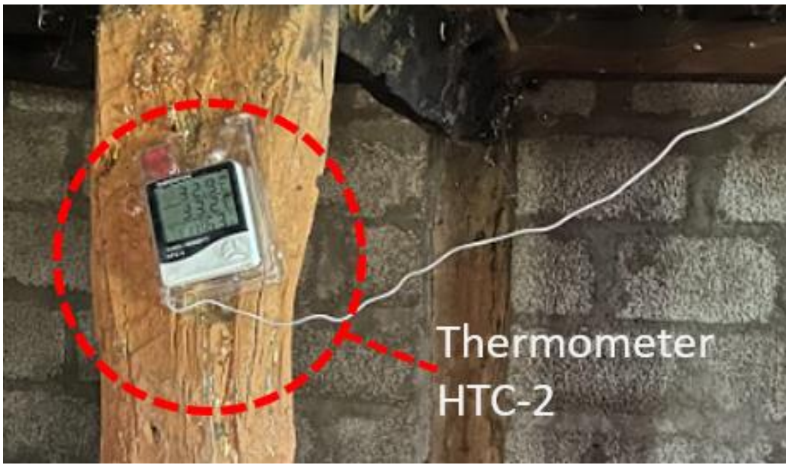


Figure 3-4 Thermometer HTC-2

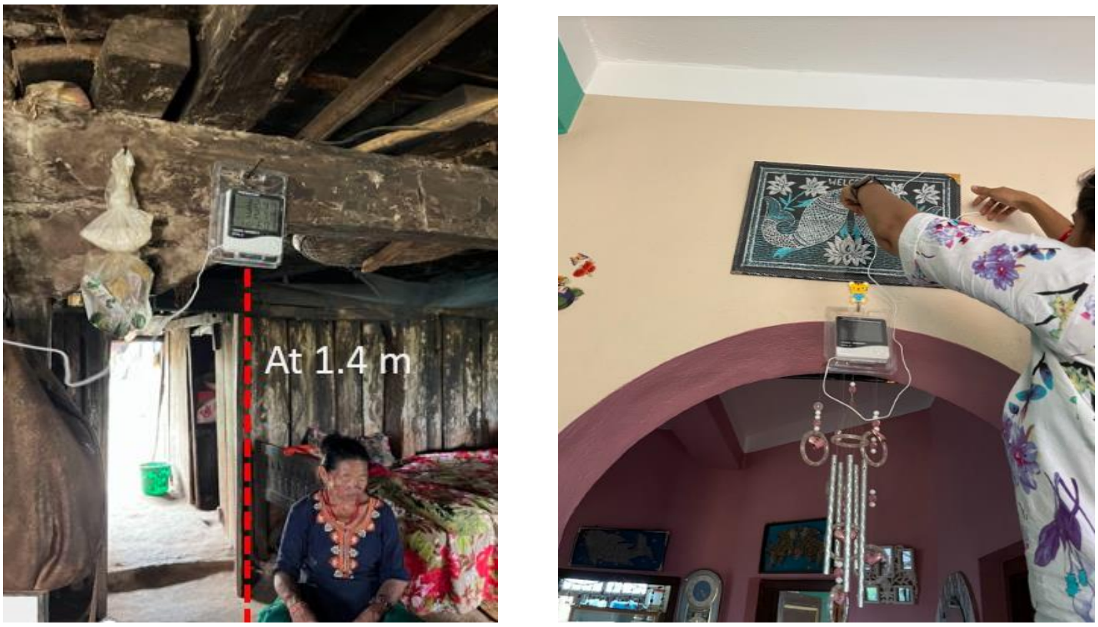


Figure 3-5 placement of room thermometer

Questionnaires

According to (Mugenda&Mugenda, 1999) surveys provide in-depth solutions to challenging issues. Because of how simple and inexpensive it is to create and deliver questionnaires, they are also a common form of data collection. Surveys provide data that is largely objective, making them the most useful. The study used questionnaires which will be focused in the people perception of people in the thermal comfort of their residential building according to the season. The researcher will therefore prepare questionnaires for the sampled population. The information given by the respondents would be used to understand to what extent the quality of life is affected by the change in the building materials used in traditional and residential buildings.

The survey's questionnaire was created to elicit respondents' subjective opinions on a variety of thermal comfort factors, such as temperature, humidity, and airflow, as well as information about the orientation and construction style of the building, the materials used, the types of residential buildings, and their overall level of thermal comfort. A thorough evaluation of the literature in the relevant topic was used in the selection and design of the questionnaire. After preparing a structured questionnaire in order to study and analyzed the thermal comfort of case study area. The questionnaire including demographic, socio-economic and energy consumption pattern information. The structured questionnaire will be integrated in Kobo tool for field survey in mobile devices. Additionally, checklist will also be prepared to be filled manually by the surveyor to understand the assumptions of people regarding their housing, thermal behavior and thermal sensitivity, favored weather, etc.

Calibrating and pretesting of the questionnaire and checklist will be undertaken among the selected number of total sample frame. Some irrelevant and non-quantitative questions will be omitted and revision will be done. Thus, the final questionnaire and checklist will be deployed by the surveyor. The field data collected will be used to correlate several variables and analyze them.

The research will be carried out within the framework of research ethics in social conduct. Questionnaires will be prepared avoiding offensive and discriminatory questions. Data will be collected through voluntary response of the correspondents.

Total respondent are taken from the family member of each residential building where

Modern residential building =14 respondent

Traditional residential building=15 respondent

Hybrid residential building = 11 respondent

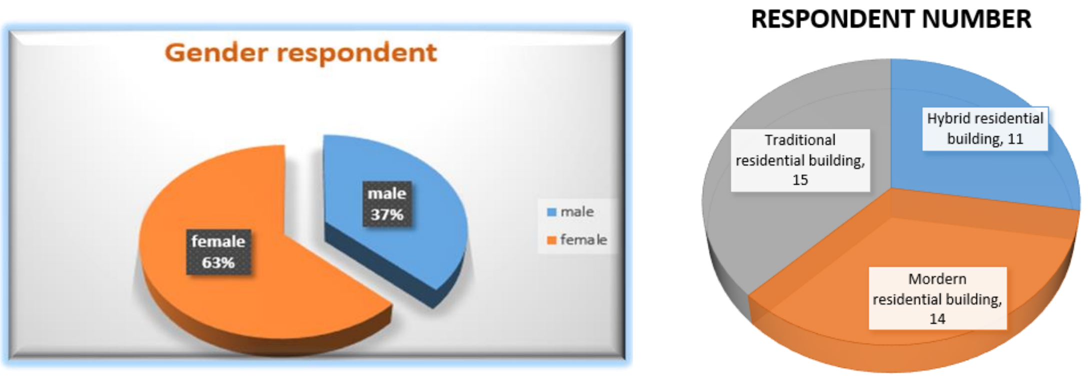
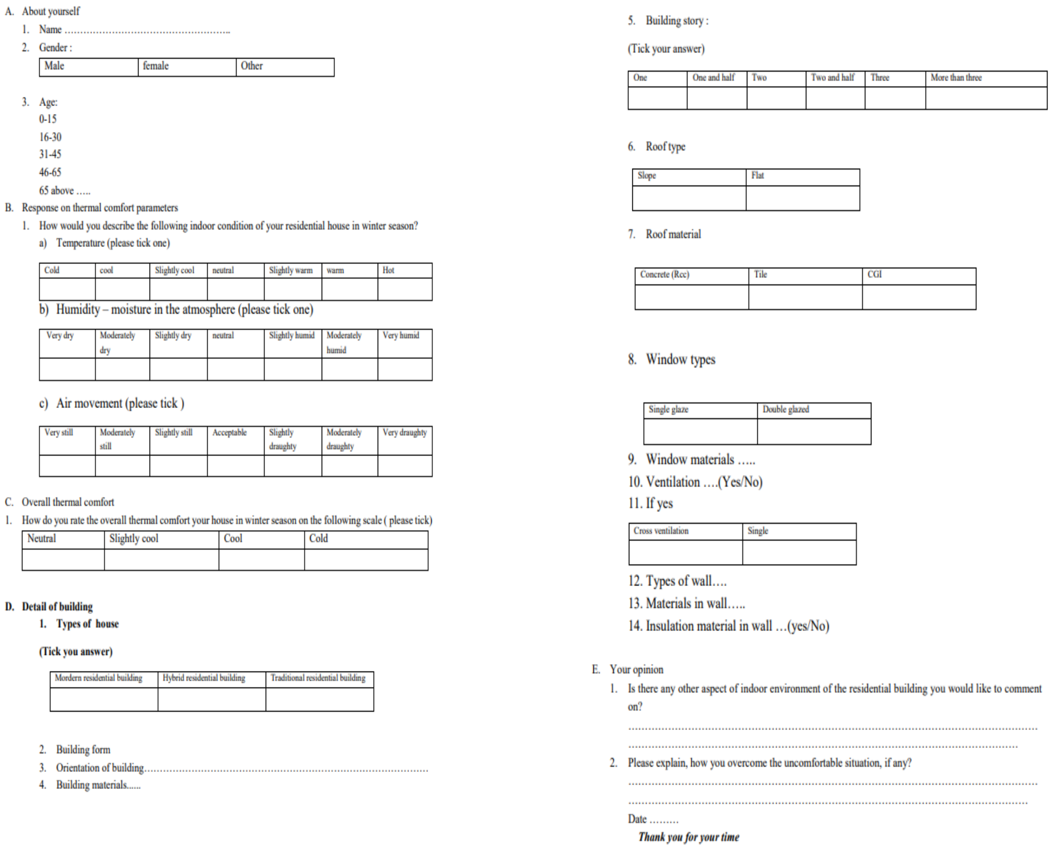


Figure 3-6 Respondent in graphical representation



A. About yourself
1. Name ………………………………………………..
2. Gender :

Male	female	Other

3. Age:
0-15
16-30
31-45
46-65
65 above …..

B. Response on thermal comfort parameters
1. How would you describe the following indoor condition of your residential house in winter season?
a) Temperature (please tick one)

Cold	cool	Slightly cool	neutral	Slightly warm	warm	Hot

b) Humidity – moisture in the atmosphere (please tick one)

Very dry	Moderately dry	Slightly dry	neutral	Slightly humid	Moderately humid	Very humid

c) Air movement (please tick)

Very still	Moderately still	Slightly still	Acceptable	Slightly draughty	Moderately draughty	Very draughty

C. Overall thermal comfort
1. How do you rate the overall thermal comfort your house in winter season on the following scale (please tick)

Neutral	Slightly cool	Cool	Cold

D. Detail of building
1. Types of house

(Tick you answer)

Mordern residential building	Hybrid residential building	Traditional residential building

2. Building form
3. Orientation of building……………………………………………………………………………
4. Building materials……

5. Building story :

(Tick your answer)

One	One and half	Two	Two and half	Three	More than three

6. Roof type

Slope	Flat

7. Roof material

Concrete (Rcc)	Tile	CGI

8. Window types

Single glaze	Double glazed

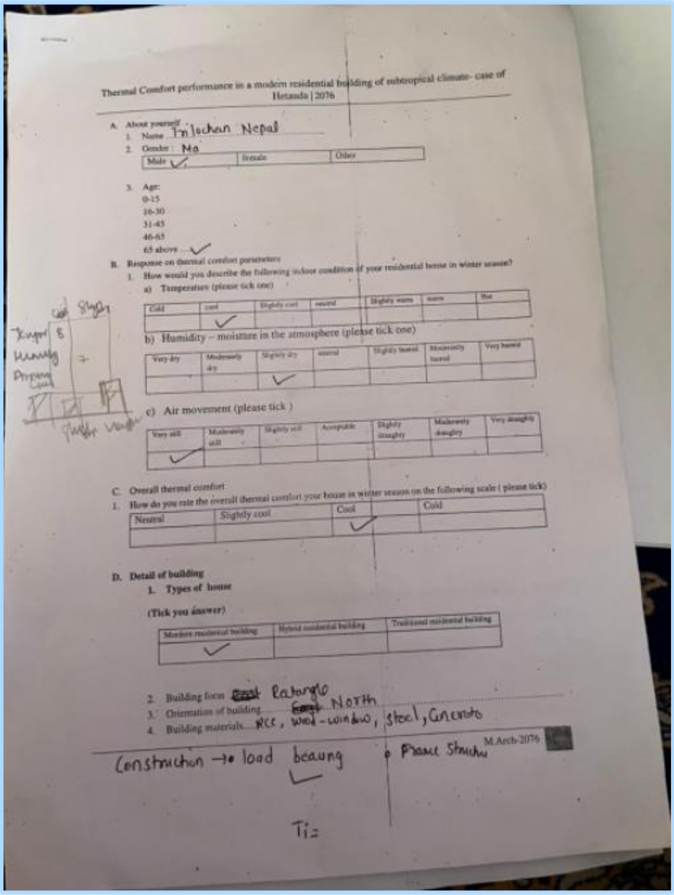
9. Window materials …..
10. Ventilation ….(Yes/No)
11. If yes

Cross ventilation	Single

12. Types of wall….
13. Materials in wall…..
14. Insulation material in wall …(yes/No)

E. Your opinion
1. Is there any other aspect of indoor environment of the residential building you would like to comment on?
………
………
2. Please explain, how you overcome the uncomfortable situation, if any?
………
………
Date ………
Thank you for your time

Figure 3-7 Questions sample



Thermal Comfort performance in a modern residential building of subtropical climate- case of Hetauda | 2076

A. About yourself
1. Name Trilochan Nepal
2. Gender : Ma

Male ✓	female	Other

3. Age:
0-15
16-30
31-45
46-65
65 above ✓

B. Response on thermal comfort parameters
1. How would you describe the following indoor condition of your residential house in winter season?
a) Temperature (please tick one)

Cold	cool	Slightly cool	neutral	Slightly warm	warm	Hot
	✓					

b) Humidity – moisture in the atmosphere (please tick one)

Very dry	Moderately dry	Slightly dry	neutral	Slightly humid	Moderately humid	Very humid
		✓				

c) Air movement (please tick)

Very still	Moderately still	Slightly still	Acceptable	Slightly draughty	Moderately draughty	Very draughty
✓						

C. Overall thermal comfort
1. How do you rate the overall thermal comfort your house in winter season on the following scale (please tick)

Neutral	Slightly cool	Cool	Cold
		✓	

D. Detail of building
1. Types of house

(Tick you answer)

Modern residential building	Hybrid residential building	Traditional residential building
✓		

2. Building form Ratangle
3. Orientation of building North
4. Building materials RCC, wood-window, steel, Concrete

M.Arch-2076

Construction → load bearing ✓ Frame Structure

Ti=

Figure 3-8 Answer sheet

Observation

The act of direct data collection by observation involves noticing, hearing, smelling, and testing things as they happen in the real world (Bowen, 2009). Through observation, the researcher validated verbal reports by comparing them with the actual behavior. The study was able to observe the orientation of building, size of openings, materials etc.

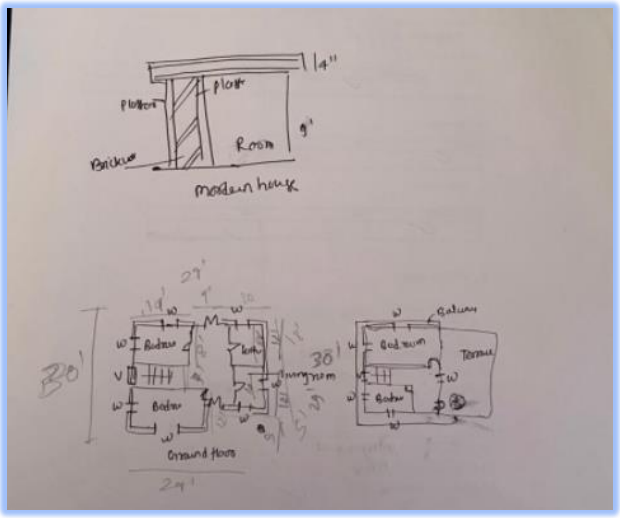


Figure 3-9 Plan sketch observation

Building orientation

Orientation of buildings affects the amount of solar radiation trapped by the buildings. So this indicator that has been looked upon is building orientation. Building orientation plays vital role in how thermal comfort is maintained in the building.

Material properties U value – thermal transmittance

Thermal transmittance is the amount of heat that moves through a unit area of a building section in a unit time for every unit temperature differential in the air on either side of the section under steady-state conditions (Code on a building's envelope thermal performance).The thermal transmittance of the materials like mud brick, brick, roof materials, roof materials of all types of the investigated house will be calculated and analyzed in the research, on the basis of which thermal performance has been assessed.

Size of opening in the building

The size of the opening also affects the amount of heat flow inside the building, so it directly affects the thermal performance of the building. So the size of opening of investigated residential building will be observed and will be calculated.

Interviews

A list of inquiries the interviewer asks the respondent during the interview is known as an interview schedule (Mugenda&Mugenda, 1999). A versatile and adjustable method of gathering information is an interview. In general, interviews provide the highest levels of cooperation and the lowest rates of rejection, they give good response quality, and they are a multi-method data collecting strategy that incorporates strategies for questioning, cross-examining, and probing (Owens, et al., 2002). In this study, key informants were first identified and then interview guides were used to ask information from owner or the member of the investigated residential building about the residential building condition. Also grab the information in the future suggestion according the respondent so that can be helpful in recommendation time.


Figure 3-10 Interview at field

Mapping, Sketching and Photography

All the details of investigated residential buildings will be mapped in the google earth photo and then will be sketched and take the photographs of all the investigated residential houses.

Secondary source

A document or recording that discusses material that was first offered in another source may be considered a secondary source. A primary source is a person having firsthand knowledge of a problem or a document produced by such someone; a secondary source contrasts with a primary source, which is an artless source of the material being addressed.

Documents Analysis

A collection of materials and information from books, journals, articles, magazines, and newspapers that contributed to the study will be made and examined. The information's primary focus was on the thermal comfort capabilities of various residential structures in Nepal's subtropical environment.

So, the climatic data of the recent Ten years of the nearest metrological station to the case area has been collected from the Department of Hydrology and Metrology, GoN. The climatic data included monthly mean maximum (Tmax) and monthly mean minimum (Tmin) air temperature,monthly rainfall data and monthly humidity data. Tmax and Tmin were only used for calculation and analysis whereas rainfall data and humidity data has not been incorporated in calculation. The other types of secondary data that have been collected are population data of Padam pokhari Hetauda and housing typology in the case area. It has been assessed from a report that was published by local government.

Mahoney tables present the findings of a thermal comfort analysis that mostly relied on temperature and humidity data, together with suggested design principles. There are a total of four tables. The monthly mean maximum and lowest temperature data can be compiled in Mahoney tables together with similar morning (AM) and afternoon (PM) humidity data Indicators in the Mahoney tables are six (i.e., three humidity indicators, H1-H3 and three arid indicators, A1-A3). These indications are based on thermal stress (during the day and at night), rainfall, humidity levels, and the monthly mean temperature range. These indicators are calculated for each month of the year to produce data that serves as design advice.

In order to use bioclimatic charts, the average monthly condition must first be determined. For each month, the average of the daily maximum temperature is calculated. The minimal daily absolute humidity average is used to generate the point. The average of the daily minimum temperature and the average of the daily maximum absolute humidity combine to generate equivalent quantities. The best passive technique for that month will depend on where the line segment connecting the two spots is placed. Mechanical air conditioning is required in hot climates to maintain a comfortable environment. To the left of the comfort zone (CZ), heating is required to regain comfort. If the shift is modest, solar heating can be used, but if the temperature is too low, mechanical heating is required. Heavy building contributes to the high thermal mass effect by absorbing heat that would otherwise be emitted overnight. Night ventilation will assist heat escape via windows while it's hot and dry outdoors, potentially with the help of fans. Passive Solar Heating Zone (PSH), Air Movement Zone (AM), Winter and Summer Comfort Zone (CZ), High Mass Night Ventilation Zone (HMNV), and Evaporative Cooling Zone have been calculated for Hetauda City (EC).

Data Analysis

Data collected from the field through questionnaire survey will be studied and analyzed using tools like Kobo tool box software, SPSS statistical software tool, Ms-Excel 2016 and manual checklist. Whether the association between variables are significant or not will be found out.

3.1.3 Conceptual frame work

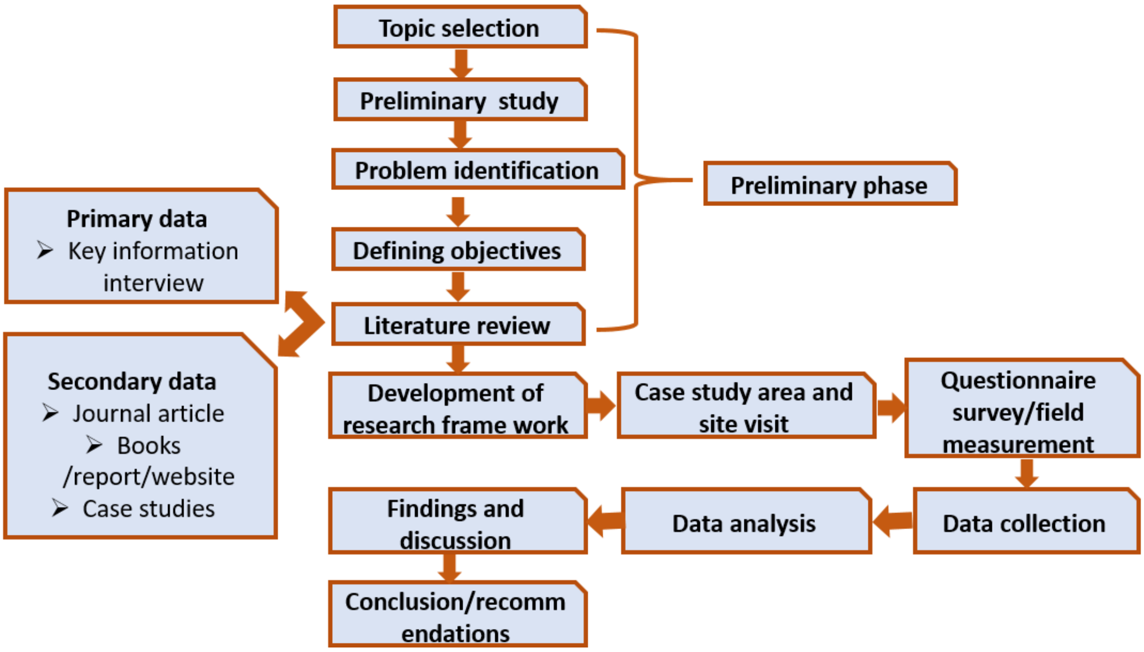


Figure 3-11 Conceptual framework

Chapter 4: **CASE STUDY**

Padam Pokhari ward no. 12 is an portion of the Makwanpur District in the Bagmati Province of central Nepal's Hetauda sub-metropolitan metropolis. In 2073 different families, there were 11,838 people residing in Nepal at the time of the 1991 census. It is bordered to the east by Churiyamai and Hetauda, to the north by Basamadi, to the west by Handikhola, and to the south by the Parsa district. Padam pokhari is growing day by day in the basis of building. Many traditional house is replacing by modern residential building. All types of the residential building can be seen in case study area. Mostly modern and hybrid residential building can be seen in the site rather than traditional building. Modern residential building used the modern technology and materials where traditional residential building use locally available material and technology.

Figure 4-1Padampokhari residential building

4.1.1 Climatic data of Padam pokhari,Hetauda

The 10 years (2011-2021) climate data of nearest station of the case area i.e, Hetauda was taken from Department of hydrology and metrology in order to analyses the climatic condition. The average of 10 year data of ambient temperature, relative humidity and precipitation was taken. The summer and winter data were separated in which peak summer month may, June and winter January and February were taken.the data can be seen below from Department of hydrology and metrology, government of Nepal.

