TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

# A STUDY ON THERMAL PERFORMANCE OF TRADITIONAL RESIDENTIAL BUILDINGS IN KATHMANDU VALLEY

BY
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The thesis entitled "A study on thermal performance of traditional residential buildings in Kathmandu valley" submitted by Sushil Bahadur Bajracharya in partial fulfillment of the requirement for the degree of Ph. D. in Architecture and Urban Planning has been accepted by Institute of Engineering Research Committee upon the recommendation of Supervisor, Department Research Committee and approved from following examiners:

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# INSTITUTE OF ENGINEERING

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**DEPARTMENT OF ARCHITECTURE AND URBAN PLANNING**

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled "A study on thermal performance of traditional residential buildings in Kathmandu valley" submitted by Sushil Bahadur Bajracharya in partial fulfillment of the requirement for the Doctorate of philosophy in Architecture and Urban Planning.

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**ABSTRACT**

This thesis seeks to investigate in to the aspects of thermal behavior of traditional residential buildings in traditional settlements of Kathmandu valley. It inquires how people have been living in these traditional houses in winter as well as in summer from generation to generation for many centuries. Till today, the quality of traditional houses of Kathmandu is same as in the Lichhabi and Malla period more than fifteen hundred years back. This thesis posits that, it is possible to achieve thermally comfortable environment in cool winter and hot summer in Kathmandu through the use of time-tested, thermally comfortable traditional design, materials and technology.

The present thesis takes a closer look at the theories, practice and psychology of thermal environment in general and residential environment of Kathmandu in particular. Nicol (Humphreys 1978) has conclusively identified that, the indoor neutral comfort temperature of any acclimatized population directly relates to the mean outdoor temperature. Thus the neutral comfort temperature varies for every geographical region as local people adapt themselves to remain comfortable (Humphreys 1978). However, there are no studies done in Nepal that have reported thermal comfort and thermal behavior of traditional residential building in traditional settlement of Kathmandu valley. There are however few studies done in Nepal that have reported evaluation of thermal comfort in different building in different climatic regions of Nepal.

It begins with a brief review of the concept of traditional residential building from the past to the present followed by analysis of climate of Kathmandu and short review of passive design aspects of various controls used in composite climate. This thesis then proceeds to analyze the detailed field data collected, with a view to identify the indoor thermal environment with respect to outdoor thermal environment in different seasons taking into consideration various variables such as design, planning, orientation, material, construction technology, room height, etc. This collected field data is then compared with the contemporary residential buildings of Kathmandu. Therefore, a detailed field data has been conducted, in order to get a deeper understanding of thermal behavior of these buildings in traditional settlement of Kathmandu. Regression analysis has then been performed to obtain thermal performance of

buildings with different conditions. A new formula was invented from regression analysis to predict indoor air temperature from outdoor temperature in these buildings. The regression equation obtained for Kathmandu is tested with Nicol's data (Nicol et al. 1994) and Rijal data for Bhaktapur of Kathmandu valley in Nepal.

This thesis then analyzed the data collected in a laboratory with experiments of different materials and construction technology adopted in traditional, contemporary and modern green buildings in Nepal. This collected lab data has been analyzed with a view to identify the role of materials and technology with collected field data for indoor thermal environment.  There is field information about the thermal comfort sensation, preference and recommendation of residents of different buildings of these settlements. The thesis concludes that, thermal behavior of traditional residential building, adapted in various ways to the changing thermal regime for thermal comfort is better than that of contemporary buildings. It finds evidence to prove that planning, material and technology used better for local climate are to the satisfaction of the local people.

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# CHAPTER 1: INTRODUCTION

## 1.1 General

The title of the present research is "A study on thermal performance of traditional residential buildings in Kathmandu valley." There is a general perception that traditional architecture is better in terms of thermal environment than contemporary architecture (Tiwari et al. 2004). The present study has been set out to investigate thermal environment of traditional residential buildings in traditional settlement of Kathmandu. The study also compares the thermal environment of the contemporary residential building with traditional buildings of Kathmandu. The research was initiated in May 2008 under the Trans-Himalayan University Network for Development, Education and Research (THUNDER) program in the Department of Architecture and Urban Planning, Institute of Engineering, Tribhuvan University.

The traditional Newari residential architecture of Kathmandu valley was planned around neighborhood residential square with linear alleys and courtyard system. In Newari architecture of Kathmandu, this type of traditional building developed, most probably, from very early Malla period (Scheibler 1982). The plan of the building is square or rectangular and symmetrical in shape located around courtyard or street. Rooms are arranged around the street or courtyard. The most prominent characteristic of traditional building in Kathmandu is brick exposed thick external wall. Material of construction is sun dried brick, burnt brick, tile, stone, mud and wood. Mostly the four-storied residence is an attached type of building oriented to court or street.

The basic traditional house of private residential square was designed with vertical spatial planning around a courtyard or street. Security considerations and the need to use as little irrigable land for building purposes, caused the Newari house to be vertically oriented (Korn 1976). The vertically oriented planning has direct influence on life style of people in these traditional buildings. So there is a consideration of spatial planning with different spaces for different purpose. The vertical spatial planning consists of utility rooms in ground floor (*Chheli*), bedrooms in first floor (*Chotan*), living room and bed in second floor (*Matan*) and kitchen, dining and store in attic (*Baiga*). The plan incorporates along with staircase and dormer window (*Makapwa*) or cat’s hole (*Bhau pwa*) in sloped roof for ventilation. Two rooms in first floor are separated by central wall. In second floor, living room and bed are separated by central post and wooden partition of two bays. The living room with large window admits low sun light in winter and cool breeze in summer.

The building has exposed brick façade which is red in color and rough in texture. The uneven numbers of windows are placed in each storey. Central window of living is fitted with glazed and timber shutters. A large projection of slope roof acts as effective shading device during summer and also protects from driving monsoon rain. The external exposed brick wall is nearly 60 cm in thickness. The thick multilayer wall of Burnt Red brick (*pakki apa)*, Sun dried brick (*kachi apa*) and mud plaster is placed from outside to inside in external walls. The foundation of structure is built of natural stones. Mud or tile flooring with wooden plank is supported by wooden joist in all floors. In attic, slope roof of clay tiles is constructed with well-compacted mud supported by wooden planks and joists. Normally floor height is less than seven feet. Till today, we can see people living in this type of traditional Newari residential buildings in Kathmandu valley. This type of residences is free running without artificial heating and cooling system. The ground floor and attic is not used during night time. Till today, occupants enjoy good thermal environment in this building.

Today, we can see degradation of traditional architecture from the cityscape. Nowadays, a growing number of residential buildings in Kathmandu designed and constructed using modern concept, materials and technology imported from the globalized world instead of traditional form, materials and technology. When modern material and technology were introduced more than 50 years back in Kathmandu, people started to construct new types of houses. The houses are constructed with modern artificial materials like RCC, metal, glass, cement, GI sheet instead of traditional materials. These contemporary buildings are affecting not only the aesthetic value but also degrading traditional architecture. Also there were different technical problems not satisfying the people especially due to lack of thermal comfort. In developing countries like Nepal, maximum number of modern contemporary building is constructed of masonry material without thermal insulation. These buildings are cold in winter and hot in summer.

One of  the most important objective of building design is providing thermal comfort ultimately to the occupant (Nicol et al. 2012).If a building is not comfortable, the building forces the occupants to take actions, which are likely to be energy intensive to make occupant comfortable. The thermal comfort is thus essential for user satisfaction in a building. It is now widely accepted that poor indoor thermal comfort has several adverse affect on the occupants, resulting in ill health, irritability, anxiety, increased crime rate and incidence of anti social behavior. The provision of sustainable thermal comfort indoor seeks a deeper understanding of climate, site, material and building form for the designer.

The understanding of thermal comfort and standard varies from past to present. There are new theories and understandings for comfort and standards. According to ASHRAE (2004), the thermal comfort is that condition of mind which expresses satisfaction with the thermal environment. The environmental conditions required for comfort are not same for everyone. There are large variations, physiologically and psychologically, from person to person, so it is difficult to satisfy everyone in a space. ASHRAE Standard 55 (2004) is derived from different data base for naturally conditioned buildings. According to terms and definition of CEN Standard EN15251, the adaptation is physiological, psychological or behavioral adjustment of building occupants to the interior thermal environment in order to avoid discomfort. In naturally ventilated buildings these are often in response to changes in indoor environment induced by outside weather conditions.

Nicol et al. (2012) in their book entitled the principle and practice of adaptive thermal comfort studied, discussed and derived the new theory of adaptive thermal comfort. Thermal comfort is a basic requirement for happiness and productivity in the workplace. Thermal comfort is that state of mind which expresses satisfaction with the thermal environment. The thermal sense is located in the brain and the skin. Its purpose is to keep body temperature constant and warn of dangers possible. The studies indicate that comfort is achieved by the occupants adapting to the building. The study focused that comfort has to be done within existing climatic, social, economic, architectural and cultural context. The Nicol graph (Fig.2.1) starts from findings that the temperature which people find comfortable indoor varies with the mean outdoor temperature. This is true for people in buildings which are free running and not mechanically heated or cooled. According to Prof. Nicol, the 'comfort temperature' is the temperature which people find comfortable in a given situation. According to Nicol graph, the indoor comfort temperature in Kathmandu valley is nearly 26$^{o}$ C in summer and 19 $^{o}$ C in winter (Table 2.1). In national context, the comfort indoor temperature for several places of Nepal in winter and summer was calculated by Rijal by using Griffiths method (Griffiths 1990, Rijal et al. 2008).According to Rijal, the indoor comfort temperature for Bhaktapur in Kathmandu valley is nearly 26$^{o}$C in summer and 15 $^{o}$C in winter (Table 2.1 & Rijal et al. 2010).This result is important to compare the thermal performance of traditional and modern buildings in this study.

In developed countries, government regulation plays important role to maintain quality and comfortable living standard inside buildings. In developing countries, most of high-income people construct high-class buildings with control system like HVAC, heating and cooling for their comfort. But people especially who live in new locally made modern houses in Kathmandu have many problems of heating and cooling in winter as well as in summer. In winter, they maintain their thermal comfort inside the building by using electric, kerosene or gas heater, lighting firewood that affects the health of occupants, unsafe for fire hazard and environmental problem inside as well as outside. In summer, they use electric fan, air cooler etc. for cooling.

Nowadays, architect and energy experts have been developing zero energy building where as all indigenous architecture has been designed with respect to microclimate and ecology. Microclimate control around the building is always important in indigenous design. The indigenous building has less impact on environment and it is more energy efficient (Gupta 1984). Rijal et al. (2010) in their report has made various evaluations of thermal comfort studies in different buildings in different climatic regions of Nepal. However, there are no studies done in Nepal reporting how are the thermal behavior and comfort related in traditional residential building in Kathmandu of Nepal. This is seen as a knowledge gap. So it should be studied scientifically to find out all the advantages of traditional residence compared to modern residence of Kathmandu valley with respect to thermal comfort.

History shows the importance of relationship between human activity and nature. In traditional architecture this harmony with nature was an important design element.

The traditional architecture could be one of the key issues for sustainable building design for modern buildings. However traditional forms of architecture are decreasing dramatically and replaced by artificial materials, modern designs and new alien technology. We have to stop the substitution of traditional architecture by modern architecture. We need strong policies and research to sustain the concept and practicalities of traditional residential buildings in traditional settlement of Kathmandu valley (Rijal 2012). This research will discuss the thermal environment and improvement of these building by relating to the thermal comfort. So this study explores to create an understanding of traditional building design and custom with respect to thermal comfort in a composite climate of Kathmandu. This shall be helpful to conserve traditional architecture of Kathmandu with its merit on thermal performance for future. The research developed new principle for thermal comfort and energy efficiency from traditional for new houses. The research developed new equation to predict the indoor thermal environment with help of outdoor temperature. In the context of today's energy-crisis, more specifically the Nepalese context, this research is very relevant, as the research findings lend weightage to the argument for not only conserving but increasing residential buildings using traditional technology, which are more energy- efficient.

## 1.2 Relevance of current international research

Most of the international thermal comfort research is concentrated in UK, Japan, Australia, European countries and in a few developing countries. Most of research studies were done in office environment in both naturally ventilated and air conditioned buildings. However, there had been a few studies in residential environment in various countries like China, Greece, India, Nepal, etc. (Madhavi 2010) are also reported in the current literature. Nowadays, many research studies are done in vernacular architecture in many developing and developed countries for development of sustainable architecture and conservation purpose.

The thermal comfort studies from similar climatic regions conducted in similar types of are only broadly useful. It has been shown by Rijal that subjects of thermal sensation, adaptation in different climates and cultures of Solokhumbu, Bhaktapur, Kaski, Dhading and Banke districts of Nepal. A few studies in residential environment in these districts of Nepal are reported (Rijal 2002) in the current literature. Therefore, a detailed study on the thermal comfort and thermal behavior of traditional residential building is very useful to provide prescriptive design recommendations. Also it should find out how indigenous architectural form, material, technology should be developed with new theory and application to address comfort of people in the future. This will also help to conserve the traditional houses and architecture of Kathmandu with its more thermally comfort and energy efficient traditional materials and technology.

## 1.3 Purpose of Research

The purpose of this research is to find out how the materials, forms and construction technology of traditional houses in Kathmandu addressed thermal comfort of the occupant for long time in the history. It also aims to examine the thermal comfort for the people from the traditional and modern houses of Kathmandu nowadays. The study aims to examine how the traditional houses of Kathmandu may inform thermal comfort for future with the same materials, building forms and construction technology. It studies to find out any need of correction in the traditional houses to address thermal comfort of occupant in future. The purpose of this research is to help to stop the degradation of traditional architecture from cityscape of Kathmandu. Another main purpose is to help for conservation of this architecture with its materials, technology and form in future. It will study to develop modern houses with the concept of traditional building planning, design form, material and technology.

## 1.4 Objectives of Research

This research has following objectives:

1. To evaluate thermal performance of traditional houses
2. To compare thermal performance of traditional houses with modern houses
3. To know perception of people for thermal comfort in traditional residential building
4. To develop new equation to predict the indoor thermal environment with the help of outdoor temperature
5. To experiment to study role of materials and technology used for traditional, modern and green houses for the thermal performance
6. To compare thermal performance of traditional, modern and selected green materials for creating thermally comfortable buildings

7. To help for conservation of energy efficient traditional building

## 1.5 Research Questions

Having looked at the above objectives, the research tries to seek answers to the following questions.

1. How do the characteristics of thermal environment of traditional residential building compare with modern residential building of Kathmandu?
2. How could the indoor thermal environment be predicted with the help of outdoor temperature?
3. How do the people find thermal comfort in traditional residential building?
4. How is the indoor thermal environment affected by building materials and technology?
5. What are the potential recommendations of the material, technology and building design for thermal comfort and energy saving?

## 1.6 Research Philosophy – Positivism and Post-Positivism

Trochim (2006) explains the two philosophies in scientific research: Positivism and Post- Positivism (Groat & Wang 2002). Positivism is based on observed facts and measurements based on objective collection of data, systematic procedure for analysis and verifiability. Post- Positivism begins from the stand point that objectivity is never achieved perfectly, but one can only approach it, that all measurement is fallible. Post-Positivism also emphasizes the importance of multiple observations, each of which may possess different type of errors. Groat and Wang (2002) sum up that, positivist assumes that objectivity can be achieved in the research process, whereas post positivism presumes that objectivity is a legitimate goal that may be imperfectly realized.

These two being two philosophies, the question of which direction to take is a matter of decision making that impact the whole research. While the former demands absoluteness in data collection, a near impossible proposition in a research which relies on field measurements and recording of occupant responses in natural environments, the later is more realistic and allows for types of error. Therefore, this thesis relies on positivist philosophy. Hence it sets forth to collect large data, covering a multitude of aspects to build in reliability and check for statistical significance.

## 1.7 Outline and organization of the Thesis

This thesis is organized into seven main chapters. It begins with introduction of research including research question, purpose, objectives and organization in chapter 1. Chapter 2 includes the literature study. It begins with thermal comfort and vernacular study in national, neighboring and international context. It deals with thermal standards and reviews traditional residential building ending with observation of the present contemporary building. An analysis of traditional building design along with various passive design features in a composite climate of Kathmandu has been discussed in this chapter. Chapter 3 includes the research methodology. It starts with types of methodology, sets research design, methods of investigation, research area and data gathering and develops the analysis method setting the theoretical basis for the rest of the research.

The dialectic of thermal behavior of traditional building is taken in chapter 4, aiming to progress in the direction set by the research questions. This chapter is the main foundation of the present research. This chapter presents the description of investigated buildings and variables. It includes the methods of monitoring thermal environment in building and field data recording. It is followed by regression analysis, results and discussion. Chapter 5 draws attention to the analysis of feeling, preference and psychology of thermal comfort of the local residents in their residence to support the research questions. Chapter 6 highlights the lab experiments and explains impact of thermal comfort through the building material and technology. The data and results of these chapters 5 and 6 designed to support the main research chapter 4 with evaluation of thermal environment of traditional houses. Chapter 7 summarizes discussions and findings of previous chapters. It revisits the research questions and then draws conclusion and recommendations. It sets directions for future research and relevance of current work to the multi dimensional discipline of traditional as well as contemporary building design.

## 1.8 Expected output

The thermal performance of traditional houses was better in the past in the history. Till today, the traditional residential buildings maintain comfortable temperature compared to modern residential buildings in winter and summer without being mechanically heated or cooled. The materials and technology used in traditional building are better for thermal comfort for people. The material and technology used in modern buildings do not satisfy comfort expectation of the resident.  This will create awareness among local people to design and construct traditional houses again in future. Till today, the materials and technology used in traditional house continue to be better for thermal comfort in Kathmandu.

The research seeks to show positive factors that influence in better thermal comfort. The research will focus role of planning, orientation, material, technology, thermal wall etc. in thermal performance. The study will analyze perception of local people in traditional and modern building. The findings will develop guidelines for design, byelaws and research for architects, conservationist, researcher, local government and people of Kathmandu. The expected output and conclusions shall be such that it will be useful for making guidelines for thermal comfort of houses of Kathmandu for future. The research shall help to promote energy efficient traditional residential buildings of Kathmandu and support the cause for conservation of these thermally comfortable buildings. The results shall review existing bye laws of Kathmandu valley. The researcher being a full time faculty member of the Department of Architecture and Urban Planning, Institute of Engineering, the outcome of the research will also be instrumental in setting up a future elective course of Department of Architecture and Urban Planning, Institute of Engineering, Tribhuvan University, Nepal.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

The literature review is the most important part in early stage for any research work. This shall identify the related research by showing gaps in theory and practice in research result. This chapter focuses on different studies done in traditional building of Kathmandu. The study includes the literature review of works done related to this research in national and international context. This chapter also includes the national and international standard for indoor thermal environment. Then it explains the typology of traditional and modern residential building. This will provide a foundation for the data analysis which is continued in the following chapter. This chapter ends with the conclusion of this specific chapter.

This chapter includes the review of traditional architecture and thermal study done in Nepal, India and other countries in international context. Also the chapter studies and reviews the thermal comfort standards developed and used in most of developed and developing countries for building design and construction. This study reviews the knowledge gap in theory and practice for thermal study as a whole and especially in Nepal. This will lead to develop research question of this study. There had been few works done related to thermal topic in Nepal. There are few works in thermal environment in traditional vernacular houses of Nepal. But a detailed study on thermal behavior of traditional residential buildings in traditional settlements of Kathmandu is seen as one of the most acute gap in knowledge for further research.

There had been many international thermal comfort research in residential buildings in developed countries like UK, Italy, Japan, Australia and few in developing countries in India, Middle East countries and China. However a few studies has been done in residential environment in various countries like Greece, Iran, Spain, Malaysia, Libya, Israel, Zambia etc. Today, there are widely used international standards that relate specifically to thermal comfort. These thermal comfort standards are: ISO Standard 7730 (2005), ASHRAE Standard 55 (2004) and CEN Standard EN15251 (2007).These standards are followed in most of developed and developing countries for thermal comfort in building design and construction. All these standards are under continuous reviews so it is necessary to check for updates. There are new theories and understandings for thermal comfort and standards varying varies from past to present. There is new theory for thermal comfort for vernacular houses in the present. This new theory of adaptive comfort is used for vernacular houses. Nicol et al. (2012) "the principle and practice of adaptive thermal comfort" derived the new theory of adaptive thermal comfort which will be discussed in this chapter.

## 2.2 Thermal study in National context

There are few works done related to thermal comfort in vernacular buildings in different regions of Nepal. One of the works done was by Rijal (2004), entitled "Analysis and Evaluation of Thermal Environment in Traditional Vernacular Houses of Nepal". A first doctoral thesis was done in thermal study in traditional vernacular houses of Nepal from Kyoto University, Japan in 2004. In this research, the author focused on thermal environment study of traditional vernacular houses in five districts of different climatic regions of Nepal. He had done surveys, investigation and evaluation regarding thermal sensation, thermal preference, and neutral temperature in traditional building of Terai, Hilly and Mountain regions of Nepal. Another works done was also by Rijal (2000) entitled, "Investigation and Evaluation on Thermal Environment in Traditional Vernacular Houses in Nepal". A master thesis was done in thermal study in traditional vernacular houses of Nepal from Kyoto University, Japan. In this research, the author focused on the survey of thermal environment of traditional vernacular houses in different districts of different regions of Nepal. He had done surveys and evaluation in traditional vernacular houses of different region of Nepal. The findings show that residents are satisfied with thermal comfort condition of their traditional houses of different climatic condition in Nepal which is very valuable study indeed.

Rijal (Rijal et al. 2002; 2004; 2010; 2012) studied, discussed and published many research papers in Nepal and abroad regarding thermal comfort, thermal sensation, thermal preference, neutral temperature, fire wood consumption, thermal improvement and sustainable building design of the traditional houses of different regions of Nepal. People in the regions adapt well to the neutral environment, as a result of which neutral temperatures are different in different climates in Nepal (Rijal et al. 2002). In his study two surveys of the thermal environment and thermal sensation were conducted in indoor and semi-open spaces of the traditional houses in both summer and winter in five districts Banke, Bhaktapur, Dhading, Kaski and Solokhumbu of Nepal. The results show that residents are highly satisfied with thermal condition of their traditional houses since they adjust well to the thermal conditions. The results shown in Bhaktapur shall be studied and compared in this study for thermal condition of traditional houses. But a detailed study on thermal performance of traditional residential buildings compared with contemporary buildings in traditional settlements of Kathmandu is seen as the widest gap in knowledge for further research. So questions arise that shall we compare the thermal environment of traditional residential building with modern residential building of Kathmandu? Shall we compare the characteristics of thermal environment of traditional with modern residential building?

One of the most important research work done in thermal comfort in Nepal is establishment of mean comfort temperature during winter and summer for five different places of Nepal including Bhaktapur of Kathmandu valley by Rijal (Rijal et al. 2010). There was already established mean comfort temperature during winter and summer in all developed countries. The mean comfort temperature 15 $^{o}$ C during winter and 26 $^{o}$ C summer for Bhaktapur of Kathmandu valley (Rijal et al. 2010) is taken as reference point to compare and study the comfort temperature for Kathmandu in this study. As there was already established mean indoor comfort temperature in Nepal, then shall we invent new equation for prediction of the indoor thermal environment with help of outdoor temperature from metrological forecast? The traditional architecture could be one of the key issues for sustainable building design for different climates and cultures (Rijal et al. 2012). Traditional architecture adapted to the climates and cultures by using local building materials and techniques but this architecture is disappearing dramatically, being replaced by artificial materials, modern designs and alien technology. He reports need of strong policies and research to preserve the concepts and practicalities of this architecture. To develop the strong policies and research to preserve the concepts and practicalities of this architecture, we need to discuss also the potential of traditional material, technology and building design for thermal comfort. Also there is a need to discuss the energy saving from traditional material, technology and building design. The detailed study on traditional material, technology and building design for thermal comfort and energy efficiency should be studied in this study.

Another research paper "climate responsive building design in the Kathmandu valley" done by Upadhyay et al. (2006) focused on the design guidelines and recommendation for new building using the Bioclimatic chart, Mahoney table, climatic factors and climate consciousness of traditional buildings of Kathmandu. The design recommendation provides on the orientation, layout of buildings, size and position of window and characteristics of wall and roofs. The paper indicates that traditional architecture of Kathmandu valley is the outcome of centuries of optimization of material use, construction techniques and climate consideration. However contemporary buildings are being built with little consideration of climate. Vernacular architecture helps to understand the climatic and technological limitation of the past in order to formulate design guidelines for future. The study explores strategy for energy efficiency and climate consciousness in modern buildings in the Kathmandu valley.

Some thermal study researches were done in traditional houses in high altitude of Nepal. Fuller et al. (2009) have done one of the works in improving thermal comfort of traditional architecture in high altitude in remote area of northwest Nepal. The study investigated ways to improve comfort levels in traditional Humli houses with simple and low cost strategies. The study recorded temperature data only in four rooms of only one Humli house for 12 days in April 2007. The study indicates that comfort levels of the houses is far below than internationally recognized standard but it should be compared by new principle of adaptive thermal comfort for these houses (Nicol et al. 2012). The study (Fuller et al. 2009) recommended creation of sunspaces at the entrance to the living rooms which will increase average internal temperatures by 1.7 and 2.3 $^{o}$ C. This study recommended with increased insulation levels and sunspaces which reduces comfort level dissatisfaction by over fifty percent. This study was based on a small set of data in only one house which is not sufficient to draw conclusions in general.

Another thermal study research was done in traditional houses of Lomathang in high altitude of Nepal. Rijal et al. (2006) conducted a 4 - day research in thermal comfort study of 36 residents in Lomathang in Mustang district of northwestern part of Nepal. The study found that the residents of three houses were highly satisfied with the thermal conditions of their houses in 3705 m altitude in mountainous region. The findings show that people are well adapted to the thermal environment of traditional houses, as a result of which the neutral temperature is lower than the thermal comfort standard. This is very important to be noticed to study the thermal comfort in vernacular architecture of Kathmandu as well as all over the world. The findings that people are well adapted to the thermal environment of traditional houses in Lomathang much more practical for vernacular houses compared to Fuller research in a Humli house indicates that a comfort level of a house is far below than internationally recognized standard.

For thermal study with respect to climate of Kathmandu, one of the important quotations is written by Levi (1908), the well known French historian in his book, Le Nepal. He visited nearly 115 years back in January 1898 in Nepal from India for two months. He walked in and around in Kathmandu valley for field study of historical research in winter months of January and February. But he wrote in his diary and published in the book that in 15 th January, he recorded 3-5 $^{o}$ C in the morning, after ten o'clock it warms to 25 $^{o}$ C, then 28 $^{o}$ C, 30 $^{o}$ C and 32 $^{o}$ C at two o' clock. It seems maximum temperature and diurnal temperature range very high at that time when there is any temperature recorded in Nepal. In 20 th January, he recorded -2 $^{o}$ C in the morning and it warms to 3 $^{o}$ C at eight o'clock. But he wrote in the book that he felt very hot during day in direct Sun to work in 26 th February in Kathmandu. The day is short so that it was not easy to work for him. But during January, the temperature rises up to 32$^{o}$ C in afternoon in Kathmandu; it should be noted for this research also. In January, the temperature rises up to 32$^{o}$ C which is not true nowadays. He felt very hot in sunny day in the field and cold in the morning and evening in his naturally ventilated building. He tried to say that weather with coolness and warmness in Kathmandu during winter depends upon the Sun. This is true that direct Sun light has high intensity in low latitude (27$^{o}$ N) of Kathmandu if the atmosphere is clear. The climate of Kathmandu directly depends upon the solar radiation. This historical book also gives some weather data and climatic condition of Kathmandu at that time which should be important information for this research.

There are few works done related to traditional buildings in Nepal. These works focused to conservation of traditional buildings in Nepal. One of the works done in conservation of traditional architecture of Kathmandu was Scheibler (1982),"Building today in a historical context: Bhaktapur, Nepal". The book was published as a doctoral thesis from the Swiss federal Institute of Technology; Zurich, Switzerland after Giovanni had worked in urban development project in Bhaktapur, Nepal as an architect. He had his own view to conserve the traditional architecture with 'appropriate western technology'. His proposal was new at that time in seventies but using of plastic foil (PVC) under the clay tiles and mud in sloped roof substructure but it decay eaves board of traditional building. The proposal of using pre-cast concrete floors instead of timber floor for the reduction of cost is bit controversial to indigenous technology and conservation of traditional architecture. In my opinion, indigenous technology would be better than 'western technology' for the renovation of traditional buildings. A good example can be seen in renovation of fifty five window palace '*Pachpanne Jhyale Durbar'* of Bhaktapur with traditional mud and brick technology instead of using imported RCC technology and materials. The study focused in conservation but there is not any study related to thermal aspect of traditional architecture.

Korn (1976), in "The traditional architecture of the Kathmandu valley" -wrote the most striking of architectural features in traditional Newari buildings, are the huge projecting roofs which protect the walls of brick and mud mortar from the powerful monsoon rains and strong sunlight. The overhang in case of dwellings is generally of about 1m. The building form can control heat, light and rainfall in different season to create a safe and comfortable internal environment. Korn presents detailed features of different types of buildings with drawings of traditional architecture of Kathmandu. But there was no study and explanation about the thermal performance of these buildings. The drawings used in the book are one of best documentation in Nepalese traditional architecture of Kathmandu. Some of the drawings have been used for this research also.

Ranjitkar (2006) in "Heritage Homeowner's Preservation Manual" wrote a good manual for local people for conservation of their houses in traditional way. He organized chapters from introduction to maintenance in three languages. He wrote it in English, Nepali and local Newari languages with text, drawings, details and photographs. He gave good advices to local people how to conserve and maintain these buildings. He also wrote that thick masonry wall has advantages of thermal insulation from outside temperature without any calculation and temperature data. Also he mentioned surkhi mortar better than modern cement mortar in these houses. But there were no detailed studies and explanations about the thermal performance of these buildings. How do the people find thermal comfort in traditional residential building should be answered through the new research? How is the indoor thermal environment affected by a thick wall? These questions shall be raised in traditional buildings as people feel it is better than modern houses. What is minimum temperature in the morning of winter in modern and traditional houses? How much temperature difference in these houses? If these questions were answered then we can say traditional houses better in the morning of winter than modern houses in this way concretely. There is a lack of this type of research especially in traditional buildings in Nepal which shall be answered through this study.

Dongol (2007) in Elements of Nepalese Temple architecture described the structural wall construction consists of three layers of brick with few cross bonds with good drawings and photographs. These structural walls have sun-dried bricks in the inner part, wedge-shaped bricks called *Dachi apa* on the outer surface and brick fragment in the middle. To protect clay mortar being washed away by rain, minimum brick joints are provided by using *Dachi apa*. Besides its wedge shape it is less porous and has a smooth surface to make it durable and prevents deterioration. This three layer wall construction technology describes the indigenous wall technology but there is no study for energy conservation and thermal study in traditional house. The drawings used in the book are one of best of Nepalese traditional architecture of Kathmandu.

The first book of its kind ever written by a Nepali author Parajuli (1986) is "Experiences in preservation and restoration in a medieval town". Real problems and prospects of preservation and restoration were written with well illustrated drawings and photographs of buildings. The book covers the renovation of residential building and for the first time the floor heating system in Timila house of Bhaktapur, Nepal. This also shows good documentation for preservation and restoration of traditional building in Kathmandu but there is no description about thermal behavior of these buildings.

Tiwari et al. (2004), "Culture in Development Conservation of Vernacular Architecture" focused on the conservation of vernacular architecture of hilly region of Nepal. This study identifies changes in architecture and planning in vernacular architecture in hilly region of Nepal. The paper proposed on conservation of vernacular architecture with case study and analysis of Salle village in Dhading district of middle hill of Nepal. The study proposed some policy for development approaches based on principle of sustainability with a policy of usage of local building material which will lead to conservation of vernacular architecture.

Harrison (1996) in "Himalayan buildings – recording vernacular architecture Mustang and the Kailash" focused on the conservation of vernacular architecture of mountain region of Nepal and India. The booklet published with recorded detail site plan, drawings of materials and technology used in vernacular architecture of this region. The booklet gives opportunity to study the regional vernacular architecture. This booklet is useful for study of local building material and technology which will lead to conservation of vernacular architecture.

Toffin (1981) edited and published a book "Man and his house in the Himalayas" which deals mainly with popular forms of traditional architecture of different ethnic people of Nepal and India. The topic "The Kathmandu Valley: The Newar world" focused in the construction techniques with wall, floor, attic roof used for traditional residential buildings. It gives the detail of woodwork used in roof, stair and window with sketches which is very helpful to researcher and student. This is useful for study of local building material and technology which will lead to conservation of traditional architecture. The book deals with the general description to detailed construction techniques of traditional houses but nothing much about the thermal behavior of traditional houses.

Isaacson (1987), “Architecture & construction management – in the highland and remote areas of Nepal" published a book after facing real problems during his ten years of work experience in Nepal. He writes that his book argues that wherever possible, local building styles, methods and materials should be used for small buildings. There are several advantages to this approach. The book shows modern building of Dhankuta influenced by local building styles, methods and materials wherever possible as he wrote. This should be important to study for the application of traditional form, material and technology in modern building in future. But this research has not made any research about thermal performance. This study will make a research of thermal performance.

Bernier (1981) published a book "The Nepalese Pagoda – Origin & Style" which focuses mainly on description of art and architecture of Kathmandu. He has described brick, stone and wood as the exterior form of traditional architecture of Kathmandu. He wrote "The Newar house confronts the viewer with broad expanses of brick, punctuated by windows that vary in size from very small at ground level to very large on upper storey". "The aesthetic system to which the Newar subscribes requires the use in architecture of brick and wood in absolute combination". The book is helpful to know the description of traditional architecture in detail with form, material and technology.

Joshi (1989) published a book "Kathmandu *Upatekaka Kalatmak Jyalharu*", Royal Nepal Academy, Kamaladi, Kathmandu, Nepal about the carved windows of Kathmandu valley in Nepali language. The book focuses on role and description of decorative windows in society. It gives technical detail used for woodwork in decorative window which focuses mainly art and architecture of Kathmandu. The study of traditional residential building shall be incomplete without the study of windows used from very small at ground level to very large on upper storey. The book is helpful to study the detail of each and every about form, material and technology of carved windows in traditional architecture.

There are few research works done in Nepalese architecture. One of the works done was Pokharel (1994), “Identity and Synthesis of Nepali Architecture”. A doctoral thesis was done in Nepalese architecture from University of York, UK in 1994. In this research, author focused study of traditional vernacular houses as well as modern buildings from past to present in different regions of Nepal. He had done surveys, investigation and evaluation regarding in traditional and modern building of Terai, Hill and Mountain regions of Nepal. It gives the detail description of Nepalese architecture with sketches which is very helpful to researcher and student. This is useful to study for conservation of traditional architecture. The book focused on general description of traditional and modern buildings but has not mentioned about the thermal comfort of traditional houses.

Other works done in Nepalese architecture was Pant (2002) "A study of the spatial formation of Kathmandu valley towns-the case of Thimi". A doctoral thesis was done in spatial formation in Nepalese architecture from Kyoto University in Japan in 2002. In this research, author focused on study of traditional vernacular houses and formation of settlement planning of Kathmandu valley from past. The research has done surveys, investigation and evaluation regarding settlements. It gives the detail description of Nepalese settlement planning with sketches which is very helpful to researcher and student. This is very useful for conservation of traditional architecture and urban planning. The book deals with detailed description of traditional planning but does not mention about the thermal studies of traditional houses.

Pahadi (2002) published the book, "Passive Building – concept and design" in Nepal. The book is well organized and covers all the topics of climatology, thermal aspects, lighting and acoustics. The book is applicable to use design aids in creating comfortable building through passive solar design. The author gave some good example of building design with respect to climate in the context of Nepal. The book is useful to study the theory of thermal comfort with two groups of variables. First one is personal variables with metabolism and clothing. Another is environmental variables with air temperature, wind, humidity and solar radiation. This book is a good reference for students, researchers and architects.

VSBK (2008) published a Rat Trap Bond manual with a practical solution on how to economize on brick and cement with quality. Building materials are getting more and more expensive as can be seen in the escalating of bricks, cement and steel bars. It shares that this technology saves 30 % on bricks, 50 % on cement and 130MJ energy and emits 30 kg less $CO_2$ than English bond which is very true in modern context. This is true. But one of important things is that it did not focus so much in the fact that this technology is also good for thermal comfort. The 110 mm air cavity inside brickwork works as a good insulation in modern buildings. But this is not mentioned in the manual with experiments. The material and technology is important for modern building as new alternative material and technology in Nepal for future.

The bye-laws with respect to thermal aspects and traditional buildings should also be discussed in this literature review chapter. This is important in this research for discussion, analysis and development in future with conclusion. The latest Bye-law (2064) of Kathmandu valley was developed, published and implemented in 2064.Chapter -4 consist of bye-laws of Bhaktapur in which traditional cultural residential zone is separated for the conservation purpose. This shall help to conserve the traditional residential buildings. The bye-laws of traditional cultural residential zone are better for the conservation purpose of traditional residential buildings among the five municipality of the valley. This bye-law consists and promotes the traditional building form, reuse of traditional opening, exposed brick wall, restriction of basement, etc. So these bye-laws shall be implemented in all traditional settlements of Kathmandu valley for the conservation of traditional architecture.

There are many studies done in traditional buildings related to conservation aspects in Nepal. But there is not any study done related to thermal behavior of traditional residential buildings of Kathmandu with respect to materials, technology and form of building in Nepal. This is the knowledge gap which should be addressed in this research. But Rijal had done some research in thermal aspects in vernacular houses in different parts of the country. Rijal established the mean comfort temperature 15 $^{o}$ C during winter and 26 $^{o}$ C during summer for Bhaktapur of Kathmandu valley (Rijal et al. 2010). This is taken as reference point to compare and analyze the mean comfort temperature for Kathmandu in this study. Rijal (2012) report wrote that traditional architecture is decreasing dramatically, being replaced by artificial materials, modern designs and alien technology. He reports need of strong policies and research to preserve the concepts and practicalities of this architecture. To develop the strong policies and preserve this architecture, we need to discuss also the potential of traditional material and technology with its merit. Also there is a need to discuss the energy saving from traditional material, technology and building design. So this study focuses for the detailed study of traditional material, technology and building design for thermal comfort and energy efficiency. This study shall focus to invent new equation for prediction of the indoor thermal environment with the help of outdoor temperature.

Many writers have written that thick masonry wall of traditional buildings has advantages of thermal insulation from outside temperature without any calculation and temperature data. Research into environmental qualities and performance of the traditional buildings has been carried out in recent years (Meir & Roaf 2006). The thermal performance of traditional houses is better than that of modern houses (Ahmad et al. 1985, Algifri et al. 1992) but there were no detailed studies about the thermal performance of materials and technology of these buildings. How is the indoor thermal environment affect by thick wall? These questions shall be raised in traditional buildings as people feel better in terms of thermal comfort than the modern houses. What is maximum temperature in the summer in modern and traditional houses? What is minimum temperature in the winter in modern and traditional houses? How much temperature difference can be found in these houses? If these questions were answered then we can say traditional houses are better in the winter and summer than modern houses. This type of research is lacking especially in traditional buildings in Nepal which shall be answered by this study.

### 2.3 Thermal study in neighboring countries

Madhavi (2010) in a study entitled "Understanding the climate sensitive architecture of Marikal, a village in Telangana region in Andhra Pradesh, India" calls for a code of practice balancing modern and the vernacular. The study shows that architecture and climate are engaged in a happy marriage in any indigenously developed settlement. The study analyzed a vernacular settlement of Marikal in composite climate of India, as part of a large development project. Marikal's form and structure are a result of centuries of evolutionary process and knowledge transfer, reflecting a set of varying physical and nonphysical determinants forces such as climate and geology, religion, socio-culture values, economics, technology and administrative factors.

The occupants adaptively synchronize their activity with spatial environmental qualities of the space in their highly climate sensitive traditional houses. But the house form of Marikal is transforming like in traditional houses of Kathmandu due to their social forces and availability of electric controls in the recent decades. The study concludes that villagers associate higher social value to concrete houses due to the imported urban imagery and consider them inspirational, despite experiencing higher thermal discomfort in them. This result is somehow true in our context also in Kathmandu. People of Nepal also associate higher social value to so called modern concrete houses instead of traditional buildings in the traditional settlements. So our study is also similar to call for a code of practice balancing modernization with the vernacular architecture in future.

Bhatia (1991) in a book entitled “Laurie Baker-Life, Work, Writings” describes Bakers' works for more than 40 years in India using local material, technology and form. He wrote in a very notable that “the timber roof is adequate to cope with the climatic extremes in summer, monsoon and winter”. “Himalayan architecture was a perfect example of vernacular architecture- simple, efficient inexpensive”. “This housing demonstrated hundreds of years of building research on coping with local materials, local climatic patterns”. “My observation is that vernacular architecture almost always has optimum solutions to all our problems of building.” His design is always based on vernacular architecture and local climate which encouraged to do this research.

In neighboring country India, many indigenous technologies had been developed for heating and cooling of buildings. Gupta (1984) wrote passive system that the coolness of an old building on a hot summer afternoon never fails to improve the visitor and makes one wonder how the indigenous builders could create such comfortable buildings without the aid of modern scientific knowledge. “Every properly designed indigenous building uses more than one of the cooling methods to achieve satisfactory thermal condition”.” Microclimate control around the building is always important in indigenous design.” The valuable indigenous cooling methods used in India were explained with examples, illustrations clearly in his paper. This thermal comfort study shall be helpful to this research also.

For heating purpose in India, Prakash (1991) "Solar Architecture & Earth Construction- in the Northwest Himalaya" wrote that Building should be designed to be compact and attention should be paid to the creation of various thermal zones so that habitable rooms are located on the sunny side. Entrances to buildings should be through air locks as far as possible. The book explains the status of building design and construction in high altitude Himalayan cold area of Ladakh, India. The traditional and changing state of design of buildings from rammed earth construction to modern solar architecture in Ladakh is demonstrated through case studies with illustrations, graphs and calculation. The traditional and changing state of design of buildings in Ladakh shall be examples to compare in our context also.

Many indigenous technologies had been developed for cooling of buildings in hot climate of India. Kulbhushan and Jain (2000) wrote on a summer day, the temperature rises to $50^{o}$ C and the night drop down to as low as $20^{o}$ C in Indian desert but people in sharing and attempt to comprehend their life. Houses are compactly organized and sharing walls to protect each other from harsh climate in urban settlement. The courtyard is the most central space of the house in desert architecture where as courtyard is a similar space of the neighborhood houses in Kathmandu. The author interestingly reveals that the *Zharookha* can also be compared with the *"ghoonghat"* – a veil used by women in this part of the country comparing the privacy of life in building and women. But if one can compares it with the harsh climate of desert then this kind of *Zharookha* and *ghoonghat* needed in their life for comfort. The combination of traditional technologies of mud, brick, stone and timber with architectural elements and planning were well described with illustration. The valuable indigenous form, materials and technology for cooling methods in desert architecture of India were explained with examples, illustrations clearly in this book. This book shall be helpful to compare courtyard planning, technology and natural materials of Kathmandu in this research.

The another author Koenigsberger et al. (1975) published a book after working for ten years in India entitled Manual of Tropical Housing and Building. The book covers all the topics of climatology, thermal aspects, lighting and acoustics. The thermal conductivity, resistivity and transmittance of material and construction impact on the cooling and heating in interior of building. The theory of these terminologies has defined and described in this book very well. The thermal conductivity, resistivity and transmittance value of some materials and constructions were given in its appendix which is very helpful to compare in this study. The thermal balance in a building is maintained if the sum of the equation given in chapter 3.2.1 of the book is zero. This is important in this study. The book is also applicable to use design aids in different climates mostly in Tropical and sub-tropical region. The author gave good example of Baghdad city of Iraq for design aids using Mahoney tables to record the most essential climatic data, diagnosis of the climate and develops a series of climatic indicators and translates these into performance specifications or sketch design recommendations. The book is a good reference for theoretical knowledge for this research and also for students, researchers and architects.

Housing and Urban Development Corporation (HUDCO) India (1986) published a small booklet in Mud Architecture aiming to highlight advantages and disadvantages of mud for use in future housing programs in India. It describes mud as viable and attractive building materials with useful technical information. It attempts to solve the housing problems of India by using this material again in future with its improvements. It wrote that mud architecture can be an appropriate and sustainable solution to the urban and rural housing problem in India. It wrote that rooms in mud houses are often dark and badly ventilated but they provide comfortable living in the extremes of the tropical climate – warm in winter and, and cool in summer. Mud houses thus represent the best use of local resources and adjustment to local climate. The booklet is small in size but it has more information with report, policy, material, technology, guidelines and institution of mud architecture for researcher, architects, engineers and students. This booklet is helpful to know mud architecture of India and compare it with that in Nepal in my research.

Hudco  (Housing and Urban Development Corporation) India (1991) a book entitled in Reaching Homes to the people has been a pioneer in propagating the scientific use of mud technology. Over 65 million of nearly 118 million houses in India are of mud construction. The relevance of traditional building materials like mud in the context of modern technology and construction methods needs to be reassessed. It wrote that mud architecture can be an appropriate and sustainable solution to the housing problem in India. The book has more information with design, technology of mud, stabilized mud and examples of project works for researcher, architects, engineers and students.

Jagadish (2007) a book entitled in Building with Stabilized Mud wrote that stabilized mud has been in vogue in different parts of the world for nearly six decades. The material is appropriate and sustainable solution to the housing. The book guides researcher, architects, engineers and students with technology of stabilized mud. The author explained only technical use of Stabilized Mud in building in detail. He starts with selection of material, manufacture cost, etc. but did not write the thermal performance in his book. Jagadish et al. (2007) also wrote about the alternative technology needed to solve the problem of development in a developing country rather than high technology. The use of stabilized mud block, alternative mortars, filler slab and prefabricated roofs and masonry vaults and domes technologies and examples were given in this book. All the alternatives were developed from the traditional materials and technology. The book has more information with alternative material and technology for researcher, architects, engineers and students but does not mention about the thermal properties of these materials and technology.

Another author Majumdar (2002) in his book entitled in Energy – efficient buildings in India, edited and published the well organized and informative book from teri (Tata Energy Research Institute) India. It describes benefits of buildings tuned with nature and informs professional designers, builders and planners to bond their projects with the earth rather than other values. The book provides the benefits of energy- efficient buildings with examples, response to climate, traditional and innovative techniques, materials and renewable energy system. Most of the buildings in the book had designed considering heating and cooling for comfort using minimum alternative and natural energy and selecting appropriate materials, technology and building form. Most of the examples are designed considering climate with modern and traditional knowledge which must create better thermal comfort. This book is a good reference to study energy efficient buildings of India for students, researchers, planner and architects.

The author Krishan et al. (2001) published a book Climate Responsive Architecture – A Design Handbook for Energy Efficient Buildings, which covers the topics of principles and elements of Design and Design data. The book is applicable to use design tools for different climates of India. Different authors have written in different topics related to design with respect to climate. The main interesting topic for my research is Climate and Thermal Comfort in India which was written by Prof. Fergus Nicol. Prof. Nicol is one of the leading researchers of the world in adaptive thermal comfort. He wrote about the temperature standard, thermal comfort, ASHRAE standard and thermal comfort in India which are very useful in this research to broaden theoretical knowledge in this field. So the book is a good reference for students, researchers and architects.

There are many researches done in traditional buildings related to conservation aspects in India. But there are few studies done related to materials, technology and form of building with respect to thermal comfort. This is the knowledge gap which should be studied in future. Traditional architecture is decreasing dramatically, being replaced by artificial materials, modern designs and technology in India also. Researchers need to preserve this traditional architecture and develop the strong policies. Many writers wrote thick construction of traditional building has advantages of thermal condition without any calculation and temperature data. But there were no detailed studies about the thermal performance of building materials and technology. How is the indoor environment affected by this type of construction? These questions shall be raised in traditional buildings. If these questions were answered then we can say that traditional houses are better in the winter and summer than modern houses. We need to discuss also the potential of traditional material and technology with its merit. Also there is a need to discuss the energy saving from traditional material, technology and building design. So this study focuses on the detailed study of traditional material, technology and building design for thermal comfort and energy efficiency. This type of research is lacking especially in traditional buildings in Nepal which shall be answered through this study.

### 2.4 Thermal study in other countries

A number of researchers from round the world have dealt with the view that traditional architecture is more climate conscious than contemporary architecture in the world. They also wrote that there is a need to revive from old principles of theory and practices of traditional architecture than contemporary architecture in the world. Many researchers have discussed about vernacular architecture saying that it can play a part of role in future built environments of modern buildings. They argue that there are valuable lessons to be learnt from traditional knowledge, skills and expertise of the vernacular builders of the world. One of this knowledge is thermal comfort in traditional architecture.

Algifri et al. (1992) research compares the thermal behavior of adobe and concrete houses in Yemen which is important for this study. Their results show that the thermal appropriateness of the mud construction is a major saving of energy consumption for cooling and producing adobe houses. They wrote that traditional mud construction has been common for centuries in Yemen, where some buildings stood for 500 years. In contrast to modern buildings, these traditional buildings are cheap and thermally efficient. Most houses are of sun-dried mud bricks (adobe) with straw. The straw provides the thermal insulation and storage in adobe brick. The paper investigates the effect of building materials on the energy requirement and cost for providing comfortable living environment. Algifri et al. (1992) research is important to highlight the thermal behavior of traditional adobe and modern concrete houses for this study.

Meir and Roaf (2006) wrote in their research that dwellings are built to serve a variety of functions, but one of the most important is to create living conditions that are acceptable to their occupants, particularly in relation to prevailing climate. The materials, form, volume, services all that are used in house contribute to generate the micro climate of that house. The methodology used for this study is interesting to know the performance of vernacular buildings. The thermal performance of building with high thermal mass proved to be better in highland and mountain regions than the low lands and more humid coastal plains. Curved roof were found to perform thermally better than flat ones by promoting more comfortable indoors. The traditional materials, construction methods can be modified with minimal economic and environmental costs either by local traditional solutions or by using innovative processes based on traditional building methods, such as recycled or re-used waste materials. Today knowledge is important to provide more resilient and regionally appropriate for buildings to survive existences of twenty-first century. The result and discussions is important to be noticed in this study to compare with this study. This study is important before to start this research to broaden knowledge for thermal study in traditional architecture.

Lindsay and Vellinga (2005) edited a famous book, Vernacular Architecture in the Twenty-First Century where they wrote that Vernacular Architecture still occupies a significant position in a time of rapid technological developments and globalization. The book discussed about how vernacular can play a part in future built environments. The authors argue that there are valuable lessons to be learnt from traditional knowledge, skills and expertise of the vernacular builders of the world. One interesting fact written is that though actual numbers do not exist and estimates vary, vernacular dwellings, built by their owners and inhabitants using locally available resources and technologies, are presently believed to constitute about 90 percent of the world's total housing stock. The approximately 800 million dwellings of the world cannot be ignored within the context of future research for housing. All forms of vernacular architecture are built to meet specific needs, accommodating the values, economics and ways of living of the cultures that produce them. This book gives the lessons to understand challenges, importance and opportunity of vernacular buildings of world.

Tassiopoulou et al. (1996) research compares two types of traditional dwelling in Greece to study thermal behavior. Since 1945 as in Nepal, new type of buildings were quickly adopted with modern concept and materials like RCC concrete, blocks, brick in Greece also. Many of these modern buildings had relatively poor thermal performance in warm-temperate climate of Greece. Many beneficial design features of vernacular buildings have been ignored. There is also now a greater awareness of the importance of socio cultural identity and of the need to conserve traditional buildings and townscapes. The study analyzed the thermal performance throughout the year. The results show that 28 $^{o}$ C would be considered to be a comfortable room temperature in Greece which is also true within comfort range in summer condition in Kathmandu (Nicol & Rijal standard -Table 2.2).The study concluded that the vernacular dwelling in its historic context was predicted to have been comfortable in use during both summer and winter.

The research of Ahmad et al. (1985) may be a good example to compare with buildings of Kathmandu in material, construction and old age with respect to thermal comfort. Their study shows that the indoor temperature is 35 $^{o}$ C in modern house whereas the indoor temperature is only 28$^{o}$C in traditional house in the old city in the same summer period in Ghadames, Libya. They wrote in the old city some buildings nearly 600 years old are still in a reasonably good condition with careful maintenance. Clay mixed with organic matter is its main building material. The family use heavy weight construction in the ground for summer day and relatively light weight in first floor for winter. Modern housing developments show very little regards for the local culture, climate and geographical resources. New buildings, therefore consume large amount of energy to maintain indoor thermal comfort. The study shows the old houses can provide a year round comfortable environment, however the new houses are unable to provide indoor comfort in summer as well as winter. This study with case of thermal comfort in traditional and modern buildings is important in the case of Kathmandu for comparison.

The paper of Ahmadreza et al. (2012) on residents' perception of earthen dwellings in Iran findings show that traditional buildings are not considered to be out–of- date, but residents noticed highly cultural and historic values of their house. The study of vernacular spaces, buildings, places and urban areas retain certain valuable positive aspects which are still relevant to the current challenges for building sustainable environment. That is why these buildings are still cited in academic literature as model of sustainable practice. However some negative factors have also been assigned to vernacular earth houses including low structural stability, low space efficiency, difficult internal access and inconvenient clean up and maintenance. The research focuses the balance between positive and negative factors. If the negative factors outweigh positive ones then no balance is removed. These factors justify why vernacular houses are replaced by modern counterparts or used for new purposes. This study is true for Kathmandu in Nepalese context as well as all over the world.

Ahmadreza (2011) in the paper on vernacular architecture questions of comfort and practicability as a study of the environmental performance and sustainability of vernacular architecture with case study in Iran. In case of vernacular passive cooling strategy in Iran, the system as a whole does not indeed manage to reduce the indoor temperature of houses, but it does so only to a certain extent and under specific circumstances. The study focuses good example that none of ground floor rooms in buildings with only vernacular passive cooling systems has a comfortable temperature throughout an entire typical summer day. This means that the inhabitants are left with the basement as the only place in house that is consistently cool. The study indicates that the choices people make in relation to the continuation or abandonment of specific traditions are influenced by a variety of factors: the environmental performance of the spaces, forms and features of a building, and a whole range of cultural factors with cost, convenience, cleanliness, aesthetic, functionality and health. The study provides a number of important conclusions for vernacular architecture which is useful for every part of the world.

Hanafi (1994) in his paper shows that the traditional Malay house is a climatically responsive building evolved from centuries of experience and observations of climate and nature. But the forces of modernization and changes in values override the established forms of building to produce new forms which are unable to withstand the challenge of the Malaysian climate. Therefore traditional values and qualities of Malay houses undergo a reappraisal, advantages and disadvantages and their applicability to improving housing quality. The paper compares both traditional and modern houses. In the hot humid climate of Malaysia neither traditional nor modern housing techniques provide a completely satisfactory solution to meeting ideal human thermal comfort requirements nowadays. There is a need to produce a new solution drawing on the advantages of both housing types, whilst taking in to consideration the changing needs of the Malaysian population. There is an urgency for designers to acquire a better understanding of the relationships between climate, building and man. Hanafi outlines some of the choices with diagrammatic sketches and makes comparisons between traditional and new forms of construction. This study is true for Kathmandu in Nepalese context also.

Rahman (1995) in his paper compared traditional Malay house and modern low-cost housing in Malaysia. The study found the Malaysian Comfort Temperature has been found 25.5 to 28.5 $^{o}$ C which may falls down to 28 $^{o}$ C under the comfort zone temperature of Kathmandu only for summer (Table 2.2). At night time, the traditional Malay houses cool rapidly and almost leveled with the outdoor air temperature whereas the modern houses retain higher air temperature throughout night in hot humid climate in Malaysia. In Malaysia neither traditional nor modern housing techniques provide a completely satisfactory solution to meeting ideal human thermal comfort requirements nowadays. The result shows that the traditional Malay houses were still the better choice for overall thermal comfort in comparison with modern house.

The research paper entitled on "A Thermal Comfort Field Survey in the cool season of Zambia" by Malama and Sharples (1997) show that the contemporary houses performed better than the traditional house in cool season of Zambia. The study was made in typical traditional and contemporary houses of Zambia. The study was done in the cool season only not in all seasons of the whole year. The results of the thermal comfort survey only in cool season proved that the both type of contemporary and traditional houses are uncomfortable in the cool season in Zambia. The study concluded that traditional houses are more uncomfortable than contemporary houses in this season but it should be studied for both seasons in hot and cool seasons to draw the conclusion.

Malama and Sharples (1996) result shows that the roof is the most important component of the house with regard to passive cooling in the tropical upland climate. The study concluded that improvements in either the construction or colour of the roof surface had significant impacts the internal temperatures. The study was done in low-cost housing in tropical upland climates of Zambia. Some of the characteristics of the climate and topography are similar to Kathmandu to compare and study. The altitude, annual rainfall, high solar radiation and cold season are similar to Kathmandu. During summer, the average indoor temperature is 27.2 $^{o}$ C while comfort limit is 30 $^{o}$ C in Zambia whereas indoor temperature is 26 $^{o}$ C while comfort limit is 28$^{o}$C in Kathmandu. The study also wrote the weakness of the Model used that it has no provision for considering the effects of shading devices. Also wrote all input data are assumed to be repeated on a 24 hour cycle, which leads to some error.

A book written by Rapoport (1969) "House Form and Culture" describes well about conceptual frame work and affecting factors for great variety of houses and its form. One should notice following phrases to research in traditional architecture. "Characteristics of primitive and vernacular buildings are that they typically respond to climate very well". "Building needs to respond to heat, cold, ground and sky radiation, wind and other stress and the various parts of building may be considered as environmental control devices"."Provide a "heat sink", absorbing heat during the day & reradiating it during the night, thus increasing the time lag." "Traditional housing better satisfies in many areas than new housing". He also quoted "So, traditional housing is much more acceptable in developing countries". Rapoport suggests, by looking at vernacular design as a model system. This phrases and views should be studied through research which will be tested in my research for traditional architecture of Kathmandu.

Another related work done was a Master degree thesis research by Paruj (2005) “Lessons from traditional architecture: Design for a climate responsive, contemporary house in Thailand” from University of Portsmouth. He compared the performance of internal thermal comfort of traditional Thai houses with typical contemporary Thai houses of different regions of Thailand. The research questions were helpful to arise me research questions in this research also, such as “Do traditional Thai houses perform better than a typical contemporary Thai house inefficiently creating comfortable internal conditions?” “Can we learn anything from traditional Thai houses to improve comfort & energy efficiency in contemporary houses?” The research method and parameters with building form and building materials were very much useful to this research.

The heating and cooling of buildings have been big deal for people all over the world. After energy crisis in the 70’s, North Americans became more energy conscious and more willing to save energy. The energy cost for heating and cooling of building became so high. So Sordi (1984), "GUIDEBOOK-A brave Renewable World” published to guide for homeowners to save energy reducing dependence over non-renewable energy. The book covers topic from energy conservation techniques to photovoltaic. Simple methods were described with design, drawings, details, calculation, and tables for energy conserving features. The technology described in the book shall be fruitful for energy conservation and cost saving in our traditional and modern buildings.

