A SUSTAINABLE HOUSING APPROACH TO KATHMANDU, NEPAL

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To all children who will someday come to this world to live as I

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LIST OF ABBREVIATIONS

BCM	Billion Cubic Meter
CBS	Central Bureau of Statistics
CFC	Chlorofluorocarbon
COP	Coefficient Of Performance
DBT	Dry Bulb Temperature
EERE	Energy Efficiency and Renewable Energy
ET	Effective Temperature
GDP	Gross Domestic Product
GNP	Gross National Product
HVAC	Heating Ventilation and Air Conditioning
ICIMOD	International Center for Integrated Mountain Development
NEA	Nepal Electricity Authority
RH	Relative Humidity
SWERA	Solar and Wind Energy Resource Assessment
WBT	Wet Bulb Temperature

Abstract of Thesis Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements
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Climate change, environmental degradation and resource depletion are not only the problems of any one country or a region but are global issues. The 1987 World Commission on Sustainable Development declared that our future depends upon sustainable development which can be obtained only if more concern is given to energy, environment and our future. Housing, being one of the major parts of built environment, is internationally getting main theme of sustainability for all housing strategies to be sustainable.

The strategies for sustainable housing in developed and developing nations are different. Rather they are relatively newer concepts in developing nations. Human settlement and urbanization are being developed without any concern to environment, energy, and human health. Sustainable planning, design and construction strategies are slowly being primary concerns in these nations. This research is intended to reflect the current scenario of housing in Kathmandu, Nepal and propose energy efficient and sustainable housing. For this, a case of a housing proposal is selected and passive design strategies and energy efficient construction are applied to one of the housing

unit. The results for energy consumption are then compared to the original designs. Similarly, rain water harvesting is proposed for water management.

CHAPTER 1
INTRODUCTION

About 40% of the energy is consumed by the buildings worldwide (Eicker, 2009). This statistic emphasizes the importance of energy efficient and sustainable buildings. An energy efficient and sustainable housing refers to the design of housing which reduces the total energy consumption, uses renewable energy and locally available resources and technology. Developed nations have already started sustainable housing construction whereas in developing nations, sustainable housing is not getting enough emphasis. In this research, the current scenario of housing in Kathmandu is studied and a housing unit is considered as a reference case for analysis. A proposal is given for the energy efficient and sustainable housing unit. The proposed design is focused on passive design strategies, use of available resources and technology, and renewable energy. In addition, rain water harvesting is proposed as water management within the housing unit.

1.1 Background

For the last few hundred years, especially after the industrial revolution, human population has increased tremendously. Population growth has resulted in an increase of the built environment, resource consumption, energy use, waste disposal, and other interventions in the natural environment. Environmental degradation, resource depletion and deterioration of quality of life are no longer new phenomena. The reserves of fossil fuels are being consumed at a rate of two million times faster than their formation process (Daniels, 1994). This scenario of energy consumption and environmental degradation is getting worse everyday and in a non-linear fashion. The two major threats from these issues to our environment are global warming and ozone depletion.

The industrial revolution and technological advancement have dramatically changed human life. Human beings are consuming energy and resources in the form of fossil fuel combustion, burning biomass etc. The end product of all of such methods of energy consumption is carbon dioxide. In addition to this, industries and the built environment are producing greenhouse gases such as methane, nitrous oxide, water vapor etc. These greenhouse gases trap infrared radiation emitted by the sun and prevent re-radiation from the surface of the earth, resulting in an increase of the temperature of the atmosphere. This increase in temperature, commonly known as global warming, has very wide impact on the environment such as rising of sea levels, coastlines, violent storms, melting glaciers, intensity of precipitation, agriculture, forestry, and wild life. The consequences of such environmental destruction and ecological imbalance created by global warming could be the displacement of people, the occurrence of more and severe natural disasters, impact on food supplies, reduction of bio-diversity, and degradation of the average quality of life.

Among the greenhouse gases, carbon dioxide is a major contributor to the greenhouse effect. So the reduction of carbon dioxide is the primary goal of tackling the global warming problem. The major cause of carbon dioxide emission is the consumption of fossil fuel. So, one approach to reduce global warming is to switch from fossil fuel to natural gas and to achieve a higher efficiency in the transformation and utilization of energy. Similarly, another approach might be to switch from fossil fuel consumption to renewable and emission free energy resources, such as solar energy, geothermal energy, wind energy, hydroelectric energy etc. (Daniels, 1994).

There is a protecting layer in the stratosphere (the layer of atmospheric air between 10 to 25 miles) above the surface of the earth which is known as the ozone layer. This layer serves to attenuate harmful ultraviolet radiation to the earth. Certain chemicals such as CFC (chlorofluorocarbon) which are used as a refrigerant in refrigerators and air conditioners, halons used for fire suppression etc. are thinning the layer of ozone. In addition, CFCs in combination with carbon dioxide further enhances greenhouse effect. So the simple solution of the ozone depletion problem is the reduction of CFC and other ozone depleting compounds.

The global concern about the energy consumption and environmental threatening started after the fuel crisis of 1970s. As stated earlier, buildings account for about 40% of the energy consumed worldwide (Eicker, 2009). Among the buildings, residential sector consume significant portion of the energy used. In the present context, the main source of energy for residential sector is electricity, fossil fuel consumption, and burning of biomass. Reducing energy consumption in residential buildings can significantly reduce the global energy consumption. This can be achieved with the climate responsive design of residences and use of appropriate energy technology.

In the same way, another resource that is getting global importance is water. Scarcity of water has started in many countries, especially in the third world. Everyday, people are dying of poor drinking water. Sources of water are being polluted by industrial byproducts, human generated waste and agricultural toxins. So, the water use can also be reduced by the appropriate technology for recycling water and use of water efficient fixtures.

1.2 Statement of Problem

For the past few decades, Nepal has been facing an energy shortage. There is a regular power cut off of five to fifteen hours depending upon the season. There has not been any step taken to solve the problems of power shortage by both private and government sector. Thus people living in the city cannot use any electrical appliances, computers, television etc. which are now considered as basic needs of urban dwellers. On the other hand, land value has increased tenfold in the last twenty years. People are living in a very compact urban area where buildings barely get direct sunlight. The houses are built of material that has high thermal transmittance and with very thin external walls. Similarly, the existing supply of drinking water to the inhabitants of Kathmandu is not sufficient. These are making the houses more inhabitable and people are compromising with comfort living even though they are paying high prices for their dwellings.

1.3 Research Objectives

The primary objective of the research is to investigate the major issues of thermal comfort in the housings of Kathmandu valley and propose energy efficient building design. Similarly, the research has the secondary objective which is to propose a solution for water management in a housing unit in brief. The research is intended:

a. To investigate the thermal performance of the residential houses that are currently being built
b. To calculate the energy consumption of those residential houses
c. To modify the design of house with the integration of passive solar design strategies
d. To find out how much energy is reduced in the proposed house

e. To provide solution for water management

1.4 Significance of Research

Until recently, there has not been much research done to see how much energy can be reduced by the passive solar housing design in the residential sector of the Kathmandu valley. So the owners or builders are skeptical in constructing sustainable housing due to unfamiliarity of its performance. This research gives a comparative analysis of energy consumption between existing non-passive solar housing and proposed passive solar housing.

1.5 Research Hypothesis

The study of climatic analysis of Kathmandu, vernacular architecture, modern residential construction and the theories of passive design can help in designing a building that has a comfortable living environment and is energy efficient and sustainable.

1.6 Scope and Limitations of Research

The research is based on the literature study and data that are available from online sources. In the climatic study, some of the data used are of secondary sources. The housing that is taken as reference for analysis is a design proposal for the housing project in Kathmandu which is the research region of this project. The scope of study is to analyze one of the housing units of the entire housing complex and propose a design solution for that unit.

This research has the following limitations:

a. The research is limited to one of the units of the entire housing complex and is not focused on the planning level of sustainable housing.

b. The research is limited to only the design of sustainable housing and not the life cycle analysis of building and cost.

1.7 Summary

Resource depletion due to built environment is getting attention all over the world. Urban areas of Nepal are also facing the problem of resource shortage. This research addresses basically four different resources that are directly associated with the housing settlement: energy, land, material and water. A passive solar housing is designed and compared with a reference case of current housing design for its energy demand. The research draws a conclusion of the amount of energy use that can be reduced with the design of passive solar houses. Similarly, a renewable alternate energy and rain water harvesting are proposed as a sustainable solution of resource consumption in housing. The research is limited to one unit of housing and not an entire planning and cost analysis. It is expected that this research gives an idea of sustainable housing and its performance to the designers, owners and builders in the case of Kathmandu, Nepal.

CHAPTER 2
LITERATURE REVIEW

2.1 Historical Background of Sustainable Construction

The history of sustainable development traces back to the 5th of June, 1972, in Stockholm, Sweden, when 113 nations attended the United Nations Conference on the Human Environment for the discussion on the issues of climate change, population growth, and socio-economic development. The conference threw light on the equal opportunity of all the people to secure a good quality of life in the present as well as for the future (UN Stockholm Declaration 1972).

In 1983, the United Nations set up a commission, headed by Norwegian Prime Minister, Gro Harlem Brundtland, to look at both environmental and economic issues of the world. The commission published the final report known as "Our Common Future" in 1987, which emphasized international governments to look at reducing the effects of human activities on the environment for future generations and called it "Sustainable Development". Brundtland's definition of sustainable development in his own words is "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UNCED, 1987).

From June 3 to 14, 1993, two decades after Stockholm Declaration, the United Nations met for the Conference on Environment and Development (UNCED) and held the "Earth Summit", in Rio de Janeiro, to debate on the issues of environmental protection, economic development and social equality. This summit made an important agreement called Agenda 21, which committed international governments, the United Nations Systems, and other Major Groups, to look at ways for better life for all the people. It is a plan for sustainable development in the 21st century with an aim to provide a healthy life, good quality environment, and a healthy economy for all the people in the world. It is a guideline for governments, entrepreneurs, organizations, and individuals for making decision for development that help economic and environmental issues of our society.

2.2 Sustainability and the Built Environment

The scope of sustainable development covers three dimensions of development: social, economic and environmental (UNCED, 1987). The built environment, one of the major parts of human civilization, is affected by all these three dimensions of sustainable development. Built environment consists of people and infrastructures in a fixed location on the earth. People are associated with the infrastructure to perform their economic or social activity. So, the environment is affected by the consumption of energy and resources and generation of waste. As such, creating a sustainable built environment is a part of sustainable development.

The ability to meet basic human needs is related to the human settlement and their performance (Agenda 21, 2002). In 1996, another international plan was published which is known as Habitat Agenda. Habitat Agenda is basically focused on the role of human settlement in sustainable development. The built environment, especially the construction sector, has a major role in sustainable development of human settlement as construction industry uses substantial amount of global resources and is also responsible for waste emissions (Agenda 21, 2002).

The socio-economic structure, education and skill, available resources, technological advancement, cultural values, issues of development and their priorities in developing nations and developed nations differ significantly. These nations require a different approach of creating a sustainable environment. Therefore a special Agenda 21 for *Sustainable Construction in Developing Countries* was commissioned as a part of Agenda 21 (Agenda 21, 2002).

2.3 Sustainable Construction: Principles and Practices

Kibert (1994), in the proceedings of the first international conference of CIB, has proposed six principles of sustainable construction- conserve, reuse, recycle, protect nature, non-toxics and quality. These principles of sustainable construction are discussed as below:

Conserve. Excessive resource consumption is one of the major issues of the modern civilization. The very first principle of conservation focuses on reducing the overconsumption of resources and energy. It recommends the use of passive strategies in the design of buildings, highly efficient system of operation and maintenance and durable construction material.

Reuse. Reusing of resources that have already been extracted can significantly reduce the energy or resource consumption for extraction of new resources or recycling of the existing resources. Good examples can be the reuse of gray water for landscaping and reusing concrete as a base for road construction.

Recycle/Renewable. The third principle proposed by Kibert is renewing or recycling previously used resources. Sometimes those resources that cannot be reused can be recycled e.g. steel, aluminum, and glass etc. of demolished building. Renewable resources include solar, wind power, biomass etc.

Protect Nature. The human intervention in nature has created many problems such as pollution of water sources and agricultural land, deforestation, shortage of fossil fuel etc. So this principle basically focuses on minimizing human intervention on nature and protecting natural environment not just to sustain but also to restore the degraded environment.

Non Toxics. All toxic materials like lead, mercury, asbestos and dioxins must be eliminated and if not handled with care. Recently, such materials after its life cycle are being returned to manufacturer for reuse or recycling. A good example of reducing toxics may be xeriscaping to minimize application of pesticides, herbicides, fungicides and fertilizers that ultimately end up polluting ground water.

Quality. Quality in sustainable construction implies to planning and designing built environment so as to develop a human settlement that uses less energy and resources such as automobile trips, increase interpersonal activity, promote passive thermal measures of comfort etc. This principle also focuses on creating good quality indoor and outdoor environment by the appropriate resources, design, technology and appliances.

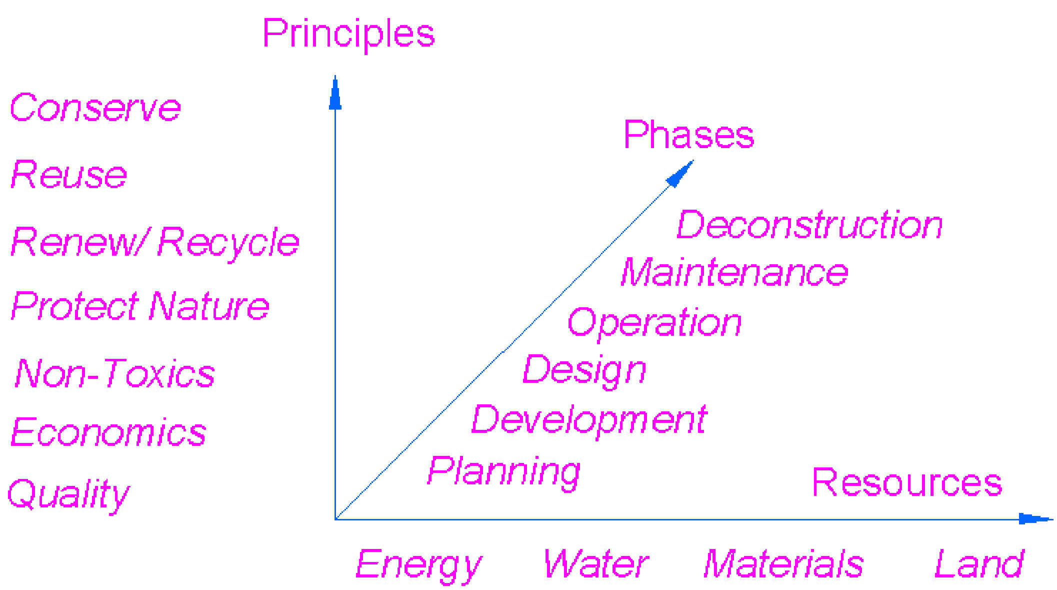


Figure 2-1. Conceptual Model for Sustainable Construction (Source: Kibert, 2004)

In the same proceedings, Kibert (1994) has also developed a conceptual model for sustainable construction which consists of three axes of principles, resources and time of construction. The intersection of the three axes is a decision point for determining what should be accomplished with regard to minimizing the resource consumption and preventing environmental damage. This model depicts the overall idea of sustainable construction, facilitates the decision making process during any time and serves as a checklist for sustainability issues of the construction (Kibert, 1994).

2.4 Resources for Sustainable Construction

2.4.1 Energy

For the last few hundred years, especially after the industrial revolution, energy consumption has increased tremendously. As stated in Chapter 1, human beings are consuming reserves of fossil fuels at a rate two million times faster than their formation process (Daniels, 1994). Energy consumption is increasing everyday and in a non-linear fashion. After the oil crisis of 1970s there has been global concern about energy use, particularly in shifting from non-renewable energy to renewable energy use.

Energy is consumed in different sectors such as transportation, industries, buildings and others. Buildings account for about 40% of the total energy consumed worldwide (Eicker, 2009). As such much attention is being given in conserving energy in planning and designing energy efficient buildings. Energy is required in buildings for heating and cooling of house and running electrical appliances.

Various climatic factors such as temperature, humidity, solar radiation, precipitation, wind speed, wind direction and rainfall affects on human comfort. To adjust to the extremes of climatic factors, human use different technologies to heat, cool, light and ventilate their built environment and make their living conditions suit their physical comfort. For this they require a significant amount of energy. Thus, to conserve and reduce energy use in buildings is one of principles of sustainable construction. There are basically two methods of reducing energy through design and operation: passive and active methods.

2.4.1.1 Passive method

It is well known that the solar energy is the ultimate source of energy. Trapping solar radiation for building heating and other household energy can significantly reduce the energy bill of a house. Solar energy can be utilized using passive solar design or active solar devices. Passive solar design is the design of building which operate without mechanical assistance or with very little. In this, the building by itself or sometimes external elements such as other buildings or structures, trees and water bodies are used to control the thermal environment within the building. The main objective of passive solar design is to use natural resources such as solar energy, wind, water and earth as thermal, lighting and air control elements.

Passive Heating. Balcomb et al. (1979) say: “To the extent that the thermal energy balance is wholly by natural means, such as radiation, conduction, or natural convection and solar energy contributes a significant portion of the total energy requirements, about more than one-half, then the building can be called as passive solar-heated structure.” To design a passive solar home, it is necessary to understand the passive heating system elements. For passive solar heating, U.S. Department of Housing and Urban Development (1981) identifies passive system elements as collector, absorber, storage, distribution and control or heat regulation device.