Geography/Land feature: Parallel inner Terai valley enclosing ranges of hills and mountain

Ambient temperature winter: Day 21.33°C, Night 8.35°C

Relative Humidity: Winter (Dec-Feb): 80%

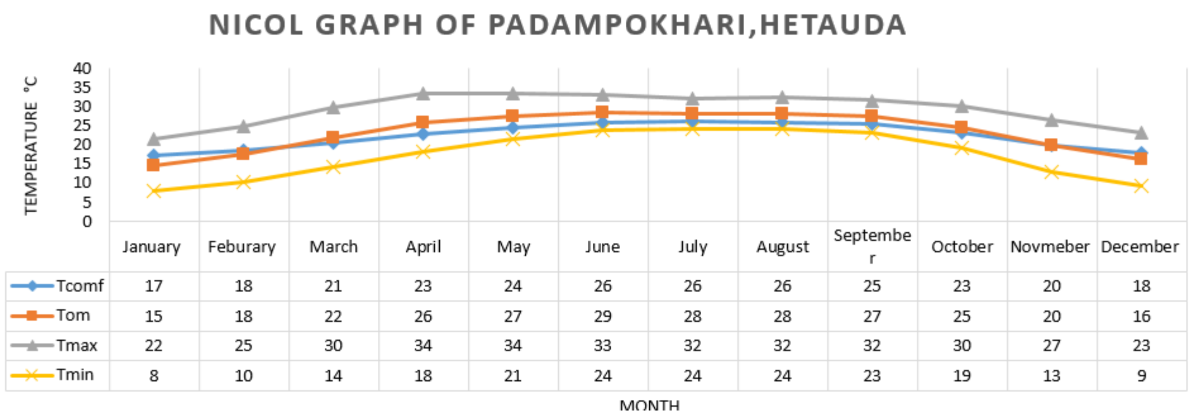
Precipitation: 250 mm

Winds: Variable (Usually NNE)

4.1.2 Comfort Temperature for Padam Pokhari, Hetauda

The below figures show Nicol Graphs for Padam pokhari which start finding the temperature in which people find comfortable to live, in which indoor air temperature varies with a mean outdoor air temperature of outdoor temperature. It has been calculated from 10 years of climatic data (2011 to 2021) of Hetauda assessed of Hetauda assessed from Department of Hydrology and Metrology, Government of Nepal. The comfort temperature of Hetauda has been calculated using the Nicol formula shown in equation (i)

= 0.54 Tom + 12.9....... (i)



	January	Feburary	March	April	May	June	July	August	Septembe r	October	Novmeber	December
Tcomf	17	18	21	23	24	26	26	26	25	23	20	18
Tom	15	18	22	26	27	29	28	28	27	25	20	16
Tmax	22	25	30	34	34	33	32	32	32	30	27	23
Tmin	8	10	14	18	21	24	24	24	23	19	13	9

Figure 4-2 Nicol graph for Hetauda

The figure 32 demonstrates the 12-month mean maximum temperature (Tmax), mean outdoor temperature (Tom), and monthly comfort temperature. It is simpler to calculate the monthly mean maximum temperature (Tmax), monthly mean minimum temperature (Tmin), monthly mean outdoor temperature (Tom), and monthly comfort temperature using the formula above.

= 0.54 Tom + 12.9....... (i)

Where,

Tcomf=comfort temperature

Tom= mean outdoor temperature

The table 12 shows the mean comfort temperature of Hetauda

As shown in table 4-1, the lowest temperature in which the people of Padam pokhari feel comfortable is 17°C during winter, whereas the highest temperature in which the people of Padam Pokhari,Hetauda feel comfortable is 26°C during winter.

Table 4-1Nicol comfort temperature for Hetauda winter

S.N.	Thermal sensation	Thermal scale	Nicol summer (Tc)	Nicol winter (Tc)	Comfort category	Remark
1	Hot	3	34	24	Very comfortable	
2	Warm	2	33	23	Uncomfortable	
3	Slightly warm	1	32	22	Comfortable	Comfortable zone
4	Neutral	0	31	21	Very comfortable	
5	Slightly cool	-1	30	20	Comfortable	
6	Cool	-2	29	19	Uncomfortable	
7	cold	-3	28	18	Very uncomfortable	

4.2 Fieldworks

4.2.1 Detail of investigated house

In order to explore the difference in internal and outdoor temperatures and to compare whether homes were thermally suitable to live in, nine different types of residential buildings have been chosen for the measurement of humidity and air temperature. Based on indications such as measurements of the houses' orientation, size of their openings, air temperature, and the materials they were made of, the researched homes were chosen. On the basis of these parameters the findings has been formulated. The nine different types of house investigated were:

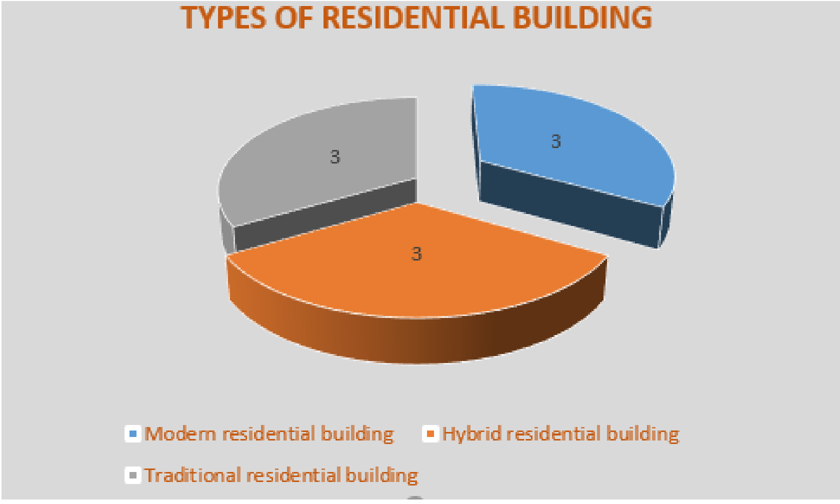


Figure 4-3 Different types of house for field survey

First types of House 1: Three different Modern residential building: one and half storied modern frame structure building with brick wall and flat concrete roof

Modern residential house 	Modern residential house M 	Modern residential house M3 

Second types of House 2: Three different Traditional residential building: two-storied with mud brick, wooden wall, and slope tile roof

Traditional residential house T 	Traditional residential house 	Traditional residential house 

Third types of House 3: Three different Hybrid residential building: two storied with wooden wall and slope tile roof and half of modified with CGI roof

Hybrid residential house H2	Hybrid residential house H1	Hybrid residential house H1
		

Modern residential building

In order to determine the characteristics of the existing residential buildings in PadamPokhari, Hetauda, a study of contemporary residential buildings was done. The poll asked questions about household characteristics, such as sociodemographic and household size, as well as dwelling features, such as primary building materials and construction style. Questionnaires were filled and plans were drawn. It was found that modern residential buildings were constructed using modern materials and techniques. This type of house is generally called a modern residential building at case study site. The two modern residential buildings are selected for comparison with other types of building at site. First modern residential building whose owner is Chiran Nepal named as M1 another modern residential building M2 whose owner is Indira Adhikari last modern residential building M3 whose owner is Shova Tamang.

U-vale calculation of modern residential house M1, M2&M3

Table 4-2 U-value calculation of modern residential house M1, M2, M3

Building envelope (thickness)	Thermal Conductivity (W/(m·K))	R-value(thickness/conductivity)	U-value
Wall			

Outer brick wall 9" Cement plaster on both side of wall 12mm	1.15 0.72	0.2 0.016 0.016 Total R-Value=0.232	**4.3 W/m²K**
Roof			
Bitumen 20mm Rcc 100mm Plaster 12mm	0.25 0.2 0.72	0.8 0.5 0.016 Total R-value =0.596	**1.6 W/m²K**
Window single glazed	0.78	0.20	**4.8 W/m²K**

House 1: modern residential building MThe residential building is built in 2010. The family consists of 5 member. The covered area of the house is approximately 800 sq.ft. Of ground floor, which is oriented toward south direction. The ground floor consist of a kitchen, 2 bedroom and one living room. And first floor consist of two bedroom and one toilet with terrace. Figure 4-4 presents a photo of the front of the chosen house.

Figure 4-4 modern residential building M1

Building materials: modern residential building M1 is constructed with similar modern materials like brick, cement, steel, aluminum and glass.

Wall: the wall is specially constructed with modern materials like brick, cement and steel. The thickness of outer wall is 9 inch with cement plaster and inner wall thickness is 4 inch.

Roof: the flat roof can be seen in the residential building. The concrete is used in the roof material.

Insulating materials: no any insulating materials in the building.

Window/door: the single glazed glass were used in modern residential building. Glass. Aluminum, wood are used as materials. Good cross ventilation can be seen in this building.

Flooring: the tile flooring can be seen in this house.

Data Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in living room at ground floor of the building. In a house, the living room can be used to gauge the interior temperature throughout the entire structure. In another study, for outdoor temperature external wall of the residential building is taken. To calculate Minimum air temperature of winter season, four different types of residential building were selected and room thermometer HTC-1 was used for continuous 7 days of winter i.e. (13th February- 19th February) at two time a day to calculate the minimum temperature. To calculate maximum air temperature of summer season nine different types of residential building were selected and room thermometer HTC-2 was used for continuous 15 days i.e. (may 18th- June 1st) at center of ground floor of each buildings. The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2 pm, and at night 7pm to calculate the maximum air temperature of summer season. To prevent measurement inaccuracies brought on by radiation from the floor and surrounding surfaces, the room thermometer was situated in the middle of the rooms and at a height of 1.4 meters. The measurements taken in the living of residential buildings were considered. The temperature and humidity were monitored using an HTC-2 room thermometer. The maximum and minimum mean temperature of modern residential building M1 is given below in Graph of annex E.

House 2: modern residential building M2

The residential building is built in 2010. The family consists of 6 member. The covered area of the house is approximately 1200 sq. ft. Of ground floor, which is oriented toward south direction. The ground floor consist of a kitchen, 2 bedroom and one living room. And first floor consist of two bedroom and one toilet with terrace. Figure 4-5 presents a photo of the front of the chosen house.

Figure 4-5 modern residential building M2

Building materials: modern residential building M1 is constructed with similar modern materials like brick, cement, steel, aluminum and glass.

Wall: the wall is specially constructed with modern materials like brick, cement and steel. The thickness of outer wall is 9 inch with cement plaster and inner wall thickness is 4 inch.

Roof: the flat roof can be seen in the residential building. The concrete is used in the roof material.

Insulating materials: no any insulating materials in the building.

Window/door: the single glazed glass were used in modern residential building. Glass. Aluminum, wood are used as materials. Good cross ventilation can be seen in this building.

Flooring: the tile flooring can be seen in this house.

Data Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in living room at ground floor of the building. In a house, the living room can be used to gauge the interior temperature throughout the entire structure. In another study, for outdoor temperature external wall of the residential building is taken. The monitoring was done in summer for continuous 15 days i.e. (may 18th- June 1st). The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2pm, and at night 7pm. To prevent measurement inaccuracies caused by radiation from the floor and adjacent surfaces, the room thermometer was situated in the middle of the rooms and at a height of 1.4 m. The measurements taken in the living of residential buildings were considered. The temperature and humidity were monitored using an HTC-2 room thermometer. The maximum and minimum mean temperature of modern residential building M2 is given below in Graph of annex D.

House 3: modern residential building M3

Figure 4-6 modern residential building M3

The residential building is built in 2009. The family consists of 7 member. The covered area of the house is approximately 1100 sq.ft. of ground floor, which is oriented toward south direction. The ground floor consist of a kitchen, 2 bedroom and one living room. And first floor consist of three bedroom and one toilet with terrace. Figure 4-6 presents a photo of the front of the chosen house.

Building materials: modern residential building M1 is constructed with similar modern materials like brick, cement, steel, aluminum and glass.

Wall: the wall is specially constructed with modern materials like brick, cement and steel. The thickness of outer wall is 9 inch with cement plaster and inner wall thickness is 4 inch.

Roof: the flat roof can be seen in the residential building. The concrete is used in the roof material.

Insulating materials: no any insulating materials in the building.

Window/door: the single glazed glass were used in modern residential building. Glass. Aluminum, wood are used as materials. Good cross ventilation can be seen in this building.

Flooring: the tile flooring can be seen in this house.

Data Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in living room at ground floor of the building. In a house, the living room can be used to gauge the interior temperature throughout the entire structure. In another study, for outdoor temperature external wall of the residential building is taken. The monitoring was done in summer for continuous 15 days i.e. (may 18^{th}- June 1^{st}). The air temperature data was taken at

3 different times a day i.e., morning 7Am, day 2pm, and at night 7pm. To prevent measurement inaccuracies brought on by radiation from the floor and surrounding surfaces, the room thermometer was maintained in the middle of the rooms at a height of 1.4. The measurements taken in the living of residential buildings were considered. The temperature and humidity were monitored using an HTC-2 room thermometer. The maximum and minimum mean temperature of modern residential building M3 is given below in Graph of annex E.

Hybrid residential building

The characteristics of the existing residential structures in PadamPokhari, Hetauda, were determined by the hybrid residential building survey. The survey asked questions about housing characteristics, primary building materials, construction style, household characteristics (such as socio-demographics and household size), and more. Questionnaires were filled and plans were drawn. It was found that hybrid residential buildings were constructed using modern mixed materials and techniques of modern and traditional ways. This type of house is generally called a hybrid residential building at case study site. The three hybrid residential buildings are selected for comparison with other types of building at site. First hybrid residential building whose owner is Rina yonjan named as H1, second hybrid residential buildings of owner Lila devi Nepal is named as H2 and last one is hybrid house is of Trilochan Nepal. Both hybrid residential buildings have different characteristics and features. First hybrid residential building is more into traditional techniques, second hybrid residential building use more modern techniques and material in buildings and last third hybrid residential building use more modern techniques and material in building.

U-value calculation of hybrid residential building H1, H2&H3

The building envelope makes the different u value of the building. Where hybrid buildings have the same envelope and same materials in residential buildings. H1 and H2 have 2 inch thick wood wall and also 9 inch hollow concrete block in wall.

Table 4-3U-value of hybrid residential building H1,H2&H3

Building envelope (thickness)	Thermal Conductivity (W/(m·K))	R-value(thickness/conductivity)	U-value
Wall			

Wooden wall	0.12	0.45	**2.2 W/m²K**
Roof			
Tile CGI	1.43 36.86	6 0.17	**0.16 W/m²K Tile** **5.88W/m²KCGI**
Window wood	0.12	0.91	**1.09 W/m²K**
Wall			
Hollow concrete block9" Plaster Firs floor Wooden wall	1.95 0.72 0.12	0.1179 0.016 0.016 Total R-Value=0.1499 0.45	**6.67 W/m²K** **2.2 W/m²K**
Roof			
CGI Sheet 28 gauge	36.86	0.17	**5.88 W/m²K**
Window single glazed	0.78	0.20	**4.8 W/m²K**

House 4: Hybrid residential building H1

The residential building is built in 1998 and seem to be in very bad condition. The family consists of 5 members. The covered area of the house is approximately 300 sq. ft. of the ground floor. The ground floor consists of a kitchen plus a bedroom without any partition. And the first-floor use as storage. The front view of the chosen house is seen in the photo in Figure 4-7.

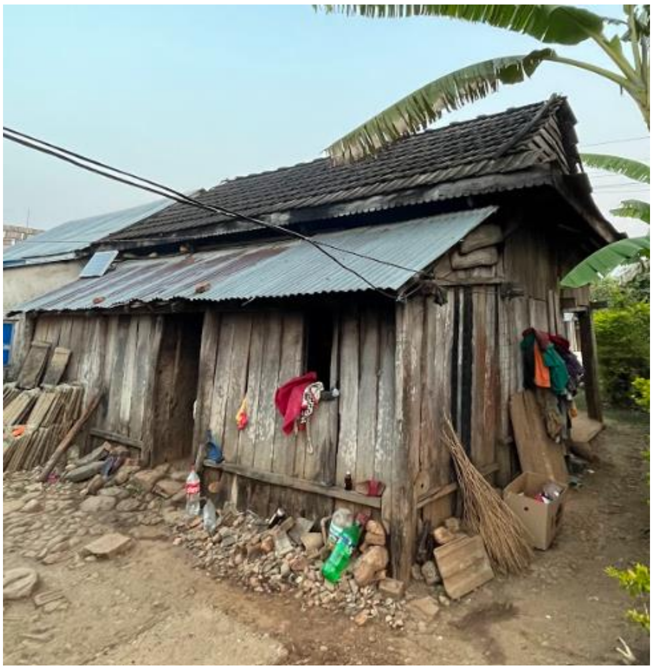


Figure 4-7 Hybrid residential building H1

Building form: The building form is a rectangle.

Building materials: Residential buildings H1 use both traditional and modern materials like hollow concrete block, wood, CGI sheet.

Roof: the sloping roof can be seen in the residential building. The CGI sheet and tile are used in the roof material.

Insulating materials: No insulating materials in the building.

Wall: The wall is of the west side is material of hollow concrete block. The thickness of hollow concrete block is about 9inch.the rest of the side of wall is done by wood materials which is 2 inch thickness. First floor wall is made of wood which thickness is 2 inch.

Window/door: The window and door are made of the wooden material.

Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in center of ground floor of the building. The center of a home's ground floor can be chosen to symbolize the interior temperature of the entire structure. In another study, for outdoor temperature external wall of the residential building is taken. To calculate Minimum air temperature of winter season, four different types of residential building were selected and room thermometer HTC-2 was used for continuous 7 days of winter i.e. (13th February- 19th

February) at two time a day to calculate the minimum temperature. To calculate maximum air temperature of summer season nine different types of residential building were selected and room thermometer HTC-2 was used for summer for continuous 15 days i.e. (may 18th- June 1st) at center of ground floor of each buildings. The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2 pm, and at night 7pm to calculate the maximum air temperature of summer season. In order to prevent measurement inaccuracies caused by radiation from the floor and surrounding surfaces, the room thermometer was maintained in the middle of the rooms at a height of 1.4 m. The maximum mean temperature of modern residential building H1 is given below in of annex E.

House 5: Hybrid residential building H2

Figure 4-8 hybrid residential building H2

The residential building is built in 1997 and seem to be in good condition. The family consists of 4 members. The covered area of the house is approximately 500 sq. ft. of the ground floor. The ground floor consists of a kitchen plus a bedroom without any partition. And the first-floor use as storage. The front view of the chosen house is seen in the photo in Figure 4-8.

Building form: The building form is a rectangle.

Building materials: Hybrid residential buildings H2 use both traditional and modern materials like hollow cement block, wood, CGI sheet.

Roof: the sloping roof can be seen in the residential building. The CGI sheet is used in the roof material.

Insulating materials: No insulating materials in the building.

Wall: The wall is specially constructed with hybrid materials like hollow cement blocks and wood. The thickness of the outer wall is 9 inch of materials hollow concrete block. First-floor wall thickness is about 2inch.

Window/door: the single glazed glass were used in modern residential building. Glass. Aluminum, wood are used as materials. Good cross ventilation can be seen in this building.

Flooring: The concrete flooring can be seen in this house.

Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in center of ground floor of the building. The center of the ground floor of a house might be chosen to symbolize the temperature inside the entire structure. In another study, for outdoor temperature external wall of the residential building is taken. To calculate Minimum air temperature of winter season, four different types of residential building were selected and room thermometer HTC-2 was used for continuous 7 days of winter i.e. (13th February- 19th February) at two time a day to calculate the minimum temperature. To calculate maximum air temperature of summer season nine different types of residential building were selected and room thermometer HTC-2 was used for for continuous 15 days i.e. (may 18th- June 1st) at center of ground floor of each buildings. The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2 pm, and at night 7pm to calculate the maximum air temperature of summer season. To prevent measurement inaccuracies brought on by radiation from the floor and surrounding surfaces, the room thermometer was maintained in the middle of the rooms at a height of 1.4 m. The temperature and humidity were monitored using an HTC-2 room thermometer. The maximum and minimum mean temperature of modern residential building H2 is given below in graph of annex E.

House 6: Hybrid residential building H3

The residential building is built in 2000 and seem to be in good condition. The family consists of 6 members. The covered area of the house is approximately 500 sq. ft. of the ground floor. The ground floor consists of a kitchen plus a bedroom without any partition. And the first-floor use as storage. The front view of the chosen house is seen in the photo in Figure 4-9.

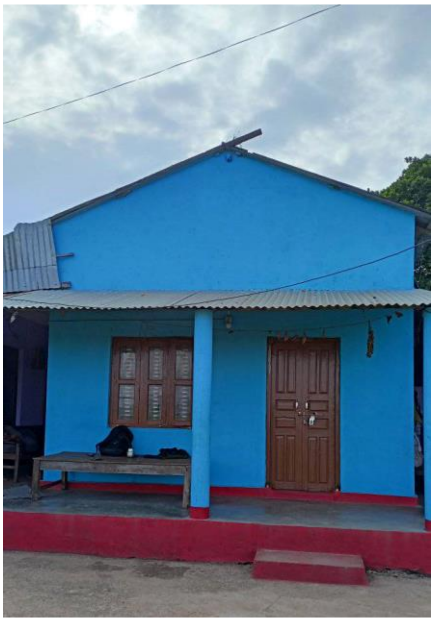


Figure 4-9 Hybrid residential building H3

Building form: The building form is a rectangle.

Building materials: Hybrid residential buildings H2 use both traditional and modern materials like hollow cement block, wood, CGI sheet.

Roof: the sloping roof can be seen in the residential building. The CGI sheet is used in the roof material.

Insulating materials: No insulating materials in the building.

Wall: The wall is specially constructed with hybrid materials like hollow cement blocks and wood. The thickness of the outer wall is 9 inch of materials hollow concrete block.

Window/door: the single glazed glass were used in hybrid residential building. Glass,wood are used as materials. Good cross ventilation can be seen in this building.

Flooring: The concrete flooring can be seen in this house.

Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in living room at ground floor of the building. A home's living room can be chosen to represent the interior temperature of the entire structure. In another study, for outdoor temperature external wall of the residential building is taken. The monitoring was done in summer for continuous 15 days i.e. (may 18^{th}- June 1^{st}). The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2pm, and at night 7pm. In order to prevent measurement inaccuracies caused by radiation from the floor and surrounding surfaces, the room thermometer was maintained in the middle of the rooms at a height of 1.4 m. The measurements taken in the living of residential buildings were considered. The temperature and humidity were monitored using an HTC-2 room thermometer. The maximum and minimum mean temperature of modern residential building H3 is given below in Graph of annex E.

Traditional residential buildings

The characteristics of past residential buildings in PadamPokhari, Hetauda, were determined through a traditional residential building survey. Household factors, such as sociodemographic and household size, as well as dwelling features, such as primary materials and construction type, were all included by the survey. . Questionnaires were filled and plans were drawn. It was found that traditional residential buildings were constructed using traditional materials and techniques. This type of house is generally called a traditional residential building at case study site. Traditional residential buildings is selected for comparison with other types of building at site. Traditional residential building whose owner is Maya Devi Neupane named as T1, another traditional building is selected of Dorje lopchan with is named as T2 and last one of Biswas goley which is named as T3.

U-value calculation of T

The building envelope makes the different u value of the building. Where traditional buildings have traditional materials in there envelopes. Traditional residential buildings have a wall of 14 inches thick with sun-dried brick on the ground floor and at first-floor use of wood with 2 inches thick in traditional residential building.

Table 4-4 U-value calculations of traditional residential buildings

Building envelope (thickness)	Thermal Conductivity (W/(m·K))	R-value(thickness/conductivity)	U-value
Wall			
Sun-dried brick 14” Mud Plaster	0.9 0.65	0.3944 0.017 0.017 Total R-Value=0.4284	**2.3 W/m²K**

First floor Wooden wall	0.12	0.45	**2.2 W/m²K**
Roof			
Tile	1.43	6.25	**0.16 Wm²K Tile**
Window wood	0.12	0.91	**1.09 W/m²K**

House 7: Traditional residential building T1

The residential building is built in 1993 and seem to be in good condition. The family consists of 5 members. The covered area of the house is approximately 300sq. ft. of the ground floor. The ground floor consists of a kitchen plus a bedroom without any partition. And the first-floor use as storage. The front view of the chosen house is seen in the photo in Figure 4-10.

Figure 4-10 Traditional residential T1

Building form: Both traditional residential building form is rectangle.

Building materials: Traditional residential building T is constructed with similar traditional materials like sun dried brick, wood and mud.

Wall: the wall is specially constructed with traditional materials like sun-dried brick, mud plaster. The thickness of the outer wall is 14 inches with mud plaster and sun-drieded brick.

Roof: The sloping roof can be seen in the residential building. The tile is used as roof material.

Insulating materials: no insulating materials in the building.

Window/door: Door and window are made of a wood materials.

Flooring: The mud flooring can be seen in this house.

Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in center of ground floor of the building. A house's ground floor center can be chosen to symbolize the interior temperature throughout the entire structure. In another study, for outdoor temperature external wall of the residential building is taken. To calculate Minimum air temperature of winter season, four different types of residential building were selected and room thermometer HTC-2 was used for continuous 7 days of winter i.e. (13th February- 19th February) at two time a day to calculate the minimum temperature. To calculate maximum air temperature of summer season nine different types of residential building were selected and room thermometer HTC-2 was used for continuous 7 days i.e. (may 16th- may 22nd) at center of ground floor of each buildings. The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2 pm, and at night 7pm to calculate the maximum air temperature of summer season. In order to prevent measurement inaccuracies caused by radiation from the floor and surrounding surfaces, the room thermometer was maintained in the middle of the rooms at a height of 1.4 m. The temperature and humidity were monitored using an HTC-2 room thermometer. The maximum and minimum mean temperature of modern residential building T1 is given below in graph of annex E.

House 8: Traditional residential building T2

The residential building is built in 1995 and seem to be in good condition. The family consists of 8 members. The covered area of the house is approximately 300sq. ft. of the ground floor. The ground floor consists of a kitchen plus a bedroom without any partition. And the first-floor use as storage. Figure 4-11 shows the selected house's floor plan and front view.