A book written by Groat and Wang (2002) in Architectural Research Methods, well describe about conceptual frame work for architectural research. The book was dedicated to only architectural research in two parts. One part has domain of architectural research and other part with seven research strategies. This book should be studied before to start any architectural research. This book was very helpful to design research methodology as well as to start frame work. Also the book is useful to organize chapters during research work. This book is also very much helpful when one starts writing the thesis in architectural research.

There are many studies done in traditional buildings related to thermal studies, sustainable development and conservation aspects in the world. In every part of the world, the traditional vernacular architecture is decreasing dramatically. These are replaced by modern designs, new materials and technology in the world. Researchers report needs to preserve this architecture. Many writers say this is sustainable architecture which saves environment of the world. Many writers wrote about advantages of material, technology and form of this building in the world. But there were no detail study in materials and technology for thermal performance of building. How does the indoor environment affected by this type of construction? But there is no any such study done related to materials, technology and form of building with respect to thermal comfort. If these questions were answered then we can say traditional houses are better than modern houses. We need to discuss the energy saving from traditional material, technology and building design. So this study focused on traditional material, technology and building design for thermal comfort and energy efficiency. This type of research is lacking in the world which shall be answered through this study.

## 2.5 National and International standard for thermal comfort

The understanding of thermal comfort and standard varies from past to present. There are new theories and understandings for comfort and standards. The adaptive thermal comfort standards were already developed in Europe and America. There are three well-known and widely used international standards that relate specifically to thermal comfort: ISO Standard 7730 (2005), ASHRAE Standard 55 (2004) and CEN Standard EN15251 (2007). All these standards are under continuous review; so it is necessary to check for updates. Nowadays, "Adaptive" approach to thermal comfort which is now finding an increasing international following for thermal comfort understanding. In particular Prof. Nicol Fergus was jointly responsible with Michael Humphreys to develop the "Adaptive" approach in modern theory of thermal comfort. The Nicol adaptive thermal comfort shall be discussed in this chapter as international standard. Following Nicol adaptive thermal comfort, Rijal also did many researches and derived some standard as national standard in Nepal. The thermal comfort reviewed and developed by Rijal shall be discussed in this chapter as thermal standard for Kathmandu.

The American society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) defines thermal comfort for a person as "that condition of mind which expresses satisfaction with the thermal environment." The ASHRAE standard was first international standard to include an adaptive standard that applies for 'naturally conditioned' buildings also. The standard uses the relation between the indoor comfort temperature and the outdoor temperature in naturally condition buildings in which the principal means of control of indoor temperature is use of windows. The thermal environmental condition for human occupancy was approved by the ASHRAE standard committee on 24 Jan 2004. The purpose of this standard is to specify the combination of indoor thermal environment factors and personal factors that will produce thermal environment conditions acceptable to a majority of occupants within space. The environmental conditions required for comfort are not same for everyone. There are large variations, physiologically and psychologically, from person to person, so it is difficult to satisfy everyone in a space. According to ASHRAE, there are six primary factors that must address when defining condition of thermal comfort. The primary factors are: Metabolic rate, Clothing insulation, Air temperature, Radiant temperature, Air speed and Humidity. All these six factors vary with time. ASHRAE introduces that on a scale ranging from hot to cold the state of thermal comfort is described as "neutral". This "neutral" state of thermal comfort for Kathmandu was used in Table2.2 in this study from Nicol and Rijal comfort graph and table (Table 2.1& Fig.2.1).

The adaptive standard CEN Standard EN15251 was developed by the comite European de Normalization (CEN) is similar to ASHRAE Standard 55. The adaptive standard in EN15251 and ASHRAE Standard 55 are derived from different data base for naturally conditioned buildings. According to terms and definition of CEN Standard EN15251, the adaptation is physiological, psychological or behavioral adjustment of building occupants to the interior thermal environment in order to avoid discomfort. In naturally ventilated buildings these are often in response to changes in indoor environment induced by outside weather conditions. According to acceptable indoor temperature for design of buildings without mechanical cooling systems of CEN Standard EN15251, includes 3 categories of temperature limits for use as outlined as in figure 2.2. ISO Standard 7730 sets out the calculation and use the index and criteria for local comfort. This standard specifies 'classes' or 'categories' of buildings according to range of PMV (predicted mean value).

In this study, only some of the ASHRAE standards were followed as guidelines to study for thermal comfort in chapter 3, 4 and 5. The ASHRAE scale of thermal comfort and categories were followed and developed as guidelines to compare adaptive thermal comfort of Nicol and Rijal data (Table 2.2) in this chapter. The comfort temperature and comfort zone of three categories from Table 2.2 was developed from ASHRAE scale. This was used to compare the evaluation of thermal behavior of experimented houses in chapter 4. Some of the ASHRAE standards were followed as guidelines to design sample of questionnaire survey for thermal comfort of occupants in chapter 5. A table with sample of questionnaire survey for occupants was designed and developed regarding informative appendix E – thermal environment survey of ASHRAE table. A table of questionnaire survey in Table.5.1 has been developed with name of surveyor, occupant name, date, occupant activity, building type and few questions.  A Table.5.1 designed nine scale systems referring seven scale system of thermal sensation scale of the ASHRAE to quantify people's thermal sensation in the questionnaire survey. The question of thermal sensation is prepared with nine scale, o as neutral, + 1 slightly warm, - 1 slightly cool, +2 warm, -2 cool and others with referring this appendix E. This survey is discussed, analyzed and results drawn in the chapter 5.

### 2.6 Nicol and Rijal - Adaptive Comfort Temperature for Kathmandu

There are new theories and understandings for thermal comfort and standards that vary from past to present. Nowadays, "Adaptive" approach to thermal comfort is increasing internationally as new understanding. Prof. Michael Humphreys and Prof. Nicol Fergus from United Kingdom developed the "Adaptive" approach of thermal comfort. They did many researches in building physics and human thermal comfort. They led substantial thermal comfort research projects in the UK and Pakistan. Nicol et al. (2012) paper on titled "the principle and practice of adaptive thermal comfort" studied, discussed and derived the new theory of adaptive thermal comfort. Thermal comfort is a basic requirement for happiness and productivity in the workplace. Thermal comfort is that state of mind which expresses satisfaction with the thermal environment. The thermal sense located in brain and the skin. Its purpose is to keep body temperature constant and warn of dangers of this. Thermal discomfort is associated with cold hands and feet and heat discomfort is associated with flushed skin and with more sweating. The studies define comfort as achieved either by the occupants adapting to the building or by the occupants adapting the building to suit them. The study opens that comfort has to be done within existing climatic, social, economic, architectural and cultural context.

The Nicol graph (Nicol et al. 1994) is an approach to develop customary temperature for naturally ventilated buildings. The Nicol graph starts from findings that the temperature which people find comfortable in indoors varies with the mean outdoor temperature. This is very true for people in buildings which are free running and not mechanically heated or cooled. According to Nicol, the 'comfort temperature' is the temperature which people finds comfortable in a given situation. Humphreys and Nicol (2000) gave an equation for indoor comfort temperature $T_c$ for free running buildings as: $T_c = 13.5 + 0.54\ T_{o.}$ Using this equation, a comfort temperature can be calculated for each month of the year knowing outdoor temperature $T_{o.}$ This Nicol equation was used in Table 2.1 and Figure 2.1 to get the indoor comfort temperature in Kathmandu valley. According to Nicol graph (Table 2.1 & Fig. 2.1) the indoor comfort temperature in Kathmandu valley is $26^o$ C in summer and $19^o$ C in winter.

In national context, Rijal also did many researches and derived some standards in Nepal. Rijal published many research papers regarding adaptive thermal comfort of the traditional houses of different regions of Nepal. The comfort indoor temperature for several places of Nepal in winter and summer was calculated by Rijal by using Griffiths method (Griffiths 1990, Rijal et al.2008).In his research; he developed the comfort indoor temperature for Banke, Bhaktapur, Dhading, Kaski and Solokhumbu district. It is interesting to know that the comfort indoor temperature is different in different places due to different climates in Nepal. According to Rijal, the indoor comfort temperature for Bhaktapur in Kathmandu valley is $26^o$ C in summer and $15^o$ C in winter (Table 2.1 & Fig. 2.1) which shall be more appropriate to Kathmandu as he developed it from field survey.

The Nicol and Rijal result is important to compare the thermal performance of traditional and modern buildings in this study in Kathmandu. Therefore, the comfort temperature is $26^o$ C in summer and $19^o$ C in winter (Nicol et al. 1994) and $26^o$ C in summer and $15^o$C in winter (Rijal et al. 2010) in Kathmandu valley were taken as comfort standard to compare the thermal performance of traditional and modern buildings in Kathmandu in this study.

The comfort zone is developed with the formula $T_{cz} = T_C \pm 2\,^{o}C$. The thermal sensation with comfort categories and temperature for comfort zone were calculated and shown in Table2.2. Then comfort zone temperature shall $15 \pm 2\,^{o}C$ in winter and $26 \pm 2\,^{o}C$ in summer in Kathmandu according to Rijal. According to Nicol, comfort zone temperature shall be $19 \pm 2\,^{o}C$ in winter and $26 \pm 2\,^{o}C$ in summer in Kathmandu. The Table2.2 shows the comfort zone temperature is $13^{o}$ C in winter and $28\,^{o}$ C in Kathmandu according to Rijal. According to Nicol, comfort zone temperature is $17^{o}$ C in winter and $28^{o}$ C in Kathmandu. The both comfort zone temperature same in summer but during winter it differs between Rijal and Nicol. This mean comfort temperature and comfort zone shall be used as adaptive thermal comfort standard in chapter 4 in this study to compare adaptive thermal comfort level in the traditional and modern houses of Kathmandu.

Table 2.1 Mean outdoor air temperatures and indoor comfort temperature according to Nicol and Rijal $T_c$ graph for Kathmandu

| | Average Temperature | Average High Temperature | Average Low Temperature | | | Average Precipitation mm | Highest Recorded Temperature C | Lowest Recorded Temperature C | Average Number of Days Above 90F/32C Days | Average Number of Days Below 32F/0C | Most Rain Reported in a Month mm | Average Morning Relative Humidity % | Average Evening Relative Humidity % | Average Dew Point C | Average Wind Speed km/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Tc (Nicole) | Tc (Rijal et al. 2010) | | | | | | | | | | |
| Jan | 10 | 15 | 4 | 18.9 | 15.2 | 10 | 25 | -2 | | 3 | 60 | 97 | 65 | 5 | 8 |
| Feb | 12 | 17 | 6 | 20.0 | | 10 | 26 | -1 | | 1 | 40 | 96 | 58 | 6 | 9 |
| Mar | 15 | 21 | 10 | 21.6 | | 30 | 30 | 2 | | | 70 | 94 | 50 | 7 | 14 |
| Apr | 19 | 25 | 13 | 23.8 | | 30 | 33 | 5 | | | 90 | 90 | 48 | 10 | 12 |
| May | 21 | 26 | 17 | 24.8 | 25.6 | 100 | 35 | 8 | 1 | | 240 | 92 | 59 | 15 | 12 |
| Jun | 23 | 26 | 20 | 25.9 | | 200 | 37 | 12 | 1 | | 330 | 93 | 70 | 18 | 9 |
| Jul | 23 | 26 | 21 | 25.9 | | 370 | 31 | 15 | | | 590 | 96 | 80 | 20 | 9 |
| Aug | 23 | 26 | 21 | 25.9 | | 320 | 32 | 16 | | | 560 | 95 | 79 | 20 | 8 |
| Sep | 22 | 25 | 19 | 25.4 | | 180 | 32 | 13 | | | 300 | 97 | 78 | 18 | 8 |
| Oct | 19 | 23 | 15 | 23.8 | | 50 | 32 | 7 | | | 180 | 97 | 73 | 14 | 9 |
| Nov | 15 | 20 | 9 | 21.6 | | | 30 | 2 | | | 20 | 97 | 71 | 10 | 8 |
| Dec | 11 | 16 | 5 | 19.4 | | 10 | 23 | -1 | | 1 | 70 | 98 | 68 | 6 | 8 |

Table 2.2 Adaptive Indoor Comfort Temperatures and Comfort Zone from Nicol and Rijal comfort temperature ($T_c$) in summer and winter for Kathmandu

| S.No. | Thermal Sensation | Thermal Scale | Nicol Summer | Tc (oC) Winter | Rijal Summer | Tc (oC) Winter | Comfort Category | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | Hot | 3 | 32 | * | 32 | * | Very Uncomfortable | |
| 2 | Warm | 2 | 30 | * | 30 | * | Uncomfortable | |
| 3 | Slightly Warm | 1 | 28 | * | 28 | * | Comfortable | Comfort Zone |
| 4 | Neutral | 0 | 26 | 19 | 26 | 15 | Very Comfortable | |
| 5 | Slightly Cool | -1 | * | 17 | * | 13 | Comfortable | |
| 6 | Cool | -2 | * | 15 | * | 11 | Uncomfortable | |
| 7 | Cold | -3 | * | 13 | * | 9 | Very Uncomfortable | |

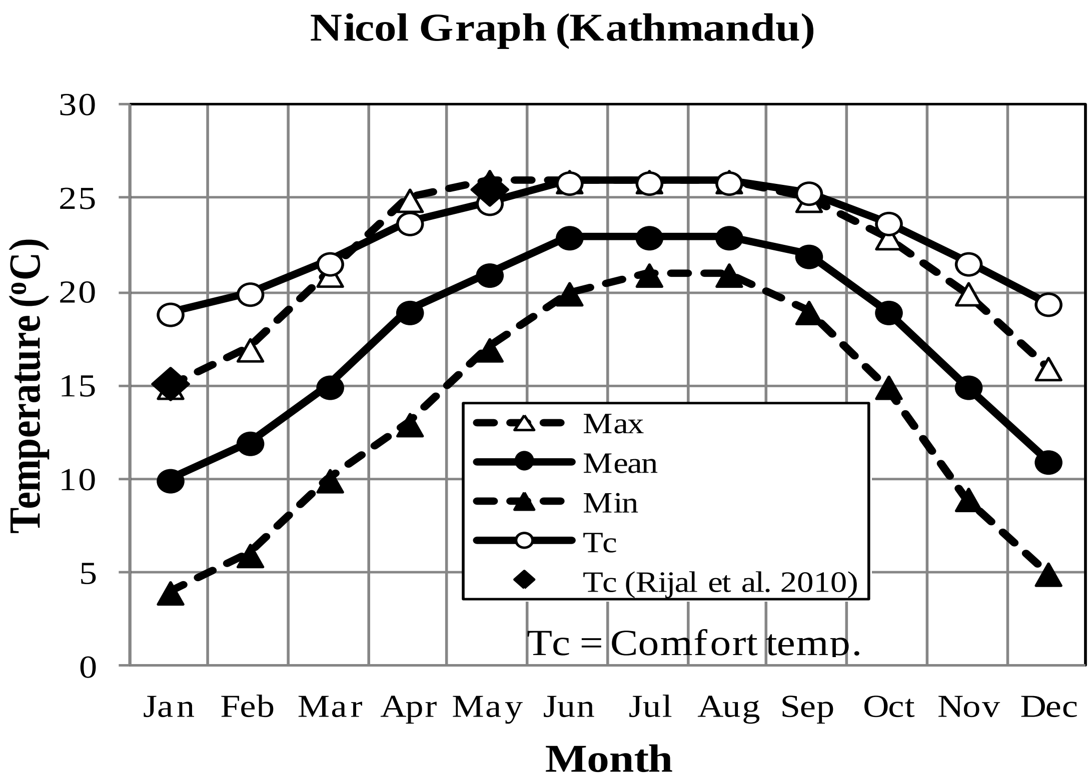



Fig. 2.1 Outdoor air temperatures and the indoor comfort temperature ($T_c$) for residential buildings of Kathmandu, Nepal (Source: Nicol graph (1994) & Rijal et al. 2010)

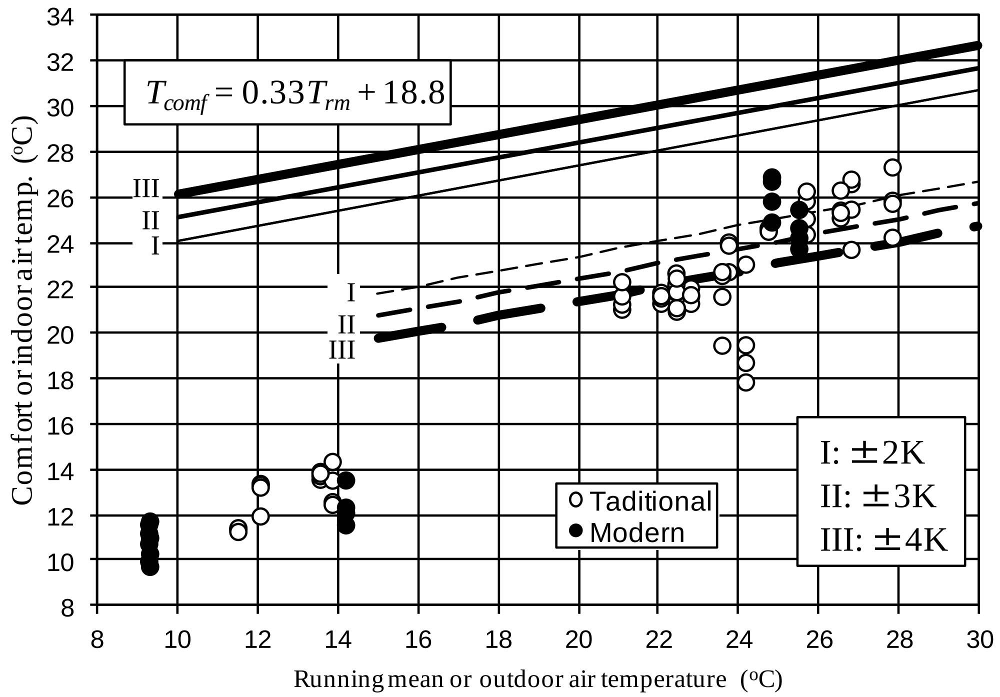



Fig. 2.2 Comfort temperature ($T_{comf}$) and mean outdoor air temperatures for residential buildings of Kathmandu, Nepal (Source: CEN)

**2.7 Traditional residential building**

### 2.7.1 History and geography

Nepal is a small Himalayan republic between India and China which lies in between 26 $^{o}$ 22' -30$^{o}$27' N and 80 $^{o}$40' - 88 $^{o}$ 12' E (Fig. 2.4) .Though Nepal is a small and landlocked country, it is interesting that it has almost all climate of the world from low land of south to high land of north. Nepal has only 147,181 square Kilometre land area. But the climate varies from sub-tropical to tundra due to the wide altitude difference from 60 to 8848 metre. The early history of Nepal starts from Kathmandu valley which is the capital of Nepal. Kathmandu lies in central part in hilly region of the country. There were three major traditional towns of Kathmandu, Bhaktapur and Lalitpur in the valley. In these towns, where the builders in medieval times have created own comfortable residences with urban environment considering climate by special passive design. It is said that the civilization of Kathmandu started with Maha Manjushree, according to Buddhism and Pradhumna, son of Lord Krishna according to Hinduism when they had drained the lake and establish the settlement with traditional shelter with natural material.

Fig. 2.3 Views of traditional residential buildings of Kathmandu valley

The human civilization has developed with new shelter hut from bamboo, timber, straw and mud. With the passage of time, new materials and construction technology were searched to create human safety and comfort as in every civilization. Same way, people of Kathmandu had developed own civilization many centuries ago building traditional houses in traditional settlement of Kathmandu. They used own traditional materials, technology and forms considering geography, religion, culture, tradition and climatology of the valley. The architecture of Kathmandu valley has been developed from experience of thousands of years. People survived in this building from generation to generation. These residential buildings have special characteristics like slope roof, thick construction technology, brick exposed wall, low floor height, multilayer wall, vertical space planning, row planning, etc.


Fig. 2.4 Map of Nepal in between India and China

### 2.7.2 Climate of Kathmandu

Kathmandu lies in subtropical region but due to altitude nearly 1200 metre above sea level, it has composite climate. Generally, it is divided into four seasons: winter, summer, autumn and spring. But the Kathmandu's climate has three distinct seasons, i.e. cool dry, hot dry and warm wet seasons. The cool dry season lasts from November to March. It is characterized by low temperature of about mean minimum of $3^o$ C during night (Table 2.3). December, January and February are the coldest months. Sometime, the temperature goes below $0^o$ C during night and it was recorded minimum $-2^o$ C. The winter months have a mean maximum air temperature is about $19^o$ C during day. The relative humidity is low 50-60% during winter. Sky is fuggy in the morning during winter.

The climate of Kathmandu is generally dry and hot in May and June. The summer months have a mean maximum air temperature is about $30^o$ C and minimum is about $20^o$ C. It has a very high diurnal range more than $10^o$ C. During summer, the relative humidity is 50-60% and sky is sunny. The main feature of this season is hot days and warm nights.

Fig. 2.5 Views of Kathmandu Valley

Generally monsoon season is warm wet and it lasts from June to August months. The total rainfall is more than 1000 mm in a year. But ninety percent of rainfall occurs during only monsoon season. During this season, rainfall of about 800 to 1000 mm may occur. The relative humidity is high during monsoon season. The relative humidity is around 78% during monsoon period in the last ten years (2002-2011) according to Meteorological Department of Government of Nepal. The sky is cloudy. The landscape is relatively flat as it is valley. The vegetation grows quickly in monsoon period.

In summary, due to altitude, Kathmandu has cool during winter nights. Kathmandu lies in low latitude 27$^{o}$ N, solar radiation is high during summer. During sunny days, solar radiation is also high in winter. So the day time is warmer than night time during winter. To achieve thermal comfort, it is important that the high level of solar radiation and high temperature are allowed through thermal mass with passive technology in the building interior in winter. The summary of mean climatic data (2002-2011) of Kathmandu from Meteorological Department, Government of Nepal was shown in Table 2.3.

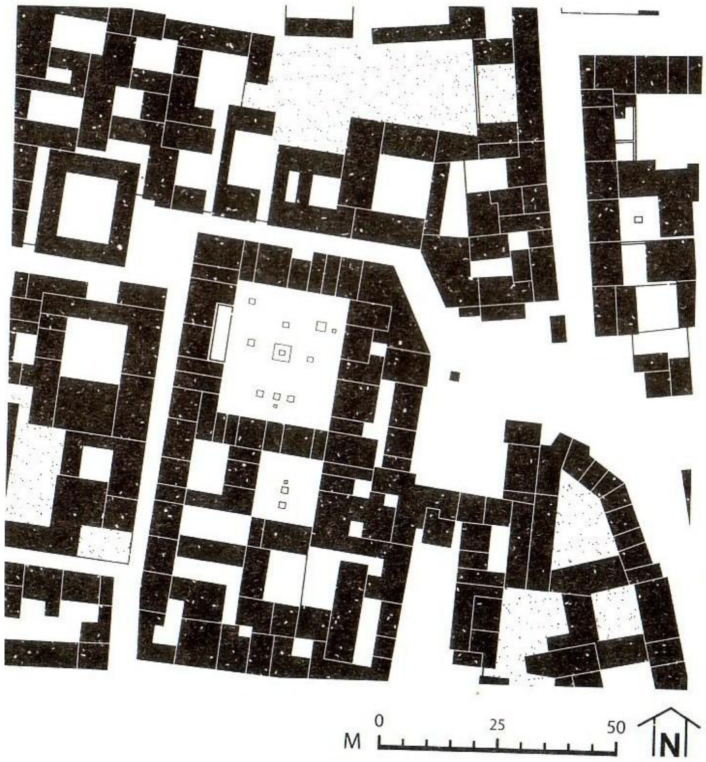
Table 2.3 Climatic data of Kathmandu (Source: Meteorological Department, Government of Nepal)

| | |
|---|---|
| Climatic feature | Composite climate |
| Landscape | Relatively flat |
| Vegetation | Abundant vegetation |
| Solar radiation | Intense in summer & diffused in monsoon |
| Ambient temperature: | |
| Summer day | mean maximum 30$^{o}$ C |

| | |
|---|---|
| Night | mean minimum 20$^o$ C |
| Winter day | mean maximum 19$^o$ C |
| Night | mean minimum 3$^o$ C |
| Diurnal variation | > 10$^o$ C |
| Relative humidity | 78% (Monsoon) & 50-60% (Summer & Winter) |
| Precipitation | >1000 mm per year |
| Winds | Variable |
| Sky conditions | Clear sky (Summer) & Generally overcast (Monsoon) |

### 2.7.3 Planning

Kathmandu valley is situated in the hilly region of the Nepal. There were three major traditional towns of Kathmandu, Bhaktapur and Lalitpur in the valley. In all these towns, the builders in medieval times had created own comfort residences with urban environment considering climate by special passive design. These towns show a distinct set of public open spaces with clear hierarchy of social cultural activity. These are the Palace (*Durbar*) square, market square, residential neighborhood square and private residential square (Tiwari1988). The residential neighborhood and private residential square were planned with linear alleys and courtyard system, which is often opportunity to use the climatic factors like sun, wind, humidity etc.




1.3 Tadhan Tol, Kathmandu

Fig. 2.6 A traditional settlement of Kathmandu valley (Source: Korn 1976)

The simple geometrical square or rectangle shaped residential courtyard with surrounding row residential buildings blocks create own microclimate giving the much needed direct and indirect heat gain from sun and protect from cool breeze from outside in cool winter. These open spaces gain heat during the day and emit heat during night. The two sides of building blocks open toward either street or courtyard (Fig. 2.6). The direct radiation received maximize through the thermal mass of its open courtyard and surrounding buildings. The enclosed courtyard acts as a common social activity space in winter days and summer evenings. The size of the courts are nearly equal to height of the building i.e. 3-4 storey (Fig. 2.7).

### 2.7.4. Three-dimensional plan form

In Newari architecture of Kathmandu, this type of building developed, most probably, from early Malla period (Scheibler1982). The basic traditional house of private residential square (Fig. 2.7) was designed with vertical spatial planning around a courtyard or street. Security considerations and the need to use as little irrigable land for building purposes, caused the Newari house to be vertically oriented (Korn 1976). The building plan covers nearly 54 square metres land which is very less compared to modern practice in Kathmandu. So this type of house has to be vertically oriented as said by Korn. The house consists of three to four storeys with utility rooms in heavy ground floor (*Chheli*). The bed rooms are located in first floor (*Chotan*). The living room is located in second floor (*Matan*) and kitchen, dining, puja and store in attic (*Baiga*).

Fig. 2.7 A traditional house of private residential square (*Chukachhen*) in Patan

The main consideration of residents' life style is to spend more time engaging in social activity in warm spaces in winter and cool spaces in summer. In this way, comfortable spaces first floor and second floor use as living spaces where as the less comfortable spaces attic and ground floor are used always as buffer space during hot and cool night. The plan incorporated along with staircase and ventilation (*Bhau pwa*) in slope roof for ventilation. The open space height of the courtyard is maximum ten meters. The main consideration in winter is to achieve thermal comfort with increasing solar gain in building and courtyard. This is effectively done by the combined effect of direct and indirect solar gain of lower winter Sun through openings, external special thick wall and thermal mass of courtyard. Mostly stone or bricks are paved as thermal mass on courtyard. The enclosed courtyard acts as a social activity space in winter days and summer evenings (Fig.2.7). This was largely confirmed by the results of the field study, laboratory study and questionnaire survey in the following chapters.

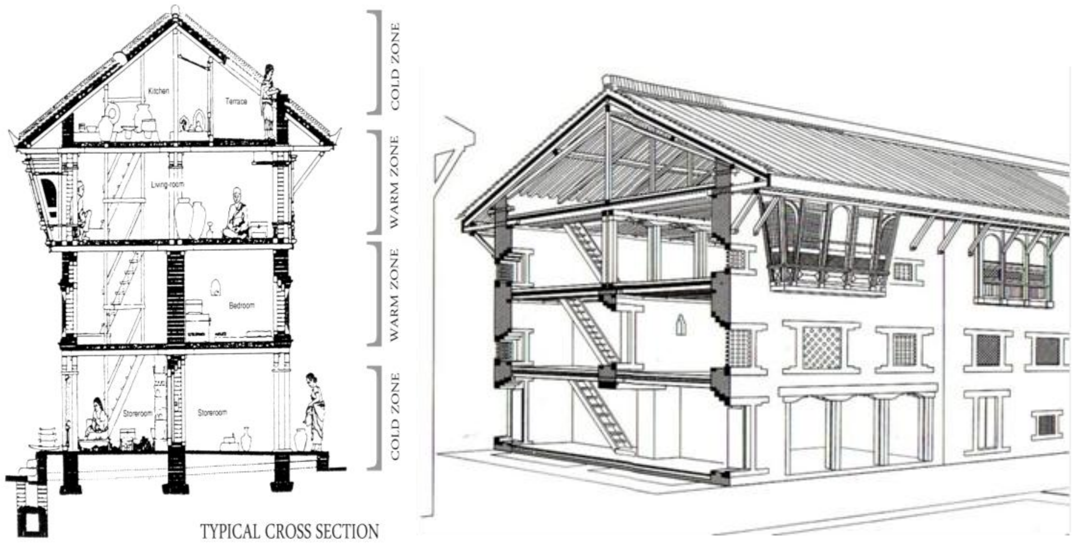



Fig.2.8 Three-dimensional vertical plan of traditional residential building of Kathmandu (Source: Korn 1976)

### 2.7.5. Material and Construction Technology

The traditional architecture of the valley developed with mud architecture as in most of part of ancient architecture of the world. The major building material is sundried brick, burnt brick, mud mortar, mud plaster, clay tile, timber and stone (Fig 2.9). The external exposed brick wall built with dull color and rough surface acts as absorbent of solar light and heat. The thick load bearing wall of 450 to 600 mm built with multilayer of Burnt Red brick *(pakki apa*), Sun dried brick *(kachi apa*) and mud plaster placed from outside to inside in external walls. One layer of burnt bricks are used to exposed for weather resistance where as sun dried bricks are use in ¾ part of wall in inner side. Mostly the central load bearing wall consists of 450 mm built with only Sun dried brick *(kachi apa*) and mud plaster. These thick walls act as thermal mass in traditional building. The thick multilayer of Burnt Red brick *(pakki apa*), Sun dried brick *(kachi apa*) and mud plaster placed from outside to inside in external walls may use as storage of solar heat gain.

The openings are generally solid with small glazed surface or lattice timber shutters. The thick floor with combination of mud, brick, timber plank and joist also act as thermal mass. Similarly, a thick slope roof consists of clay tiles, compacted mud supported by wooden plank and joist (*Dalin*). A thick sloped roof of clay tiles compacted with mud supported by wooden plank and joist (*Dalin*) has large time lag and it reduces heat loss. A large projection of slope roof acts as effective shading device not only for the openings but also for the walls in summer and also protects from monsoon rain. The raised peti (*Pha*) as a part of foundation constructed around the residence also protects from dampness and monsoon rain. The peti (*Pha*) constructed around courtyard towards façade of the residence. All doors and windows open towards the front or back courtyard of two bay maximum 6 metres depth residence. Openings are generally of moderate size fitted with solid or lattice timber shutters. Openings act as an important design element.

Fig. 2.9 Timber joist, brick, mud mortar and clay tiles as building materials used in traditional residential building

### 2.7.6 Building form and facade

Generally, the façade developed in traditional building such a way that it consists of golden proportion with perfect square or rectangular. Mostly the rectangular plan has nearly 9 metres length by 6 metres width. The ceiling height is low with nearly two metres.  The traditional building consists of three-four storeys with slope roof. So the façade is nearly nine to ten meters high. A clay tile roof is used with $25^{o}$ to $35^{o}$ slope. Mostly a slope roof is used as traditional architectural form to drain off easily the heavy rainfall during monsoon season of Kathmandu .Also nearly 1 metre long projected slope roof acts as effective shading device not only for the larger openings but also for the walls in summer and also protects from driving rain.


Fig. 2.10 Views of traditional residential buildings in traditional settlements of Kathmandu valley

The building in traditional architecture has exposed brick façade which is red in color and rough texture. Small lattice window is placed in ground floor. Either lattice or single window is located mainly in bedroom in first floor. A larger dormer window (*Sanjhya*) is placed below the roof projection in living room of second floor. All doors and windows open towards the front or back façade because of two bay maximum six meter depth residence. Openings act as an important design element in Newari architecture. The plan is incorporated along with staircase and ventilation (*Bhau pwa*) in slope roof for ventilation. The open space height of the courtyard is maximum of ten meters. Façade design is in symmetric geometry with odd number of window in each floor. But most of building façade does not repeat the same window vertically. It creates aesthetic quality in façade in this building.

### 2.7.7 Passive building design

The literature review and field studies show that cluster planning, orientation, land use form, mud architecture, thick walls, thick floor, low volume room were the most wide spread vernacular passive heating and cooling system in composite climate of Kathmandu. This was largely confirmed by the results of the field study, laboratory study and questionnaire survey in the following chapters. The main consideration of design in winter is to achieve thermal comfort with increasing solar gain in building and courtyard. This is effectively done by the combined effect of direct and indirect solar gain of lower winter Sun through openings, external special thick wall and thermal mass of courtyard. Mostly stone or bricks are paved as thermal mass on courtyard. The enclosed courtyard acts as a social activity space in winter days and summer evenings. It is desirable to higher rate of temperature rise of the interior during day time in winter. The thick load bearing wall of nearly 450 mm or 600 mm built with multilayer of burnt red brick (*pakki apa*), sun dried brick (*kachi apa*) and mud plaster placed from outside to inside in external walls. It may lead to use as storage of solar heat gain for time lag min 8 -10 hours (Tiwari 1988). The combined effect of thermal mass of courtyard and external thermal wall of residence is effective to increase direct solar gain and stores solar energy as indirect gain in the thermal mass as passive design.

Eighty percent (80 %) of materials used in these buildings is based on natural mud. All the materials are of low conductivity value that is bad conductor of heat. The eighty percent (80 %) of materials do not need timber or coal as fuel to manufacture. The only twenty percent (20%) of materials like burnt brick & clay tile need timber or coal as fuel to burn. So, this building uses less carbon emission materials which save environment and energy. The buildings were designed with vertical spatial planning for security considerations and to use less irrigable land for building purposes. This is why traditional residence is often designed vertically. As already described in this chapter, the building covers nearly 54 square metres which is less than 2 *Anna* (1 *Anna* = 31.81 square metres) urban lands. It saves urban land coverage compare to present practice in Kathmandu. The planning of traditional settlement such that it encourages all urban facility in walking distance. There is no need of any vehicles to visit market, primary school, medical shop, temple etc. This reduces pollution and saves surrounding environment when compared to present practice. The compact planning reduces the heat island effect also. Above all, the objective is to provide comfortable conditions inside the building together.

Another important aspect of all these traditional buildings was application of color and texture. The rough exposed brick textures and dull color used increases the solar heat gain in winter in cold region whereas micro shading with projected textures and white color façade are used to provide shading and reflection for the cooling effect in Jaisalmer, India (Valsson & Bharat 2008). The projected slope roofs in traditional residences to protect from rain and sun were designed in Kathmandu for summer and monsoon period. There is no cross ventilation to loss heat in living spaces as window is placed in only one exposed wall. A nearly 1 metre long projection of slope roof acts as effective shading device for the large openings (*Sanjhya*) but also for the walls from high Sun angle in summer. It also protects from driving rain in monsoon season. The ventilation system is unique in traditional buildings. The hot air escapes vertically through staircase and ventilation (*Bhau pwa*) on slope roof in summer. Mostly small lattice window or lattice design is used in single window in traditional building in Kathmandu. This lattice window is placed for normal ventilation without any shutter in bed room especially in the first floor. This lattice window always located parallel to street or courtyard such that it is only enough to exchange air for natural ventilation. But larger window (*Sanjhya*) is located such a way in living in second floor that it projected to catch more ventilation from open street. The cross ventilation system is used in this floor to dissipate heat in summer in some houses (Fig.2.8).

One of the important aspects of all vernacular buildings was arrangement of activities in different space and time. Warmer upper floors and exposed courtyard were used for daytime activities and attic and ground floor as buffer space in cool winter night in Kathmandu whereas cooler lower floors and shaded courtyards were used for daytime activities and upper floors and terraces for nighttime sleeping in Jaisalmer, India (Valsson & Bharat 2008). Excessive moisture comes from ground soil, so, ground floor has been used as buffer and utility space only not as living space. All the types of traditional residences with courts system in different climate has combined effect of courtyard and the thick construction leading to a large time lag which effectively attenuating the external ambient conditions. In all different climate, the passive design system with building form, courtyard planning, natural materials and construction technology of roof, wall and floor effectively used to achieve desirable comfort level in built up environment. So in historical time, climatic consideration is reflected in traditional buildings, settlement and town.

### 2.8 Modern residential building

Fig. 2.11 Views of modern residential buildings in traditional settlements of Kathmandu

Nowadays, people like to design and construct new houses with modern concept and new materials and technology imported from the globalized world instead of traditional form, materials, technology in Kathmandu (Fig. 2.11) as in India (Madhavi 2010) and many part of the world (Ahmadreza 2012). When modern material and technology were introduced more than 60 years back in Kathmandu, people have been started to construct new types of houses. These new residences have compromised not only the aesthetic value but also reduced level of thermal comfort compared with traditional residences. The houses constructed with modern artificial materials like RCC, metal, glass, cement, GI sheet instead of traditional materials.

There were different technical problems and not satisfying the people especially due to lack of thermal comfort. In developing countries like Nepal, maximum number of modern building is constructed of masonry material without thermal insulation. They have lack of knowledge about construction technology suitable for them.As discussed about the vertically oriented planning and life style of people in traditional buildings, there is no consideration of spatial planning with different spaces for different purpose in modern residential building. The vertical spatial planning system with utility rooms, bedrooms, living room and kitchen, dining were not allocated in special floor as in traditional buildings. Also there is no any consideration to use thermal mass with thick construction in these modern buildings.

In developed countries, government regulation plays important role to maintain quality and comfort living standard inside buildings. In developing countries, there is a tendency that high-income people construct high-class buildings with control system like HVAC, heating and cooling for their comfort of living. But people especially who live in new locally made modern houses in Kathmandu have much more problems of heating and cooling in winter as well as in summer. In winter, they maintain their thermal comfort inside the building by using electric, kerosene or gas heater, lighting firewood that affects the health of occupants, unsafe for fire hazard and environmental problem inside as well as outside. In summer, they use electric fan, air cooler etc. for cooling.

This research focused and considered to study the thermal performance of modern residential building located in traditional settlement of Kathmandu. So the site plan is same as neighborhood traditional residential buildings with linear cluster and courtyard system. The basic modern house were designed and constructed replacing the traditional houses but there is lack of vertical spatial planning as in traditional planning. The house consists of three to four floors. The ceiling height is nearly or more than eight feet which is higher than traditional houses. The major building material is burnt brick, cement mortar, cement plaster, timber, aluminium and RCC. All the materials are artificial and high conductivity value (Koenigsberger et al. 1975).

The construction system is frame structure with RCC column, beam and slab. The modern building construction is built with thin external wall of 230 mm brickwork, partition of 110 mm brickwork and a thin flat roof of RCC slab with 110 mm thick. Generally façade of modern residence is nine to twelve meters high i.e. 3 to 4 storey. The building in modern architecture has either cement plaster or exposed brick façade. There is no any consideration to achieve thermal comfort with increasing solar gain in building in winter as in traditional principle. Openings are generally moderate size fitted with glass in timber or aluminium shutters. A small horizontal projection of roof slab acts as protection from monsoon rain. This building was studied and compared with traditional buildings largely by the results of the field study, lab study and questionnaire survey in following chapters.

### 2.9 Conclusion

This part of the chapter deals with conclusions drawn from the literature reviews of theory and practices. This chapter has attempted to develop a frame for the research.

Any research method is equally important as the research outcome. The theory and practice of thermal comfort in traditional building in national & international context has been studied with help of literature review. The international ASHRAE, CEN, standard and modern adaptive theory of Nicol were studied and compared. Then national research and standard of Rijal were studied and compared with international standard and theory.

After this literature review, it is understood that there is generally a perception that the traditional architecture has better thermal comfort than contemporary architecture in Nepal and world. Many researchers discussed the sustainability of architecture with traditional knowledge for future. They discussed the design, form, planning better for thermal comfort in traditional knowledge. But there are few studies focused in material and technology side to elaborate the traditional knowledge for thermal comfort. Hence, this study has adopted field and lab study to fulfill knowledge gap between theory and practice in thermal comfort and performance. Then this study is designed to study in energy efficient traditional buildings of Kathmandu valley.

Perhaps this research is experimental research to answer mainly five research questions. The research questions developed mainly to focus in thermal performance of traditional building and compared it with modern building. Also it focuses in to how traditional, modern and green material and technology react in different thermal condition. How people feel with these buildings nowadays. How material, technology and design can be developed for thermal comfort and energy saving in future. These questions are discussed with the different literature study and finalized.

# CHAPTER 3: RESEARCH METHODOLOGY

## 3.1 Introduction

A research methodology should state the approach adopted right from the start (Pokharel 1994). A well designed research methodology is very important in scientific research. Research being a scientific endeavour, involves the scientific method, a systematic step by step procedure following the logical process of reasoning. It is therefore necessary to evolve a theoretical framework objectively purporting the fundamental principles on which the scientific method is based to proceed with the data collection, to help to solve the research questions raised in the chapter one. In this research, the methodology is conceived to be combining all the methods and processes that are to be used into sequential order to help progress in a structured manner.

This chapter attempts to define research methods. Hence the chapter begins with the types of methodology used for research in the world. Then it explains the research design for this study with a process in different stages using a figure. It explains the method of gathering data in field and lab for quantitative research as well as household survey for qualitative. Then it describes the analysis, discussion and draw conclusion. This chapter also explains the instruments and tools and sample of the research. In addition, it explains the data collection and analysis techniques. This chapter ends with the conclusion of this specific chapter. A diagrammatic methodology chart has been prepared for this thesis (Fig. 3.1).All the facts have been stated objectively and this report explains the procedure adopted without any prejudice or bias or concealment.

## 3.2 Types of Methodology

Research defines a search for knowledge to establish facts. Research has been often stated as a challenge in which one has not only to follow the rules contained by existing state of arts. Hence, a researcher is always challenged for understanding the existing state of art and to locate the new knowledge to contribute for further use. Researches could be generally classified into two broader groups according to their outputs. The first one is basic research which deals more on understanding the reality and the next one is progressive in the sense that it seeks the applicability of the outputs.

There are generally three types of researches in the world. First one is exploratory research as its name suggests explores the knowledge considering that there are fairly less known or unknown about the questions and answers. This refers to historic researches where testing of authenticity of reports and observations published earlier by other researchers. Similarly, it restates or corrects the earlier stances. Hence, it could be said that it opens a new avenue in existing knowledge base which might be used for future. The second one is explanatory research which is descriptive in nature. Its source of information is current status of phenomena. Generally it describes what really exist with respect to variables and existing conditions in a situation. This type of research is carried out in development works. Explanatory researches are generally carried out in social science disciplines.

The third one is experimental research and it is carried out in a controlled environment. The environment is created being based on fabricated setting. Such setting is fabricated in order to observe the artificially produced phenomenon. It always has a controlled setting and purpose of the research is clear at the point of departure. This is straight forward approach of investigation. This type of research is mostly used for natural science disciplines in the laboratories. Experiments are not solely done in natural science researches. They are carried out in social science researches as well where fields are considered as the laboratories.

The present research is experimental research on the basis of existing condition of the traditional buildings in the urban settlements of Kathmandu valley. This research has attempted to prove itself to be an applied research. The primary purpose of research is discovering thermal performance systems in traditional buildings for the human knowledge of our world. As we know, any kind of academic research is expected to establish a new knowledge for better understanding of the existing set of knowledge. In this sense, it could be stated that the final outcome of the research has either to challenge the existing set of knowledge or to contribute for its better understanding.

This research has attempted to understand the existing set of knowledge on thermal performance of traditional buildings in case of Kathmandu. This research was developed in Department of Architecture and Urban Planning. The research carried out in the area of making disciplines must contribute to the implementation its outcome on the field. In other words, it has to have the power of applicability and practicality without leaving behind the essence of academic rigor in to it. Architecture always has accepted the social aspect in to it. So has the discipline of urban planning, management and development. This research has oriented itself in physical components of the society. This research is also carried out to see if traditional technology can contribute to develop modern residential building for more thermal comfort.

### 3.3 Research design

In order to fulfill the objective and answer the research questions, the present research has adopted mixed method. This research has two basic methods of investigation. It has both quantitative and qualitative components. The research has designed and divided in to three areas to study the thermal performance of traditional residential building. One of quantitative methods adopted was experimental research which was carried out intensively in field as well as in a controlled environment lab. This research study investigates thermal performance mainly with different field experiment focusing especially the role of materials and technology.

This research is designed as mainly applied research and main purpose of research is to discover the thermal performance of traditional buildings. In this sense, the main research focuses to field study with monitoring thermal performance of different residences for a year which is described in main the chapter 4. The field experimental research carried out in traditional residences in Patan and Kirtipur of the Kathmandu valley. The chapter 4 contains evaluation of thermal environment of buildings with field data, sample analysis, regression analysis, followed by discussion and aiming to draw the results and conclusions. The other experimental research area carried out in a lab. The experimental research adopted in a controlled environment lab in the architecture department of Pulchowk campus. The chapter 6 contains the laboratory experiments with data, analysis, discussion and results.

The next qualitative method adopted as household questionnaire survey to access the thermal comfort of the residents of different buildings in traditional settlements of Kathmandu valley. The qualitative household questionnaire survey adopted for the residents of different buildings in traditional settlements of Kathmandu valley. The objective of qualitative household questionnaire survey is to study the perception of thermal sensation and comfort of local people in traditional and modern residential building. Chapter 5 contains the qualitative study of thermal comfort survey with data, analysis, discussion and results. Chapter 5 and 6 with qualitative survey and lab experiment are supporting study for main study chapter 4 in this study. So the analysis, discussion and results of this main chapter 4 is further compared and analyzed with analysis, discussion and results of the chapter 5 and 6 with qualitative survey and lab experiment in the conclusion chapter 7 in this study.

The process of research methodology is divided into four stages as shown above (Fig. 3.1). The first stage begins with the literature review aimed to raise the research questions and develops the research. It is followed by preliminary study of thermal environment in residential buildings ending in selection of case study areas. Based on the variable identified, thermal studies in field and laboratory are designed, practiced, tested and standardized in the second stage.

The third stage begins with mainly the field study with monitoring thermal performance in traditional and modern residential buildings. Also the controlled thermal lab is established, experimented and collected lab data of different materials and technology to compare the field study. The questionnaires are designed, tested and developed for qualitative surveys also to compare data from field. This stage contains collection of meteorological data, followed by data coding, error checking and tabulation. The fourth part contains data analysis, regression analysis, followed by testing and triangulation, aiming to draw the final conclusions and recommendation and directions for future research. All the data collected from field and household questionnaire survey was analyzed statistically with the help of SPSS software.

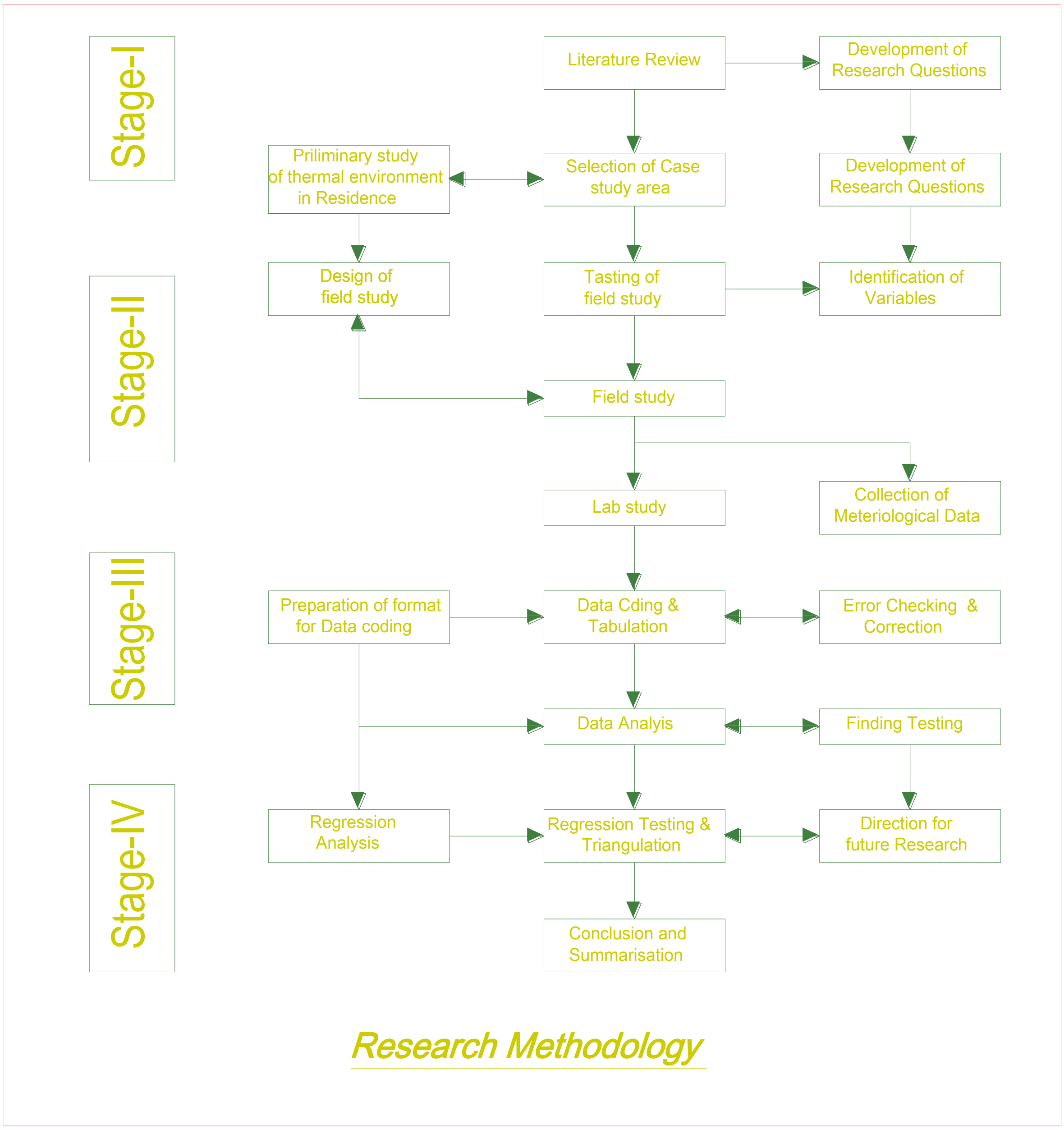



Fig. 3.1 Process of research methodology

### 3.4 Field research area

This is main study area of this research. The research is mainly design to study and monitoring the thermal performance of traditional residential building in traditional settlement of Kathmandu valley. The experimental field research is focused in traditional residences in different towns of the Kathmandu valley. Sample of fourteen residences has been randomly selected in Kathmandu, Bhaktapur, Patan and Kirtipur towns of the Kathmandu valley. In this study, in order to compare with traditional building, modern buildings were selected in old traditional settlement where traditional buildings were built in the past. In order to see the practical use with respect to thermal comfort, five out of fourteen traditional and two modern residences in Patan and Kirtipur of the valley have been considered as research sample.

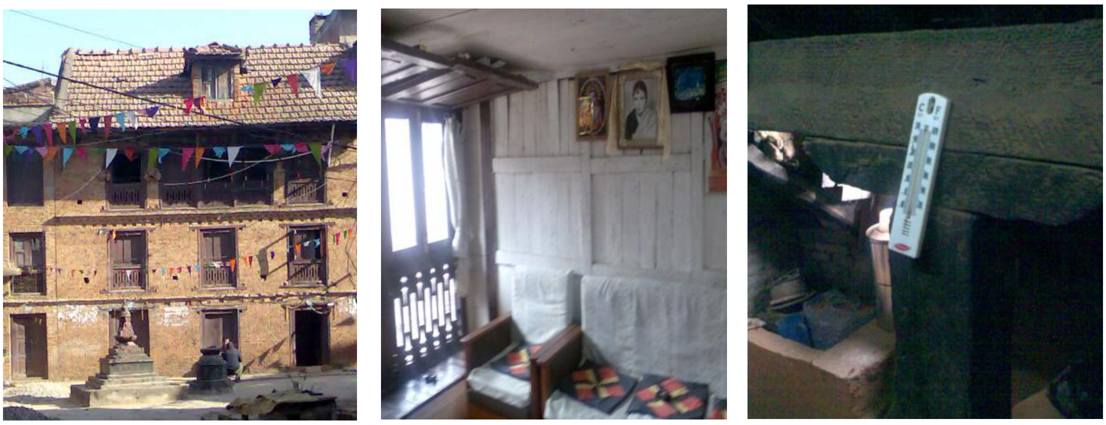


Fig. 3.2  Exterior and interior views and a wall thermometer (Omsons) located 1.5 metre above the floor in attic of house No.1 (D.B. Maharjan house in Devdhoka, Kirtipur)

There were nearly 11700 temperature data collected in five spaces of seven houses in three times a day for continuous thirty days in four summer, winter, autumn and spring seasons in one year during field experiment. There were nearly 9000 temperature data collected in five traditional houses during the field experiment. Same way, there were nearly 2700 temperature data collected in two modern houses in three times a day for continuous thirty days in winter and summer seasons to compare with traditional building. The indoor and outdoor thermal environment was monitored for two seasons  in two modern houses.

Nearly thirty days temperature was recorded in these seasons with the ordinary wall thermometer (Omsons ISO 9001:2000 Company) manually. The temperature was recorded three times a day; at seven o' clock in the morning, two o' clock in the day and ten o' clock in evening from ground floor to attic vertically. The study of temperature reading is to focus to read the maximum and minimum temperature variation in each space of indoor and outdoor during twenty four hours of a day in that season. All the information of physical condition, climate, microclimate and life style were gathered. All the field data monitoring thermal environment were studied, analyzed and drawn findings.

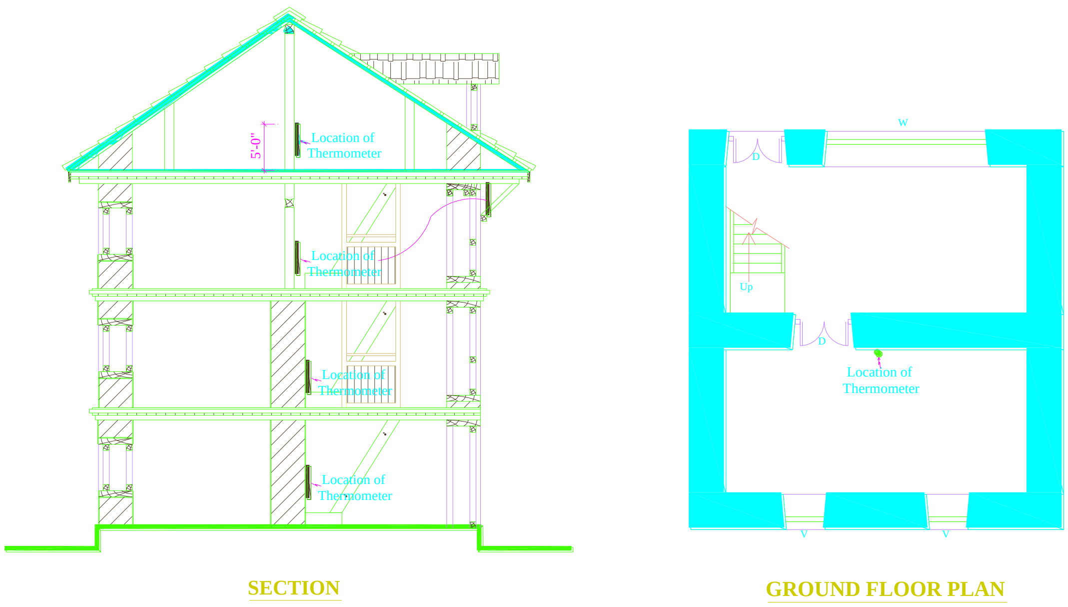



Fig. 3.3 Views of locations of wall thermometers (Omsons ISO 9001:2000 Company) inside and outside of the building

A mini pilot study for field experiment was tested as a trial in a residential building of Dan Bahadur Maharjan at Dev Dhoka in Kirtipur before to collect massive field data in all selected buildings. The information of building design, materials, construction technology and building forms were collected in the field. The design drawings of existing building were prepared with measurements. There were nearly 75 temperature data were collected in a five days for a mini pilot research. The investigation of these thermal performance data of the building were conducted by measuring air temperature in indoor and outdoor spaces.

Table: 3.1 Sample of a mini research data in traditional house No. 1 (Dan B. Maharjan house in Devdhoka, Kirtipur)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | COLLECTION OF TEMPERATURE DATA (Indoor outdoor temperature) | | | | | | | |
| Residence: Dan Bahadur Maharjan | | | Address: Devdhoka, Ward No. 2, Kirtipur | | | | | |
| S.NO. | DATE | TIME | OUTDOOR | INDOOR TEMPERATURE (Celcius) | | | | REMARK |
| | (Bhadra/Sept) | | Celcius | GF(Chheli) | Bed I F | Living II F | Attic Kit | |
| 1 | 066.5.19 | 700 | | | | | | |
| | 09.Sept.4 | 1400 | 28 | 28 | 28 | 28 | 29 | |
| | | 2200 | 21 | 21 | 22 | 22 | 23 | Raining |
| 2 | 066.5.20 | 700 | 19 | 20 | 20 | 20 | 21 | |
| | 09.Sept.5 | 1400 | 23 | 20 | 20 | 20 | 21 | Raining |
| | | 2200 | 19 | 20 | 21 | 21 | 23 | |
| 3 | 066.5.21 | 700 | 15 | 22 | 23 | 22 | 21 | |
| | 09.Sept.6 | 1400 | 24 | 21 | 22 | 23 | 26 | |
| | | 2200 | 18 | 20 | 20 | 20 | 20 | Raining |
| 4 | 066.5.22 | 700 | 18 | 22 | 22 | 22 | 21 | |
| | 09.Sept.7 | 1400 | 24 | 22 | 22 | 22 | 25 | |
| | | 2200 | 20 | 21 | 21 | 22 | 23 | |
| 5 | 066.5.23 | 700 | 19 | 20 | 22 | 22 | 21 | |
| | 09.Sept.8 | 1400 | 24 | 21 | 21 | 22 | 24 | |
| | | 2200 | 18 | 20 | 20 | 20 | 20 | Raining |

The air temperatures were measured for five days in September month in this mini pilot research. There were five measurement points in a building. The indoor measurement points were 1.5 metre above the each floor level (Fig.3.3). The four points were inside from ground floor to top floor. The one outdoor point was located outside the living room in third floor below the roof overhang. Five thermometers were calibrated with measured temperature data in one space. Then five thermometers were located in such a way to avoid direct sunlight throughout the day. The measured temperature data were calibrated. Then field experimental carried out for different buildings which are explained in chapter 4.