Collector. Collector is the glazing through which solar radiation enters inside the house. The solar collector should face 30 degrees of true south in order to get maximum radiation. It should not be blocked or shaded during 9 a.m. to 3 p.m. during the period when solar radiation is required to heat the house. Area of collector depends upon the amount of heat needed to maintain thermal balance.

Absorber. Absorber is the dark and solid surface of the storage elements. This could be wall, floor or partitions. Its main function is to absorb solar radiation.

Storage. Storage is the main thermal mass of the house. It could be an external wall, floor, partitions or water filled containers. Absorber mainly absorbs solar radiation during the day and storage stores the heat and reradiates during the night.

Distribution. Distribution is the process by which heat is dissipated to interior. Distribution can be through conduction, convection or radiation.

Control or Heat Regulation Device. This is the device that controls the overheating, under-heating or heat loss through the building. This can be movable insulation, electronic sensing devices, operable ventilations, shading devices or overhangs etc.

All these elements of passive solar design can be designed for three basic approaches to heat gain which are direct gain, indirect gain and isolated gain ((U.S. Department of Housing and Urban Development, 1981), They are discussed below:

Direct Gain. Direct gain is one of the popular and simple approaches of passive solar heating. In this, the solar radiation is trapped through large a south-facing glazing. The heat is absorbed and stored by thermal mass such as concrete floor, thick masonry walls or ceiling with exterior insulation. Basically building thermal mass acts like solar collector and also helps to warm air which can be circulated to other cold parts of house through convective heating. The other advantages of direct gain can be natural lighting and view. Sometimes direct gain can overheat the space especially during summer days. In this period other passive strategies can be designed to block solar radiation such as overhangs, shading devices, plantation etc.

Indirect Gain. In the indirect gain of solar heating approach, there is a thermal mass in between south-facing glazing and the main living space which absorbs and stores the radiation. Trombe wall is a good example of indirect gain. Trombe wall is a thick wall of concrete, masonry that separates living space and glazing and also absorbs and stores radiation. This stored heat is reradiated to the living space during nights. Trombe wall can also have vents in the bottom and the top which helps in creating convective heat flow. The thermal mass is painted with dark colors so as to absorb maximum solar radiation.

Isolated Gain. Isolated gain, or more specifically a green house, is basically a combined effect of direct-gain and storage-wall systems. It is the process of heating by the use of a greenhouse effect or atrium space. Using this approach, the thermal mass of the greenhouse is heated during the day and reradiates during the nights. It also heats the air which by convection heats the other areas of the house as well. Besides heating, it also serves as buffer zone between the main living space and outdoor, thereby reducing heat loss.

Passive Cooling. Passive cooling is the method of cooling house using building design, layout, and natural cooling effects. Passive cooling can be achieved through various approaches such as shading, ventilation and insulation.

Shading. Solar gain can be controlled effectively using shading devices. In temperate climate, the winter sun is favorable while summer sun is not. Solar altitude angle in summer is larger, about 70° to 90° while in winter it is about 35° to 45° depending upon the latitude of a place.

Ventilation. Ventilation is the process of cooling the building interior with the help of external wind and proper design of openings in the building. The performance of cross ventilation, ventilation on the two opposite sides or two adjacent sides, is the result of size and position of openings. Various studies have shown that if the outlet is slightly bigger than inlet, the ventilation effects can be achieved better (Achard and Gicquel, 1986). Likewise, Achard and Gicquel say that if the wind direction is perpendicular to the inlet, the outlet must be created in the adjacent wall whereas if the wind is in certain angle to the inlet, say about 45 degrees, then the outlet must be created in the opposite wall for better circulation of air inside the room. In the same way, if the openings are in the corner, then the air flows along the wall which is called the "wall jet" effect.

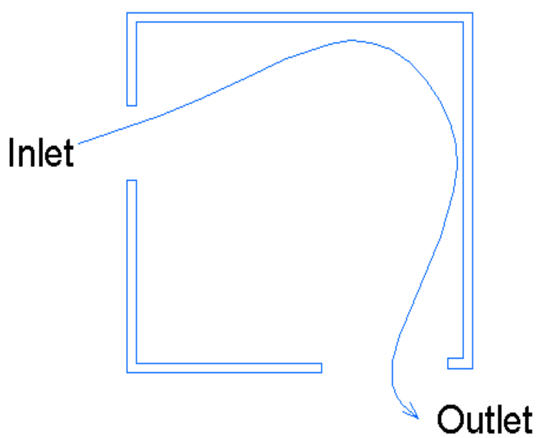


Figure 2-2. Floor Plan Showing Wall Jet Effect with Smaller Inlet and Larger Outlet

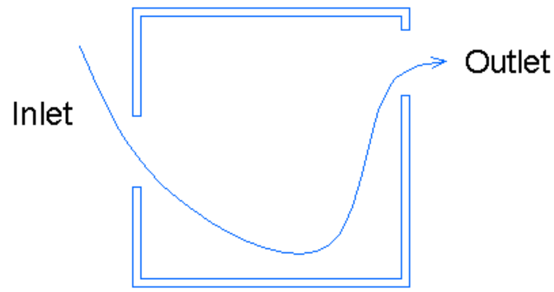


Figure 2-3. Floor Plan Showing Opposite Openings for Angular Wind

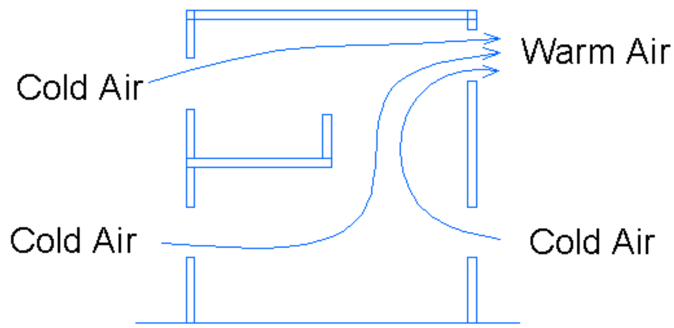


Figure 2-4. Vertical Section Showing Stack Effect

Stack effect is another method of ventilating the warm air inside a building. When the air gets heated, its density decreases and rises creating a convective loop of air cold and warm air flow. This is shown in the Figure 2-4.

Insulation. Insulation is the layer of material or sheet that is used to control transfer of heat or cold through a surface. Insulating material has to have low thermal transmittance (U-value) which decreases thermal transmittance. Insulating is more effective when it is placed on warmer or colder side rather than the side where comfort temperature is required. Insulating can be of two basic types: fixed and movable insulation.

Fixed Insulation. Fixed insulation is constructed permanently and on the exterior surface of the building. Fixed insulation prevents the heat absorbed and stored at the interior surface e.g. a direct gain floor or wall from being lost to the external air in winter (Steve Winter Associates, 1998). Good examples of fixed type of insulation may be cellulose, polystyrene, fiberglass, cotton insulation etc.

Movable Insulation. Movable insulation is the insulation that is not permanent and can be moved or removed when desired. Such types of insulation are generally used in collectors like windows and are operated periodically to reduce nighttime and cloudy-day loss and daytime heat gain (Steve Winter Associates, 1998). It can be curtains, drapes, shades, rigid panels, shutters etc. Movable insulation can be installed on the exterior or on interior surface depending upon the type of insulation and the amount of thermal control required. The side of insulation facing the exterior surface should be light colored so that it reflects the radiation and does not allow the air between collector and insulation to be heated rapidly.

2.4.1.2 Active method

Active method of design for energy efficiency is the method which involves mechanical devices for balancing the thermal comfort and other energy use. There are various active methods of renewable energy technologies such as hydroelectric power, geothermal energy, nuclear energy, wind energy and solar energy.

Hydropower. Hydropower is the energy generated from the current of moving water. Hydropower is a renewable energy as the water used to generate energy can be replenished by precipitation. As hydropower does not produce carbon dioxide or any harmful emissions, it is considered as one of the best sources of renewable energy. It is also cheapest form of energy as once the power plant is installed, the water is free and it can run for a very long period of time with little maintenance

Biomass. Biomass is the conversion of organic matter into energy (ASHRAE, 2006). It is basically plants that are grown to produce energy, especially heat energy. Forest residues, yard garbage, pallet burners, wood chips and other plants and animals can be used for biomass. Wood is one of the largest biomass energy sources. In Kathmandu, wood is not easily available and it is very expensive to produce energy from wood.

Wind Energy. Wind energy is the conversion of kinetic energy of wind mass to electrical energy. Wind mass blowing in high speed has large amount of kinetic energy which with the use of turbine can be converted to electrical energy. This is particularly good where there is enough wind round the year. In the context of Kathmandu, wind speed average is 2 m/s. So it may not be appropriate for generating wind energy.

Solar Energy. Solar energy is the primary source of energy that supplies heat energy, light energy, ocean currents, and other alternate sources of energy (ASHRAE, 2006). Photovoltaic (PV) energy is one form of energy that is transformed from light energy or the solar radiation into electric energy with the use of PV panels. PV system is a semi-conductor based system. The electric energy converted by PV system is direct current electricity. PV systems contain PV cells in array which trap light energy and converts into direct current. Power conditioner changes direct current into alternate current and battery stores the energy. The number of cells and the number of battery depends upon the energy requirement. The PV system has many different advantages such as that it is stand alone, it has zero emission, environment friendly, takes very little space for installation, is easy to manage, can be used in small residential to large commercial buildings, is cost effective and has been tested over last 40 years for its performance and economy. According to the rule of thumb for PV output, it is about 80% on partly cloudy days, 50% on hazy humid days and 30% on overcast days (Lechner, 2008). In the same way, the cost per watt for PV energy has significantly decreased for the last 30 years and is close to being economical (Lechner, 2008). In the case of Kathmandu, people have been using solar energy for water heating. In the same way, solar PV panels can be used for generating electricity for the household energy consumption.

2.4.2 Water

Due to rapid urbanization, deforestation, pollution of sources, water is becoming an important issue in many cities of the world. In the third world, especially where cities have been developed without any infrastructure planning and management, scarcity of water has been started. For the last few decades, as a temporary remedy, people have used deep ground water source which has already resulted water shortage.

In the household activity, besides drinking, water is used for bathing, flushing toilet, washing, and gardening. Except drinking, water use can be reduced using water efficient fixtures such as low-flow toilets. Using rainwater as much as possible for bathroom and landscape use is the best way to reuse water. In general, rainwater harvesting is cheaper, easy to build and manage for household water use. Similarly, graywater (wastewater from sinks and showers) can be reused for flushing, gardening and other inferior use of water using onsite wastewater treatment such as wetland construction (Yudelson, 2007). Constructed wetlands have advantage of cost effectiveness to build, operate and manage wide varieties of volume of water can be treated.

2.4.3 Materials

Materials in construction are the basic elements that constitute a building. Building materials in the past used to be natural materials such as stone, wood, straw, bamboo, clay etc. As the construction industry became larger, these materials started getting scarce and expensive. So the new building materials, especially manufactured in industry, were seen in the market such glass, concrete, PVC etc. Some of these materials have problems of disposing because of their non-decomposition character, non-renewability and lack of secondary use. So, the concept of reduce, reuse and recycle in the selection of construction material is important.

Wood is only the renewable construction material. But in some cities, especially in the cities of third world, wood may not be readily available because of deforestation. Brick, concrete, concrete block, steel etc can be reused in construction in various ways. Steel, glass, plastics are the construction materials can be recycled. Similarly, construction materials should also be healthy to the occupants and environment friendly. Materials containing asbestos, high VOC content, lead etc. should be avoided as much as possible.

2.5 Summary

Sustainable construction has major role in sustainable development as construction industry uses substantial amount of global resources and is also responsible for waste emissions. Kibert (2004) has developed a model for sustainable construction which emphasizes on conserving, reusing, recycling, protecting nature, using non-toxics, economy and quality of indoor environment for using different resources such as energy, water, land and material at different phases of construction like planning, development, design, operation, maintenance and deconstruction. Energy conservation can be achieved using passive and active method.

Passive Design can be used for both passive heating and cooling. Passive heating of a building can be achieved by various techniques such as direct gain, indirect gain and isolated gain. Likewise, passive cooling can be achieved using shading, ventilation and insulation. In the same way, there are various methods that are developed for energy generation for building and other uses. They are hydropower, biomass, wind energy, solar energy etc. Although Nepal has high potential for hydropower, currently there are not enough hydropower projects that can meet the present energy demand. So, solar energy might be the best alternate in the case of housing energy supply.

Similarly, water is another major resource to be addressed for sustainable housing. Various water efficient fixtures are available for lowering the water use in built environment. Graywater can be reused for other inferior use such as landscaping or flushing toilets etc. Likewise, rain water harvesting is another good option for recycling water being easy in installation, operation and maintenance.

In the same way, land is another resource that has to be addressed while designing sustainable housing. This can be achieved using various strategies such as compact planning, vertical space arrangement, developing Brownfield etc.

Materials should also be selected appropriately for constructing a sustainable housing. Good materials for sustainable housing can be locally available materials which are durable, have good thermal performance to the specific climate and recyclable or reusable after deconstruction.

CHAPTER 3
RESEARCH METHODOLOGY

The research was done based on three major parts: study of literature, study of climate and architecture of Kathmandu and design and analysis of housing case. Recommendations drawn from the climatic and architectural study of Kathmandu are used for the design of proposed housing for the analysis of energy consumption. These three parts of study are divided into six different chapters based upon the area of study and analysis.

The review of literature included the study of the background of sustainable housing, sustainability and the built environment, principles of sustainable construction and resources of sustainable construction. The design strategies for effective use of different resources were also studied.

The next step of the research was the study of research region. The research region was the Kathmandu Valley. Background study of Kathmandu, energy supply and consumption situation and climatic statistics were studied in this chapter. Different online resources were used for the study of this section.

Another part of research was the study of climate of Kathmandu. The climatic data obtained from SWERA (Solar and Wind Energy Resource Assessment) were analyzed using five different climatic analysis tools developed by different scientists: Degree Days, Effective Temperature, Bioclimatic Chart, Psychrometric Chart and Mahoney Tables. Similarly, the next step of the research was to study the architecture of Kathmandu. In this section, the study of design, construction materials and techniques of both vernacular and modern day housing were done. Different research papers, reports and books were used for the study of this section of the research.

Another chapter included the design alternates that were developed for the research region. These design alternates were based on the recommendations from climatic analysis and study of architecture of Kathmandu. The design recommendations for this research were also provided in this chapter. Recommendations drawn by previous researchers were also incorporated in this chapter.

The last part of the research project was the design and analysis of housing case. For the analysis of housing, a housing case of Kathmandu was selected. The housing selected was one of the proposals of housing design for the real project. For the analysis, one of the housing units was selected and studied for energy consumption. Then the housing unit was modified based on the recommendations from the climatic analysis and vernacular architecture of Kathmandu. The proposed design was analyzed for energy consumption and compared with the reference case. Similarly, a solution for water management within the housing unit was also provided in brief. The research framework is outlined in the Table 3-2.

Software Programs. Various software programs were used for calculation and analysis in this research. Those software programs are mentioned in the Table 3-1.

Table 3-1. Software Programs Used for the Research

Software Programs	Use
Design Builder	Calculation of Energy Consumption
AutoCAD	Drawings
Solar Calculator	PV Panels Calculations

Table 3-2. Research Framework

Section	Major Area of Study	Details of Area of Study	Sources
Literature Review	Sustainable Construction	Historical Background Sustainability and the Built Environment Principles of Sustainable Construction Resources of Sustainable Construction	Research Papers Books
Study	Research Region	The Kathmandu Valley Energy Situation Water Climate	Research Reports Various Online Sources
	Climatic Analysis	Effective Temperature Bioclimatic chart Psychrometric Chart Mahoney Tables	Climatic Analysis Tools Developed by Different Scientists and Organizations
	Architecture of Kathmandu	Vernacular Architecture Modern Day Housing	Books Research Documents
Design and Analysis	Reference Case	Design and Analysis	Research
	Proposed Design	Based on Recommendations from climatic study and architecture of Kathmandu	Research
	Proposed Case	Analysis	Research
	Comparison	Comparison Reference and Proposed Cases	Research

CHAPTER 4
RESEARCH REGION: THE KATHMANDU VALLEY

The region for the research for the project is the Kathmandu Valley, capital city of Nepal. Nepal is a landlocked country bordered to the north by People's Republic of China and to the South, East and West by the Republic of India. It is almost rectangle in shape with 800 km by 240 km elongated towards the east and the west and comprises a total of 147,181 sq. km of land. Geographically, it is divided lengthwise into three belts- mountain region in the north, mid hills in the center and lower plain belt in the south.