Figure 4-11 Traditional residential house T2

Building form: Both traditional residential building form is rectangle.

Building materials: Traditional residential building T is constructed with similar traditional materials like sun dried brick, wood and mud.

Wall: the wall is specially constructed with traditional materials like sun-dried brick, mud plaster. The thickness of the outer wall is 14 inches with mud plaster and sun-drieded brick.

Roof: The sloping roof can be seen in the residential building. The tile is used as roof material.

Insulating materials: no insulating materials in the building.

Window/door: Door and window are made of a wood materials.

Flooring: The mud flooring can be seen in this house.

Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in center of ground floor of the building. A house's ground floor center can be chosen to symbolize the interior temperature throughout the entire structure. Another study uses the residential building's exterior wall to measure outdoor temperature. The monitoring was done in winters for 1 weeks in summer season. The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2pm, and at night 7pm. To prevent measurement inaccuracies caused by radiation from the floor and adjacent surfaces, the room thermometer was placed in the middle of the rooms at a height of 1.4 meters. The temperature and humidity were monitored using an HTC-2 room thermometer. The maximum and minimum mean temperature of modern residential building T2 is given below in graph of annex E.

House 9: Traditional residential building T3

The residential building is built in 1995 and seem to be in good condition. The family consists of 5 members. The covered area of the house is approximately 300sq. ft. of the ground floor. The ground floor consists of a kitchen plus a bedroom without any partition. And the first-floor use as storage. Figure 4-12 shows the selected house's floor plan and front view.

Figure 4-12 Traditional residential house T3

Building form: Both traditional residential building form is rectangle.

Building materials: Traditional residential building T is constructed with similar traditional materials like sun dried brick, wood and mud.

Wall: the wall is specially constructed with traditional materials like sun-dried brick, mud plaster. The thickness of the outer wall is 14 inches with mud plaster and sun-drieded brick.

Roof: The sloping roof can be seen in the residential building. The tile is used as roof material.

Insulating materials: no insulating materials in the building.

Window/door: Door and window are made of a wood materials.

Flooring: The mud flooring can be seen in this house.

Measurement:

For the study air temperature and relative humidity were monitored by room thermometer in center of ground floor of the building. The center of a home's ground floor can be chosen to symbolize the interior temperature of the entire structure. In another study, for outdoor temperature external wall of the residential building is taken. The monitoring was done in winters for 1 weeks in season. The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2pm, and at night 7pm. To prevent measurement inaccuracies brought on by radiation from the floor and surrounding surfaces, the room thermometer was maintained in the middle of the rooms at a height of 1.4 m. The temperature and humidity were monitored using an HTC-2 room thermometer. The maximum and minimum mean temperature of modern residential building T3is given below in graph annex E.

Chapter 5: **DATA ANALYSIS, DISCUSSION & FINDINGS**

5.1 Summer data collection

5.1.1 Data presentation

The table from annex E shows the mean maximum air temperature of nine different types of building at 9 different locations of each house. Nine different locations at the center wall of ground floor of each house was chosen for measurement of indoor air temperature from which mean maximum indoor temperature was calculated. The air temperature data was taken three different times i.e., morning, day & night. In the similar manner the mean maximum outdoor temperature of five different house was calculated. As seen in the table above difference in temperature in indoor and outdoor air temperature i.e., is seen maximum in 2.2 in summer condition. If we compare air temperature of traditional residential buildings with other investigated modern residential building, the difference of 2.6 was seen. This is the considerable difference which shows that the investigated modern building are 2.6 warmer during summer. Also, if we compare air temperature of traditional residential buildings with other investigated hybrid residential building residential building, the difference of 2.5 was seen. This is the considerable difference which shows that the investigated hybrid building are 2.5 warmer during summer.

5.1.2 Data analysis

Annex E shows the graphs plot of indoor and outdoor temperature of modern residential building. The graphs shows that all the nine indoor temperature in investigated modern residential building during summer was greater than outdoor temperature during morning time i.e., 7:00, whereas the maximum temperature variation was seen during day time the temperature difference of almost 2 °C was seen. In the similar manner during night time at 7 pm the temperature variation was least. The reason for the maximum air temperature variation in indoor and outdoor may be due to the 1.2-2.2 of modern material which have high U-value. Due to this temperature variation the investigated modern building was found uncomfortable to love in.

5.1.3 Comparison of indoor and outdoor air temperature in summer

Nine analyzed residences' summertime internal and outdoor air temperatures were plotted in a graph and compared, with the results appearing in the figures Annex E.

Annex E graphs show the average air temperature inside and outside of nine houses at various times during the morning, day, and night in the summer. During morning and day time the indoor air of modern residential building varies considerably with outdoor temperature i.e. T is negative. The modern residential buildings, the indoor temperature was seen higher than outdoor temperature. Where traditional residential building considerably cooler inside by 1-2 °C than outdoor temperature. Hybrid residential seem to be warmer inside the built space as in outside. So these two modern and hybrid residential buildings are thermally less comfortable to live in as compared with traditional residential building, because the temperature inside is higher than the temperature outside. The temperature difference was also seen negative in hybrid residential building. If we compared T of traditional residential building with T other types of residential building the difference is about 2.5 °C.

5.1.4 Prediction of indoor temperature by regression analysis in summer

The prediction of indoor air temperature of nine different houses has been done by using regression analysis method. A total 540 data were plotted from each houses of 60 data set for analysis. Liner regression model is developed. The equation developed by regression analysis of nine different types of building is given below

Modern residential RCC house:

Ti=0.3861 To+17.356

Hybrid residential house:

Ti=0.5874To+12.439

Traditional residential house:

Ti=0.9368To+3.475

Where,

Ti= indoor temperature in °C

To=Outdoor temperature in °C

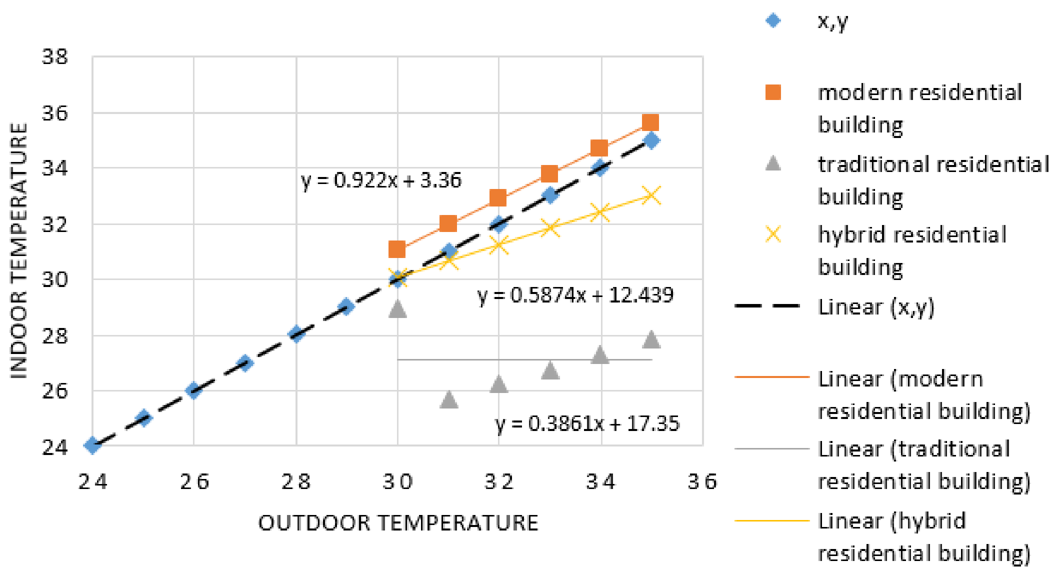


Figure 5-1Regression analysis of indoor and outdoor temperature of nine different building in summer

Table 5-1 Regression analysis table of summer

House type	No.of sam	Equation	R2	To	Ti	To-Ti
modern residential builing M	24	Ti=0.922To+3.36	0.7491	20	21.8	-1.8
				21	22.722	-1.722
				22	23.644	-1.644
				23	24.566	-1.566
				24	25.488	-1.488
				25	26.41	-1.41
				26	27.332	-1.332
				27	28.254	-1.254
				28	29.176	-1.176
				29	30.098	-1.098
				30	31.02	-1.02
Traditional residential house T	24	Ti=0.3861To+17.3	0.5737	20	25.078	-5.078
				21	20.2276	0.7724
				22	20.7722	1.2278
				23	21.3168	1.6832
				24	21.8614	2.1386
				25	22.406	2.594
				26	22.9506	3.0494
				27	23.4952	3.5048
				28	24.0398	3.9602
				29	24.5844	4.4156
				30	25.129	4.871
Hybrid residential building H	24	Ti=0.5874To+12.4	0.7636	20	24.187	-4.187
				21	24.7744	-3.7744
				22	25.3618	-3.3618
				23	25.9492	-2.9492
				24	26.5366	-2.5366
				25	27.124	-2.124
				26	27.7114	-1.7114
				27	28.2988	-1.2988
				28	28.8862	-0.8862
				29	29.4736	-0.4736
				30	30.061	-0.061

The above figure 5-3 shows regression analysis of nine investigated house in summer, which is developed in MS excel 2016. The three different equation represent relation between indoor Ti and outdoor To air temperature and R2 represents the coefficient of determination, which helps to determine the accuracy of the equation. The findings of the regression analysis shows that the maximum variation of more than 4°C cooler seen in traditional residential house

5.1.5 Summer (perception)

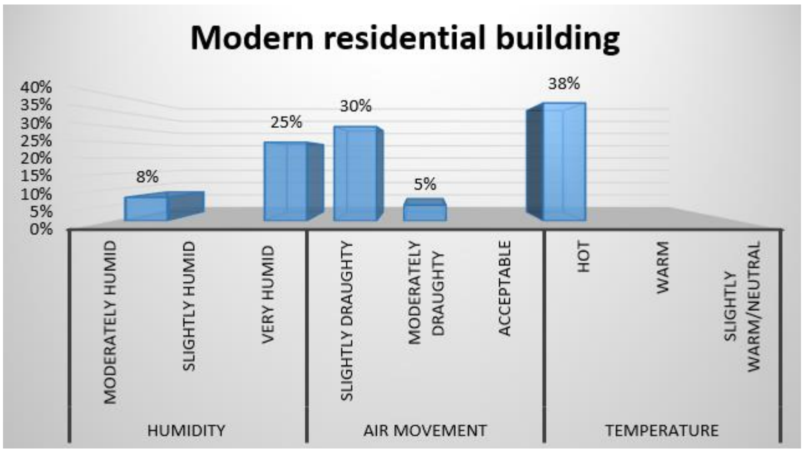


Figure 5-2 Distribution of subjective response of modern residential building in summer season

The above figure shows that distribution of subjective response on temperature in summer season of modern residential building. While 38 % of the residents of modern residential buildings voted for hot temperature inside residential building. 30 % voted for slightly draughty and 5 % voted for moderately draughty air movement inside modern residential building. 25% voted that very humid inside the built space.

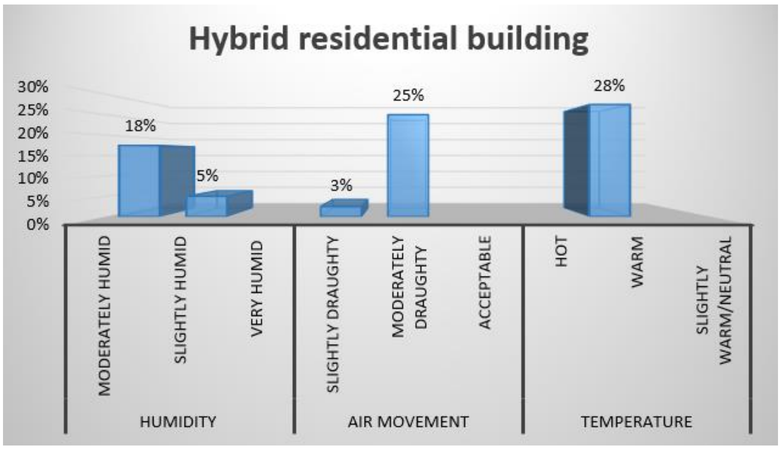


Figure 5-3 Distribution of subjective response of hybrid residential building in summer season

The above figure shows that distribution of subjective response on temperature in summer season of hybrid residential building. While 28 % of the residents of hybrid residential buildings voted for warm temperature inside residential building. 25 % voted for moderately draughty and 3 % voted for slightly draughty air movement inside hybrid residential building.18 % voted that moderately humid inside the built space 5% voted for slightly humid inside hybrid residential building.

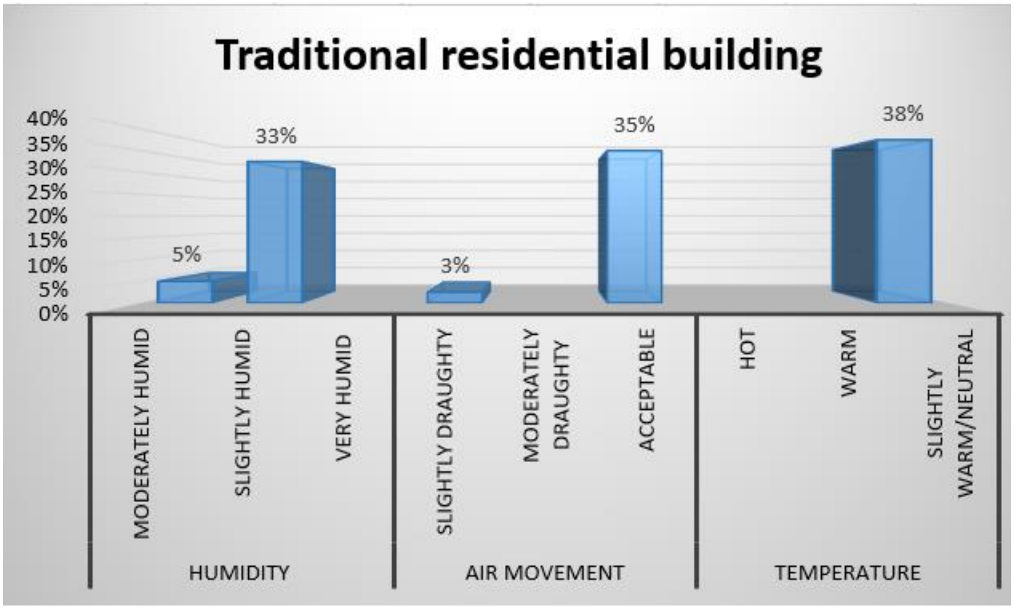


Figure 5-4 Distribution of subjective response of traditional residential building in summer season

The above figure shows that distribution of subjective response on temperature in summer season of hybrid residential building. While 38 % of the residents of traditional residential buildings voted for slightly warm/ neutral temperature inside residential building. 35 % voted for acceptable and 3 % voted for slightly draughty air movement inside traditional residential building.33% voted that slightly humid inside the built space 5% voted for moderately humid inside traditional residential building.

5.2 Winter data collection

5.2.1 Data presentation

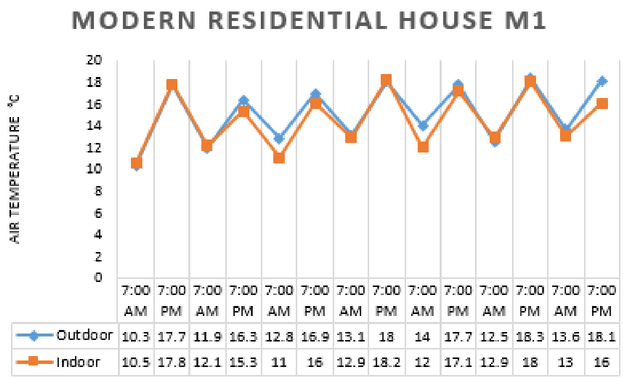
Table 5-2 Mean minimum and maximum temperature of residential building in site area of winter

	Day1		Day2		Day3		Day4		Day5		Day6		Day7	
Time	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM
Modern residential building M1														
Outdoor	10.3	17.7	11.9	16.3	12.8	16.9	13.1	18	14	17.7	12.5	18.3	13.6	18.1
Indoor	10	17	12	16	12.3	17.1	13	17.3	14.5	18	12	17.5	11	18.3
Mean max outdoor	14		14.1		14.85		15.55		15.85		15.4		15.85	
Mean max indoor	13.5		14		14.7		15.15		16.25		14.75		14.65	
ΔT	**0.5**		**0.1**		**0.15**		**0.4**		**-0.4**		**0.65**		**1.2**	
Modern residential building M2														
Outdoor	10.3	17.7	11.9	16.3	12.8	16.9	13.1	18	14	17.7	12.5	18.3	13.6	18.1
Indoor	10.5	17.8	12.1	15.3	11	16	12.9	18.2	12	17.1	12.9	18	13	16
Mean max outdoor	14		14.1		14.85		15.55		15.85		15.4		15.85	
Mean max indoor	14.15		13.7		13.5		15.55		14.55		15.45		14.5	
ΔT	**-0.15**		**0.4**		**1.35**		**0**		**1.3**		**-0.05**		**1.35**	
Hybrid residential building H1														
Outdoor	10.3	17.7	11.9	16.3	12.8	16.9	13.1	18	14	17.7	12.5	18.3	13.6	18.1
Indoor	11.1	17.8	12	17.1	12.4	17.7	12.9	18.1	14.1	17.9	12.9	19.1	13.3	19.3
Mean max outdoor	14		14.1		14.85		15.55		15.85		15.4		15.85	
Mean max indoor	14.45		14.55		15.05		15.5		16		16		16.3	
ΔT	**-0.45**		**-0.45**		**-0.2**		**0.05**		**-0.15**		**-0.6**		**-0.45**	
Hybrid residential building H2														
Outdoor	10.3	17.7	11.9	16.3	12.8	16.9	13.1	18	14	17.7	12.5	18.3	13.6	18.1
Indoor	11.2	18	10.3	17.8	12.9	17.7	12.8	18.5	14.2	18	12.5	18.5	14.4	19.1
Mean max outdoor	14		14.1		14.85		15.55		15.85		15.4		15.85	
Mean max indoor	14.6		14.05		15.3		15.65		16.1		15.5		16.75	
ΔT	**-0.6**		**0.05**		**-0.45**		**-0.1**		**-0.25**		**-0.1**		**-0.9**	
Traditional residential building T														
Outdoor	10.3	17.7	11.9	16.3	12.8	16.9	13.1	18	14	17.7	12.5	18.3	13.6	18.1
Indoor	12.5	18.3	14	17	14.3	17.5	14.9	19	15	18.9	13.9	18.9	14.5	19.7
Mean max outdoor	14		14.1		14.85		15.55		15.85		15.4		15.85	
Mean max indoor	15.4		15.5		15.9		16.95		16.95		16.4		17.1	
ΔT	**-1.4**		**-1.4**		**-1.05**		**-1.4**		**-1.1**		**-1**		**-1.25**	

Above table clearly shows the air temperature of 5 different residential building during the time of field visit in two different time i.e., 7am and 7pm in winter season. Center of ground floor was chosen for measurement of indoor air temperature from which mean maximum indoor temperature was calculated. As seen in the above table difference in temperature in indoor and outdoor air temperature i.e. ΔT is seen minimum in investigated traditional house is -1.4°C in summer season. The pilot survey result shows that if we compare air temperature of traditional residential house with other investigated residential building i.e. modern and hybrid residential building, the difference of -1.2°C can be seen in modern residential building and -1.1°C can be seen in hybrid residential buildings. This is the considerable difference which shows that the investigated traditional residential building are 1.2°C warmer then modern residential building and 1.1°C warmer hybrid residential building during winter season as per pilot survey.

5.2.2 Data analysis

Below figure shows the graphs of indoor and outdoor air temperature of five different types of residential buildings in winter. The graphs shows that all the indoor temperature during morning time i.e., 7 AM and during night time 7 PM to find the minimum temperature. In traditional residential building it seems to be air temperature seems to be higher than outdoor air temperature. This imples that the investigated traditional house is warmer at morning and night time in winter season. In contrary the investigated modern residential house was seen be to cooler at morning, day and night time. Due to material used in the modern residential building temperatures variation the modern house is more cooler in winter where traditional seem to be warmer in winter also comfortable to live in.



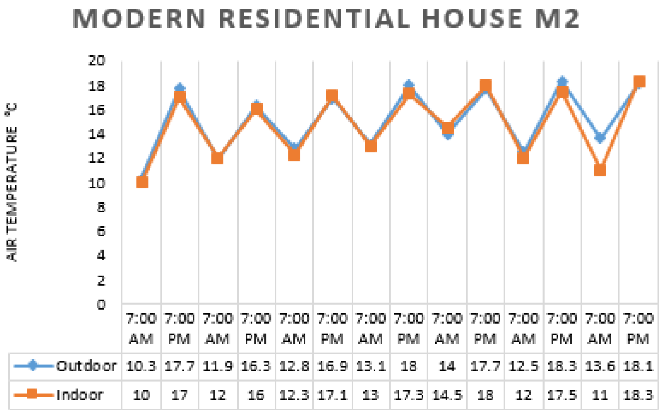
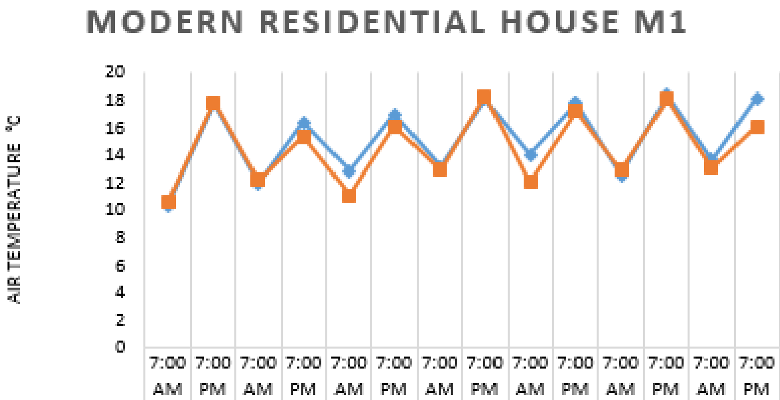


Figure 5-5 measurement of indoor and outdoor of temperature of modern residential building M1, M2

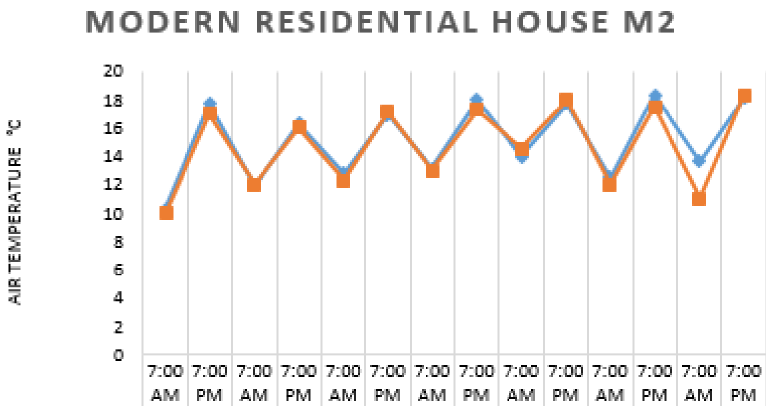
5.2.3 Comparison of indoor and outdoor air temperature in winter

The indoor and outdoor air temperature of winter of five types of different residential building was compared and was plotted in the graph which shows the results. Below figures shows mean outdoor and indoor air temperature of five investigated residential buildings during winter season. i.e,

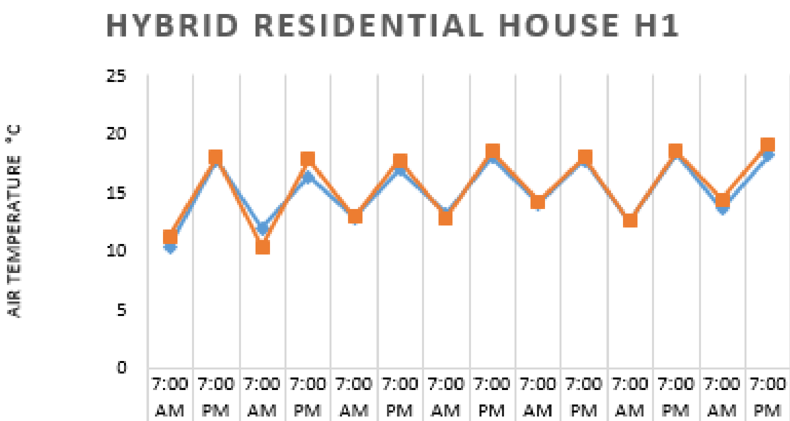
During morning 7 am and 7 pm time the ambient indoor air temperature of traditional residential building was seen higher than outdoor air temperature i.e. ΔT was seen negative. It implies that the investigated traditional residential building is considerably wamer by 1-1.2 °C in the similar manner, if we see the difference in air temperature in modern residential building the indoor temperatures were also seen lower, than outdoor temperature i.e. ΔT was seen to be negative. But the value was less than traditional and hybrid residential building. This implies that these two houses are thermally less comfortable to live in than traditional residential building during winter season. The temperature difference was also seen negative in hybrid residential building.