### 3.5 Laboratory research area

This is another study area of this research. The lab research area is supporting study for main field study in this research. One of the most important factors for thermal performance of any building is the material and technology. The study contains the lab experiments of thermal behavior of different materials and technology. This lab experiment shows how materials get affected by high or low temperature in a controlled environment. The lab experiment area focused to study the thermal behavior of different individual materials, combination of different materials, thickness of materials used in different types of wall in traditional, modern and green buildings.

The lab study focused on study of multilayer wall of burnt brick (*pakki apa*), sun dried brick (*kachi apa*) and mud mortar as well as modern wall of burnt bricks and cement mortar and modern green wall of compressed stabilized earth block (CSEB). The study area concentrated especially on materials and technology in wall which can be compared with the field experiment data for conclusion. To study the role of thermal performance of material, technology of building with experiments, a controlled laboratory was established in the architecture department of Pulchowk campus.

Before start the laboratory experiment of all materials and technology of different walls, a mini pilot experiment was tested in the environment of laboratory. For this purpose, the insulated thermal box was designed and constructed. The box was equipped with heater for heating and compressor and air blower device for cooling. AC duct was installed to blow hot or cool air for heating and cooling. A 490 mm thick traditional wall was constructed inside the thermal box (Fig. 3.4).

The wall for experiment was constructed in the middle part of the box. The outer layer of wall considered as south side where AC system was installed for heating and cooling. The six thermo sensors were located in six locations inside the box. The first sensor R1 located in air of outer layer in south part of wall. It records the air temperature as outdoor air in a lab. The second, third, fourth and fifth sensors R2, R3, R4and R5 were located within middle level of the wall. These sensors record the surface temperature data of different layers in a wall. The last sixth sensor R6 located in air of inner layer in north part of the wall. It records the air temperature as indoor air in a laboratory.

The maximum temperature of 36$^{o}$C of hot air was passed through outer layer to know the heating effect in each layer of wall and inside layer in this thermo box. First of all, date, time and temperature of lab were recorded in a paper. After the power was switched on, initial temperatures of six layers were recorded to compare after heating effect. The maximum temperature was fixed for heating to blow the hot air.

The maximum temperature of 36$^{o}$C was set in changeover switch to control the temperature for blowing hot air constantly. The air was blown for five hours in the lab. Then the final temperatures were recorded in all six layers for comparison of heating effect in each layer. The more detail of methods, analysis, discussion and results of lab experimental works carried out in chapter 6.


Fig. 3.4 Views of sensor R6, wall inside the thermal box and multiple temperature recorder (Instron IDI-302) in a lab for Mini research

Table: 3.2 Sample data of a mini lab experiment in a laboratory

| | | | | | |
|---|---|---|---|---|---|
| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
| | | STUDY OF HEATING EFFECT | | | |
| | 600mm THICK TRADITIONAL BRICKWALL | | | | |
| | (110 BURNT BRICK + 490 UNBURNT BRICK) | | | | |
| Date: 2068.11.19 (2 March 012) | | | | Lab Temp : 21°C | |
| Time: 10:30 | Blowing heat at 36°C | | | | |
| Time : 3:30 | Reading at 35°C as outside temp | | | | |
| S.NO. | SYNBOL | TEMP (°C) | TEMP (°C) | LAYER | REMARKS |
| | | INITIAL | AFTER 5 Hrs | | |
| 1 | R1 | 21 | 35 | Outside | |
| 2 | R2 | 21 | 31 | Burnt brick | 110 mm |
| 3 | R3 | 21 | 19 | Unburnt brick | |
| 4 | R4 | 21 | 19 | Unburnt brick | |
| 5 | R5 | 21 | 18 | Unburnt brick | |
| 6 | R6 | 21 | 18 | Inside | |

### 3.6 Qualitative study area

This is the third study area of this research. As present research has adopted mixed research method, it has more quantitative and less qualitative components. So this qualitative research is supporting study for main field study in this research. This qualitative research is designed to study the thermal comfort of residents in different types of residential building in traditional settlement of Kathmandu valley. Tthis questionnaire survey has not been done intensively with local occupants as compared to previous thermal comfort study done in Nepal (Rijal et al. 2010). But the inferences of previous thermal comfort study done in Bhaktapur, Nepal by Rijal also have considered in this study. The household questionnaire survey was designed with reference to previous thermal comfort study done in Nepal by Rijal (Rijal et al. 2010) and ASHRAE thermal comfort standard.

This questionnaire survey was developed later and done with only fifty local occupants of selected residence in participatory methods. Household is a house and its occupants regarded as one unit. The questionnaire is a set of printed questions with choice of answers and devised for the purposes of statistical study. The survey is an investigation of opinions and experiences of occupants. Altogether five areas were conceptualized to seek the answer to the existing information regarding the thermal comfort, thermal sensation, thermal preference and recommendation for type of building for future. The detail of methods, analysis and findings of household questionnaire survey carried out in chapter 5.

An orientation was given to local assistants before starting questionnaire survey. The pilot survey area was chosen householders of residential buildings at Konti in Patan of the Kathmandu valley. Before collecting detailed household survey, a pilot survey had tested and reviewed the answers from questionnaire survey with local assistants. There are mainly three different types of residential buildings. They are traditional, modern and mixed type residential building. The survey focused on the answer of question like thermal behavior for comfort environment and opinion for future building in the traditional settlements of Kathmandu.  This mini study clarifies people's perception for thermal comfort, sensation, perception and willingness to construct type of residential building in core city area for future. The sample (Table 3.3) of household questionnaire survey was discussed and analyzed with experts and local assistants. Then the sample of questionnaire form (Table 5.2) organized and printed in Nepali language and translated in English.

Fig. 3.5 Views of household questionnaire survey for Mini pilot survey

Table 3.3 A sample of household questionnaire survey for Mini pilot survey

काठमाडौं उपत्यका शहरी क्षेत्रमा निर्मित आवाशीय घरहरुको

तातो - चिसोपनाको अनुभव विषयक प्रश्नावली

सर्भेयरको नाम : सुनिला महर्जन मिति : 2063/4/15

नाम : पूर्ण बहादुर तण्डुकार

उमेर : 82 वर्ष लिङ्ग : महिला / पुरुष / अन्य

पेशा : किसान

ठेगाना : कीर्तिपुर, ओ. पु. 22 वडा नं. : 22

घरको बनोट : क) परम्परागत शैलीको घर ख) नयाँ ढाँचाको ढलान घर
ग) मिश्रित परम्परागत एवं ढलान घ) अन्य

प्रश्न नं. १) यस घरमा तपाइको तातो - चिसोको अनुभव कस्तो छ ?
- ४) धेरै जाडो - ३) जाडो - २) चिसो - १) अलिकति चिसो
०) ठिक १) अलिकति तातो २) तातो ३) गर्मी ४) धेरै गर्मी

प्रश्न नं. २) यस घरमा तपाइलाई तातो - चिसोको आनन्दपन कस्तो लाग्छ ?
०) आनन्द १) अलिकति आनन्द २) अलिकति असुविधा
३) असुविधा ४) धेरै असुविधा

प्रश्न नं. ३) यस घरमा तपाईको न्यानो - शितलको चाहना के छ ?
- २) न्यानो चाहिन्छ - १) अलिकति न्यानो चाहिन्छ ०) यत्तिकै ठिक छ
१) अलिकति शितलता चाहिन्छ २) शितल चाहिन्छ

प्रश्न नं. ४) हाल तपाईको शरीरमा पसिना आइरहेको छ ?
०) छैन १) अलिकति छ २) केहि मात्रामा छ ३) धेरै छ ।

प्रश्न नं. ५) हाल तपाईको कार्यशीलता के छ ?
१) पल्टिरहेको २) बसेर आराम गरी रहेको ३) बसेर काम गरी रहेको
४) उभि रहेको ५) उभिएर काम गरी रहेको

प्रश्न नं. ६) तपाईको शरीरको कुनै भाग तातो वा चिसो छ ?
१) छ २) छैन

प्रश्न नं. ७) तपाई यस घरमा अहिलेको जाडो वा गर्मी वातावरण खप्न सक्नु हुन्छ कि हुँदैन ?
१) सक्छु २) सक्दिन

प्रश्न नं. ८) यदि नयाँ घर निर्माण गर्नु परेमा तपाई तातो - चिसो अनुभवको आधारमा कस्तो घर निर्माण गर्न चाहनु हुन्छ ?
१) परम्परागत शैली र बनोटको परम्परागत घर
२) नयाँ ढाँचाको ढलानको घर
३) मिश्रित नयाँ तथा पुरानो ढाँचाको घर
४) अन्य तरिकाको घर

### 3.7 Analysis, discussions and results

This part of the chapter deals with analysis, discussions and results. This is the most important part of the study which analyses the collected research data. It starts with preliminary data analysis after tabulation of data. Then it will check for error in data and corrected with tabulation. The data is further analyzed by Regression analysis with the help of SPSS statistical analysis system. The findings were discussed with results of other researches in the different part of the world. Then the study draws the results from research data, analysis and discussion.

In this research, three separate quantitative and qualitative studies described in different chapters. The chapter 4, 5 and 6 are designed with three separate study area of field, laboratory and qualitative survey. Each chapter consists of introduction, description of study, description of data, analysis, discussion, result and conclusion. The main chapter 4 focuses on evaluation of thermal environment of traditional building from field experiment data. Chapter 5 focused on evaluation of thermal comfort of residents from the questionnaire survey. Chapter 6 focused on evaluation of material and technology of wall from lab experiments. All three chapters have analysis, discussions and results to answer the research questions. Both quantitative and qualitative analysis was involved to gain understanding of the thermal performance and comfort in traditional building.

### 3.8 Conclusion

This part of the chapter deals with conclusions drawn from methodology. The methodology has attempted to develop a frame for the research. The research has adopted method for thermal comfort and thermal performance from field and laboratory experiments. Any research method is equally important as the research outcome. Perhaps this research is experimental research. One experiment is the analysis of thermal performance of traditional buildings in composite climate of Kathmandu. It monitors thermal performance under field in which research compares the thermal performance of traditional house. The research had adopted one more research method to compare with field study. This is to monitor thermal performance under laboratory in which research compares characteristics of different materials and constructions of traditional building.

Another research question that how does the thermal comfort in traditional houses compares with building in recent time? One of the methods to answer this is questionnaire survey. This shall gather information how people feel still today about their traditional houses compare to modern houses. Household surveys are time-consuming and perhaps sometimes irritating. How this knowledge is adaptable for development of more thermal comfortable and energy efficient residential building in Kathmandu? This shall be answered through conclusions drawn from results of these studies in the conclusion chapter 7.

# CHAPTER 4: EVALUATION OF THERMAL ENVIRONMENT OF TRADITIONAL RESIDENTIAL BUILDING

## 4.1 Introduction

This chapter attempts to investigate thermal environment with field experiments. The present study set out to investigate thermal environment of traditional residential buildings in traditional settlement of Kathmandu. The study also compares the thermal environment of the contemporary residential building with the traditional building of traditional settlement of Kathmandu. This study clarifies the thermal environment of the traditional and modern residential building in a composite climate of Kathmandu. This work is a major research which concludes with the inferences drawn from the different analysis on theory and practice and presents data framework that will guide the research. This chapter is the most important part for the research work. This shall identify the related research by showing gaps in theory and practice in research result or methods.

## 4.2 Description of investigated residential buildings

The study area is located in traditional residential buildings in traditional settlement of Kathmandu valley. Fourteen numbers of different traditional residences were selected as research sample randomly with photographs and drawings in Kathmandu, Bhaktapur, Patan and Kirtipur. Among them, six residences selected in street façade pattern and six residences selected in courtyard type. The data of house form, materials used and construction details of roof, wall, floor and opening were also collected.

This paper focuses randomly on only five selected residences among these residences for detailed study for evaluation of thermal environment with measurement of temperature data. Also only two modern residences were selected for detailed study with measurement of temperature data to compare with traditional buildings. The description of investigated residential buildings was listed in the Table 4.1 below. The detailed measured drawings with floor plans, elevations, section, site plan and location plan of these building were presented in the Appendix.

Table 4.1 Description of the investigated residential buildings

| S.No. | House | Type | Location | Area | Layout | Orientation | Construction | Planning | Roof |
|---|---|---|---|---|---|---|---|---|---|
| 1 | D B Maharjan | Traditional | Dev Dhoka | Kirtipur | Street | South | Loadbearing | Vertical | Slope |
| 2 | A Maharjan | Traditional | Yelmul | Patan | Courtyard | South | Loadbearing | Vertical | Slope |
| 3 | S Maharjan | Traditional | Subahal | Patan | Street | North | Loadbearing | Vertical | Slope |
| 4 | N D Maharjan | Traditional | Dupat | Patan | Courtyard | North | Loadbearing | Vertical | Slope |
| 5 | N L Maharjan | Traditional | Pilanchhe | Patan | Courtyard | East | Loadbearing | Vertical | Slope |
| 6 | P Tandukar | Modern | Konti | Patan | Street | East | Frame | Not Vertical | Flat |
| 7 | R M Shrestha | Modern | Kobahal | Patan | Courtyard | West | Frame | Not Vertical | Flat |

### 4.3 Description of field data

There were nearly 11700 temperature data collected in 26 variables out of which nearly 9000 temperature data collected from five traditional and 2700 temperature data from two modern residential buildings. A mini pilot field experiment and collection of field data was already described in research methodology in chapter 3.All these data were collected with the author's assistants and householders after success of mini pilot experiment.

The assessment of thermal behavior of the building involves the measurement of air temperature in indoor and outdoor spaces of investigated residential buildings in this study. It has no provision for considering the effect of relative humidity, mean radiant temperature, air movement and clothing which affects the thermal balance of human body. There are many researchers who have done much work in thermal comfort measuring these indexes.

This study focuses to investigate the thermal performance of building; so it focuses to measure air temperature manually in all seasons of whole year with maximum number of data. It focuses on survey of the opinion of residents for thermal behavior in these houses in following chapter to compare with findings of this chapter. Same way, this study has laboratory experiment to assess thermal behavior in following chapter to compare with this chapter. This shall answer the research questions.

Some samples of recorded field temperature data of different seasons were displayed below in the Tables 4.2 and 4.3.The Table 4.2 shows the samples of the recorded field temperature data of these investigated buildings in Nepali cum Newari language. Table 4.3 shows the samples of the tabulated field temperature data translated in English. Other samples of the field temperature data of these investigated building were shown in Appendix.

All the mean recorded field temperature data of winter and summer seasons were tabulated and summarized. This mean recorded field temperature data of all evaluated buildings are presented in the Table 4.4. These data were further analyzed by Regression equation for detailed analysis and presented in this chapter. The field data monitoring thermal behavior of investigated residential buildings were analyzed, discussed and drawn results in this chapter.

Table 4.2 a) Sample of field temperature data of January in a residence No. 1 (Dan B. Maharjan, Devdhoka, Kirtipur)

तापक्रमको विवरण (हुँदै हुनेमा भित्रमा तापक्रम)

घरधनीको नाम (हुँदै हुने घरधनी): दान ब. गुरुङ        ठेगाना (गाउँ): देवटोला, कीर्तिपुर

| सि.नं. | महिना गते | समय (घडी) | बाहिरी (भित्रे) तापक्रम (degree celcius) | घर भित्रको (हुँदै हुने) तापक्रम (degree celcius) | | | | कैफियत |
|---|---|---|---|---|---|---|---|---|
| | | | | अङ्गेना (हेर्ने) | पहिलो तल्ला (जम्मा) | टेवा तल्ला (स्टोर) | दुईतल (बैग) | |
| १ | माघ १ २०६६ | बिहान ६⁰⁰ | ८ | १२ | १२ | १२ | ११ | |
| | | दिउँसो १४⁰⁰ | २४ | १४ | १५ | १८ | २० | |
| | | साँझ १०⁰⁰ | १२ | १३ | १३ | १३ | १२ | |
| २ | २ | बिहान ६⁰⁰ | ८ | १२ | १२ | १२ | ११ | |
| | | दिउँसो १४⁰⁰ | २४ | १६ | १६ | १८ | १८ | |
| | | साँझ १०⁰⁰ | १२ | १२ | १२ | १२ | १२ | |
| ३ | ३ | बिहान ६⁰⁰ | ८ | १३ | १२ | १२ | ११ | |
| | | दिउँसो १४⁰⁰ | २५ | १६ | १६ | १७ | १८ | |
| | | साँझ १०⁰⁰ | १२ | १३ | १३ | १३ | १२ | |
| ४ | ४ | बिहान ६⁰⁰ | ७ | १३ | १२ | १२ | १२ | |
| | | दिउँसो १४⁰⁰ | २४ | १६ | १६ | १७ | १७ | |
| | | साँझ १०⁰⁰ | १२ | १५ | १४ | १४ | १२ | |
| ५ | ५ | बिहान ६⁰⁰ | ८ | १३ | १३ | १२ | १२ | |
| | | दिउँसो १४⁰⁰ | २२ | १५ | १६ | १७ | १८ | |
| | | साँझ १०⁰⁰ | ११ | १३ | १३ | १३ | १३ | |
| ६ | ६ | बिहान ६⁰⁰ | ७ | १२ | १२ | १२ | ११ | |
| | | दिउँसो १४⁰⁰ | २३ | १४ | १५ | १६ | १८ | |
| | | साँझ १०⁰⁰ | ११ | १२ | १२ | १२ | १२ | |
| ७ | ७ | बिहान ६⁰⁰ | ७ | १३ | १२ | १२ | १२ | |
| | | दिउँसो १४⁰⁰ | २२ | १६ | १७ | १८ | २० | |
| | | साँझ १०⁰⁰ | १२ | १२ | १२ | १२ | १२ | |
| ८ | ८ | बिहान ६⁰⁰ | ७ | १२ | १२ | १२ | ११ | |
| | | दिउँसो १४⁰⁰ | २० | १३ | १४ | १४ | १५ | |
| | | साँझ १०⁰⁰ | १२ | १२ | १२ | १३ | १२ | |
| ९ | ९ | बिहान ६⁰⁰ | ८ | १२ | १२ | १२ | ११ | |
| | | दिउँसो १४⁰⁰ | २३ | १५ | १६ | १८ | १८ | |
| | | साँझ १०⁰⁰ | ११ | १२ | १३ | १३ | १२ | |
| १० | १० | बिहान ६⁰⁰ | ७ | १२ | १३ | १२ | ११ | |
| | | दिउँसो १४⁰⁰ | २० | १५ | १६ | १८ | १८ | |
| | | साँझ १०⁰⁰ | ११ | १२ | १३ | १३ | १२ | |

Table 4.2 b) Sample of field temperature data of January in a residence No. 1 (Dan B. Maharjan, Devdhoka, Kirtipur)

तापक्रमको विवरण (हे दुने र पिनेमा तापक्रम)

घरधनीको नाम (हे‍ पुखाल): दान ब. महर्जन    ठेगाना (थाय्): देवढोका, कीर्तिपुर

| क्र.सं. | महिना गते | समय (ई) | बाहिरी (पिने) तापक्रम (degree celcius) | घर भित्रको (हे दुने) तापक्रम (degree celcius) भुइँतल्ला (क्वने) | पहिलो तल्ला (च्वता) | दोस्रो तल्ला (स्वता) | बुइगल (बैगा) | कैफियत |
|---|---|---|---|---|---|---|---|---|
| १ | माघ | बिहान ६:०० | ६ | १३ | १३ | ११ | ११ | |
| | ११ | दिउँसो १४:०० | १८ | १६ | १६ | १८ | १८ | |
| | २०६६ | साँझ १०:०० | ६ | १४ | १५ | १२ | १२ | |
| २ | १२ | बिहान ६:०० | [illegible] | ११ | १२ | ११ | ११ | |
| | | दिउँसो १४:०० | ११ | १२ | १२ | १२ | १२ | |
| | | साँझ १०:०० | ९ | ११ | ११ | ११ | १० | |
| ३ | १३ | बिहान ६:०० | ८ | १३ | १३ | १२ | १२ | |
| | | दिउँसो १४:०० | १५ | १४ | १४ | १३ | १५ | |
| | | साँझ १०:०० | १० | १३ | १३ | १३ | १२ | |
| ४ | १४ | बिहान ६:०० | ७ | १३ | १३ | १२ | ११ | |
| | | दिउँसो १४:०० | २० | १५ | १५ | १५ | १६ | |
| | | साँझ १०:०० | ११ | १४ | १५ | १४ | १४ | |
| ५ | १५ | बिहान ६:०० | ६ | १३ | १३ | १० | १० | |
| | | दिउँसो १४:०० | २१ | १६ | १६ | १६ | १७ | |
| | | साँझ १०:०० | ११ | १५ | १५ | १३ | १२ | |
| ६ | १६ | बिहान ६:०० | ७ | १४ | १४ | १३ | १२ | |
| | | दिउँसो १४:०० | २४ | १५ | १६ | १७ | १८ | |
| | | साँझ १०:०० | ८ | १२ | १२ | ११ | १० | |
| ७ | १७ | बिहान ६:०० | १० | १४ | १४ | १२ | १० | |
| | | दिउँसो १४:०० | २३ | १८ | १८ | १८ | १८ | |
| | | साँझ १०:०० | १३ | १४ | १४ | १६ | १६ | |
| ८ | १८ | बिहान ६:०० | ८ | १४ | १४ | १३ | १२ | |
| | | दिउँसो १४:०० | २३ | १८ | १८ | १९ | २० | |
| | | साँझ १०:०० | १२ | १५ | १५ | १४ | १५ | |
| ९ | १९ | बिहान ६:०० | ८ | १४ | १४ | १३ | १२ | |
| | | दिउँसो १४:०० | २४ | १३ | १३ | १८ | १९ | |
| | | साँझ १०:०० | १२ | १५ | १३ | १३ | १३ | |
| १० | २० | बिहान ६:०० | ७ | १३ | १३ | १२ | ११ | |
| | | दिउँसो १४:०० | २४ | १५ | १५ | १८ | १९ | |
| | | साँझ १०:०० | १३ | १३ | १४ | १४ | १३ | |

Table 4.3 a) Tabulated sample of field temperature data of January in a residence

No.1 (Dan B. Maharjan, Devdhoka, Kirtipur)

| | TEMPERATURE DATA OF JANUARY 2010 (MAGH 2066) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | COLLECTION OF TEMPERATURE DATA (Indoor outdoor temperature) | | | | | | | |
| Residence: Dan Bahadur Maharjan | | | Address: Devdhoka, Ward No. 2, Kirtipur | | | | | |
| | | | | | | | | |
| S.NO. | DATE | TIME | OUTDOOR | INDOOR TEMPERATURE (Deg Celcius) | | | | REMARK |
| | (JAN/MAGH) | | degcelcius | GF(Chhell) | Bed I F | Living II F | Attic Kit | |
| 1 | 066.10.1 | 700 | 8 | 12 | 12 | 12 | 11 | |
| | 010.Jan.15 | 1400 | 24 | 14 | 15 | 19 | 20 | |
| | | 2200 | 12 | 13 | 13 | 13 | 12 | |
| 2 | 066.10.2 | 700 | 8 | 12 | 12 | 12 | 11 | |
| | | 1400 | 24 | 16 | 16 | 18 | 19 | |
| | | 2200 | 12 | 12 | 12 | 12 | 12 | |
| 3 | 066.10.3 | 700 | 8 | 13 | 12 | 12 | 11 | |
| | | 1400 | 25 | 16 | 16 | 17 | 18 | |
| | | 2200 | 12 | 13 | 13 | 13 | 12 | |
| 4 | 066.10.4 | 700 | 7 | 13 | 12 | 12 | 12 | |
| | | 1400 | 24 | 16 | 16 | 17 | 17 | |
| | | 2200 | 12 | 13 | 14 | 14 | 12 | |
| 5 | 066.10.5 | 700 | 8 | 13 | 13 | 12 | 12 | |
| | | 1400 | 22 | 15 | 16 | 17 | 19 | |
| | | 2200 | 11 | 13 | 13 | 13 | 13 | |
| 6 | 066.10.6 | 700 | 7 | 12 | 12 | 12 | 11 | |
| | | 1400 | 23 | 14 | 15 | 16 | 18 | |
| | | 2200 | 11 | 12 | 12 | 12 | 12 | |
| 7 | 066.10.7 | 700 | 7 | 13 | 12 | 12 | 12 | |
| | | 1400 | 22 | 16 | 17 | 18 | 20 | |
| | | 2200 | 12 | 12 | 12 | 12 | 12 | |
| 8 | 066.10.8 | 700 | 7 | 12 | 12 | 12 | 11 | |
| | | 1400 | 20 | 13 | 14 | 14 | 15 | |
| | | 2200 | 12 | 12 | 12 | 13 | 12 | |
| 9 | 066.10.9 | 700 | 8 | 12 | 12 | 12 | 11 | |
| | | 1400 | 23 | 15 | 16 | 18 | 18 | |
| | | 2200 | 11 | 12 | 13 | 13 | 12 | |
| 10 | 066.10.10 | 700 | 7 | 12 | 13 | 12 | 11 | |
| | | 1400 | 20 | 15 | 16 | 18 | 18 | |
| | | 2200 | 11 | 12 | 13 | 13 | 12 | |
| 11 | 066.10.11 | 700 | 6 | 10 | 12 | 11 | 11 | |
| | | 1400 | 19 | 17 | 17 | 18 | 19 | |
| | | 2200 | 6 | 14 | 15 | 12 | 12 | |
| 12 | 066.10.12 | 700 | 5 | 11 | 12 | 11 | 11 | |
| | | 1400 | 11 | 12 | 12 | 12 | 12 | |
| | | 2200 | 9 | 11 | 11 | 11 | 10 | |
| 13 | 066.10.13 | 700 | 8 | 13 | 13 | 13 | 12 | |
| | | 1400 | 15 | 14 | 14 | 13 | 15 | |
| | | 2200 | 10 | 13 | 13 | 13 | 12 | |
| 14 | 066.10.14 | 700 | 7 | 13 | 13 | 12 | 11 | |
| | (Magh) | 1400 | 20 | 15 | 15 | 15 | 16 | |
| | 010.Jan.28 | 2200 | 11 | 14 | 15 | 14 | 14 | |
| 15 | 066.10.15 | 700 | 6 | 13 | 13 | 10 | 10 | |
| | | 1400 | 21 | 16 | 16 | 16 | 17 | |
| | | 2200 | 11 | 15 | 15 | 13 | 12 | |
| 16 | 066.10.16 | 700 | 7 | 14 | 14 | 13 | 12 | |
| | 010.Jan.30 | 1400 | 24 | 15 | 16 | 17 | 18 | |
| | | 2200 | 8 | 12 | 12 | 11 | 10 | |

Table 4.3 b) Tabulated sample of field temperature data of June in a residence No.2 (Asharam Maharjan, Yelmul Tole, Patan)

| | TEMPERATURE DATA OF JUNE 2010 (ASHAD 2067) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | COLLECTION OF TEMPERATURE DATA (Indoor outdoor temperature) | | | | | | | |
| Residence: Asharam Maharjan | | | Address: Yelmul tole, Tarinani, Ward No.8, Patan | | | | | |
| | | | | | | | | |
| S.NO. | DATE | TIME | OUTDOOR | INDOOR TEMPERATURE (o C) | | | | REMARK |
| | (June/Ashad) | | o C | GF(Chheli) | Bed I F | Living II F | Attic Kit | |
| 1 | 067.3.4 | 700 | 24 | 24 | 25 | 24 | 24 | |
| | 18-Jun-10 | 1400 | 26 | 26 | 25 | 26 | 26 | |
| | | 2200 | 24 | 24 | 24 | 24 | 25 | |
| 2 | 067.3.5 | 700 | 23 | 24 | 25 | 24 | 24 | |
| | | 1400 | 26 | 26 | 26 | 25 | 26 | |
| | | 2200 | 25 | 25 | 24 | 24 | 24 | |
| 3 | 067.3.6 | 700 | 24 | 24 | 23 | 24 | 25 | |
| | | 1400 | 26 | 26 | 25 | 26 | 26 | |
| | | 2200 | 23 | 24 | 23 | 24 | 25 | |
| 4 | 067.3.7 | 700 | 24 | 23 | 24 | 25 | 25 | |
| | | 1400 | 26 | 26 | 26 | 27 | 26 | |
| | | 2200 | 23 | 24 | 24 | 25 | 25 | |
| 5 | 067.3.8 | 700 | 24 | 24 | 25 | 25 | 24 | |
| | | 1400 | 26 | 26 | 26 | 26 | 26 | |
| | | 2200 | 25 | 24 | 25 | 24 | 25 | |
| 6 | 067.3.9 | 700 | 23 | 24 | 23 | 23 | 24 | |
| | | 1400 | 26 | 26 | 26 | 25 | 26 | |
| | | 2200 | 24 | 24 | 23 | 24 | 25 | |
| 7 | 067.3.10 | 700 | 23 | 24 | 25 | 25 | 25 | |
| | | 1400 | 26 | 27 | 26 | 27 | 27 | |
| | | 2200 | 25 | 26 | 25 | 25 | 25 | |
| 8 | 067.3.11 | 700 | 25 | 26 | 25 | 26 | 25 | |
| | | 1400 | 27 | 26 | 26 | 27 | 27 | |
| | | 2200 | 25 | 24 | 24 | 24 | 25 | |
| 9 | 067.3.12 | 700 | 24 | 25 | 24 | 24 | 24 | |
| | | 1400 | 27 | 26 | 26 | 27 | 26 | |
| | | 2200 | 24 | 24 | 24 | 25 | 25 | |
| 10 | 067.3.13 | 700 | 24 | 24 | 23 | 25 | 23 | |
| | | 1400 | 27 | 26 | 26 | 27 | 25 | |
| | | 2200 | 24 | 25 | 24 | 25 | 24 | |
| 11 | 067.3.14 | 700 | 24 | 24 | 25 | 24 | 25 | |
| | | 1400 | 27 | 26 | 27 | 27 | 27 | |
| | | 2200 | 25 | 25 | 25 | 25 | 25 | |
| 12 | 067.3.15 | 700 | 24 | 24 | 25 | 24 | 25 | |
| | | 1400 | 27 | 26 | 26 | 26 | 27 | |
| | | 2200 | 26 | 25 | 25 | 26 | 26 | |
| 13 | 067.3.16 | 700 | 24 | 25 | 26 | 24 | 25 | |
| | | 1400 | 27 | 26 | 27 | 26 | 26 | |
| | | 2200 | 25 | 25 | 25 | 25 | 24 | |
| 14 | 067.3.17 | 700 | 24 | 24 | 24 | 24 | 24 | |
| | | 1400 | 27 | 26 | 26 | 26 | 27 | |
| | | 2200 | 24 | 24 | 26 | 24 | 24 | |

Table 4.4 a) Mean recorded field temperature data in a residence No.1 (Dan B. Maharjan, Devdhoka, Kirtipur)

| Table of mean recorded air temp in traditional residential building of Residence No 1 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | D B Maharjan, Dev Dhoka, Kirtipur | | | | | | | | | | |
| | TEMPERATURE IN WINTER ( C) | | | | | TEMPERATURE IN SUMMER ( C) | | | | | |
| Space | Morning | Day | Evening | Max | Min | Diurnal | Morning | Day | Evening | Max | Min | Diurnal |
| | Mean | Mean | Mean | | | Range | Mean | Mean | Mean | | | Range |
| Outdoor | 7.5 | 22.0 | 11.1 | 22.0 | 7.5 | 14.5 | 22.2 | 30.4 | 24.2 | 30.4 | 22.2 | 8.2 |
| G Floor | 12.5 | 15.2 | 13.0 | 15.2 | 12.5 | 2.7 | 23.1 | 25.4 | 24.7 | 25.4 | 23.1 | 2.3 |
| I Floor | 12.6 | 15.3 | 13.3 | 15.3 | 12.6 | 2.7 | 23.9 | 26.0 | 25.3 | 26.0 | 23.9 | 2.1 |
| II Floor | 12.6 | 16.7 | 13.0 | 16.7 | 12.6 | 4.1 | 24.2 | 27.3 | 26.0 | 27.3 | 24.2 | 3.1 |
| Top Floor | 11.3 | 17.7 | 12.6 | 17.7 | 11.3 | 6.4 | 23.4 | 29.2 | 26.2 | 29.2 | 23.4 | 5.8 |

Table 4.4 b) Mean recorded field temperature data in a residence No.2 (Asharam Maharjan, Yelmul Tole, Patan)

| Table of mean recorded air temp in traditional residential building of Residence No 2 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Asharam Maharjan, Yelmul tole, Patan | | | | | | | | | | | |
| | TEMPERATURE IN WINTER ( C) | | | | | | TEMPERATURE IN SUMMER ( C) | | | | | |
| Space | Morning | Day | Evening | Max | Min | Diurnal | Morning | Day | Evening | Max | Min | Diurnal |
| | Mean | Mean | Mean | | | Range | Mean | Mean | Mean | | | Range |
| Outdoor | 8.8 | 14.3 | 11.7 | 14.3 | 8.8 | 5.5 | 23.7 | 26.2 | 24.3 | 26.2 | 23.7 | 2.5 |
| G Floor | 9.8 | 13.6 | 11.4 | 13.6 | 9.8 | 3.8 | 23.9 | 25.9 | 24.3 | 25.9 | 23.9 | 2.0 |
| I Floor | 9.6 | 13.8 | 11.4 | 13.8 | 9.6 | 4.2 | 24.0 | 25.9 | 24.3 | 25.9 | 24.0 | 1.9 |
| II Floor | 9.8 | 13.9 | 11.4 | 13.9 | 9.8 | 4.1 | 24.0 | 25.8 | 24.2 | 25.8 | 24.0 | 1.8 |
| Top Floor | 9.6 | 13.6 | 11.2 | 13.6 | 9.6 | 4.0 | 23.7 | 25.7 | 24.1 | 25.7 | 23.7 | 2.0 |

Table 4.4 c) Mean recorded field temperature data in a residence No.3 (Sanjay Maharjan, Subahal, Patan)

| Table of mean recorded air temp in traditional residential building of Residence No 3 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sanjay Maharjan, Subahal, Patan | | | | | | | | | | | |
| | TEMPERATURE IN WINTER ( C) | | | | | | TEMPERATURE IN SUMMER ( C) | | | | | |
| Space | Morning | Day | Evening | Max | Min | Diurnal | Morning | Day | Evening | Max | Min | Diurnal |
| | Mean | Mean | Mean | | | Range | Mean | Mean | Mean | | | Range |
| Outdoor | 9.2 | 16.3 | 12.3 | 16.3 | 9.2 | 7.1 | 25.4 | 29.2 | 25.9 | 29.2 | 25.4 | 3.8 |
| G Floor | 11.2 | 13.2 | 11.8 | 13.2 | 11.2 | 2.0 | 23.1 | 24.4 | 23.7 | 24.4 | 23.1 | 1.3 |
| I Floor | 12.2 | 14.9 | 13.8 | 14.9 | 12.2 | 2.7 | 24.9 | 26.1 | 25.6 | 26.1 | 24.9 | 1.2 |
| II Floor | 11.8 | 15.0 | 13.9 | 15.0 | 11.8 | 3.2 | 25.5 | 27.6 | 26.9 | 27.6 | 25.5 | 2.1 |
| Top Floor | 11.8 | 14.8 | 13.8 | 14.8 | 11.8 | 3.0 | 25.6 | 28.0 | 26.9 | 28.0 | 25.6 | 2.4 |

Table 4.4 d) Mean recorded field temperature data in a residence No.4 (Narayan D. Maharjan, Dupat, Patan)

| Table of mean recorded air temp in traditional residential building of Residence No 4 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Narayan Devi Maharjan, Dupat, Patan | | | | | | | | | |
| | TEMPERATURE IN WINTER ( C) | | | | | | TEMPERATURE IN SUMMER ( C) | | | | | |
| Space | Morning | Day | Evening | Max | Min | Diurnal | Morning | Day | Evening | Max | Min | Diurnal |
| | Mean | Mean | Mean | | | Range | Mean | Mean | Mean | | | Range |
| Outdoor | 10.7 | 15.2 | 13.7 | 15.2 | 10.7 | 4.5 | 25.8 | 29.9 | 28.0 | 29.9 | 25.8 | 4.1 |
| G Floor | 9.0 | 10.9 | 10.1 | 10.9 | 9.0 | 1.9 | 23.3 | 25.4 | 24.1 | 25.4 | 23.3 | 2.1 |
| I Floor | 9.2 | 11.8 | 11.0 | 11.8 | 9.2 | 2.6 | 24.6 | 27.2 | 26.0 | 27.2 | 24.6 | 2.6 |
| II Floor | 10.4 | 12.9 | 12.0 | 12.9 | 10.4 | 2.5 | 24.7 | 26.8 | 23.9 | 26.8 | 24.7 | 2.1 |
| Top Floor | 10.9 | 13.8 | 13.0 | 13.8 | 10.9 | 2.9 | 26.3 | 28.7 | 27.2 | 28.7 | 26.3 | 2.4 |

Table 4.4 e) Mean recorded field temperature data in a residence No.5 (Nanda L. Maharjan, Pilanchhe, Patan)

| Table of mean recorded air temp in traditional residential building of Residence No 5 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Nanda Lal Maharjan, Pilanchhe, Patan | | | | | | | | | |
| | TEMPERATURE IN WINTER ( C) | | | | | | TEMPERATURE IN SUMMER ( C) | | | | | |
| Space | Morning | Day | Evening | Max | Min | Diurnal | Morning | Day | Evening | Max | Min | Diurnal |
| | Mean | Mean | Mean | | | Range | Mean | Mean | Mean | | | Range |
| Outdoor | 10.9 | 16.1 | 14.4 | 16.1 | 10.9 | 5.2 | 24.1 | 28.7 | 26.3 | 28.7 | 24.1 | 4.6 |
| G Floor | 14.0 | 14.7 | 14.4 | 14.7 | 14.0 | 0.7 | 24.9 | 26.4 | 25.1 | 26.4 | 24.9 | 1.5 |
| I Floor | 11.3 | 13.4 | 13.2 | 13.4 | 11.3 | 2.1 | 24.4 | 26.1 | 24.9 | 26.1 | 24.4 | 1.7 |
| II Floor | 12.0 | 14.8 | 14.0 | 14.8 | 12.0 | 2.8 | 24.5 | 26.5 | 25.1 | 26.5 | 24.5 | 2.0 |
| Top Floor | 10.0 | 14.3 | 13.1 | 14.3 | 10.0 | 4.3 | 24.6 | 28.1 | 26.4 | 28.1 | 24.6 | 3.5 |

Table 4.4 f) Mean recorded field temperature data in a modern residence No.1 (Rudra M. Shrestha, Kobahal, Patan)

| Table of mean recorded air temp in modern residential building of Residence No 1 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Rudra Man Shrestha, Kobahal-9, Patan | | | | | | | | | |
| | TEMPERATURE IN WINTER ( C) | | | | | | TEMPERATURE IN SUMMER ( C) | | | | | |
| Space | Morning | Day | Evening | Max | Min | Diurnal | Morning | Day | Evening | Max | Min | Diurnal |
| | Mean | Mean | Mean | | | Range | Mean | Mean | Mean | | | Range |
| Outdoor | 7.0 | 10.7 | 10.1 | 10.7 | 7.0 | 3.7 | 23.6 | 26.0 | 24.7 | 26.0 | 23.6 | 2.4 |
| G Floor | 9.5 | 10.2 | 10.1 | 10.2 | 9.5 | 0.7 | 24.3 | 25.2 | 25.2 | 25.2 | 24.3 | 0.9 |
| I Floor | 10.5 | 11.6 | 11.4 | 11.6 | 10.5 | 1.1 | 25.3 | 26.2 | 26.0 | 26.2 | 25.3 | 0.9 |
| II Floor | 10.0 | 11.0 | 11.0 | 11.0 | 10.0 | 1.0 | 26.0 | 27.9 | 26.8 | 27.9 | 26.0 | 1.9 |
| Top Floor | 10.8 | 11.8 | 12.2 | 12.2 | 10.8 | 1.4 | 25.4 | 27.8 | 26.9 | 27.8 | 25.4 | 2.4 |

Table 4.4 g) Mean recorded field temperature data in a modern residence No.2 (Purna Tandukar, Konti, Patan)

| Table of mean recorded air temp in modern residential building of Residence No 2 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Purna Tandukar, Konti, Patan | | | | | | | | | | | | |
| Space | TEMPERATURE IN WINTER ( C) | | | | | | TEMPERATURE IN SUMMER ( C) | | | | | |
| | Morning Mean | Day Mean | Evening Mean | Max | Min | Diurnal Range | Morning Mean | Day Mean | Evening Mean | Max | Min | Diurnal Range |
| Outdoor | 12.6 | 16.3 | 12.9 | 16.3 | 12.6 | 3.7 | 23.4 | 26.4 | 25.7 | 26.4 | 23.4 | 3.0 |
| G Floor | 11.1 | 12.1 | 11.4 | 12.1 | 11.1 | 1.0 | 24.7 | 24.9 | 24.8 | 24.9 | 24.7 | 0.2 |
| I Floor | 11.6 | 12.9 | 11.8 | 12.9 | 11.6 | 1.3 | 23.3 | 23.5 | 23.3 | 23.5 | 23.3 | 0.2 |
| II Floor | 11.9 | 13.1 | 12.1 | 13.1 | 11.9 | 1.2 | 24.6 | 24.8 | 24.5 | 24.8 | 24.6 | 0.2 |
| Top Floor | 12.6 | 15.2 | 12.9 | 15.2 | 12.6 | 2.6 | 24.2 | 24.8 | 24.5 | 24.8 | 24.2 | 0.6 |

## 4.4 Analysis, discussions and results

### 4.4.1 Indoor and outdoor air temperature of traditional buildings

As we discussed in literature chapter in this thesis, according to Nicol et al. (1994) and Rijal et al. (2010), the mean comfort temperature is $26^o$ C in summer and $19^o$ C in winter and $26^o$ C in summer and $15^o$ C in winter in Kathmandu valley respectively. The comfort zone temperature is minimum $13^o$ C in winter and maximum $28^o$C in summer in Kathmandu according to Rijal. According to Nicol, comfort zone temperature is minimum 17 $^o$C in winter and maximum $28^o$C in summer in Kathmandu (Table 2.2). This result is important to compare the thermal performance of traditional and modern buildings in this study. These temperatures were taken as thermal comfort standard to compare thermal comfort of the residences of Kathmandu in this research.

In order to clarify air temperature, the results were analyzed by dividing each traditional building in different seasons. The figure 4.1 shows the mean indoor and outdoor air temperatures of traditional buildings in all four seasons over one year period with 95% confidence interval (CI). The most of traditional building indoor air temperature was lower than outdoor during day time in the summer. The outdoor mean maximum air temperature ranges from 25 to 28°C whereas indoor mean maximum air temperatures range from 25 to 26°C. This temperature lies in perfect mean comfort temperature during summer according to both Nicol and Rijal.

During winter, in most of traditional buildings indoor air temperature was either same or higher than outdoor air temperatures during morning and evening. The outdoor mean maximum air temperature ranges from 11 to 14°C whereas indoor mean maximum air temperatures range from 12 to 15°C. This temperature lies in comfort zone and perfect mean comfort temperature during winter according to Rijal. But according to Nicol standard, this temperature lies in little less than comfort zone temperature during winter.

According Nicol et al. (2012), the new theory of adaptive thermal comfort says that thermal comfort is a basic requirement for happiness and productivity in the workplace. The study defines comfort as achieved either by the occupants adapting to the building or by the occupants adapting the building to suit them. The study emphasized that comfort has to be done within existing climatic, social, economic, architectural and cultural context. This is very true for people in buildings which are free running and not mechanically heated or cooled. The result shows that the traditional residential building maintains adaptive thermal comfort in summer. But during winter, this building shows indoor thermal environment nearly in comfort zone without any mechanical heating or cooling compared to Rijal standard.

But during winter, it is little bit less than comfort zone temperature in these naturally ventilated buildings compared to comfort zone of Nicol standard. So it shows mean comfort standard and comfort zone of Rijal et al. (2010) being more appropriate in this research as he did research with field data in Bhaktapur, Nepal. But residents feel better and comfortable in this building according to questionnaire survey (Chapter 5) in this research. Why people feel comfortable in this temperature also? This question shall be raised. The answer may be either people feel comfortable due to life style of vertical planning or due to radiant heat from materials and technology used in wall, floor and ceiling with high thermal mass. This shall be discussed in lab experiment in chapter 6.

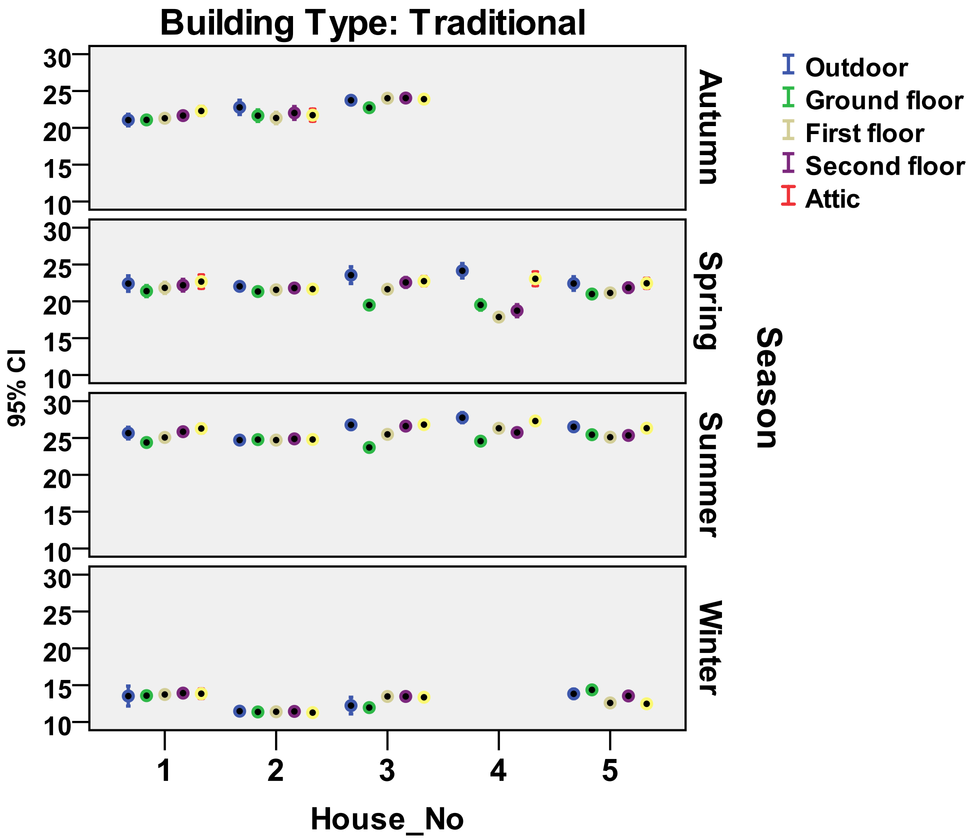



Fig. 4.1 Indoor and outdoor air temperature in traditional residential buildings during winter, spring, summer and autumn seasons

**4.4.2 Indoor and outdoor air temperature of traditional building compare to modern building**

In order to compare the thermal behavior of traditional and modern buildings, air temperature were analysed by dividing in two different seasons of winter and summer over one year period with 95% confidence interval (CI). The figure 4.2 shows normally during summer, mean indoor air temperature of traditional buildings were less than mean outdoor air temperature whereas mean indoor air temperature of modern buildings were higher than mean outdoor air temperature. The mean indoor air temperature during summer is 24.5°C, 25.5°C, 25.8°C and 26°C from ground to attic respectively when 26.3°C outdoor in traditional building. Similarly, the mean indoor air temperature during summer 25°C, 26°C, 27°C and 27°C ground to attic respectively when nearly 25°C outdoor in modern building. The indoor mean air temperatures range from 24 to 26°C in traditional building when nearly 26°C outdoor and indoor mean air temperatures range from 25 to 27°C in modern building when nearly 25°C outdoor. This shows that traditional residential buildings were minimum 1 to 2°C cooler than modern residential buildings during summer.

Same way, during winter, in most of traditional residences, mean indoor air temperature was either nearly same or little bit higher than mean outdoor air temperatures (12.5°C). But in modern residences indoor air temperature was either nearly same or 1°C lower than mean outdoor air (11.5°C) temperature. This shows that traditional residential buildings were 1 to 2°C warmer than modern residential buildings during winter.

As we discussed in this chapter, mean comfort standard and comfort zone of Rijal et al. (2010) are more appropriate in this research to compare field temperature data as they did with field data in Bhaktapur, Nepal. According to Rijal et al. (2010), the adaptive comfort temperature is $26^{o}$ C in summer and $15^{o}$C in winter in Kathmandu valley. The comfort zone temperature is minimum $13^{o}$C in winter and maximum $28^{o}$C in summer in Kathmandu. This result is important to compare the thermal performance of traditional and modern buildings in this study. The result shows that the modern residential building also maintains perfect adaptive thermal comfort in summer. But during winter, this building shows indoor thermal environment less than (11.5-$12.5^{o}$C) nearly comfort zone ($13^{o}$C) compared to Rijal standard. Also residents feel not so much comfortable in this building according to findings of questionnaire survey in chapter 5of this research.

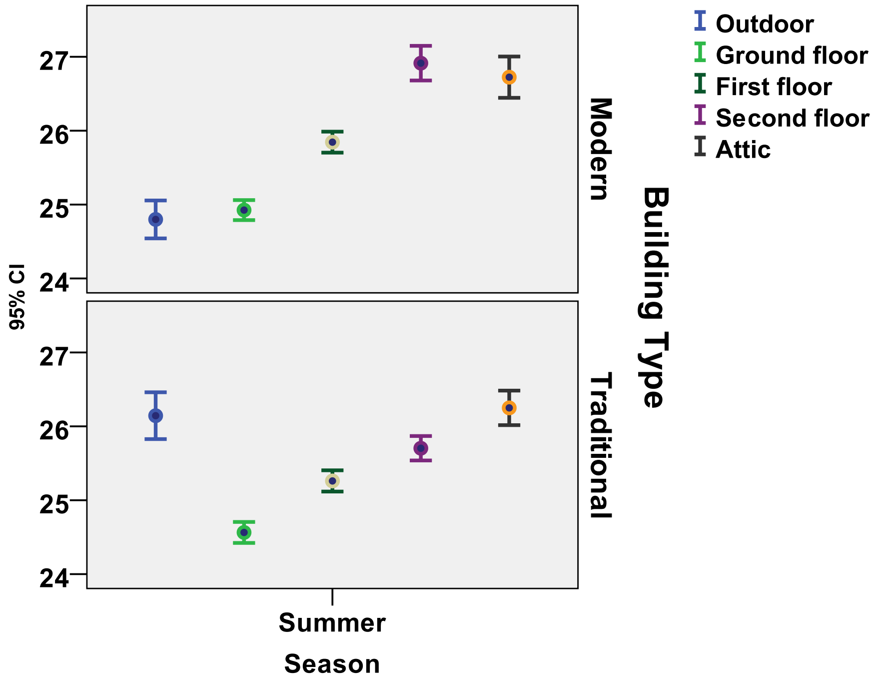



Fig. 4.2 Comparison of indoor and outdoor air temperature in traditional and modern residential buildings during summer season

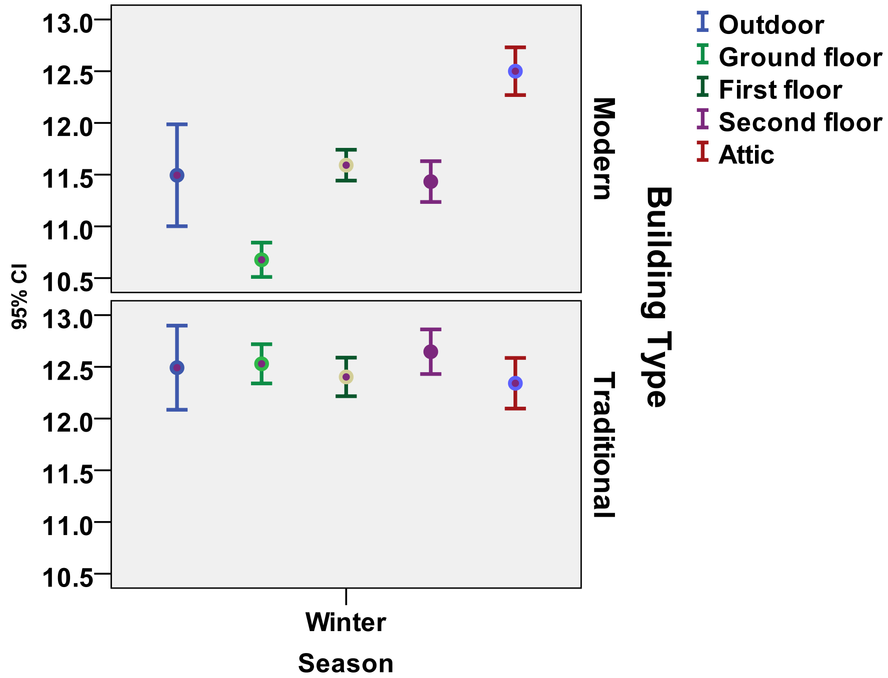



Fig. 4.3 Comparison of indoor and outdoor air temperature in traditional and modern residential buildings during winter season

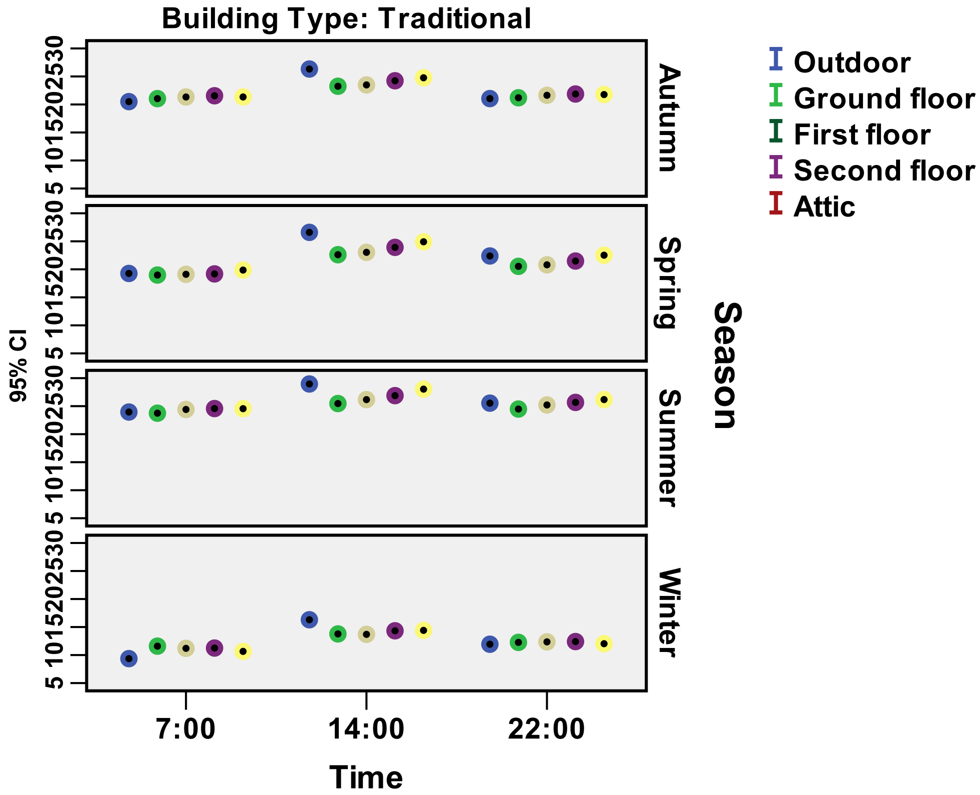



Fig. 4.4 Indoor and outdoor air temperature in traditional residential buildings during different time and seasons

In order to know the thermal behavior of buildings, air temperature were analyzed further by dividing the traditional and modern building in two different seasons of winter and summer three times a day. The figure 4.4 shows the daily mean outdoor and indoor air temperature in the morning, day and evening of different seasons in traditional buildings. During summer daytime in traditional buildings maximum indoor temperature is less than outdoor temp in each space whereas in modern building maximum indoor temperature is nearly the same or more than outdoor temperature in each space. During winter morning and evening, in traditional buildings, indoor temperature is more than outdoor temp in each spaces whereas in modern building indoor temperature is nearly the same or less than outdoor temperature in each spaces.

The figures 4.4 and 4.5 show the daily mean outdoor and indoor air temperature in the morning, day and evening of different seasons in traditional as well as modern buildings. During summer daytime, the indoor mean air temperatures range from 26 to 27°C in traditional building when nearly 29°C outdoor whereas indoor mean air temperatures range from 27  to 29°C  in modern building when nearly 27°C outdoor. These findings show that traditional residential buildings were minimum 1 to 2°C cooler than modern residential buildings during summer.

Same way, during winter morning time, the indoor mean air temperatures range from 12 to 13°C in traditional building when nearly 9°C outdoor whereas indoor mean air temperatures range from 10 to 11°C  in modern building when nearly 10°C outdoor. This shows that traditional residential buildings were minimum 2°C warmer than modern residential buildings during winter. This data shall be compared to previous study (Rijal et al.2002). They reported the room temperature of vernacular building was 3.8-5.5 K higher than outdoor temperature in winter nighttime and 3.2 K lower than outdoor temperature in summer daytime. The result showed that earth and wooden floors, mud, brick and stone walls are effective in keeping cool in summer and warm in winter (Rijal et al.2002).That is why, the traditional buildings performs better thermal comfort.

According to adaptive thermal comfort standard of Rijal et al. (2010), the traditional buildings were within comfort or comfort zone but modern residential buildings were warm during daytime of summer. But during morning and evening of winter, the traditional buildings were slightly cool which falls in nearly comfort zone but modern residential buildings were cool. According to findings of questionnaire survey in this research, most of residents feel comfortable in traditional building but not so much comfortable in modern buildings. If we compare this field experiment data with the feeling of respondents, the results becomes true in this case.

The research of Ahmad et al. (1985) may be a good example to compare with the results of these buildings of the Kathmandu.  They write clay mixed with organic matter is the main building material. The family use heavy weight construction in the ground for summer day and relatively light weight in first floor for winter.  Their research shows that the indoor temperature is 35°C in modern house whereas it is only 28°C in traditional house in the old city in the same summer period in Ghadames, Libya. New buildings, therefore consume large amount of energy to maintain indoor thermal comfort. The study shows that the old houses can provide a year round comfortable environment; however the new houses are unable to provide indoor comfort in summer as well as winter.