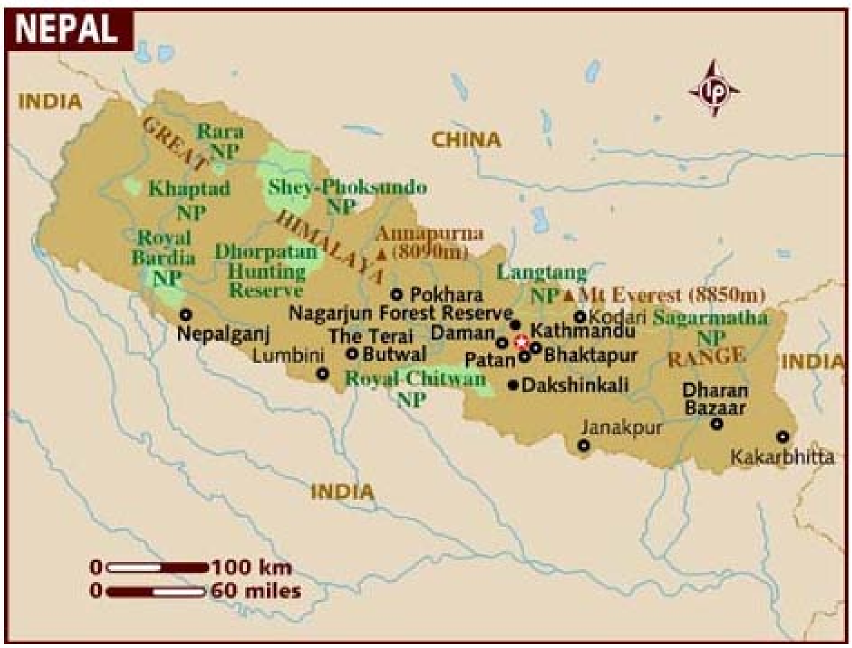


Figure 4-1. Map of Nepal

The northernmost belt is the rugged Himalayas running from the eastern to the western part and is situated at 4000 m or more above sea level. Human habitation and economic activities are very limited in these parts. The central strip comprises of lush green mountains and valleys which is situated between1000 m to 4000 m above sea level. Kathmandu, the capital of Nepal, lies in this region. This region has slightly better economic potential compared to high Himalayan belt, especially in the lower hills of below 2500 m altitude and valleys. On the southernmost part is a belt of lowland fertile plain, called Terai which is about 300 m to 1000 m above sea level and is the extension of Gangetic Plain of India. It also includes several valleys in western and central Nepal. Because of plain fertile land and fed by various rivers from the mountains and hills, the region is well known for its agriculture and forest (Andrea Matles Savada, 1991).

The World Bank defines developing countries as the countries having GNP per capita of less than US $7000. The GNP of Nepal is $268 (as of 2005) and GDP per capita is $1200 (CIA Factbook, 2009) which means it is a developing nation. The total population of Nepal is 28,563,377(CIA Factbook, 2009), population density is 184 people per square kilometers and 15% of them live in urban area. The table below shows some of the statistics on geographical distribution of Nepal.

Table 4-1. Geographical Distribution

Distribution	Statistics
Area	147,200 Sq.Km.
Water	2.8%
Land Under Cultivation	17%
Wild Pasture Land	15%
Forest	26%

(Source: http://www.studentsoftheworld.info/country_information.php?Pays=NEP)

4.1 The Kathmandu Valley

The Kathmandu Valley is located at 27°42' north and 85°22' east and 1337 meters above the sea level. There are three districts in the valley- Kathmandu, Lalitpur and Bhaktapur which are also the major cities of the valley. The area of Kathmandu valley is 665 square kilometers. According to the population census of 2001, the population of Kathmandu valley is 995,966 (CBS, 2001). Since the last fifty years, the population has increased by almost 60.5%. The total number of household in Kathmandu is 235,387.

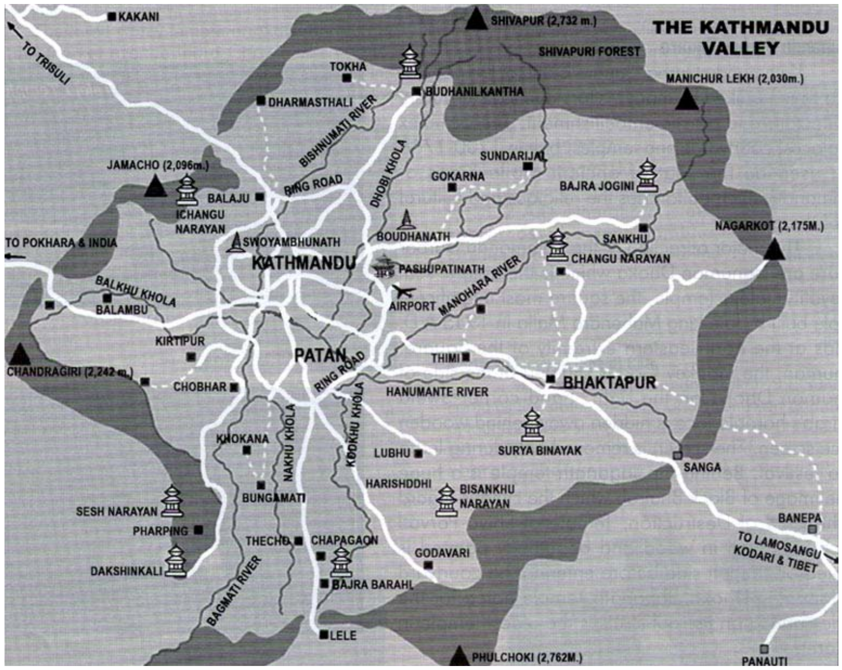


Figure 4-2. Map of Kathmandu

4.1.1 Settlement

There are four ancient cities (Kathmandu, Lalitpur, Bhaktapur and Kirtipur) in the Kathmandu valley which were built around two to six hundred years ago. These cities were planned in terms of infrastructure, housing, water supply. These were economically sustaining at that period. But, due to tremendous increase of population and urbanization, these ancient cities started experiencing unplanned growth. People started buying land and erecting building in an informal way. After buildings started to be built, the infrastructure such as roads, water supply, electricity etc. were developed which is completely opposite of planning concepts.

In the last decade, some private companies have started developing formal housing program for fulfilling the residential demand of Kathmandu. These companies provide housing on a bigger scale like about 30 to 150 housing units along with other amenities. Some of these housing are relatively better in terms of planning within the housing complex, even though at a very small scale.

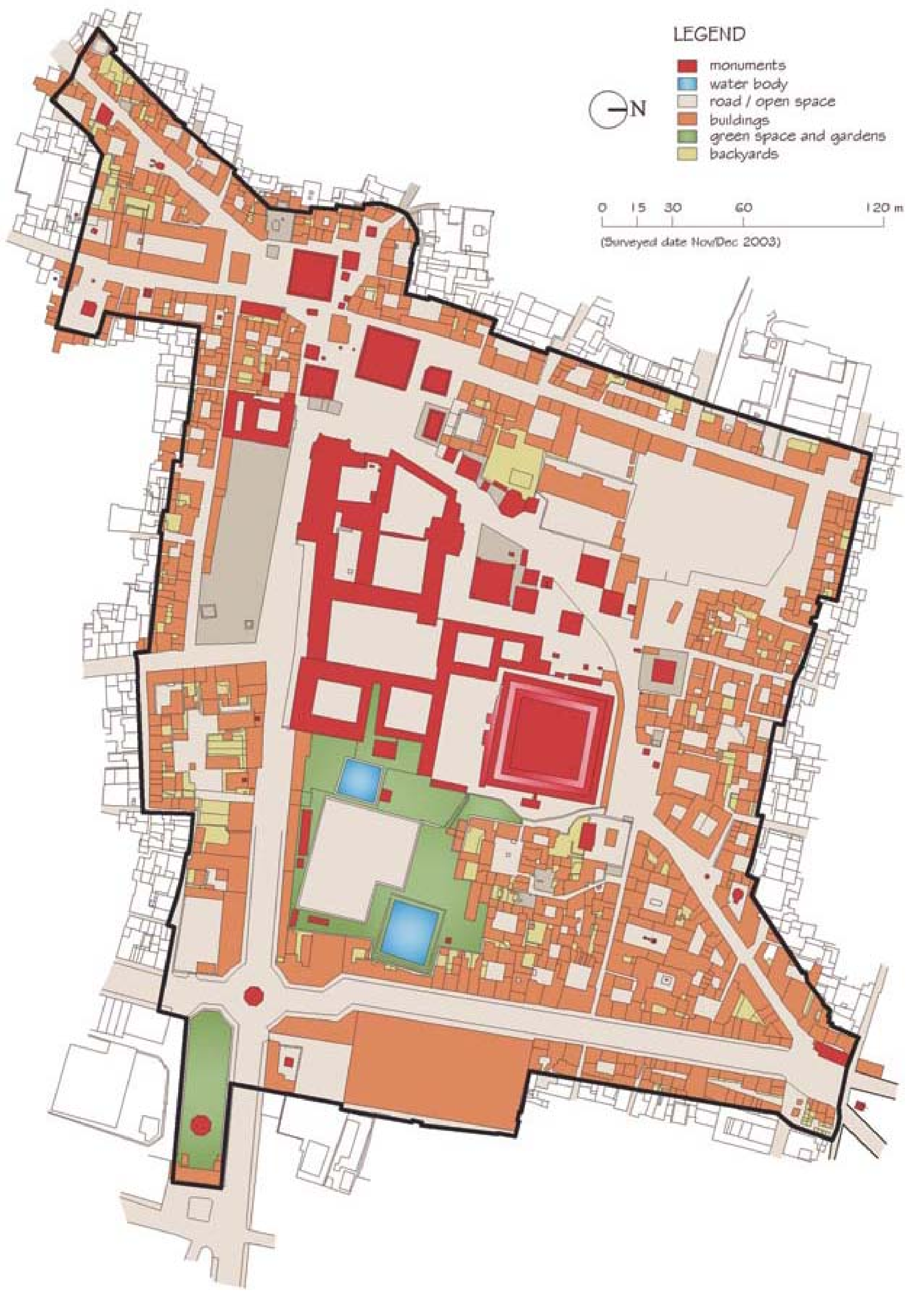


Figure 4-3. Ancient Settlement of Kathmandu (Source: UNESCO, 2004)

4.1.2 Climate

The altitude of Nepal varies from 60 meters above the sea level to the top of the world, 8848 meters, within a distance of about 240 kilometers. Primarily due to this difference in altitude, Nepal has five different climates which are:

a. Tropical and Subtropical Zone (60 to 1200 meters)

b. Temperate Zone (1200 to 2400 meters)

c. Cold Zone (2400 to 3600 meters)

d. Arctic Zone (4400 to 8848 meters)

(All the climatic data in this section are taken from SWERA)

Table 4-2. Monthly Air Temperature at °C

Air Temperature	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Max.	21.6	26.0	27.7	30.0	31.0	30.0	31.0	31.0	29.0	30.6	27.0	24.8
Mean Min.	-0.8	0.0	1.0	7.6	9.0	14.0	19.0	18.5	15.3	9.4	5.4	0.6
Range	22.4	26.0	26.7	22.4	22.0	16.0	12.0	12.5	13.7	21.2	21.6	24.2

(Source: SWERA)

Table 4-3. Monthly Relative Humidity in %

Relative Humidity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Max.(AM)	100	100	100	100	100	100	100	100	100	100	100	100
Mean Min.(PM)	31	25	23	16	31	39	46	44	54	31	29	28
Average	77	72	70	61	73	80	86	85	85	79	81	77

(Source: SWERA)

Table 4-4. Other Climatic Data

Other Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	13.9	22.0	42.2	69.4	138.2	241.2	402.7	336.7	212.2	51.7	7.2	3.4
Windspeed (m/s)	0.8	1	1.3	1.5	1.3	1.3	0.7	0.7	0.8	0.8	0.6	0.7
Wind direction	SW	SW	W	SW	W	SW	SW	SW	SW	SW	W	W

(Source: SWERA)

Kathmandu valley lies between 27°36' to 27°50' north and 85°7' to 85°37’ longitude at an altitude of about 1337 meters above the sea level, which is in temperate zone. Here the climate is comfortably mild with neither severe winter nor heavy tropical heat and rain. Kathmandu has temperate climate with four distinct seasons: autumn, winter, spring and summer. In the summer, the mean of monthly maximum temperature reaches upto 31.0°C while in winter the mean of monthly minimum temperature goes down to -0.8°C. The daily average temperature ranges from 9.2°C in January to 23.3°C in July with average diurnal temperature range of 17.6°C. Similar to temperature, the humidity also fluctuates daily and seasonally. The average monthly maximum humidity in the morning is 100% whereas during daytime, the average monthly minimum reaches down to 28% in December and 46% in July. The daily average humidity is 61% in April and 86% in July.

Average annual rainfall of the Kathmandu valley is around 1540mm. Due to monsoon phenomenon higher rainfall is observed during March through September months. The average wind speed is about 0.95 m/s and the maximum wind speed reaches up to 13.4 m/s in May. The prevailing wind direction in the Kathmandu valley is westerly. The average hour of sunshine is about 6.3 hours and it varies between 3.3 hours to 8.4 hours. The sun path diagram, Figure 4-4, shows the solar altitude angle and azimuth angle for different time of a day for any month of a year. The sun's angles at noon during equinox (March 21 and September 22) is 62.3°, summer solstice (June 22) is 85.8° and winter solstice (December 22) is 38.8°

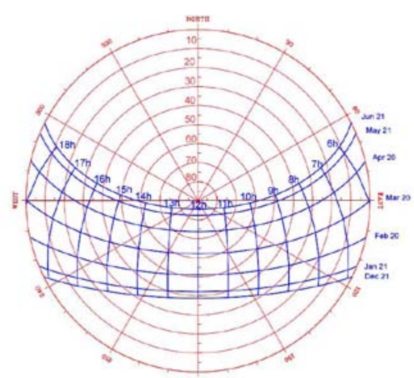


Figure 4-4. Sun Path Diagram for Kathmandu (Source: www.giasma.com)

4.1.3 Energy Supply and Consumption

As the housing demand increases, the demand for energy consumption also increases. In 2008, the energy demand increased by about 10.76% and will continue to increase in the future by approximately about ten times of the current demand (NEA, 2009).

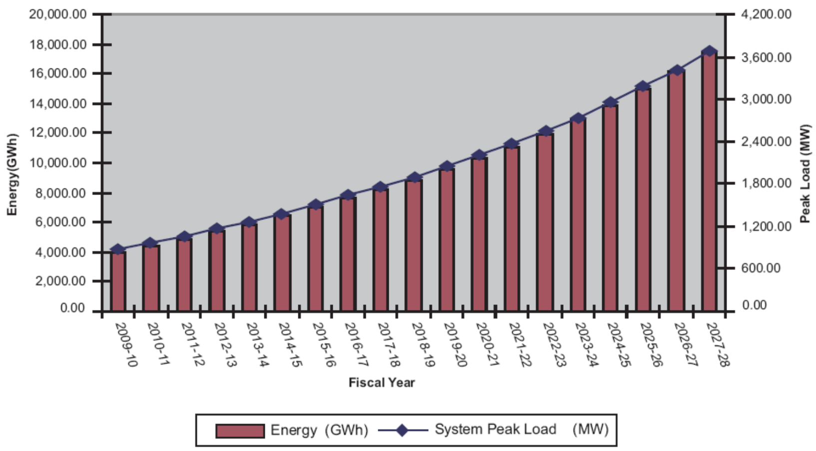


Figure 4-5. Energy Demand Forecast for the Next 17 Years (Source: NEA, 2009)

There is a shortage of energy due to high demand and low supply of energy. So there is a power cut off everyday and the duration of load shedding is also increasing every year (NEA, 2009) which is shown in Figure 4-6. The load shedding increases up to 16 hours per day in dry season and 4-5 hours in wet season. Nepal Electricity Authority (NEA) is trying to increase supply and also motivate the consumers to use electricity efficiently (NEA, 2009).

In the context of Kathmandu, biomass and wind energy are not good options of renewable energy as both biomass and wind are not enough to produce energy in urban context. Hydropower would be the best option because of high potential for hydropower. But the use of hydropower in smaller scale projects, especially in urban area, is very limited. Also it has higher initial investment, transportation difficulties and cost. Photovoltaics (PV) system of solar energy would be best option to generate energy in local level with available technology. Currently, most of houses use solar energy for water heating.

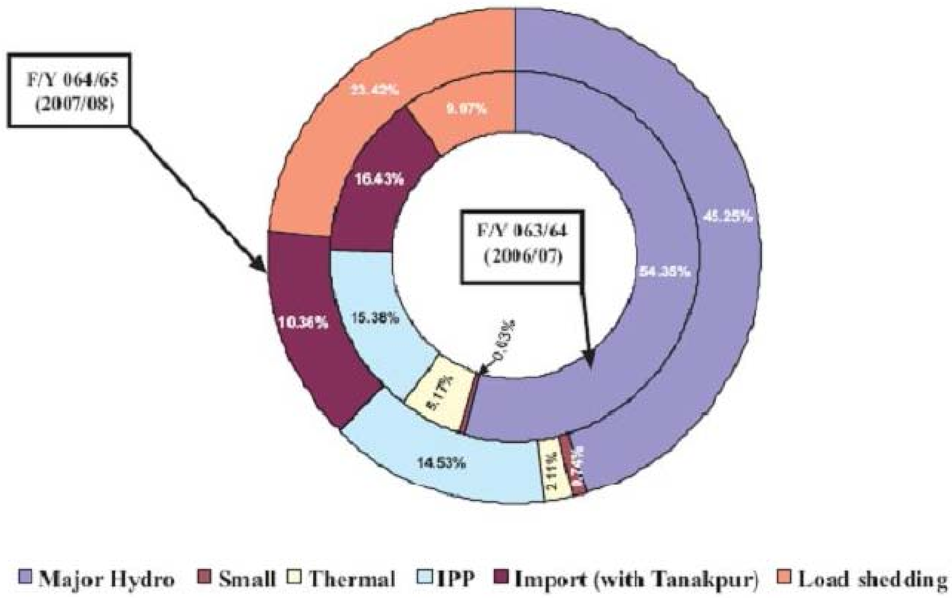


Figure 4-6. Increasing Load Shedding (Source: NEA, 2009)

4.1.4 Water

According to National Water Plan (2005), only 72% of total population of Nepal has access to basic water supply. Currently, most of the urban water supply systems are not delivering drinking water sufficiently. Major sources of water in Nepal are the rivers that flow from the melting of ice caps in the Himalayas. There are more than six thousand rivers in Nepal which drain from the north to the south towards Ganges. In addition to that, there is a potential of ground water resources in the lowland pains of southern Nepal. Although Nepal has 250 BCM (Billion Cubic Meter) of potential water, only 15 BCM has been used for social and economic purpose. Until recently, only water from small and medium rivers is used for drinking, irrigation and hydropower and larger rivers from Himalayas are left untapped. There is an extreme variation of water availability in those medium and small rivers. So water from the rainfall during monsoon seasons should be well utilized for various uses.