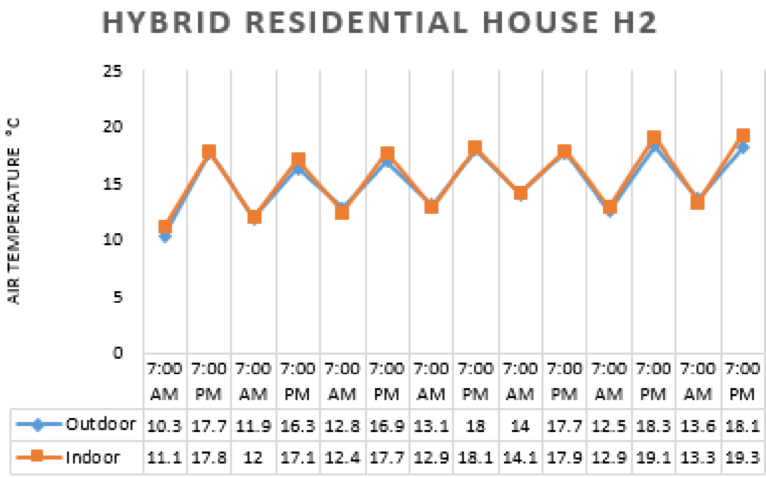
	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM
Outdoor	10.3	17.7	11.9	16.3	12.8	16.9	13.1	18	14	17.7	12.5	18.3	13.6	18.1
Indoor	10.5	17.8	12.1	15.3	11	16	12.9	18.2	12	17.1	12.9	18	13	16



	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM
Outdoor	10.3	17.7	11.9	16.3	12.8	16.9	13.1	18	14	17.7	12.5	18.3	13.6	18.1
Indoor	10	17	12	16	12.3	17.1	13	17.3	14.5	18	12	17.5	11	18.3



	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM	7:00 AM	7:00 PM
Outdoor	10.3	17.7	11.9	16.3	12.8	16.9	13.1	18	14	17.7	12.5	18.3	13.6	18.1
Indoor	11.2	18	10.3	17.8	12.9	17.7	12.8	18.5	14.2	18	12.5	18.5	14.4	19.1



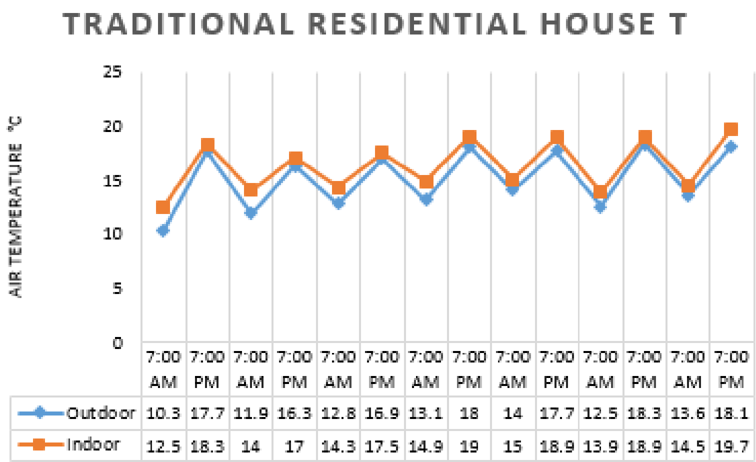


Figure 5-6 Measurement of indoor and outdoor air temperature of nine different building during winter

5.2.4 Prediction of indoor temperature by regression analysis in winter

The prediction of indoor air temperature of nine different houses has been done by using regression analysis method. A total 540 data were plotted from each houses of 60 data set for analysis. Liner regression model is developed. The equation developed by regression analysis of nine different types of building is given below

Modern residential RCC house:

$Ti=0.5446To +6.0125$

Hybrid residential house:

$Ti=0.5446To+6.0125$

Traditional residential house:

Ti=0.442 To +8.791

Where,

Ti= indoor temperature in °C

To=Outdoor temperature in °C

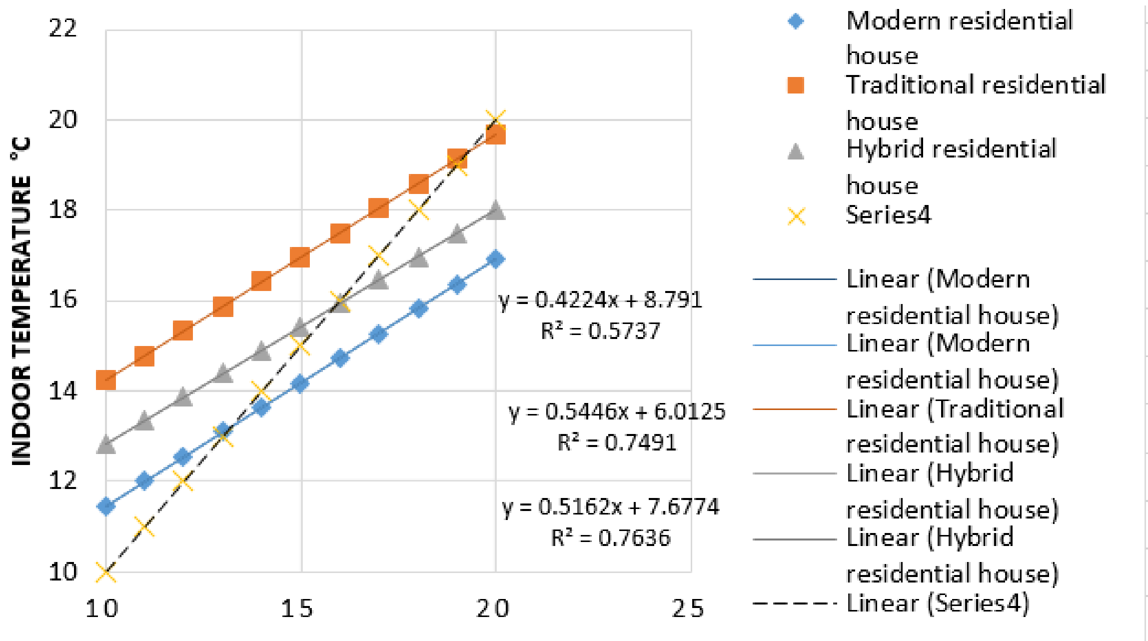


Figure 5-7 Regression analysis of indoor and outdoor air temperature of five different houses in winter seaso

House type	No.of sample	Equation	R2	To	Ti	To-Ti
modern house				10	11.4585	-1.4585
				11	12.0031	-1.0031
	24	Ti=0.5446To+6.0125	0.7491	12	12.5477	-0.5477
				13	13.0923	-0.0923
				14	13.6369	0.3631
				15	14.1815	0.8185
				16	14.7261	1.2739
				17	15.2707	1.7293
				18	15.8153	2.1847
				19	16.3599	2.6401
				20	16.9045	3.0955
Traditional residential house T				10	14.237	-4.237
				11	14.7816	-3.7816
	24	Ti=0.4224To+8.791	0.5737	12	15.3262	-3.3262
				13	15.8708	-2.8708
				14	16.4154	-2.4154
				15	16.96	-1.96
				16	17.5046	-1.5046
				17	18.0492	-1.0492
				18	18.5938	-0.5938
				19	19.1384	-0.1384
				20	19.683	0.317
Hybrid residential building				10	12.8394	-2.8394
				11	13.3556	-2.3556
	24	Ti=0.5162To+7.6774	0.7636	12	13.8718	-1.8718
				13	14.388	-1.388
				14	14.9042	-0.9042
				15	15.4204	-0.4204
				16	15.9366	0.0634
				17	16.4528	0.5472
				18	16.969	1.031

				19	17.4852	1.5148
				20	18.0014	1.9986

Above figure show the regression analysis of different types of investigated building in winter, which is developed in Microsoft excel 2016. The three different equation represent relation between indoor “Ti”and outdoor “To”air temperature and “R^2” represents the coefficient of determination, which helps to determine the accuracy of equation. The trend line of five different types of residential building can be seen plotted in the graph. By analyzing and comparing the trend lines of different types of residential building, the trend line of traditional residential house is titled below the intermediate dotes line at about 14°C outdoor temperature. In comparison to other residential buildings under investigation, it demonstrates that the typical residential building maintains a comfortable temperature in the cold as well. The linear regression model for different types of houses has been developed for different types of house.

5.2.5 Winter (perception)

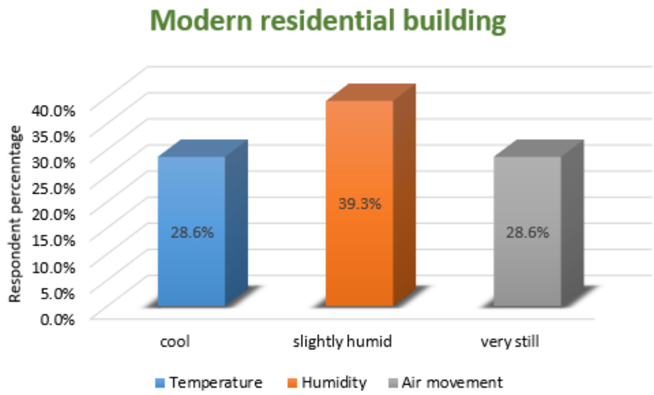


Figure 5-8 Distribution of subjective response in modern residential building in winter season

The dispersion of subjective reactions to temperature in a modern residential structure throughout the winter is depicted in the above figure. In contrast to the 28.6% of modern residential building inhabitants who chose chilly temperatures, 39.3% of building residents chose a slightly humid environment. Where 28.6% of the residents of modern buildings voted for very still air movement inside the residential building.

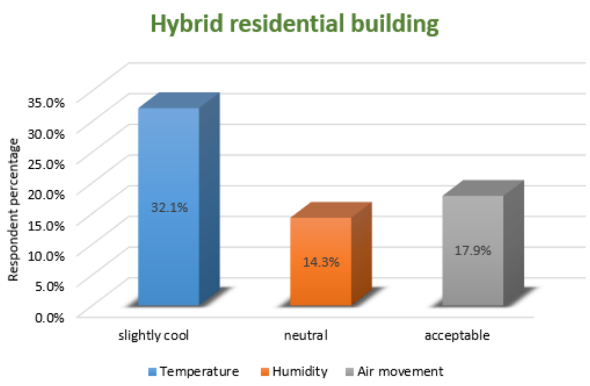


Figure 5-9 Distribution of subjective response in hybrid residential building in winter season

The distribution of subjective reactions to temperature in a hybrid residential building over the winter is depicted in the above figure. While 14.3% of inhabitants in hybrid residential buildings voted for neutral humid humidity, 32.1% of residents of modern residential buildings chose chilly temperatures. Where 17.9% of the residents of hybrid residential buildings voted for acceptable air movement inside the residential building.

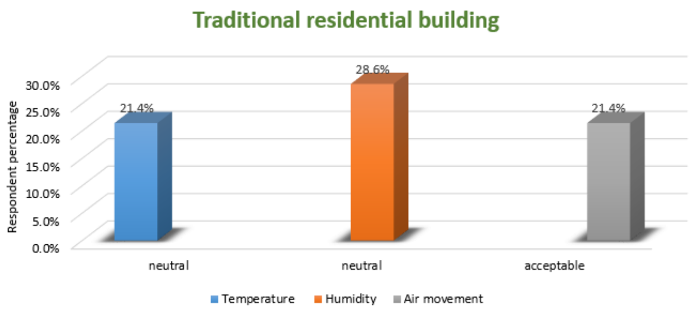


Figure 5-10 Distribution of subjective response in traditional residential building in winter season

The distribution of subjective reactions to temperature in a standard residential building during the winter is depicted in the above figure. While 28.6% of building inhabitants chose neutral humid humidity in traditional residential buildings, only 21.4% of residents of traditional residential buildings chose neutral/warm temperature. Where 21.4% of the residents of traditional residential buildings voted for acceptable air movement inside the residential building.

5.3 Data discussion

5.3.1 Comparison of U-value of different types of residential building

Table 5-3 Comparison of U-value of different types of residential building

Modern residential building	Hybrid residential building	Traditional residential building
Building envelope | **U-value** Wall | 4.3 W/m^2K Roof | 1.6 W/m^2K Window (single glazed) | 4.8 W/m^2K	**Building envelope** | **U-value** Wall wooden wall | 2.2 W/m^2K **Roof** Tile | 0.16 W/M^2k CGI | 5.88 W/M^2k Window wood | 1.09 W/m^2K	**Building envelope** | **U-value** **Wall** Ground floor sundried brick | 2.3 W/m^2K First floor wooden wall | 2.2 W/m^2K **Roof** Tile | 0.16 W/M^2k Window wood | 1.09 W/m^2K

From the above table can see the comparison between the different types of residential buildings around the case area. Modern residential U-Value seem to be highest in comparison with other types of a residential houses. Modern residential building walls and windows have the highest U-Value, it may be because of material use in the building construction. In Hybrid residential building U-value, roof with CGI sheet seem to be highest. CGI sheet is the modern materials so it does not perform good thermal inside the building in hybrid residential building. Traditional residential building U-vale is very low in comparison with other residential buildings. So traditional residential building perform a good thermal performance inside the building in comparison with other residential building.

5.3.2 Subjective analysis (perception)

Summer:

The distribution of subjective feedback on overall thermal comfort during the winter for three different types of residential buildings is depicted in the below figure 5-11 graphic. While 38% of inhabitants of contemporary buildings chose hot, 28% of residents of hybrid buildings chose warm, and 38% of residents of traditional structures chose /slightly warm neutral thermal inside the building, the results were quite different for the other types of buildings. Same as in the humidity case 33% respondent voted as traditional residential building have slightly humid humidity inside the building where 25% of the residents of modern buildings voted for very humid inside the building. In case of air movement acceptable air movement can be seen in the traditional residential building where in case of modern residential building 30 % people voted slightly draughty air movement inside the modern residential building. From all overall thermal comfort it is prove that people also feel the good thermal comfort inside the traditional residential building. This study makes it abundantly evident that energy-intensive technologies are necessary in contemporary structures in order to achieve good thermal comfort levels through ventilation. To survive in unfavorable conditions and find thermal comfort, all of the residents of modern homes rely on fans. However, Padampokhari's ancient residential structures are exceptionally good at providing passive thermal comfort during the summer. The survey's findings are in line with the numerous scientific investigations already completed by researchers.

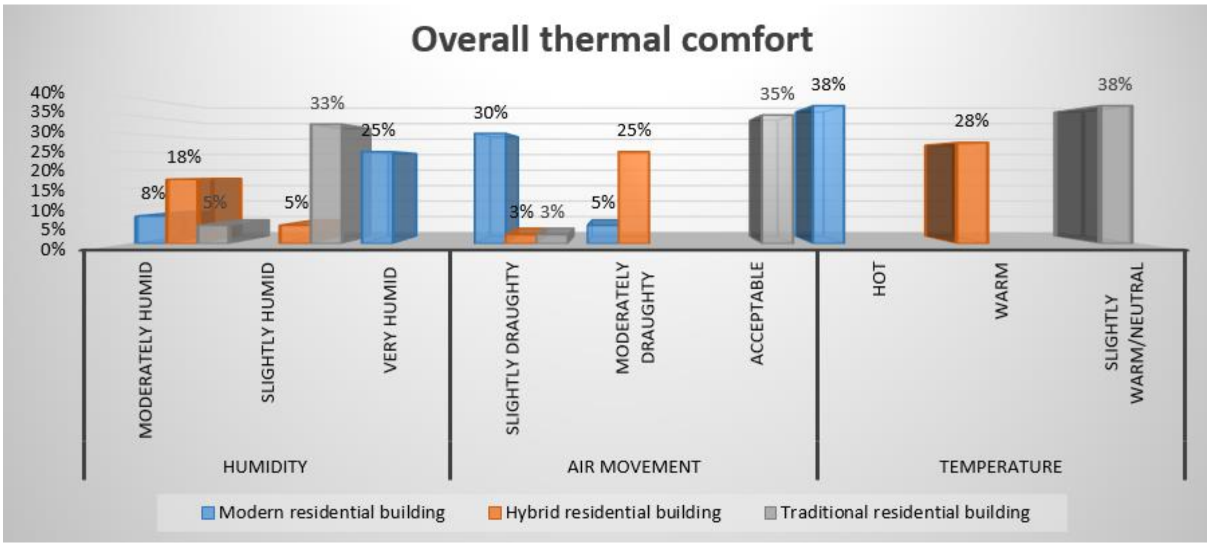


Figure 5-11Overall thermal comfort in summer season in residential building

The analysis of the obtained data was done based on the ground of the key informant survey. The opinions of the respondents were compared and analyzed to withdraw the conclusion from the key informant survey. Below is the list of questions prepared and distributed to the respondents.

1. Is there any other aspect of the indoor environment of the residential building you would like to comment on?
2. Please explain, how you overcome the uncomfortable situation if any.

According to the respondents, of the modern residential building. Respondent feels extremely hot during the summer it may be because of the materials like wall material during construction. Modern house respondent commented on the wall material. “Due to wall material like cement, brick more heat transfer from the outside easily inside the building.” Also, they said that they use the fan during the time of summer.

According to the respondents, of the hybrid residential building. Respondent feels warm during the summer it may be because of the materials like brick, and concrete hollow block. People use alternative ways if there have an uncomfortable situation like fan to cool up the building.

According to the respondents, of the traditional residential building. Respondent feels neutral during the summer it may be because of the materials like wood, sundried brick, tile. Also there is no uncomfortable situation inside the building.

Winter:

The graphic fig 5-12 displays the subjective response distribution for three different types of residential buildings' overall thermal comfort during the winter. 36% of residents of hybrid buildings chose the somewhat cooler thermal comfort option, compared to 44% of residents of modern structures thermal comfort and 32 % voted for the neutral thermal comfort of traditional residential building.

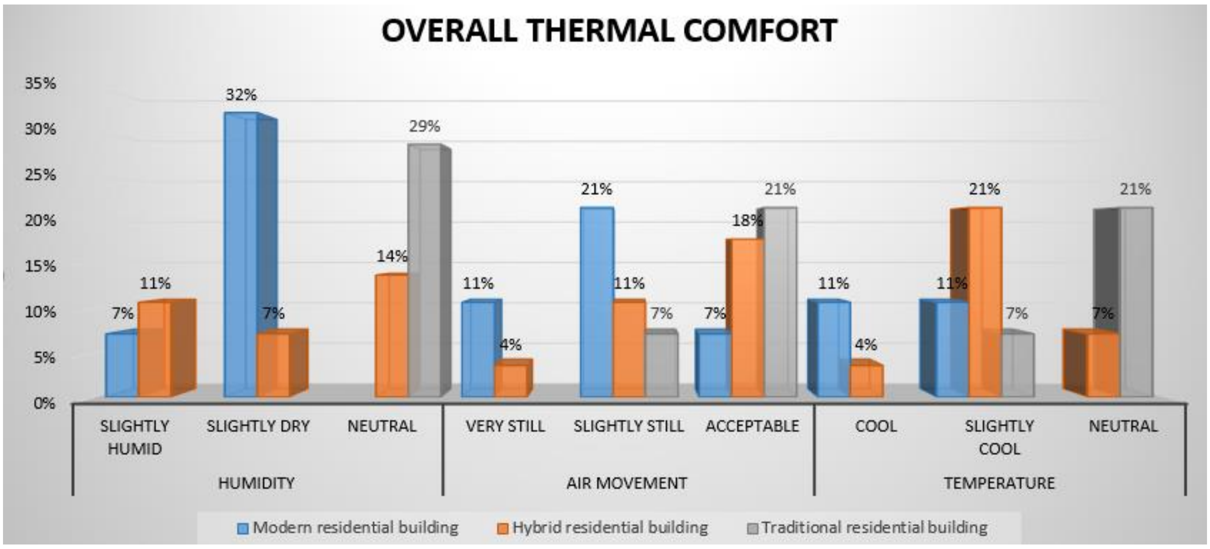


Figure 5-12 Overall subjective result of thermal comfort in winter

The above figure shows that distribution of subjective response on over all thermal comfort in winter season of 3 types of residential building in winter season.11% said it that modern residential building is cool and 11% respondent voted for slightly cool and 21% respondent people said that traditional residential; building feel neutral/warm during winter climate. Same as in the humidity case 29% respondent voted as traditional residential building have neutral humidity. In case of air movement good air movement can be seen in the traditional residential building where in case of traditional only 7 % people voted as acceptable air movement inside the modern residential building. So that is prove that people also feel the good thermal comfort inside the traditional residential building. This study makes it abundantly evident that energy-intensive technologies are necessary in contemporary structures in order to achieve good thermal comfort levels through ventilation. All of the residents of modern homes rely on heaters to stay warm and survive in difficult situations. However, Padampokhari's traditional homes are exceptionally good at providing passive thermal comfort throughout the colder months. The survey's findings are in agreement with the numerous researchers' previous scientific investigations.

The analysis of the obtained data was done based on the ground of the key informant survey. The opinions of the respondents were compared and analyzed to withdraw the conclusion from the key informant survey. Below is the list of questions prepared and distributed to the respondents.

1. Is there any other aspect of the indoor environment of the residential building you would like to comment on?
2. Please explain, how you overcome the uncomfortable situation if any.

According to the respondents, of the modern residential building. Respondent feels extremely cool during the winter it may be because of the materials like concrete.M1 house respondent commented on the tile flooring. “Due to tile flooring more cold transfer from the floor.” Also, they said that they use the heater during the time of winter.

According to the respondents, of the hybrid residential building. Respondent feels slightly cool during the winter it may be because of the materials like wood, brick, and concrete hollow block. People use alternative ways if there have an uncomfortable situation like clothes, fire at the fireplace but they don’t use any mechanical device to heat up the building.

According to the respondents, of the traditional residential building. Respondent feels neutral during the winter it may be because of the materials like wood, sundried brick, tile. Also there is no uncomfortable situation inside the building.

5.3.3 Comparison of subjective answer by respondent

The subjective perception of people in different season in winter and summer can be easily seen in table in below.

Table 5-4 summer answer

Modern residential building	Hybrid residential building	Traditional residential building
According to the owner of modern residential building, ➢ In extreme hot climate ✓ Use of fan ➢ What makes hot ✓ It may be due to the wall closeness ➢ What change indoor ✓ Wall material, large window for air movement	According to the owner of modern residential building, ➢ In extreme hot climate ✓ Use of fan ➢ What makes hot ✓ It may be due to the wall roof material like CGI sheet ➢ What change indoor ✓ Roof material, large window for air movement	According to the owner of modern residential building, ➢ In extreme hot climate ✓ Use of air from window ➢ What makes hot ✓ No hot ➢ What change indoor ✓ No any change

Table 5-5 winter answer

Modern residential building	Hybrid residential building	Traditional residential building
➢ According to the owner of modern residential building , ➢ In extreme cold climate ✓ Use of heater ➢ What makes cold ✓ Because of tile flooring ➢ What change indoor ✓ Flooring material	➢ According to the owner of hybrid residential building , ➢ In extreme cold climate ✓ Use of fireplace, fire ➢ What makes cold ✓ Because of unmaintained wood wall ➢ What change indoor ✓ No any change	➢ According to the owner of traditional residential building , ➢ In extreme cold climate ✓ Use of cloths ➢ What makes cold ✓ No cold ➢ What change indoor ✓ No any change

From above table comparison of subjective perception of people it is clear that modern residential building people feel cold in extreme cold season and feel hot in extreme hot season. According to perception of people there should be make change in construction technology, material in traditional residential building. But in modern residential building according to the people there should make change in modern residential building in wall material and in roof material.

Table 5-6 Respondent answer

Modern residential building	Hybrid residential building	Traditional residential building
Summer :	**Summer:**	**Summer:**

• Hot inside than outdoor temperature **Winter :** • Cold inside than outdoor temperature	• Warm inside than outdoor temperature **Winter :** • Cool inside than outdoor temperature	• Cool inside then outdoor temperature **Winter :** • warm inside than outdoor temperature

Subjective answer also proved that traditional residential perform the best thermal performance in winter and summer season. As the standard of living in society rises, there is an increasing amount of worry about the quality of the indoor environment. In order to provide thermal comfort indoors, the climatic factors are crucial. Creating a good, comfortable indoor environment throughout the year is the primary goal of construction. Many international research have been conducted on the topics of thermal comfort and building energy efficiency. The greatest way to create a comfortable, healthy, and energy-efficient indoor atmosphere is to install a passive system in the building. To attain thermal comfort indoors, passive tactics and techniques used in traditional buildings are crucial.