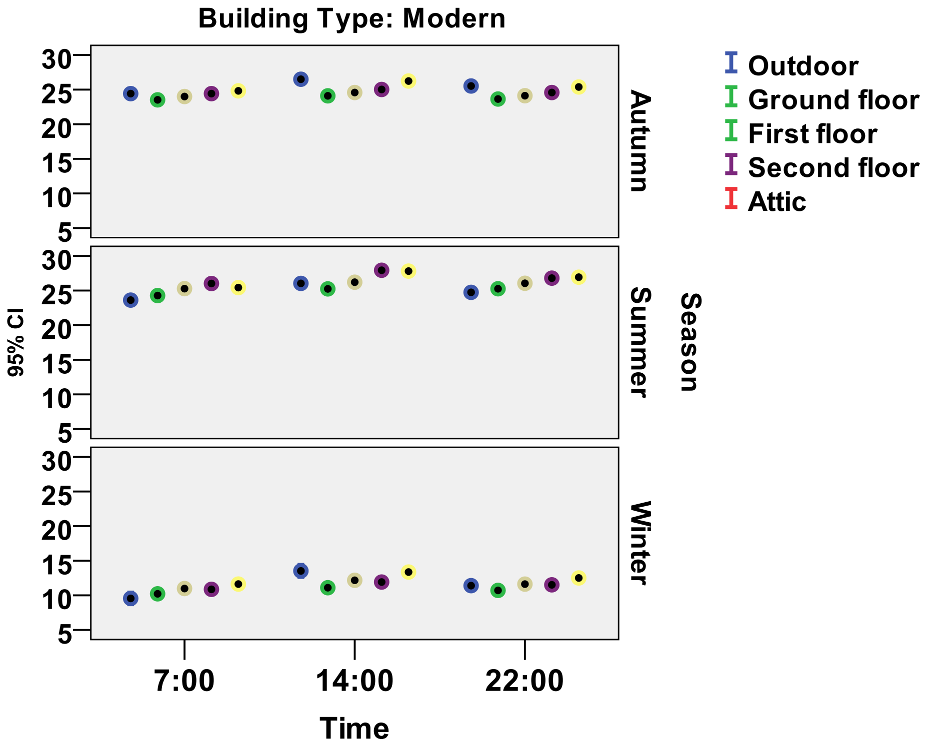



Fig. 4.5 Indoor and outdoor air temperature in modern residential buildings during different time and seasons

These findings show that traditional residential buildings were better in terms of thermal comfort with 1 to 2$^{o}$ C than modern residential buildings during both summer and winter seasons. This result is very important in the field of energy saving and energy efficiency building design and construction. This is also important for national economy if we conserve, design and construct this kind of building in the future. In developed countries like Japan and Europe, if there is a difference of 1°C temperature thermal energy calculated economize energy as a minimum of ten percentage (Nicol et al. 2012). In the UK 10 % of the heating energy used in winter is typically saved by lowering 1 K in the indoor temperature (Nicol et al. 2012).This shows that this type of building saves energy for heating and cooling from 10- 20% in the budget of residents each year. It can have a huge impact on national budget of a country as well as comfort level of local people. So this result is also important for the design and construction of modern building with traditional principles for comfort and energy save and design energy efficient building in future.

### 4.4.3 Evaluation of indoor and outdoor air temperature due to planning

The results of this field experimental study till now shows that traditional buildings of Kathmandu had a better adaptive thermal comfort in summer and winter in the past and till now. The field experimental study shows that traditional buildings had a better adaptive thermal comfort than modern residential buildings of Kathmandu. This study seeks to know the factors that affect the thermal performance of traditional buildings. To investigate the thermal performance due to building planning, the indoor and outdoor air temperature of traditional building compared to courtyard and street type over one year period with 95% confidence interval (CI).The mean air temperature of both buildings types is shown in figure 4.6 and 4.7.

The figure 4.6 shows in courtyard type building, indoor air temperature in the winter morning little bit higher than outdoor air temperature. It also shows that daytime temperature is less than outdoor air temperature during summer. The figure 4.7 shows how in a street adjoining building, indoor air temperature in the winter morning is much higher than outdoor air temperature. It also shows that daytime temperature is much less than outdoor air temperature during summer.

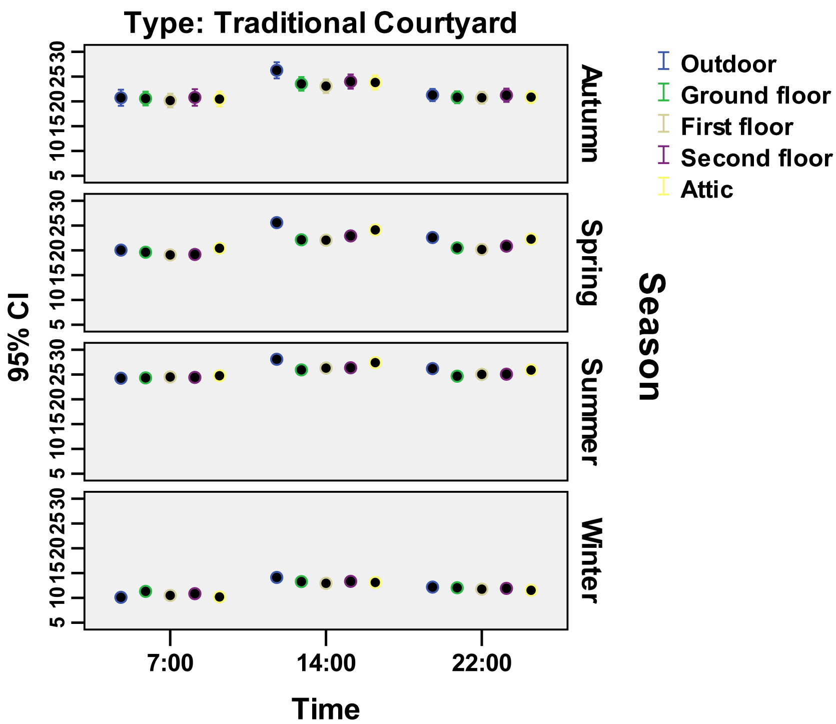



Fig.4.6 Indoor and outdoor air temperature in different time and seasons in courtyard type traditional residential buildings

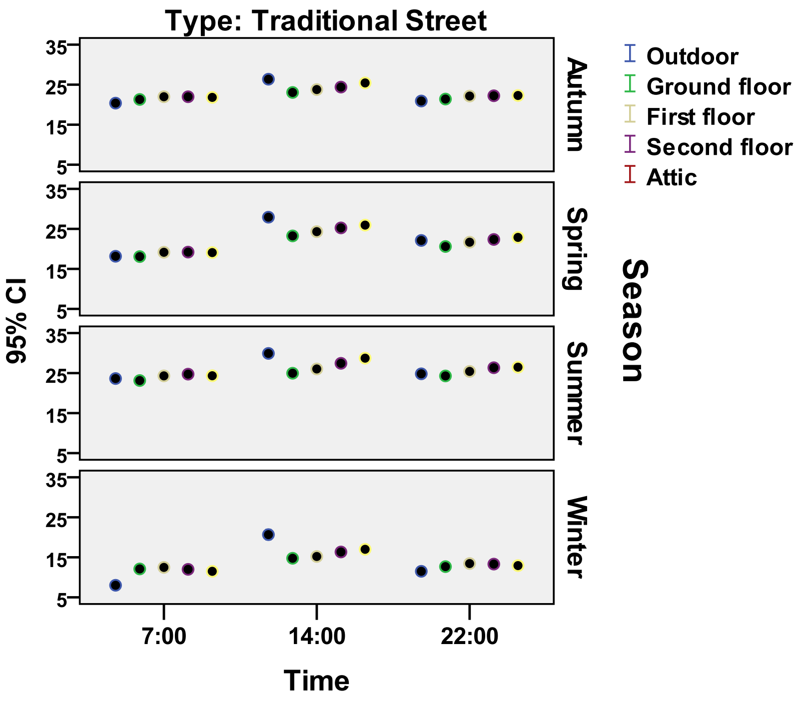



Fig. 4.7 Indoor and outdoor air temperature in different time and seasons in street type traditional residential buildings

During winter and summer, the figures 4.6 and 4.7 show that street type buildings were much better than courtyard pattern. The indoor temp of street type has much more temperature than outdoor in cool morning and evening than courtyard type. During summer, in street type buildings daytime indoor temp has much less temp than courtyard type. This indicates that the street type residence is much better than the courtyard type. The study compares thermal performance of traditional building based on planning. The study compared the indoor air temperature of traditional buildings in street and courtyard type during winter and summer. The street facing buildings were much better than courtyard pattern.

The study shows the indoor air temperature of street type buildings have much more than courtyard type buildings in cool morning and evening. During summer, in street type buildings daytime indoor temp has much less temp than courtyard type. This indicates that the street type residence is much better than the courtyard type. Compared to courtyard building, the street type building is cooler than courtyard type building in summer, because it gets cool breeze through street patterns. The street pattern has less exposure to sky compared to courtyard type building; so the street type building warmer in winter.

### 4.4.4 Evaluation of indoor and outdoor air temperature due to vertical planning

To investigate the thermal performance of a building, the indoor and outdoor air temperature difference of each floor of traditional building is compared. The mean air temperature difference of each floor of both buildings is shown in the figures 4.8, 4.9, 4.10, 4.11 and 4.12. During summer, figure 4.8 shows that indoor air temperature in ground floor was less than nearly $2^{o}$ C than outdoor in traditional building. The figure 4.9 shows indoor temperature of first floor was less than nearly $1^{o}$C. Same way, the figure 4.10 shows indoor air temperature of second floor were less than nearly $0.5^{o}$C and in indoor temperature of attic it was nearly same as outdoor air temperature. This shows that when floor rises, the temperature difference decreases from 2 to $0^{o}$C during summer.

During winter, figure 4.12 shows that indoor air temperature of ground floor is nearly the same as outdoor temperature in traditional residential building. During summer in modern building, indoor air temperature of second floor was more than nearly $2^{o}$C (2.11 $^{o}$C) than outdoor air temperature i.e. warmer in summer. When we compare with the traditional residence, the indoor and outdoor air temperature difference in modern residence is smaller in morning, day and evening. These floor wise comparative results also show that the traditional residential building is effective in keeping cool in summer and nearly warm in winter compared to modern building.

If we compare with the life style and space planning of traditional building, the practice of living style prove this variation of indoor air temperature decreases from 2 to $0^{o}$C from lower floor to upper. The local people like to spend their time and activity during very hot and cool night in lower floors than in attic. That is why bed room is located in first floor and the living room in the second floor. The bigger window (*Sanjhya*) is located only in living room on the second floor for efficient cross ventilation in summer and for direct and indirect solar heat gain in winter. For these reasons, smaller windows are located on the lower floors.

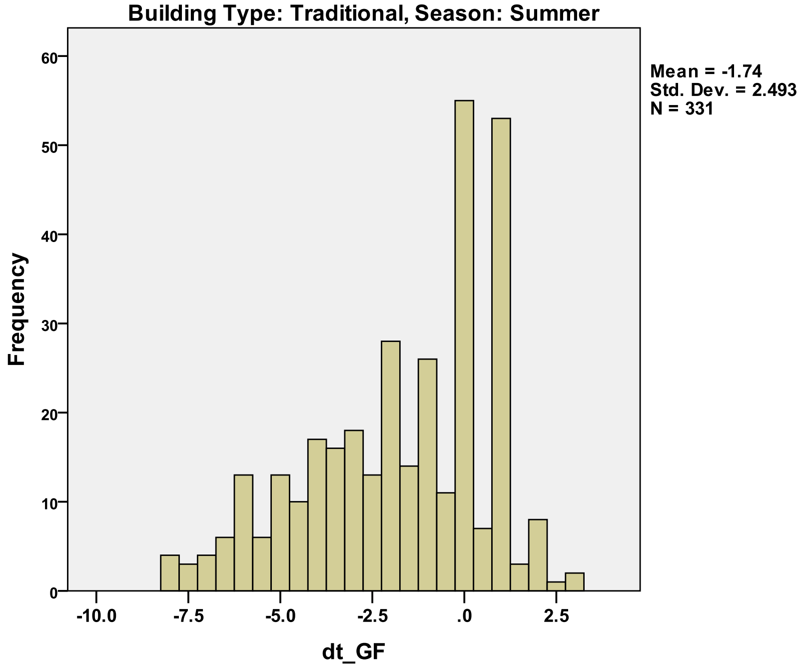



Fig.4.8 Difference between the indoor ground floor and outdoor air temperature (dt_GF) in traditional residential buildings during summer season

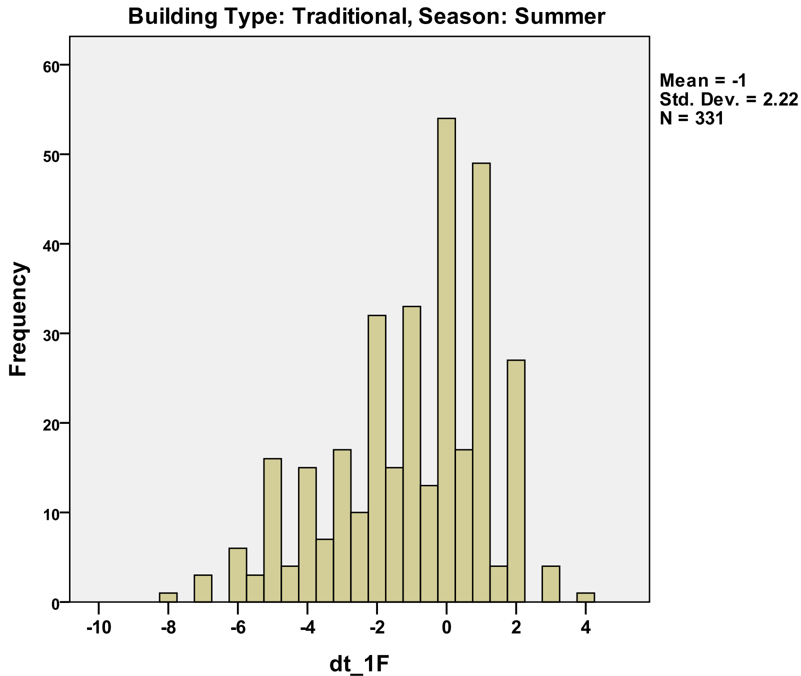



Fig.4.9 Difference between the indoor first floor and outdoor air temperature (dt_1F) in traditional residential buildings during summer season

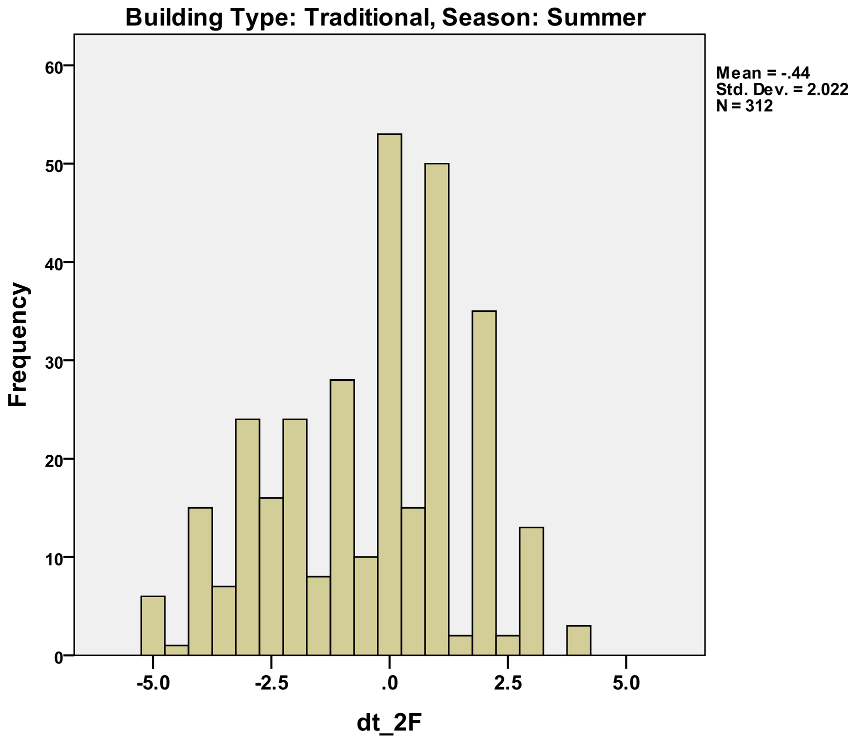



Fig.4.10 Difference between the indoor second floor and outdoor air temperature (dt_2F) in traditional residential buildings during summer season

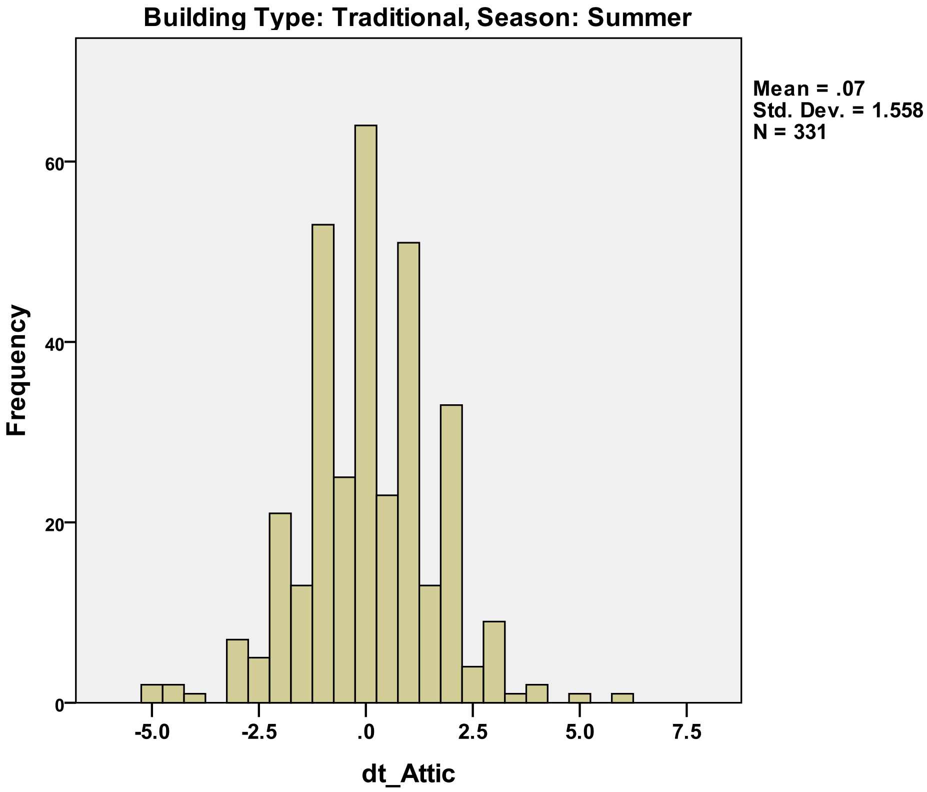



Fig.4.11 Difference between the indoor attic and outdoor air temperature (dt_Attic) in traditional residential buildings during summer season

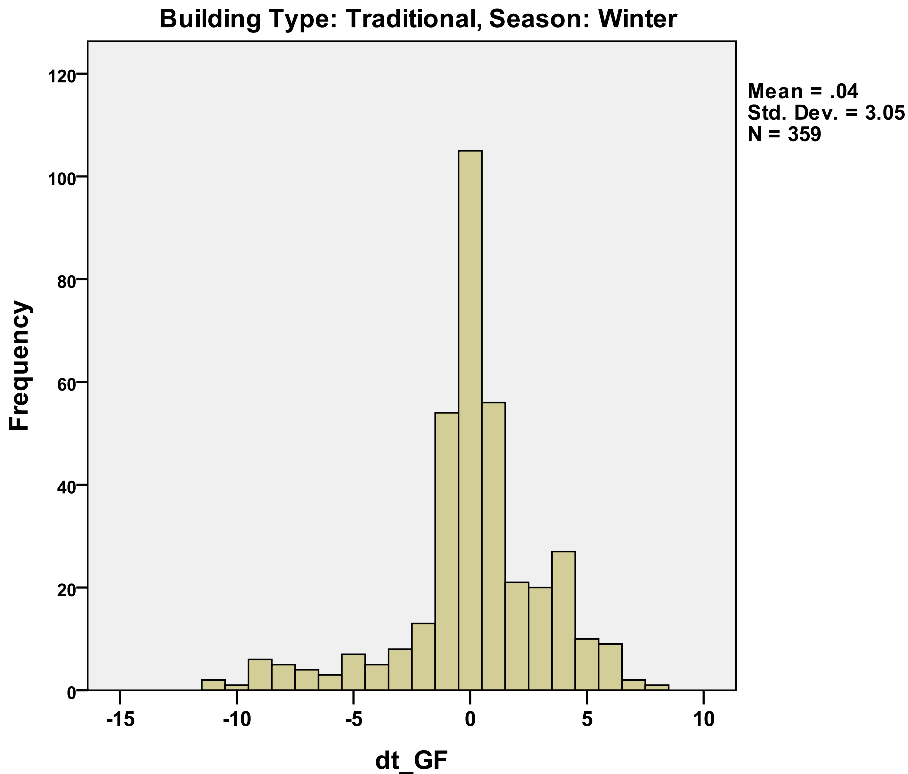



Fig.4.12 Difference between the indoor ground floor and outdoor air temperature (dt_GF) in traditional residential buildings during winter season

**4.4.5 Evaluation of indoor and outdoor air temperature due to building orientation**

In order to clarify air temperature by orientation, the results were analyzed by dividing each traditional building in different orientation. Figures 4.13, 4.14 and 4.15 show the mean indoor and outdoor air temperatures of all traditional buildings in all four seasons over one year period with 95% confidence interval. Figure 4.15 shows the North facing building is better during day time in summer because of the indoor temperature of 26-27 $^{o}$C which is 3 to 4$^{o}$C less than outdoor maximum of 30$^{o}$C. During winter evening also, this building performs better than the other due to heavy thermal mass wall in the south face. That is why indoor temperature during this times same or 1-2$^{o}$C more than outdoor air temperature. Figure 4.15 shows that the orientation of a building does not affect in the heating and cooling of building in traditional building in Kathmandu. This may be due to cluster system with courtyard and street planning. This may be due to the heavy thermal wall location effects in the heating and cooling of the building. Because during daytime of summer, all the outdoor and indoor temperature were nearly the same in all buildings; but outdoor evening temperature of 3 to 5$^{o}$ C higher than morning temperature and in same way, the indoor temperature in evenings little bit 1to 2$^{o}$C higher than morning.

As the size, location and heating facilities of the rooms impose certain limitation on their use, the courtyard becomes a vital component of the house itself (Korn 1976). It should be noted that the openings and main façade of traditional building in urban area of Kathmandu is oriented towards open spaces of either courtyard or street. It is not directed towards to Sun or toward South orientation as practiced in most of traditional buildings in hilly and mountain region of Nepal. The courtyard system is the most significant element of climatic utility in a cool composite climatic region. The courtyard or open street acts as a thermal mass and light well for surrounding buildings in Kathmandu. Bay window is projected towards street or courtyard to enter light and heat inside in winter and cool breeze to improve cross ventilation in summer. That is why; the north oriented building also creates comfort environment in traditional neighborhood settlement of Kathmandu. Also it should be noted that lattice window is used in bed room without considering direct solar radiation but located towards either the alley or courtyard. It heats or cools indoor environment considering thermal environment of alleys and courtyard indirectly by passive system of solar indirect gain through thermal mass of outdoor courtyard, street or indoor wall, floor and roof.

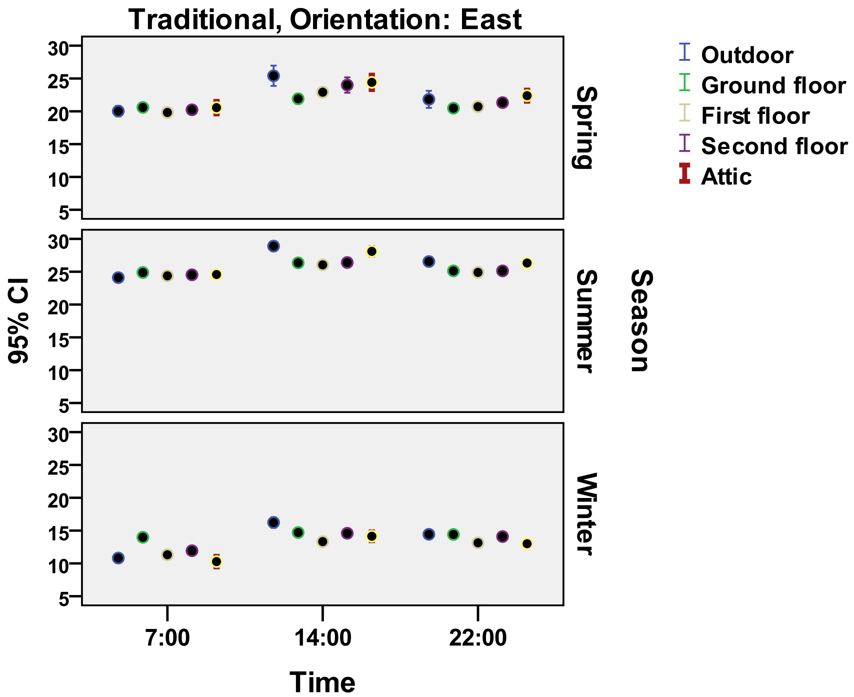



Fig.4.13 Air temperature in different time and seasons in East oriented traditional residential buildings

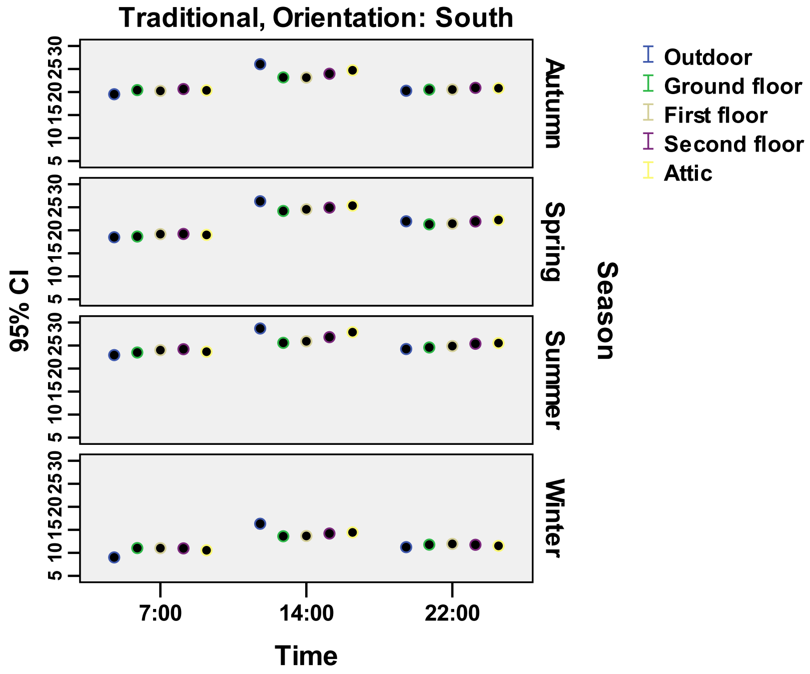



Fig.4.14 Air temperature in different time and seasons in South oriented traditional residential buildings

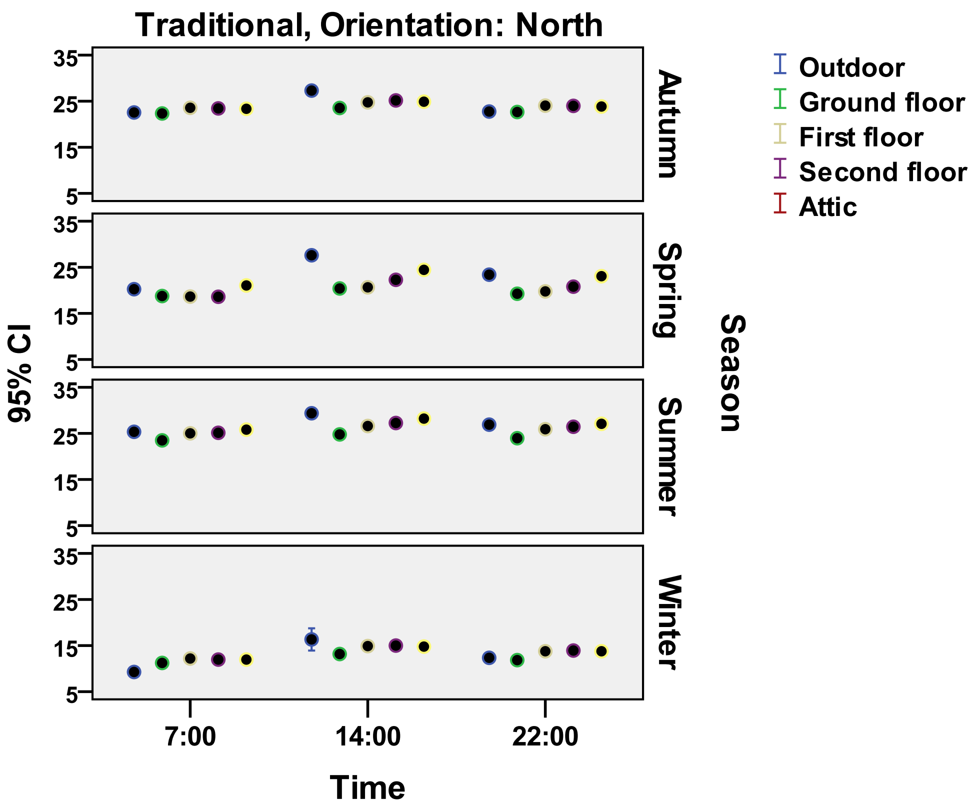



Fig.4.15 Air temperature in different time and seasons in North oriented traditional residential buildings

### 4.4.6 Evaluation of indoor and outdoor air temperature due to the wall

In order to clarify indoor air temperature, the results were analyzed by dividing each external wall in different seasons. The figure 4.16 shows the mean indoor and outdoor air temperatures of all traditional buildings in all four seasons over one year period with 95% confidence interval (CI). The figure shows that thick wall creates indoor temperature same or little higher than outdoor in winter morning and evening and same or lower in summer daytime where as thin wall of 230 mm creates vice versa. The most important result of this study shows that thick traditional wall create either same or 1°C warmer in indoor during winter and either same or minimum 1°C cooler during summer than outdoor air temperature. But the modern 230 mm external wall creates either same or 1°C cooler in indoor (except attic) during winter and either same or maximum 2°C warmer during summer than outdoor air temperature.

The figure shows that the thick walls are mainly responsible to create indoor temperature more comfortable than thin wall. So, maximum indoor air temperature was lower than outdoor in the summer in most of traditional buildings. Same way, most of traditional building maximum indoor air temperature was higher than outdoor in the winter. The outdoor mean maximum air temperatures range from 25 to 28$^{o}$C whereas indoor mean maximum air temperature ranges from 25 to 26$^{o}$C during summer. The figure shows that the thick or thin wall behavior works in higher temperature during summer time than in winter.

Meir and Roaf (2006) wrote that the thermal performance of building with high thermal mass proved to be better in highland and mountain regions than the low lands and more humid coastal plains. The laboratory experimental results of this research also proved that thick traditional wall creates reverse action in indoor. When temperature rises outside the indoor temperature reduces. Same way, when temperature reduces outside the indoor temperature rises. That is why; in most of traditional building maximum indoor air temperature was lower than outdoor in the summer.

Same way, most of traditional building maximum indoor air temperature was higher than outdoor in the winter. The research of Ahmad et al. (1985) may be a good example to compare with buildings of Kathmandu in material and construction with respect to thermal comfort. Their research shows that the indoor temperature 35$^{o}$C in modern house whereas only 28°C in traditional house in the old city in the same summer period in Ghadames, Libya. Clay mixed with organic matter is the main building material. The family use heavy weight construction in the ground for summer day and relatively light weight in first floor for winter.

The study shows the old houses can provide a year round comfortable environment, however the new houses are unable to provide indoor comfort in summer as well as winter. The research of Algifri et al. (1992) compares the thermal behavior of adobe and concrete houses in Yemen. Their results show the thermal appropriateness of the mud construction is a major saving of energy consumption for cooling and producing adobe houses which is very true in Kathmandu. In contrast to modern buildings, these traditional buildings are thermally efficient. Most houses are of sun-dried mud bricks (adobe) with straw. The straw provides the thermal insulation and storage in adobe brick.

This result was also proved by laboratory experiment in this research. The lab experimental research identified the traditional 600 mm thick wall being the best with reverse effect in the indoor thermal environment both in winter and summer. One of the important outcomes of this lab work, the sun burnt brick has maximum role to create thermal environment better in summer and winter condition in the traditional buildings. This works as thermal mass which creates reverse effect of thermal environment. This creates coolness in summer and warmth in winter in traditional building.

The most important result of this study shows that thick traditional wall not only creates either same or 1°C warmer during winter but also same or minimum 1°C cooler during summer than outdoor air temperature. Compared to modern walls, this type of wall saves minimum 1-2°C temperature in both hot and cool seasons for thermal comfort. But this also saves lot of energy. It saves minimum 10 -20% energy for either heating or cooling in these building both in summer and winter than a modern building (Nicol et al. 2012). It gives knowledge for saving energy and prepares an energy efficient design. This could be done in further research study in future.

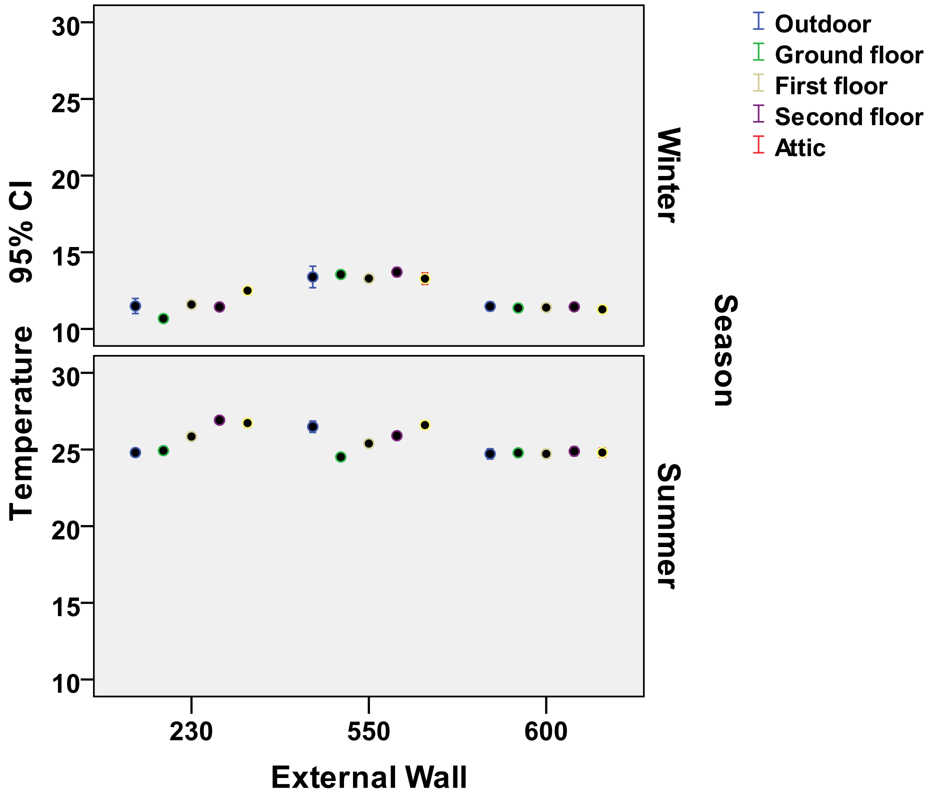



Fig.4.16 Indoor air temperature due to external wall in buildings

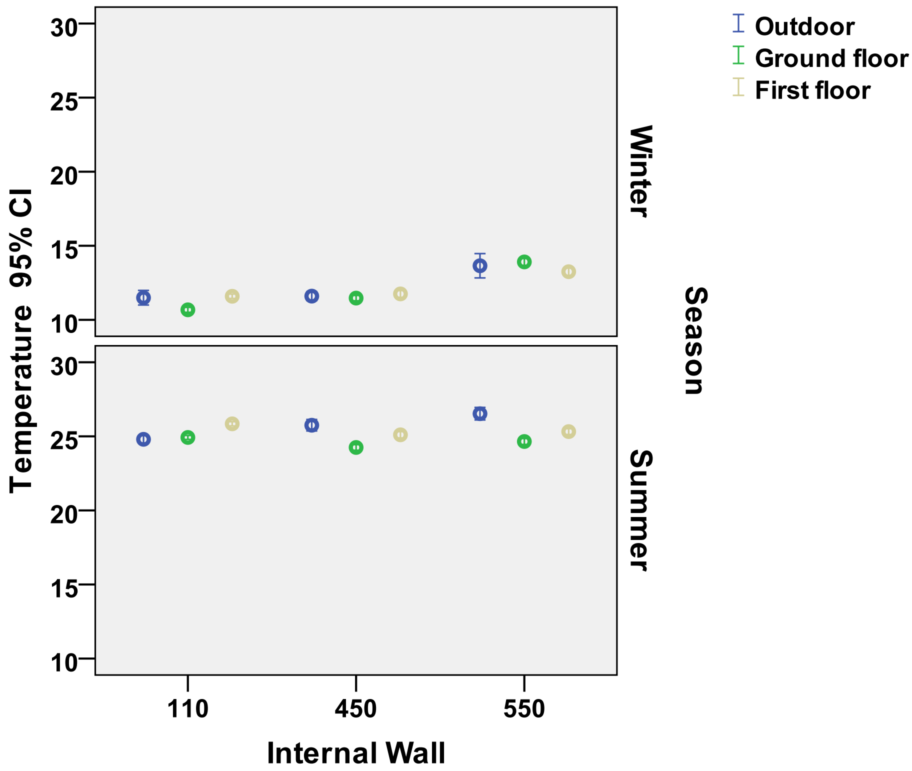



Fig.4.17 Indoor air temperature due to internal wall in buildings

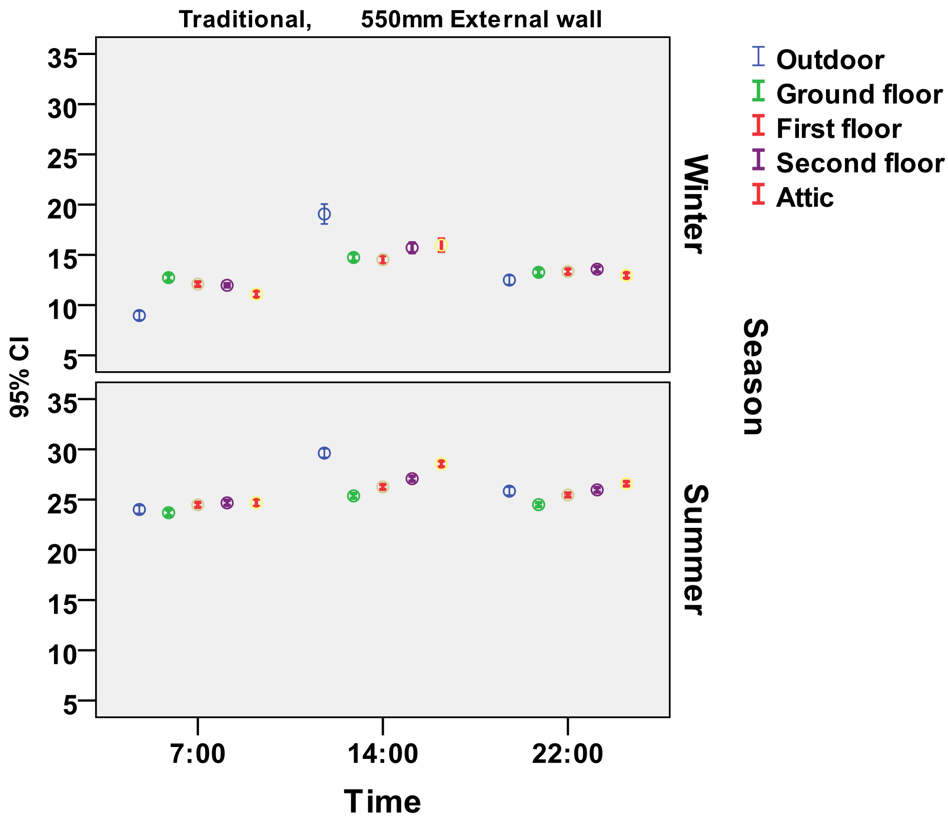



Fig.4.18 Indoor air temperature due to550mm external wall in buildings

### 4.4.7 Evaluation of indoor and outdoor air temperature due to roof

In order to clarify air temperature, the results were analyzed by dividing each traditional slope and modern flat roof in two different seasons winter and summer over one year period with 95% confidence interval. Figure 4.20 shows every time that the mean indoor air temperature in attic of modern flat roof is always higher than outdoor temperature during summer and winter. The modern material and construction always encourage to flow heat faster. Whereas figure 4.19 shows that traditional slope roof creates nearly 2$^{o}$C lower than outdoor temperature during daytime in summer and nearly 1-2$^{o}$C higher than outdoor temperature in winter morning.

The figures show that traditional slope roof with traditional material and construction always flow heats lower and create better thermal environment than modern practice. Whereas figure 4.20 shows that modern flat roof creates temperature nearly 2$^{o}$C higher than outdoor temperature every time in summer. During winter, it is nearly the same during day and evening and nearly 1-2$^{o}$C more in morning than outdoor air temperature. The results show that traditional slope roof performs better indoor thermal environment than flat roof. The traditional form, material and construction always create better indoor thermal environment than modern practice.

The result is similarly noticed by Meir and Roaf (2006) in their study comparing curved and flat roof. They wrote in their research that curved roof were found to perform thermally better than flat ones by promoting more comfortable indoors. They wrote that the results showed a domed or vaulted roof absorbing more solar radiation than in corresponding flat roof. However, the main reason for improved indoor conditions under a curved roof is exactly this enlarged surface area. It elaborates that the worst indoor temperature conditions measured and simulated were within buildings with light roofs. The study mentioned that over fifty percent of the thermal loads of buildings originate in the roof. Therefore insulating a flat roof will have a much more profound effect than replacing it with a curved roof. This result and discussion is very important to compare with this study.

The study of Malama and Sharples (1996) found that the roof is the most important component of the house with regard to passive cooling in tropical upland climate. Improvement in roof surface with colour or construction had significant impacts in internal temperature. This has been proved in this study with comparison of two roofs. In the context of Kathmandu, roof is not only inclined but also heavier than modern thin RCC flat roof. That is why, traditional form, material and construction always create better indoor thermal environment than modern practice.

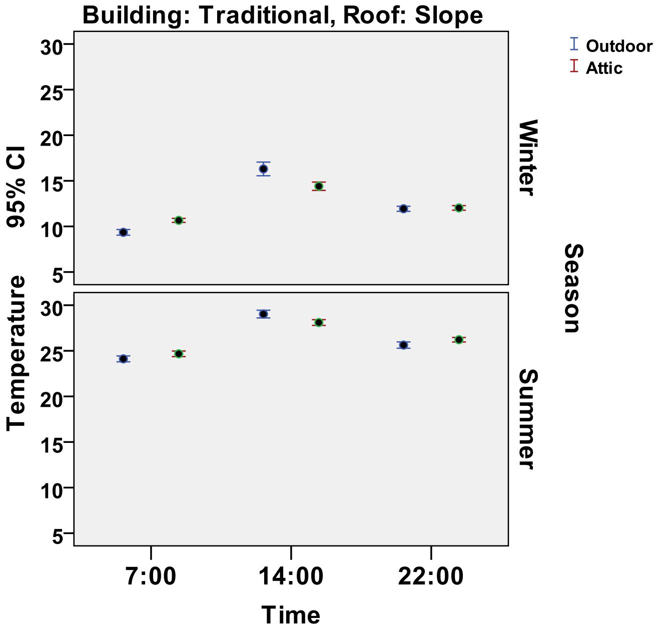



Fig.4.19 Indoor air temperature due to slope roof in different time and seasons in traditional residential buildings

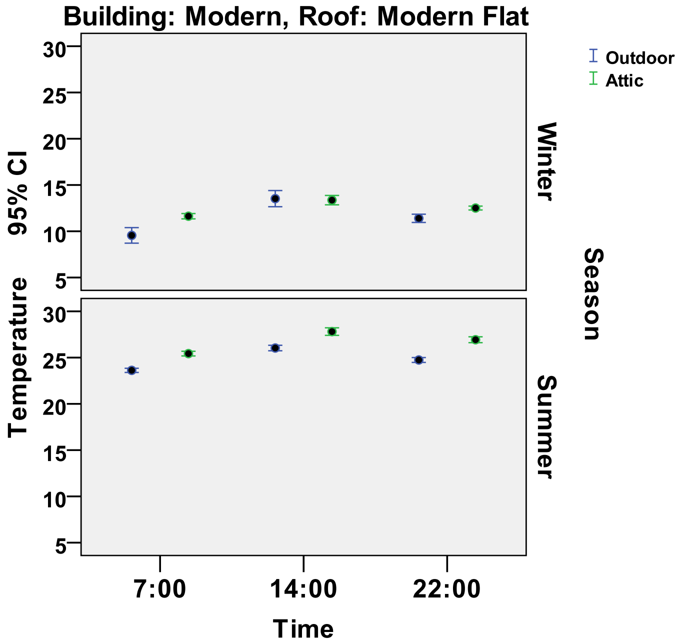



Fig.4.20 Indoor air temperature due to flat roof in different time and seasons in modern residential buildings

### 4.4.8 Evaluation of indoor and outdoor air temperature due to room height

In order to clarify air temperature, the results were analyzed by dividing floor height of each room in two different winter and summer seasons. The figure 4.21 shows that the lower the room height is better the thermal performance in a building. During winter, lower room height of 1700 mm has 13 – 14$^{o}$C whereas 2500 mm has 10-11$^{o}$C mean indoor air temperature. The lower room height of 1700 mm has nearly 3$^{o}$C higher indoor air temperature than room height of 2500 mm during winter.

Same way, the figure shows that during summer mean indoor air temperature of lower room height of 1700 mm has 1- 2$^{o}$C less than outdoor temperature and mean indoor air temperature of higher room height of 2500 mm has 1- 2$^{o}$C more than outdoor air temperature. So both summer and winter season, the lower the room height better is the thermal performance. The tradition residential building has lower room height than modern residential building in Kathmandu.

Generally, from the field studies in Kathmandu, the size and height of a room of traditional residence is smaller than a room of modern residences. The volume of a bed room of traditional buildings is nearly 15 cubic metres (2.4m x3.3m x2m) where as the volume of a bed room of modern buildings is minimum 29 cubic metres (3m x3.6m x2.7m).Volume of spaces of traditional building is nearly two times less than modern building. This result shows that these traditional residences have better thermal performance than modern residences in Kathmandu.

The volume of air of any space directly demands energy to create comfort thermal condition during extreme cold and hot season. This is very true in mechanically ventilated buildings than free running buildings. A big room requires more heating or cooling energy to create a comfortable thermal condition than in a small room. This is very true in traditional bed room which demands less energy to heat and cool in traditional building compared to modern building. That is why, figure 4.4 shows indoor air temperature were warmer in evening than morning during winter due to passive solar energy stored in thermal mass of wall and floor in traditional building.

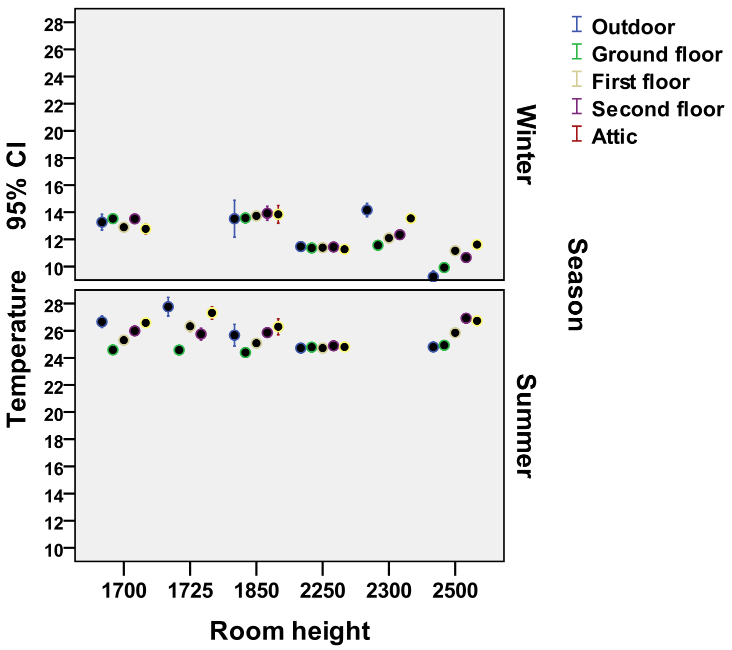



Fig.4.21 Indoor air temperature due to room height in residential buildings in winter and summer

### 4.5 Prediction of Indoor air temperature by Regression analysis

One of the most important findings of this research is the equation to predict of indoor air temperature by Regression analysis. This research has presented the nearly 6458 field data from thermal measurement of the indoor and outdoor thermal environment of traditional as well as modern residential buildings in Kathmandu. Nearly 6458 air temperature data were collected in five spaces in three times a day for thirty days in four seasons in one year during field experiment of five traditional and two modern houses. The indoor and outdoor thermal environment was monitored manually with the ordinary wall thermometer. All this temperature reading is used in regression analysis for searching the most important equations as a finding of this research. That is the equation to predict indoor air temperature by Regression analysis.

The metrological department always forecasts the weather data. This equation can be used to predict the indoor air temperature of a residential building knowing outdoor air temperature from metrological department. The Figures below (Fig.4.22, 4.23, 4.24, 4.25) show the examples of regression analysis in different spaces of traditional and modern residential buildings. Figure 4.26 shows the relation between indoor and outdoor air temperature in traditional and modern residential buildings. Table 4.5 shows the result of the linear regression analysis of the indoor and outdoor air temperature following the each floor of traditional and modern residential buildings. The equations for overall mean indoor temperature of traditional and modern residential buildings was also found in Table 4.5. The equations for overall mean of traditional and modern residential buildings are given below.

Traditional residential building, $T_i = 0.8905T_o + 1.6125$.... (1)

Modern residential building, $T_i = 0.9392T_o + 1.3379$ …..(2)

Where;

$T_i$ : Indoor air temperature (°C), $T_o$ : Outdoor air temperature (°C),

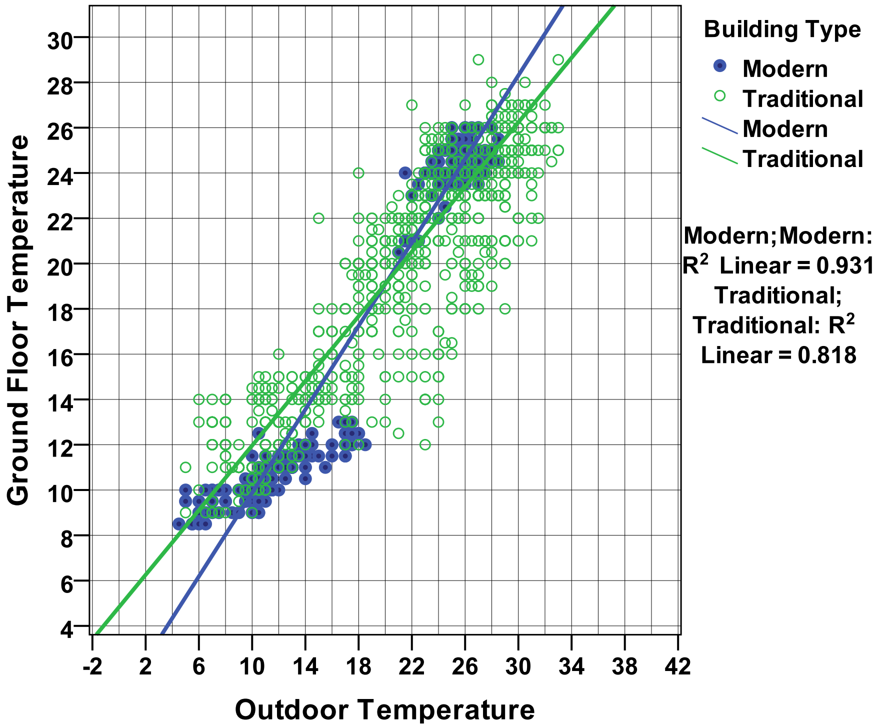



Fig.4.22 Regression analysis of the ground floor and outdoor air temperature in traditional and modern residential buildings

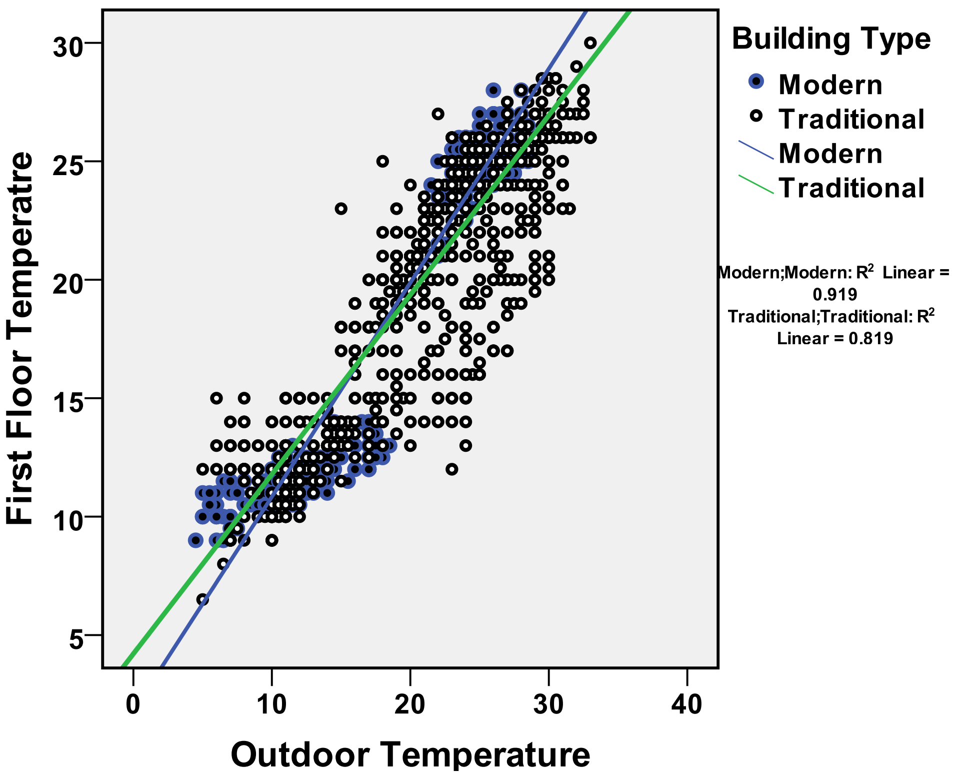



Fig.4.23 Regression analysis of the first floor and outdoor air temperature in traditional and modern residential buildings

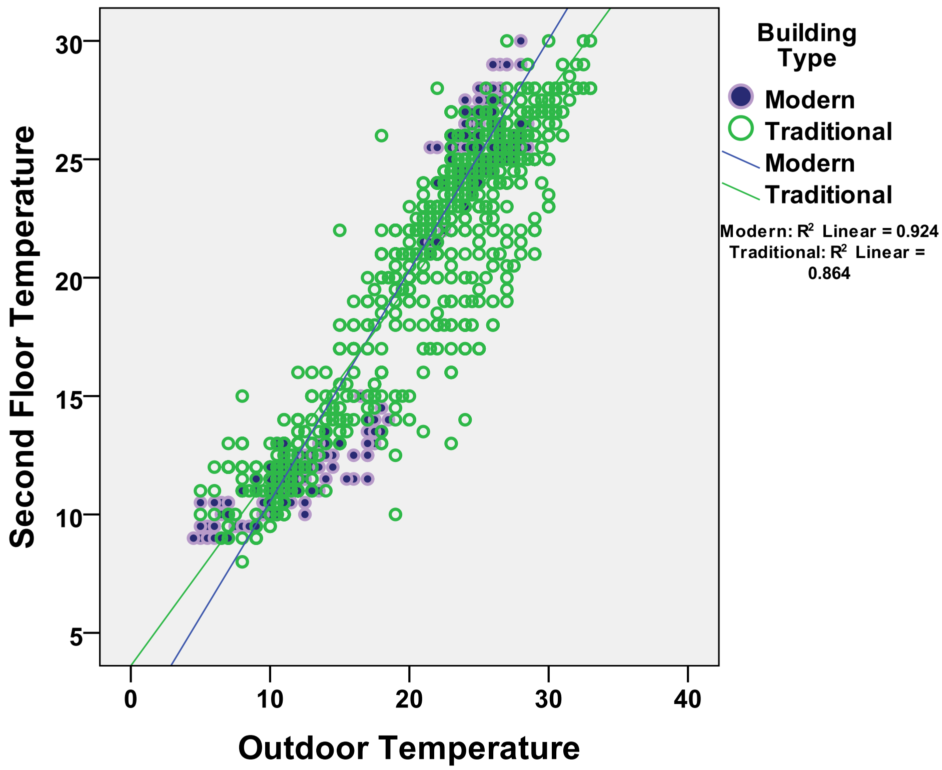



Fig.4.24 Regression analysis of the second floor and outdoor air temperature in traditional and modern residential buildings

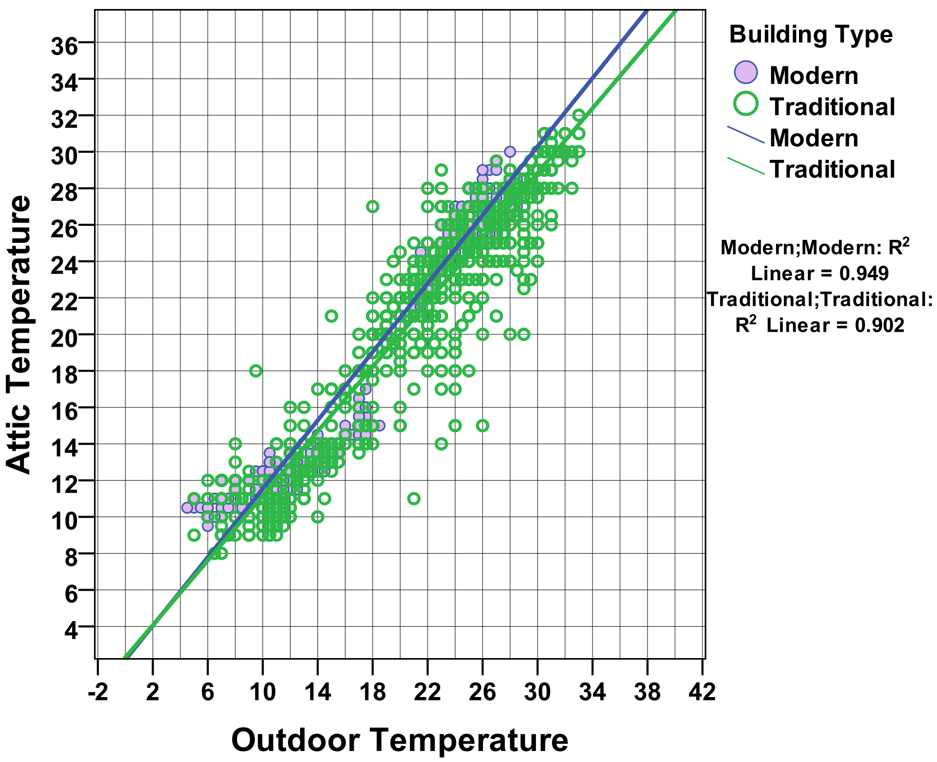



Fig.4.25 Regression analysis of the attic and outdoor air temperature in traditional and modern residential buildings

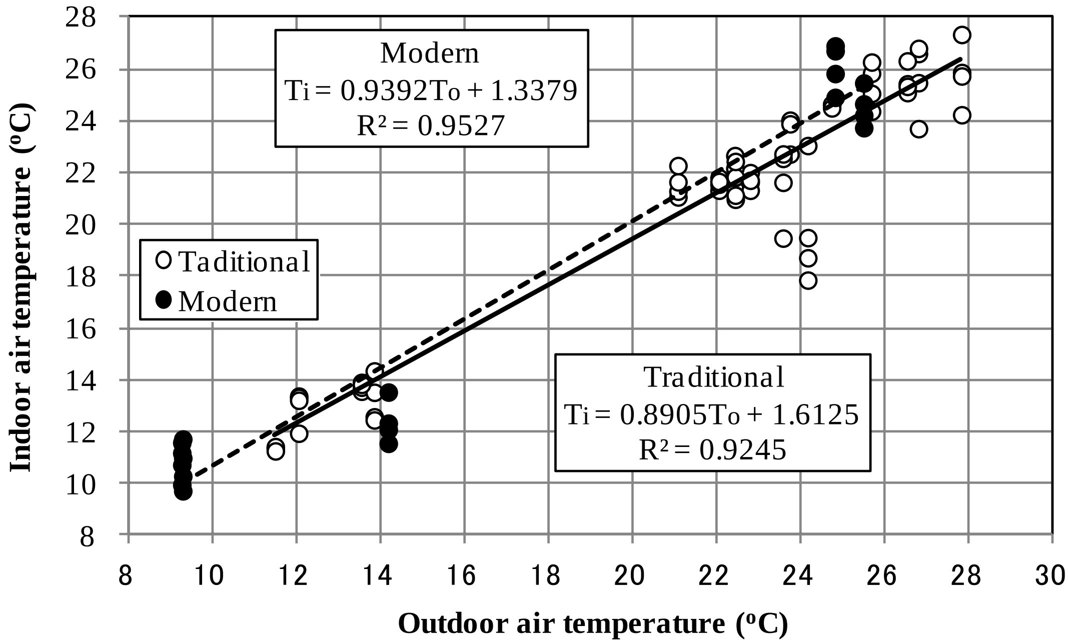



Fig. 4.26 Relation between indoor and outdoor air temperature in traditional and modern residential buildings

An example was conducted below to predict the indoor air temperature of a residential building. According to Regression analysis from the Table 4.5, we know the following equation: $T_i$ =0.714$T_o$+4.829 for ground floor

In traditional building,

If outdoor, $T_o$ =10°C

We know, for ground floor indoor air temperature;

$T_i$ =0.714$T_o$+4.829

$T_i$ =0.714 X 10 +4.829

$T_i$ =7.14 +4.829

$T_i$ = 11. 97°C in indoor

Say $T_i$ = 12°C in indoor

According to regression equation, when outdoor air temperature is 10°C, the indoor air temperature in ground floor of traditional residential building is 12°C. Same way, the Table 4.5 shows that when outdoor air temperature is 30°C high, then indoor air temperature 25-27°C in traditional whereas 27-28.4°C in modern residential building.