4.2 Summary

The region for the research was Kathmandu, Nepal. Kathmandu was an ancient city that developed about six to eight hundred years before. It has a temperate climate. Due to rapid urbanization, the traditional city of Kathmandu was expanded without any planning of human settlement and infrastructure. So, currently it is facing challenges of energy demand, drinking water, land and other urban amenities.

CHAPTER 5
CLIMATIC STUDY FOR HOUSING DESIGN

5.1 Climate of Kathmandu

The climate of Kathmandu is discussed in the last Chapter 4. Based on those climatic data, climatic analysis is done using various tools that are developed by other researchers. From these climatic analyses, design strategies have been developed in the following sections.

5.2 Climatic Analysis for Design Strategies

Design strategies for sustainable housing are based on a wide range of factors such as prevailing climatic conditions, available resources, construction materials, technologies, housing requirements, lifestyle etc. Climate is one of the major factors of sustainable design as buildings are designed in response to climate so as to make indoor environment physically comfortable. Human comfort depends upon physiological, environmental and cultural factors. According to Givoni (1976), comfort can be defined as the sensation of complete physical and mental well-being of a person within a built environment. To draw comfort requirements for different climate researchers have developed various tools. These tools give some recommendations that are helpful in designing climate responsive buildings in any specific climate. Some of those tools that are used in this research are Effective Temperature, Bioclimatic Chart, Psychrometric Chart and Mahoney Tables. These are discussed as below:

5.2.1 Effective Temperature

Effective temperature was the first scale developed by Houghton and Yaglou in 1923, working at American Society of Heating and Ventilating Engineers. Effective temperature is defined as “the temperature of still, saturated atmosphere, which would, in absence of radiation, produce the same effect as the atmosphere in question" (Koenigsberger et al., 1974). It is one of the methods of plotting comfort zone in a given area. It uses maximum and minimum dry bulb and wet bulb temperatures in Effective temperature monogram, assuming that people are wearing normal business clothing.

From the Figure 5-1, it can be seen that the maximum or daytime effective temperature are in comfort zone for the months from March to June and from August to November. On the other hand, there is not any month when there is comfort temperature for the minimum or nighttime effective temperature.

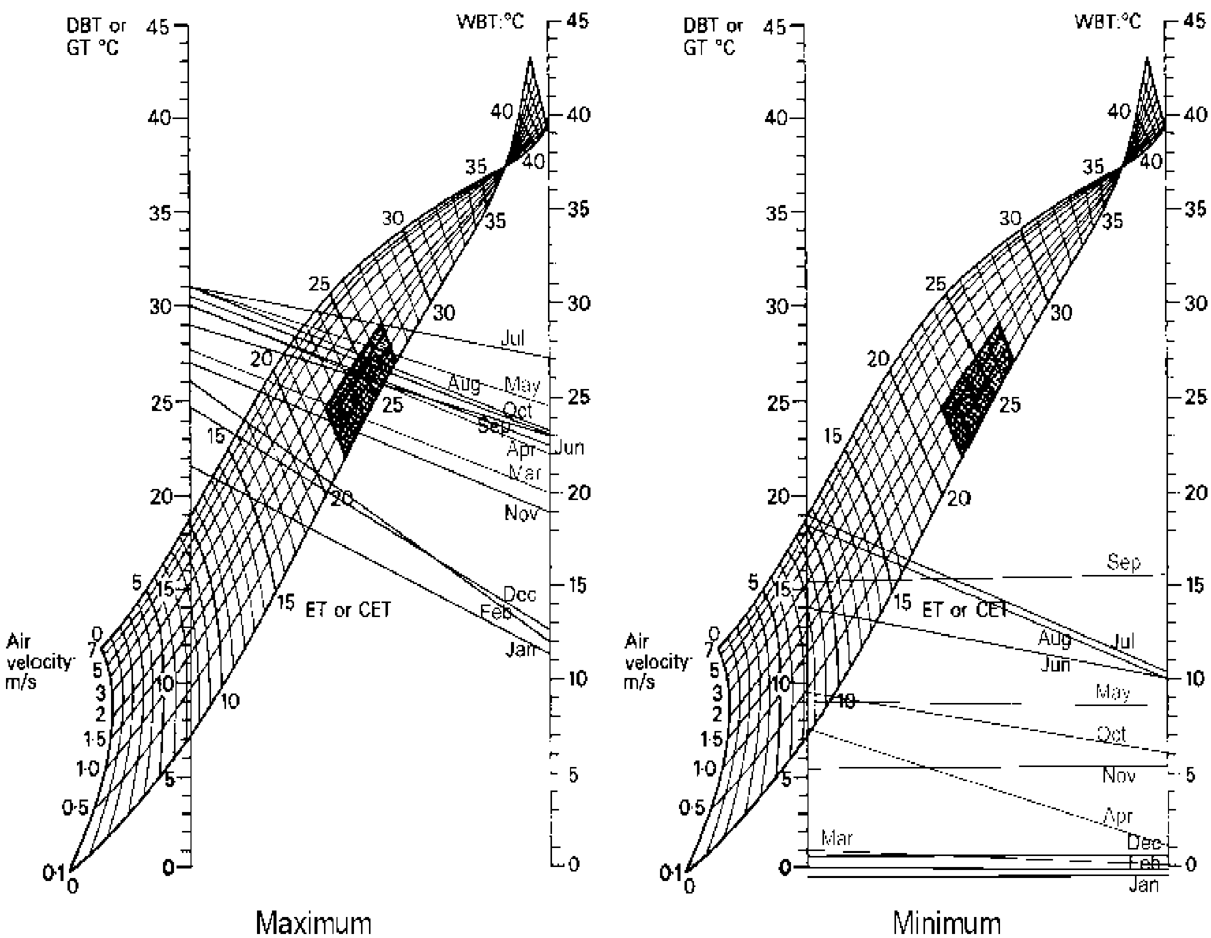


Figure 5-1. Maximum and Minimum Effective Temperatures for Kathmandu

Table 5-1. Effective Temperature

Temp.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. DBT°C	21.6	26.0	27.7	30.0	31.0	30.0	31.0	31.0	29.0	30.6	27.0	24.8
Max. WBT°C	11.2	12.0	20.0	22.0	24.6	22.4	27.0	23.2	23.0	23.0	19.0	12.7
Max. ET°C	18.2	20.5	23.9	26.7	27.0	25.9	28.5	26.5	25.9	26.4	23.2	20.1
Min. DBT°C	-0.8	0.0	1.0	7.6	9.0	14.0	19.0	18.5	15.3	9.4	5.4	0.6
Min. WBT°C	-0.8	-0.2	0.0	1.0	8.6	10.0	10.3	10.0	15.3	6.0	5.4	0.6
Min. ET°C	-0.8	0.0	1.0	7.5	9.0	14.3	16.5	16.2	15.3	9.4	5.4	0.6

5.2.2 Bioclimatic Chart

V. Olgay, in 1962, developed a chart, known as Bioclimatic Chart, in which comfort zone is defined in terms of dry bulb temperature and relative humidity (Olgyay, 1962). This chart shows how the comfort zone is affected by the wind, radiation and shading. This graph can be used to evaluate comfort conditions and propose some design strategies. The comfort zone is in the center with winter and summer ranges indicated separately. The chart also recommends the radiation needed zone, wind needed zone and shading needed zone to make the environment balanced and comfort.

In the Figure 5-2, the climatic data of Kathmandu valley is plotted. The bottom point of the straight line is the average minimum temperature with the AM (ante meridiem) relative humidity whereas the upper point of the line is the average minimum temperature with the PM (post meridiem) relative humidity. The temperature versus humidity chart depicts that the daytime temperature of March, April, May and October fall under comfort zone while nighttime temperature fall below comfort zone. November through February falls under radiation required zone whereas June through September falls above the comfort zone that need a wind speed of about 2 m/s to make it comfortable. The chart suggests that heating is needed in January, February, March, April, May, October, November and December for different time periods.

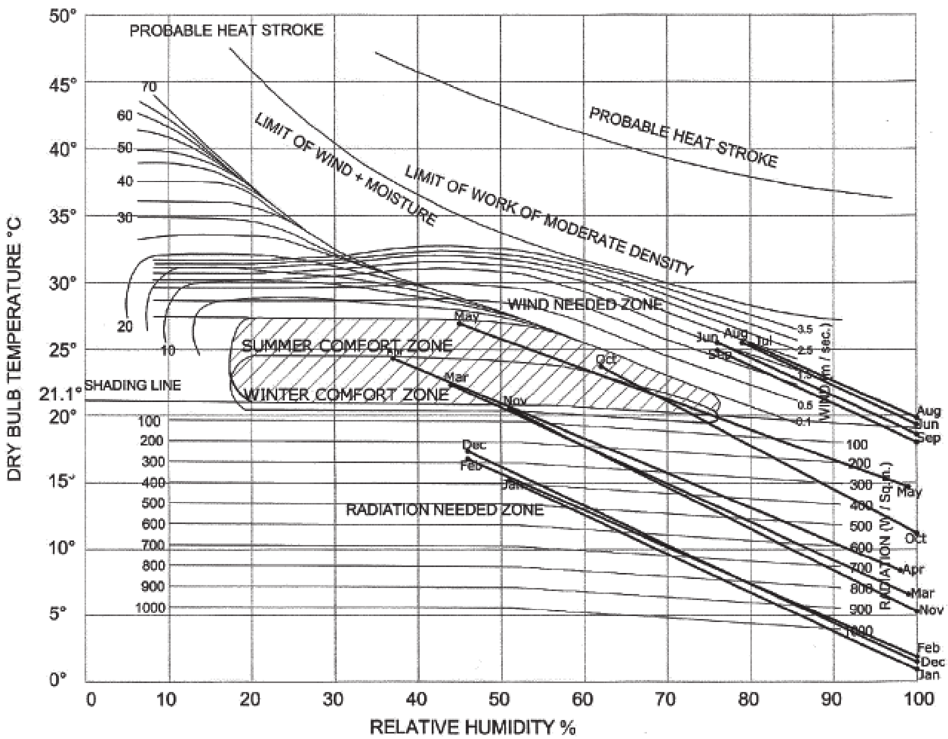


Figure 5-2. Bioclimatic Chart for Kathmandu

5.2.3 Psychrometric Chart

Psychrometrics is the study of thermodynamic properties of gas-vapor mixtures. Psychrometric chart is a graph used to design and analysis of air conditioning systems. ASHRAE's Psychrometric chart depicts human comfort in relation to temperature and humidity. The chart also suggests energy-conservation design and establishes a process whereby a designer can match solutions to climatic conditions when climatic data of a given site is plotted on the chart. In this chart, different zones are plotted to indicate design requirements based upon monthly average temperature and humidity of Kathmandu. These zones are:

a. comfort zone

b. passive solar heating zone

c. evaporative cooling zone (direct and indirect)

d. air movement zone

e. cooling with high thermal mass zone

f. internal gains and shading zone

The plot shows that for most of the months, passive solar heating strategies should be implemented. December through February requires conventional heating in addition to passive solar designs. Similarly, June to September fall under above comfort zone where provisions for air movement, internal gains and shading should be applied. The remaining months - April, May and October are under comfort zone for daytime temperature while nights still are slightly cold.

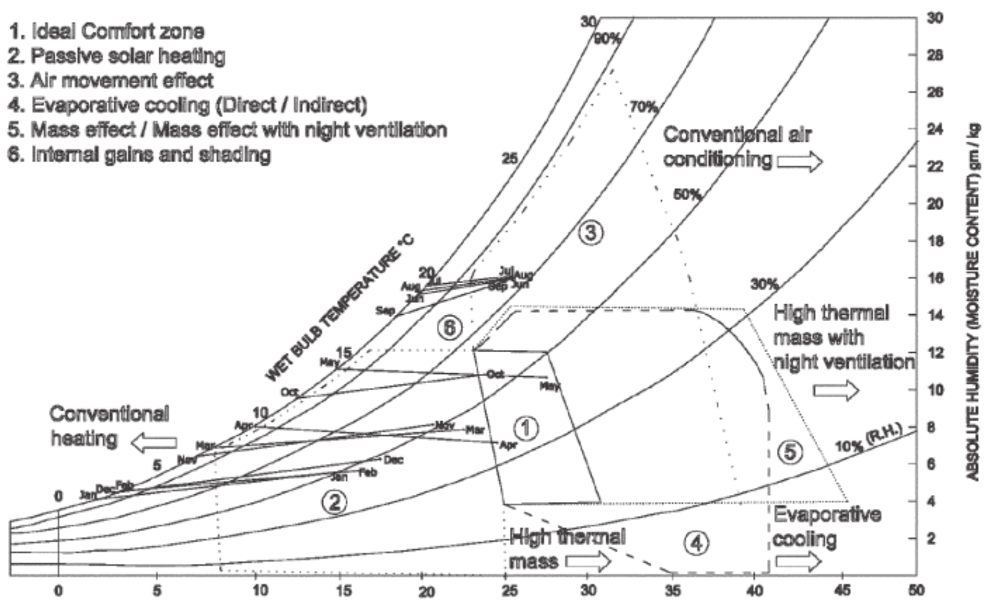


Figure 5-3. Psychrometric Chart for Kathmandu

5.2.4 Mahoney Tables

The Mahoney tables, named after architect Carl Mahoney who worked with O. H. Koenigsberger and M. Evans, are a series tables developed especially to address the design requirements for composite climates (Koenigsberger et al., 1973). Mahoney Tables provide more detailed design recommendations based on the analysis of temperature, humidity, wind, precipitation and comfort conditions for a given location. There are three tables in which Table-1(Table 5-2 to Table 5-7) is used to record the climatic data. Table-2 (Table 5-8 and Table 5-9) diagnoses the climate and develops climatic indicators. Similarly, Table-3 (Table 5-10 and Table 5-11) interprets the climatic indicators into design recommendations for that area.

Annual Mean Temperature (AMT) and Annual Mean Temperature Range (AMR) are calculated with the mean maximum, minimum and mean range of each month. Similarly, average monthly humidity is categorized to Humidity Groups- Group 1, below 30%; Group 2, 30-50%; Group 3, 50-70% and Group 4, above 70%. The humidity groups and temperature variations are used to find thermal comfort limits which are also linked with annual mean temperature (AMT). There are three categories of annual mean temperature (AMT): above 20°C, between 15 to 20°C and below 15°C. These AMT classifications and humidity groups are used to define thermal stress comfort limits for days and nights. The mean temperature is categorized into three temperature indicators: H (Hot) - if the mean is above limit; O (Comfort)- if the mean is within limit and C (Cold)- if the mean is below limit. Basically it indicates the indoor condition of thermal stress.

When the comfort limits are set, there is a pre-design table that indicates the provision that could be taken to generate acceptable pre-design conditions for indoor environment. These pre-design conditions are classified as indicators such as humidity indicator and arid indicator which are explained below.