From the Nicol graphs of the Hetaera we can see that the people feel comfortable with in the 19 °C. And neutral temperature is 20.082 °C. Below 18°C people feel uncomfortable with the climate. The comfort temperature excludes all temperatures that humans may find to be cozy. It is obvious that there are many acceptable temperature changes that won't be uncomfortable. The permissible range of variance will change over time. This is due to the fact that people can adapt to change more drastically and comfortably the longer it takes them to do it. The design would incorporate both the steady-state and active thermal properties of the free-running structures. People of traditional residential building feels good very comfortable because traditional house area made of locally available materials like mud, wood, sundried bricks etc. where in modern residential building found to be uncomfortable it may be because of material which has been used in residential building. These modern residential building many not be accepted by the environment or climate.

U-Value: To put it simply, the U-Value is a value assigned to a particular area of your structure to measure how well they are limiting the transfer of heat (roofs, walls, floors etc.). A better insulation material has a lower U-Value. It implies that the home will be comfortable all year round. From the above calculation of U-value it is prove that the traditional residential building have less U-value than other types of house so that traditional residential envelope and materials are very good insulator during the winter season as well in summer season.

The materials used in the construction of Traditional residential houses like tile roof and sun dried brick wall have very low U-values due to which the heat loss is very low. It is well-known fact that the material having a high U-value has high heat loss whereas the material having low heat value has low heat loss Where in modern residential building have highest U-value which directly make the residence cool in cold temperature and make hot during the hot season.so the technique of the traditional building should be used in other types of the residential house for healthy life. Also by using less U-value generation envelope help to save the energy and which directly help in economy sector too. But in the modern residential building people feel cold during winter and hot during summer so that they have to use some external mechanism for making the building comfortable which directly effect in economy. Concept of Matoghar should be implement in upcoming residential buildings.

Table 5-7 U-value table

Modern residential building	**Hybrid residential building H1**	**Hybrid residential building H2**	**Traditional residential building**	**Remark**
Building envelope: U-value Wall: 4.3 W/m^2K Roof: 1.6 W/m^2K Window (single glazed): 4.8 W/m^2K	Building envelope: U-value Wall wooden wall: 2.2 W/m^2K **Roof** Tile: 0.16 W/M^2k CGI: 5.88 Window wood: 1.09 W/m^2K	Building envelope: U-value **Wall** Ground floor Hollow concrete block: 4.3 W/m^2k First floor wooden wall: 2.2 W/m^2 Roof CGI: 5.88 W/m^2K Window (single glazed): 4.8 W/m^2K	Building envelope: U-value **Wall** Ground floor sundried brick: 2.3 W/m^2K First floor wooden wall: 2.2 W/m^2K **Roof** Tile: 0.16 W/M^2k Window wood: 1.09 W/m^2K	➢ Wall with **sundried and wood perform better** for good thermal comfort ➢ **Burnt brick** may be **replaced** by other **alternative materials** ➢ Roof with CGI is have highest U-value it should be replace either by **RCC or by tile roof** ➢ Better to use **wooden window**

Building material: From the above figure of materials used in all different types of building. Modern residential buildings use the same materials in any place of the world whether it is suitable or not for the place. Both modern residential use all most all the similar materials like cement, steel, glass. Where in case of hybrid residential building two hybrid residential building are selected where both the different have material where in H1 we can found that residential building blend more in to traditional materials and some modern materials can be seen in the this house. Where in another hybrid building seems be modern with traditional materials. In hybrid building seem to be both warm and cool during winter. It is not constantly warm all the day. Material used in residential building directly affect in the economy and U-value. The material used in traditional building are locally available materials and which can be accepted by the environment. But material used in modern building is got from the far from the society which cost costly during time of construction and which can't be accepted by the environment and climate. So that modern building become hot during time of hot and cold during time of cold weather. The research that has been carried out in winter shows that the investigated traditional residential house has better thermal performance. It may be due to the use of locally available materials and construction technology.

Table 5-8 Building material

Modern residential building	Hybrid residential building	Traditional residential building
▪ Cement ▪ Brick ▪ glass	▪ Concrete hollow block ▪ CGI sheet ▪ wood ▪ & mud tile	▪ Sundried brick ▪ Wood ▪ Mud Tile ▪ and mud
❑ High cost ❑ Affect the both indoor &outdoor environment ❑ No sustainable	❑ Mixed of modern and locally available materials ❑ Less expensive than modern residential building ❑ Very less sustainable	❑ Locally available materials ❑ Low cost ❑ Adapted by society ❑ No bad depletion  Source :ink.springer.com/article/10.1007/s11625-018-0627-5

Comparison of Air temperature winter

By comparison of the air temperature which is recorder with in the 7 days.it can clearly see that modern residential building doesn't perform well thermal comfort inside the building. Like in hybrid residential building it also does not perform well in thermal comfort. However the hybrid residential building is perform good thermal indoor environment in comparison with modern residential building. But the result of traditional residential building is very good. It perform the best thermal comfort inside the building. The research shows that the thermal performance of the investigated traditional residential house is better in winter in comparison to other investigated houses of Padam pokhari, Hetauda. The temperature difference of traditional residential building seem to be 1-1.4°C was seen in winter where indoor of traditional residential building seem to be warmer. From all the aspect like in material, U-value it seems to be good in traditional residential building.

Comparison of Air temperature summer

By comparison of the air temperature which is recorder with in the 15 days.it can clearly see that modern residential building doesn't perform well thermal comfort inside the building. Like in hybrid residential building it also does not perform well in thermal comfort. However the hybrid residential building is perform good thermal indoor environment in comparison with modern residential building. But the result of traditional residential building is very good. It perform the best thermal comfort inside the building. The research shows that the thermal performance of the investigated traditional residential house is better in summer in comparison to other investigated houses of Padam pokhari, Hetauda. The temperature difference of traditional residential building seem to be 2-2.4°C was seen in summer where indoor feel cooler. From all the aspect like in material, U-value it seems to be good in traditional residential building.

5.4 Design strategies

The term design strategies is used to describe the connection between corporate strategy and design thinking. The bioclimatic charts and Mahoney tables are the best way to recommended design for the building design. The bioclimatic charts, and Mahoney tables can be used for analyzing climatic parameters for recommendation of building design. The main goal of creating a bioclimatic building chart is to establish the comfort zone and limits of various design approaches.

5.4.1 Bioclimatic chart for Hetauda

By plotting climatic data (Temperature and Humidity) of 10 years of Hetauda district in the chart, it is confirmed that most of the months are hot and air movement must be incorporated in the design. After finding the six different zones in bioclimatic chart, average monthly temperature and relative humidity data has been plotted to form a line segment. From which different passive design strategies have been tabulated for three regions. Figure 5-7, 8 shows the different strategies for each month.

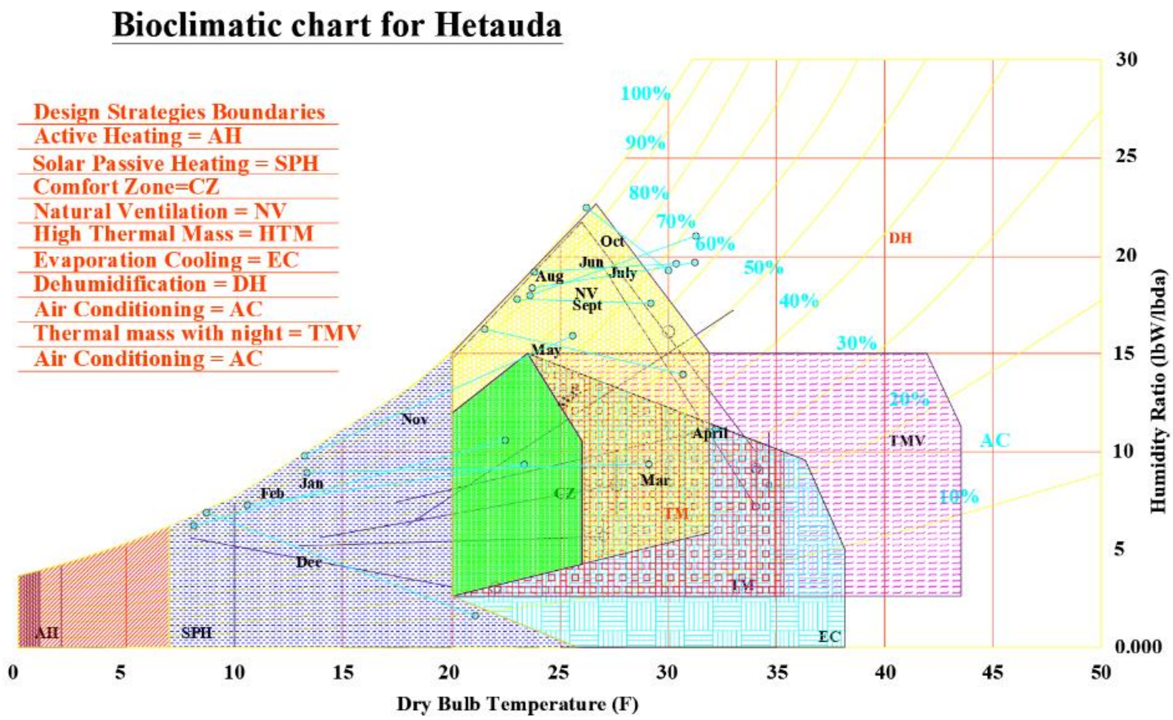


Figure 5-13 Bioclimatic chart for Hetauda

Above figures shows that the bioclimatic chart of Hetauda with maximum temperature. A long duration of day time temperature in September, November, may, march and April, require the natural ventilation zone. The months June, July and October are the hottest months with the day temperature exceeds more than 30 degree centigrade. During this period, active cooling – dehumidification is needed to maintain room temperature when the air movement cannot fulfill the cooling demand. Where January and February day time falls into a comfortable temperature of Hetauda.A short duration of morning time temperature in January, February, March, November and December falls in passive solar heating (PSH) zone. In this phase passive strategies cannot fulfill the heating demand. Active heating is needed at night time of December because the temperature goes below 10°C. May June, July, August, September and October are hot, and provision of air movement is recommended for building design strategies, these six months are the hottest months with a short duration of day time temperature goes above 31°C. During this period, passive strategies cannot fulfill the cooling demand and active cooling (AC) is needed to maintain room temperature.

Above Figure 5-13 shows that in hetauda region, most of the months lie in air movement zone (AM). So, passive cooling strategies are strongly recommended in the design to maintain the indoor thermal environment. The bioclimatic chart Figure 5-14 shows that in maximum temperature of Hetauda region, most of the months are relatively hot and provision of air ventilation movement (passive cooling strategies) is strongly recommended for the building design strategy. It is advised to build settlements with a dispersed layout, deciduous trees facing east and west, and open spaces that allow for breeze penetration yet provide shelter from chilly and brisk winds. Ideally, the structure's longitudinal axis would run east-west, limiting the amount of the building envelope that is exposed to direct sunlight in the east and west directions. For tiny sites, the orientation may, however, be determined by its facing. An opening should be placed in a building so that the air circulation can be improved naturally, or in other words, without the need of a mechanical system. Long walls that have apertures should face the windward direction. Building form is recommended to have open elongated rectangular plan with rooms having diagonal cross ventilation. The material and technology recommended are lights walls and slope or flat roof with locally available insulating material as recommended by Rijal (2012), Shahi et al. (2021) and Thapa et al. (2019). White color and smooth texture reflects sun light and heat. So bright and smooth exterior color is recommended in roof and wall to reflect solar radiation in sub-tropical region and tile or marble is recommended for the flooring.

5.4.2 Design guidelines from Mahoney table for Hetauda

The recommendations from Mahoney table provide preliminary design recommendations. Table 5-4 summarizes the design guidelines for Hetauda regions recommended by the Mahoney table. It suggests that in sub-tropical region; layout should have open space for breeze penetration, should be of east-west elongated plan having single blanked room for cross ventilation with medium size opening (25-40%) in north and south walls, light walls and roofs with insulation. These design guidelines be used to shape the modern residential building.

Table 5-9 Design guidelines from Mahoney table

Features	Subtropical -Hetauda
Layout / spacing	Open spacing for breeze penetration but protection from hot and cold wind
Building orientation	Orientation north and south (long axis east-west)
Air movement	Single blanked room for cross ventilation
Opening size and location	25-40 % in north and south walls at body height on windward side
Walls, floors & roofs	Light walls, slope roof or flat roof with insulation
External features	Adequate rainwater drainage

5.5 **Proposed strategies for modern residential building design for Hetauda**

Designing for thermal comfort is a continuously growing field, and new ideas are shaping every day by return to the past techniques as well as developing new ones. But to design for thermal comfort efficiently, one has to have sufficient knowledge and familiarity with the native climate condition to correctly assess the sun movement, wind direction, and effects of rain and snow. (Lamsal & Bajracharya, Passive Solar Building Design Strategies in Lalitpur, Pokhara and Dharan cities of Nepal, 2016) Has developed the passive strategies in three different cities of Nepal. Where Dharan lies with same altitude, climatic condition as compared with Hetauda city. So same passive design strategies can be used in modern residential building recommended through Mahoney table and bioclimatic chart in Hetauda.

From analyzing climate parameters through Mahoney table and bioclimatic chart, following design strategies has been proposed for upcoming future constructed residential building in Hetauda. The design model for proposed modern residential building strategies has follow the following points.

Table 5-10 Design model toolkit for Padampokhari,Hetauda

Features	Hetauda
Site planning	Water bodies at S-W corner, deciduous trees at East &West
Building orientation	E-W direction
Opening size and location	40-80% of floor area, maximum at north with cross ventilation
Lintel height	8’ with ventilation
Building form	E-W elongated
Material &technology	CHB or soil cement stabilized block or Brick wall with 8” cavity or slope roof or flat roof with insulation
Shading device projection	2’6”-3’ : vertical shading at east and west direction, horizontal shading at south and north
Building envelope, texture and color	Light, wall, texture, smooth finishing
Flooring	Marble, tile
Floor height	10’
Terrace garden	most

Chapter 6: CONCLUSION/RECOMMEMDATION

6.1 Conclusion

Thermal observation of our environment is another term for thermal comfort. Building thermal comfort is directly impacted by two key environmental variables, including air temperature and relative humidity. Buildings have low thermal performance because the thermal performance of the building is not taken into account during the design and construction phases. Modern residential buildings use mechanical air-conditioning systems to achieve internal thermal comfort after construction, but these systems are also environmentally damaging and energy-intensive. This was not the case before the beginning of the modern air-conditioning systems. The research was set toward the objective to assess thermal performance for thermal comfort of residential buildings of Hetauda incorporating its improvement in design strategies for thermal comfort, which was supported by other objectives. The defined objective has been fulfilled since the field research has qualitative as well as quantitatively by using room thermometer HTC-1,HTC-2 proved that the investigated traditional residential house is cooler in summer and warmer in winter, also show better thermal performance than other investigated houses. Also by Nicol graph results that comfort temperature of Hetauda which is 24-25°C in summer and 18-19°C in winter. The key findings of research are: investigated traditional residential building maintains the thermal performance of investigated traditional residential house was seen well since it was found to be 1-1.4°C warmer in winter and 1-1.2°C cooler in summer. Traditional house thermally comfortable to live in winter and summer which has been verified through calculation and regression analysis and comparison table. Hybrid residential house seems to be better thermal performance than modern residential building. And modern house seem to be cool by 1-2 °C in winter and 1-2.2°C warm in summer which create uncomforted indoor environment it may be because of during the design and construction phase the thermal performance of the building is not considered. The objective to suggest improvement design strategies has been also been fulfilled through literature study. Passive design is a good method to building design that makes use of the building architecture to reduce energy consumption and enhance thermal comfort for better thermal performance in modern residential buildings. By the best design with the local climatic condition of residential building helps to achieve thermal comfort. Main strategies of subtropical climate of Nepal area solar passive heating reduce direct solar gains in winter and passive cooling in summer though building orientation and shadings, which enhance air movement and rain protection.

The research was set another objective to compare the thermal performance of the modern residential house with other types of houses. For this objective Thermal performance of five different types of residential buildings are investigated, where 2 hybrid residential building merged traditional architecture with modern materials 2 residential building with all new modern materials and technology & 1 with all the traditional technology and materials was investigated during the transition period between winters seasons. Also nine different types of residential buildings are investigated, where 3 hybrid residential building merged traditional architecture with modern materials 3 residential building with all new modern materials and technology & 3 with all the interim between the summer seasons, conventional techniques and materials were examined. From the comparison with materials used in residential building, the use of modern materials in modern residential building and the presence modern materials, effect of modern materials and construction technology are found to cold indoor in winter and hot indoor in summer which make the environment uncomfortable. In comparison in maintenance of different types of residential building modern and hybrid seems to be well maintained where in traditional residential buildings poor maintenance can be seen , those factors which caused declining traditional architecture in everyplace. Comparison on the basis of U-value it is found that traditional residential buildings have low U-value than other types of residential building. Where modern residential building have high U-value which make the building very cold in cold weather and hot in the time of summer. These modern residential building many not be accepted by the environment or climate. In comparison in thermal performance with in all types of residential building People of traditional residential building feels good very comfortable because traditional residential building area made of locally available materials like mud, wood, sundried bricks etc. Where such material have less U-value in compare with modern materials, where in modern residential building found to be uncomfortable it may be because of material which has been used in residential building. In this way this project concludes by answering the entire objective.

6.2 Recommendation

Due to limited time it is impossible to take measure of other season temperature data, only summer, winter temperatures are measured. It will be best and accurate result will generated if possible to cover all the season like spring, autumn etc. so, it is recommended to researchers to incorporate air temperature of all four season to validate research objective more accurately. It will be best if data logger is used in field to collect temperature data of different residential building. By using data logger it will help to collect the data of each hour and it will provide the best result ,where room thermometer is doesn't provide the accurate data as well as it is more manual to be used. So for more data and for best result the further work can be carried out by using data logger incorporating other climatic factors like rainfall/humidity and more accurate.

In fields it is clear that traditional residential building seems to be with bad condition. Maintenance works, preservation things seems to be less in field in comparison with other types of residential buildings. So that the primary stakeholders, who are inhabitant of traditional residential house in Hetauda are recommended to carry regular or time to time maintenance, air tightness, green techno fitting of whole the traditional residential building and must know about importance of their vernacular architecture. If this have been done then the result of traditional residential building thermal performance would be better than this result. Now a day's modern residential building seems to be more into modern technology and without knowing about the climate of site area, which doesn't blend and belongs to that certain place. So many people live in modern residential building feels uncomfortable and also they feel hot in summer and cold in winter. So it is advised that architects and designers always gather basic climatic data from meteorological stations closer to the intended site and study such data for climatic design wherever they are.

It is recommended to the researchers that the improvement design strategies can be practically carried out in the field. Location, climate, culture, available local resources, and expertise should give appropriate considerations while designing for residential building by the designers/architects to provide the fundamental function of buildings in the subtropical region.People are adopting modern materials in their residential building; it may be they have less knowledge about the importance of locally available materials and technology. So, Small awareness programs in the subtropical regions should be organized for the architects, local peoples who build residential houses by modern techniques using local resources. Recommendation for different types of residential building is given below table:

Table 6-1 Recommendation for different types of residential building is given below table

Modern residential building	Hybrid residential building	Traditional residential building
• Insulation material • Planning and design	• Use of locally available materials	• Time to time maintenance

• Thermal mass • Evaporative cooling • Terrace garden	• Replace the material like CGI sheet instead use tile roof	• Aware owner and government sector people to protect the traditional buildings

One of the investigated modern residential building of owner chiran Nepal has been selected for applying the design strategies which has been recommended from above Mahoney table and bioclimatic chart. Which is made of modern technology and materials. Some of the recommend design has been proposed to improve the thermal performance of the building.

Figure 6-1 building selected for applying design strategies which has been recommended

The recommendation for design has been given below which has been proposed is given below:

Site planning: Existing building have concrete flooring. Green garden water resistant flooring has been proved around the site. Site designed in compact planning with deciduous trees in east and west direction has been proposed. Site plan should be proposed in such a way that help to block the sun light from west and east direction for existing investigated modern residential building.so proposed site plan have the more trees on west and east direction with deciduous trees. Lot of green plan has been proposed in all the site plan.

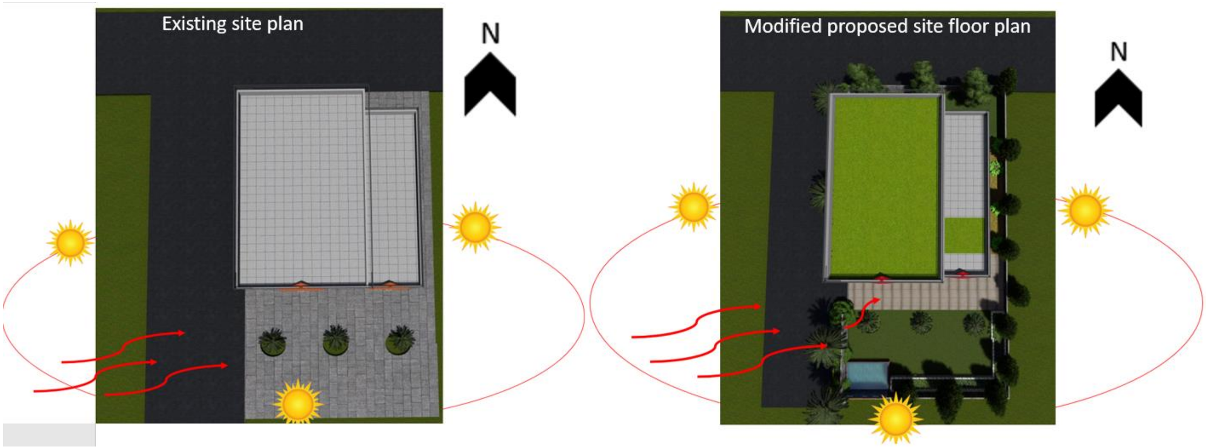


Figure 6-2 Existing/proposed site plan of investigated residential building

Building orientation: As per Mahoney table suggestion. Building should have E-W elongated plan. Orientation of building should be faraway from Sun for cooling purpose during long hot season in Hetauda. It's better to maximize building face towards north, north east and northwest for living spaces. Living spaces like bed, living, kitchen, dining, etc. located towards north direction. Main living spaces and openings locate removed from Sun light. it's better to locate buffer spaces like stair, veranda in south and south west. Maximum intensity of sun light focuses from south and south west direction during 12 noon to six evening. Therefore the bad orientation is south west for living spaces. That the main entrance is at south direction has been proposed.

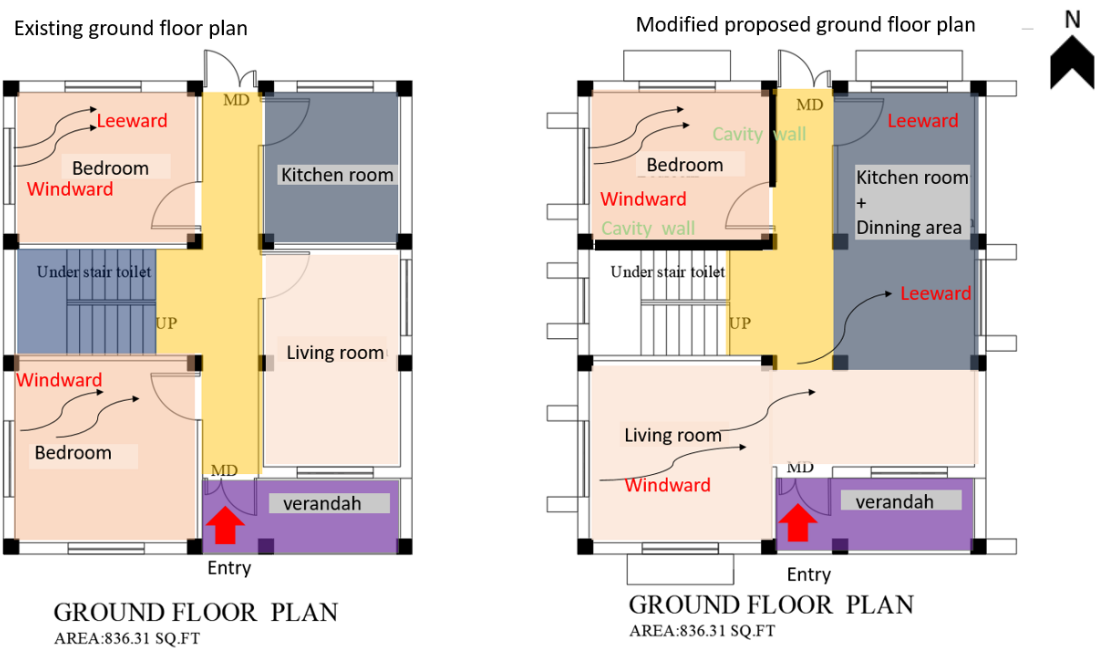


Figure 6-3 Existing/proposed ground floor plan of modern investigated residential building

Opening: There are fewer apertures in older residential structures. The location of the opening has been planned so that it would naturally promote air circulation inside the building. Opening size has been proposed 40-80 % of floor area. It is proposed to provide 8' lintel height with ventilation to ventilate hot air from the room. Stack ventilation effect is recommended in Hetauda city. Good cross ventilation has been proposed in proposed modern residential building. Water bodies is proposed or placed at the S-W direction where cool breeze can be direct enter toward the indoor space.