Table 4.5 Equations of the indoor and outdoor air temperature from Regression analysis

| Type | Floor | n | Equation | $R^2$ | S.E. | p | Tp Max °C | Tp Min °C |
|---|---|---|---|---|---|---|---|---|
| Traditional | Ground | 1292 | $T_i$=0.714$T_o$+4.829 | 0.82 | 0.009 | <0.001 | 24.8 | 12.0 |
| | First | 1295 | $T_i$=0.758$T_o$+4.211 | 0.82 | 0.010 | <0.001 | 25.4 | 11.8 |
| | Second | 1276 | $T_i$=0.806$T_o$+3.610 | 0.86 | 0.009 | <0.001 | 26.2 | 11.7 |
| | Attic | 1295 | $T_i$=0.885$T_o$+2.301 | 0.90 | 0.008 | <0.001 | 27.1 | 11.2 |
| Modern | Ground | 325 | $T_i$=0.922$T_o$+0.655 | 0.93 | 0.014 | <0.001 | 26.5 | 9.9 |
| | First | 325 | $T_i$=0.904$T_o$+1.802 | 0.92 | 0.015 | <0.001 | 27.1 | 10.8 |
| | Second | 325 | $T_i$=0.975$T_o$+0.805 | 0.92 | 0.016 | <0.001 | 28.1 | 10.6 |
| | Attic | 325 | $T_i$=0.937$T_o$+2.165 | 0.95 | 0.012 | <0.001 | 28.4 | 11.5 |
| Traditional | All | 5158 | $T_i$=0.890$T_o$+1.612 | 0.92 | | <0.001 | 26.5 | 10.5 |
| Modern | All | 1300 | $T_i$=0.939$T_o$+1.338 | 0.95 | | <0.001 | 27.6 | 10.7 |

where;

$T_i$ : Indoor air temperature (°C),

$T_o$ : Outdoor air temperature (°C),

n: number of sample,

p: significant level of the regression coefficient, S.E.: Standard error, $R^2$: Coefficient of determination,

$T_{p\,max}$ °C: Predicted indoor air temperature when outdoor air temperature is 28° C,

$T_{p\,min}$ °C: Predicted indoor air temperature when outdoor air temperature is 10° C.

**4.6 Conclusion**

The results have been interesting from both the research point of view and educational one. The research has identified traditional residential buildings maintain 25 - 26°C during summer season and 12-15°C during winter. This finding shows that the traditional residential building maintains comfort temperature in hot summer according to both Nicol and Rijal comfort temperature of ($T_c$) 26°C (Table 2.2). Especially in the morning and evenings during winter season, these buildings are 2 to 3°C less than comfort temperature ($T_c$) 15°C (Table 2.2 & Rijal et al. 2010) for people in "free running" building of Kathmandu. But the traditional residential building maintains comfortable temperature within comfort zone in winter according to Rijal comfort zone with ($T_c$) 13°C (Table 2.2). But the result shows that traditional residential buildings were 1 to 2°C warmer during winter and 1 to 2°C cooler during summer than modern residential buildings. The thermal performance study of such traditional building proved to be better in highland of Kathmandu in past and present.

There is a general perception that traditional architecture has a better thermal environment than contemporary architecture (Tiwari et al.2004).The current research has established that to a great degree of certainty compared to modern residential buildings, the traditional buildings had a better thermal performance in both winter and summer seasons. The findings show that indoor air temperatures were lower than outdoor during summer whereas indoor air temperatures were higher than outdoor during winter in the traditional buildings. Whereas indoor air temperatures were the same or higher than outdoor in summer and indoor air temperatures were lower than outdoor in winter in modern residential buildings. This shows that outdoor environment directly affect modern buildings whereas this is not same in the traditional buildings. The result that traditional buildings were 1 to 2°C warmer during winter and 1 to 2°C cooler during summer than modern residential buildings could be compared in other part of the world. As Ahmad et al. (1985) observed, the old houses can provide a year-round comfortable environment but new houses are unable to provide indoor comfort in summer as well as in winter. This is true in case of Kathmandu also.

One of the important outcomes of this study, from monitoring field experiment data, is the finding of new equation with the help of linear regression to predict indoor air temperature by knowing the outdoor air temperature. The indoor air temperature could be predicted from outdoor air temperature of weather forecast by meteorological department. If we know the outdoor air temperature, we can predict the indoor air temperature using the equation as a whole of traditional and modern building. Also we can predict the indoor air temperature using the linear regression equation of each floor in traditional and modern building. The result shows that when outdoor air temperature is 30$^{o}$C then indoor air temperature is 26.5$^{o}$C in traditional whereas it is 27.6$^{o}$C in modern residential building which is also true from the field results.

The research has shown variety of positive factors that influence a better thermal comfort. The study compared thermal performance of traditional building based on site planning. The street type buildings were better than courtyard pattern. The indoor air temperature of street type buildings is higher than courtyard type buildings in cool morning and evening. During summer, street type buildings daytime indoor temperature has lower than courtyard type. This indicates that the street type residence is better than the courtyard type. The finding shows that when floor rises up vertically, the indoor air temperature is better in ground and first floor than second and attic floor in summer. More open to sky area, more better will be the outdoor environment effects.

This research finding has identified one of the most important aspects that are orientation of a building does not effect in the heating and cooling of traditional building in Kathmandu. Even in North facing building, it is noted that thermal environment is better during day time in summer because of the indoor temperature 3-4$^{o}$C less than outdoor temperature of 30$^{o}$C. During winter evening also, this building has better thermal performance than others due to heavy thermal wall placed in south face.

The findings show thick thermal walls are mainly responsible to create indoor temperature more comfortable than thin wall. The thick or thin wall behavior works in higher temperature during summer and winter. The 550 or 600 mm thick thermal wall creates indoor temperature same or little higher than outdoor in winter morning and evening and same or lower in summer daytime whereas a thin wall of 230 mm creates vice versa. These thermal walls are mainly responsible to create indoor temperature more comfortable than thin wall. That is why; most of traditional buildings indoor air temperature is comfortable in the summer and winter.

The most important result of this study shows that this study quantified the thermal behavior with temperature of traditional residential buildings and modern residential buildings. It quantified temperature in degree regarding how much warmer and cooler it was in traditional residential buildings compared to modern building. The most important result of this study shows that traditional residential buildings were 1 to 2°C thermally comfortable than modern residential buildings during winter and summer. It saves lot of energy. It saves 10 -20% energy for either heating or cooling in these building both in summer and winter as in the UK (Nicol et al. 2012). If we calculate in housing sector in national scenario, it gives knowledge for energy saving as well as efficient housing design. This type of energy saving has very much meaning in developed countries like Japan, USA, Russia, etc. where they use maximum budget for heating and cooling energy to maintain indoor thermal comfort. This should be studied in further research in future.

The findings from the field study show the thermal performance of such traditional building proved to be better in Kathmandu in past and present. These findings from field study could be better to develop modern houses in future. The planning, material, technology, orientation, floor height, roof etc. factors for thermal comfort may be new paradigm to design new houses to maintain thermal comfort and save energy in future. Also these results were more tested in field with qualitative questionnaire survey to know peoples' perception in following chapter 5. These field results were further tested in laboratory with experiments in chapter 6.

# CHAPTER 5: THERMAL COMFORT OF RESIDENTS

## 5.1 Introduction

This chapter discusses the thermal comfort of residents to find out background for thermal performance of the traditional buildings. The science of thermal comfort has been concerned with predicting what set of temperature corresponds most closely to this comfort feeling, and how tolerant people are of deviations from it. Scientists investigating thermal comfort survey treat the human organism as a "meter" of thermal comfort. The meter is calibrated in "comfort votes" - the description on a scale from hot to cold which best describes the person's impression of the thermal environment.

This section of the thesis deals with description of data, analysis, discussion and results of household questionnaire survey. This chapter has taken into consideration the previous thermal comfort study done in Nepal by Rijal et al. (2010). The survey was conducted in fifty households in the selected residential buildings in Patan and Kathmandu as presented in the previous chapter on Research Methodology. This survey of the thermal sensation, comfort and preference in a residential building and recommendation for building type was conducted in real life situations in urban settlements of Kathmandu. This study is used to support the study of main chapter 4 of this thesis.

### 5.2 Description of study samples

The study areas were chosen householders of different types of residential buildings in traditional urban settlement of Kathmandu valley. There are mainly three different types of residential buildings in traditional urban settlement of Kathmandu valley. They are: 1) Traditional residential building 2) modern contemporary residential building 3) Mixed type residential building. The study areas focused on households of urban settlements of Kathmandu, Patan and Kirtipur of the valley. The samples are selected randomly from among local residents of these houses in urban settlements of Kathmandu, Patan and Kirtipur of the valley.

### 5.3 Description of Survey

The surveys focus on answers of questions related to thermal sensation, thermal comfort, thermal preference and opinion for constructing building in future were conducted. These studies clarify the peoples' opinion for thermal comfort in traditional and modern residential building in traditional settlements of Kathmandu. The samples of questionnaire form (Table 5.1 & 5.2) is prepared with the study of questionnaire forms in Rijal et al. (2010).Then this sample of questionnaire form is developed after conducting mini pilot survey (Table 3.3) with the assistants as described in research methodology chapter 3.The survey were conducted in Nepali and Newari languages as shown in sample of questionnaire form below in Table 5.2. The sample of questionnaire form translated in English shown below in Table 5.1.

Table 5.1 The translated sample of questionnaire form (English Translation)

SAMPLE OF QUESTIONNAIRE SURVEY ABOUT OCCUPANTS' FEELING FOR THERMAL PERFORMANCE OF RESIDENTIAL BUILDINGS IN URBAN SETTLEMENT OF KATHMANDU VALLEY

Name of the surveyor: Date:

• Name of the respondent:
• Age: Sex: Male / Female
• Occupation:
• Address: Ward No.:

Type of house:

1. Traditional 2. Modern RCC 3.Mixed (Traditional style with RCC) 4. Other

Q.No.1) How do you feel the thermal sensation in this house?

-4. Very cold -3. Cold -2. Cool -1.Slightly cool 0.Neutral 1. Slightly warm 2. Warm 3. Hot 4. Very hot

Q.No.2) How do you feel the thermal comfort in this house?

0. Comfortable 1. Slightly comfortable
2. Slightly uncomfortable 3. Uncomfortable 4.Very uncomfortable

Q.No.3) What is your thermal preference in this house?

-2. Much warmer -1. Slightly warmer 0. No change
1. Slightly cooler 2. Much cooler

Q.No.4) Do you feel your skin became moist?

0. None 1. Slightly 2. Moderate 3. Profuse

Q.No.5) Your activity now:

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

Q.No.6) Do you have any cold or hot part in your body?

1. Yes 2.No.

Q.No.7) Can you accept present cold or hot environment or not?

1. Yes 2.No.

Q.No.8) If you need to construct a new house then as per your thermal sensation which type of residential building you want to construct?

1. Traditional style residence with traditional technology
2. Modern RCC residence
3. Mixed type residence of Modern RCC & traditional look
4. Other type

Table 5.2 Sample of questionnaire form (In Nepali language)

**काठमाण्डौ उपत्यका शहरी क्षेत्रमा निर्मित आवाशीय घरहरुको**
**तातो-चिसोपनाको अनुभव विषयक प्रश्नावली**

सर्भेयरको नाम : .................... मिति :...........
नाम :....................
उमेर :................... लिङ्ग : महिला/पुरुष/अन्य
पेशा : ..................
ठेगाना : .................... वडा नं. ...............

**घरको बनोट :** क) परम्परागत शैलीको घर ख) नयाँ ढाँचाको ढलान घर
ग) मिश्रित परम्परागत उवं ढलान घ) अन्य

**प्रश्न नं. १) यस घरमा तपाईको तातो - चिसो अनुभव के कस्तो छ ?**

-४) धेरै जाडो -३) जाडो -२) चिसो -१) अलिकति चिसो
०) ठिक १) अलिकति चिसो २) तातो ३) गर्मी ४) धेरै गर्मी

**प्रश्न नं. २) यस घरमा तपाइको तातो - चिसोको आनन्दपन कस्तो लाग्छ ?**

०) आनन्द १) अलिकति आनन्द २) अलिकति असुविधा

३) असुविधा ४) धेरै असुविधा

**प्रश्न नं. ३) यस घरमा तपाईको न्यानो - शितलको चाहना के छ ?**

-२) न्यानो चाहिन्छ -१) अलिकति न्यानो चाहिन्छ ०) यत्तिकै ठिक छ

१) अलिकति शितलता चाहिन्छ २) शितल चाहिन्छ

**प्रश्न नं. ४) हाल तपाईको शरिरमा पसिना आइरहेको छ ?**

०) छैन १) अलिकति छ २) केहि मात्रामा छ ३) धेरै छ

**प्रश्न नं. ५) हाल तपाईको कार्यशीलता के छ ?**

१) पल्टिरहेको २) बसेर आराम गरी रहेको ३) बसेर काम गरी रहेको

४) उभिरहेको ५) उभिएर काम गरीरहेको

**प्रश्न नं. ६) तपाईको शरिरको कुनै भाग तातो वा चिसो छ ?**

१) छ २) छैन

**प्रश्न नं. ७) तपाई यस घरमा अहिलेको जाडो वा गर्मी वातावरण खप्न सक्नुहुन्छ कि हुदैन ?**

१) सक्छु २) सक्दिन

**प्रश्न नं. ८) यदि नयाँ घर निर्माण गर्नु परेमा तपाई तातो - चिसो अनुभवको आधारमा कस्तो घर निर्माण गर्न चाहनुहुन्छ ?**

१) परम्परगत शैली र बनोटको परम्परागत घर

२) नयाँ ढाँचाको ढलानको घर

३) मिश्रित नयाँ तथा पुरानो ढाँचाको घर

४) अन्य तरिकाको घर

Fig.5.1 Views of types of different households for questionnaire survey in Kathmandu

### 5.4 Thermal comfort survey

#### 5.4.1 Thermal comfort words in Nepal

The Nepalese questionnaires survey form and the translated form in English is shown in table5.1.There are many words related to thermal comfort in Nepalese language. For example; "*Thikka*" for normal thermal condition neither hot "*Tato*" nor cool "*Chiso*". For this reason, "*Thikka*", "*Tato*", "*Chiso*" for feeling of thermal sensation were used in question no 1. Same way "*Ananda*" for comfortable thermal condition and for uncomfortable "*Asubida* " were used in question no 2 for thermal comfort in the house. "*Alikati Nyano*" for need warm and "*Thikka*" for OK comfortable and "*Alikati Shital* " for need little cool were used in question no 3 for thermal preference in the house. The words used in these samples of questionnaire form (Table 5.1 & 5.2) are also prepared with the study of questionnaire forms in Rijal et al. (2010).

#### 5.4.2 Thermal sensation scale

As scientists treat the human organism as a "meter" of thermal comfort for investigating thermal comfort survey, a questionnaire survey developed with comfort votes on a scale from hot to cold. The English questionnaire survey is shown in table 5.1. To evaluate thermal sensation of occupants, a 9 - point thermal sensation scale was used in question no 1. Same way, a different point thermal sensation scale was used in other questions as shown in the table 5.1.

The thermal sensation scale used in these samples of questionnaire form (Table 5.1 & 5.2) is also prepared with the study of questionnaire forms in Rijal et al. (2010). The meaning, relationships and evaluation methods of the questionnaires were described to all subjects individually and in group to maintain accuracy for the responses. Most of the people are Newar but all of them know Nepali very well. Those elder women, who were unable to answer in Nepali, were asked in their mother tongue in Newari language.

#### 5.4.3 The people (Subjects)

As the science of thermal comfort, researchers investigating thermal comfort survey treat the human organism as a "meter" of thermal comfort of people. The meter is calibrated in "comfort votes" – the description on a scale from hot to cold. It describes the person's impression of the thermal environment in a scale as shown in table 5.1.

The description with name of respondent, age, sex, occupation, location and date are shown in the table 5.1. The total number of respondent was 50 of 50 households. Respondents were generally local and healthy people and of age between 17 and 77. At the time of questionnaire, they were sitting down, resting or working.

### 5.4.4 Method of subjective evaluation

The survey was carried out by the author and his local assistants. Subjects were asked orally reading the questionnaire forms. The collected answers were filled up by author and his local assistants. To get an accurate answer, question such as "How do you feel the thermal sensation in this house?" were asked. If they were not able to differentiate the values of scale, they were asked to explain the sensation numerically -4, -3,-2,-1, 0,+1,+2, +3 and +4. For example 0 for neutral and comfortable, +1 for slightly warm, -1 for slightly cool, +2 for warm, -2 for cool and so on. The centre point of this scale of comfort is neutral with 0 in scale (Rijal et al. 2010). This numerical scale helps to quantify in computer as well as minimizes error with 9 scale system.

### 5.4.5 Evaluated buildings

There were mainly four types of buildings in traditional urban settlement of Kathmandu. The types of evaluated buildings were 1) traditional residential building 2) modern residential building with RCC 3) Mixed type of building (Traditional style with RCC) 4) other (Other than these three types). The plans, section and facades of these types of building were shown in appendix. The views of these types of building were as shown in figure 5.2. So the evaluated residential buildings were categories in to four types in questionnaire survey.

### 5.4.6 Period

The survey was carried out for local people of 50 different households during one season. The survey was carried out for thirty days during autumn season which is neither hot nor cold season in Kathmandu. A total of 8 different thermal sensations and their opinion were collected. The sensations were collected only in daytime. The survey gathered total of 700 data from 14 variables.

## 5.5 Display of questionnaire survey data

Table 5.3 Sample of questionnaire survey (In Nepali language)

काठमाडौं उपत्यका शहरी क्षेत्रमा निर्मित आवाशीय घरहरुको

तातो - चिसोपनाको अनुभव विषयक प्रश्नावली

सर्भेयरको नाम : [illegible] मिति : २०६३/५/२

नाम : रीता [illegible]

उमेर : २४ वर्ष लिङ्ग : महिला/पुरुष/अन्य

पेशा : [illegible]

ठेगाना : [illegible] वडा नं. : ६

घरको बनोट : क) परम्परागत शैलीको घर ख) नयाँ ढाँचाको ढलान घर

ग) मिश्रित परम्परागत एवं ढलान घ) अन्य

प्रश्न नं. १) यस घरमा तपाइको तातो - चिसोको अनुभव कस्तो छ ?

- ४) धेरै जाडो - ३) जाडो - २) चिसो - १) अलिकति चिसो

०) ठिक १) अलिकति तातो २) तातो ३) गर्मी ४) धेरै गर्मी

प्रश्न नं. २) यस घरमा तपाइलाई तातो - चिसोको आनन्दपन कस्तो लाग्छ ?

०) आनन्द १) अलिकति आनन्द २) अलिकति असुविधा

३) असुविधा ४) धेरै असुविधा

प्रश्न नं. ३) यस घरमा तपाईको न्यानो - शितलको चाहना के छ ?

- २) न्यानो चाहिन्छ - १) अलिकति न्यानो चाहिन्छ ०) यत्तिकै ठिक छ

१) अलिकति शितलता चाहिन्छ २) शितल चाहिन्छ

प्रश्न नं. ४) हाल तपाईको शरीरमा पसिना आइरहेको छ ?

०) छैन १) अलिकति छ २) केहि मात्रामा छ ३) धेरै छ ।

प्रश्न नं. ५) हाल तपाईको कार्यशीलता के छ ?

१) पल्टिरहेको २) बसेर आराम गरी रहेको ३) बसेर काम गरी रहेको

४) उभि रहेको ५) उभिएर काम गरी रहेको

प्रश्न नं. ६) तपाईको शरीरको कुनै भाग तातो वा चिसो छ ?

१) छ २) छैन

प्रश्न नं. ७) तपाई यस घरमा अहिलेको जाडो वा गर्मी वातावरण सप्न सक्नु हुन्छ कि हुँदैन ?

१) सक्छु २) सक्दिन

प्रश्न नं. ८) यदि नयाँ घर निर्माण गर्नु परेमा तपाई तातो - चिसो अनुभवको आधारमा कस्तो घर निर्माण गर्न चाहनु हुन्छ ?

१) परम्परागत शैली र बनोटको परम्परागत घर

२) नयाँ ढाँचाको ढलानको घर

३) मिश्रित नयाँ तथा पुरानो ढाँचाको घर

४) अन्य तरिकाको घर

Fig.5.2 Views of Traditional, Modern and Mixed type residential buildings in traditional urban settlements of Kathmandu valley

### 5.6 Analysis, discussions and results

#### 5.6.1 Discussion on the thermal sensation

This questionnaire survey of the thermal comfort and environment was conducted in real life situations in autumn. The research participants were asked how they feel of the thermal sensation in their house. There were nine sensation scales to answer with neutral, slightly warm, slightly cool to very hot and very cold. The figure 5.3 shows that the eighty three percent (83%) of people living in traditional residential building feel neutral neither cool nor warm in the same traditional residential buildings. But only twenty four percent (24%) people living in modern building feel neutral in their residence. Forty percent (40%) of people feel slightly warm and twenty percent (20%) of people feel hot in their modern residence (Fig. 5.4). Fifty percent (50%) of people living in mixed residential building feel slightly cool and other fifty percent (50%) of people feel slightly warm (Fig. 5.5).

The research finding shows that eighty three percent (83%) of the people feel neutral in traditional buildings whereas only twenty four percent (24%) of people living in modern building feel neutral in their residence. Overall sixty percent (60 %) of residents feel warm and uncomfortable in their modern residence. These findings also show that the peoples' perception is very contrasting in traditional and modern building. This shows most of the local people find thermal sensation far better in traditional buildings than modern buildings.

The field study result of this research ( Fig.4.2 & 4.3) also shows that traditional residential buildings were 1 to 2°C warmer during winter and 1 to 2°C cooler during summer than modern residential buildings in the field. This proved that traditional buildings satisfy thermal comfort better than modern building. Rijal et al. (2010) also found that the highest frequency of vote is neutral in vernacular houses in Bhaktapur and other part of Nepal. But, he did not compare his result with modern houses.

Many international researchers wrote that traditional building create indoor environment better than modern house. In Yemen, people were more satisfied with traditional Adobe houses than modern concrete houses (Algifri et al.1992). As Ahmad et al. (1985) have observed the old traditional houses can provide a year-round comfortable environment but modern houses are unable to provide indoor comfort in summer as well as in winter. This is also very true in the case of Kathmandu from field study and questionnaire survey in real life situations.

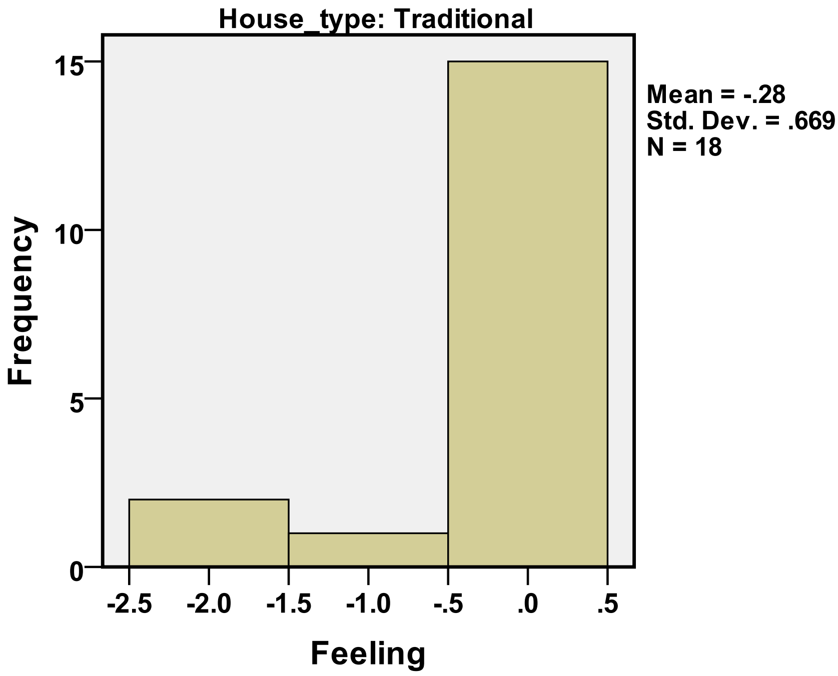



Fig. 5.3 Graph of thermal sensation of local residents in traditional building

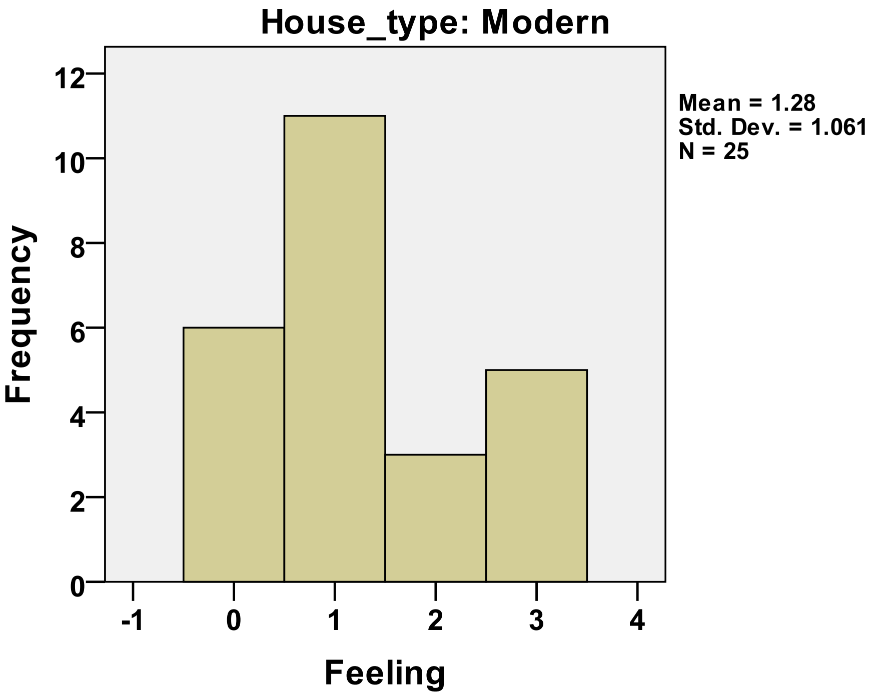



Fig. 5.4 Graph of thermal sensation of local residents in modern building

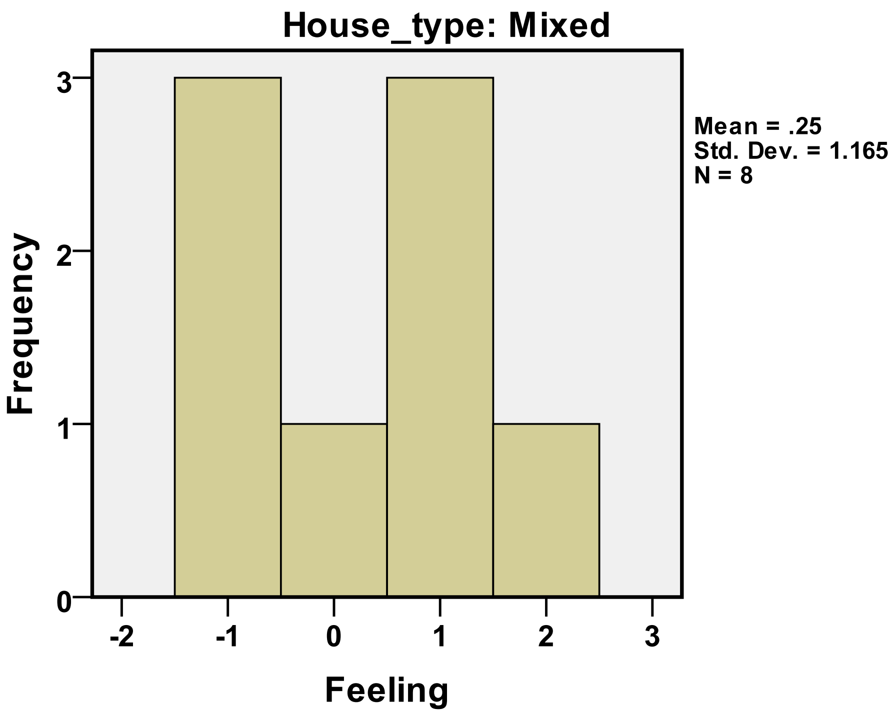



Fig. 5.5 Graph of thermal sensation of local residents in mixed type building

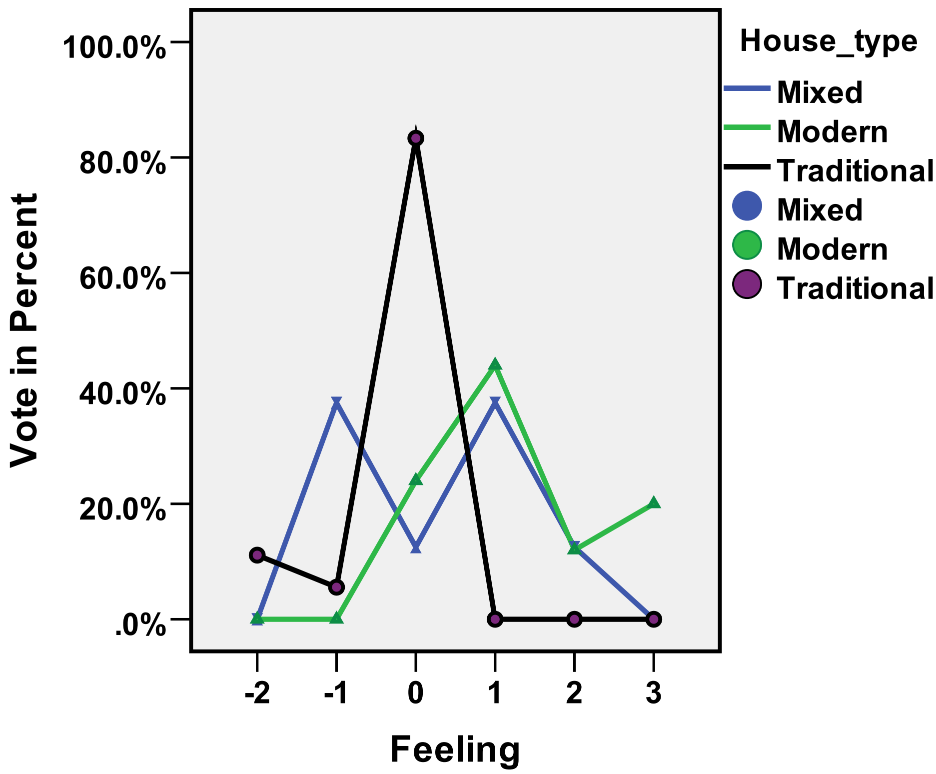



Fig. 5.6 Percentage of thermal sensation of local residents in different building

### 5.6.2 Discussion on the thermal preference

The objective of this survey is to find out the thermal comfort and environment in traditional and other residential building in real life situations in traditional settlement of Kathmandu. Another question is about thermal preference in different houses. Another question asked to research participants was what their thermal preference in their house was. There were five sensation scales to answer this question from much warmer to much cooler and no change for perfect preference (Table 5.1).

The figure 5.7 shows that the seventy five percent (75%) of people living in traditional residential buildings feel no change during cool and hot seasons in the traditional residential buildings. Only nearly twenty percent (20%) of people living in modern buildings feel no change during cool and hot seasons in their residence (Fig.5.8). Forty-five percent (45%) of people feel slightly cooler and thirty five percent (35%) of people much cooler in their modern residence. Nearly forty percent (40%) of people living in mixed residential building feel no change neither cooler nor warmer during cool and hot seasons and other nearly forty percent (40%) of people feel slightly warmer in hot season in mixed type residential building (Fig.5.9).

There is a general perception that traditional architecture has a better thermal environment than contemporary architecture (Tiwari et al.2004).This is supported by the survey results that seventy five percent (75%) of people living in traditional residential building feel no change neither cooler nor warmer during cool and hot seasons. But only nearly twenty percent (20%) of people living in modern building have same feeling in their house. This contrasting result also shows the peoples' perception in traditional and modern building. This shows that most of local people find thermal comfort better in traditional buildings in winter as well as in summer. This is true all over the world in review of many international researchers written that people are more satisfied with traditional houses than modern concrete houses (Algifri et al.1992, Ahmad et al. 1985, Meir and Roaf 2006).

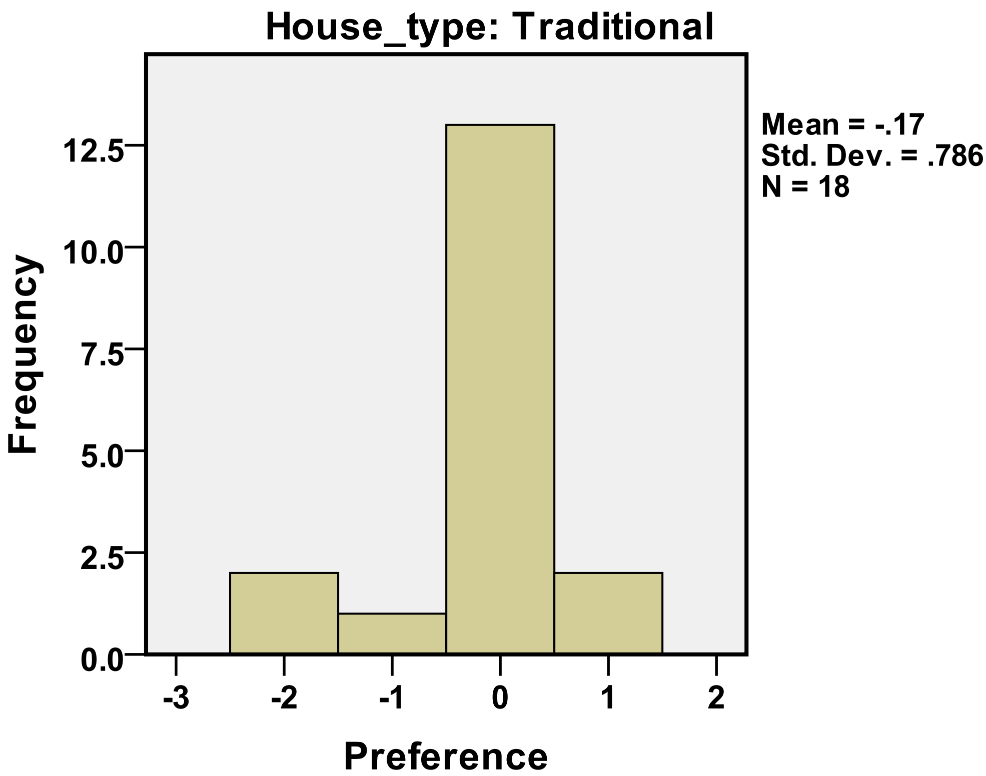



Fig. 5.7 Graph of thermal preference of local residents in traditional building

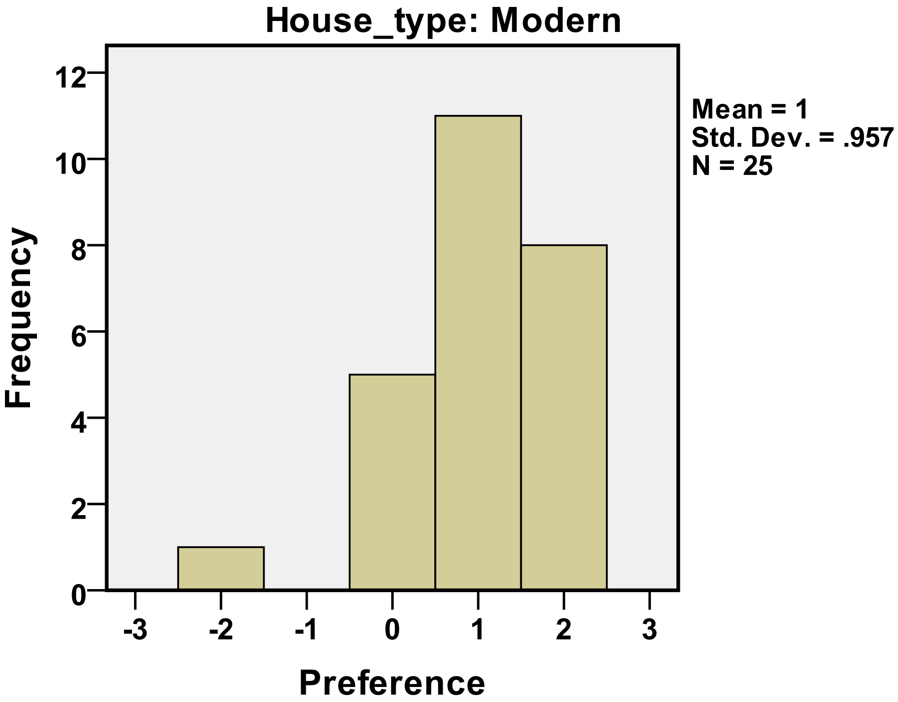


Fig. 5.8 Graph of thermal preference of local residents in modern building

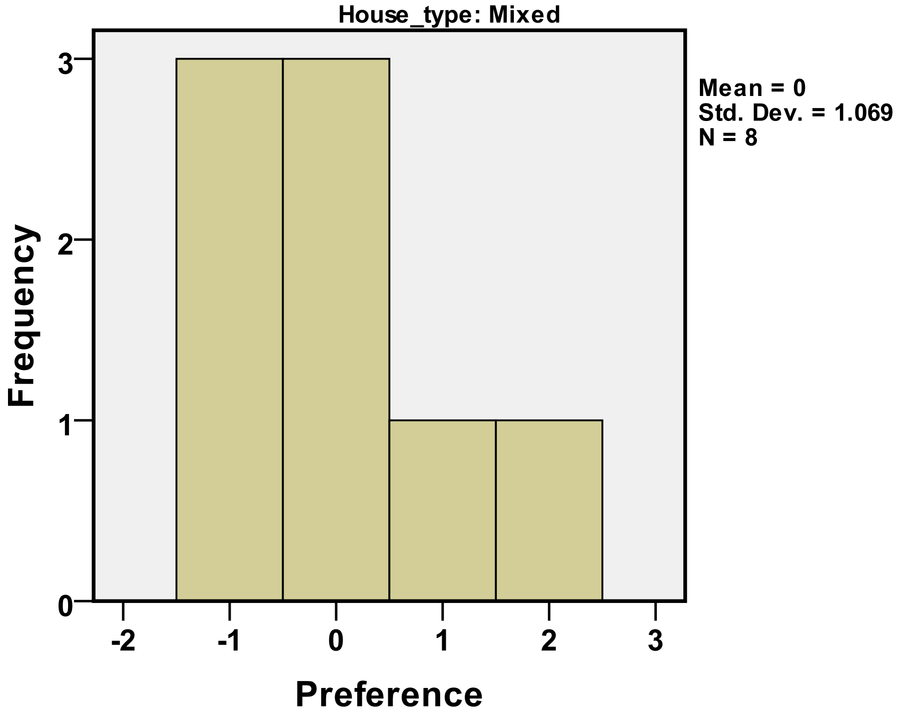


Fig. 5.9 Graph of thermal preference of local residents in mixed type building

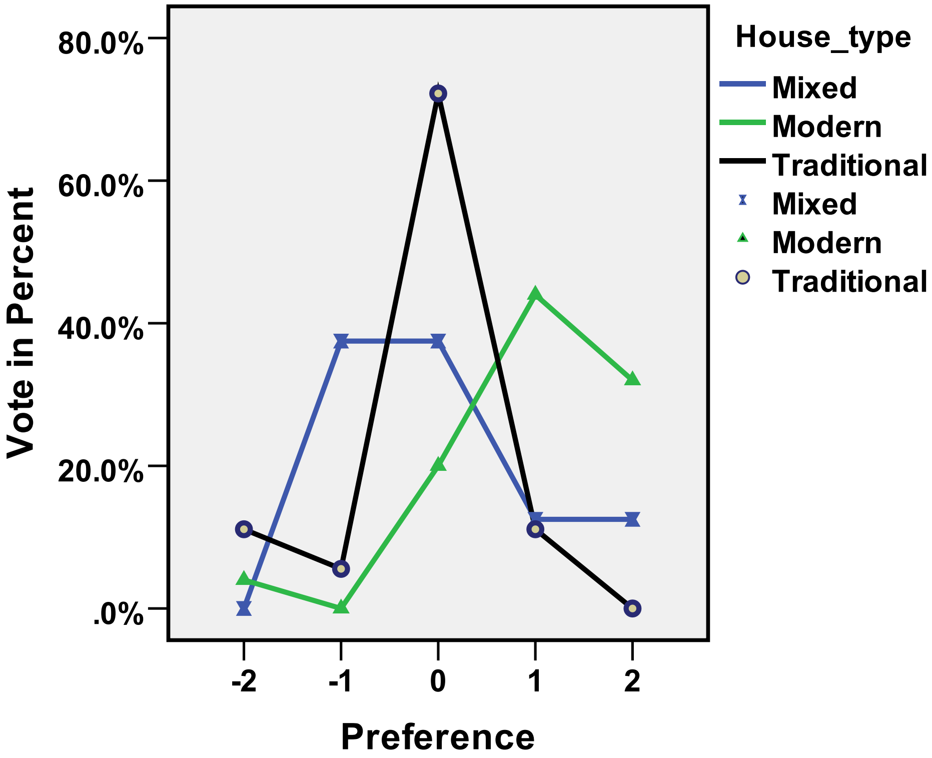



Fig. 5.10 Percentage of thermal preference of local residents in different building

### 5.6.3 Discussion on the thermal comfort

The most important question is how people feel of the thermal comfort in their house in general. This objective is to find their opinion about thermal comfort in their house in general during winter and summer. The research participants were asked how they feel about the thermal comfort in their house. There were four answers with rating system of comfortable, slightly uncomfortable, uncomfortable and very uncomfortable. The figure 5.11 shows that the seventy eight percent (78%) of residents living in traditional residential building feel comfortable in the traditional residential buildings. Only twenty percent (20%) of people living in modern building feel comfortable in their residence (Fig. 5.12). Fifty two percent (52%) of people feel uncomfortable and eight percent (8%) of people feel very uncomfortable in their modern residence. Fifty percent (50%) of people living in mixed residential building feel slightly uncomfortable and other fifty percent (50%) of people feel uncomfortable (Fig.5.13).

The research findings show that traditional buildings are better in thermal comfort than other type of building. The seventy eight percent (78%) residents of traditional residential building feel comfortable compared to twenty percent (20%) residents of modern residential building. Overall sixty percent (60 %) residents feel uncomfortable in their modern residence. The seventy eight percent (78%) residents feel comfortable may be due to radiant heat from surroundings walls, ceiling and floor in traditional buildings. The radiant heat is gained by thick construction of ceiling, wall and floor from human body and internal heat from lamps, etc. in traditional buildings but this type of construction system is not used in modern buildings. The findings show the people perception very contrast in traditional and modern building. This show the positive points about thermal comfort in traditional buildings compared to modern building as in Libya (Ahmad et al. 1985).

Ahmad et al. (1985) research may be a good example to compare with buildings of the Kathmandu in material, construction and oldness with respect to thermal comfort. The research of Ahmad et al. (1985) shows that the indoor temperature 35$^{o}$C in modern house whereas the indoor temperature only 28$^{o}$C in traditional house in the old city in the same summer period in Ghadames, Libya. The study shows the old houses can provide a year round comfortable environment, however the new houses are unable to provide indoor comfort in summer as well as winter. That is why; seventy eight percent (78%) residents feel thermal comfort in traditional buildings in Kathmandu.

Rijal et al. (2006) thermal study research done in traditional houses in Lomathang in Mustang district of Nepal found that the residents of three houses were highly satisfied with the thermal conditions of their houses in 3705 m altitude in mountainous region. The findings show that people are well adapted to the thermal environment of traditional houses, as a result of which the neutral temperature is lower than the thermal comfort standard. This is very important to be noticed to study the thermal comfort in vernacular architecture of Kathmandu as well as all over the world. The findings that people are well adapted to the thermal environment of traditional houses in Lomathang much more practical for vernacular houses compare to Fuller et al. (2009) research in a Humli house that indicates that comfort levels of a house far below than internationally recognized standard.

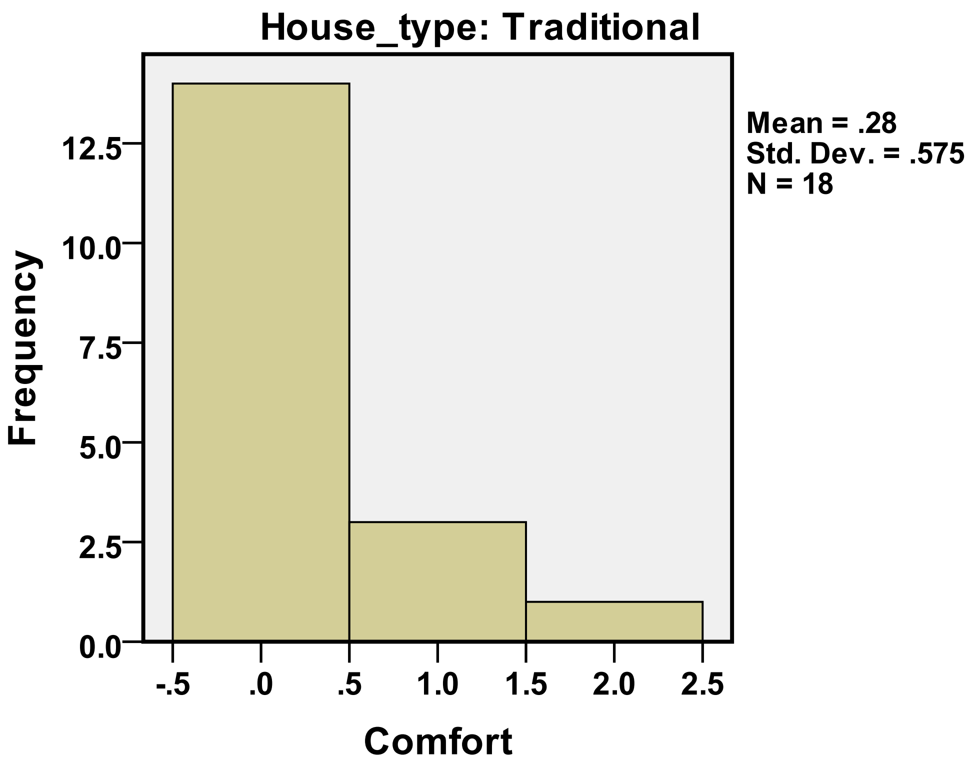



Fig. 5.11 Graph of thermal comfort of local residents in traditional building

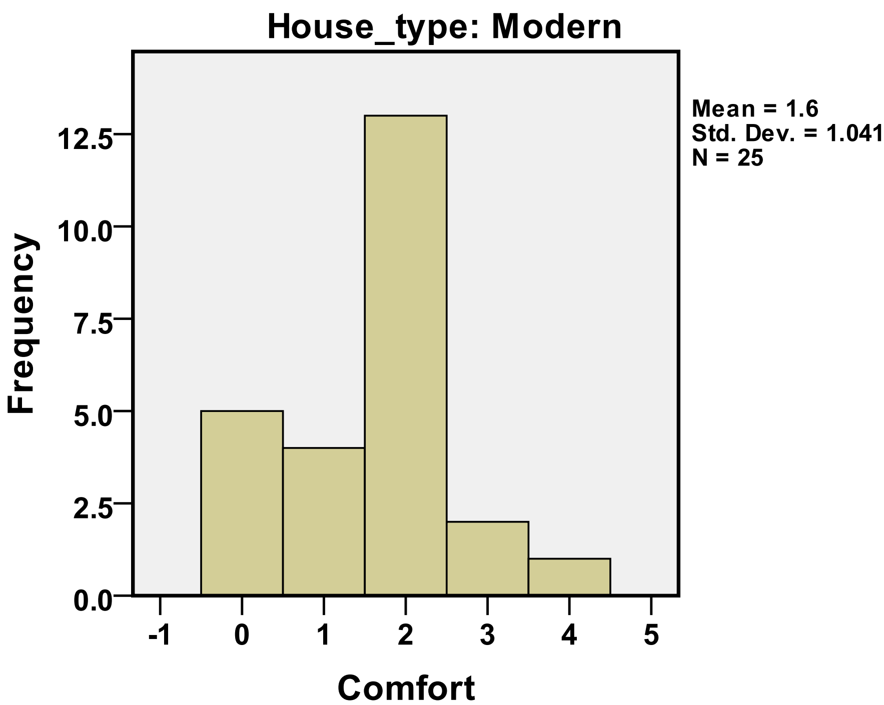



Fig. 5.12 Graph of thermal comfort of local residents in modern building

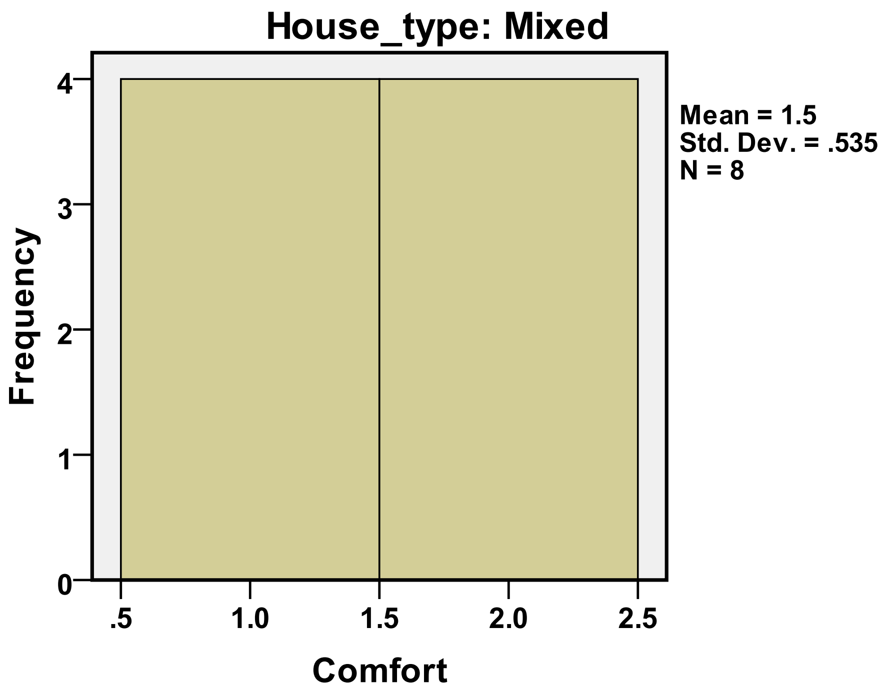



Fig. 5.13 Graph of thermal comfort of local residents in mixed type building

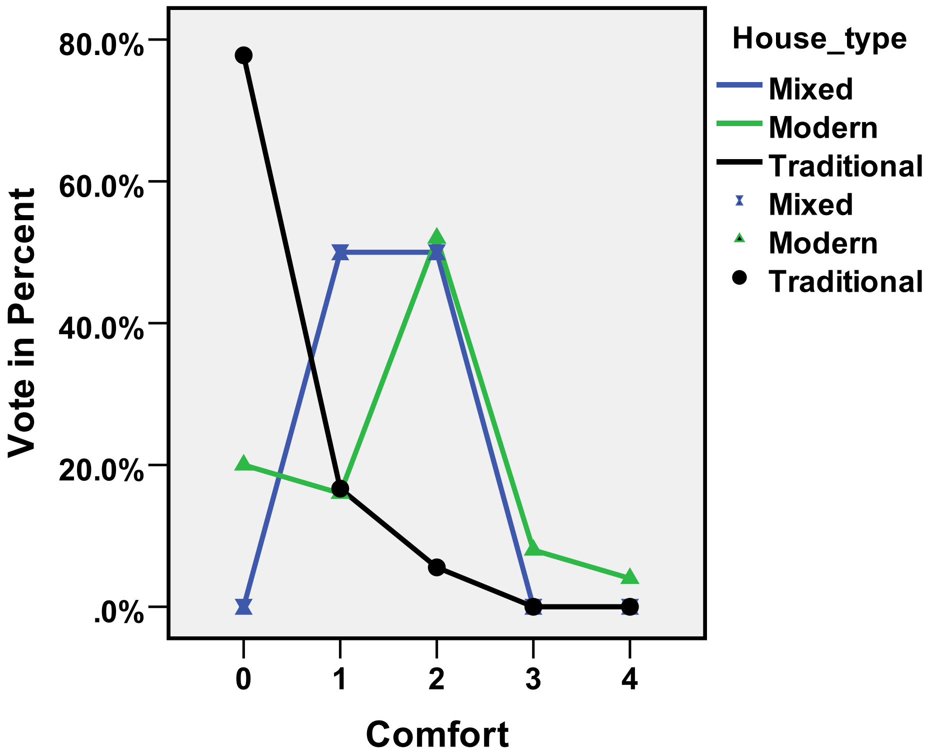



Fig. 5.14 Percentage of thermal comfort of local residents in different building

### 5.6.4 Discussion on the recommendation

The research participants were asked if they need to construct a new house then as per their thermal sensation which type of residential building would they want to construct. There were four answers for different types of building. Figure 5.15 shows that among the total sixty seven percent (67%) of residents living in traditional residential building like to construct their house in the same traditional residential buildings with traditional technology. Thirty eight percent (38%) of people living in modern building like to construct their house in the traditional residential buildings with traditional technology (Fig.5.16) and only twelve and half percent (12.5%) of people living in mixed residential building like to construct their house in the traditional style (Fig.5.17).

In total forty-four (44%) of percentage residents of different residential buildings like to construct the traditional residential building in traditional way. The research findings show that traditional buildings are not out-of-date but more acceptable to local people. Still today, people demand and they like to construct their house in traditional style using traditional technology. This finding shows the positive aspects of traditional buildings to design and construction in future.

The same finding shows in Ahmadreza (2012) paper on residents' perception of earthen dwellings in Iran. The findings show that traditional buildings are not considered to be out–of- date, but residents noticed highly cultural and historic values of their house. Lindsay and Vellinga (2005) wrote that vernacular style can play a significant role in future built environment. The study of vernacular buildings and urban areas retain certain valuable positive aspects which are still relevant to the current challenges for building sustainable environment. That is why these buildings are still cited in academic literature as model of sustainable practice. This study is very true for Kathmandu in Nepalese context as well as all over the world.