H1- air movement is required for humid conditions

H2- air movement is desirable for humid conditions

H3- protection from rain is required

A1- thermal capacity is necessary for making indoor space comfortable

A2- provision for outdoor sleeping is desirable

A3- protection from cold is required in arid climate with lower temperature

The total value of each type of indicator is used to determine design recommendations for 8 different parts which are summarized as follows:

a. The orientation of the house should be along north and south (long axis- on east-west)
b. Open space should be created for wind breeze but with the protection from hot and cold wind
c. Rooms should be single banked with permanent provision for air movement
d. Openings should be 25-40% of floor area
e. Window should be at windward side walls at body height
f. Walls should be light with low thermal capacity and short time lag
g. Roof should be light and insulated
h. Windows and walls should be protected from heavy rain

Table 5-2. Monthly Mean Air Temperature

Temperature °C	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	High	Low	AMT	AMR
Mean Max.	21.6	26.0	27.7	30.0	31.0	30.0	31.0	31.0	29.0	30.6	27.0	24.8	31.0	-0.8	15.1	31.8
Mean Min.	-0.8	0.0	1.0	7.6	9.0	14.0	19.0	18.5	15.3	9.4	5.4	0.6				
Mean Range	22.4	26.0	26.7	22.4	22.0	16.0	12.0	12.5	13.7	21.2	21.6	24.2				

Table 5-3. Monthly Mean Relative Humidity

Relative Humidity %	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly Mean Max.(AM)	100	100	100	100	100	100	100	100	100	100	100	100
Monthly Mean Min.(PM)	31	25	23	16	31	39	46	44	54	31	29	28
Average	77	72	70	61	73	80	86	85	85	79	81	77
Humidity Group	4	4	3	3	4	4	4	4	4	4	4	4

Table 5-4. Humidity Group

Humidity Group:		
	1	If Average RH is: Below 30%
	2	30-50%
	3	50-70%
	4	Above 70%

Table 5-5. Other Climatic Data

Other Climatic Data	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Rainfall (mm)	13.9	22.0	42.2	69.4	138.2	241.2	402.7	336.7	212.2	51.7	7.2	3.4	1540.8
Wind speed (m/s)	0.8	1	1.3	1.5	1.3	1.3	0.7	0.7	0.8	0.8	0.6	0.7	
Wind direction (prevailing)	SW	SW	W	SW	W	SW	SW	SW	SW	SW	W	W	

Table 5-6. Comfort Limit

Comfort Limits	AMT over 20°C		AMT 15 - 20°C		AMT below 15°C	
Humidity Group	Day	Night	Day	Night	Day	Night
1	26-34	17-25	23-32	14-23	21-30	12-21
2	25-31	17-24	22-30	14-22	20-27	12-20
3	23-29	17-23	21-28	14-21	19-26	12-19
4	22-27	17-21	20-25	14-20	18-24	12-18

Table 5-7. Temperature Diagnosis

Diagnosis °C	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	AMT
Monthly Mean Max.	21.6	26.0	27.7	30.0	31.0	30.0	31.0	31.0	29.0	30.6	27.0	24.8	15.1
Day Comfort: Upper	25	25	28	28	25	25	25	25	25	25	25	25	
: Lower	20	20	21	21	20	20	20	20	20	20	20	20	
Monthly Mean Min.	-0.8	0.0	1.0	7.6	9.0	14.0	19.0	18.5	15.3	9.4	5.4	0.6	
Night Comfort: Upper	20	20	21	21	20	20	20	20	20	20	20	20	
: Lower	14	14	14	14	14	14	14	14	14	14	14	14	
Thermal Stress: Day	O	H	O	H	H	H	H	H	H	H	H	O	
: Night	C	C	C	C	C	O	O	O	O	C	C	C	

Table 5-8. Comfort Indicators

Indicators	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Humid: H1		√			√	√	√	√	√	√	√		8
: H2	√										√		2
: H3						√	√	√	√				4
Arid : A1			√	√									2
: A2													0
: A3													0

Table 5-9. Comfort Zone Requirement

Applicable When	Indicator	Thermal Stress		Rainfall	Humidity	Monthly Mean Range
		Day	Night		Group	
Air movement essential	H1	H			4	
		H			2,3	Less than 10
Air movement desirable	H2	O			4	
Rain protection necessary	H3			Over 200mm		
Thermal capacity necessary	A1				1,2,3	More than 10
Outdoor sleeping desirable	A2		H		1,2	
		H	O		1,2	
Protection from cold	A3	C				
	H (Hot): If mean is above limit					
	O (Comfort): If mean is within limit					
	C (Cold): If mean is below limit					

Table 5-10. Recommendations

Indicator from Table 2								
H1	H2	H3	A1	A2	A3			
8	2	4	2	0	0			
LAYOUT								
			0-10		5 12	√	1	Orientation north and south (long axis east-west)
			11,12		0-4		2	Compact courtyard planning
SPACING								
11,12							3	Open space for breeze penetration
2 10						√	4	As 3, but protection from hot and cold winds
0,1							5	Compact layout of estates
AIR MOVEMENT								
3 12						√	6	Rooms single banked, permanent provision for air movement
1,2			0-5					
			6 12				7	Double banked rooms, temporary provisions for air movement
0	2 10							
	0,1						8	No air movement
OPENINGS								
			0,1		0		9	Large openings, 40-80%
			11,12		0,1		10	Very small openings, 10-20%
Any other conditions						√	11	Medium openings, 20-40%
WALLS								
			0 2			√	12	Light walls, short time lag
			3 12				13	Heavy external and internal walls
ROOFS								
			0 5			√	14	Light, insulated roof
			6 12				15	Heavy roofs, over 8 hour time lag
OUTDOOR SLEEPING								
				2 12			16	Space for outdoor sleeping required
RAIN PROTECTION								
		3 12				√	17	Protection from heavy rain necessary

Table 5-11. Detail Recommendations

Indicator from Table 2								
H1	H2	H3	A1	A2	A3			
8	2	4	2	0	0			
SIZE OF OPENING								
			0,1		0		1	Large, 40-80%
					1 12		2	Medium, 25-40%
			2 5			√		
			6 10				3	Small, 15-25%
			11,12		0-3		4	Very Small, 10-20%
					4 12		5	Medium, 25-40%
PROTECTION OF OPENING								
3 12						√	6	In north and south walls at body height on windward side
			0 5					
1 2			6 12				7	As above, opening also in internal walls
0	2 12							
PROTECTION OF OPENING								
					0 2		8	Exclude direct sunlight
		2 12				√	9	Provide protection from rain
WALLS AND FLOORS								
			0 2			√	10	Light, low thermal capacity
			3 12				11	Heavy, over 8 hour time lag
ROOFS								
			0 2				12	Light, reflecting surface, cavity
10 12			3 12			√	13	Light, well insulated
			0 5					
0 9			6 12				14	Heavy, over 8 hour time lag
EXTERNAL FEATURES								
				1 12			15	Space for outdoor sleeping
		1				√	16	Adequate rainwater drainage

5.3 Summary

Kathmandu has a temperate climate with four distinct seasons: autumn, winter, spring and summer. The winter temperature reaches low to about 0°C and summer temperature reaches up to about 30°C. The summer has heavy monsoon rain whereas winter is dry. Climatic analysis is done for Kathmandu to get some idea for designing passive solar house. Various tools developed by previous researchers have been used to analyze the climate.

Effective Temperature shows the number of months that are above or below or within comfort zone at night and day time based on wet and dry bulb temperatures. So according to effective temperature graph, only eight months' day time temperatures are within comfort zone and all other are above or below comfort zone. Similarly, for night time, it falls below comfort zone for round the year.

Bioclimatic Chart is another tool for climatic analysis which is plotted with monthly data of relative humidity and dry bulb temperature. This chart depicts that March, April, May and October are in comfort zone. Likewise, June, July and August need wind and also shadings in the openings during daytime whereas December to February requires radiation during daytime. In the morning, heating is required from September to June.

In the same way, Psychrometric Chart depicts human comfort in relation to temperature and humidity. It also suggests energy conservation design. According to this char, the only months that are under ideal comfort zone are April, May and October during day time. All other months during daytime requires heating or cooling depending upon season. Similarly, winter months require internal heat gain and conventional heating during night time.

Another tool that was used for climatic analysis was Mahoney Tables. Mahoney Tables are developed based on the monthly temperatures, humidity, wind and precipitation. This table recommends the orientation, openings, air movement, type of walls and roofs and rain protection for a building. These recommendations can be applied to passive solar design.

CHAPTER 6
ARCHITECTURE OF KATHMANDU VALLEY

6.1 Vernacular Architecture of Kathmandu

According to Gabriel Arboleda (2006), vernacular architecture refers to the buildings constructed by local people in an informal way, rather than by architects using design methodologies. Wagner (1980) defines it as the architecture that resulted over long period of time or even centuries with the combined effect of use of resources, climatic conditions, and social organization of households.

The vernacular architecture of Kathmandu has resulted over the last six centuries. So they are also commonly known as traditional architecture. The traditional settlement of Kathmandu valley is generally found in elevated lands and is characterized by grid pattern. The houses are developed in row-housing pattern with narrow alleys between the rows. Generally, houses are courtyard type with interconnections among them. Courtyards are linked with enclosed passages at the ground floor. The common use of courtyards is for outdoor sitting area, play-space for children, and social and cultural functions.

6.1.1 Building Planning

Since land was scarce and competed for agriculture, traditional houses were planned in vertical arrangement. They are generally three to four floors high and grouped together to create interconnected courtyards. The buildings are normally six meters in depth and four to eight meters in length (Korn, 1976). The ground floor is used for storage of farm equipment, shelter for animals, or shop front. Generally, the first floor has bedrooms while the second floor is used both for bedrooms and living area. The attic or top floor is used as kitchen and prayer room. According to Parajuli (1986), during 14th to 16th century, houses were smaller with one-room deep floor plan with single or double story. In the 16th to 18th century, two-room deep floor plans with three to four stories buildings were common. Later in the 18th to 20th century, buildings were more spacious with larger windows and open floor plans in the ground floor.

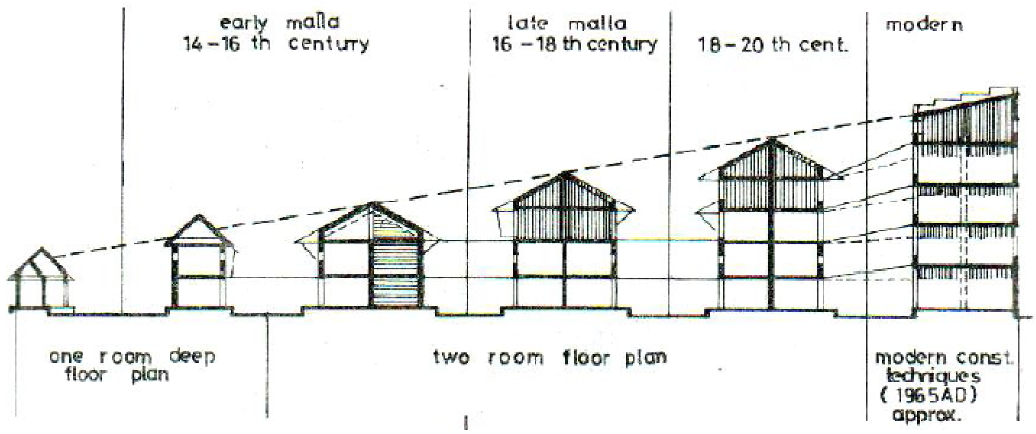


Figure 6-1. Development of Traditional Architecture of Kathmandu Valley over the Last Six Centuries (Source: Parajuli, 1986)

6.1.2 Construction Materials

In the past, wood was abundant in Kathmandu valley. Naturally, the most widely used materials were wood, clay brick and tiles. The external walls are about half meter to one meter thick depending upon the height and size of the building. The walls are constructed of sun-dried brick with external veneer of good quality burnt clay bricks with mud mortar. Walls have high time lag with low U-value. The sun-dried bricks absorb 10 to 20 times more moisture than burnt bricks making the indoor environment more comfortable (Upadhyay, et al., 2006). Also, sun dried bricks have lower density than burnt brick which means they are good for thermal resistance.

The U-value for the 505 mm thick walls of traditional buildings with mud plaster is 1.014 W/m^2°C, time lag is 12.5 hours and indoor surface temperature is 17.63°C (Shrestha, 2009).

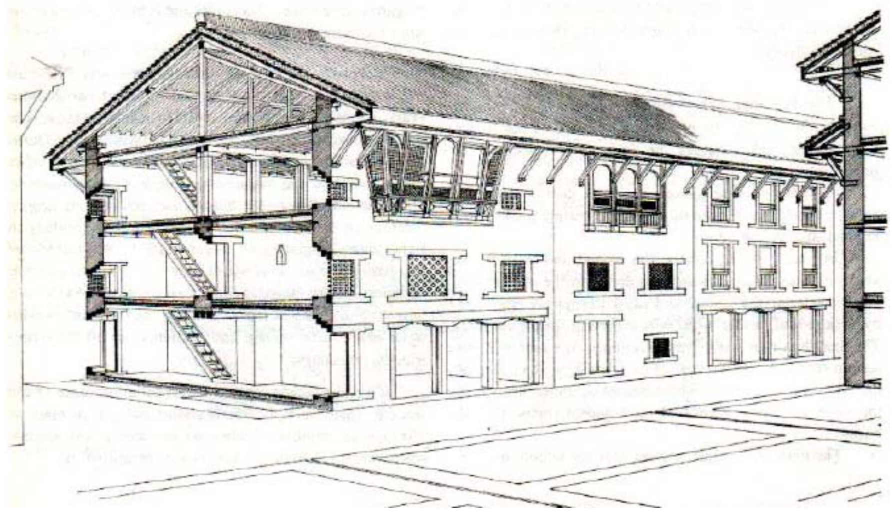


Figure 6-2. Traditional Building Showing Section (Source: Korn, 1976)

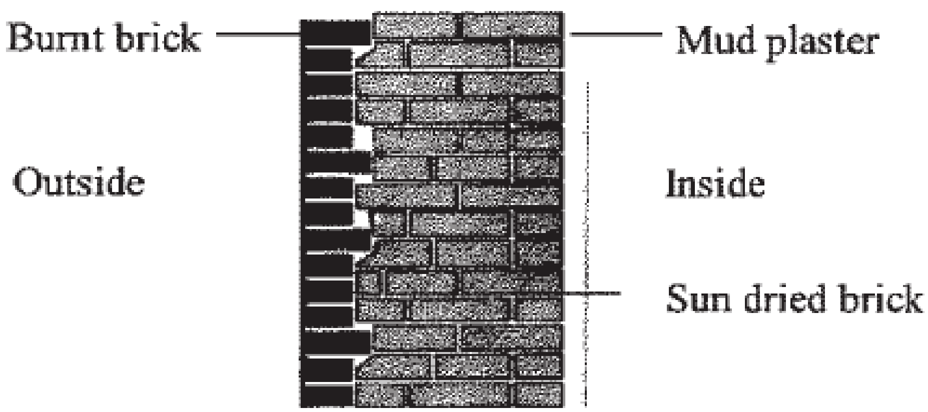


Figure 6-3. Wall Section of Traditional House (Source: Korn, 1976)

Similarly, roofs are constructed with wooden rafters and board over the rafters. The roofing material is clay tiles fixed with mud over the wooden board. For the roof of 143mm without rafter, the U-value is 1.30 W/m^2°C, time lag is 4.86 hours and indoor surface temperature is 17.6°C (Shrestha, 2009). Although, the overall U-value of the roof is higher than that of the walls, the attic space is used for kitchen and food storage generally in the mornings and the evenings which functions as a buffer to living space.

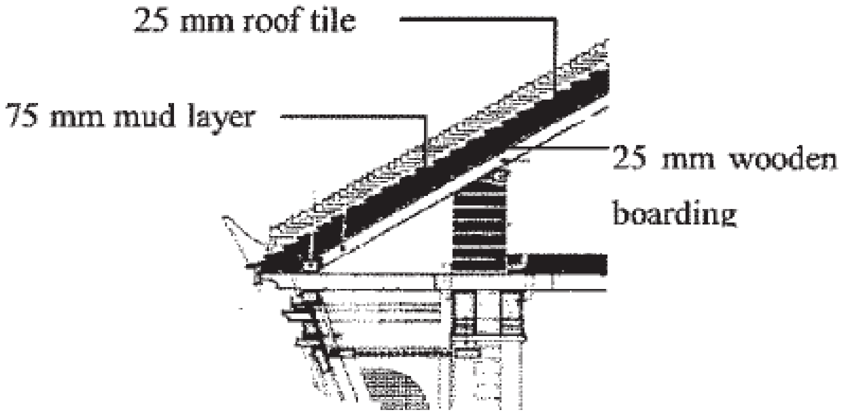


Figure 6-4. Roof Section of Traditional House (Source: Korn, 1986)

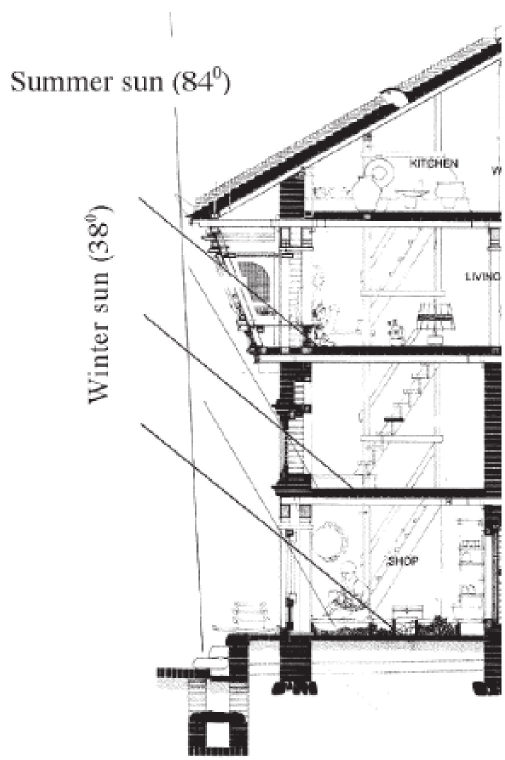


Figure 6-5. Section of Traditional House Showing Light Penetration through Openings (Source: Korn, 1976)

In the past, people spent most of their day time outdoors. So, large openings were not necessary to keep the rooms well lit during the day. The area of the opening is about 10 percent of the total floor area (Upadhyay, et al., 2006). The roof overhang was sufficient to shade direct sunlight during the summer and allow radiation during the winter. But in buildings of last two centuries, large openings can be seen. Some of them even replaced wooden lattice and shutter with metal screen and glass panels. Considering traditional openings with single glass panel of 6mm thickness and 20% wooden frame, U-value would be 5 W/m^{2}°C (Szokolay, 2008).

6.2 Current Housing Scenario in Kathmandu

With the tremendous increase in population for the last few decades, housing demand has also increased resulting in the shortage of land and local resources. At the same time, the lifestyle of people, mostly in urban areas like Kathmandu, is also changing due western influence and technological development. With all these changes, construction of houses has also changed dramatically. The traditional construction materials are being replaced by concrete, steel and glass. Currently there are two ways of housing construction: informal and formal housing.

6.2.1 Informal Housing

Until late nineties, the housing development was informal. People used to buy small plots of land and build their houses at their own will. Technical planning by the government or consultation with technicians for the construction was lacking. Even today, majority of construction is informal and without any involvement of architects and engineers. These individually built houses neither demonstrate any traces of traditional architecture nor are they visually pleasing to be labeled as modern architecture. They are simply mini-towers with three to four rooms and four to six stories erected in narrow alleys of traditional cities. Due to dense settlement and taller construction, there are not many possibilities for capturing solar radiation and wind to make the house comfortable to live in. They do not even have active methods of heating or cooling houses.