Figure 6-4 3pespective view of proposed modern residential building

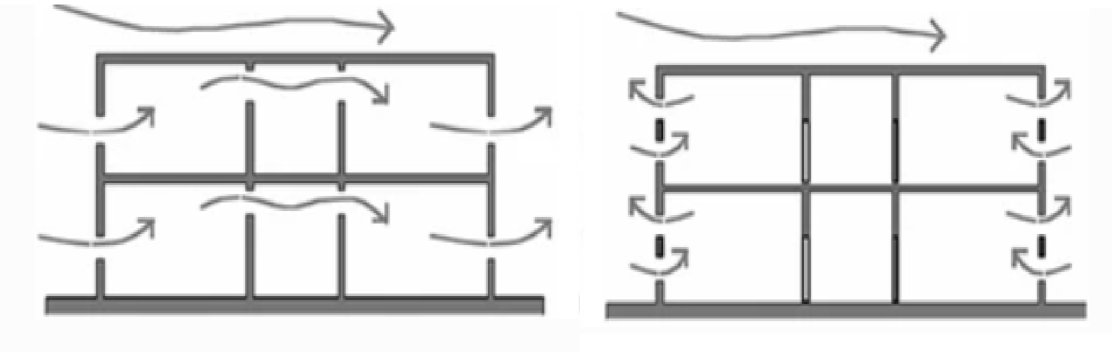


Figure 6-5 cross ventilation concept

Building form: Building form is better to have open elongated rectangular plan with rooms having diagonal cross-ventilation so such strategies has been proposed. Openings are places at long wall in buildings face towards windward direction. Floor height 10 feet has been proposed as to escape hot air.

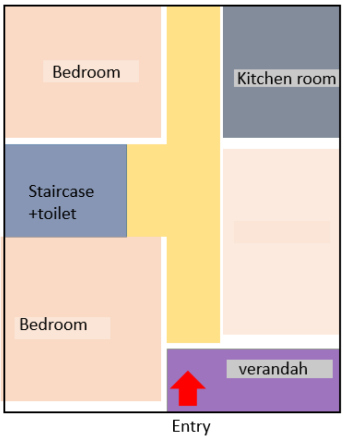


Figure 6-6 Proposed elongated plan

Material and Technology: Materials and technology of wall, roof, floor and partition has been proposed in such a way that have maximum time lag with low U value. Building materials for wall recommended for the Hetauda city is Cavity wall construction with 4" exterior and interior Brick wall with 8" air cavity which has 1.61 U-value and large time lag. Concrete hollow block or soil cement block has been proposed modern residential building.

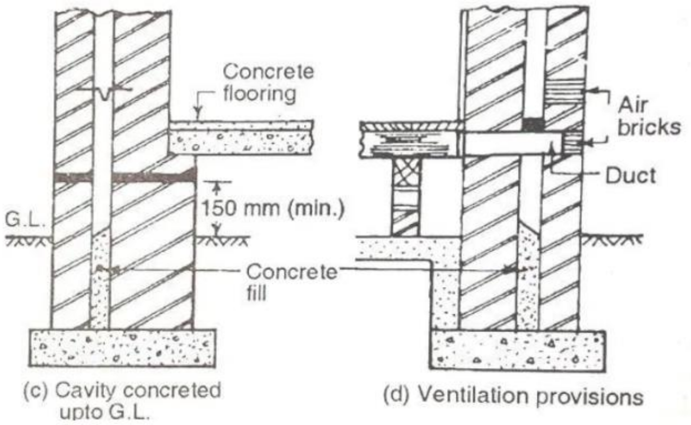


Figure 6-7 cavity wall concept

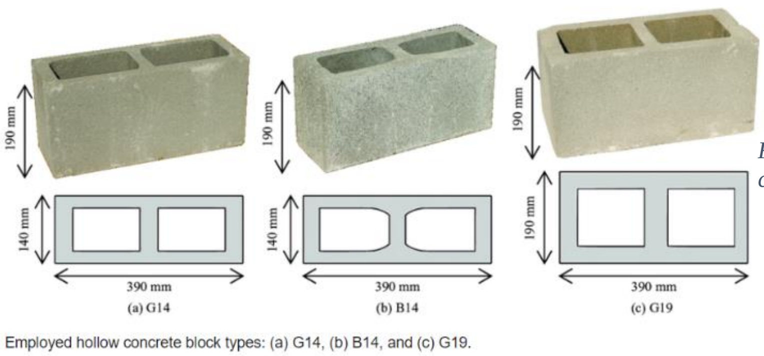


Figure 6-8 proposed wall material i.e., hollow concrete block

Source: www.google.com

Shading devices: Existing building used to have 1'9"-2' projection. Minimum projection that is 2'9" inch of projection to avoid direct sunlight has been proposed. Shading devices should exclude the direct sunlight. So vertical shading has been proposed at west and east direction and horizonatal shading has been proposed at south and north direction to avoid the direct sun light inside the built surface. So it is necessary to design shading devices in a building to protect from direct sunlight. Tress also plays vital role to provide the shade in building.

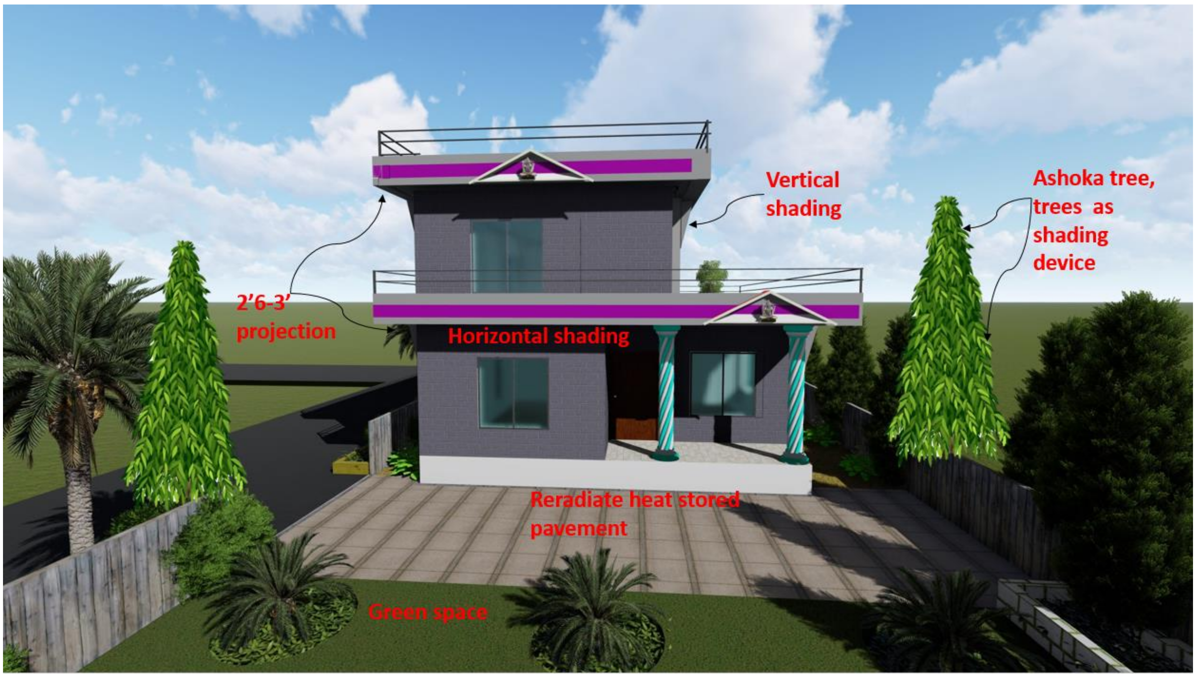


Figure 6-9 3D view of proposed modern residential building

Terrace garden: Terrace garden is proposed in modern residential building with complete water resistance materials. Green pocket are placed at different part of the building surrounding.

6-10 Proposed terrace garden

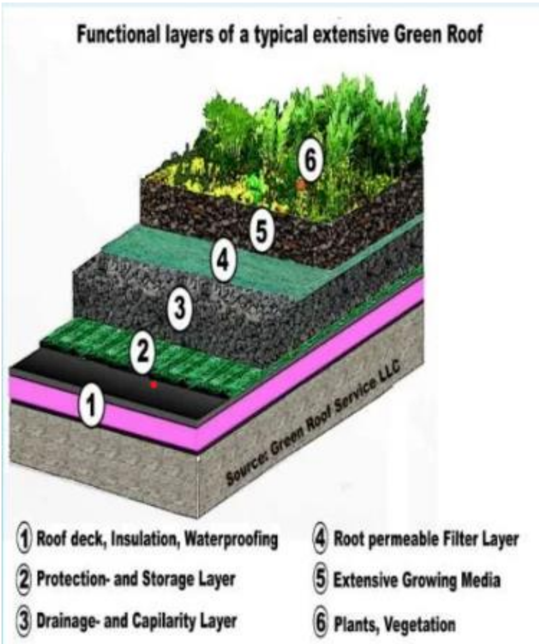


Figure 6-11 Terrace garden

Source pinterest.com

External spaces:

1. Pavements, dry ground-heat quickly
2. Night- reradiate heat stored
3. Trees, plants water-shade

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ANNEX

Annex A: Plagiarism check

Annex B: Questions ask during survey

Annex C: Answer of respondent

Annex D: Data collection during field survey

Annex E: Graphical representation of Data during field survey

Annex F: Article published in IOE graduate conference

ANNEX A: PLAGIARISM CHECK

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ANNEX B: QUESTIONNAIRE SURVEY

ANNEX B: QUESTIONNAIRE SAMPLE

A. Interview status
1. Time:
2. Temperature:

3. Respondent Status:
a) Sitting
b) Standing
c) Running
d) Walking
e) Other

4. Interview location
a) Open space
b) Semi-open space
c) Closed space

B. About yourself
1. Name ……………………………………………..
2. Gender :
   Male female Other

3. Age:
   a) 0-15
   b) 16-30
   c) 31-45
   d) 46-65
   e) 65 above …..

C. Response on thermal comfort parameters
1. How would you describe the following indoor condition of your residential house in summer season?
   a) Thermal comfort sensation (please tick one)

Cold	cool	Slightly cool	neutral	Slightly warm	warm	Hot

b) Humidity – moisture in the atmosphere

Very dry	Moderately dry	Slightly dry	neutral	Slightly humid	Moderately humid	Very humid

c) Ventilation (Air movement)

Very still	Moderately still	Slightly still	Acceptable	Slightly draughty	Moderately draughty	Very draughty

D. Detail of building

1. **Types of house**

(Tick you answer)

Mordern residential building	Hybrid residential building	Traditional building	residential	Other

2. Building form
3. Orientation building……………………………………………………………………………
4. Building materials and technology......
5. Building story :

(Tick your answer)

One	One and half	Two	Two and half	Three	More than three

6. Roof type

Slope	Flat	Mixed

7. Roof material

Concrete (Rcc)	Tile	CGI	Other

8. Window types

Single glaze	Double glazed	Wood shutter

9. Window materials …..
10. Ventilation ….(Yes/No)
11. If yes

Cross ventilation	Single

12. Types of wall….
13. Materials in wall…..

14. Insulation material in wall …(yes/No)

E. Your opinion

1. Is there any other aspect of the indoor environment of the residential building you would like to comment on?
……
2. Please explain, how you overcome the uncomfortable situation if any?
………

Date ………

Thank you for your time

ANNEX C: ANSWER OF RESPONDENT

Time	Temperature (Â°C)	Respondent status	Interview location	Name	Gender	Age	How would you describe the indoor thermal comfort of your residential house in summer season?	How would you describe the indoor humidity-moisture in the atmosphere of your residential house in summer season?	How would you describe the indoor ventilation (air movement)of your residential house in summer season?	Type of house	Building form
15:00	30	sitting	semi-open space	Nanda Kumari Nepal	female	65 and above	hot	moderately humid	moderately draughty	hybrid residential building	Rectangle
15:15	30	sitting	semi-open space	Dhurba kumari Nepal	female	46-65	hot	moderately humid	moderately draughty	hybrid residential building	Rectangle
15:30	30	sitting	semi-open space	Naha Devi Nepal	female	46-65	hot	moderately humid	moderately draughty	hybrid residential building	Rectangle
15:45	30	sitting	semi-open space	Trilochan Nepal	male	46-65	hot	moderately humid	moderately draughty	hybrid residential building	Rectangle
16:00	29	sitting	semi-open space	Rupa Nepal	female	16-30	hot	moderately humid	moderately draughty	hybrid residential building	Rectangle
16:15	29	sitting	semi-open space	Suikriti Nepal	female	0-15	hot	moderately humid	moderately draughty	hybrid residential building	Rectangle

14:00	31	standing	semi-open space	Chiran Nepal	male	31-45	hot	moderately humid	moderately draughty	modern residential building	Rectangle
14:10	31	sitting	semi-open space	Gita Kumari Poudel Nepal	female	31-45	hot	moderately humid	moderately draughty	modern residential building	Rectangle
14:30	31	sitting	semi-open space	Ujjwal Nepal	male	16-30	hot	moderately humid	moderately draughty	modern residential building	Rectangle
14:45	31	sitting	semi-open space	Utsav Nepal	male	16-30	hot	moderately humid	moderately draughty	modern residential building	Rectangle
13:15	31	sitting	semi-open space	Lila Devi Nepal	female	65 and above	hot	moderately humid	moderately draughty	modern residential building	Rectangle
1:10	31	sitting	semi-open space	Hari Prasad Nepal	male	31-45	warm	moderately humid	moderately draughty	hybrid residential building	Rectangle
13:20	31	sitting	semi-open space	Sushila Aryal	female	31-45	hot	moderately humid	moderately draughty	hybrid residential building	Rectangle
9:00	28	standing	open space	Uma Lama	female	46-65	warm	moderately humid	slightly draughty	traditional residential building	Rectangle
9:10	28	sitting	semi-open space	Bishal lama	male	31-45	warm	moderately humid	slightly draughty	traditional residential building	Rectangle
9:20	28	standing	semi-open space	Biswas lama	male	31-45	warm	moderately humid	slightly draughty	traditional residential building	Rectangle
9:30	28	sitting	semi-open space	Bishnu Lama	male	31-45	warm	moderately humid	moderately draughty	traditional residential building	Rectangle

9:45	29	sitting	semi-open space	Samar Lama	male	0-15	warm	moderately humid	slightly draughty	traditional residential building	Rectangle
10:00	29	sitting	semi-open space	Ban Kumari Yonjan	female	46-65	warm	moderately humid	very draughty	hybrid residential building	Rectangle
10:10	29	sitting	semi-open space	Reena yonjan	female	16-30	hot	moderately humid	very draughty	hybrid residential building	Rectangle
10:20	29	sitting	semi-open space	Muna Yonjan	female	16-30	hot	very humid	moderately draughty	hybrid residential building	Rectangle
10:30	29	sitting	semi-open space	Juna yonjan	female	16-30	hot	moderately humid	moderately draughty	hybrid residential building	Rectangle
9:40	29	sitting	semi-open space	Rojana Yonjan	female	31-45	warm	moderately humid	moderately draughty	hybrid residential building	Rectangle
7:00	27	sitting	open space	Suku Maya Lama	female	65 and above	slightly warm	slightly humid	acceptable	traditional residential building	Rectangle
7:10	27	standing	open space	Pema Dorje Lama	male	46-65	slightly warm	slightly humid	moderately draughty	traditional residential building	Rectangle
7:20	27	sitting	semi-open space	Suntali lama	female	31-45	slightly warm	slightly humid	acceptable	traditional residential building	rectangle
8:00	27	sitting	closed space	Sujan Lama	male	16-30	hot	very humid	very draughty	modern residential building	Rectangle
8:10	27	sitting	closed space	Saru Lama	female	31-45	hot	very humid	very draughty	modern residential building	Rectangle

8:15	27	sitting	closed space	Hissi Lama	female	16-30	hot	very humid	very draughty	modern residential building	Rectangle
8:20	27	sitting	closed space	Samir Lama	male	0-15	hot	very humid	very draughty	modern residential building	Rectangle
11:00	29	sitting	closed space	Dharmaras Shrestha	male	46-65	hot	very humid	very draughty	modern residential building	Rectangle
11:10	29	sitting	closed space	Gopina Shrestha	female	46-65	hot	very humid	very draughty	modern residential building	Rectangle
11:20	29	sitting	closed space	Krishna Shrestha	male	16-30	hot	very humid	very draughty	modern residential building	Rectangle
11:30	30	sitting	closed space	pritima Rajbhandari	female	31-45	hot	very humid	very draughty	modern residential building	Rectangle
11:45	30	sitting	closed space	Ratish Shrestha	male	16-30	hot	very humid	very draughty	modern residential building	Rectangle
12:00	30	standing	semi-open space	Maya Neupane	female	65 and above	slightly warm	slightly humid	moderately draughty	traditional residential building	Rectangle
0:10	30	standing	semi-open space	Surya Neupane	male	46-65	neutral	slightly humid	slightly draughty	traditional residential building	Rectangle
12:20	30	sitting	semi-open space	Ranjita Neupane	female	31-45	neutral	neutral	acceptable	traditional residential building	Rectangle
12:30	30	sitting	semi-open space	Nirjana Neupane	female	0-15	neutral	neutral	acceptable	traditional residential building	Rectangle

12:40	30	sitting	semi-open space	Nipana	female	0-15	neutral	slightly humid	slightly draughty	traditional residential building	Rectangle

orientation of building	Building material and technology	Building story	Roof type	Roof material	Window type	window material	ventilation (if yes)	Types of wall	Material in wall	Insulation material in the wall	Is there any other aspect of the indoor environment of the residential building you would like to comment on?	Please explain, how you overcome the uncomfortable situation if any?
East	mixed of traditional and modern material and technology	two	slope	CGI	single glaze	glass ,wood	single	hollow concrete block wall	hollow concrete block, cement, concrete	no	very hot due to roof	using fan
East	mixed material and technology	two	slope	CGI	single glaze	glass and window	single	hollow concrete block wall	Hollow concrete block, cement,concrete	no	some time we feel very hot	using fan
East	Hybrid material and	two	slope	CGI	single glaze	Glass , window	single	hollow concrete block wall	hollow concrete block,	no	Hot during summer	using fan

	technology								cement, concrete			
East	Hybrid material and technology	two	slope	CGI	single glaze	Glass , wood	single	Hollow concrete block wall	Hollow concrete block, cement, concrete	no	Hot during summer	using fan
East	Hybrid material and technology	two	slope	CGI	single glaze	Glass, wood	single	Hollow concrete block wall	Hollow concrete block, cement, concrete	no	Hot during summer	Using fan
East	Hybrid material and technology	two	slope	CGI	single glaze	Glass, wood	single	Hollow concrete block wall	Hollow concrete block, cement, concrete	no	Hot during summer	Using fan
south	modern material and technology	two	flat	concrete (RCC)	single glaze	Glass, wood, aluminum	single	Brick wall	Brick, concrete, cement	no	Hot during summer	using fan
South	modern material and technology	two	flat	concrete (RCC)	single glaze	Glass, wood, aluminum	single	Brick wall	Brick, concrete, cement	no	Hot during summer	using fan
South	modern material and technology	two	flat	concrete (RCC)	single glaze	Glass, wood, aluminum	single	Brick wall	Brick wall	no	Hot during summer	using fan

South	modern material and technology	two	flat	concrete (RCC)	single glaze	Glass, wood, aluminum	single	Brick wall	Brick, concrete, cement	no	Hot during summer	using fan
South	modern material and technology	two	flat	concrete (RCC)	single glaze	Glass, wood	single	Hollow concrete block wall, wood wall	Hollow concrete block, cement, concrete, wood	no	hot during summer	using fan
South	hybrid material and technology	two	slope	Tile and CGI	single glaze	Glass, wood	single	Hollow concrete block wall	Hollow concrete block, cement, concrete	no	Hot during summer	Using fan
South	Hybrid material and technology	two	slope	Tile and CGI	single glaze	Glass, wood	single	Hollow concrete block wall	Hollow concrete block, cement, concrete	no	Hot during summer	Using fan
South	traditional material and technology	two	slope	tile	wood shutter	wood	single	mud brick wall	mud brick, mud	no	moderate	No any uncomfortable situation
south	traditional material and technology	two	slope	tile	wood shutter	wood	single	mud brick wall	mud brick,mud,wood	no	Moderate	No any uncomfortable situation

South	traditional material and technology	two	slope	tile	wood shutter	Wood	single	mud brick wall	mud brick,mud,wood	no	Moderate	No any uncomfortable situation
South	traditional material and technology	two	slope	tile	wood shutter	wood	single	mud brick wall	mud brick,mud,wood	no	Moderate	No any uncomfortable situation
South	traditional material and technology	two	slope	tile	wood shutter	Wood	single	mud brick wall	mud brick,mud,wood	no	Moderate	No any uncomfortable situation
South	hybrid material and technology	two	slope	Tile and CGI	wood shutter	wood	single	Hollow concrete block ,wood wall	Hollow concrete block ,wood	no	hot during day time in summer	fan
south	Hybrid material and technology	two	slope	Tile and CGI	wood shutter	wood	single	Hollow concrete block ,wood wall	Hollow concrete block ,wood	no	Hot during day time in summer	using fan
South	Hybrid material and technology	two	slope	Tile and CGI	wood shutter	Wood	single	Hollow concrete block, wood wall	Hollow concrete block ,wood	no	Hot during day time in summer	fan

South	hybrid material and technology	two	slope	Tile and CGI	wood shutter	Wood	single	Hollow concrete block ,wood wall	Hollow concrete block ,wood	no	Hot during day time in summer	fan
South	Hybrid material and technology	two	slope	Tile and CGI	wood shutter	wood	single	Hollow concrete block ,wood wall	Hollow concrete block ,wood	no	Hot during day time in summer	fan
North	traditional material and technology	two	slope	tile	wood shutter	wood	cross ventilation	mud brick,mud wall	mud brick,mud	no	Moderate in summer	nothing
North	Traditional material and technology	two	slope	tile	wood shutter	wood	cross ventilation	mud brick wall	mud brick,mud,wood	no	No any uncomfortable situation	nothing
north	Traditional material and technology	two	slope	tile	wood shutter	wood	cross ventilation	mud brick wall	mud brick, mud, wood	no	Moderate	nothing
south	modern material and technology	two	flat	concrete (RCC)	single glaze	Glass, wood	single	Bick wall	brick, concrete, cement	no	very hot	using fan

South	modern material and technology	two	flat	concrete (RCC)	single glaze	glass, wood	single	brick wall	brick ,concrete, cement	no	very hot	using fan
south	modern material and technolgy	two	flat	concrete (RCC)	single glaze	glass, wood	single	brick wall	brick, cement, concrete	no	very hot inside	using fan
south	modern material and technology	two	flat	concrete (RCC)	single glaze	brick, cement, concrete	single	brick wall	brick, cement, concrete	no	very hot in indoor	fan
south	modern material and technology	two	flat	concrete (RCC)	single glaze	glass,wood	single	brick wall	brick, cement, concrete	no	very hot	fan
south	modern material and technology	two	flat	concrete (RCC)	single glaze	glass, wood	single	brick wall	brick, concrete, cement	no	very hot inside	fan
south	modern material and technology	two	flat	concrete (RCC)	single glaze	glass, wood	single	brick wall	brick, concrete, cement	no	very hot in indoor	fan
south	modern material and	two	flat	concrete (RCC)	single glaze	glass, wood	single	brick wall	brick, concrete, cement	no	very hot	fan

	technology											
South	modern material and technology	two	flat	concrete (RCC)	single glaze	glass, wood	single	brick wall	brick, cement, concrete	no	very hot	fan
east	traditional material and technology	two	slope	tile	wood shutter	wood	single	mud brick wall	mud, mudbrick, wood	no	I feel cool inside building	Nothing
East	Traditional material and technology	two	slope	tile	wood shutter	wood	single	mud brick wall	mud, mud brick, wood	no	I feel neutral inside building	nothing
East	Traditional material and technology	two	slope	tile	wood shutter	wood	single	mud brick wall	mud, brick, wood	no	neutral inside	nothing
east	traditional material and technology	two	slope	tile	wood shutter	wood	single	mud brick wall	mud, mud brick, wood	no	i feel cool inside	nothing

East	Traditional material and technology	two	slope	tile	wood shutter	wood	single	mud brick wall	mud, mud brick, wood	no	moderate	fan