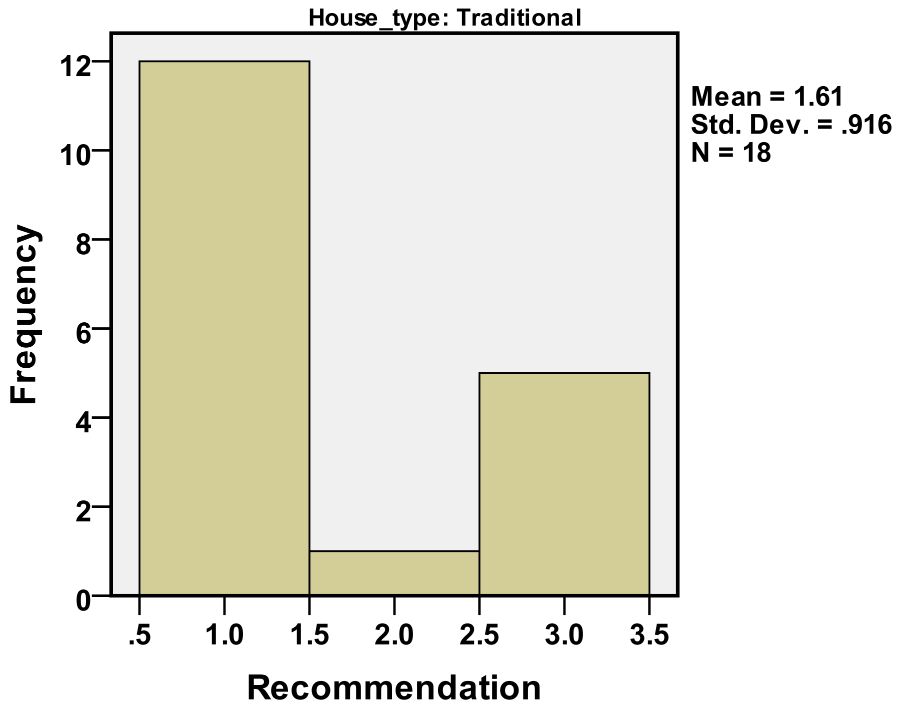



Fig. 5.15 Graph of Recommendation vote of local residents of traditional building

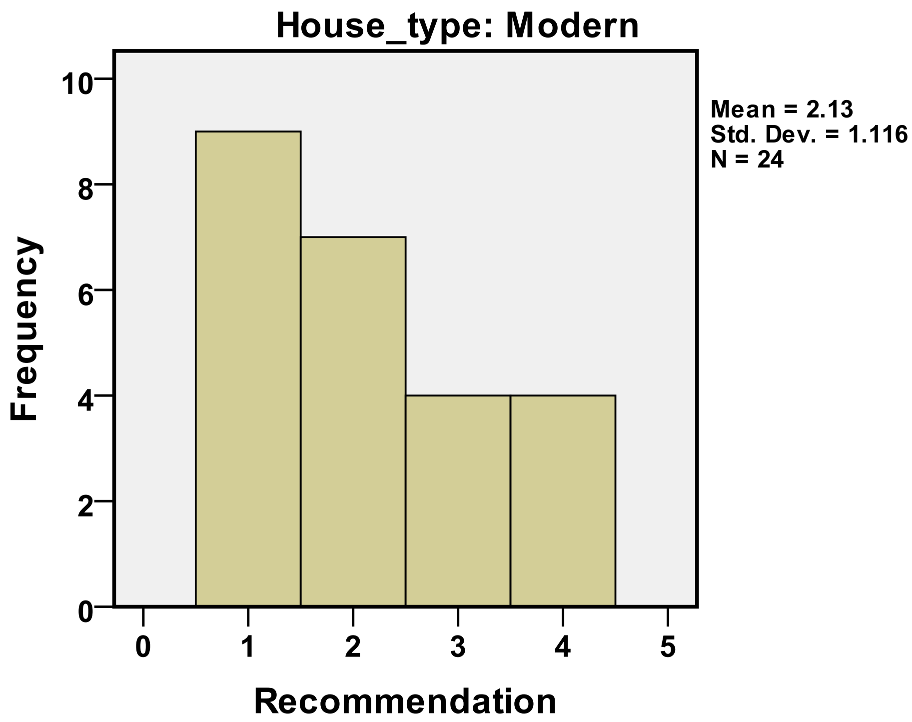



Fig. 5.16 Graph of Recommendation vote of local residents of Modern building

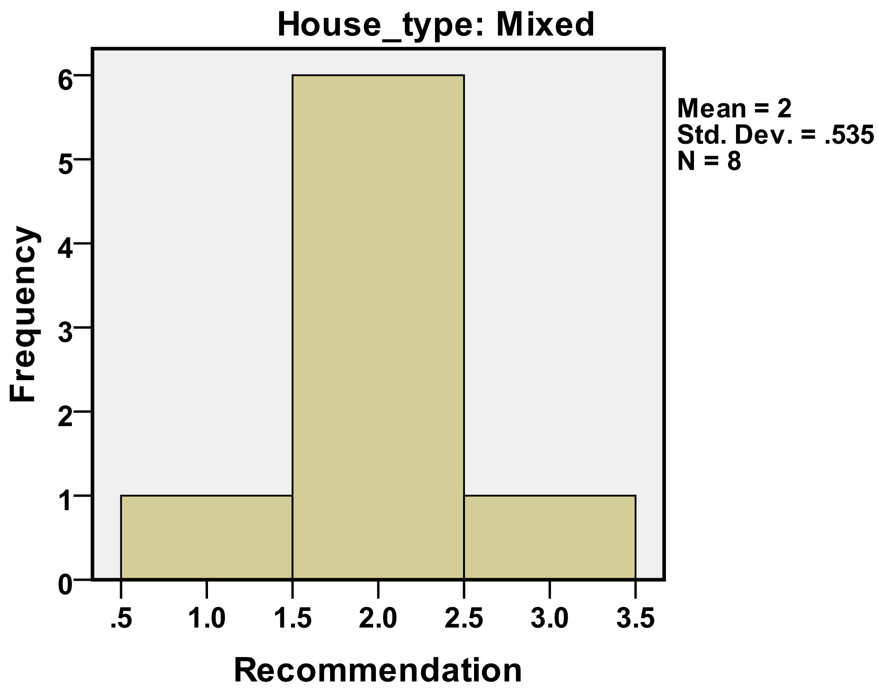



Fig. 5.17 Graph of Recommendation vote of local residents of mixed building

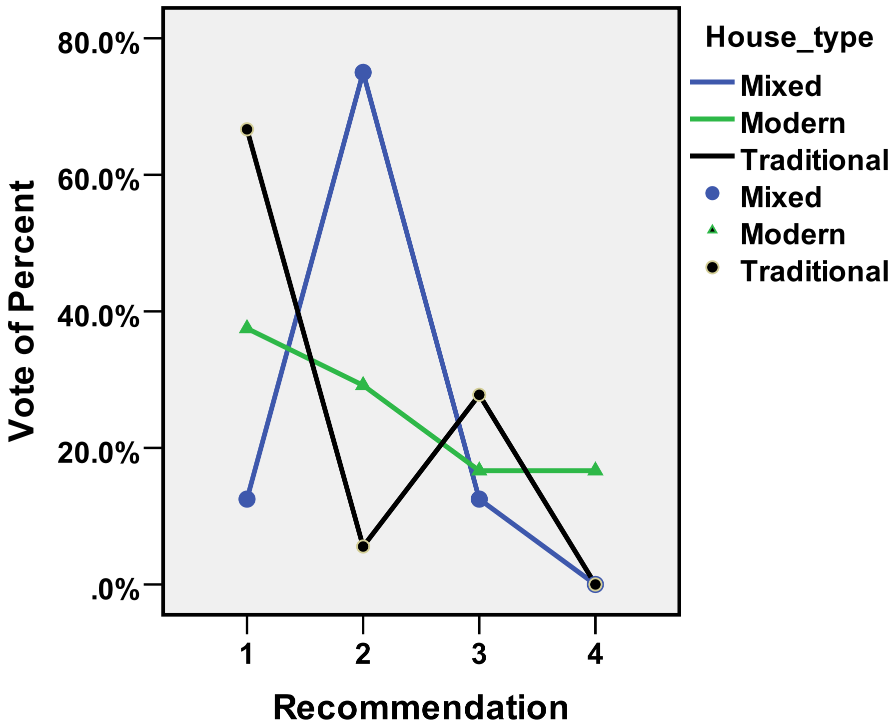



Fig. 5.18 Percentage graph of local residents willing for type of building construction for future

## 5.7 Conclusion

The results shown variety of positive aspect attributed to traditional residential buildings of Kathmandu. These positive attributes relate to better thermal performance than modern building, higher rate of willingness for construction and better comfort feeling in traditional building in both summer and winter season. The research finding shows that traditional buildings are not out-of-date but more acceptable to local people in Kathmandu. If we compare this in Iran, same types of study results were found in Iran. The people of Iran also noticed highly cultural and historic values of their traditional houses (Ahmadreza 2012).

Till today, this demand of local residents show the positive aspects in traditional buildings compared to modern buildings. In total, forty-four (44%) percentage of resident of different residential buildings and sixty seven percent (67%) of residents of traditional residential buildings like to construct their house in traditional style using traditional technology. These opening shows very strong results pointed towards traditional buildings in Nepal as in other places of world.

In particular, this survey has some drawbacks in this study that it has collected data with only 50 household in only one season. It could be better to study with more household in winter and summer seasons. But the results were compared with other researches done in Nepal and other countries. This result compared with those of other studies was found to be similar. Rijal et al. (2006) study found that the residents of three houses were highly satisfied with the thermal conditions of their houses in high altitude in Lomathang of mountainous region in Nepal. The result shows that people are well adapted to the thermal environment of their traditional houses. This is very important to study the thermal comfort in vernacular architecture of Kathmandu.

In addition, the findings show that the local peoples' perception is very contrasting in traditional and modern buildings in Kathmandu. Overall, seventy eight percent (78%) of residents of traditional residential building feel comfortable in their building whereas sixty percent (60 %) of residents feel uncomfortable in their modern residence. Neither of the surveys shows that eighty-three percent (83%) of people feel neutral neither cool nor warm in traditional buildings whereas only twenty four percent (24%) of people living in modern building feel neutral in their residence. As studies done in Libya (Ahmad et al. 1985) and Yemen (Algifri 1992), they also find traditional old building more comfortable compared to modern building in Kathmandu. This result is supported and already proved by the field data and results of chapter 4 of this study.

Finally we can say why people feel that traditional residential building has better thermal performance than modern residential building in Nepal and all over the world. There is a general perception that traditional architecture has a better thermal environment than contemporary architecture (Tiwari et al.2004). This proves the general perception that traditional architecture has better thermal environment than contemporary architecture. This shows how local people find thermal comfort far better in traditional buildings than modern buildings. This result show that most of the people living in traditional and modern building still like to construct the traditional building in future.

This finding is good for architects, conservationist, researcher, local government and people of Kathmandu to develop guidelines for design, byelaws, and research in future. The bye-law (2064) of Kathmandu valley consists of traditional cultural residential zone of Bhaktapur in chapter -4. These bye-laws of traditional cultural residential zone are better for traditional residential buildings of the valley for the conservation purpose. This bye-law promotes the traditional building form, reuse of traditional opening, exposed brick wall, restriction of basement, etc. So these bye-laws shall be implemented in all traditional settlement of Kathmandu valley in all five municipality and other small Newar towns for the conservation of traditional architecture.

# CHAPTER 6: THERMAL EXPERIMENT OF DIFFERENT MATERIAL AND TECHNOLOGY IN A LABORATORY

## 6.1 Introduction

It is understood that every traditional building performs better thermal environment than contemporary building. There were many researches generally proving that the thermal performance of traditional dwellings is better than that of modern dwellings (Ahmad et al.1985, Algifri et al. 1992, Meir & Pearlmutter 1995, Rijal 2010). A qualitative understanding can easily be formed from the information. However, a quantitative analysis is necessary to give the information needed to prove better thermal comfort. But no such study can be found in Nepal and world, so this study focuses on the measurement of thermal performance in laboratory experiments. But for this various factors influence the result.

To know practically the thermal performance of materials and technology, laboratory research was designed in this study and correlated with other factors. The laboratory experiment has the following three main objectives. First one is to know how the different building materials can get affected by thermal environment. Second one is how do the thickness of any construction get affected by thermal environment. Finally, how the traditional, modern and green materials of any construction get affected by thermal environment.

The research has collected data through the laboratory experiment. This chapter is designated for the analysis of collected laboratory data. Analysis of the data mentioned here in helps the research to answer the research question. This part will also explain the validity of the processed data. This chapter concludes with the findings of the research. These data will lead the chapter to extract the findings. Findings from the data would be presented as the conclusion of this chapter.

**6.2 Description of study samples**

The laboratory study area focuses on study of practical materials and technology used in traditional, modern and new green buildings in Kathmandu. The laboratory experiments focuses on thermal behavior of different types of walls used in traditional, modern and new green buildings. Mainly three types of walls traditional, modern and compressed stabilized earth block (CSEB) were tested in a laboratory. The laboratory study is experiments with thermal behavior of sundried bricks combination of sundried and burnt bricks with mud mortar, burnt bricks with cement mortar and CSEB block of different walls in different thickness.

The laboratory experiments mainly focused on thermal behavior of sundried bricks, mud mortar, burnt bricks, cement mortar, CSEB block. Also the study focuses on thermal behavior of different thickness of walls with these materials. The thermal performance of traditional thick multilayer wall of burnt brick (*pakki apa*), sun dried brick (*kachi apa*) and mud mortar were studied. The thermal performance of traditional thick multilayer wall of burnt brick (*pakki apa*), sun dried brick (*kachi apa*) and mud mortar were studied. Also the thermal performance of CSEB block wall of CSEB block and mud mortar were studied. All these materials and constructions were experimented, studied, discussed and drawn results in this chapter.

## 6.3 Description of experiment method

### 6.3.1 Setting up of a Laboratory with Thermal box

First of all, a building science laboratory with insulated thermal box was designed and established in the architecture department of Pulchowk campus (Fig. 6.1). The insulated thermal box with heating cum cooling air conditioning system was designed and constructed with the help of Associate Professor Susan Bajracharya, expert in air conditioning engineering of Mechanical Department of Pulchowk campus.  The figure 6.1 shows the outer thermal box of 1.5 m x 0.75 m x 0.75 m size and inner thermal box of 1.4 m x 0.6 m x 0.6 m size constructed with water proof ply boards.

Fig. 6.1  An insulated thermal box with air conditioning system in a building science laboratory, Department of Architecture, Pulchowk Campus

The thermocole was used as insulation in between two ply boxes for better insulation to prevent the heat loss from inside. The box was equipped with air conditioning system with heating and cooling compressor device, change over controller switch, a multiple temperature recorder with sensors (Instron IDI-302)  and AC duct. After the completion of all the construction, it is tested to blow hot air for heating and cool air for cooling inside. The maximum temperature of hot air blown inside was set up at 36°C for summer condition and minimum 9°C for winter condition of Kathmandu.

### 6.3.2 Experiment and data preparation in a Laboratory

Fig. 6.2 A wall constructed for experiment in the insulated thermal box in the laboratory

Figure 6.2 shows the construction of wall inside the box. A wall for experiment was constructed in the middle part of the box. The outer layer of wall considered as south side where air conditioning (AC) system was installed for heating and cooling. The six thermo sensors were located in six locations inside the box. The first sensor R1 located in air of outer layer in south part of wall. It records as outdoor air temperature in the thermal box in the lab. The second, third, fourth and fifth sensors R2, R3, R4and R5 were located within the wall. These sensors record the surface temperature of different layers within a wall. The last sixth sensor R6 located in air in north part of the wall. It records as the indoor air temperature in the thermal box in the lab.

Several experimental tests were done with the construction of traditional wall in a lab. The test results were calibrated. The maximum of 36 °C of hot air was passed through outer layer (R1) for five hours to know the effect of summer condition in each layer of wall (R2, R3, R4, R5) and inside the wall (R6). Same way, minimum of 9°C cool air blown through outer layer (R1) for five hours to know the effect of winter condition in each layer of wall (R2, R3, R4, R5) and inside layer in this thermo box (R6). During experiment, first of all, date, time and temperature of lab were recorded. After the power was switched on, initial temperature of six layers was recorded to compare after heating and cooling effect.

The maximum temperature was fixed for heating to blow the hot air. The 36$^{o}$C was set in changeover switch to control the temperature for blowing hot air constantly as summer condition. Same way, for cooling 9$^{o}$C was set in changeover switch to control the temperature for air conditioning as winter condition. The air was blown for 5 hours in the lab. Then the final temperature was recorded in all six layers for comparison of heating and cooling effect in each layer as summer and winter conditions. A mini pilot experiment was carried out successfully as described in chapter 3 (Fig. 3.4 & Table 3.2).

**6.4 Laboratory data presentation**

Several experimental tests were carried out with different materials and technology of traditional, modern and CSEB walls in a lab. The experimental tests were carried out with summer and winter condition in 600 mm thick traditional wall, 450 mm thick traditional wall, 230 mm thick modern wall, 110 mm thick modern wall and 200 mm thick CSEB wall. The experimental tests data were shown in the following tables.

Table 6.1 Lab temperature readings after heating effect as summer condition in a 600 mm traditional wall

| | | | | | |
|---|---|---|---|---|---|
| | **STUDY OF THERMAL PERFORMANCE IN LAB** | | | | |
| | | **STUDY OF HEATING EFFECT** | | | |
| | **600mm THICK TRADITIONAL BRICKWALL** | | | | |
| | (110 BURNT BRICK + 490 UNBURNT BRICK) | | | | |
| Date: 2068.11.28 (11 March 012) | | | | Lab Temp: 21°C | |
| Time:12:00 | Blowing heat at 36°C | | | | |
| Time: 4:45 | Reading at 35°C as outside temp | | | | |
| **S.NO.** | **SYNBOL** | **TEMP (°C)** | **TEMP (°C)** | **LAYER** | **REMARKS** |
| | | **INITIAL** | **AFTER 5 Hrs** | | |
| 1 | R1 | 21 | 35 | Outside | |
| 2 | R2 | 21 | 31 | Burnt brick | 110 mm |
| 3 | R3 | 21 | 19 | Unburnt brick | |
| 4 | R4 | 21 | 19 | Unburnt brick | |
| 5 | R5 | 21 | 18 | Unburnt brick | |
| 6 | R6 | 21 | 18 | Inside | |
| 6 | R6 | 21 | 18 | Inside | |

Table 6.2 Lab temperature readings after cooling effect as winter condition in a 600 mm traditional wall

| | | | | | |
|---|---|---|---|---|---|
| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
| | | STUDY OF COOLING EFFECT | | | |
| | 600mm THICK TRADITIONAL BRICKWALL | | | | |
| | (110 BURNT BRICK + 490 UNBURNT BRICK) | | | | |
| Date: 2068.12.17 (29 March 012) | | | | Lab Temp : 22°C | |
| Time:12:00 | Cooling from 21°C | | | | |
| Time: 4:45 | Reading at 12°C as outside temp | | | | |
| **S.NO.** | **SYNBOL** | **TEMP (°C)** | **TEMP (°C)** | **LAYER** | **REMARKS** |
| | | **INITIAL** | **AFTER 5 Hrs** | | |
| 1 | R1 | 21 | 12 | Outside | |
| 2 | R2 | 20 | 15 | Burnt brick | 110 mm |
| 3 | R3 | 20 | 20 | Unburnt brick | |
| 4 | R4 | 20 | 22 | Unburnt brick | |
| 5 | R5 | 20 | 22 | Unburnt brick | |
| 6 | R6 | 21 | 23 | Inside | |

Table 6.3 Lab temperature readings after heating effect as summer condition in a 450 mm traditional wall

| | | | | | |
|---|---|---|---|---|---|
| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
| | | STUDY OF HEATING EFFECT | | | |
| | 450mm THICK TRADITIONAL BRICKWALL | | | | |
| | (110 BURNT BRICK + 340 UNBURNT BRICK) | | | | |
| Date: 2068.12.22 (4 April 012) | | | | Lab Temp : 23°C | |
| Time:11:15 | Blowing heat at 36°C | | | | |
| Time: 4:55 | Reading at 36°C as outside temp | | | | |
| **S.NO.** | **SYNBOL** | **TEMP (°C)** | **TEMP (°C)** | **LAYER** | **REMARKS** |
| | | **INITIAL** | **AFTER 5 Hrs** | | |
| 1 | R1 | 16 | 36 | Outside | |
| 2 | R2 | 16 | 30 | Burnt brick | 110 mm |
| 3 | R3 | 17 | 20 | Unburnt brick | |
| 4 | R4 | 19 | 20 | Unburnt brick | |
| 5 | R5 | 19 | 19 | Unburnt brick | |
| 6 | R6 | 20 | 21 | Inside | |

Table 6.4 Lab temperature readings after cooling effect as winter condition in a 450 mm traditional wall

| | | | | | |
|---|---|---|---|---|---|
| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
| | | STUDY OF COOLING EFFECT | | | |
| | 450mm THICK TRADITIONAL BRICKWALL | | | | |
| | (110 BURNT BRICK + 340 UNBURNT BRICK) | | | | |
| Date: 2068.12.21 (3 April 012) | | | | Lab Temp : 22°C | |
| Time:11:30 | Cooling from 21°C | | | | |
| Time: 4:45 | Reading at 9°C as outside temp | | | | |
| **S.NO.** | **SYNBOL** | **TEMP (°C)** | **TEMP (°C)** | **LAYER** | **REMARKS** |
| | | **INITIAL** | **AFTER 5 Hrs** | | |
| 1 | R1 | 22 | 9 | Outside | |
| 2 | R2 | 21 | 14 | Burnt brick | 110 mm |
| 3 | R3 | 20 | 19 | Unburnt brick | |
| 4 | R4 | 20 | 20 | Unburnt brick | |
| 5 | R5 | 20 | 21 | Unburnt brick | |
| 6 | R6 | 22 | 22 | Inside | |

Table 6.5 Lab temperature readings after heating effect as summer condition in a 230 mm modern wall

| | | | | | |
|---|---|---|---|---|---|
| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
| | | STUDY OF HEATING EFFECT | | | |
| | 230 mm THICK MODERN BRICKWALL | | | | |
| | | (230 BURNT BRICK ) | | | |
| Date: 2068.12.24 (6 April 012) | | | | Lab Temp: 22°C | |
| Time:10:15 | Blowing heat at 36°C | | | | |
| Time: 4:55 | Reading at 36°C as outside temp | | | | |
| **S.NO.** | **SYNBOL** | **TEMP (°C)** | **TEMP (°C)** | **LAYER** | **REMARKS** |
| | | **INITIAL** | **AFTER 5 Hrs** | | |
| 1 | R1 | 21 | 36 | Outside | |
| 2 | R2 | 21 | 31 | Burnt brick | |
| 3 | R3 | 21 | 29 | Burnt brick | |
| 4 | R4 | 21 | 26 | Burnt brick | |
| 5 | R5 | 21 | 25 | Burnt brick | |
| 6 | R6 | 21 | 25 | Inside | |

Table 6.6 Lab temperature readings after cooling effect as winter condition in a 230 mm modern wall

| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
|---|---|---|---|---|---|
| | | STUDY OF COOLING EFFECT | | | |
| | 230 mm THICK MODERN BRICKWALL | | | | |
| | | (230 BURNT BRICK ) | | | |
| Date: 2068.12.26 (8 April 012) | | | | Lab Temp: 22°C | |
| Time:12:00 | Cooling from 20°C | | | | |
| Time: 4:55 | Reading at 11°C as outside temp | | | | |
| S.NO. | SYNBOL | TEMP (°C) | TEMP (°C) | LAYER | REMARKS |
| | | INITIAL | AFTER 5 Hrs | | |
| 1 | R1 | 20 | 11 | Outside | |
| 2 | R2 | 20 | 14 | Burnt brick | |
| 3 | R3 | 20 | 15 | Burnt brick | |
| 4 | R4 | 21 | 18 | Burnt brick | |
| 5 | R5 | 21 | 20 | Burnt brick | |
| 6 | R6 | 21 | 21 | Inside | |

Table 6.7 Lab temperature readings after heating effect as summer condition in a 110 mm modern wall

| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
|---|---|---|---|---|---|
| | | STUDY OF HEATING EFFECT | | | |
| | 110 mm THICK MODERN BRICKWALL | | | | |
| | | (110 BURNT BRICK ) | | | |
| Date: 2068.12.29 (11 April 012) | | | | Lab Temp: 22°C | |
| Time:11:00 | Blowing heat at 36°C | | | | |
| Time: 4:55 | Reading at 36°C as outside temp | | | | |
| S.NO. | SYNBOL | TEMP (°C) | TEMP (°C) | LAYER | REMARKS |
| | | INITIAL | AFTER 5 Hrs | | |
| 1 | R1 | 20 | 36 | Outside | |
| 2 | R2 | 19 | 31 | Burnt brick | |
| 3 | R3 | 20 | 30 | Burnt brick | |
| 4 | R4 | 20 | 28 | Burnt brick | |
| 5 | R5 | 20 | 27 | Burnt brick | |
| 6 | R6 | 20 | 26 | Inside | |

Table 6.8 Lab temperature readings after cooling effect as winter condition in a 110 mm modern wall

| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
|---|---|---|---|---|---|
| | | STUDY OF COOLING EFFECT | | | |
| | 110 mm THICK MODERN BRICKWALL | | | | |
| | | (110 BURNT BRICK ) | | | |
| Date: 2069.1.5 (17 April 012) | | | | Lab Temp: 22°C | |
| Time:10:30 | Cooling from 16°C | | | | |
| Time: 4:55 | Reading at 13°C as outside temp | | | | |
| **S.NO.** | **SYNBOL** | **TEMP (°C)** | **TEMP (°C)** | **LAYER** | **REMARKS** |
| | | **INITIAL** | **AFTER 5 Hrs** | | |
| 1 | R1 | 16 | 13 | Outside | |
| 2 | R2 | 16 | 13 | Burnt brick | |
| 3 | R3 | 16 | 13 | Burnt brick | |
| 4 | R4 | 16 | 14 | Burnt brick | |
| 5 | R5 | 17 | 15 | Burnt brick | |
| 6 | R6 | 19 | 19 | Inside | |

Table 6.9 Lab temperature readings after heating effect as summer condition in a 200 mm CSEB wall

| | STUDY OF THERMAL PERFORMANCE IN LAB | | | | |
|---|---|---|---|---|---|
| | | STUDY OF HEATING EFFECT | | | |
| | 200 mm THICK CSEB BLOCK WALL | | | | |
| | (200 SUNBURNT CSEB BLOCK ) | | | | |
| Date: 2069.6.28 (14 Oct 012) | | | | Lab Temp: 23°C | |
| Time:11:00 | Blowing heat at 36°C | | | | |
| Time: 4:40 | Reading at 41°C as outside temp | | | | |
| **S.NO.** | **SYNBOL** | **TEMP (°C)** | **TEMP (°C)** | **LAYER** | **REMARKS** |
| | | **INITIAL** | **AFTER 5 Hrs** | | |
| 1 | R1 | 22 | 41 | Outside | |
| 2 | R2 | 23 | 30 | CSEB | |
| 3 | R3 | 23 | 28 | CSEB | |
| 4 | R4 | 23 | 26 | CSEB | |
| 5 | R5 | 23 | 26 | CSEB | |
| 6 | R6 | 23 | 24 | Inside | |

## 6.5 Analysis, discussion and results

### 6.5.1. Thermal performance of traditional walls

### 1. Traditional external wall of 600 mm thick

Normally, this type of wall used as external wall in traditional residential buildings of Kathmandu. This wall consists of one layer of burnt brick on outer side and sun burnt bricks inside. The outer layer burnt brick is normally 110 mm thick and inner layer sun burnt brick is 490 mm thick with mud mortar. In the lab, same type of wall was constructed in a thermal box as shown in the figure 6.2. The figure 6.5 graph shows the heating effect as summer condition in outdoor layer in R1 and then different layers in second, third, fourth and fifth layers R2, R3, R4 and R5 located within the wall. The last sixth R6 located of in inner part of the box is recorded as indoor air temperature of a building in the laboratory.


Fig. 6.3 View of manufacture of Sun dried brick (*Kachi Apa*) in Kathmandu valley

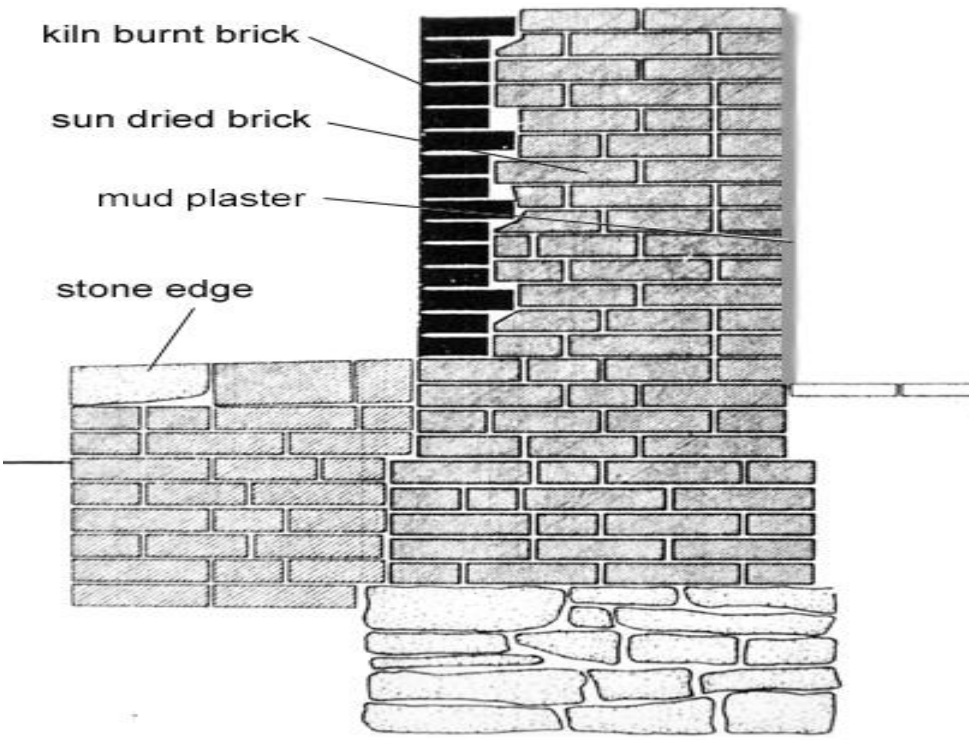


Fig. 6.4 A sectional view of traditional external wall with burnt brick and sun dried brick (Source: Korn 1976)

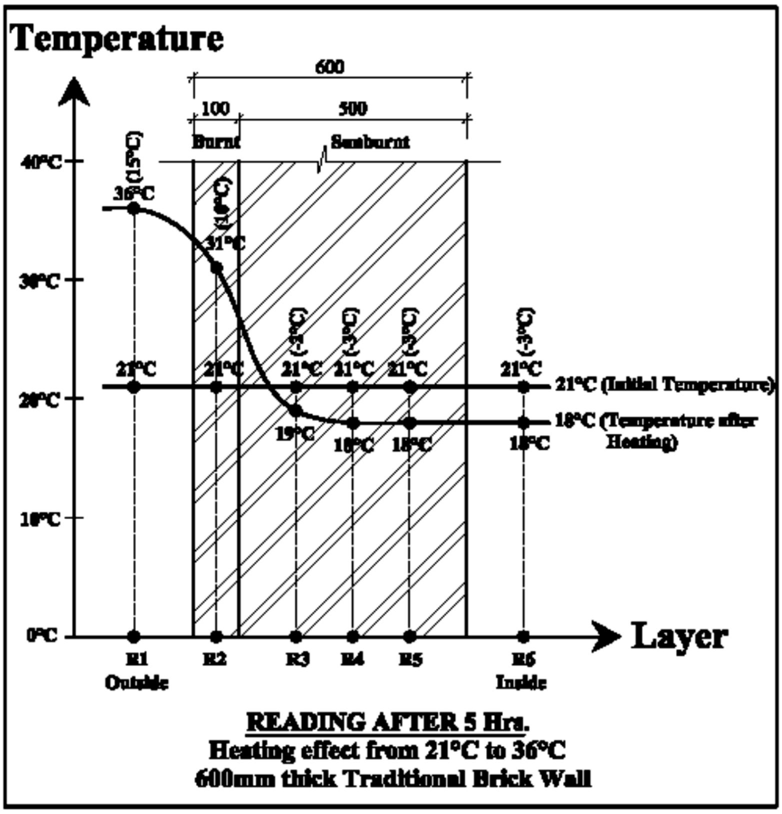



Fig. 6.5 Temperature gradient after heating effect as summer condition in a 600 mm thick traditional wall in the laboratory

After the experiment, the heating effect was observed as follows:

Initially, $T_{out} = 21^oC$ & $T_{in} = 21^oC$

Heating effect after 5 hours blowing hot air @ $36^oC$

Finally, $T_{out} = 36^oC$ & $T_{in} = 18^oC$

Figure 6.5 shows that the wall has adverse effect when outdoor temperature rises up the indoor temperature falls down. The graph shows that outdoor temperature directly effects only in the external layer of burnt brick of 110 mm thick. After 5 hours, the rate of heat flow in burnt brick faster layer only. The $10^oC$ temperature rises up ($21-31^oC$) in this layer R2 whereas in inner layers temperature decreases from $2-3^oC$ ($21-18^oC$). The adverse effects starts from the internal layers R3 of sun burnt brick. It cannot changes to internal layer R3, R4 and R5 of sun burnt brick of 490 mm thick. That is why the indoor temperature in layer R6 also remains same as layer R5.The indoor temperature ($T_{in}$) in R6 remains 18°C decreases from 3°C instead of initial temperature reading 21°C. This shows the reverse effect in inside when temperature rises in outdoor. This graph shows that this traditional thick wall cools indoor environment in summer.

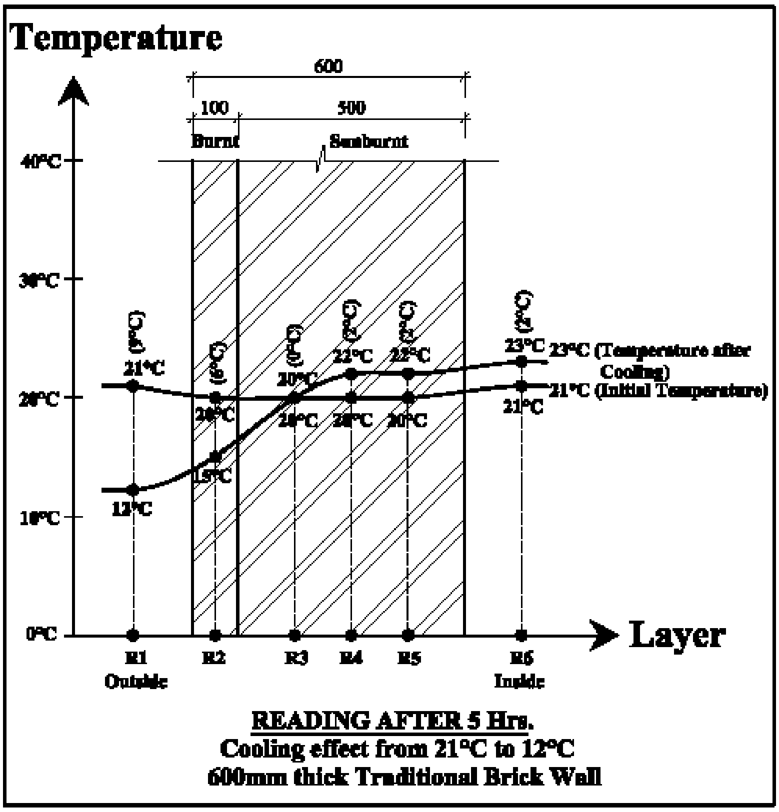



Fig. 6.6 Temperature gradient after cooling effect as winter condition in a 600 mm thick traditional wall in the laboratory

After the experiment, the cooling effect was observed as follows:

Initially, $T_{out}$ = 21°C & $T_{in}$ = 21°C

Cooling effect after 5 hours blowing cool air @ 10°C

Finally, $T_{out}$ = 12°C & $T_{in}$ = 23°C

Similarly when it cools in R1 layer as consider as outside, the indoor temperature rises up with 2°C from 21 to 23°C. The temperature of inner layer R3 of sun burnt brick remains constant 20 to 20°C. But the temperature of inner layer R4 and R5 of sun burnt brick rises from 20 to 22°C. The Figure 6.6 shows that the wall has adverse effect when outdoor temperature cools down the indoor temperature rises up. The graph shows that outdoor temperature directly effects only in the external layer of burnt brick of 110 mm thick. After 5 hours, the rate of heat flow faster in burnt brick only. The 5$^{o}$C temperature decreases in this layer R2 of burnt brick whereas in inner layers of sun burnt brick the temperature rises from 0 -2$^{o}$C.

The adverse effects starts from the internal layers R3 of sun burnt brick. That is why the indoor temperature in layer R6 also remains nearly same as layer R5. The indoor temperature ($T_{in}$) in R6 remains 23$^{o}$C instead of initial temperature reading 21$^{o}$C. This shows the reverse effect in inside when temperature decreases in outside. This graph shows that this traditional thick wall warms up indoor environment during winter in traditional buildings till this 12$^{o}$C outdoor temperature.

If we compare the thermal transmittance (U- value) of traditional and modern brickwork, we get the rate of heat flow in 600 mm thick traditional wall has four times less than 230 mm thick modern wall. The thermal transmittance value of 600 mm thick traditional brickwork has only 0.63 W/m$^{2o}$C compared to 2.67 W/m$^{2o}$C of 230 mm thick modern brickwork (Table 6.11). The heating and cooling graphs (Fig.6.5 & 6.6) from laboratory tests show that the traditional thick wall has reverse effect in indoor environment during winter and summer in traditional buildings keeping warms in winter and cool in summer. This is one of the best findings to know the thermal performance in traditional technology of traditional building of Kathmandu.

**2. Traditional external wall of 450 mm thick**

This is a common wall used in traditional residential buildings of Kathmandu. This wall consists of one layer of burnt brick on outer side and sun burnt bricks inside. The outer layer burnt brick is normally 100 mm thick same as above but inner layer sun burnt brick is 350 mm thick with mud mortar. In the lab, same type of wall was constructed in a thermal box as shown in figure 6.2.

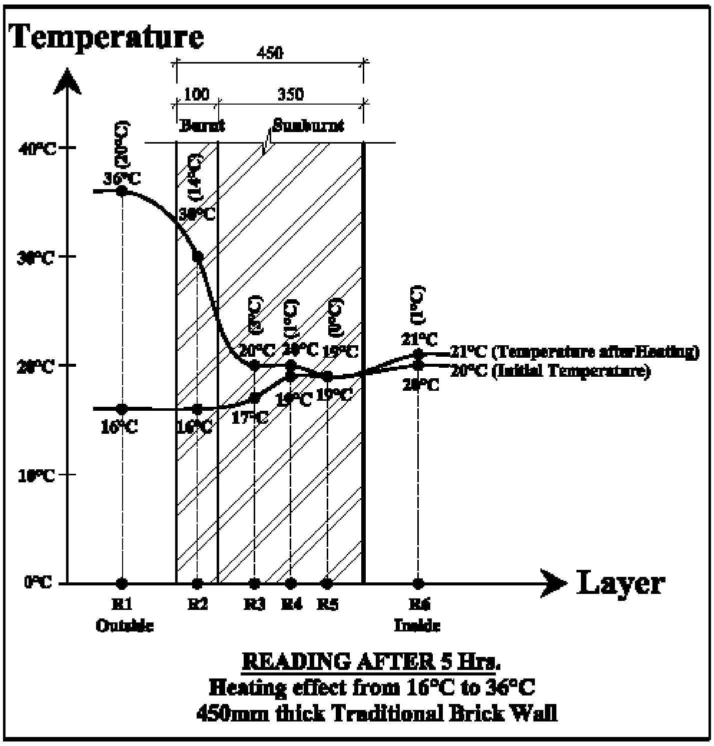



Fig. 6.7 Temperature gradient after heating effect as summer condition in a 450 mm thick traditional wall in the laboratory

After the experiment, the heating effect was observed as follows:

Initially, $T_{out} = 16^oC$ & $T_{in} = 20^oC$

Heating effect after 5 hours blowing hot air @ $36^oC$

Finally, $T_{out} = 36^oC$ & $T_{in} = 21^oC$

In the laboratory, this wall shows outdoor environment having less effect on inside environment when layer R1 outdoor temperature rises up from 16 to $36^oC$ for five hours (Fig. 6.7). The temperature of indoor Layer R6 rises only one degree from 20 to $21^oC$. The graph shows that outdoor temperature directly effects only in the external layer of 100 mm thick burnt brick where temperature rises from 16 to $30^oC$. It shows that temperature rises in layer R2 of burnt brick with $14^oC$ within five hours. But it cannot effect to internal layer of sun burnt brick so much. In inner layer R3, temperature rises in sun burnt brick with max $3^oC$ within five hours but in layer R4 only $1^oC$ and R5 remains same temperature.

This shows that rate of flow of heat is nearly five times more in burnt brick than sun dried brick. The indoor R6 temperature rises only one degree after five hours. The graph shows outdoor environment has no effect on inside environment in this type of wall. The indoor temperature ($T_{in}$) in R6 remains 21$^{o}$C instead of initial temperature reading 20$^{o}$C. This shows that the either no or less effect inside the wall when temperature rises in outside of the wall. This graph shows that this traditional thick wall maintain same indoor environment without adverse effect of outdoor thermal environment in summer.

Similarly the cooling effect graph shows that when blowing cool air at 9$^{o}$C for five hours in layer R1 as outdoor air temperature, the inside temperature remains same from 22 to 22$^{o}$C. The cooling effect graph also shows that outdoor temperature directly effects only in the external layer of 100 mm thick burnt brick but it cannot cool to internal layer of sun burnt brick. It shows that temperature reduces in burnt brick with 7$^{o}$ C within five hours from 21 to 14$^{o}$C. But it cannot affect the internal layer of sun burnt brick so much. In inner layer R3 temperature reduces with 1$^{o}$C, layer R4 no change and in layer R5 temperature rises with 1$^{o}$C within five hours adverse effect. Finally Indoor temperature remains same as previous 22$^{o}$C. The graph shows outdoor environment has no effect on inside environment in this type of wall. The indoor temperature ($T_{in}$) in R6 remains 22$^{o}$C the same as initial temperature reading 22$^{o}$C. This shows the no effect in inside when temperature decreases in outside. This graph shows that this traditional thick wall has similar indoor environment without effecting the outdoor environment during winter in traditional buildings till this 9$^{o}$C outdoor temperature.

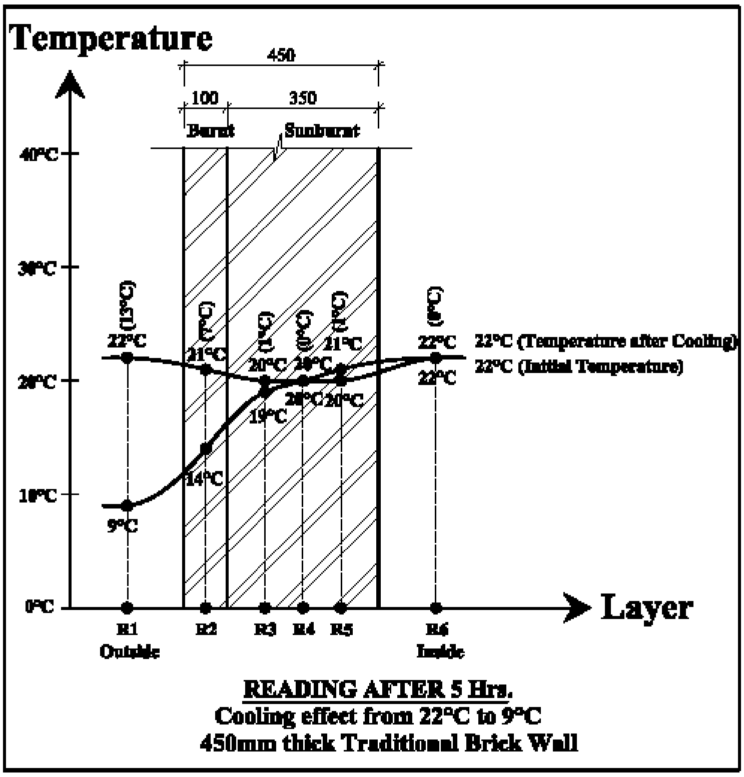



Fig. 6.8 Temperature gradient after cooling effect as winter condition in a 450 mm thick traditional wall in the laboratory

After the experiment, the cooling effect was observed as follows:

Initially, $T_{out} = 22^oC$ & $T_{in} = 22^oC$

Cooling effect after 5 hours blowing cool air @ $10^oC$

Finally, $T_{out} = 9^oC$ & $T_{in} = 22^oC$

**6.5.2. Thermal performance of modern wall**

**1. Modern wall of 230 mm thick**

This is a common wall used in contemporary residential buildings of Kathmandu as well as all part of country nowadays. This wall consists of 230 mm thick only burnt brick in cement mortar. In the lab, same type of wall was constructed in a thermal box as shown in figures 6.1 and 6.2.

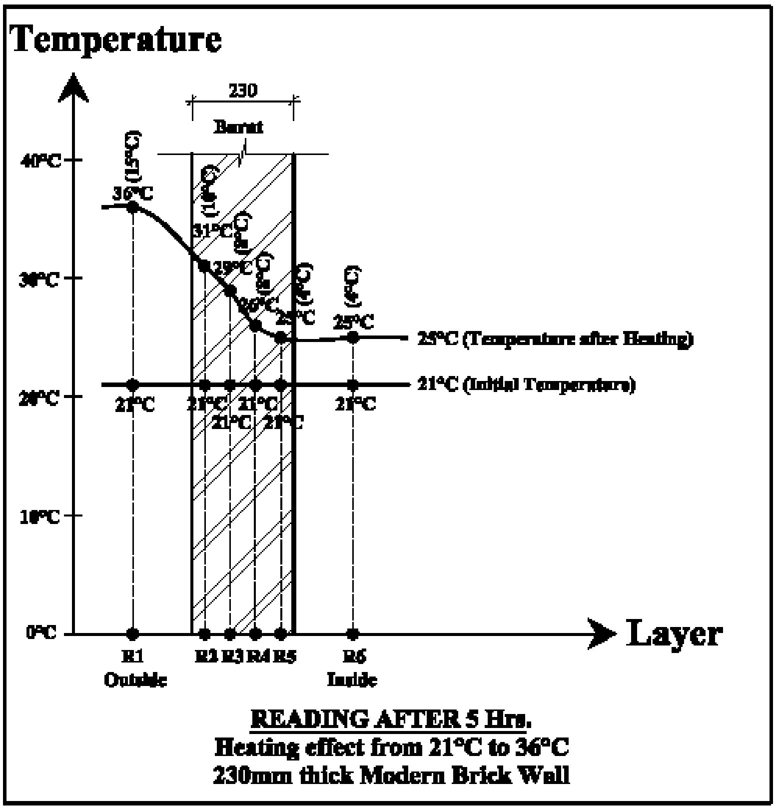



Fig. 6.9 Temperature gradient after heating effect as summer condition in a 230 mm thick modern wall in the laboratory

After the experiment, the heating effect was observed as follows:

Initially, $T_{out} = 21^oC$ & $T_{in} = 21^oC$

After 5 hours blowing hot air @ $36^oC$

Finally, $T_{out} = 36^oC$ & $T_{in} = 25^oC$

This figure 6.9 graph shows that inside thermal environment directly changes when outdoor temperature rises up. When temperature rises in layer R1 consider as outdoor from 21 to $36^oC$ within five hour, the indoor environment layer R6 directly warms up with $4^oC$ from 21 to $25^oC$. The graph shows that outdoor temperature directly affects indoor environment. It shows that temperature rises with $10^oC$ in first layer of wall R2 (31 - $21^oC$), $8^oC$ in second layer R3 (29- $21^oC$), $5^oC$ in third layer R4 (26- $21^oC$), $4^oC$ in last layer R5 (25-$21^oC$) of modern 230 mm thick wall within five hours. Finally, indoor environment layer R6 directly warms up with $4^oC$ rise in temperature from 21 to $25^oC$ within 5 hours.

This shows that rate of flow of heat is very fast in modern wall of burnt brickwork. This shows that the temperature rises in inside proportionately when temperature increases in outside. This proved that the outdoor environment has direct effect on indoor environment with construction of this type of wall.  That is why; the field study (Fig.4.16) shows that indoor temperature increases with raise in outdoor thermal environment during summer in modern building.  That is why; the field study (Fig.4.2) shows that modern buildings were nearly 2$^{o}$C warmer than traditional buildings during summer.

After the experiment, the cooling effect was observed as follows:

Initially, $T_{out}$ = 20$^{o}$C & $T_{in}$ = 21$^{o}$C

After 5 hours blowing cool air @ 10$^{o}$C

Finally, $T_{out}$ = 11$^{o}$C & $T_{in}$ = 21$^{o}$C

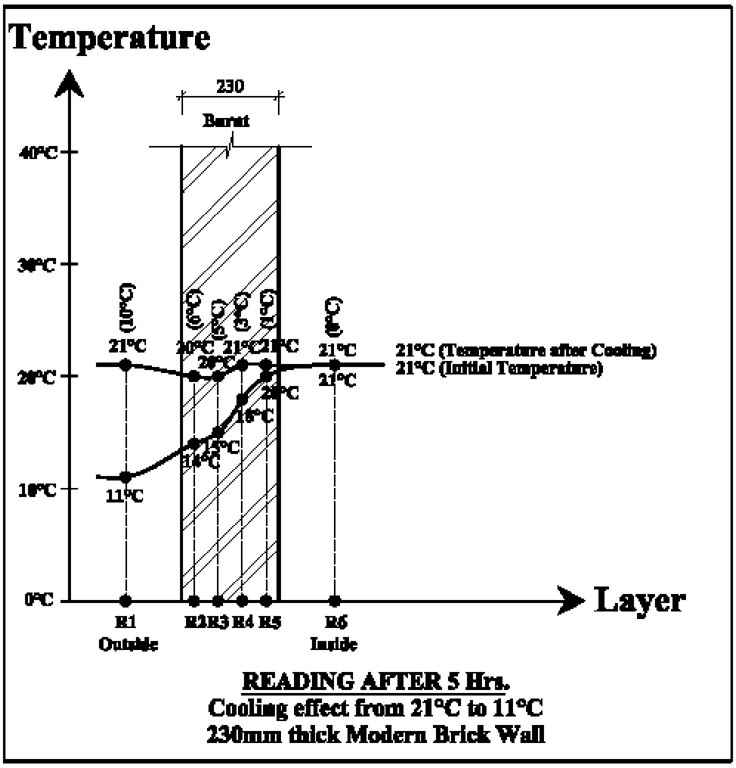



Fig. 6.10 Temperature gradient after cooling effect as winter condition in a 230 mm thick modern wall in the laboratory

Similarly, when blowing cool air at 11$^{o}$C for five hours (Fig.6.10), the indoor temperature remains same from 21 to 21$^{o}$C. The cooling effect graph shows that temperature reduces effect in inner first layer R2 with 6°C (20-14°C), second layer R3 with 5°C (20 -15°C), third layer R4 with 3°C (21-18°C ) and final last row R5 with 1°C (21-20°C) of the wall. Finally Indoor temperature remains constant 21°C. The graph shows cooling effect on layer R2, R3 and 4 inside the wall when cooling till 11°C. The graph shows outdoor environment has no effect on indoor environment in this type of wall when cooling till 11°C. More cooling is needed to see the cooling effect in this experiment but it was not possible in this experiment to reduce the temperature less than 11°C. This graph shows that this modern wall has similar indoor environment without effecting the outdoor environment during winter till this 11°C outdoor temperature.

**2. Modern wall of 110 mm thick**

This is a common wall used in contemporary residential buildings of Kathmandu. This wall is used in interior as well as in exterior. This wall consists of 110 mm thick only burnt brick in cement mortar. In the lab, same type of wall was constructed in a thermal box as shown in the figure 6.2.

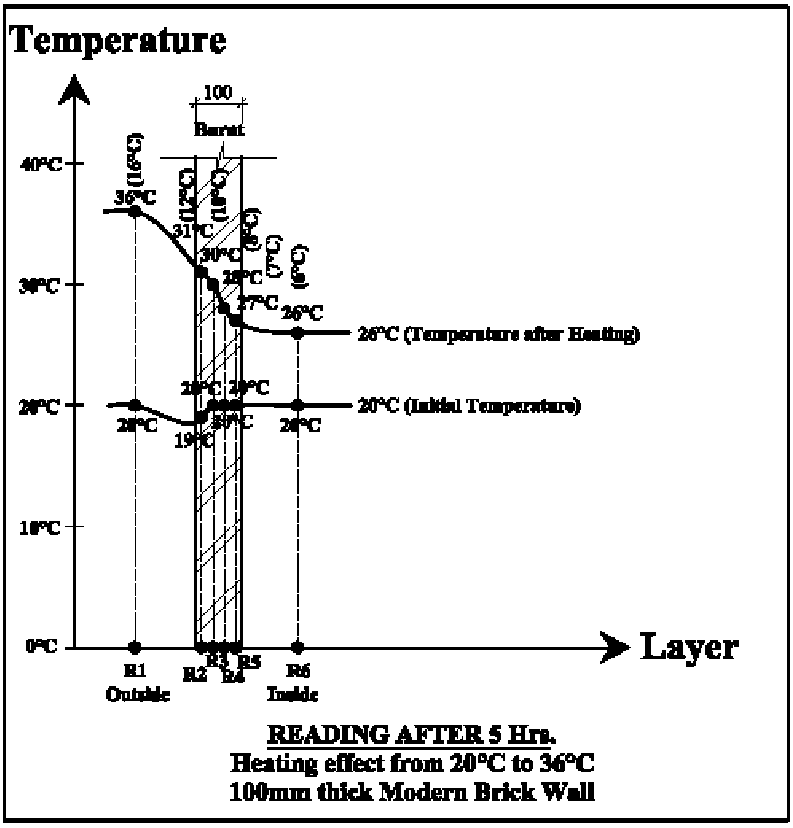



Fig. 6.11 Temperature gradient after heating effect as summer condition in a 110 mm thick modern wall in the laboratory

After the experiment, the heating effect was observed as follows:

Initially, $T_{out} = 20^oC$ & $T_{in} = 20^oC$

After 5 hours blowing hot air @ $36^oC$

Finally, $T_{out} = 36^oC$ & $T_{in} = 26^oC$

The figure 6.11 shows changes inside thermal environment directly raising temperature from 20 to $26^oC$ when outdoor temperature rises up from 20 to $36^oC$ within five hours. The graph shows that outdoor temperature directly affects the indoor environment. It shows that temperature rises with $12^oC$ in first layer R2 (31-$19^oC$), $10^oC$ in second layer R3 (30 - $20^oC$), $8^oC$ in third layer R4 (28- $20^oC$), $7^oC$ in last layer R5 (27 - $20^oC$) of modern wall within five hours.

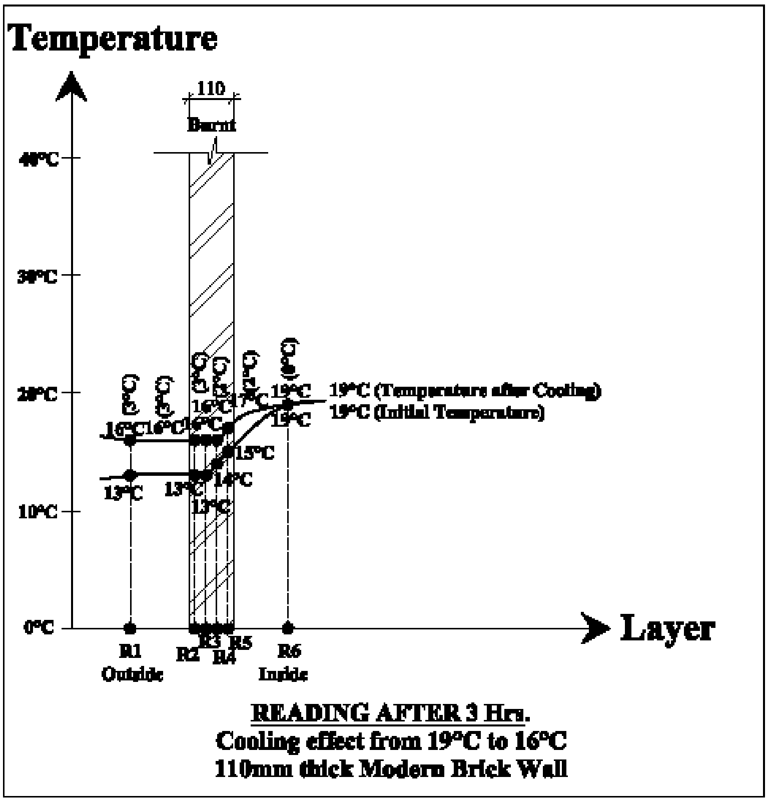



Fig. 6.12 Temperature gradient after cooling effect as winter condition in a 110 mm thick modern wall in the laboratory

This shows that rate of flow of heat very fast in modern thin wall. This shows the indoor temperature rises $6^oC$ proportionately when temperature increases from 20 to $36^oC$ in outside. This is true if the thermal transmittance (U- value) of thin and thick brickwork is compared. The transmittance value of thin 110 mm thick brickwork has

3.64 $W/m^{2o}C$ and 2.67 $W/m^{2o}C$ of 230 mm thick brickwork which is higher compared to traditional and CSEB wall (Table 6.11 & Koenigsberger et al. 1975). This proved that the outdoor environment has direct effect on indoor environment with construction of this type of wall. That is why; the field study (Fig.4.16) shows that indoor temperature increases with rise in outdoor thermal environment during summer in modern building.

After the experiment, the cooling effect was observed as follows:
Initially, $T_{out}$ = 16°C & $T_{in}$ = 19°C
After 5 hours blowing hot air @ 13°C
Finally, $T_{out}$ = 13°C & $T_{in}$ = 19°C

Similarly when blowing cool air at 13°C for five hours (Fig.6.12), the indoor temperature was remain same from 19 to 19°C. The cooling effect graph shows that temperature reduces affect in inner first layer R2 with 3°C (16-13°C) , second layer R3 with 3°C (16-13°C), third layer R4 with 2°C (16-14°C ) and final last row R5 with 2°C (17-15°C) of the wall. Finally Indoor temperature remains constant 19°C. The graph shows cooling effect on layer R2, R3 and 4 inside the wall when cooling till 13°C. The graph shows that outdoor environment has no effect on indoor environment in this type of wall when cooling till 13°C. More cooling is needed to see the cooling effect in this experiment but it was not possible in this experiment to reduce the temperature less than 13°C. So this reading was not considered to study and analyzed in this study.

### 6.5.3. Thermal performance of green CSEB wall

The compressed stabilized earth block (CSEB) is known as green material nowadays. The concept of CSEB block is developed from traditional sun burnt brick. It does not need to bake as burnt brick but strength is developed by compression. This CSEB block is manufactured directly in a construction site with the help of AURAM – 300 machine. It consists of silt, clay, sand and only five percent of cement. The block can be manufactured in different shape and size by different type of key of AURAM – 300 machine.

Fig. 6.13 Views of CSEB block, manufacture of CSEB by AURAM -300 machine and the CSEB model classroom building in the Department of Architecture, Pulchowk campus, Lalitpur, Nepal

The blocks are used to construct wall, floor and roof in a building. This special block used in some contemporary green school buildings in different parts of Nepal. A model classroom was designed and constructed in the preemies of the Department of Architecture in Pulchowk campus under supervision of this researcher in 2009. This block also used in other part of the world like in India, USA, France etc. The wall is constructed with CSEB block in cement and mud mortar in the model classroom building of the Department of Architecture (Fig.6.13). In the lab, same type of wall was constructed in a thermal box as shown in the figures 6.1 and 6.2.