Figure 6-6. Informal Housing

Figure 6-7. Informal Housing

6.2.2 Formal Housing

The housing construction changed to some degree in the late nineties. Formal housing planning and apartment development started and these new constructions were designed and supervised by technical experts, at least to some cases and to some extent. Formal housing is a planned housing complex with about 20 to 100 housing units. These houses are generally designed and engineered by qualified professionals. As a result, they are relatively better in terms of their planning and construction. These formal housing are generally detached or semi-detached (twin), two to three stories individual houses. Besides these, there are some apartments which are about six to ten stories. Each flat is sold or rented individually.

Figure 6-8. Formal Housing (Source: Comfort Housing, 2009)

Figure 6-9. Formal Housing (Source: Civil Homes, 2009)

6.2.3 Thermal Performance of Modern Day Housing

In most residential constructions, regardless of whether they are informally or formally built, the construction material and technology are very similar. Generally, they are built with full brick wall (230 mm) or half brick wall (110 mm) with 10 to 12 mm plaster on both or only on single side. The roofs are 100mm reinforced concrete with about 50 mm floor finish and 12 to 15 mm cement plaster. There is no use of insulation and false ceiling for thermal control. The openings are usually 5 mm ordinary glass window with wooden or aluminum frames. Double glazing is not common in Kathmandu. According to Shrestha, the U-value for these walls is 1.903 $W/m^{2}°C$ and for roofs is 3.069 $W/m^{2}°C$ which are higher than the required for the buildings of Kathmandu (Shrestha, 2009). Similarly, the time lag for walls is 6 hours and for roofs is 3.7 hours which are also not sufficient to maintain the thermal comfort of building. Windows with single glass of 6mm thickness and with 10% wooden frame, U-value would be 5.3 $W/m^{2}°C$ (Szokolay, 2008).

Table 6-1 shows that the time lag for both walls and roofs has decreased significantly indicating that the thermal environment of the modern day houses is not comfortable unless other heating and cooling methods are used.

Table 6-1. Thermal Performance Comparison

Building Elements	Thickness (m)	U-Value ($W/m^{2}°C$)	Time Lag (Hours)
Traditional			
Walls	0.505	1.104	12.5
Roofs	0.148	1.300	4.8
Modern Day			
Walls	0.254	1.903	6.0
Roofs	0.164	3.069	3.7

Source: Shrestha, 2009)

6.3 Summary

The vernacular architecture of Kathmandu has very settlement with interconnected courtyards. The buildings are planned in vertical space arrangement. The construction materials are brick walls with mud mortar, clay tile roof and wooden roof structures, window shutters and frames. The walls are about half meter to a meter thick depending upon building height and size. The time lag for half meter thick wall is about 12.5 hours and for a roof is about 4.8 hours.

On the other hand, the construction of modern day housing is quite different from that of vernacular architecture. These housing are developed individually and without any planning of infrastructure and settlement. Like vernacular houses, these houses are also planned in vertical space arrangement but without any interconnected courtyards. These houses are compact and very dense which do not allow enough radiation and air movement inside the houses. Recently, there are housing companies that develop housing units over a larger area. These are more formally built with some planning and under observations of technical persons. The construction materials for modern day housing, whether they are built by individuals or by housing developers, are same. Most of the housing are erected in reinforced concrete structural frame with brick walls, concrete roof, single glazed openings, wooden doors and window. Insulation in walls and roof is not common in housing. The time lag for 0.254 meter brick wall is about 6 hours whereas 0.615 meter concrete roof is 3.7 meters. The time lag for modern day housing has decreased compared to vernacular buildings creating uncomfortable thermal environment within the buildings.

CHAPTER 7
DESIGN OF HOUSING

7.1 Design Alternates

With the study passive solar homes, climatic analysis and vernacular architecture of Kathmandu, it can be seen that the most important aspect to consider while designing energy efficient and sustainable houses are the orientation of building, building envelop and the design of openings. All these aspects of design are discussed as below:

7.1.1 Site Selection

From the climatic analysis of Kathmandu, it was concluded that Kathmandu has temperate climate. Although Kathmandu does not experience extreme winter or extreme summer, there are months which require cooling in the summer and heating in the winter. For most of the year, heating is essential in residential buildings. For this, orientation of the site is very important. To capture the southern solar radiation for heating the house, a site with southern orientation is preferable. During the summer months, when house needs cooling, capturing westerly wind is appropriate. So, a site with 10° west of south is preferable. If the site is sloped, then south easterly or south westerly slopes are better as they maximize the potential for southern sun and allows higher housing densities without shadowing each other.

7.1.2 Building Planning and Orientation

While planning the housing, care should be taken not to make housing too dense to block the solar radiation during winter or cool breeze during summer. Similarly, the spacing between the buildings must be far enough so as not to create shadow on neighboring buildings. The shadow length is calculated by dividing the height of building by the tangent of solar altitude angle at a given time. This is represented in following equation;

Shadow Length (L) = Building Height (H)/ Tan (Altitude Angle(x))

where,

x = 23° (at 9am and 3 pm) and

x = 38.8° (at 12 pm) on December

During the warmer months, there can be problem of overheating of the building envelope and the inside surface. To reduce such problems by passive methods, trees, especially deciduous, can be planted to the west part. This helps in preventing summer radiation and allowing winter radiation to enter to the house. Permeable pavement or a water body also helps in reducing heat island effect during overheating period.

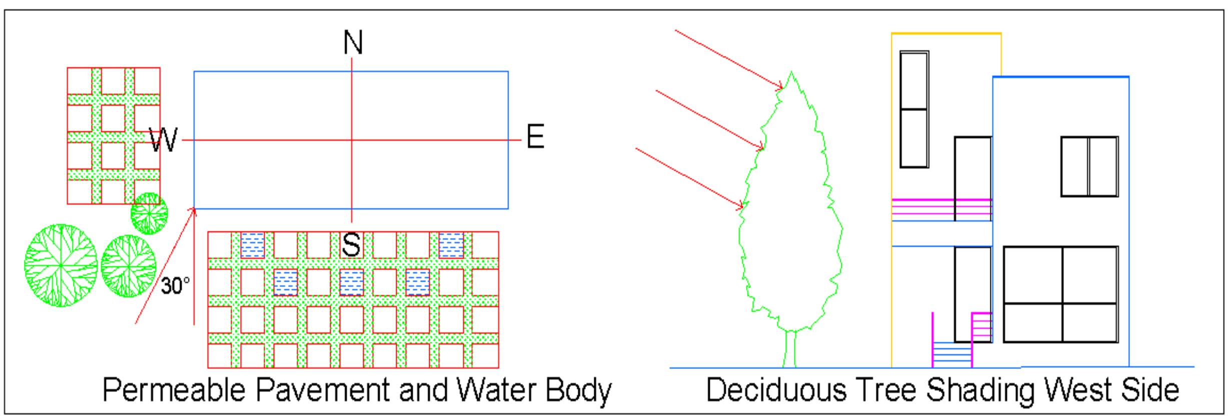


Figure 7-1. Landscaping Planning for Thermal Control

It is always not possible to find the site with exactly 10° west or east of south orientation. In such cases, buildings can be oriented towards south, especially the buildings with longer elevation, so that more solar radiation can be captured. At the same time, if the building is tilted towards 10° west or east of south, then it can even take the advantage of cooling breeze during summer months.

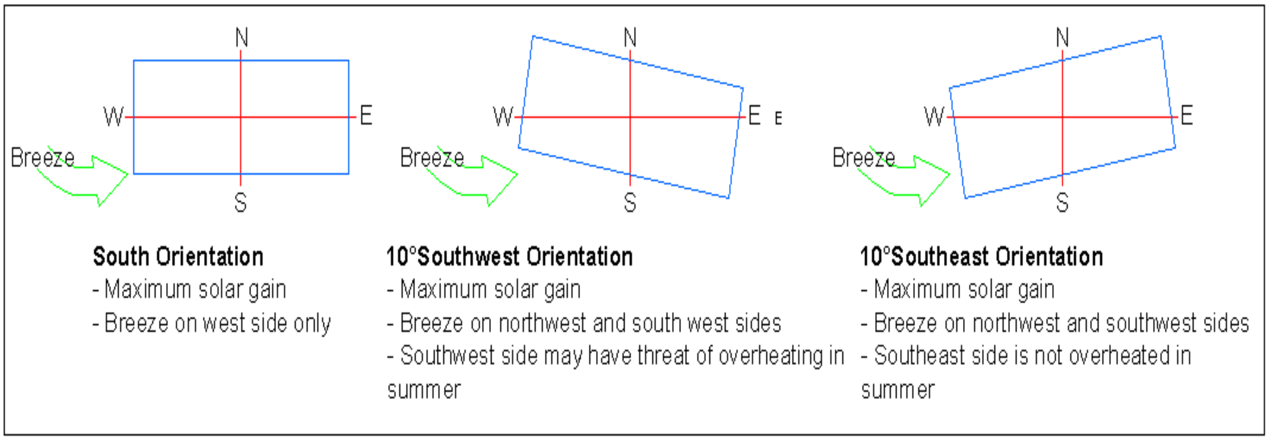


Figure 7-2. Alternate Orientations for Buildings in Kathmandu

7.1.3 Building Materials

The locally available and relatively cheap material for construction of residences in Kathmandu is brick. The traditional buildings were also constructed of bricks. Brick walls are erected with cement mortar. Bricks are basically of two types: First class brick which is strong and has good quality and do not require plastering on the external surface. Second class brick has slightly less strength and are of inferior quality to make it exposed to the external surface. So these require plaster on external surface. Besides brick, green and the locally available materials for construction are wood and stone. But the wood and stone are both very scarce and are expensive. Wood can be used for frames for the openings and door shutters. Concrete is generally used for the structural frame and roofing and ordinary glass is used for openings.

Walls. Shrestha (2009) has performed an analysis for brick wall with seven different alternates for Kathmandu. Those alternates are: full brick wall, brick wall with external insulation, with internal cladding, with internal strawboard, brick cavity wall with air gap, cavity wall with insulation in between and Rat trap bonded wall with external insulation. Climatic analysis shows that external wall need time lag of 8 to 14 hours and

U-value of less than 1.39 W/m^2°C for effective thermal balance. The U-value for full brick wall, brick wall with internal timber cladding, cavity wall, and Rat trap bonded wall without insulation are higher than the required value for Kathmandu. Likewise, the Table 7-1 shows that brick walls with external insulation of polystyrene, cavity wall with air gap in between, cavity walls with insulation and Rat trap bonded walls with external insulation have time lag of 15.5, 11.3 hours, 12 hours and 11.46 hours respectively. All other alternates have time lag which are below the required time lag for the housing of Kathmandu.

Table 7-1. Thermal Performance of Wall with Different Alternates

Walls	Thickness (m)	U-value (W/m^2°C)	Time Lag (Hours)
Full brick wall	0.254	1.903	7.5
Full brick wall with external insulation	0.294	0.695	15.5
Full brick wall with internal timber cladding	0.260	1.556	6.2
Full brick wall with internal strawboard	0.292	0.848	6.0
Cavity wall	0.282	1.491	6.8
Cavity wall with insulation (without air gap)	0.272	0.730	11.3
Cavity wall with insulation (with air gap)	0.322	0.654	12.0
Rat trap bonded wall	0.242	1.923	3.9
Rat trap bonded wall with external insulation	0.294	0.689	11.46

(Source: Shrestha, 2009)

Roofs. According to Shrestha (2009), analysis of thermal performance of roofs of contemporary construction in Kathmandu showed the time lag for those roofs to be 3.7 hours and U-value to be 3.069 W/m^2°C. Shrestha (2009) has also analyzed thermal behavior of different roofing construction such as concrete slab with insulation on top and concrete slab with suspended insulation. From the climatic study, it was concluded that roof needs U-value of 0.79 W/m^2°C and time lag of 10 hours. Both of these alternates have satisfied the criteria of U-value and time for roof construction.

Table 7-2. Thermal Performance of Roof with Different Alternates

Roof	Thickness (m)	U-value ($W/m^2°C$)	Time Lag (Hours)
Concrete slab with insulation on top	0.202	0.698	15.50
Concrete slab with suspended insulation	0.460	0.540	4.80

(Source: Shrestha, 2009)

Openings. Szokolay (2008) in his study has found that the U-value for single glazing of 6mm thick glass with 10% wooden frame is 5.3 $W/m^2°C$. Similarly, the U-value for double glazing with 10% and 20% wooden frame is 3.0 $W/m^2°C$ and 2.9 $W/m^2°C$ respectively. Szokolay has calculated the U-value for single glazing with 10% metal frame and double glazing with 10% metal frame which are 6.0 $W/m^2°C$ and 3.6 $W/m^2°C$. This shows that double glazing with wooden frame would be a good alternate to control thermal transfer through the window.

7.2 Design Recommendations

In the previous section, different alternates of design and construction of housing were discussed. Based on the previous discussion, some recommendations are provided for the design of sustainable housing for this research. They are discussed as below:

7.2.1 Site Selection and Planning

South oriented site is better in terms of passive solar design in Kathmandu. If it is sloped towards south, then it is even better. So avoiding such permanent structures and trees on the south side is recommended as these might hinder the solar radiation and wind entering into the building.

7.2.2 Orientation

The psychrometric chart and bioclimatic chart suggest that the orientation of building and openings should be towards the south. The Mahoney tables also indicated the orientation of building towards the south to get low-angled winter sun. The orientation to 10 degrees west of south is even better to get maximum solar radiation in winter (Upadhyay, et al., 2000). This also helps to get south-west and west wind during summer which can be used for cooling effect by cross ventilation during the warmer period, June to September. Mahoney tables recommend single banked construction for cross ventilation. In addition, during these months, Kathmandu gets about 80% of the rain of the entire year. So protection of wall and opening from rain during these periods is also necessary. This can be tackled with roof projection as in vernacular houses or through window projection or shading devices over windows.

7.2.3 External Wall

In the construction of wall, the Mahoney table suggests that the outer wall shall be of low thermal capacity and short time lag. In contrast to this, the study of vernacular architecture showed that the exterior wall to be of heavy mass with high thermal capacity and longer time lag. The recent construction in Kathmandu is going on with lighter external wall with short time lag. But their indoor environment is not as comfortable as in the vernacular houses; especially when it happens to be colder in winter and warmer in summer (Upadhyay et al., 2006). The thermal performance of the walls in Kathmandu should have U-value of less than 1.39 $W/m^2{}^\circ C$ and time lag of more than 8 hours, in which particularly 14 hours in the east facing rooms and 6 to 10 hours in the west facing rooms (Shrestha, 2009). As the land value is and construction material prices are high, thick walls do not seem suitable for Kathmandu. So the proposed wall can be of longer time lag with insulation on external surface or internal surface or in between two walls depending upon the need, ease of construction and efficient maintenance.

7.2.4 Floor

As Kathmandu gets enough rain during monsoon season, to prevent flood, from entering to the house, the plinth level should be above the surrounding ground level and drainage should be effective around the house. Similarly, the floor should be such that it absorbs the solar radiation during winter days and reradiate in the night time. For this, flooring with high thermal value would be better.

7.2.5 Roof

According to Upadhyay, the roof receives about 40 percent of the solar radiation over a period of a year (Upadhyay et al., 2006). Especially in the winter, when the sun angle is low, it gets even less radiation. In the vernacular houses, the attic space worked as large mass of insulating layer creating the living space more comfortable. But in today's construction, roofs are not so well insulated. So in the night time of winter, the warmer air rises up which then gets cooled faster because of higher conductance of the roof. Similarly, in summer, the roof gets higher radiation creating uncomfortable environment inside the building. Upadhyay (2006) recommends a roof with 10 hour of time lag. The U-value for the roof must be less than 0.79 $W/m^2°C$ (Shrestha, 2009). For this good insulating surface or green roof can be proposed.

7.2.6 Openings

Bioclimatic chart and psychrometric chart showed that most of the year falls below the comfort zone making it necessary to have heating arrangements. Mahoney tables also suggest that opening of 25 to 40 percent of the floor is desirable in a room for thermal as well as visual comfort. Using large openings in the south façade of the house would bring enormous amount of solar radiation as well as provide enough lighting for indoor activities. In the vernacular houses, as the indoor activities in the past were not much, the percentage of openings is about 10 to 25 depending upon the type of the room. Window with low sill height would be even better as they would enhance in heating the floor inside which would reradiate in the evening making it warmer in the night. Similarly, windows on the northern façade should be avoided as far as possible. Windows in the west and southwest can be designed to create natural cross ventilation and should not be very large as they might create a problem of heat loss during winter. For cross ventilation design, it is good to design outlet window larger than inlet for better air movement and stack effect can also be designed for multi-story buildings (Shrestha, 2009). Openings placed close to side walls and internal partitions placed closer to outlet provide good air circulation and daylighting as well. To maintain thermal comfort during extreme hot and cold days, it is recommended to use double glazing which has the U-value of less than 3.5 W/m^2°C.

7.2.7 Shading Devices and Overhang

Horizontal shading is recommended in the south façade. The shading should be designed for the summer to block and winter to capture solar radiation. From Sun path diagram for Kathmandu (Figure 4-4), solar altitude angle for is 84° in summer and 38° in winter. It is 74° in April. So if horizontal shading is designed for 74° at 3pm, it can shade up to 84° at noon. With the horizontal shading devices, the low angled winter radiation enters without any blockage at noon.