ANNEX D: DATA OF FIELD WORK OF SUMMER

ANNEX D: DATA OF FIELD WORK OF SUMMER

Day 1-day 7 data of summer

MODERN RESIDENTIAL BUILDING M1																					
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
Indoor	28.9	31.4	31.7	27.4	32	30.1	27.1	33.6	31	26.9	33.3	29.6	27.2	32.1	30	24.3	32.5	27.5	25.3	29.2	24.6
MODERN RESIDENTIAL BUILING M2																					
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
indoor	28	30.5	31.9	26	31.9	30	27	33.8	30.1	27	33.8	29.3	27.1	32.9	29.3	24.3	30.5	27.3	22.9	28.7	24.1
MODERN RESIDENTIAL BUILDING M3																					
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
Indoor	29.6	30.7	31.2	28.9	35	30.5	27.8	35.8	30.5	30.5	33.1	31.1	27.3	33.1	29	25	33.1	27.1	24.1	28.9	25.3
HYBRID RESIDENTIAL BUILDING H1																					

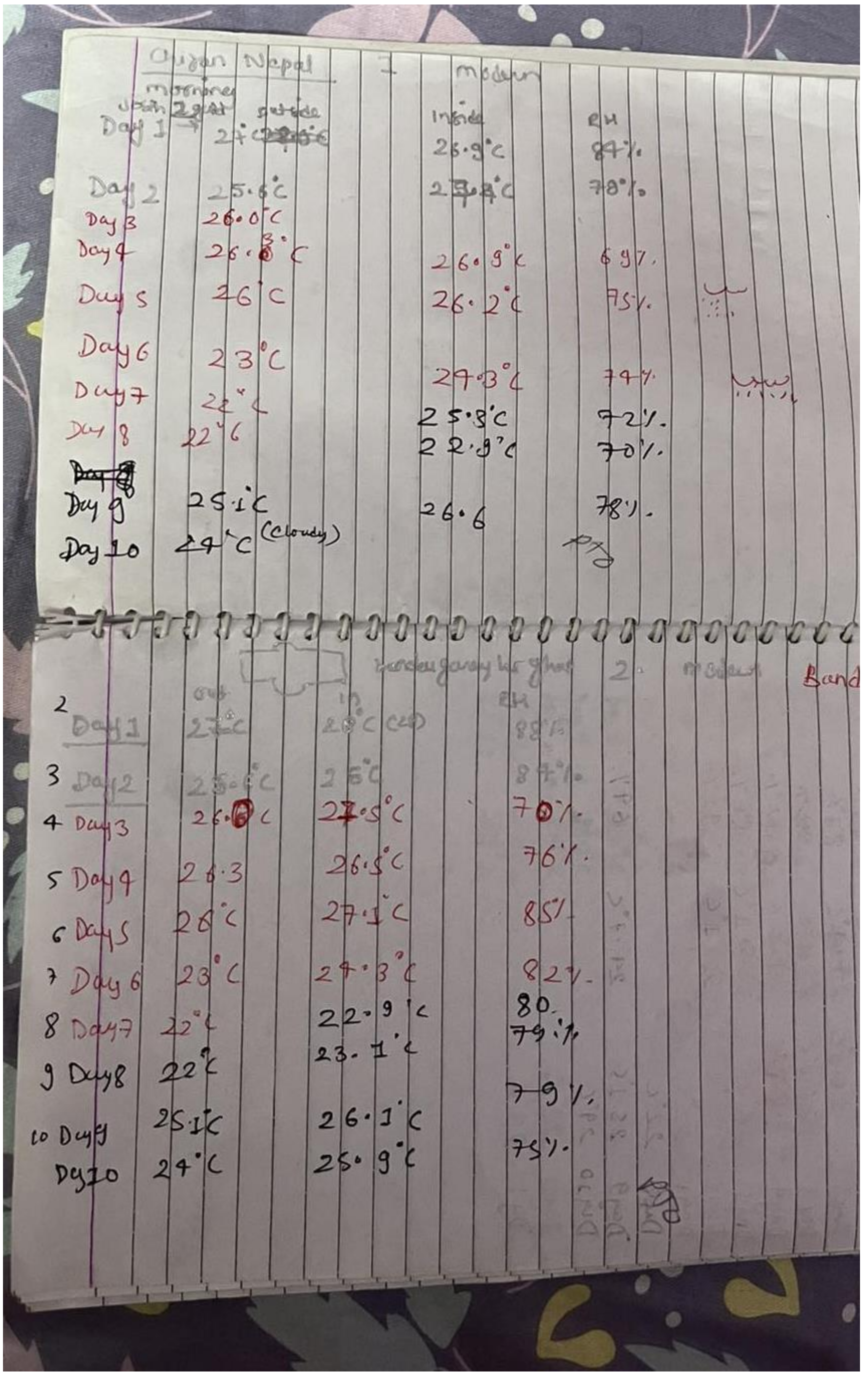
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
Indoor	27.7	31.6	31.7	25.9	31.5	30.4	26.8	33.6	29.7	28.9	32.9	29.6	26.3	32.3	28.5	24.9	30.3	26.5	22.7	29.2	24
HYBRID RESIDENTIAL BUILDING H2																					
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
Indoor	28	31.1	32	27.5	32.3	30.3	26.9	33.7	30.3	27.1	32.5	29	27.4	31.5	29	25.4	29.7	26.7	23.2	29	24
HYBRID RESIDENTIAL BUILDING H3																					
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
Indoor	27.9	32.2	30.9	26.5	32.4	30.5	27.5	34.3	30	27.2	32.9	30.3	28.3	31.2	28.9	25.1	30.7	27.6	23.6	29.2	24.1
TRADITIONAL RESIDENTIAL BUILDING T1																					
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
Indoor	26	28.7	26	23.3	29.1	27.9	24.3	31.2	28	25.3	33.6	27.5	24.9	30.1	26.1	21.6	29.2	25.1	20.9	26.9	21.9
Mean max outdoor	29.1			28.8			29.4			28.76666667			28.43333333			26.4			24.33333333		

Mean max indoor	26.9			26.8			27.8			28.8			27.0			25.3			23.2		

TRADITIONAL RESIDENTIAL BUILDING T2																					
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
Indoor	26.1	29.7	27.3	24.4	29.4	28.8	25.1	30.2	28.1	24.5	30.1	26.3	25.1	29.1	27.1	22.1	29.2	24.7	21.5	27.5	22

TRADITIONAL RESIDENTIAL BUILDING T3																					
Days	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3	23	30.2	26	22	28	23
Indoor	26.1	29.4	29	24.7	30.7	28.7	25.2	32	28.3	24.9	31.3	27.1	23.9	29	27	21.6	28.1	24.1	21.1	27	21.7

ANNEX D: DATA OF FIELD WORK OF SUMMER IN WROUGH

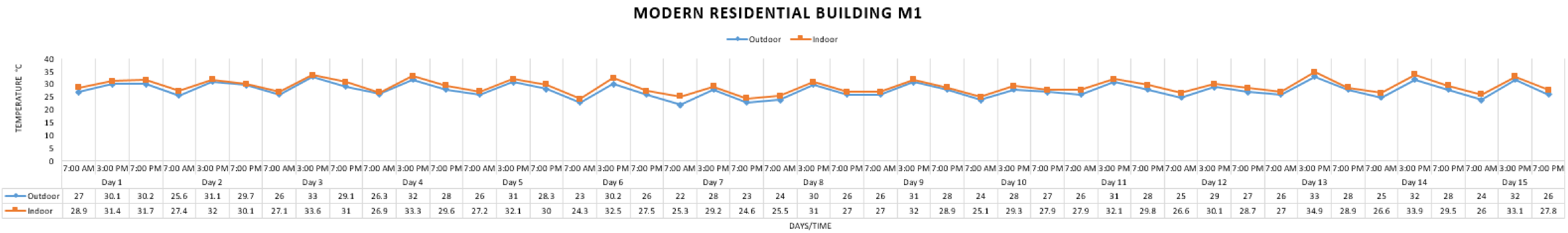


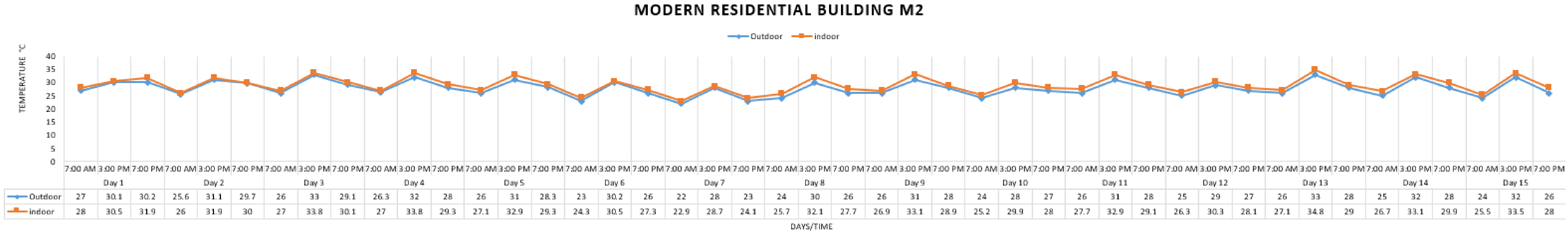
ANNEX F: GRAPHICAL /TABLE DATA REPRESENATION OF DATA OF FIELD WORK OF SUMMER

SUMMER DATA ANALYSIS

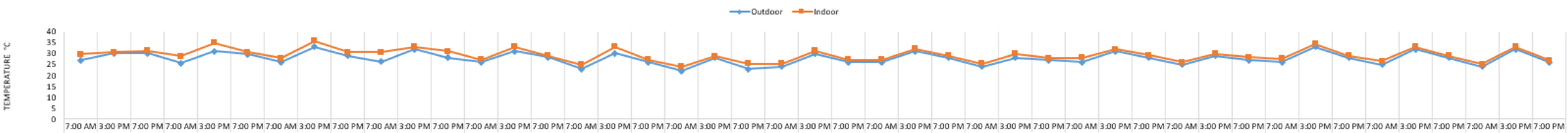
Table 0-1 mean maximum and mean minimum temperature of padampokhari ,Hetauda

S.N	MODERN RESIDENTIAL BUILDING M1			MODERN RESIDENTIAL BUILDING M2			MODERN RESIDENTIAL BUILDING M2			HYBRID RESIDENTIAL BUILDING H1			HYBRID RESIDENTIAL BUILDING H2			HYBRID RESIDENTIAL BUILDING H3			TRADITIONAL RESIDENTIAL BUILDING T1			TRADITIONAL RESIDENTIAL BUILDING T2			TRADITIONAL RESIDENTIAL BUILDING T3		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2
Indoor	28.9	31.4	31.7	28	30.5	31.9	29.6	30.7	31.2	27.7	31.6	31.7	28	31.1	32	27.9	32.2	30.9	26	28.7	26	26.1	29.7	27.3	26.1	29.4	29
Mean max outdoor	29.1			29.1			29.1			29.1			29.1			29.1			29.1			29.1			29.1		
Mean max indoor	30.7			30.1			30.5			30.3			30.4			30.3			26.9			27.7			28.2		
ΔT	-1.6			-1.0			-1.4			-1.2			-1.3			-1.2			2.2			1.4			0.9		





MODERN RESIDENTIAL BUILDING M3



DAYS/TIME	Day 1			Day 2			Day 3			Day 4			Day 5		
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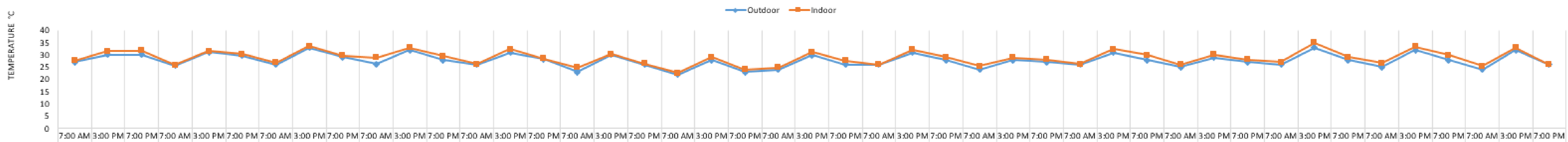
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3
Indoor	29.6	30.7	31.2	28.9	35	30.5	27.8	35.8	30.5	30.5	33.1	31.1	27.3	33.1	29

DAYS/TIME	Day 6			Day 7			Day 8			Day 9			Day 10		
	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	23	30.2	26	22	28	23	24	30	26	26	31	28	24	28	27
Indoor	25	33.1	27.1	24.1	28.9	25.3	25.5	31.3	27.1	27.1	32.2	29.1	25.3	29.9	27.9

DAYS/TIME	Day 11			Day 12			Day 13			Day 14			Day 15		
	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	26	31	28	25	29	27	26	33	28	25	32	28	24	32	26
Indoor	28	31.9	29.3	26.1	30	28.4	27.7	34.5	29.1	26.6	33	29.1	25.1	33.1	27

HYBRID RESIDENTIAL BUILDING H1



DAYS/TIME	Day 1			Day 2			Day 3			Day 4			Day 5		
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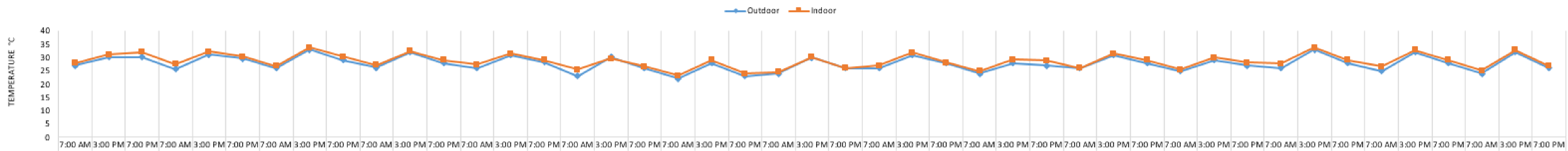
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3
Indoor	27.7	31.6	31.7	25.9	31.5	30.4	26.8	33.6	29.7	28.9	32.9	29.6	26.3	32.3	28.5

DAYS/TIME	Day 6			Day 7			Day 8			Day 9			Day 10		
	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	23	30.2	26	22	28	23	24	30	26	26	31	28	24	28	27
Indoor	24.9	30.3	26.5	22.7	29.2	24	24.9	31.1	27.7	26.1	32.1	29.1	25.5	29	28.1

DAYS/TIME	Day 11			Day 12			Day 13			Day 14			Day 15		
	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	26	31	28	25	29	27	26	33	28	25	32	28	24	32	26
Indoor	26.3	32.3	29.9	26	30.1	28.1	27.1	35	29.1	26.6	33.3	29.9	25.5	32.9	26.1

HYBRID RESIDENTIAL BUILDING H2



DAYS/TIME	Day 1			Day 2			Day 3			Day 4			Day 5		
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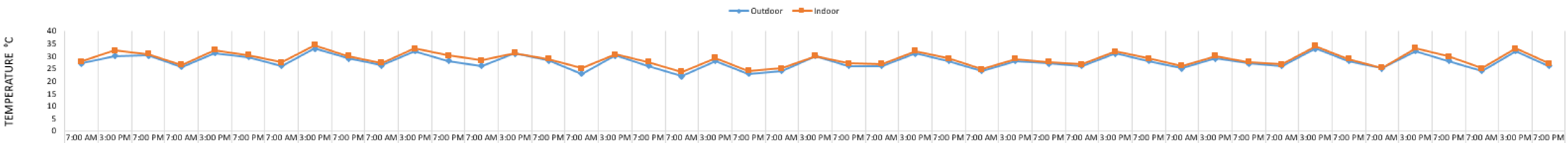
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3
Indoor	28	31.1	32	27.5	32.3	30.3	26.9	33.7	30.3	27.1	32.5	29	27.4	31.5	29

DAYS/TIME	Day 6			Day 7			Day 8			Day 9			Day 10		
	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	23	30.2	26	22	28	23	24	30	26	26	31	28	24	28	27
Indoor	25.4	29.7	26.7	23.2	29	24	24.5	30.2	26.1	27	31.9	28.1	25	29.3	28.8

DAYS/TIME	Day 11			Day 12			Day 13			Day 14			Day 15		
	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	26	31	28	25	29	27	26	33	28	25	32	28	24	32	26
Indoor	26.1	31.5	29	25.5	30	28.1	27.7	33.8	29.1	26.6	32.9	29	25.1	32.9	26.9

HYBRID RESIDENTIAL BUILDING H3



DAYS/TIME	Day 1			Day 2			Day 3			Day 4			Day 5		
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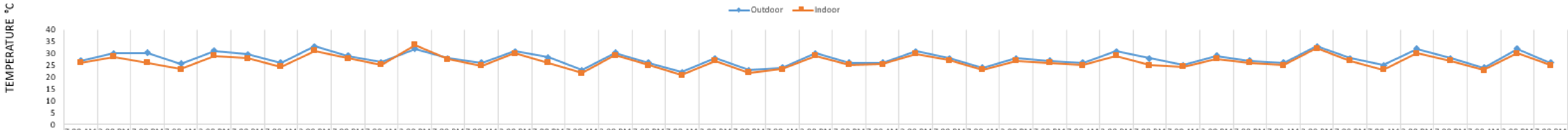
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3
Indoor	27.9	32.2	30.9	26.5	32.4	30.5	27.5	34.3	30	27.2	32.9	30.3	28.3	31.2	28.9

DAYS/TIME	Day 6			Day 7			Day 8			Day 9			Day 10		
	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	23	30.2	26	22	28	23	24	30	26	26	31	28	24	28	27
Indoor	25.1	30.7	27.6	23.6	29.2	24.1	25	30.1	27	26.9	31.9	29	24.7	28.9	27.7

DAYS/TIME	Day 11			Day 12			Day 13			Day 14			Day 15		
	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	26	31	28	25	29	27	26	33	28	25	32	28	24	32	26
Indoor	26.6	31.8	29	26.1	30	27.7	26.6	34	28.9	25.2	33.1	29.9	25.1	32.9	27

TRADITIONAL RESIDNTIAL BUILDING T1



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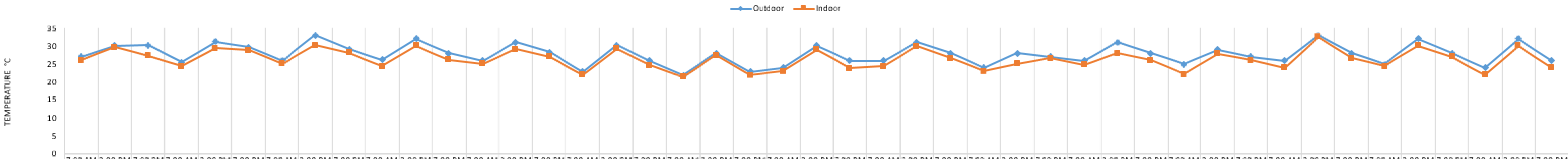
	Day 1			Day 2			Day 3			Day 4			Day 5		
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3
Indoor	26	28.7	26	23.3	29.1	27.9	24.3	31.2	28	25.3	33.6	27.5	24.9	30.1	26.1

	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
	Day 6			Day 7			Day 8			Day 9			Day 10		
Outdoor	23	30.2	26	22	28	23	24	30	26	26	31	28	24	28	27
Indoor	21.6	29.2	25.1	20.9	26.9	21.9	23.4	29.1	25.2	25.5	29.9	27.1	23.1	27	26.1

	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
	Day 11			Day 12			Day 13			Day 14			Day 15		
Outdoor	26	31	28	25	29	27	26	33	28	25	32	28	24	32	26
Indoor	25	29.1	25	24.4	27.7	26.1	25	32.1	27	23.1	30	26.9	23	30	25

DAYS/TIME

TRADITIONAL RESIDENTIAL BUILDING T2



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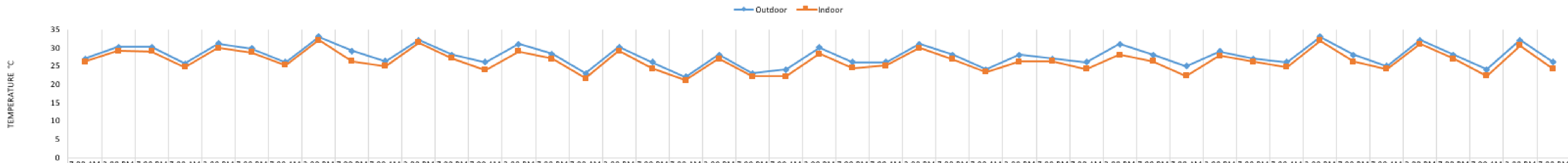
	Day 1			Day 2			Day 3			Day 4			Day 5		
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3
Indoor	26.1	29.7	27.3	24.4	29.4	28.8	25.1	30.2	28.1	24.5	30.1	26.3	25.1	29.1	27.1

	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
	Day 6			Day 7			Day 8			Day 9			Day 10		
Outdoor	23	30.2	26	22	28	23	24	30	26	26	31	28	24	28	27
Indoor	22.1	29.2	24.7	21.5	27.5	22	23.1	28.9	23.9	24.4	29.9	26.7	23.1	25.1	26.6

	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
	Day 11			Day 12			Day 13			Day 14			Day 15		
Outdoor	26	31	28	25	29	27	26	33	28	25	32	28	24	32	26
Indoor	24.9	28	26.1	22.2	27.8	26.1	24.1	32.5	26.6	24.5	30.1	27.1	22.1	30	24.1

DAYS/TIME

TRADITIONAL RESIDNTIAL BUILDING T3



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	Day 1			Day 2			Day 3			Day 4			Day 5		
Outdoor	27	30.1	30.2	25.6	31.1	29.7	26	33	29.1	26.3	32	28	26	31	28.3
Indoor	26.1	29.1	29	24.7	29.9	28.7	25.2	32	26.3	24.9	31.3	27.1	23.9	29	27

	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
	Day 6			Day 7			Day 8			Day 9			Day 10		
Outdoor	23	30.2	26	22	28	23	24	30	26	26	31	28	24	28	27
Indoor	21.6	29.1	24.3	21.1	27	22.1	22.1	28.3	24.4	25.1	29.9	26.8	23.4	26.1	26.3

	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
	Day 11			Day 12			Day 13			Day 14			Day 15		
Outdoor	26	31	28	25	29	27	26	33	28	25	32	28	24	32	26
Indoor	24.2	28	26.3	22.3	27.8	26.1	24.7	31.9	26.1	24.2	30.9	27	22.3	30.5	24.2

ANNEX F: IOE GRADUATED CONFERENCE PUBLISHED ARTICLE

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फोन- ५५२१५३१, फ्याक्स- ५५२५८३०

Date: September 20, 2022

To Whom It May Concern

This is to confirm that the paper titled "*Thermal comfort performance in a residential building of subtropical climate of Nepal –a case study of Hetauda*" submitted by **Sujata Nepal** with Conference ID **12017** has been accepted for presentation at the 12th IOE Graduate Conference being held in October 19 – 22, 2022 at Thapathali Campus, Kathmandu.

Khem Gyanwali, PhD
Convener,
12th IOE Graduate Conference

Thermal comfort performance in a residential building of subtropical climate of Nepal –a case study of Hetauda

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Abstract:

The thermal sense of the environment is referred to as thermal comfort. Thermal comfort is influenced by two main environmental variables, including air temperature and relative humidity. Up to 90% of people's time is spent inside of buildings. Buildings should therefore take into account the bioclimatic conditions of the location where they are built in order to raise the living standards of their inhabitants. Today's Modern residential buildings in the country are designed and built without considering climatic factors .The study area is carried out in Hetauda Padam pokhari Sub-metropolitan in the Makwanpur District of Bagmati Province in central Nepal.The main objective is to assess thermal performance for thermal comfort of modern residential buildings of Hetauda incorporating its improvement in design strategies for thermal comfort with comparison with modern residential building with other types of building in terms of U-value, materials, temperature etc. to incorporate design strategies for the improvement of thermal comfort performance in upcoming modern residential buildings. This research adopts the post positivism paradigm. The objective set lead towards quantitative research as well as a qualitative research method. The indoor and outdoor temperature of the different nine types of the residential house like modern, hybrid &traditional residential building of Padampokhari for 7 days summer has been collected in the field, which has been compared with each other investigated houses of case area The summer comfort temperature of padampokhari, Hetauda has been calculated using Nicol's adaptive thermal comfort model, which has been also compared with the assessed temperature of investigated residential house. The findings based on calculations and regression analysis shows that the investigated traditional residential house maintains 1-2.2°C indoor temperature in summer. Finally proposed design strategies for the newly constructed modern residential building has been suggested according bioclimatic chart and Mahoney table and recommendations at different levels has been provided for future study.

Keywords:

Thermal comfort, residential buildings, subtropical region, Air temperature, Humidity

1 Introduction

The thermal performances of a building are ruled by the factors like climatic condition, geographical location, material availability, lifestyle, and socio-cultural activities. Usually, as seen traditional houses are performing well in this context than modern houses. There were many types of research speak about building performs better thermal environment than contemporary buildings (Rijal, et al., 2010). When designing metropolitan areas and estimating how much energy is required to cool and heat buildings, thermal comfort is important. The idea of thermal comfort is "that state of consciousness that conveys happiness with the thermal environment" (Persily, 2012). According to ASHRAE (America society of heating, refrigerating and air conditioning engineers) it mainly focused in the 4 point for inner thermal comfort in a building 4 points are visual comfort, air quantity, noise level and thermal comfort which is mainly studied in this area, this is the most well studied factor, and it depends on a number of characteristics, including humidity, air conditioning temperature, outside temperature, and air speed, rather than just one.