The figure 6.14 shows changes inside thermal environment directly raising temperature from 23 to $24^{o}$C when outdoor temperature rises up from 22 to $41^{o}$C within five hours. The graph shows that outdoor temperature does not directly affects the indoor environment. It shows that temperature rises $7^{o}$C with in first layer R2 (41 - $22^{o}$C), $5^{o}$C in second layer R3 (28 - $23^{o}$C), $3^{o}$C in third layer R4 (26 - $23^{o}$C) and only $3^{o}$C in last layer R5 ($26^{-}$ $23^{o}$C) of CSEB wall within five hours. This shows that rate of flow of heat slow in this CSEB wall. The temperature in indoor R6 rises only one degree with 24 from $23^{o}$C after heating five hours.

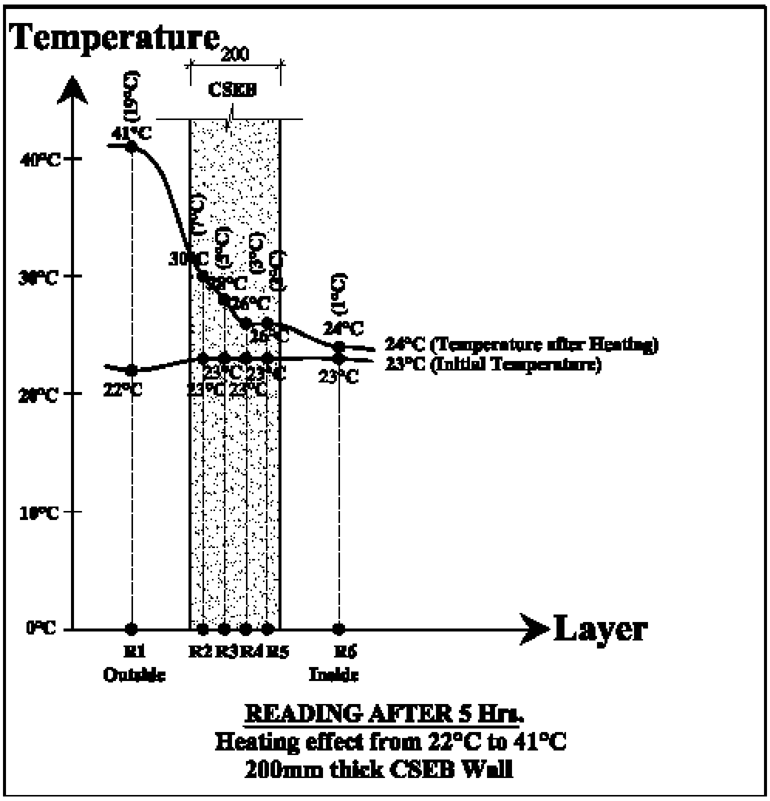



Fig. 6.14 Temperature gradient after heating effect as summer condition in a 200 mm thick CSEB wall in the laboratory

After the experiment, the heating effect was observed as follows:

Initially, $T_{out} = 22^oC$ & $T_{in} = 23^oC$

After 5 hours blowing hot air @ $36^oC$

Finally, $T_{out} = 41^oC$ & $T_{in} = 24^oC$

This shows that rate of heat flow nearly same as 450 mm thick traditional wall with combination of sun burnt brick and burnt brick. The indoor R6 temperature rises only one degree after five hours as in 450 mm thick traditional wall (Fig.6.7). This shows the either no or less effect in inside when temperature rises in outdoor. This graph shows that this CSEB wall with 200 mm thickness maintain same indoor environment without adverse effect of outdoor thermal environment in summer.

If we compare the thermal transmittance (U- value) of traditional, modern and CSEB wall, we get the rate of heat flow in 200 mm thick CSEB wall has nearly two times less than 230 mm thick modern wall. The thermal transmittance value of 200 mm thick CSEB wall has only 1.40 $W/m^{2o}C$ compared to 2.67 $W/m^{2o}C$ of 230 mm thick modern brickwork (Table 6.11). The thermal transmittance value of 200 mm thick

CSEB wall has little higher (1.40 W/m$^{2o}$C) than 0.63 and 0.85 W/m$^{2o}$C of 600 and 450 mm thick traditional brick wall (Table 6.11). But the graph (Fig.6.14) from laboratory tests show that the CSEB wall has better effect in indoor environment during winter and summer than modern brick wall. Also CSEB wall has same effect in indoor environment during winter and summer as 450 mm thick traditional wall. This wall keeps warm in winter and cool in summer without any adverse effect of outdoor environment. This is also one of the best findings to know the thermal performance of new green material and technology to use in building in future.

### 6.5.4 The comparison of the thermal performance of different walls

The different materials and technology have different rate of heat flow for thermal performance in a building. The different thermal conductivity, resistivity, resistance and transmittance (U-value) of materials and construction technology used in buildings have direct and indirect thermal effects on indoor environment. The Table 6.11 shows the comparison of the thermal conductivity, resistivity, resistance and transmittance (U-value) of different materials and construction technology tested in a lab.

The Table 6.10 shows the comparison of the thermal performance of different walls. The Table 6.10 shows that traditional 600 mm thick wall has adverse effect. When outdoor temperature rises up the indoor temperature falls down 3$^o$C (21-18$^o$C). Same way, the traditional 600 mm thick wall shows adverse effect when outdoor temperature decreases the indoor temperature rises up 2$^o$C ( 21-23$^o$C). The traditional 450 mm thick wall shows no effect in indoor environment when outdoor temperature either rises up or falls down.

Table 6.10 Comparison of the thermal performance of different walls

| S.No. | Type of Wall | Thickness mm | Thermal condition | Time Hour | air supply by AC in outer layer R 1 (o C) | Indoor Temp Initial o C | Indoor Temp Final o C | d T o C | Remark |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Traditional | 600 | Heating | 5 Hrs | 36 | 21 | 18 | 3 | Reverse effect |
| 2 | Traditional | 450 | Heating | 5 Hrs | 36 | 20 | 21 | 1 | Slow effect |
| 3 | Modern | 230 | Heating | 5 Hrs | 36 | 21 | 25 | 4 | Fast effect |
| 4 | Modern | 110 | Heating | 5 Hrs | 36 | 20 | 26 | 6 | Very fast effect |
| 5 | CSEB | 200 | Heating | 5 Hrs | 36 | 23 | 24 | 1 | Slow effect |
| 6 | Traditional | 600 | Cooling | 5 Hrs | 10 | 21 | 23 | 2 | Min effect |
| 7 | Traditional | 450 | Cooling | 5 Hrs | 10 | 22 | 22 | 0 | No effect |
| 8 | Modern | 230 | Cooling | 5 Hrs | 10 | 21 | 21 | 0 | No effect |
| 9 | Modern | 110 | Cooling | 5 Hrs | 17 | 20 | 20 | 0 | No effect |

Whereas the modern brick wall with only burnt brick shows direct affect of outdoor environment in indoor. The graph shows that the temperature rises up direct proportionately in burnt brick. The Table 6.10 shows that indoor air temperature due to traditional wall with 450 mm and modern green CSEB wall with 200 mm has similar effect with the raise in 1$^{o}$C whereas thickness is less than half of traditional building.

Table 6.11 Comparative chart of thermal transmittance and resistance of the different experimented walls and resistivity and conductivity values experimented materials (Source: Bajracharya S B & Koenigsberger et al.1975)

| S.No. | Type of Wall/ Material | Thickness | Transmittance | Resistance | Conductivity | Resistivity |
|---|---|---|---|---|---|---|
| | | T | U - value | R | K | 1/K |
| | | mm | W/m2 deg C | m2 deg C/W | W/m deg C | m deg C/W |
| 1 | Traditional brickwall | 600 | 0.63 | 1.59 | * | * |
| 2 | Traditional brickwall | 450 | 0.85 | 1.18 | * | * |
| 3 | Modern brickwall | 230 | 2.67 | 0.37 | * | * |
| 4 | Modern brickwall | 110 | 3.64 | 0.27 | * | * |
| 5 | CSEB wall | 200 | 1.40 | 0.71 | * | * |
| 6 | Burnt Brick | * | * | * | 1.21 | 0.83 |
| 7 | Sun burnt Brick | * | * | * | 0.37 | 2.68 |

### 6.5.5 The comparison of the thermal performance of different materials

The Table 6.12 shows the comparison of the thermal performance in different materials of each wall. Within traditional thick wall, rate of heat of flow very fast in external layer of burnt brick whereas either reverse or very slow in inner layers of sun burnt brickwork. The table 6.12 shows that within both traditional walls of 600mm and 450 thick, rate of heat of flow very fast in external layer of burnt brick in R2 only whereas very slow or reverse in inner R3, R4 and R5 of sun burnt brickwork. Figure 6.5 shows that within traditional walls of 600 mm, in R2 layer of burnt brick temperature raise very fast with 10$^{o}$C. But in inner layers R3, R4 and R5 of sun burnt brickwork temperature falls from 2 to 3$^{o}$C respectively. So, inside temp R6 remains 3$^{o}$C less than previous in traditional walls of 600 mm thick.

Figure 6.6 shows that when it cools outer layer R1 then R6 inner layer the temp 2$^{o}$C higher than previous. This shows that when thickness of sun burnt brick is more or equals to 500 mm, the temperature begins reverse from initial layer R3 of sun burnt brick. This table proves that if the thickness of sun burnt brick layer is more or equal to 500 mm, the rate of heat flow is reverse which creates thermal environment cool in summer and warm in winter condition by reverse effect.

Same way, Table 6.12 shows that the traditional 450 mm thick wall shows no effect in indoor environment when outdoor temperature either rises up or falls down. In R2 layer of burnt brick temp raises 14$^{o}$C very fast but in inner R3, R4 and R5 of sun burnt brickwork temp raises only by 3, 1 and 0$^{o}$C within traditional walls of 450 mm. So inside temperature raises only 1$^{o}$C higher than previous in traditional walls of 450 mm thick. From both of the walls, it shows that in the sun burnt brick layer, the rate of heat flow is either reverse or rises very slowly. This sun burnt brick has maximum role to create thermal environment better in summer and winter condition in the traditional buildings.

Table 6.12 Comparison of the thermal performance in different materials of different walls

| S.No. | Type of Wall | Thickness mm | Thermal Condition | Time Hour | Air supply by AC in outer layer R 1 (o C) | Layer | Symbol | Temp Initial o C | Temp Final o C | d T o C | Remark |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Traditional | 600 | Heating | 5 Hrs | 36 | Outside | R1 | 21 | 36 | 15 | |
| | | | | | | Burnt brick | R2 | 21 | 31 | 10 | Very fast effect |
| | | | | | | Sunburnt brick | R3 | 21 | 19 | 2 | Slow effect |
| | | | | | | Sunburnt brick | R4 | 21 | 18 | 3 | Slow effect |
| | | | | | | Sunburnt brick | R5 | 21 | 18 | 3 | Slow effect |
| | | | | | | Inside | R6 | 21 | 18 | 3 | Reverse effect |
| 2 | Traditional | 450 | Heating | 5 Hrs | 36 | Outside | R1 | 16 | 36 | 20 | |
| | | | | | | Burnt brick | R2 | 16 | 30 | 14 | Very fast effect |
| | | | | | | Sunburnt brick | R3 | 17 | 20 | 3 | Slow effect |
| | | | | | | Sunburnt brick | R4 | 19 | 20 | 1 | Very Slow effect |
| | | | | | | Sunburnt brick | R5 | 19 | 19 | 0 | No effect |
| | | | | | | Inside | R6 | 20 | 21 | 1 | Very Slow effect |
| 3 | Modern | 230 | Heating | 5 Hrs | 36 | Outside | R1 | 21 | 36 | 15 | |
| | | | | | | Burnt brick | R2 | 21 | 31 | 10 | Very fast effect |
| | | | | | | Burnt brick | R3 | 21 | 29 | 8 | Very fast effect |
| | | | | | | Burnt brick | R4 | 21 | 26 | 5 | Fast effect |
| | | | | | | Burnt brick | R5 | 21 | 25 | 4 | Fast effect |
| | | | | | | Inside | R6 | 21 | 25 | 4 | Fast effect |
| 4 | Modern | 110 | Heating | 5 Hrs | 36 | Outside | R1 | 20 | 36 | 16 | |
| | | | | | | Burnt brick | R2 | 19 | 31 | 12 | Very fast effect |
| | | | | | | Burnt brick | R3 | 20 | 30 | 10 | Very fast effect |
| | | | | | | Burnt brick | R4 | 20 | 28 | 8 | Very fast effect |
| | | | | | | Burnt brick | R5 | 20 | 27 | 7 | Very fast effect |
| | | | | | | Inside | R6 | 20 | 26 | 6 | Fast effect |
| 5 | CSEB | 200 | Heating | 5 Hrs | 36 | Outside | R1 | 22 | 41 | 15 | |
| | | | | | | CSEB | R2 | 23 | 30 | 7 | Very fast effect |
| | | | | | | CSEB | R3 | 23 | 28 | 5 | Fast effect |
| | | | | | | CSEB | R4 | 23 | 26 | 3 | Slow effect |
| | | | | | | CSEB | R5 | 23 | 26 | 3 | Slow effect |
| | | | | | | Inside | R6 | 23 | 24 | 1 | Very Slow effect |

Whereas the modern brickwork wall with only burnt brick in cement mortar shows direct effect of outdoor environment in indoor. The table shows that the temperature rises up in direct proportion to burnt brick. Same way, the Table 6.12 shows that the modern 230mm thick wall shows fast effect in indoor environment when outdoor temperature either rises up or falls down. In R2 layer of burnt brick temp raises by10$^{o}$C but in inner R3, R4 and R5 of sun burnt brickwork temperature rises only by 8 to 4$^{o}$C within this walls. Same way, in R2 layer of burnt brick temperature rises by 12$^{o}$C but in inner R3, R4 and R5 of burnt brickwork temperature rises from 10 to 7$^{o}$C in 110mm thick walls. This shows that in the burnt brick layer the temperature rises very fast. So outdoor temperature directly passes through this type of materials.

Table 6.12 shows that the green CSEB 200 mm thick wall shows no affect in indoor environment when outdoor temperature rises up. In R2 layer of CSEB layer, temp rises by 7$^{o}$C but in inner R3, R4 and R5 of CSEB layers temperature raises only by 5 to 3$^{o}$C within this wall. So inside temp layer R6 remains only 1$^{o}$C higher than previous. This shows that in the CSEB layer, the temperature rises very slowly. This 200 mm thick CSEB wall and 450 mm thick traditional wall has same effect in indoor layer R6.

### 6.6 Conclusion

This study has presented the data from the lab experiments regarding the material and technology used in buildings of Kathmandu. In this study evaluation of indoor thermal environment due to materials and technology of different walls used for traditional, contemporary and new green buildings in Kathmandu were conducted. This chapter deals in great findings on the thermal performance of the different walls with the conclusion that 600 mm traditional thick wall performs best followed by 450 mm thick traditional wall and 200 mm thick CSEB green wall. This experiment also recommends the use of traditional materials and technology or green materials and technology like CSEB for better thermal comfort in indoor environment.

The comparative study between the thermal transmittance (Table 6.11) and laboratory experimental tests of this research of traditional, modern and CSEB wall have little bit different results. The comparison of the thermal transmittance (U- value) of traditional, modern and CSEB wall shows that the U value of 600 mm thick traditional wall has four times less than 230 mm thick modern wall (Table 6.11). The U value of 200 mm thick CSEB wall has nearly two times less than 230 mm thick modern wall. The figures 6.5 and 6.6 show that the traditional thick wall has reverses effect in indoor environment during warm in winter and cool in summer. Figure 6.14 show that the CSEB wall has better effect in indoor environment than modern brick wall. Also CSEB wall has same effect in indoor environment as 450 mm thick traditional wall. This wall keeps warm in winter and cool in summer without any adverse effect of outdoor environment. This is one of the best findings that the new green material and technology with only 200 mm thick CSEB could be used for better thermal performance in building in future.

The findings show that rate of heat flow in CSEB layer is very slow than burnt brick layer of the traditional and modern walls. Compacted Stabilized Earth Block (CSEB) compressed in machine AURAM -300 is better thermal properties and its performance same like sun burnt brick  of traditional wall. To reduce thickness of sun burnt brick, the compactness should be applied. The 200 mm thick CSEB wall and 450 mm thick traditional wall has same thermal environmental effect in indoor layer R6. The thermal performance of modern CSEB wall could be better for future in modern buildings. So Jagadish et al. (2007), wrote the alternative Technology needed to solve the problem of development in a developing country rather than high technology.

Hudco India (1986) has remarked that rooms in mud houses are often dark and badly ventilated but they provide comfortable living in the extremes of the tropical climate, warm in winter and cool in summer. This is true if we compare the lab experiment results  that rate of heat flow in sun burnt layer is very slow than burnt brick layer of the traditional wall. From both of the traditional walls, the rate of heat flow is either reverse way or very slow in the sun burnt brick layer. One of the important outcome of this lab work, the sun burnt brick has maximum role to create thermal environment better in summer and winter condition in the traditional buildings.

The lab experiment shows that when thickness of sun burnt brick is more or equals to 500 mm as in traditional wall, the temperature begins reverse from initial layer R3 of sun burnt brick. This proves that if the thickness of sun burnt brick layer more or equal to 500 mm, the rate of heat flow is reverse. This works as thermal mass which create reverse effect of thermal environment. This creates cool in summer and warm in winter condition. More the thermal mass reverse will be the action in indoor environment. That is why the 600mm thick wall has the best thermal performance in indoor and used in our traditional houses. The field experiments results show that the traditional buildings were comfortable whole year round according to Rijal comfort temperature data. Also these buildings were nearly 2$^{o}$C warmer in winter and nearly 2$^{o}$C cooler in summer than modern buildings. This may be role of thermal mass which create reverse effect of indoor thermal environment as in laboratory experiment. That is why according to Hudco India (1991); over 65 million of nearly 118 million houses in India are of mud construction. So Hudco India (1986) wrote that mud houses thus represent the best use of local resources and adjustment to local climate.

# CHAPTER 7: CONCLUSION AND RECOMMENDATION

## 7.1. Introduction

This is the most important final chapter of the research. This last chapter discusses on the findings of the research. Also this chapter analyses the fulfillment of the research objectives with research questions. At the same time, this part of thesis revisits the conceptual frame and research methods adopted. It revisits the literature and existing knowledge that we discussed. This chapter discussed the research findings with other research studies in Nepal and other part of the world. Then finally the chapter draws conclusions and recommendations. The chapter concludes with policy implications and suggestions. Some recommendation shall be useful for fellow researchers and students of conservation, thermal comfort and building science.

## 7.2. Findings from the three studies

The thesis structure has been able to organize the findings of concerned chapters at their respective end. Hence, it has been easier to consolidate all of them in this chapter. This attempt could be understood as a new paradigm in thesis writing in academic arena and helpful to recall the things written in the past. The research findings both from quantitative and qualitative analysis has similar positive index attributed to traditional residential buildings of Kathmandu. The main field experimental study and supporting laboratory experiment study and qualitative survey has shown similar results to show better thermal comfort in traditional residential buildings of Kathmandu.

The findings from quantitative field study declared that the traditional residential buildings maintain mean comfort temperature below 26°C during summer which lies in perfect adaptive comfort theory of Nicol and Rijal standard. The research findings has identified traditional residential buildings maintain perfect comfort temperature in summer season. The quantitative field study also declared in the morning and evenings during winter season, these buildings create nearly 13°C which are comfortable in comfort zone of Rijal standard (Table 2.2). The research findings from qualitative survey has shown similar positive index attributed to traditional residential buildings of Kathmandu. The eighty-three percent (83%) of people feel neutral neither cool nor warm in traditional buildings. These positive attributes are better thermal performance and better comfort feeling in both summer and winter season in traditional buildings.

The research findings both from field experimental study and qualitative survey has shown similar positive index attributed to traditional residential buildings compared to modern buildings of Kathmandu. The quantitative experimental research also compared the thermal performance of traditional buildings with modern residential buildings. Compare to modern residential buildings, the traditional buildings were better thermal performance in winter and summer. The result shows that traditional residential buildings were 1 to 2°C warmer during winter and 1 to 2°C cooler during summer than modern residential buildings. Many researchers had done many thermal comfort studies with qualitative analysis only in Nepal and many parts of the world. As in Iran (Ahmad et al. 1985), these traditional houses provide a year round comfortable environment than modern houses of Kathmandu.

The findings from questionnaire surveys show overall seventy eight percent (78%) of residents of traditional residential building feel comfortable in their building whereas sixty percent (60%) of residents feel uncomfortable in their modern residence. That is why; the findings from the surveys show better thermal performance and better comfort feeling in both summer and winter season in traditional buildings than modern building. Still today, this demand of local residents show the positive aspects in traditional buildings compared to modern buildings. The findings show the local people's perception very contrasting in traditional and modern building.

This data show that most of people living in traditional and modern building still like to construct the traditional building in future. That is why; traditional buildings are not out-of-date but more acceptable to local people as compared to people of Iran who also noticed highly cultural and historic values of their traditional houses (Ahmadreza 2012). This finding is good for architects, conservationist, researcher, local government and people of Kathmandu to develop guidelines for design, byelaws and research in future.

One of the most important outcomes of this research is invention of new equation with quantitative field study. The equation is invented with the help of linear regression to predict indoor air temperature. The relation between the outdoor air temperature and indoor air temperature of the field data helped to predict indoor air temperature. The indoor air temperature could be predicted by knowing the outdoor air temperature from weather forecast of meteorological department in any time using this new equation. According to regression equation (Table 4.5), when outdoor air temperature is $10^oC$, the indoor air temperature in ground floor of traditional residential building is $12^oC$. Same way, the Table shows that when outdoor air temperature is $30^oC$ high, then indoor air temperature 25-$27^oC$ in traditional whereas 27-$28.4^oC$ in modern residential building. This prediction is also true from the quantitative field results as well as people perception from qualitative survey. This finding is good for architects, conservationist, researcher, local government and people of Kathmandu to forecast the indoor temperature in future.

The findings from both the laboratory experiments and field experiment data regarding the material and technology of wall have shown cause of the thermal performance of traditional residential buildings of Kathmandu. The lab experimental research identified the traditional 600 mm thick wall is the best with reverse effect in the indoor thermal environment both in winter and summer (Fig.6.5 & 6.6). That is why; field study finding show even in North facing buildings (Fig.4.15) have better thermal performance than others due to heavy thermal wall placed in south face.

The solar energy stored in a thermal mass has main role for heating in a building in winter. That is why, the sun burnt brick which works as thermal mass has maximum role to create thermal environment better in summer and winter condition in the traditional buildings. This proves that if the thickness of sun burnt brick layer more or equal to 500 mm, the rate of heat flow is reverse (Fig.6.5). This creates cool in summer and warm in winter condition. More the thermal mass reverse will be the action in indoor environment. That is why; the research findings identified traditional residential buildings maintain comfort temperature in summer season perfectly and comfortable in winter season.

The findings from both the field experiment data and questionnaire survey regarding the orientation have no effect in the thermal performance of traditional residential buildings of Kathmandu. The field research finding has identified that orientation of a building does not effect in the heating and cooling of traditional building in Kathmandu (Fig.4.15) as building in hilly and Himalayan part of the country. Residents of North oriented building also answered they feel better in these houses. Personally, the author also especially asked this question to residents of North oriented building, but they answered they feel better in these houses.

Levi (1908) felt very hot in Sunny day in the field during winter due to solar intensity in Kathmandu. And he felt cold in the morning and evening in his naturally ventilated individual bungalow in open area in Kathmandu. He felt the climate of Kathmandu directly depends upon the solar radiation. This is true and traditional architecture has been developed with the indirect or passive solar architecture. The passive architecture design system store the solar energy in a thermal mass which has main role for heating in a building in winter. The design concept with thermal mass is used with the combination of burnt and sun burnt brick in external wall, sun burnt brick in central wall, timber and mud floor and roof in indoor whereas stone or brick paved courtyard or alleys in outdoor. That is why, the research finding has identified that orientation of a building does not effect in the heating and cooling of traditional building in Kathmandu due to cluster system with courtyard and street planning. But the orientation of thermal mass has role to keep comfort in a building.

It should be noted that the openings and main façade of traditional building in urban area of Kathmandu is oriented towards open spaces of either courtyard or street. It is not directed towards the Sun as practiced in most of traditional buildings in hilly and mountain region of Nepal. Meir and Roaf (2006) also wrote that the thermal performance of building with high thermal mass proved to be better in highland and mountain region rather than the lowlands and more humid coastal plains which is true in buildings of Kathmandu. That is why; most of traditional building indoor air temperature is comfortable in the summer and winter with neighborhood planning.

This is very true in traditional bed room which demands less energy to heat and cool due thermal mass and small in size from the history and life style people in traditional building in the past. In the past, people use Makala (fire on a small traditional pot) to keep warm themselves during morning and evening of cold winter. It is possible to warm up in this cold morning and evening of cool winter because of thermal mass and small room size. During summer, they open the single ventilated window to operate cooling in the room which create cool inside. This is possible only due to small bed room due to low ceiling height and less surface area in a room. The findings from field study also proved, the lower the room height better for the thermal performance in summer and winter season (Fig.4.21). A big room requires more heating or cooling energy to create comfortable thermal condition than a small room. That is why; people have better thermal comfort in traditional building than modern building as per findings of qualitative survey.

The research has shown that a variety of positive factors influence in better thermal comfort in traditional building from the findings of all three field, laboratory and qualitative studies. The field study finding shows that the modern flat roof creates nearly $1^{o}$ C higher than outdoor temperature in both summer and winter in Kathmandu. This finding is supported directly or indirectly by lab and qualitative study. The traditional slope or curved roof always create better thermal environment than modern flat roof practice as in Middle East. Meir and Roaf (2006) also mentioned curved roof were found to perform thermally better than flat ones by promoting more comfortable indoors in case of vernacular architecture of Middle East. The street type buildings were much better than courtyard pattern.

The finding shows when floor rises up vertically, the indoor air temperature is better in ground and first floor than second and attic floor in summer. More the open to sky area better will be outdoor environment effects. All the data, discussion and result provide an essential foundation that the traditional buildings had better thermal comfort in the past. People were living comfortably in the past in this building. Still today people are living in it like in any other part of world. People find it more comfortable compared to modern building as studies done in Libya (Ahmad et al. 1985) and Yemen (Algifri et al.1992). The lab studies in this study from chapter 6 also support that the materials and technology provides better results in thermal comfort in this type of building in Kathmandu than modern building. These buildings are essential if we are to survive the existences of twenty-first century as vernacular know- how in a contemporary context, it shows that there is a still place for vernacular architecture in the twenty-first century (Lindsay & Vellinga 2000).That is why; local people of Kathmandu still like to construct traditional houses in future (Fig.5.18).

**7.3 Answers to the research questions**

The research achieved the targeted goal and objectives with its findings to answer research questions. There were mainly five research questions raised in this study. The research identified and proved that traditional residential building creates comfortable thermal environment throughout the year. The traditional residential buildings maintain perfect comfort with nearly 26 °C during summer season in “free running” building without mechanically cooled as per Nicol and Rijal standard. Especially in the morning and evenings during winter season, these buildings are little less than perfect mean temperature 15°C (Rijal et al. 2010) but creates nearly 13°C comfort zone temperature for people. The research results also proved that characteristics of thermal environment of traditional residential building better than the modern residential building of Kathmandu. This shall answer question raised by the first research question.

The one of the most important results is that the research has invented the linear regression equation to predict indoor air temperature by knowing the outdoor air temperature in traditional as well as modern residential building of Kathmandu. This will help to know to indoor air temperature with the help of outdoor air temperature from weather forecast of meteorological department. The year round collected field temperature data was analyzed by regression equation to relate the indoor and outdoor air temperature. The collected field temperature data and analysis help to formulate equations. This equation answered the question raised by the second research question.

The analysis and results of perception survey in this study answered how people find thermal comfort in traditional residential building as the third research question. Seventy eight percent (78%) of people living in traditional residential building feel thermally comfortable in the same traditional residential buildings with traditional technology. The eighty three percent (83%) of people living in traditional residential building feel neutral neither cool nor warm in the traditional residential buildings. These are some data of qualitative questionnaire survey which answered how people find thermal comfort in traditional residential building. These findings answered the third research question in this study.

The analysis and results of laboratory experiment proved that thick thermal mass used in a construction like wall, roof and floor are mainly responsible to create indoor environment more comfortable in summer and winter season. The study proved that traditional mud based material and technology used in traditional house are better for thermal comfort compared to modern buildings. The sun burnt heavy thermal mass affects the heating and cooling of the thermal environment in traditional building. It creates reverse action in indoor thermal environment with its thermal behavior. The lab study show that either sun burnt brick or compressed CSEB from mud behavior works better for thermal comfort during summer and winter. The lab study results proved how indoor thermal environment affected by materials and technology. This shall answer the fourth research question in this study.

The traditional mud based material and technology creates not only thermal performance better also creates clean environment, saves nature and energy efficient. So modern building design principal need to revive and refine with this materials and technology for future to save environment and energy demand in modern practice.

Traditional material, technology and design saves 1-2$^{o}$C temperature in summer and winter which means it saves 10-20 % of total energy needed for heating and cooling in a building. In Japan, saving 1°C temperature is equal to 10% of energy saving. So they had experiment many types of research for thermal comfort, energy and environments (Rijal et al. 2012).This will lead to massive energy saving in the future in Nepal.

This will be positive attributes to national economy and energy supply and demand. The alternative materials like CSEB wall also clean like traditional sun burnt brick which also saves embodied energy as well as thermal comfort better than burnt bricks. According to VSBK (2008), the Rat Trap Bond technology saves 30 % on bricks, 50 % on cement and 130MJ energy and emits 30 kg less $CO_2$ than English bond. But one of important things is that it also good for thermal comfort. The 110 mm air cavity inside brickwork works as air cavity for better insulation in modern buildings. These materials also may be alternative for future as potential material to be used for thermal comfort and energy saving in modern buildings in Nepal. These traditional material, technology, planning and design are the potential for thermal comfort and energy saving in future which shall answer the final research question raised in this study.

**7.4 Discussion**

There are many findings in this research to be discussed with other research finding before drawing conclusion. One of the research findings shows that traditional buildings are not out-of-date but more acceptable to local people. Still today, this demand of local residents show the positive aspects in traditional buildings compared to modern buildings. The findings show that the seventy eight percent (78%) of people who are resident of traditional building feel thermally comfortable in the same buildings. In total forty-four (44%) of percentage residents of different residential buildings and sixty seven percent (67%) of residents of traditional residential buildings like to construct their house in traditional residential buildings with traditional technology. Then question is why we see the dramatically degradation in the construction of these buildings in our context.

The research paper of Ahmadreza et al. (2012) from Iran reports that when traditional lifestyles and building and cities come into contact with forces of change and modernization, conflicts are bound to exist. This is very true in our context in Kathmandu also. Ahmadreza's paper on residents' perception of earthen dwellings in Iran finding shows that traditional buildings are not considered to be out–of-date, but residents noticed highly cultural and historic values in their house. The vernacular spaces, buildings, places and urban areas retain certain valuable positive aspects however some negative factors including low structural stability, low space efficiency, difficult internal access and inconvenience clean up and maintenance. The research focuses to balance between positive and negative factors. If the negative factors out weight positive ones then balance is removed. This factor justify why vernacular houses replaced by modern counterparts or used for new purposes in Iran as well as in Nepal.

The research findings show that residents feel comfortable in traditional buildings even in 13$^{o}$C during morning and evening in winter which is little less than the Nicol adaptive comfort zone (Table 2.1). But 78% residents feel comfortable may be either life style of residents with vertical spatial planning or radiant heat energy from surroundings thick walls, ceiling and floor in traditional buildings. The night use rooms like bed and living are allocated in first and second floor which have less contact with outdoor environment compared to ground floor and attic. The thermal mass with low thermal transmittance value and high thermal storage capacity of ceiling, wall and floor gains radiant heat from human body and internal heat from lamps, fire on a local stove (*makala)* etc. in traditional buildings. This may be main cause to maintain better thermal comfort in traditional buildings compared to modern buildings.

The finding has identified one of the most important aspects that are orientation of a building does not effect in the heating and cooling of traditional building in Kathmandu. This may be due to cluster system with courtyard and street planning. But the orientation and location of heavy thermal wall affect more for the heating and cooling of the building. Even in North facing building, it is noted that thermal environment is better during day time in summer because of the indoor temperature 3-4$^{o}$C less than outdoor temperature of 30$^{o}$C. During winter evening also, this building has better thermal performance than others due to heavy thermal wall placed in south face. It should be noted that the openings and main façade of traditional building in urban settlements of Kathmandu is oriented towards open spaces either courtyard or street. It is not directed towards Sun as practiced in most of traditional buildings in hilly and mountain region of Nepal.

Meir and Roaf (2006) also wrote that the thermal performance of building with high thermal mass proved to be better in highland and mountain region rather than the lowlands and more humid coastal plains which are very true in buildings of Kathmandu. Meir and Roaf (2006) also mentioned curved roof were found to perform thermally better than flat ones by promoting more comfortable indoors in case of vernacular architecture of middle-east. The main reason for improved indoor conditions under curved roof is increased surface area than flat roof. This is also applicable in the traditional slope roof of Kathmandu when compared to flat ones. The traditional slope roof creates nearly $1^oC$ lower than outdoor temperature during daytime in summer and nearly $1^oC$ higher than outdoor temperature in winter morning. The modern flat roof creates nearly $1^oC$ higher than outdoor temperature in both summer and winter. The traditional slope or curved roof always creates better thermal environment than modern flat roof practiced all over the world.

The findings show that for summer and winter season, the lower the room height better is the thermal performance. A large room requires more heating or cooling energy to create comfortable thermal condition than small room. A research finding shows volume of a room of traditional building is nearly two times less than that of a modern building. The volume air of any space directly demands energy to create comfort thermal condition during extreme cold and hot season when extra energy is needed to control thermal condition. This is true in mechanically ventilated modern buildings than free running buildings. A big room requires more heating or cooling energy to create comfortable thermal condition than a small room. This is true in traditional bed room which demands less energy to heat and cool due to small size from the history and life style of people living in traditional building in the past. In the past, people use fire on a local stove (*Makala*) to keep warm themselves which keeps warm during morning and evening of cold winter. During summer, they open the single ventilated window to operate cooling in the room which create cool inside. This is possible only due to small bed room having low ceiling height and less surface area in a room.

All the field data, discussion and result provide an essential foundation that the traditional buildings had better thermal comfort in the past. People were living comfortably in the past in these buildings. Still today people are living in it like in other part of world. People find it more comfortable compared to modern building as studies show in Libya done by Ahmad et al. (1985) and in Yemen by Algifri et al. (1992). These studies (chapter 6) show that people demand and they are willing to construct this type of building in future as compared to people of Iran who noticed highly cultural and historic values in their traditional houses (Ahmadreza 2012). The laboratory studies (chapter 6) also support that the materials and technology provide better results in thermal comfort in this type of building in Kathmandu than modern building. These buildings are essential if we are to survive the existences of twenty-first century as vernacular knows- how in a contemporary context, it shows that there is a still place for vernacular architecture in the twenty-first century (Lindsay & Vellinga 2005).

All the alternatives were developed from the traditional materials and technology. Jagadish et al. (2007), wrote the alternative Technology needed to solve the problem of development in a developing country rather than high technology.  VSBK (2008), wrote this Rat Trap Bond technology saves 30% on bricks, 50% on cement and 130MJ energy and emits 30 kg less $CO_2$ than English bond. But one of important things is that it also good for thermal comfort. The 110 mm air cavity inside brickwork works for better insulation in modern buildings. It is better to use either traditional material and technology or modern green material and technology like CSEB for thermal comfort in indoor environment of building in future.

Madhavi (2010) "Understanding the climate sensitive architecture of Marikal, a village in Telangana region in Andhra Pradesh, India" study calls for a code of practice balancing modernization with the vernacular. Marikal's form and structure are a result of centuries of evolutionary process and knowledge transfer. But the house form of Marikal is transforming like in traditional houses of Kathmandu due to their social forces and availability of electric controls in the recent decades. The study concludes that villagers associate higher social value to concrete houses due to the imported urban imagery and consider them inspirational, despite experiencing higher thermal discomfort in them. This result is somehow true in our context in Kathmandu. People of Nepal also associate higher social value to so called modern concrete houses instead of traditional buildings in the traditional settlements.

So our studies are also similar to call for a code of practice balancing modernization with the vernacular architecture in future. May be, government and local government should do something to conserve this buildings. Local government should revise byelaws for traditional residential building with traditional technology. It should have strict byelaws to design and construction of residential buildings in traditional settlement of different towns of Kathmandu valley.

The latest Bye-law (2064) of Kathmandu valley was developed, published and implemented in 2064. Chapter 4 consist of bye-laws of Bhaktapur in which traditional cultural residential zone is separated for the conservation purpose. The bye-laws of traditional cultural residential zone are  better for the conservation purpose of traditional residential buildings among the five municipality of the valley. So these bye-laws shall be implemented in all traditional settlements of Kathmandu valley for the conservation of traditional architecture.

The study shows that the traditional building creates better thermal performance, saves energy as well as environment. The existing knowledge has a knowledge gap in understanding the contemporary buildings with respect to traditional buildings. The awareness program with course should be developed to students to design and construct this building in future in architecture schools of Nepal. Revisiting in the existing knowledge and understanding of people in Nepal and abroad that traditional building has better thermal performance than modern building is still true.

### 7.5 Conclusion

The research achieved the targeted goal and objectives with its findings from three different field, laboratory and qualitative studies. It is understood that every traditional building perform better thermal environment than contemporary buildings. There were many researches generally speaking, the thermal performance of traditional dwellings is better than that of modern dwellings (Ahmad et al.1985, Algifri et al. 1992, Meir & Pearlmutter 1995, Rijal 2010). However, a quantitative analysis is necessary to give the information needed to prove better thermal comfort. A qualitative understanding can easily be formed from the information. But no such study can be found in Nepal and world, so this study focused on the measurement of thermal performance in field and laboratory experiments.

The study focused on the measurement of thermal performance in field with monitoring thermal environment for one year. To know the practically for the thermal performance of materials and technology only, laboratory experiments helped correlate with other results from field. Then the qualitative study sought to get support to these studies. The outcomes of this study show that it achieved the results and fulfills its purpose. This research has presented the data from thermal measurement in the field, laboratory and household questionnaire survey regarding the indoor and outdoor thermal environment of traditional residential buildings in Kathmandu. The research findings has identified traditional residential buildings has its own merit that it maintains thermal comfort. Compared to modern residential buildings, the traditional buildings have better thermal performance in winter and summer.

The findings show the materials and technology used in traditional building with free running better for thermal comfort for people. The material and technology used in modern buildings do not satisfy comfort expectation of the resident. The research finding show traditional residential buildings maintain slightly comfort in winter which is little less than Rijal comfort standard. Rijal et al. (2006) in his study found that the residents of houses in Lomathang were highly satisfied with the thermal conditions of their houses in 3705 m altitude in mountainous region. The findings show that people are well adapted to the thermal environment of traditional houses; as a result the adaptive neutral temperature is lower than the thermal comfort standard. This should be noticed to study the thermal comfort in vernacular architecture.

One of the most important findings is linear regression equation to predict indoor air temperature. The indoor air temperature could be predicted by knowing the outdoor air temperature from weather forecast of meteorological department. The findings show the local people's perception very contrasting in traditional and modern building. This data show that most of people living in traditional and modern building still like to construct the traditional building in future. The findings from laboratory experimental research identified the traditional 600 mm thick wall are the best with reverse effect in the indoor thermal environment both in winter and summer. That is why; field study finding show even in North facing building has better thermal performance than others due to heavy thermal wall placed in south face.

The findings show reduction of thickness of sun burnt brick, the compactness should be applied. The 200 mm thick CSEB wall and 450 mm thick traditional wall has same thermal environmental effect in indoor. The thermal performance of modern GREEN CSEB wall could be better for future in modern buildings. The feeling and willingness of people to construct traditional houses again in future should be taken seriously by the government, local government, architect, planner, academician, politician, and researcher.

One of the objectives of this research is to develop building with traditional character for future. The application of design principle of traditional building should be better to apply in modern building in Kathmandu. The new design principle should be better thermal performance of modern building with traditional building form, material and technology for future generation in Kathmandu. If possible use thick multilayer wall with sun burnt brick inside as thermal mass in exposed and central wall.

If it is not possible to use thick multilayer wall, then it is better to use 230 mm wall combination with 110 mm burnt brick outside and 110 mm sun burnt brick inside as thermal mass in exposed and central wall. If possible better to use thick layer of sun burnt brick and mud inside in wall, roof and floor. This will create not only better thermal environment but also save energy and economize in long term. It is better to use CSEB as building material and technology in wall, roof and floor in new housing for future. It reduces the building cost, saves energy to maintain thermal balance and cleans environment. It can be reused, recycled and clean materials. Its embodied energy and carbon emission is low.

The planning of housing could be in cluster in a row attached type for better thermal comfort as perceived in traditional settlement. The courtyard or attached cluster housing is preferable without considering orientation. This theory shall be better for architects and housing developers in Kathmandu. It is better to use less land and orient vertically to save costly land of Kathmandu as practiced in history to save irrigable land in Kathmandu. The sloped roof is better than flat roof. Low volume with small sized rooms is better for energy efficiency than large room. It helps to design and construct energy efficient building in future.

One of the objectives of this research is conservation of traditional residential building of Kathmandu for future. As Madhavi (2010) study calls for a code of practice balancing modernization with the vernacular in Marikal town of India somehow our studies also similar to call for a code of practice balancing modernization with the vernacular architecture in Kathmandu in future. The implementation of Bye-law with conservation purposed shall be helpful to conserve traditional residential buildings of Kathmandu for future. The latest Bye-law (2064) of Kathmandu valley was developed for conservation purpose in chapter -4 of bye-laws of Bhaktapur. The traditional cultural residential zone is separated for the conservation purpose. The bye-laws of traditional cultural residential zone are better for the conservation purpose of traditional residential buildings among the five municipality of the valley. First of all, traditional cultural residential zone is separated in all municipalities and in old towns of Kathmandu valley. Then these bye-laws shall be implemented as in Bhaktapur in all traditional settlement of Kathmandu valley for the conservation of traditional architecture.

The researcher being a full time faculty member of the Department of Architecture and Urban Planning, Institute of Engineering, Tribhuvan University, the outcome of the research will also be instrumental in setting up a future elective course in Department of Architecture and Urban Planning, Institute of Engineering Tribhuvan University, Nepal as well as in all architecture school of the country. The findings shall be published in research papers in national and international journals and conferences for awareness and further research development. The author will try to collaborate and interact with local government and government to make policy to design building with thermal comfort and conservation of traditional architecture in future with research findings.

## 7.6 Recommendation for further research

The present research achieved the targeted goal and objectives with its results. This research fulfills its objectives with quantitative and qualitative study from the field data, laboratory and household questionnaire survey regarding thermal environment of residential buildings in Kathmandu. It is better to study the impact of orientation in thermal environment of traditional residential buildings in Kathmandu in future in detail. The research finding discovered that the orientation of building does not effect in the heating and cooling of traditional building in Kathmandu. But the orientation of thermal mass has a role to keep comfort in a building. It could be noted that the openings and main façade of traditional building in urban area of Kathmandu are oriented towards open spaces of either courtyard or street. It is not directed towards Sun as practiced in most of traditional buildings in hilly and mountain region of Nepal.

The present research achieved the targeted goal with its results in laboratory work. The laboratory work established that traditional material and technology is better than modern. It could be better to do further research in full size model room than thermal box in a controlled lab. This shall give opportunity to examine all the factors that influence in thermal comfort of a room. As for example, air change rate, relative humidity, air temperature, internal heat gain from lamps, conduction, convection, evaporation etc. This shall be little bit expensive in Nepal to construct a model room with all equipments to record these measurements. But this shall give opportunity to study in detail.

The present research experiments recorded temperature data either heating or cooling in 5 hours time due to lacking of power system and office management system in the laboratory. It could be better for accuracy to do further same type of research experiments by heating or cooling for 24 hours. It could be better for accuracy to do further same type of research experiments by more cooling down till 0 $^{o}$C as present research cooled down only till 9 $^{o}$C. It could be better to do further research not only with CSEB but with more alternative green materials and technology to compare with traditional materials and technology for future.

The present research has collected approximately 11500 data in field study from different residential buildings regarding the indoor and outdoor thermal environment.

However, the massive field data were collected but for more accuracy it is better to collect these massive field data by automatic data logger machine rather than normal room thermometer manually. It could be recorded many times in each day by data logger and it is easy for simulation in computer aided software. But it is little bit expensive in Nepal as it requires many data loggers for many houses in same time period. Some automatic data logger also records the data of relative humidity and air change rate in same time which is lacking in this research.

It could be better to do further research in thermal comfort, energy and environment saving in modern residence of housing sector in future. It is better to compare the results with traditional buildings for thermal comfort, energy and environment saving. This research focused only on traditional and modern residential buildings in traditional settlement of Kathmandu. Today, a growing number of housing project with bungalow are designed and constructed with modern concept, materials and technology imported from the globalize world instead of traditional form, materials, technology.

The houses constructed with modern artificial materials like RCC, metal, glass, cement, GI sheet instead of traditional materials. These contemporary buildings have different technical problems and not satisfying the people especially due to lack of thermal comfort. It requires more artificial energy system for heating and cooling to maintain thermal comfort in winter and summer as it located in modern open settlement of Kathmandu. In Nepal, maximum number of modern building is constructed of masonry material without thermal insulation. These buildings are cold in winter and hot in summer.

The present research achieved the targeted goal with its results in qualitative survey. But in initial stages, this part of research was not focused in the research methodology. Due to this, it was surveyed later with only 50 householders. But it could be better to do this type of qualitative survey with minimum of 200 participants in future for more accuracy. It could be better to include modern bungalow houses of detached type to compare with traditional houses for comparison in future.

Today, a growing number of housing projects with bungalow were designed and constructed with modern concept, materials and technology in outskirt of the city. It could be better to measure air temperature of space and same time and ask about thermal perception to respondent (subject). This should be repeated for same respondent (subject) in different seasons in one year in future. This shall give valuable data and result in qualitative study.

The present research achieved to invent new regression equation. The new regression equation should be tested for further detail research in thermal environment of traditional as well as modern building in Nepal. This research mainly focused on thermal behavior of traditional buildings but further research should be done to compare with this research in green, sustainable and CSEB building in future.

Thermal comfort is a basic requirement of any building. It saves energy to heat and cool in a building. It also impacts on the national economy too. This impact should be studied in new research.  How to reproduce this knowledge and development of more thermal comfortable and energy efficient residential building in Kathmandu is yet to be revealed in a broader perspective. This research could be carried out further to seek such opportunities in implementing the local ideas on resource identification, their mobilization. The research has proposed the parameters to identify the building and adaptive. They could be added, modified and challenged by the researchers in the days to come.

THE END

## GLOSSARY

**Important technical words used in Newari and Nepali languages:**

| | |
|---|---|
| *Apa* | - Brick |
| *Anna* | - 31.81 square metres land |
| *Baiga* | - Attic |
| *Bhaupwa* | - Cat hole on sloped roof |
| *Chheli* | - Ground floor |
| *Chotan* | - First floor |
| *Chukanchhe* | - Private residential square |
| *Dachhi apa* | - Wedge shaped special exposed brick |
| *Dhalin* | - Timber joist |
| *Durbar* | - Palace |

| | |
|---|---|
| *Kachi apa* | - Sun burnt brick |
| *Makapwa* | - small window on sloped roof |
| *Makala* | - A fire on a local pot |
| *Matan* | - Second floor |
| *Pachpanne Jhale Durbar* | - A famous 55 window palace of Bhaktapur |
| *Pha* | - A raised platform Peti |
| *Pakki apa* | - Kiln burnt brick |
| *Sanjhya* | - A big window like dormer window |
| *Upatekaka Kalatmak Jyalharu* | - Decorative windows of Kathmandu valley |

**ABBREVIATION:**

| | |
|---|---|
| AC | - Air-conditioning |
| ASHRAE | - The American society of heating, Refrigeration and Air-Conditioning Engineers |
| AURAM- 300 | - Auram Earth equipment for manufacturing of CSEB block developed by Auroville Building Earth Institute of India |
| CEN | - Comite European de Normalization |
| CSEB | - Compressed Stabilized Earth Block |
| HUDCO | - Housing and Urban Development Corporation of India |
| HVAC | - Heat, ventilation and air conditioning |
| ISO | - International Organization for Standardization |
| RCC | - Reinforced Cement Concrete |
| THUNDER | - Trans-Himalayan University Network for Development, Education and Research |
| Teri | - Tata Energy Renewable Institute of India |
| VSBK | - Vertical Shaft Brick Kiln, A project of SDC (Swiss Agency for Development and Cooperation) Nepal |

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**APPENDIX 1: a.) A sample of recorded field Temperature data in excel table**

| | TEMPERATURE DATA OF JANUARY 2010 (MAGH 2066) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | COLLECTION OF TEMPERATURE DATA (Indoor outdoor temperature) | | | | | | | |
| Residence: Sanjaya Maharjan | | | Address: 193, Subahal,Ward No.8, Patan | | | | | |
| | | | | | | | | |
| S.NO. | DATE | TIME | OUTDOOR | INDOOR TEMPERATURE (Deg Celcius) | | | | REMARK |
| | (Jan/Magh) | | o C | GF(Chheli) | Bed I F | Living II F | Attic Kit | |
| 1 | 066.10.1 | 700 | 10 | 11 | 14 | 12 | 12 | |
| | 010.Jan.15 | 1400 | 18 | 12 | 15 | 15 | 15 | |
| | | 2200 | 12 | 11 | 11 | 13 | 13 | |
| 2 | 066.10.2 | 700 | 8 | 11.5 | 12 | 12 | 12 | |
| | | 1400 | 17 | 12 | 15 | 15 | 15 | |
| | | 2200 | 12 | 11 | 11 | 13 | 12.5 | |
| 3 | 066.10.3 | 700 | 11 | 11 | 12 | 11.5 | 11 | |
| | | 1400 | | | | | | NR |
| | | 2200 | 13 | 11 | 13 | 14 | 14 | |
| 4 | 066.10.4 | 700 | 8 | 11.5 | 12 | 12 | 13 | |
| | | 1400 | | | | | | NR |
| | | 2200 | 13 | 11 | 14 | 14 | 14 | |
| 5 | 066.10.10 | 700 | 8 | 11 | 11.5 | 11.5 | 11.5 | |
| | | 1400 | 17 | 13 | 15 | 15 | 15 | |
| | | 2200 | 13 | 12 | 14 | 15 | 15 | |
| 6 | 066.10.11 | 700 | 9 | 11 | 11.5 | 11 | 11 | |
| | | 1400 | | | | | | NR |
| | | 2200 | 12 | 11 | 15 | 14 | 14 | |
| 7 | 066.10.12 | 700 | 9 | 11 | 12 | 12 | 12 | |
| | | 1400 | 17.5 | 13 | 14 | 15.5 | 15 | |
| | | 2200 | 12 | 12 | 15 | 14 | 14 | |
| 8 | 066.10.13 | 700 | 9 | 11 | 12 | 12 | 12.5 | |
| | | 1400 | 8 | 14 | 15 | 15 | 14 | |
| | | 2200 | 13 | 12 | 15 | 15 | 14 | |
| 9 | 066.10.14 | 700 | 9 | 11 | 12 | 12 | 12 | |
| | | 1400 | | | | | | NR |
| | | 2200 | 12 | 12 | 15 | 13.5 | 13.5 | |
| 10 | 066.10.15 | 700 | 8.5 | 11 | 11 | 11 | 11 | |
| | | 1400 | 17 | 13.5 | 15 | 15 | 15 | |
| | | 2200 | 12 | 13 | 15 | 14 | 14 | |
| 11 | 066.10.24 | 700 | 9 | 11 | 11.5 | 11.5 | 11.5 | |
| | | 1400 | 17.5 | 13 | 15 | 14.5 | 14 | |
| | | 2200 | 12.5 | 13 | 14 | 13.5 | 13.5 | |
| 12 | 066.10.25 | 700 | 10 | NR | 12 | 12 | 12 | |
| | | 1400 | 17.5 | 14 | 15 | 15 | 15 | |
| | | 2200 | 12 | 13 | 14 | 14 | 13.5 | |
| 13 | 066.10.26 | 700 | 13 | 12 | 14 | 15 | 14 | |
| | | 1400 | 17.5 | 14 | 15 | 15 | 15 | |
| | | 2200 | 12 | 12 | 13 | 14 | 14 | |
| 14 | 066.10.27 | 700 | 9 | 12 | 13 | 12 | 12 | |
| | (Magh) | 1400 | | | | | | NR |
| | | 2200 | | | | | | |
| 15 | 066.11.1 | 700 | 7 | NR | 12 | 10 | 10 | |
| | Falgun | 1400 | | | | | | |
| | | 2200 | | | | | | |

## b.) A sample of recorded field Temperature data in excel table

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | TEMPERATURE DATA OF JUNE 2010 (Jestha 2067) | | | | | | | |
| | COLLECTION OF TEMPERATURE DATA (Indoor outdoor temperature) | | | | | | | |
| Residence: Dan Bahadur Maharjan | | | Address: Devdhoka, Ward No. 2, Kirtipur | | | | | |
| | | | | | | | | |
| S.NO. | DATE | TIME | OUTDOOR | INDOOR TEMPERATURE (Deg Celcius) | | | | REMARK |
| | (Jestha/June) | | o C | GF | Bed I F | Living II F | Attic Kit | |
| 1 | 010.May.31 | 700 | 19 | 22 | 23 | 22 | 22 | |
| | 067.2.17 | 1400 | 33 | 29 | 30 | 30 | 30 | |
| | | 2200 | 24 | 23 | 24 | 25 | 26 | |
| 2 | 010.June.1 | 700 | 22 | 22 | 24 | 23 | 23 | |
| | 067.2.18 | 1400 | 33 | 25 | 26 | 28 | 30 | |
| | | 2200 | 22 | 23 | 24 | 24 | 25 | Raining |
| 3 | 010.June.2 | 700 | 21 | 22 | 23 | 23 | 23 | |
| | 067.2.19 | 1400 | 32 | 25 | 26 | 28 | 31 | |
| | | 2200 | 26 | 23 | 24 | 25 | 26 | |
| 4 | 010.June.3 | 700 | 23 | 22 | 23 | 24 | 24 | |
| | 067.2.20 | 1400 | 31 | 25 | 26 | 27 | 31 | |
| | | 2200 | 24 | 24 | 25 | 24 | 25 | |
| 5 | 010.June.4 | 700 | 21 | 22 | 23 | 23 | 22 | |
| | 067.2.21 | 1400 | 28 | 24 | 25 | 26 | 27 | |
| | | 2200 | 24 | 24 | 25 | 25 | 25 | |
| 6 | 010.June.5 | 700 | 21 | 22 | 23 | 24 | 24 | |
| | 067.2.22 | 1400 | 31 | 25 | 26 | 28 | 31 | |
| | | 2200 | 24 | 24 | 25 | 25 | 25 | |
| 7 | 010.June.6 | 700 | 22 | 22 | 23 | 23 | 23 | |
| | 067.2.23 | 1400 | 33 | 25 | 26 | 28 | 31 | |
| | | 2200 | 26 | 26 | 26 | 27 | 28 | |
| 8 | 010.June.7 | 700 | 24 | 24 | 25 | 25 | 25 | |
| | 067.2.24 | 1400 | 33 | 26 | 26 | 28 | 32 | |
| | | 2200 | 25 | 26 | 26 | 27 | 28 | |
| 9 | 010.June.8 | 700 | 22 | 23 | 24 | 24 | 23 | |
| | 067.2.25 | 1400 | 32 | 26 | 27 | 28 | 30 | |
| | | 2200 | 25 | 26 | 26 | 27 | 28 | |
| 10 | 010.June.9 | 700 | 24 | 24 | 25 | 26 | 26 | |
| | 067.2.26 | 1400 | 31 | 25 | 25 | 26 | 29 | |
| | | 2200 | 25 | 26 | 26 | 27 | 27 | |
| 11 | 010.June.10 | 700 | 18 | 20 | 20 | 21 | 20 | |
| | 067.2.27 | 1400 | 30 | 25 | 25 | 26 | 28 | |
| | | 2200 | 25 | 25 | 26 | 27 | 27 | |
| 12 | 010.June.11 | 700 | 21 | 22 | 23 | 23 | 22 | |
| | 067.2.28 | 1400 | 31 | 26 | 26 | 28 | 29 | |
| | | 2200 | 25 | 25 | 26 | 26 | 27 | |
| 13 | 010.June.12 | 700 | 23 | 24 | 24 | 25 | 24 | |
| | 067.2.29 | 1400 | 31 | 23 | 23 | 28 | 30 | |
| | | 2200 | 25 | 25 | 26 | 27 | 28 | |
| 14 | 010.June.13 | 700 | 24 | 23 | 23 | 24 | 19 | |
| | 067.2.30 | 1400 | 28 | 25 | 26 | 27 | 28 | |
| | | 2200 | 25 | 25 | 25 | 26 | 25 | |
| 15 | 010.June.14 | 700 | 25 | 24 | 25 | 25 | 25 | |
| | 067.2.31 | 1400 | 26 | 25 | 25 | 25 | 27 | Cloudy |
| | | 2200 | 25 | 25 | 25 | 26 | 26 | |
| 16 | 010.June.15 | 700 | 24 | 24 | 25 | 25 | 25 | |
| | 067.3.1 | 1400 | 31 | 25 | 26 | 26 | 29 | |
| | | 2200 | 24 | 25 | 25 | 26 | 26 | |

**APPENDIX 2: a.) Sample of field experiment data used in field in Nepali and Newari language**

तापक्रमको विवरण

घरधनीको नाम: दान ब. महर्जन ठेगाना: देवढोका, ~~कीर्तिपुर~~

| सि.नं. | महिना गते | समय | बाहिरी तापक्रम (degree celcius) | घर भित्रको तापक्रम (degree celcius) | | | | कैफियत |
|---|---|---|---|---|---|---|---|---|
| | | | | भुइँतल्ला | पहिलो तल्ला | दोस्रो तल्ला | बुइगल | |
| १ | माघ २१ २०६५ | बिहान ६:०० | ८ | १२ | १३ | १३ | ११ | |
| | | दिउँसो १४:०० | २३ | १६ | १६ | १८ | २० | |
| | | साँझ १०:०० | ११ | १३ | १४ | १४ | १४ | |
| २ | २२ | बिहान ६:०० | ७ | ११ | १२ | १२ | १२ | |
| | | दिउँसो १४:०० | २३ | १२ | १२ | १३ | १४ | |
| | | साँझ १०:०० | ११ | १३ | १३ | १२ | १२ | |
| ३ | २३ | बिहान ६:०० | ७ | १३ | १३ | १३ | ११ | |
| | | दिउँसो १४:०० | २३ | १४ | १५ | १७ | १९ | |
| | | साँझ १०:०० | ११ | १२ | १३ | १३ | १२ | |
| ४ | २४ | बिहान ६:०० | ८ | १२ | १३ | १२ | १२ | |
| | | दिउँसो १४:०० | २३ | १४ | १४ | १६ | १७ | |
| | | साँझ १०:०० | ११ | १२ | १३ | १२ | १२ | |
| ५ | २५ | बिहान ६:०० | ८ | १२ | १२ | १२ | ११ | |
| | | दिउँसो १४:०० | २४ | १६ | १७ | २० | २० | |
| | | साँझ १०:०० | ११ | १२ | १३ | १३ | १२ | |
| ६ | २६ | बिहान ६:०० | ७ | १२ | १३ | १२ | १२ | |
| | | दिउँसो १४:०० | २० | १४ | १३ | १४ | १५ | |
| | | साँझ १०:०० | १२ | १३ | १३ | १३ | १३ | |
| ७ | २७ | बिहान ६:०० | ८ | १२ | १२ | १२ | ११ | |
| | | दिउँसो १४:०० | २२ | १८ | १४ | १८ | १८ | |
| | | साँझ १०:०० | १२ | १३ | १४ | १४ | १४ | |
| ८ | २८ | बिहान ६:०० | ८ | १२ | १२ | ११ | ११ | |
| | | दिउँसो १४:०० | २२ | १७ | १५ | १८ | १८ | |
| | | साँझ १०:०० | १२ | १६ | १५ | १६ | १६ | |
| ९ | २९ | बिहान ६:०० | ८ | १२ | १२ | १२ | १२ | |
| | | दिउँसो १४:०० | २४ | १७ | १८ | १८ | १८ | |
| | | साँझ १०:०० | ११ | १३ | १३ | १२ | १२ | |
| १० | फागुन १ | बिहान ६:०० | ८ | १२ | १२ | १२ | ११ | |
| | | दिउँसो १४:०० | २४ | १६ | १४ | १४ | १५ | |
| | | साँझ १०:०० | ११ | १४ | १३ | १३ | १२ | |

**b. Sample of field experiment data used in field in Nepali and Newari language**

तापक्रमको विवरण (...)