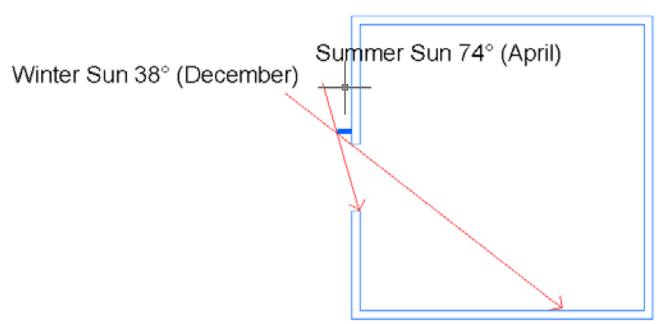


Figure 7-3. Horizontal Shading Device

7.4 Summary

The various alternates for design and construction of housing in Kathmandu is discussed in this chapter and suitable recommendations are drawn for the design and analysis of this research. The preferable site in Kathmandu is south oriented with north-south slope. Western side should have small openings for cool breeze in the winter. Shading with deciduous trees in the western side of the building is better to block summer sun and capture winter sun. Buildings should not be planned too dense to block the radiation or cool breeze. Similarly, the locally available materials for the construction are bricks, clay tiles and glass. The big thermal mass for walls and roofs may not be feasible because of high land value. So walls with external insulation would be good option. Similarly, for the roof, internal suspended ceiling can perform better thermal behavior.

CHAPTER 8
DESIGN AND ANALYSIS

8.1 Reference Building

The housing project taken for analysis is a real case housing project proposed by a group of architecture students of Tribhuvan University, Nepal. This project is located in western part of Kathmandu valley. This location is newly developed residential area. The entire area of the plot for housing development is 34,954 square meters. The site is oriented and also sloped towards the southeast. The difference in the elevation between the southeast and the northwest is about 34 meters. It has two accesses- one in the north and the other in the east. The average area of the plot for individual units is approximately 163 square meters. The design proposal has 94 housing units of two and three bedroom houses. The average area for housing units is about 50 square meters in each floor and most of them are two to three stories.

8.1.1 Design and Specifications

The housing unit considered as reference for analysis is a three bedroom unit with an approximate built up area of 140 square meters. It is oriented towards the south. The ground coverage is about 54 square meters which is about 33.6% of the site area. It has living, dining, kitchen and bathroom in the ground floor. Similarly, in the first and the second floor, there are three bedrooms and a sitting lounge. Balconies or terraces are provided for each bedroom. The housing is constructed in reinforced concrete structure. The external and the internal partition walls are of locally available brick with cement mortar. Walls are cement plastered on both sides. The roof is constructed of reinforced concrete with cement plaster finishing and does not have any internal or external insulation. Windows are of single glazed.

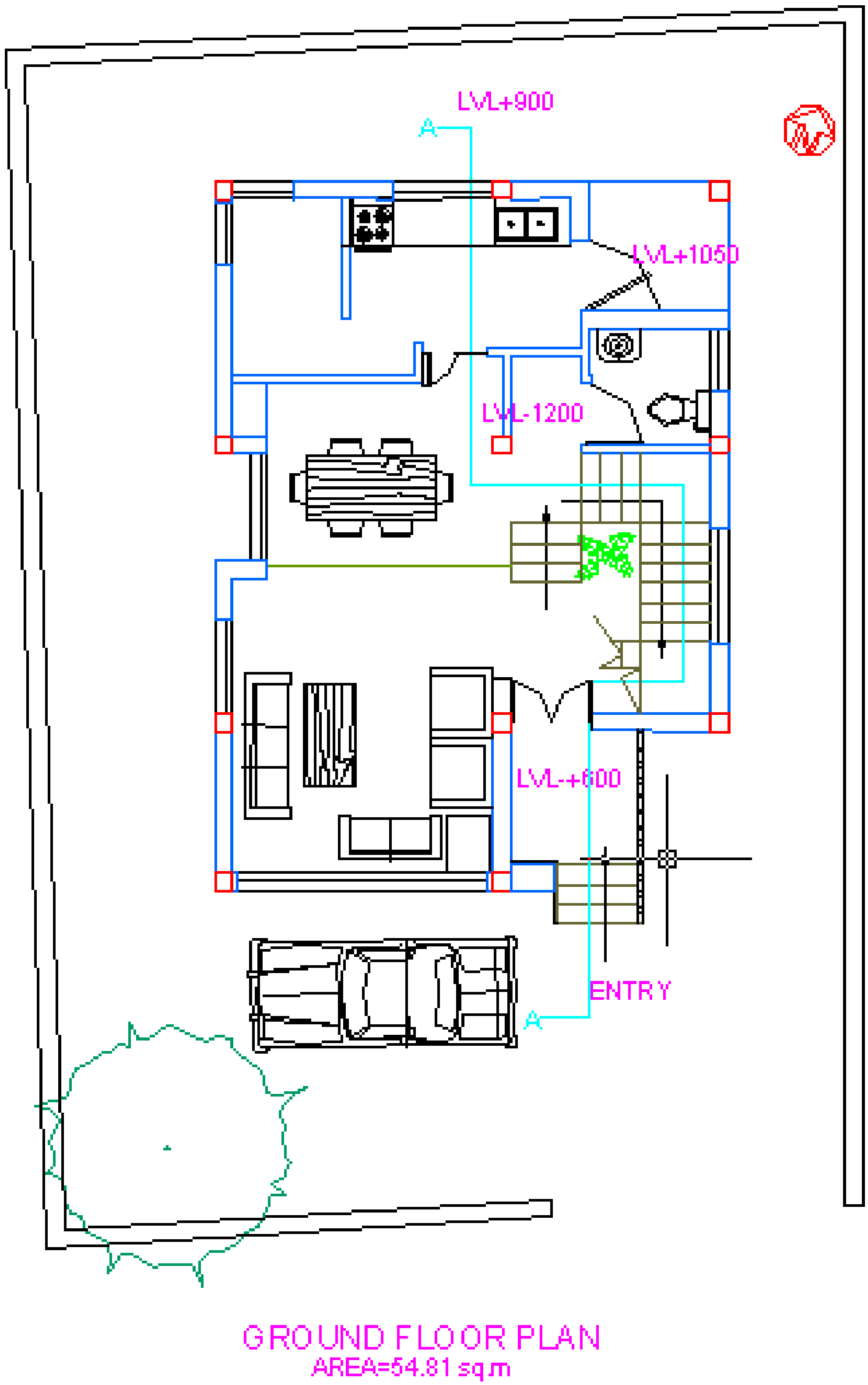


Figure 8-1. Reference Unit-Ground Floor Plan

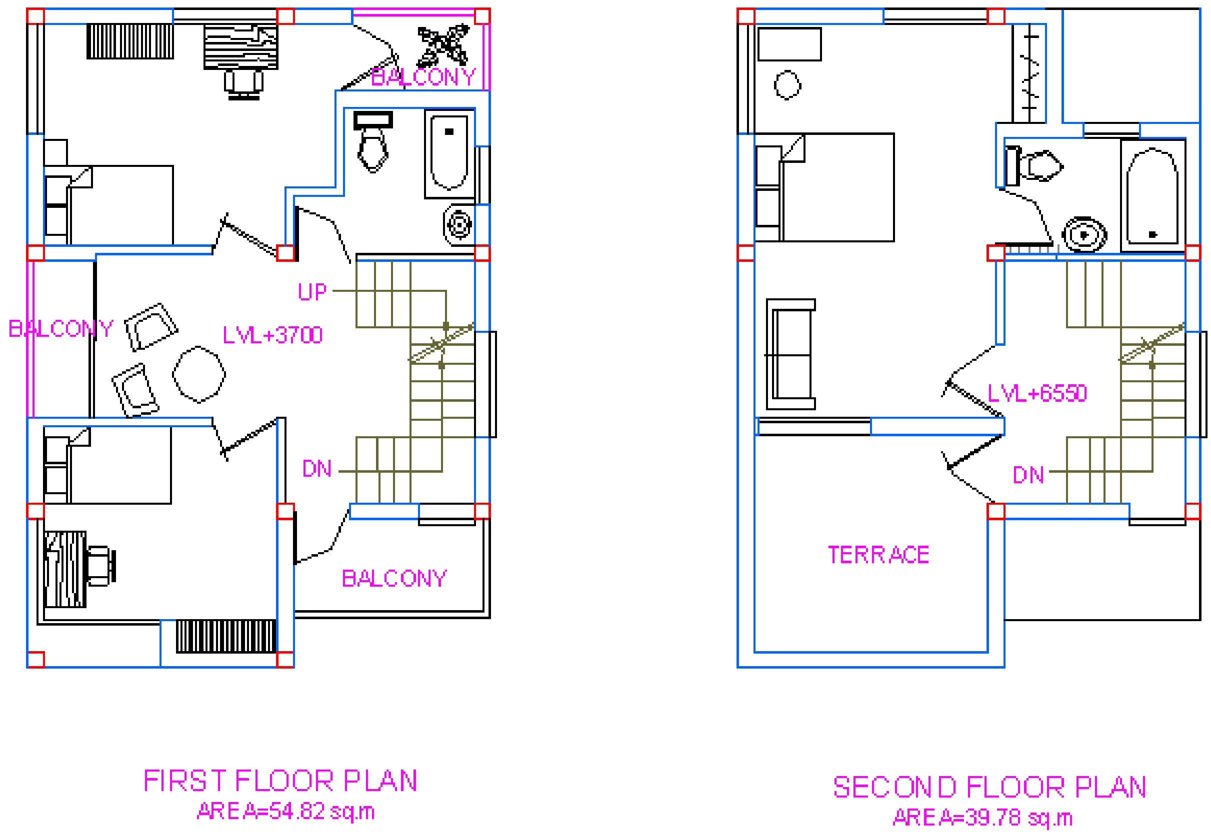


Figure 8-2. Reference Case-First and Second Floor Plans

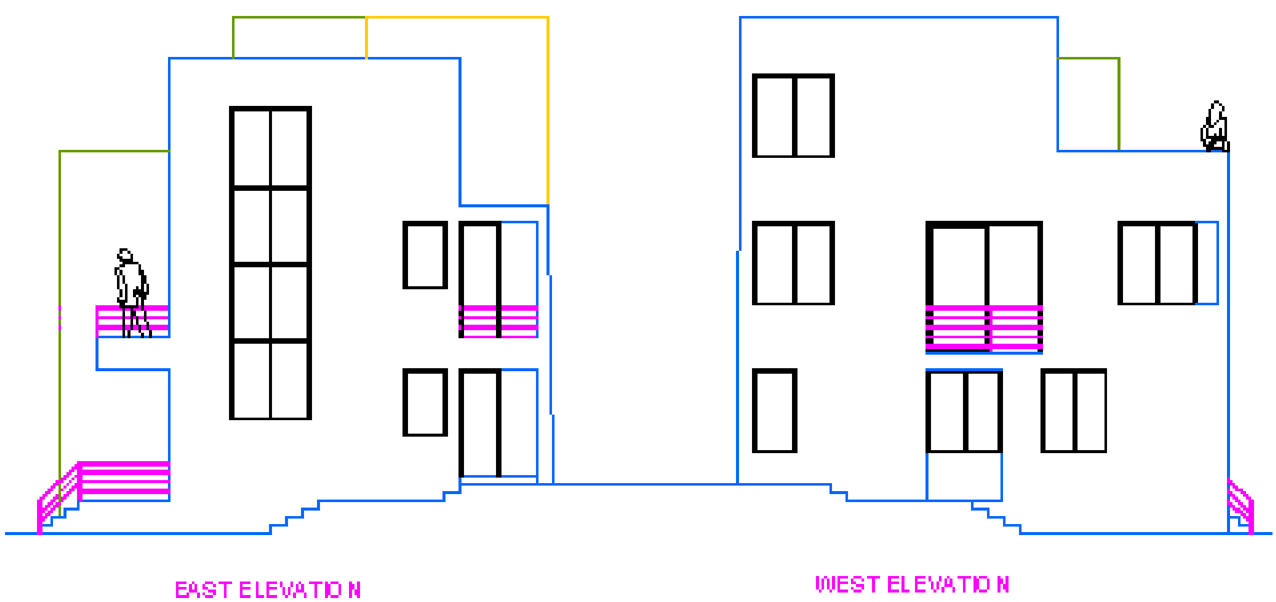


Figure 8-3. Reference Case-Elevations

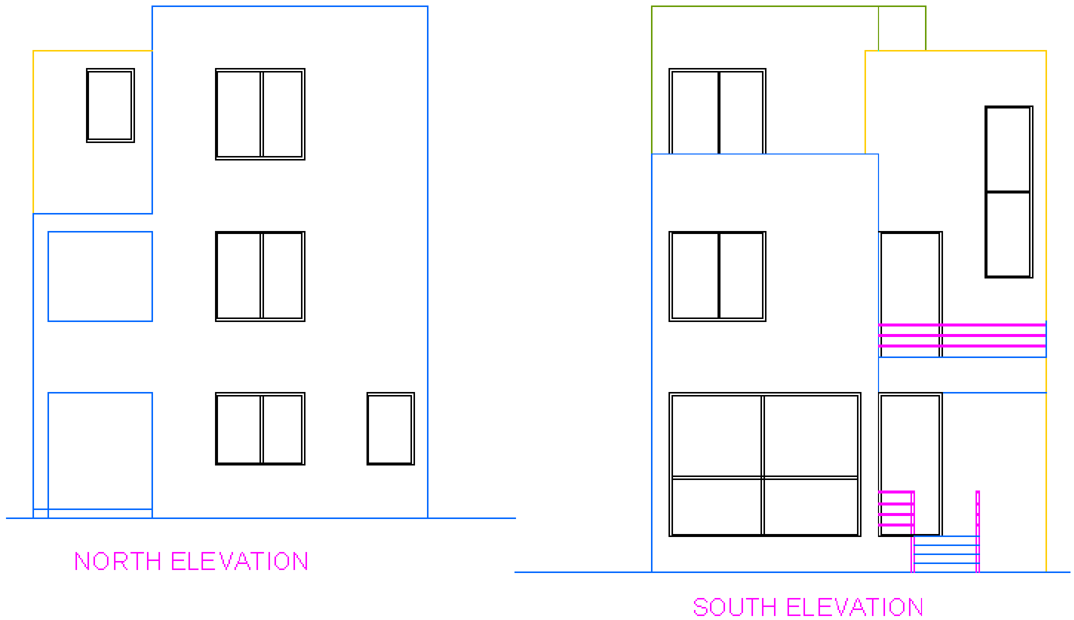


Figure 8-4. Reference Case-Elevations

Table 8-1. Specifications of Construction Materials

Building Element	Construction Material	Thickness (mm)	U Value W/ m^2°C
Exterior Wall	Brick with cement plaster on each side	254	1.903
Interior Wall	Brick with cement plaster on each side	134	2.736
Floor	Reinforced concrete with cement plaster	110	3.937
Roof	Reinforced concrete with cement plaster	110	3.937
Window	Single pane ordinary glass	5	6.0
Door	Wooden solid core flush door	35	0.33

8.1.2 Energy Simulation

Design builder was adopted for energy simulation after evaluating various software for their accuracy of energy calculation, data input capacity, and complexity of the energy consumption analysis. Design Builder runs energy calculation based on the weather data file from SWERA, local climate of the location, site orientation, building design, construction materials and their thermal properties, building use, and other details. It is recent software for simulating energy, lighting level, HVAC and other building modeling. A three dimensional building was created at first. The size of openings, construction material specifications and building element properties were defined. Then parameters for lighting HVAC, heating, cooling, building use etc. were entered. Building location, site orientation and construction materials were based on the design of the housing. For the appliances and their use, specifications used are based on the close observance of lifestyle of people of Kathmandu. Those assumptions are shown in the table below:

Table 8-2. Fixtures and Appliances Used in the House

Appliances	Types	Watt	Nos.	Hours /Day	No. of Days	Total kWh/Yr	Remarks
Lighting	FTL	40	12	6	365	1052	
	Incandescent	60	10	1	365	219	
	Decorative	40	5	1	365	73	
Cooling	Ceiling Fan	25	7	3	120	63	
Cooking	Microwave	900	1	1	365	329	
	Blender	375	1	0.285	365	39	
Miscellaneous	Refrigerator					1200	Specs
	Washer					800	Specs
	Computer	300	3	6	365	1971	
	Television	150	1	0.4	365	22	
	Iron	1000	1	0.4	365	146	
	Vacuum	300	1	0.4	365	46	
	Other	200	1	1	365	73	
Total						6,033	

Similarly, the HVAC energy consumption was simulated, using the attributes described below, in the Design Builder:

a. Set Back Temperature: Changing the thermostat back to 10 to 15 degrees significantly reduces the energy consumption (EERE, 2010). Therefore, the set back temperature was set 10 degrees below and above the comfort temperature.
b. Fuel Type: The energy source to operate the HVAC was grid electricity

c. Comfort Range: Comfort Range was taken from Effective Temperature graph, which is 22°C to 27°C.

d. Natural Ventilation: Natural ventilation was used in the design, because it can also be used to lower the temperature, especially during the summer nights when the outside temperature is lower than the inside temperature (EERE, 2010).

e. Mechanical Ventilation Cooling: In residential HVAC installation, mechanical ventilation is generally not used because of low occupancy, and hence it was neglected in the design.

f. HVAC: For HVAC system, the Packaged DX system was chosen, because in smaller buildings, it requires lower operational energy, has lower installation cost, and can be installed in a small area or even perimeter wall of the building.

g. Supply Air Temperature: Supply air temperature is the temperature of cool or warm air that is supplied by the HVAC unit. It is generally 10°C for cooling mode and 29°C for heating mode (EERE, 2010).

h. COP: Coefficient of Performance (COP) is the ratio of the output energy to the input energy. It gives the efficiency of a heat pump or chiller. The typical range of COP for residential HVAC is 2.3 to 2.9 (ESMD, 2010). In the research, COP of upper limit is taken and rounded up to 3.0.

i. Supply Air Humidity Ratio: It is the ratio of the mass of water to the mass of dry air of the supply air. From the Psychrometric chart, absolute humidity ratio can be considered to range between 4 to 11 $gmkg^{-1}$ of air.

j. Auxiliary Energy: It refers to the amount of energy supplied by heating or cooling equipments and the software automatically selected this value as 8.7 $kWhm^{-2}$.