Because most people spend up to 90% of their time indoors, the state of their indoor settings has a significant impact on how well they live (Arif, et al., 2016). Therefore, in order to raise the living standards of those who inhabit them, buildings should take into account the bioclimatic conditions of the area in which they are located (Gaitani, et al., 2007). One of the best way is Climate responsive design strategy performance good to achieve thermal comfort as it consumes less energy and proves economical in long run.

Residential Buildings are essential to society because they house the majority of the activities that individual's do, which direct consequences for both occupant health and energy consumption. Building room with good thermal comfort always improves the standard of life. According to studies done in 1987 by Altman and Stokol, when a room's temperature and humidity are high, workers' productivity in factories or offices consistently suffers. Yet consistent with in 1989, Edward realized that the value of staff pay and business development was significantly less costly than investment and maintenance costs to achieve thermal comfort. So for the great health and healthier lifetime of building as an architect always concentrate on the comfort of the client. There are several studies on the thermal performance of homes within the subtropical climate in Nepal but not in Hetauda city. The influence of modern building materials and construction technology is declining the thermal comfort performance of modern residential buildings. The use of less efficient modern materials and construction technology in comparison to traditional materials and construction technology resulted in the loss of thermal comfort performance of the modern residential building as well as declining the vernacular architecture of any place (Chaulagain, et al., 2019). So the research is needed to assess the thermal performance of all types of building in the site area to compare and analyze the effectiveness of materials that contribute to maintaining the thermal comfort performance inside the residential building.

The research has provided the current situation of construction and materials used in the modern residential building in the case area. Research also helps to know about that how people are using modern materials for construction and the drawback and goodness of materials. The research also compares the thermal comfort performance of the modern residential building with other types of residential building in case areas which help to strengthen the importance of the use of local materials which help to make building climate-responsive and more ecological in the society. The modern construction and design techniques of building homes have been widely accepted but modern architecture has not been clearly defined.

Scope of the researcher is to find out the air temperature, the humidity of the different types of a residential buildings in the case area. It also helps to know about the thermal performance of different types of a residential buildings in the case area. It helps to provide the different design strategies which can be used in upcoming modern residential buildings. The findings and results are limited to the investigated residential building which really does not generalize all the settlement residential buildings in the case area. Indoor and outdoor air temperature for summer and the rainy season is taken using a room thermometer.

2 Literature study

Thermal performance for Thermal comfort is a thermal balance for human body. According to ASHRAE the comfort or standard room temperature is 20°c ±2°c (Rijal, et al., 2010). Here in Hetauda, the Traditional style of construction has also been influenced by modernism. Traditional construction's beauty and elegance are beginning to be surpassed by RCC construction. Here at the highway axis, aluminum composite panels (ACP) are preferred. (Bajracharya, 2013)

The design, planning, and material selection in vernacular architecture are influenced by the socioeconomic, cultural, and climatic factors of various geographic areas. Different construction techniques and materials availability in the region Thermal comfort performance in modern residential building of subtropical climate- case of Hetauda affect the energy performance of vernacular architecture (National Planning Commission, 2017).

Building occupancy and operation effects on the thermal performance of the building. Building are considered to be the primary point of contact between the indoor and external environments, making them primarily accountable for the thermal conditions within. Several factors, including the building's shape, orientation, envelope, and shading devices, must be taken into account throughout the planning and construction of the structure (Yao, 2014) .

The material characteristics of a building's components are crucial in regulating the heat transmission process. We'll go through the four most crucial thermal properties: thermal conductivity, thermal resistance, thermal transmittance, and density (Gupta, 2017). In order to provide comfort and conserve energy, climatic elements might have an impact on the design and operation of a building's envelope. Understanding the general climate of neighboring regions and the microclimate is essential (Gupta, 2017). Climate variables like sun radiation, humidity, pressure, and winds have an impact on a building's thermal performance.

Architecture with good thermal comfort is most important qualities of architect. Among many parameters affecting human comfort with in the built space. Poor thermal comfort of the building effects on the efficiency of work people live inside. There is no any fixed standard or recommended ranges for thermal comfort inside the built surface. But some designing help to achieve balance with local climate.

Insulation: Efficient insulation is one of the primary requirements to achieve a comfortable inside condition. It helps to reduce the amount of heat gained during the warm season and conserves heat during the cold month. In any construction, good insulation is required, but it is especially crucial in subtropical climes (Arif, et al., 2016).

Overheat can be seen in roof of subtropical region. Using roofing materials with lighter colors that won't heat up as quickly as conventional black asphalt shingles, like terracotta shingles. Metal siding and roofing offer excellent protection against wind and moisture damage. Because they offer a layer of shade that shields walls and windows from direct sunlight, porches are popular in the south. The selection of material and structure should be done concerning the location, climate and function. Materials such as brick and stone are used in hot environments for their high thermal inertia to keep the interior cool for a longer period (Arif, et al., 2016).

Passive cooling strategy for thermal comfort in subtropical climate: The amount of active energy needed to heat and cool a place can be reduced with passive energy. The greatest way to create a comfortable and energy-efficient interior environment is through passive thermal comfort approaches. (Supic, 1982). The provision of natural ventilation through building orientation with apertures to collect prevailing winds, shading, and optimum building fabric selection all contribute to several cooling benefits. One of the best examples to explain the best thermal performance for thermal comfort passive strategies which can be used in a modern building in modern period is Mato ghar which is located at Budanilkantha, Kathmandu can use some same technology in modern building to achieve the thermal comfort inside the built surface.

3 Objective

1. To assess the thermal performance of residential buildings of Hetauda.
2. To compare the thermal performance of the modern building with other types of houses like the hybrid, traditional residential house in the case area.

4 Methodology

The research has carried using both quantitative and qualitative methodology with the pragmatic paradigm. Perception survey of the people was carried out at site for quantitative method also for comparison. The research has been carried out in padam pokhari, Hetauda with mixed settlement of traditional, modern and hybrid residential buildings. For the qualitative method, air temperature data and compared with existing situation to understand the change over time. Literatures of the place were also studied to understand different research indicators like measurement of air temperature, building orientation, thermal transmittance (U-value) of materials used and size of the openings were considered. After selection of indicators the data collection was carried out in the field. The primary data collection included the measurement of air temperature in the field whereas secondary data collection included climatic data of padam pokhari, Hetauda from direct observation of the site, Department of Hydrology and Metrology,(GoN) and demographic/housing data from report of VDC profile of Padam pokhari, Hetauda. Other methods like questionnaires survey, and mobile ethnography has been used.

4.1 Air temperature

Simple room thermometer HTC-2 is used for measuring the temperature of the buildings. To calculate maximum air temperature of summer season nine different types of residential building were selected and room thermometer HTC-2 was used for continuous 7 days i.e. (may 16th- June 23rd) at center of ground floor of each buildings. The thermometer was place at the height of 5 feet from ground for indoor air temperature measurement and the care was taken to avoid direct sunlight for outdoor air temperature measurement. The air temperature data was taken at 3 different times a day i.e., morning 7Am, day 2 pm, and at night 7pm to calculate the maximum air temperature of summer season. The assessed data were calibrated and the results and findings were drawn through calculation and regression analysis. Finally the recommendations at different levels for further works has been suggested.

5 Site and data

To fulfill the research objective, the study area has chosen where settlement have all the types of residential building like modern, hybrid and traditional residential building. Padampokhari, Hetauda is chosen for the case area. The study area is lies from approximately 20 minute way from Hetauda bazar.

Factors such as commercialization, rapid population growth, diverse lifestyle, increase in number of modern residential building, availability of modern construction materials and technology have drastically transformed architecture material and technology.

For the field data of this research, the chosen site needed to have buildings constructed with modern, hybrid and traditional technique. The sampling method will be a purposive sampling. 3 number of modern, hybrid and traditional residential building has been selected for the research.

Figure 5-1 study area

Source: google.com

5.1 Climate of Hetauda

The below figures show Nicol Graphs for Padam pokhari which start finding the temperature in which people find comfortable to live, with the help of 10 years climatic data from department of hydrology and meteorology.

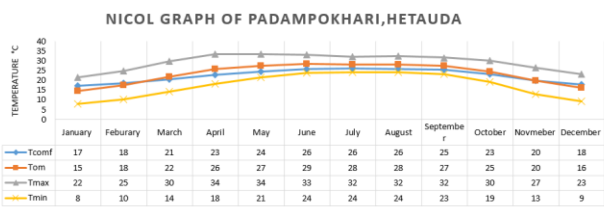


Figure 5-2 Nicol graph for Hetauda

As shown in table, the highest temperature in which the people of Padam Pokhari,Hetauda feel comfortable is 31°C during summer.

Table 5-1 Nicol comfort temperature for Hetauda

S.N.	Thermal sensation	Thermal scale	Nicol summer (Tc)	Nicol winter (Tc)	Comfort category	Remark
1	Hot	3	34	24	Very comfortable	
2	Warm	2	33	23	Uncomfortable	
3	Slightly warm	1	32	22	Comfortable	Comfortable zone
4	Neutral	0	31	21	Very comfortable	
5	Slightly cool	-1	30	20	Comfortable	
6	Cool	-2	29	19	Uncomfortable	
7	cold	-3	28	18	Very uncomfortable	

5.2 Selection of buildings

Nine different types of houses were selected for the measurement of air temperature in order to investigate the difference in indoor and outdoor temperature and compare which house was thermally comfortable to live in.

First types of House 1: Three different Modern residential building: one and half storied modern frame structure building with brick wall and flat concrete roof.

Table 5-2 U-value of modern residential building

Building envelope (thickness)	Thermal Conductivity (W/(m·K))	R-value(thickness/conductivity)	U-value
Wall			
Outer brick wall 9" Cement plaster on both side of wall 12mm	1.15 0.72	0.2 0.016 0.016 Total R-Value=0.232	**4.3 W/m²K**
Roof			
Bitumen 20mm Rcc 100mm Plaster 12mm	0.25 0.2 0.72	0.8 0.5 0.016 Total R-value =0.596	**1.6 W/m²K**
Window single glazed	0.78	0.20	**4.8 W/m²K**

Second types of House 2: Three different Traditional residential building: two-storied with mud brick, wooden wall, and slope tile roof.

Table 5-3 U-value of traditional residential building

Building envelope (thickness)	Thermal Conductivity (W/(m·K))	R-value(thickness/conductivity)	U-value
Wall			
Sun-dried brick 14" Mud Plaster First floor Wooden wall	0.9 0.65 0.12	0.3944 0.017 0.017 Total R-Value=0.4284 0.45	**2.3 W/m²K** **2.2 W/m²K**
Roof			
Tile	1.43	6.25	**0.16 Wm²K Tile**
Window wood	0.12	0.91	**1.09 W/m²K**

Third types of House 3: Three different Hybrid residential building: two storied with wooden wall and slope tile roof and half of modified with CGI roof.

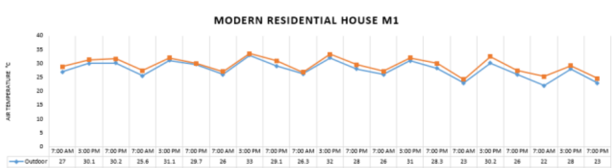
Table 5-4 U-value of hybrid residential building

Building envelope (thickness)	Thermal Conductivity (W/(m·K))	R-value(thickness/conductivity)	U-value
Wall			
Wooden wall	0.12	0.45	**2.2 W/m²K**
Roof			
Tile CGI	1.43 36.86	6 0.17	**0.16 W/m²K Tile** **5.88W/m²KCGI**
Window wood	0.12	0.91	**1.09 W/m²K**
Wall			
Hollow concrete block9''' Plaster Firs floor Wooden wall	1.95 0.72 0.12	0.1179 0.016 0.016 Total R-Value=0.1499 0.45	**6.67 W/m²K** **2.2 W/m²K**
Roof			
CGI Sheet 28 gauge	36.86	0.17	**5.88 W/m²K**
Window single glazed	0.78	0.20	**4.8 W/m²K**

6 Findings and discussions

As seen in the table 7-1 difference in temperature in indoor and outdoor air temperature i.e., is seen maximum in 2.2 in summer condition. If we compare air temperature of traditional residential buildings with other investigated modern residential building, the difference of 2.6 was seen. This is the considerable difference which shows that the investigated modern building are 2.6 warmer during summer. If we compare air temperature of traditional residential buildings with other investigated hybrid residential building residential building, the difference of 2.5 was seen. This is the considerable difference which shows that the investigated hybrid building are 2.5 warmer during summer.

6.1 Comparison of indoor and outdoor air temperature in summer



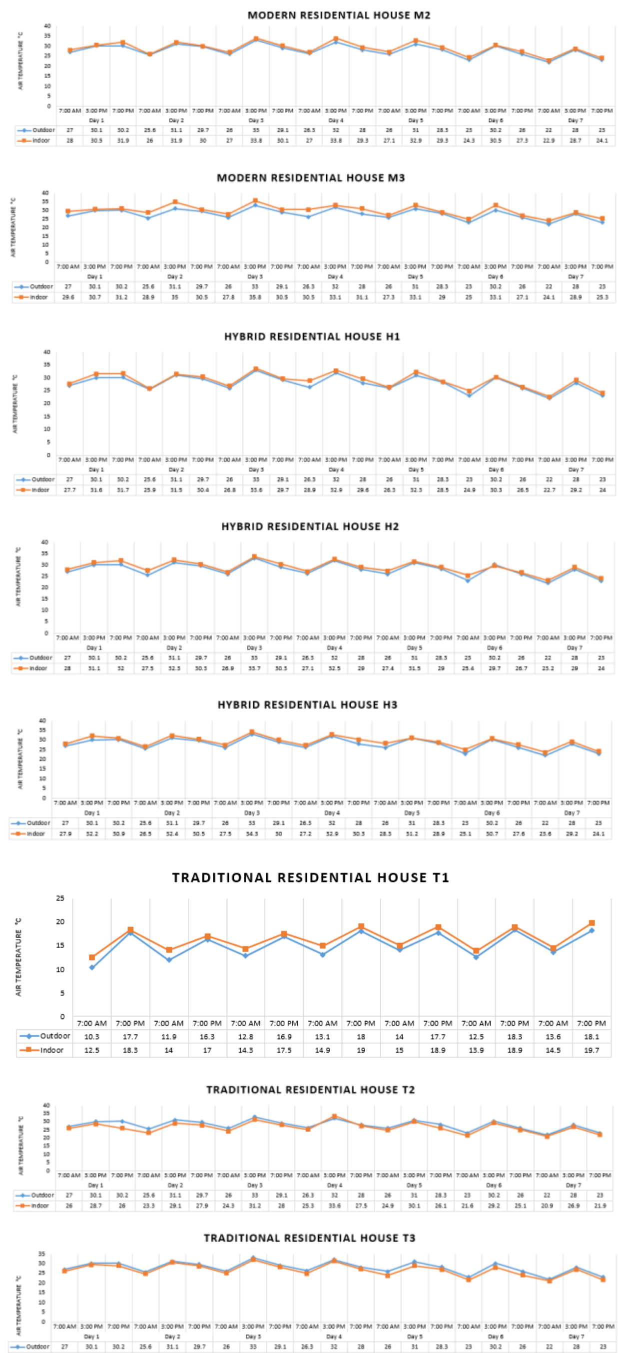


Figure 6-1 Graph of summer data of modern residential building M1,M2,M3,H1,H2,H3,T1,T2 &T3

Table 6-1 mean maximum and mean minimum temperature of padampokhari ,Hetauda of summer

S.N	MODERN RESIDENTIAL BUILDING M1			MODERN RESIDENTIAL BUILDING M2			MODERN RESIDENTIAL BUILDING M2		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2
Indoor	28.9	31.4	31.7	28	30.5	31.9	29.6	30.7	31.2
Mean max outdoor	29.1			29.1			29.1		
Mean max indoor	30.7			30.1			30.5		
ΔT	-1.6			-1.0			-1.4		

S.N	HYBRID RESIDENTIAL BUILDING H1			HYBRID RESIDENTIAL BUILDING H2			HYBRID RESIDENTIAL BUILDING H3		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2
Indoor	27.7	31.6	31.7	28	31.1	32	27.9	32.2	30.9
Mean max outdoor	29.1			29.1			29.1		
Mean max indoor	30.3			30.4			30.3		
ΔT	-1.2			-1.3			-1.2		

S.N	TRADITIONAL RESIDENTIAL BUILDING T1			TRADITIONAL RESIDENTIAL BUILDING T2			TRADITIONAL RESIDENTIAL BUILDING T3		
Time	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM	7:00 AM	3:00 PM	7:00 PM
Outdoor	27	30.1	30.2	27	30.1	30.2	27	30.1	30.2
Indoor	26	28.7	26	26.1	29.7	27.3	26.1	29.4	29
Mean max outdoor	29.1			29.1			29.1		
Mean max indoor	26.9			27.7			28.2		
ΔT	2.2			1.4			0.9		

Figure 6-1 shows the average temperature inside and outside nine dwellings in the morning, day, and night of the summer. During morning and day time the indoor air of modern residential building varies considerably with outdoor temperature i.e. T is negative. The modern residential buildings, the indoor temperature was seen higher than outdoor temperature. Where traditional residential building considerably cooler inside by 1-2 °C than outdoor temperature. The temperature difference was also seen negative in hybrid residential building. If we compared T of traditional residential building with T other types of residential building the difference is about 2.5 °C.

6.2 *Regression analysis*

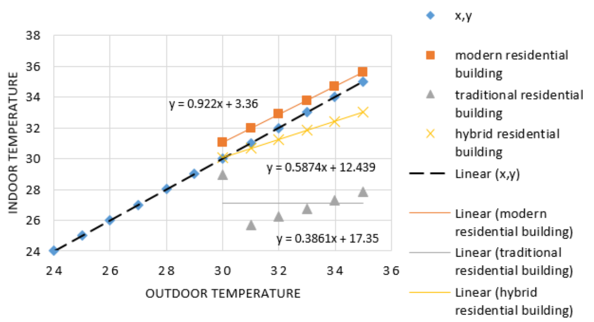


Figure 6-2 Regression analysis

Table 6-2 Regression table

House type	No.of sam	Equation	R2	To	Ti	To-Ti
modern residential builing M	24	Ti=0.922To+3.36	0.7491	20	21.8	-1.8
				21	22.722	-1.722
				22	23.644	-1.644
				23	24.566	-1.566
				24	25.488	-1.488
				25	26.41	-1.41
				26	27.332	-1.332
				27	28.254	-1.254
				28	29.176	-1.176
				29	30.098	-1.098
				30	31.02	-1.02
Traditional residential house T	24	Ti=0.3861To+17.3	0.5737	20	25.078	-5.078
				21	20.2276	0.7724
				22	20.7722	1.2278
				23	21.3168	1.6832
				24	21.8614	2.1386
				25	22.406	2.594
				26	22.9506	3.0494
				27	23.4952	3.5048
				28	24.0398	3.9602
				29	24.5844	4.4156
				30	25.129	4.871
Hybrid residential building H	24	Ti=0.5874To+12.4	0.7636	20	24.187	-4.187
				21	24.7744	-3.7744
				22	25.3618	-3.3618
				23	25.9492	-2.9492
				24	26.5366	-2.5366
				25	27.124	-2.124
				26	27.7114	-1.7114
				27	28.2988	-1.2988
				28	28.8862	-0.8862
				29	29.4736	-0.4736
				30	30.061	-0.061

The prediction of indoor air temperature of nine different houses has been done by using regression analysis method. A total 540 data were plotted from each houses of 60 data set for analysis. Liner regression model is developed. The equation developed by regression analysis of nine different types of building is given below

Modern residential RCC house: Ti=0.3861 To+17.356

Hybrid residential house: Ti=0.5874To+12.439

Traditional residential house:

Ti=0.9368To+3.475

Where,

Ti= indoor temperature in °C

To=Outdoor temperature in °

The maximum variation of more than 4°C cooler seen in traditional residential house

6.3 *Perception of people summer*

The questionnaire including demographic, socio-economic and energy consumption pattern information. The structured questionnaire has been integrated in Kobo tool for field survey in mobile devices. Total 40 respondent are taken for the survey each member of investigated residential buildings. The result of the perception is given below in graphical form

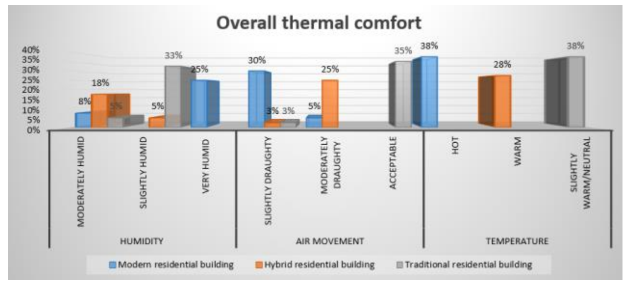


Figure 6-3 Distribution of subjective response of different types of modern, hybrid & traditional residential building

As above figure, 38 % of the residents of modern residential buildings voted for hot temperature inside residential building. 30 % voted for slightly draughty and 5 % voted for moderately draughty air movement inside modern residential building. 25% voted that very humid inside the built space.

28 % of the residents of hybrid residential buildings voted for warm temperature inside residential building. 25 % voted for moderately draughty and 3 % voted for slightly draughty air movement inside hybrid residential building.18 % voted that moderately humid inside the built space 5% voted for slightly humid inside hybrid residential building.

In typical residential buildings, 38% of the people chose a moderately warm or neutral temperature. 35% of voters said the air quality inside a traditional residential building was adequate, while 3% said it was a little drafty.33% voted that slightly humid inside the built space 5% voted for moderately humid inside traditional residential building.

7 Discussion

Modern residential U-Value seem to be highest in comparison with other types of a residential houses. Modern residential building walls and windows have the highest U-Value, it may be because of material use in the building construction. In Hybrid residential building U-value, roof with CGI sheet seem to be highest. Traditional residential building U-vale is very low in comparison with other residential buildings. Low U-value material help to perform good thermal performance of building (Walker, 2015).So traditional residential building perform a good thermal performance inside the building in comparison with other residential building.

Subjective assessment of three different residential building types' overall thermal comfort during the summer. While 38% of inhabitants of modern buildings chose hot, 28% of residents of hybrid buildings chose warm, and 38% of residents of traditional structures chose a /slightly warm neutral thermal inside the building, the results were the opposite for the other three groups. From all overall thermal comfort it is prove that people also feel the good thermal comfort inside the traditional residential building.

According to the respondents of the modern residential building, they feels extremely hot during the summer it may be because of the materials like wall material during construction. All of the occupants of the modern, hybrid residential houses depend on fan to survive in the uncomfortable conditions, to get thermal comfort, it may be because of the materials like brick, and concrete hollow block. According to the respondents, of the traditional residential building. Respondent feels neutral during the summer it may be because of the materials like wood, sundried brick, tile. Also there is no uncomfortable situation inside the building.

8 Conclusion

The first objective of research assess the thermal performance of residential buildings of Hetauda is done by using room thermometer HTC-2.The key findings of research shows: investigated traditional residential building maintains the thermal performance of investigated traditional residential house was seen 1-1.2°C cooler in summer. Also from regression analysis The maximum variation of more than 4°C cooler seen in traditional residential house during time of summer.Where modern residential building seem to be warmer than of traditional residential building. Second objective the comparison use of modern materials, U-value maintenance different types of residential clearly shows that traditional use locally available material and have low U-Value of material which directly effects on the thermal performance of building. Also the perception of people also prove that the traditional residential building perform best thermal performance in comparison with hybrid and modern residential building. Traditional residential building material have less U-value in compare with modern materials, where in modern residential building found to be uncomfortable it may be because of material which has been used in residential building. In this way this project concludes by answering the entire objective. Finally recommendations at different levels has been provided for future study. In this way this project concludes by answering the entire objective.

9 Recommendation

In fields it is clear that traditional residential building seems to be with bad condition. Maintenance works, preservation things seems to be less in field in comparison with other types of residential buildings. So that the primary stakeholders, who are inhabitant of traditional residential house in Hetauda are recommended to carry regular or time to time maintenance, air tightness, green techno fitting of whole the traditional residential building and must know about importance of their vernacular architecture. It is recommended to the researchers that the improvement design strategies can be practically carried out in the field of modern residential building. Alternative design strategies from traditional construction material and technology can be adopt in modern residential building so that improve the thermal performance of modern residential building. People are adopting modern materials without knowing the importance of modern material residential building; it may be they have less knowledge about the importance of locally available materials and technology. So, Small awareness programs in the subtropical regions should be organized for the architects, local peoples who build residential houses by modern techniques using local resources.

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