घरधनीको नाम (...): ज्ञान बहादुर प्रधान ठेगाना (...): देवढोका कीर्तिपुर

| दिन | महिना गते | समय (...) | बाहिरी (...) तापक्रम (degree celcius) | घर भित्रको (...) तापक्रम (degree Celcius) | | | | कैफियत |
|---|---|---|---|---|---|---|---|---|
| | | | | अङ्गालुन्ना (...) | पहिलो तल्ला (...) | दोस्रो तल्ला (...) | बुइगल (...) | |
| १ | असोज ६ | बिहान ६:०० | २२ | २३ | २३ | २४ | २३ | पानी परेको |
| | | दिउँसो १४:०० | ३० | २५ | २९ | २७ | २९ | |
| | | साँझ १०:०० | २३ | २४ | २४ | २६ | २५ | |
| २ | ७ | बिहान ६:०० | २४ | २५ | २६ | २६ | २६ | |
| | | दिउँसो १४:०० | ३० | २६ | २६ | २८ | २९ | |
| | | साँझ १०:०० | २४ | २५ | २६ | २६ | २६ | |
| ३ | ८ | बिहान ६:०० | २२ | २२ | २३ | २४ | १९ | पानी परेको |
| | | दिउँसो १४:०० | ३० | २५ | २६ | २८ | २९ | |
| | | साँझ १०:०० | २९ | २४ | २५ | २६ | २६ | |
| ४ | ९ | बिहान ६:०० | २२ | २३ | २३ | २४ | २३ | |
| | | दिउँसो १४:०० | २९ | २५ | २५ | २६ | २८ | |
| | | साँझ १०:०० | २९ | २४ | २६ | २६ | २६ | |
| ५ | १० | बिहान ६:०० | २३ | २४ | २५ | २६ | २५ | |
| | | दिउँसो १४:०० | ३० | २६ | २९ | २७ | २९ | |
| | | साँझ १०:०० | २३ | २४ | २५ | २६ | २५ | |
| ६ | ११ | बिहान ६:०० | २३ | २४ | २५ | २५ | २५ | |
| | | दिउँसो १४:०० | ३० | २५ | २७ | २७ | २९ | |
| | | साँझ १०:०० | २५ | २५ | २६ | २७ | २८ | |
| ७ | १२ | बिहान ६:०० | २२ | २५ | २५ | २६ | २५ | |
| | | दिउँसो १४:०० | ३१ | २६ | २७ | २८ | ३० | |
| | | साँझ १०:०० | २४ | २५ | २६ | २६ | २६ | |
| ८ | १३ | बिहान ६:०० | २३ | २५ | २५ | २५ | २४ | |
| | | दिउँसो १४:०० | ३२ | २६ | २७ | २९ | ३० | |
| | | साँझ १०:०० | २४ | २५ | २५ | २६ | २६ | |
| ९ | १४ | बिहान ६:०० | २३ | २५ | २६ | २९ | २५ | |
| | | दिउँसो १४:०० | ३२ | २६ | २७ | २८ | ३० | |
| | | साँझ १०:०० | २४ | २५ | २६ | २६ | २६ | |
| १० | १५ | बिहान ६:०० | २३ | २५ | २६ | २७ | २७ | |
| | | दिउँसो १४:०० | ३२ | २६ | २७ | २८ | ३० | |
| | | साँझ १०:०० | २४ | २५ | २६ | २६ | २६ | |

**APPENDIX 3: a.) Samples of questionnaire survey used in field in Nepali language**

काठमाडौं उपत्यका शहरी क्षेत्रमा निर्मित आवाशीय घरहरुको

तातो - चिसोपनाको अनुभव विषयक प्रश्नावली

सर्भेयरको नाम : ........ मिति : २०६९|०४|२०

नाम : ........

उमेर : ........ लिङ्ग : महिला/पुरुष/अन्य

पेशा : खेती........

ठेगाना : ........ वडा नं : १८

घरको बनोट : क) परम्परागत शैलीको घर ख) नयाँ ढाँचाको ढलान घर

ग) मिश्रित परम्परागत एवं ढलान घ) अन्य

प्रश्न नं. १) यस घरमा तपाइको तातो - चिसोको अनुभव कस्तो छ ?

- ४) धेरै जाडो - ३) जाडो - २) चिसो - १) अलिकति चिसो

०) ठिक १) अलिकति तातो २) तातो ३) गर्मी ४) धेरै गर्मी

प्रश्न नं. २) यस घरमा तपाइलाई तातो - चिसोको आनन्दपन कस्तो लाग्छ ?

०) आनन्द १) अलिकति आनन्द २) अलिकति असुविधा

३) असुविधा ४) धेरै असुविधा

प्रश्न नं. ३) यस घरमा तपाईको न्यानो - शितलको चाहना के छ ?

- २) न्यानो चाहिन्छ - १) अलिकति न्यानो चाहिन्छ ०) यतिकै ठिक छ

१) अलिकति शितलता चाहिन्छ २) शितल चाहिन्छ

प्रश्न नं. ४) हाल तपाईको शरीरमा पसिना आइरहेको छ ?

०) छैन १) अलिकति छ २) केहि मात्रामा छ ३) धेरै छ ।

प्रश्न नं. ५) हाल तपाईको कार्यशीलता के छ ?

१) पल्टिरहेको २) बसेर आराम गरी रहेको ३) बसेर काम गरी रहेको

४) उभि रहेको ५) उभिएर काम गरी रहेको

प्रश्न नं. ६) तपाईको शरीरको कुनै भाग तातो वा चिसो छ ?

१) छ २) छैन

प्रश्न नं. ७) तपाई यस घरमा अहिलेको जाडो वा गर्मी वातावरण खप्न सक्नु हुन्छ कि हुँदैन ?

१) सक्छु २) सक्दिन

प्रश्न नं. ८) यदि नयाँ घर निर्माण गर्नु परेमा तपाई तातो - चिसो अनुभवको आधारमा कस्तो घर निर्माण गर्न चाहनु हुन्छ ?

१) परम्परागत शैली र बनोटको परम्परागत घर

२) नयाँ ढाँचाको ढलानको घर

३) मिश्रित नयाँ तथा पुरानो ढाँचाको घर

४) अन्य तरिकाको घर

**b.) Sample of questionnaire survey used in field in Nepali language**

काठमाडौं उपत्यका शहरी क्षेत्रमा निर्मित आवाशीय घरहरुको

तातो - चिसोपनाको अनुभव विषयक प्रश्नावली

सर्भेयरको नाम : सुशिला महर्जन मिति : २०६९/८/१

नाम : महेन्द्र शाक्य

उमेर : ३६ वर्ष लिङ्ग : महिला/पुरुष/अन्य

पेशा : हस्तकला

ठेगाना : गुजिबहाल वडा नं. : ८

घरको बनोट : क) परम्परागत शैलीको घर ख) नयाँ ढाँचाको ढलान घर
ग) मिश्रित परम्परागत एवं ढलान घ) अन्य

प्रश्न नं. १) यस घरमा तपाइको तातो - चिसोको अनुभव कस्तो छ ?
- ४) धेरै जाडो - ३) जाडो - २) चिसो - १) अलिकति चिसो
०) ठिक १) अलिकति तातो २) तातो ३) गर्मी ४) धेरै गर्मी

प्रश्न नं. २) यस घरमा तपाइलाई तातो - चिसोको आनन्दपन कस्तो लाग्छ ?
०) आनन्द १) अलिकति आनन्द २) अलिकति असुविधा
३) असुविधा ४) धेरै असुविधा

प्रश्न नं. ३) यस घरमा तपाईको न्यानो - शितलको चाहना के छ ?
- २) न्यानो चाहिन्छ - १) अलिकति न्यानो चाहिन्छ ०) यतिकै ठिक छ
१) अलिकति शितलता चाहिन्छ २) शितल चाहिन्छ

प्रश्न नं. ४) हाल तपाईको शरीरमा पसिना आइरहेको छ ?
०) छैन १) अलिकति छ ३) केहि मात्रामा छ ३) धेरै छ।

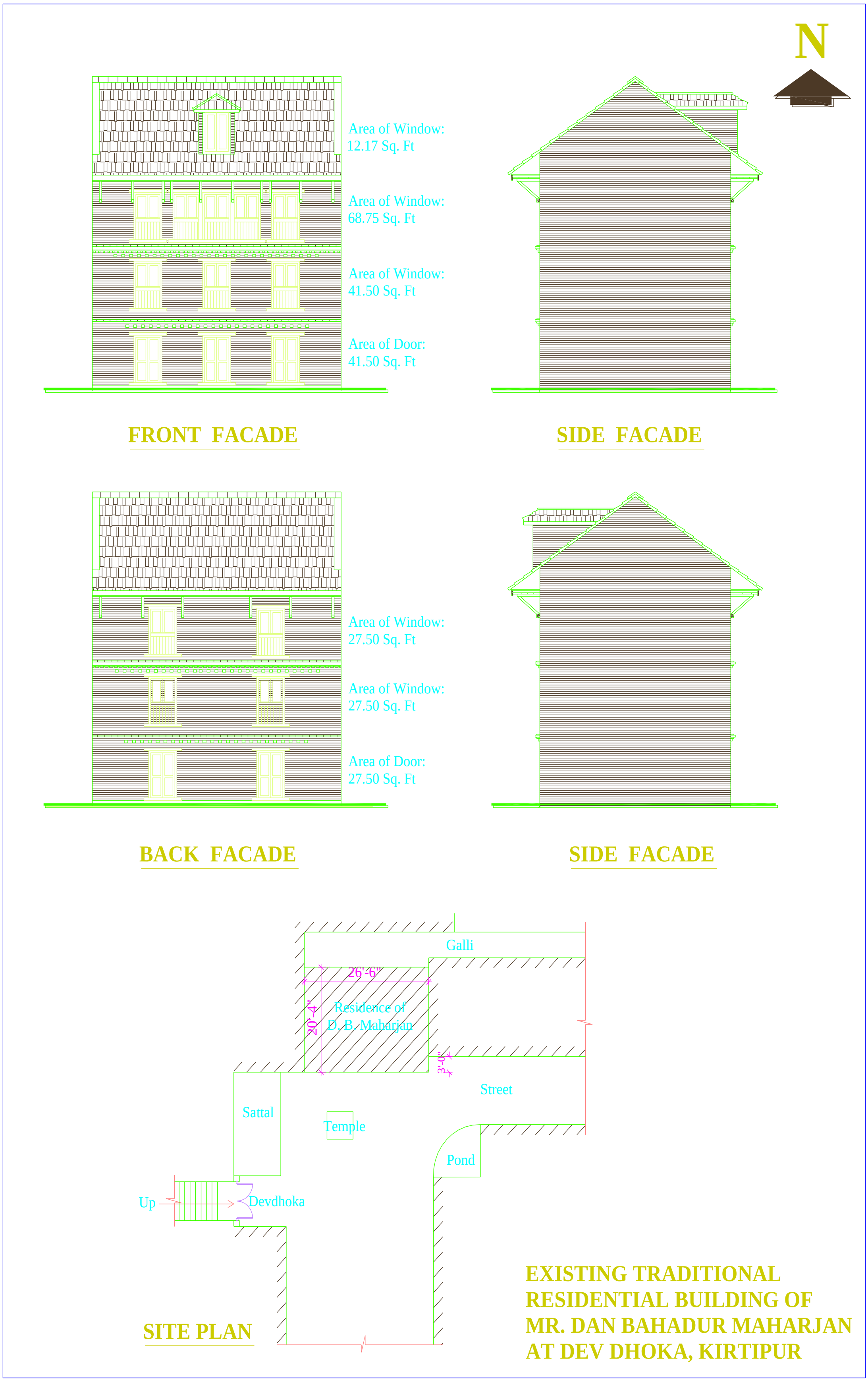
प्रश्न नं. ५) हाल तपाईको कार्यशीलता के छ ?
१) पल्टिरहेको २) बसेर आराम गरी रहेको ३) बसेर काम गरी रहेको
४) उभि रहेको ५) उभिएर काम गरी रहेको

प्रश्न नं. ६) तपाईको शरीरको कुनै भाग तातो वा चिसो छ ?
१) छ २) छैन

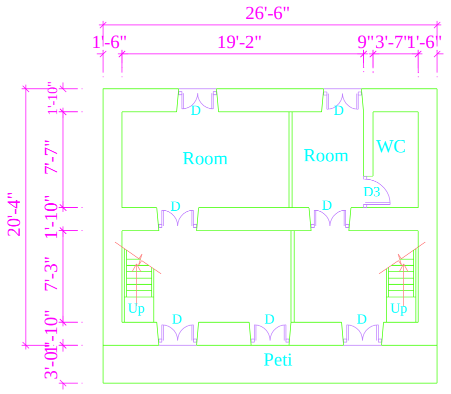
प्रश्न नं. ७) तपाई यस घरमा अहिलेको जाडो वा गर्मी वातावरण खप्न सक्नु हुन्छ कि हुँदैन ?
१) सक्छु २) सक्दिन

प्रश्न नं. ८) यदि नयाँ घर निर्माण गर्नु परेमा तपाई तातो - चिसो अनुभवको आधारमा कस्तो घर निर्माण गर्न चाहनु हुन्छ ?
१) परम्परागत शैली र बनोटको परम्परागत घर
२) नयाँ ढाँचाको ढलानको घर
३) मिश्रित नयाँ तथा पुरानो ढाँचाको घर
४) अन्य तरिकाको घर

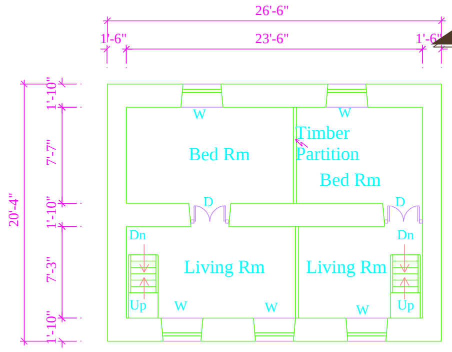
**APPENDIX 4: a.) Drawings of investigated residential building No.1**



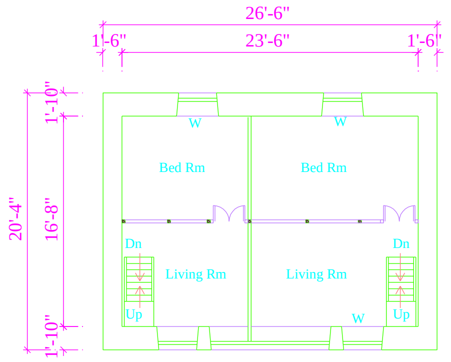
## a.) Drawings of investigated residential building No.1



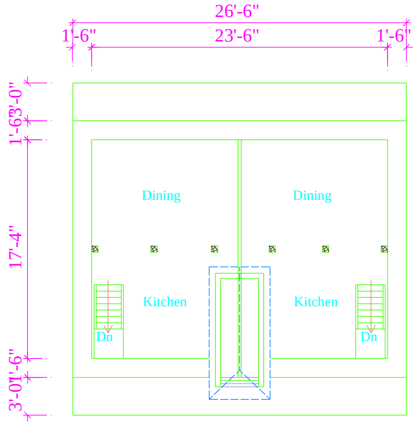

GROUND FLOOR PLAN



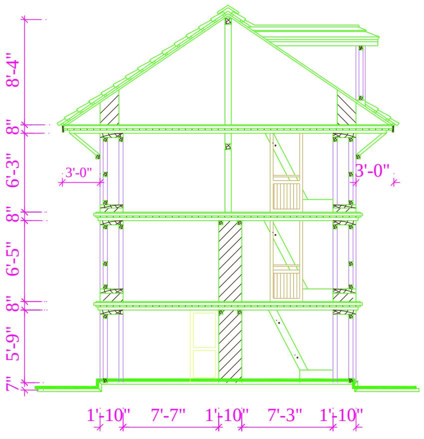

FIRST FLOOR PLAN




SECOND FLOOR PLAN




TOP FLOOR PLAN

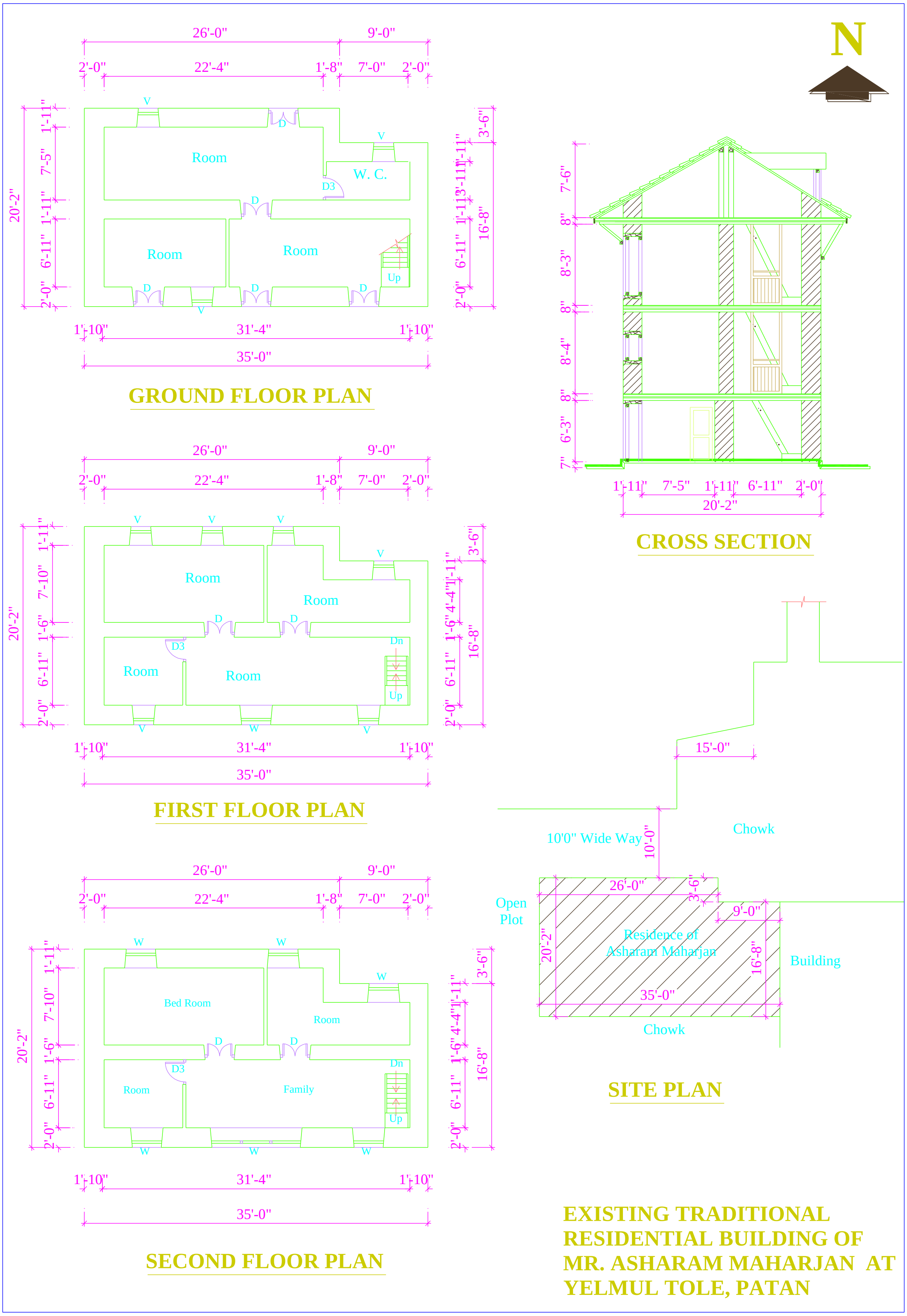



CROSS SECTION

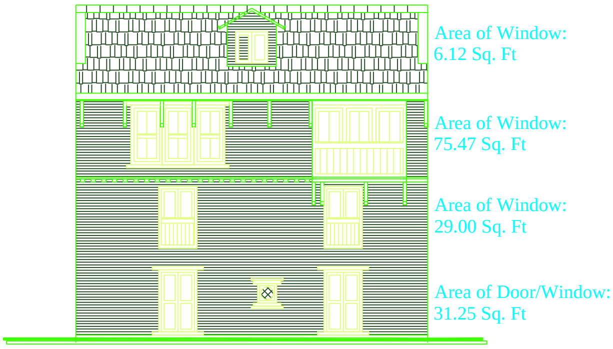
EXISTING TRADITIONAL RESIDENTIAL BUILDING OF MR. DAN BAHADUR MAHARJAN AT DEV DHOKA, KIRTIPUR

## b.) Drawings of investigated residential building No.2

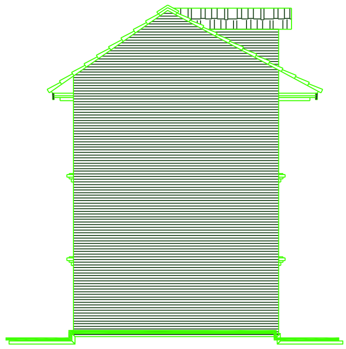
## b.) Drawings of investigated residential building No.2



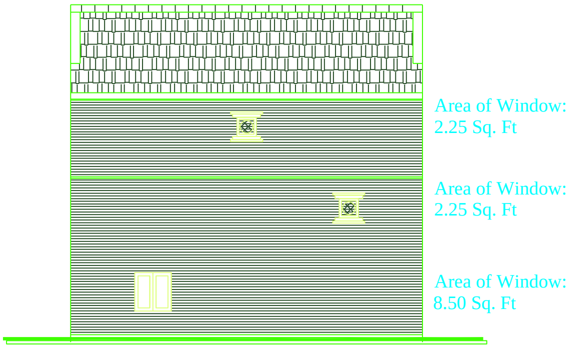
## c.) Drawings of investigated residential building No.3



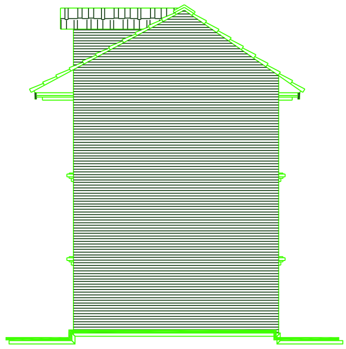

FRONT FACADE



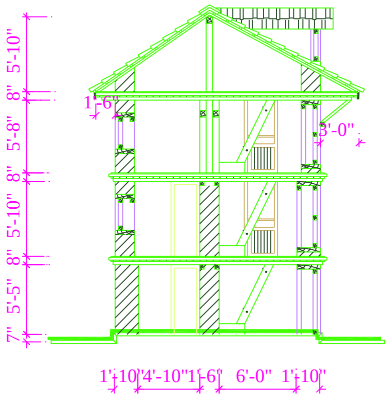
SIDE FACADE




BACK FACADE



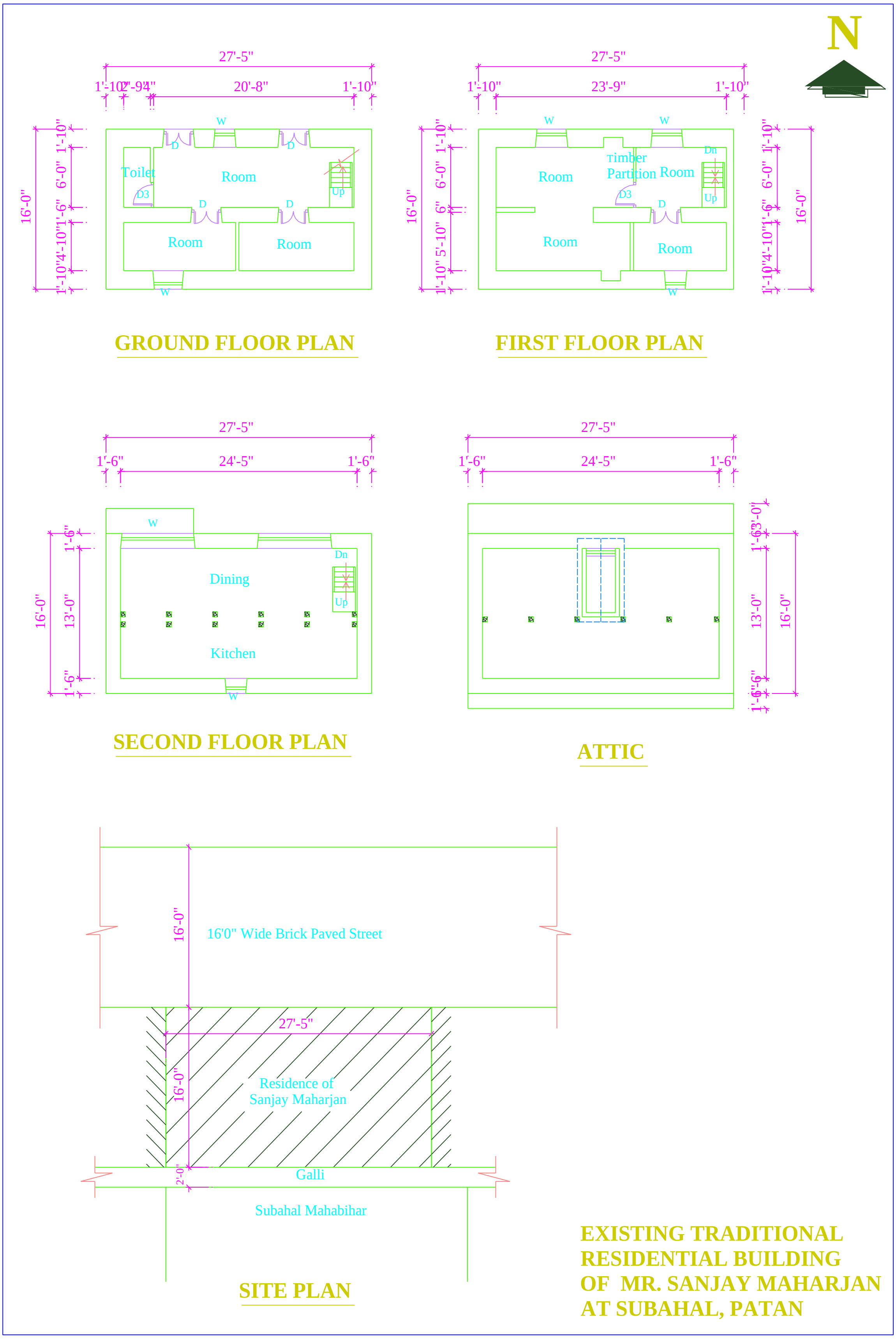
SIDE FACADE



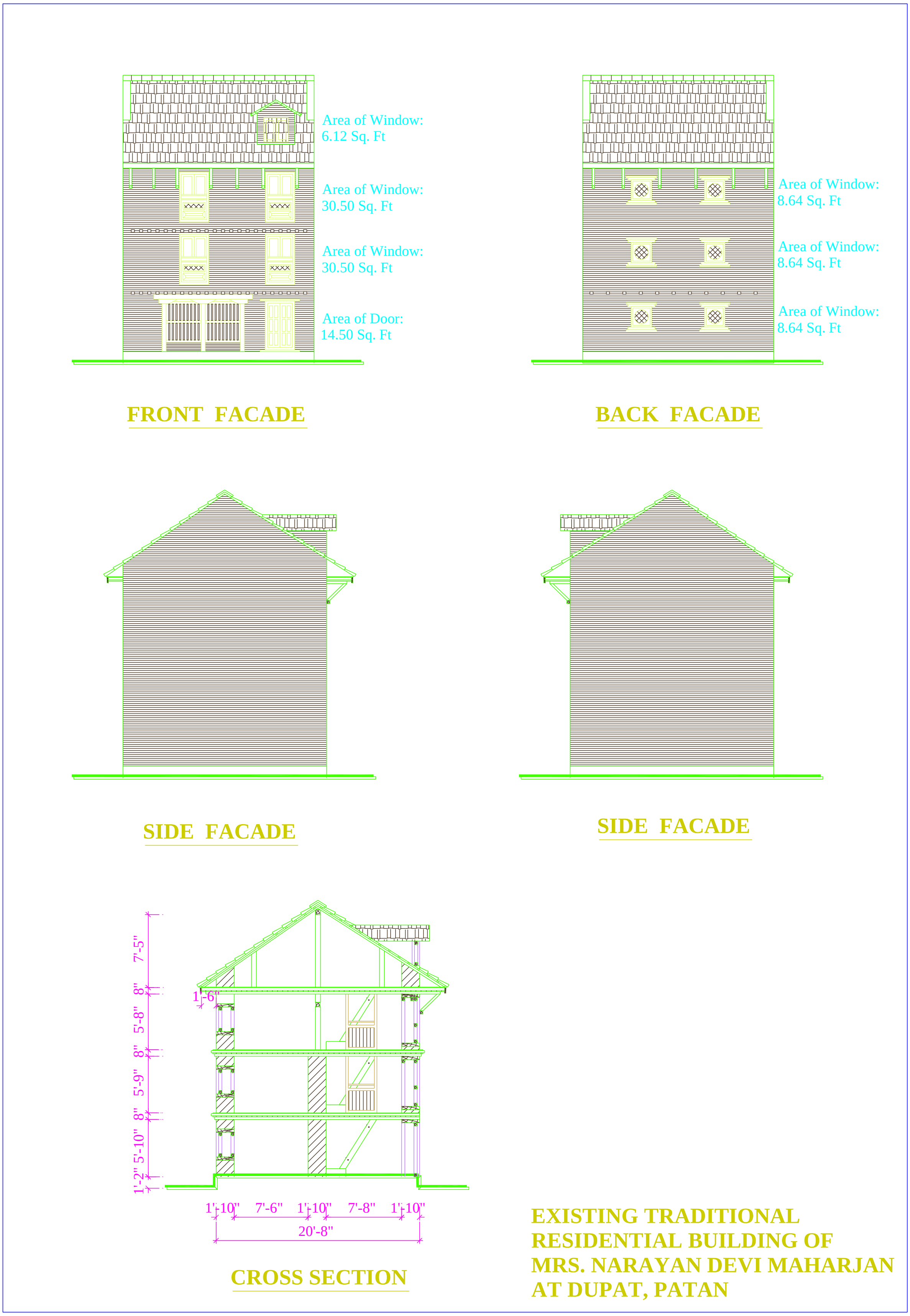

CROSS SECTION

EXISTING TRADITIONAL
RESIDENTIAL BUILDING
OF MR. SANJAY MAHARJAN
AT SUBAHAL, PATAN

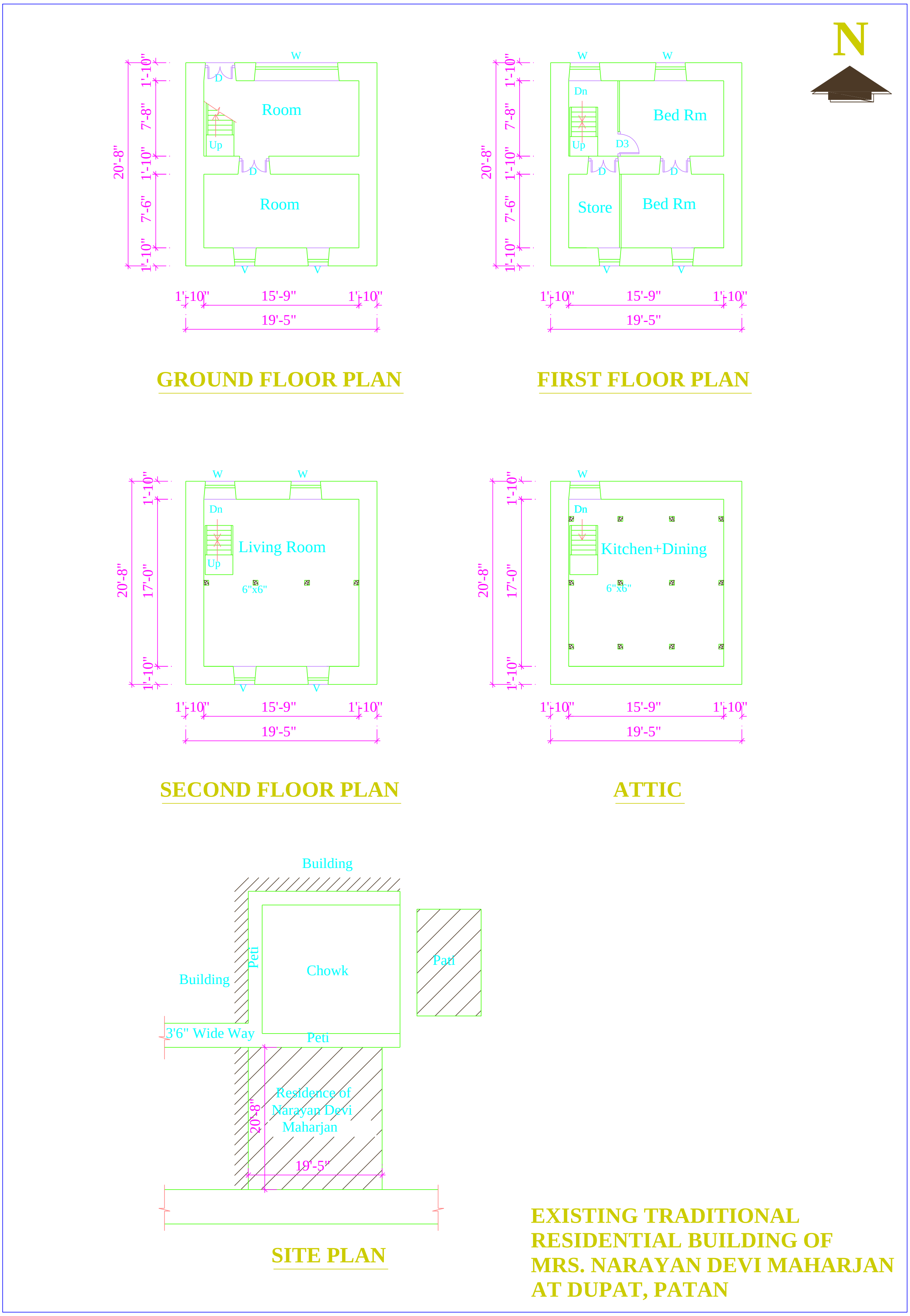
c.) Drawings of investigated residential building No.3



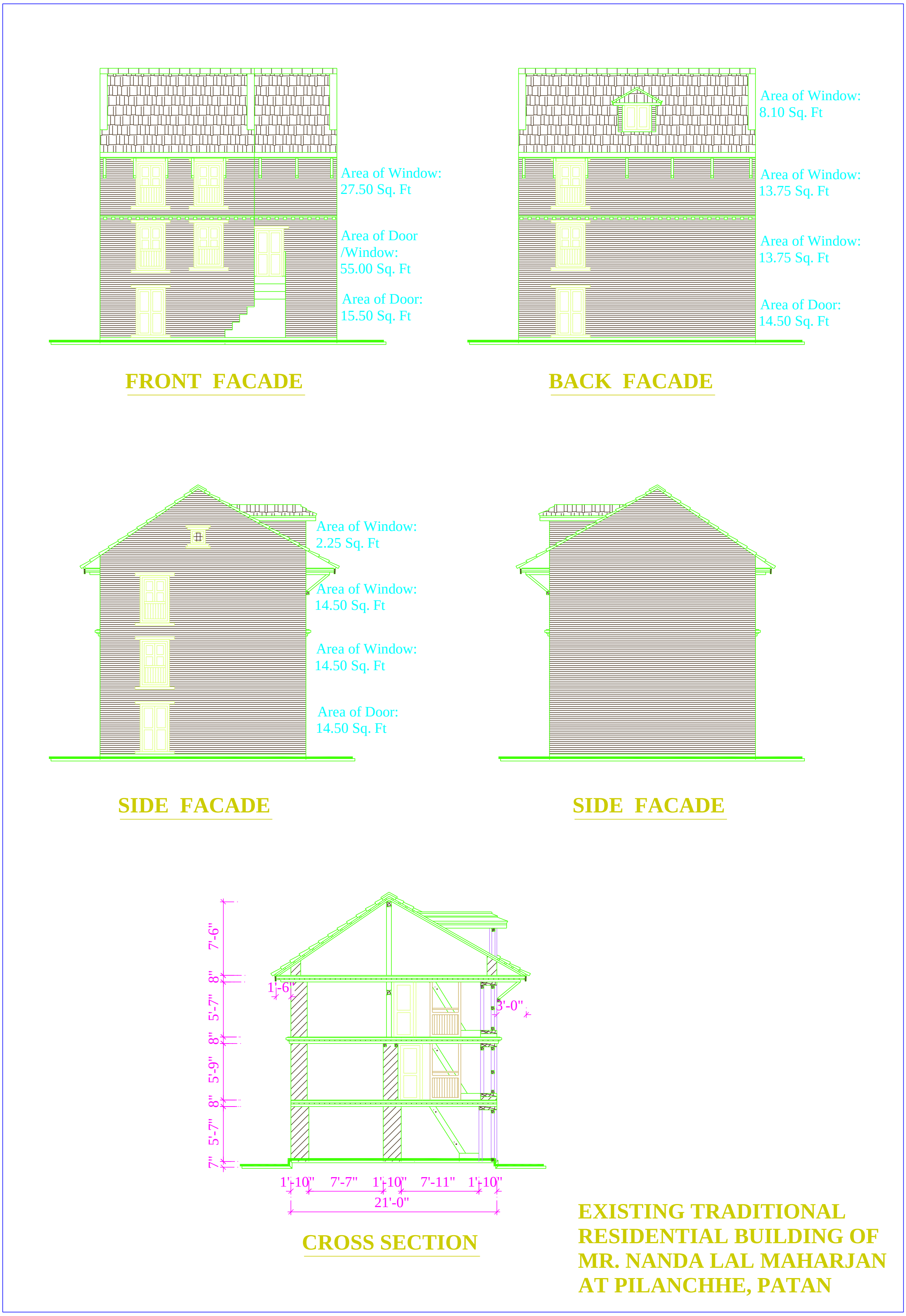
## d.) Drawings of investigated residential building No.4



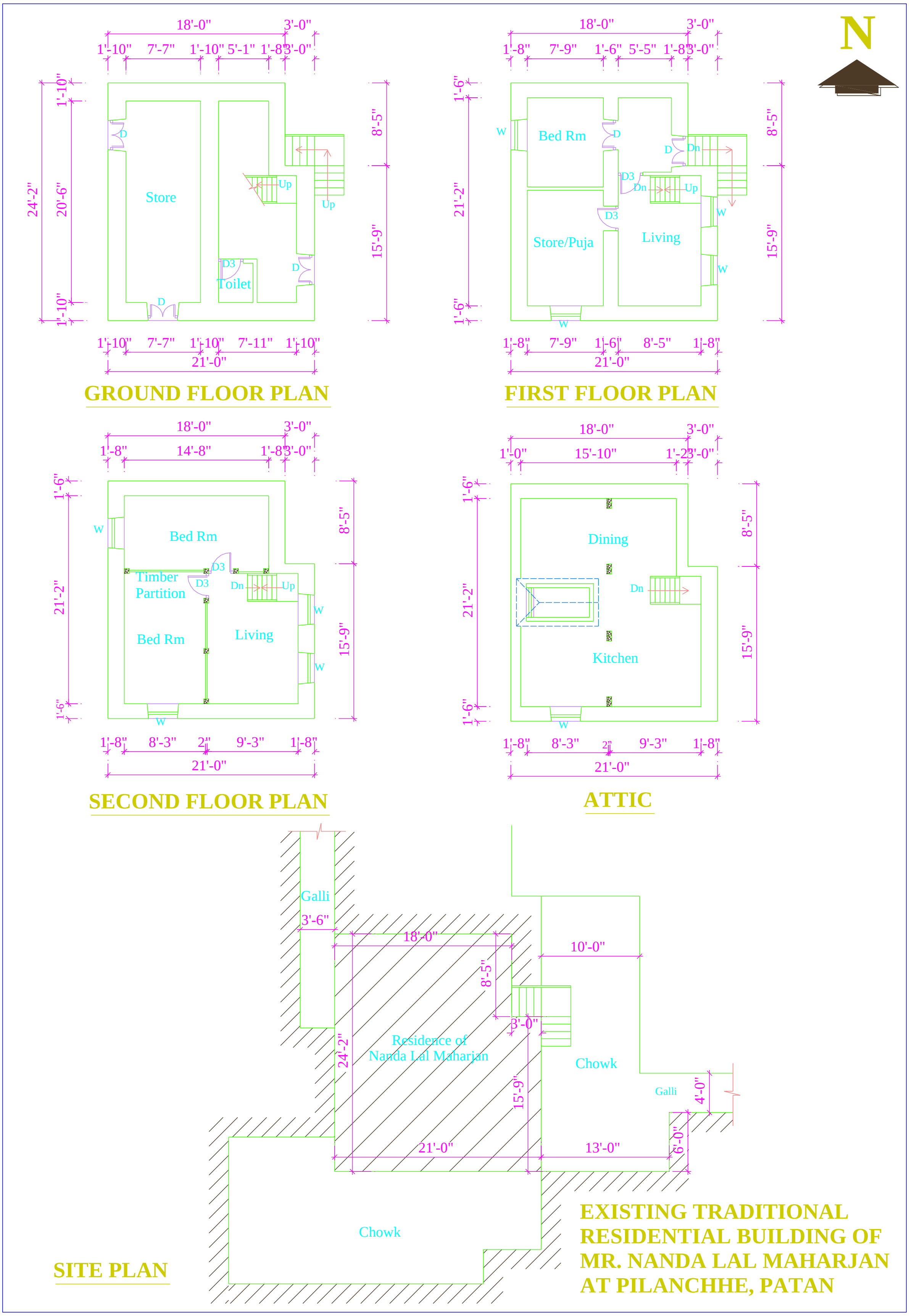
## d.) Drawings of investigated residential building No.4



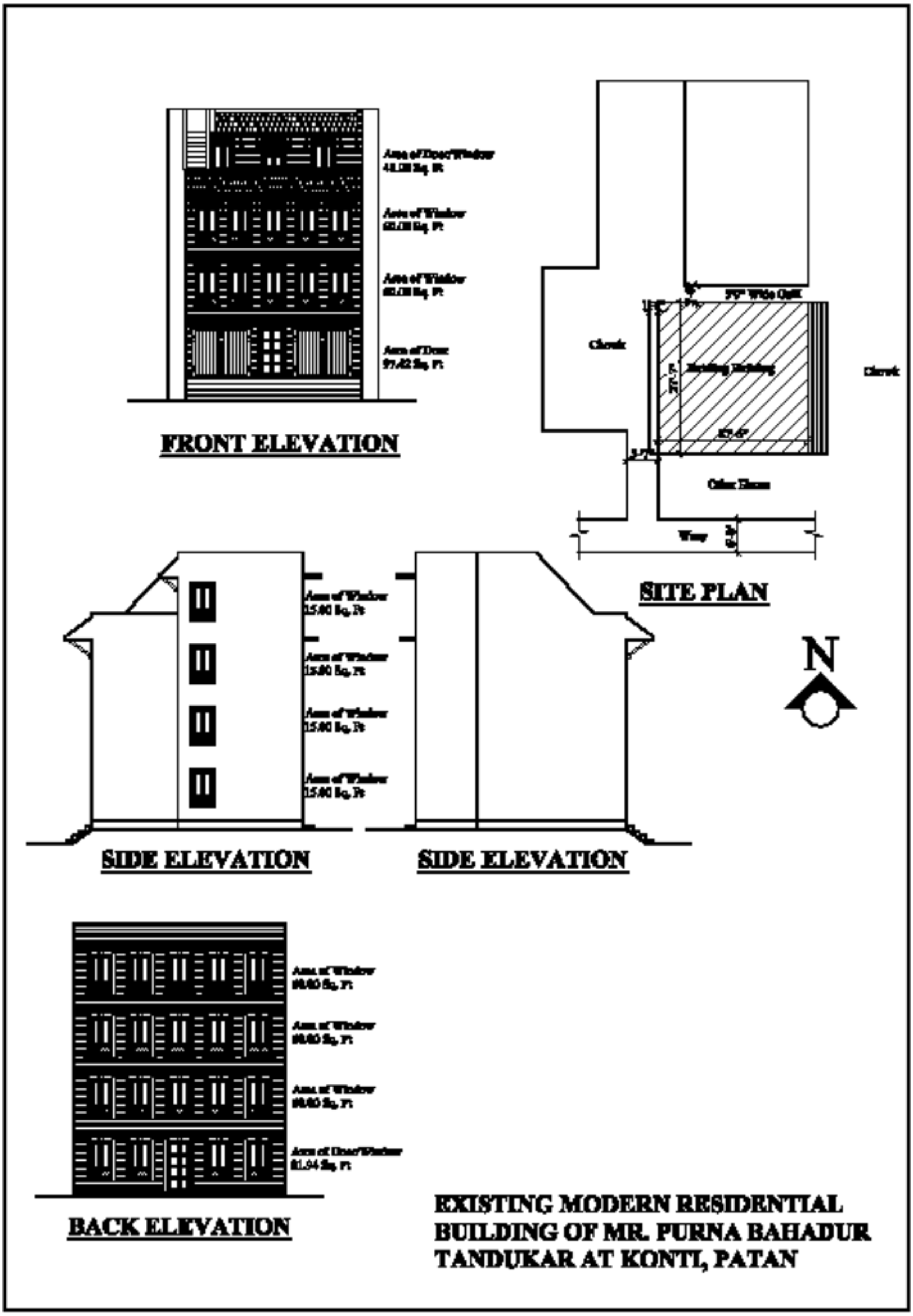
## e.) Drawings of investigated residential building No.5



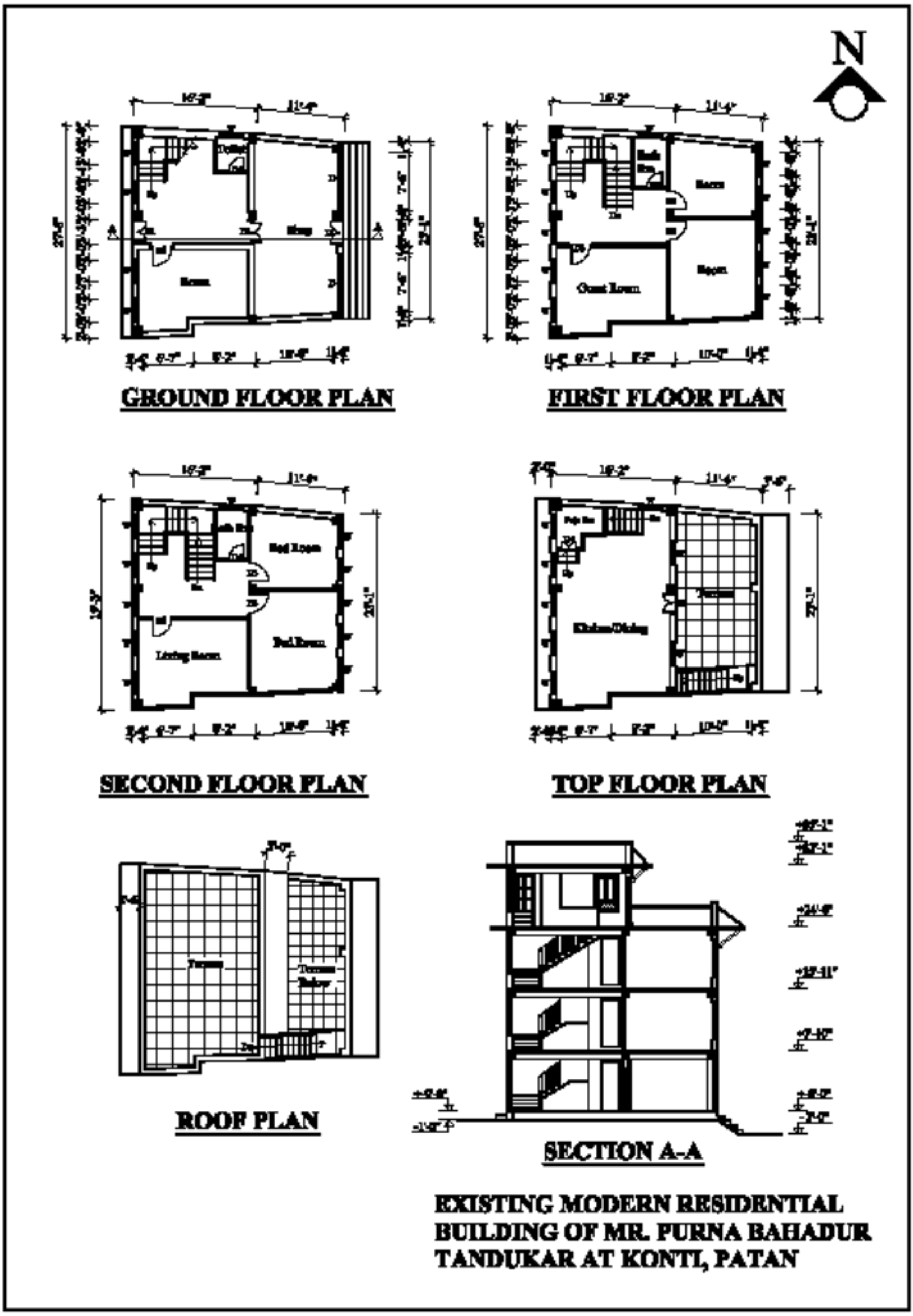
## e.) Drawings of investigated residential building No.5



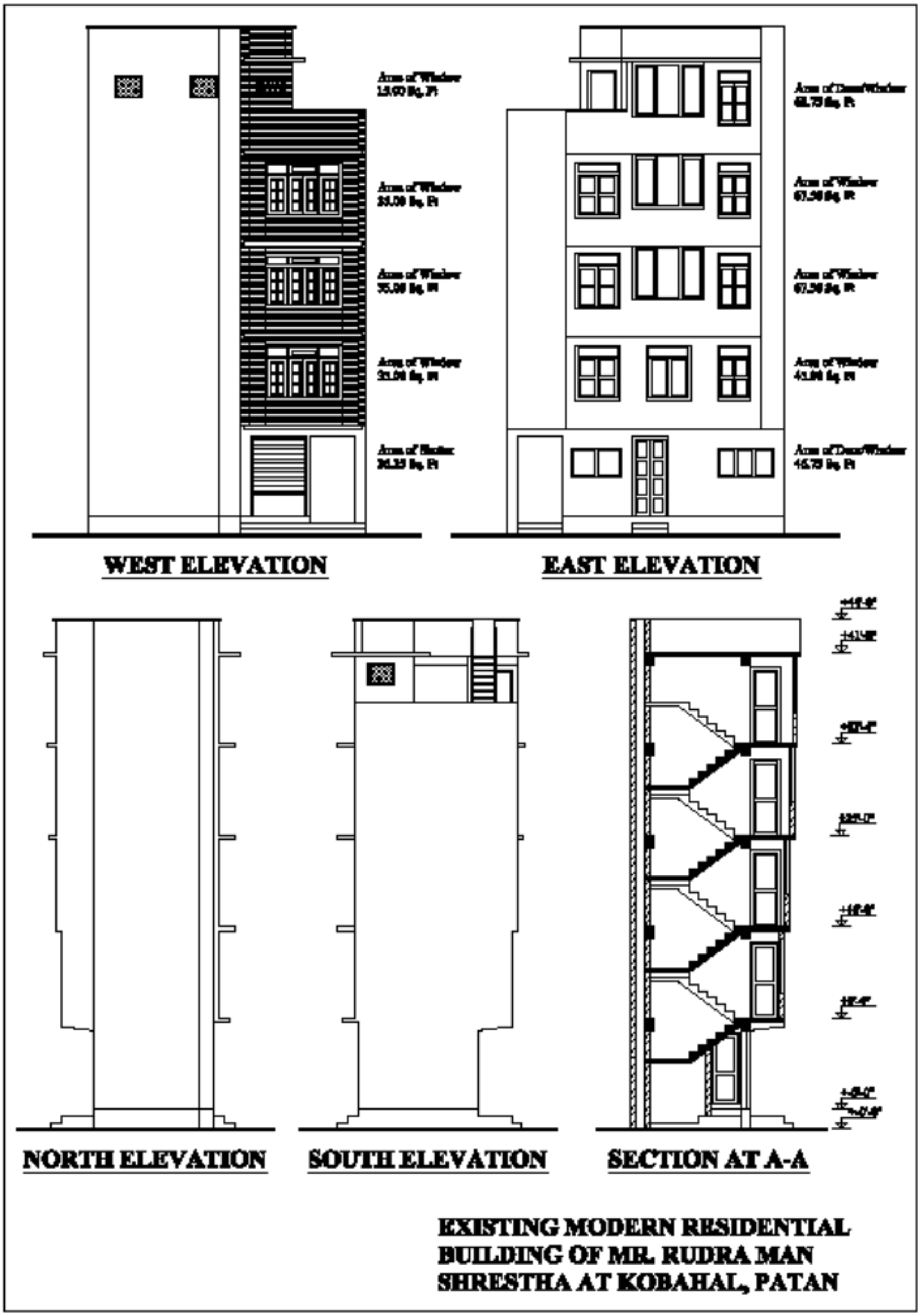
## f.) Drawings of investigated residential building No.6



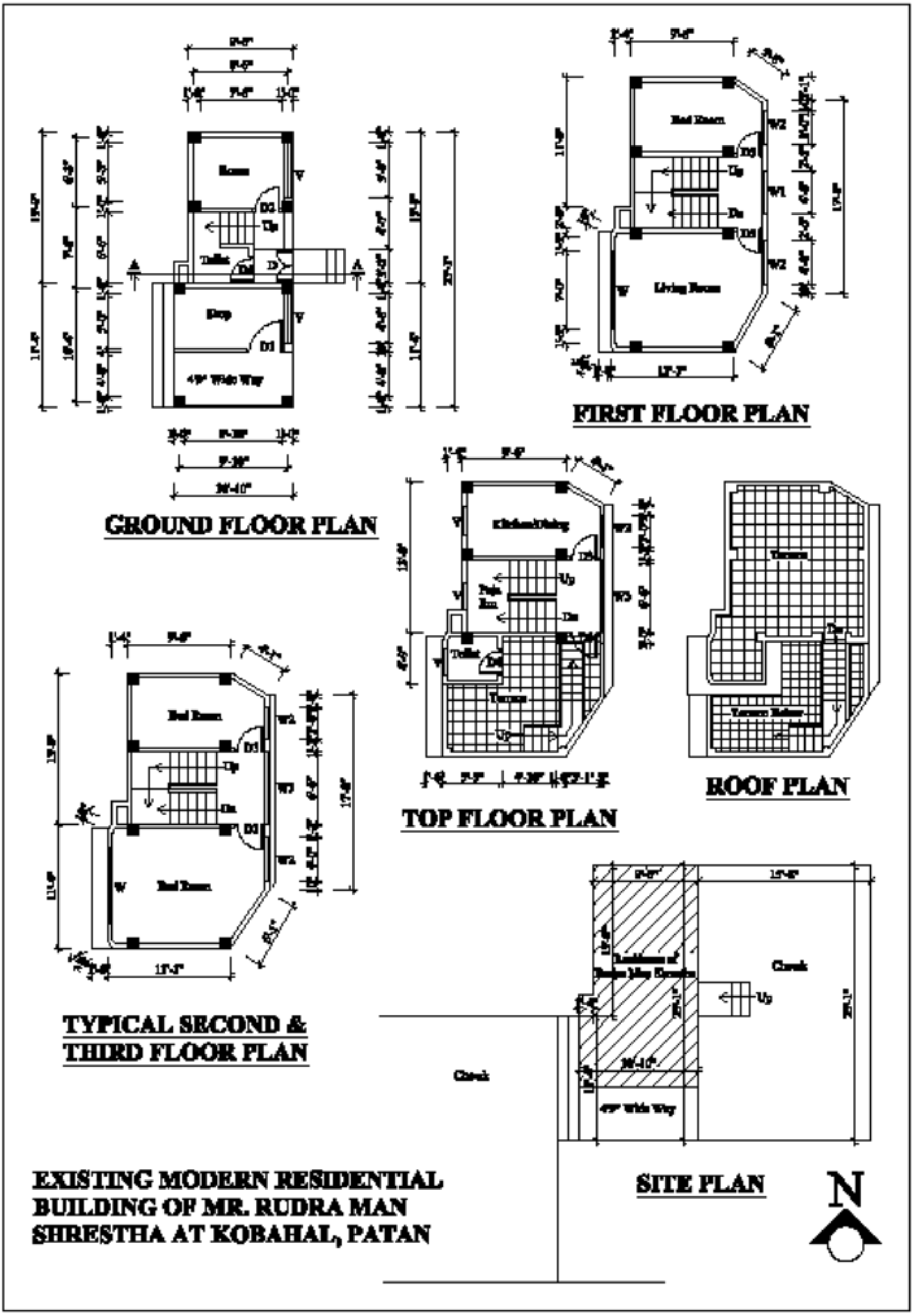
## f.) Drawings of investigated residential building No.6



**g.) Drawings of investigated residential building No.7**



## g.) Drawings of investigated residential building No.7



**APPENDIX 5: Photographs of different activities related to research works**

Photo: A guest lecture in Tokyo City University, Yokohama, Japan in November 2012


Photo: A research paper presentation in international conference RETRUD – 011 in Kathmandu in November 2011

Photo: A research paper presentation in a conference Towards Green Building in Kathmandu in October 2011


Photo: A research paper presentation in a international conference TRADITIONAL SETTLEMENTS AND HOUSING under THUNDER in Kathmandu in October 2009

***THE END***