Table 8-3. Assumptions for HVAC Calculations

HVAC Parameters	Value
HVAC- Packaged DX system	
Comfort Range	22-27°C
Heating Set Back	10°C
Cooling Set Back	37°C
Natural Ventilation Cooling	On
Mechanical Ventilation Cooling	Off
Equipments	Off
Cooling Supply Air Temperature	12°C
Heating Supply Air Temperature	35°C
COP	3.0
Supply Air Humidity Ratio (g/g)	0.01
Fuel- Electricity	Grid
Auxiliary Energy (kWh/m^2)	8.7

It can be seen that the total energy consumption for lighting is 1344 kWh per year (Table 8-4). For the appliances, the total energy consumption in a year is 4689kWh. From the Design Builder software, the total energy consumption for HVAC use was calculated as 13,494 kWh per year (Table 8-4).

Table 8-4. Energy Consumption for Reference Case

Energy	Lighting	Appliances	HVAC	Total
kWh	1344	4689	13,494	19,527

In Kathmandu, most of the houses use solar energy for water heating. The reference housing unit also has a solar water heater. As the solar water heater uses a renewable energy source, it has not been considered in energy analysis of this research both in the reference and the proposed case.

8.2 Proposed Building

The proposed building is a simple modification of the reference unit with the passive solar design strategies, and recommendations drawn in the last chapter. The area of the unit is 53 square meters in the ground and the first floor, and 40 square meters in the second floor. In the design of the proposed unit, passive design strategies have been applied. Openings in the northern facade are reduced as much as possible and increased in the southern façade. Similarly, windows are shaded with horizontal shading devices. The sizes of the openings are about 40% of the floor area in all the rooms, which is enough for daylighting. In addition, every room has windows on two sides for natural cross ventilation. The windows on the west are smaller than on the north or the south for effective air circulation.

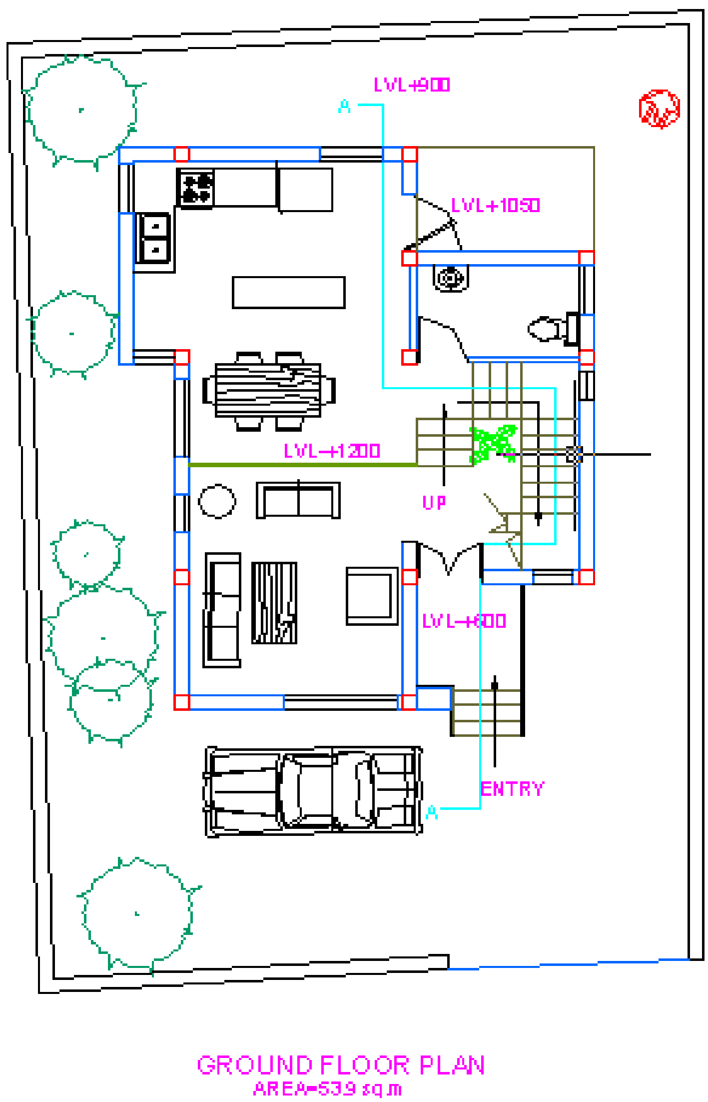


Figure 8-5. Proposed Case- Ground Floor Plan

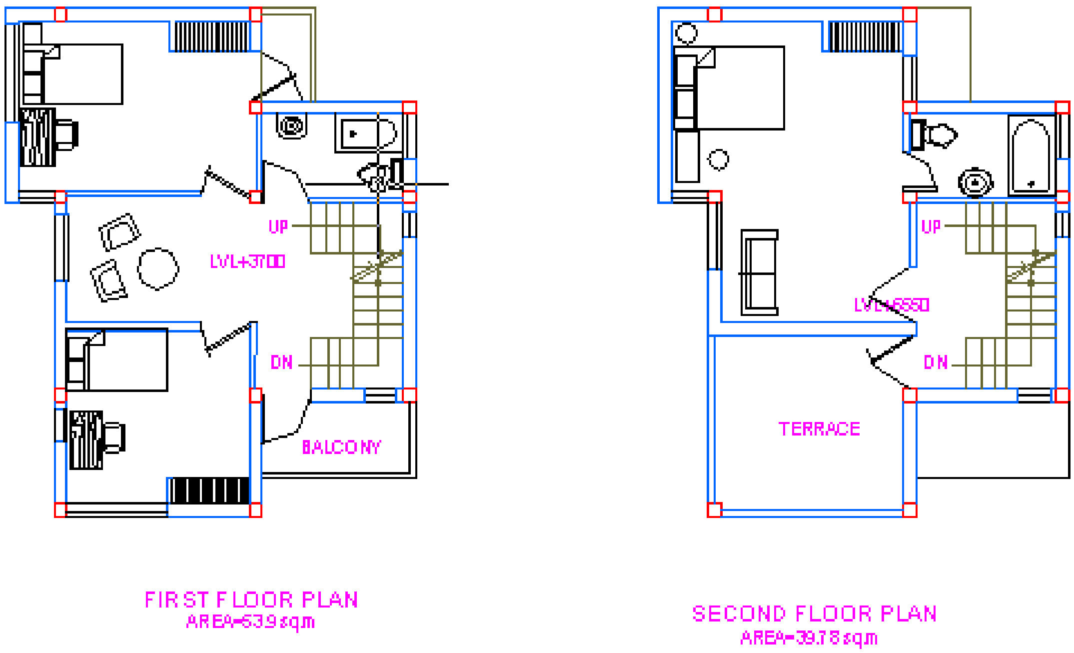


Figure 8-6. Proposed Case- First and Second Floor Plan

The construction materials for the proposed case are similar to the reference except that the walls in proposed are externally insulated the openings are double glazed. The U-value of the external walls, the roof, and the windows is decreased to almost half by the use of insulation and double glazing.

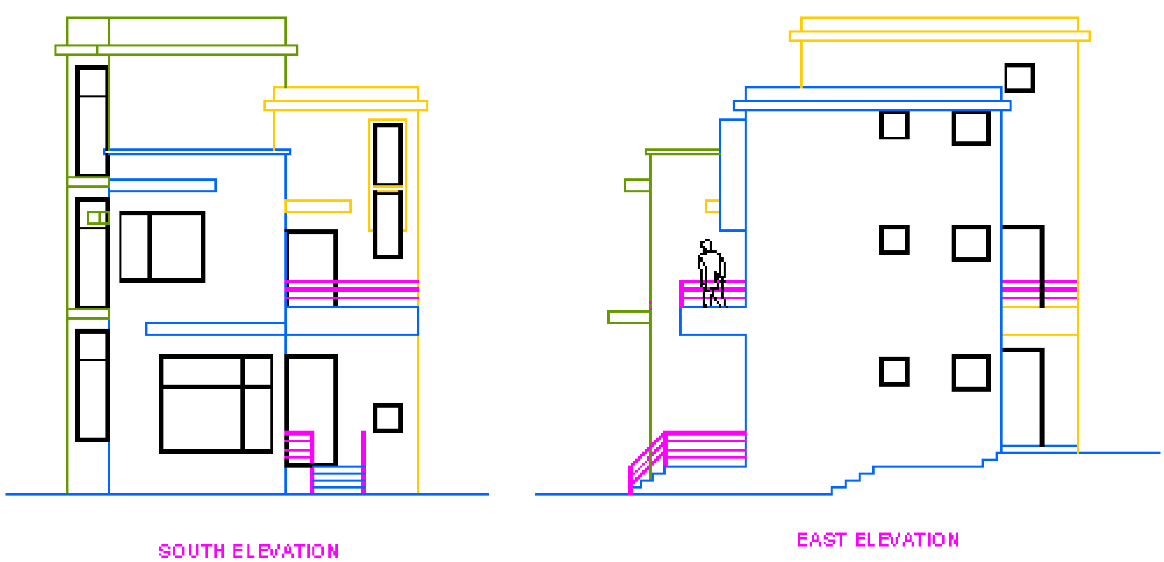


Figure 8-7. Proposed Case- Elevations

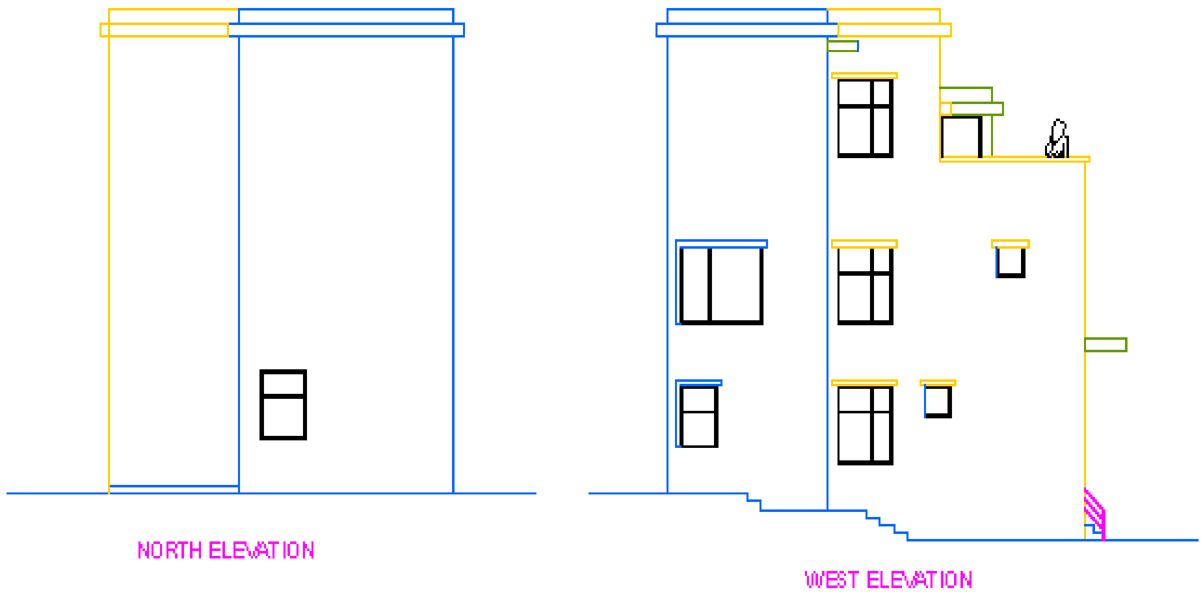


Figure 8-8. Proposed Case- Elevations

Table 8-5. Specification of Construction Materials

Building Element	Construction Material	Thickness (mm)	U-Value W/ m^2°C
Exterior Wall	Brick with polystyrene external insulation	294	0.695
Interior Wall	Brick with cement plaster on each side	134	2.736
Floor	Reinforced concrete with cement plaster	110	3.937
Roof	Reinforced concrete with suspended insulation	460	0.54
Window	Double pane ordinary glass	5	3.0
Door	Wooden solid core flush door	35	0.33

8.2.2 Energy Simulation

For the proposed case, the interior fixtures and appliances were also selected on the basis of their energy efficiency. The schedules of appliances (Table 8-6) and the building use were set constant. For the HVAC calculation, the parameters for the system were not changed to estimate energy reduction due to the implementation of passive solar design strategies.

Table 8-6. Fixtures and Appliances Used

Appliances	Types	Watt	Nos	Hours /Day	No. of Days	Total kWh/Yr	Remarks
Lighting	FTL	13	20	6	365	570	
	Incandescent	60	10	1	365	219	
	Decorative	40	5	1	365	73	
Cooling	Ceiling Fan	25	7	3	120	63	
Cooking	Microwave	900	1	1	365	329	
	Blender	375	1	0.285	365	39	
Miscellaneous	Refrigerator					1200	From Specs
	Washer					800	From Specs
	Computer	300	3	6	365	1971	
	Television	150	1	0.4	365	22	
	Iron	1000	1	0.4	365	146	
	Vacuum	300	1	0.4	365	46	
	Other	200	1	1	365	73	
Total						5,551	

The total energy consumption for lighting is 862kWh per year. For other appliances, the wattages were assumed constant as no energy efficient appliances were found. The total energy consumption for the appliances is therefore 4689kWh (Table 8-8). Similarly, the energy consumed by HVAC for heating and cooling was 2965 kWh.

Table 8-7. Assumptions for HVAC Calculation

HVAC Parameters	Value
HVAC- Packaged DX system	
Comfort Range	22-27°C
Heating Set Back	10°C
Cooling Set Back	37°C
Natural Ventilation Cooling	On
Mechanical Ventilation Cooling	Off
Equipments	Off
Cooling Supply Air Temperature	12°C
Heating Supply Air Temperature	35°C
COP	3.0
Supply Air Humidity Ratio (g/g)	0.01
Fuel- Electricity	Grid
Auxiliary Energy (kWh/m^2)	8.7

Table 8-8. Energy Consumption for Proposed Case

Energy	Lighting	Appliances	HVAC	Total
kWh	862	4689	2965	8516

8.3 Energy Comparison

Compared to the reference case, the energy consumption for lighting is reduced by about 35% and for the HVAC is reduced by about 56% (Table 8-9) in the proposed case. The total energy consumed in the proposed case is reduced by 56% from that of the reference case. This reduction is by the use of passive design strategies applied in the proposed case, the use of construction materials that have good thermal properties, and the use of energy efficient lighting fixtures.

Table 8-9. Energy Comparison between Reference and Proposed Case

Building Cases	Lighting (kWh)	Appliances (kWh)	HVAC (kWh)	Total Energy Consumed (kWh)
Reference	1,344	4,689	13,494	19,527
Proposed	862	4,689	2965	8,516
% Reduced	35	0	78	56

8.4 Active Energy

As discussed in chapter four, photovoltaic (PV) is the best option of renewable energy for residential building in the context of Kathmandu. The total energy consumption per year for the proposed house was 8516kWh. Using the web based tool called “solar calculator”, the total number of panels required for generating 8156kWh of energy per year was calculated as 20. The size of the panels selected was 1.32 meters in length and 0.86 meters in depth. This covered an area of approximately 23 square meters. The PV system also has batteries which are charged by solar energy.

8.5 Water Management

Average annual rainfall in Kathmandu is 1540.80 mm (Table 8-10). The rainfall data shows that there is significant amount of rainfall from May to September and is minimum October to April. During the rainy season, the rainwater could be harvested for household water consumption thereby reducing the water dependency from the local utilities. This also reduces the monthly water bill.

The catchment system for rainwater is the concrete roof. The first 10 to 15 minutes of rain water is used to flush dust, leaves, bird droppings etc. This water can be used for watering the front and the back yard or can be discharged into underground storm water catchment area. The second round of water can be collected into an underground tank. The average water consumption per person per day varies from 27 liters to 200 liters (John Hopkins School of Public Health, 1998). In the developing countries, 100 liters per person per day is usually taken for rain water harvesting calculation. The number of people living in the house is assumed as four. The amount of the water to be harvested based on the above assumptions is calculated as below:

Calculation of size of water tank:

Catchment area (Roof) = 50 m^2

Water consumption = 100 liters per person per day

Number of people living = 4

Period of water to be stored = 30 days

Size of tank = 100 X 4 X 30 = 12000 liters = 12 m^3

The minimum rainfall required to fill the tank = 12/50 X1000 = 240mm per month

Therefore, the size of the tank for the rainwater harvesting is 12000 liters which is designed underground. This water is then pumped to solar water heater and rooftop tank for gravity flow in bathrooms and kitchen. This rainwater can be used for household activities or also for drinking. To make the water safe to drink, additional filtration should be done along with some treatment such as reverse osmosis or ultraviolet irradiation. The minimum amount of rainfall required to fill the tank is 240mm. The access rain water after filling the tank could be recharged into ground.

8.6 Summary

One housing unit of the entire housing project was taken for the analysis of the research. The housing taken as reference case for analysis was a three-bedroom unit. It was constructed in a reinforced concrete structure with brick walls and concrete roof. There was not any type of insulation on walls and roof. Openings were single glazed. The electric appliances and fixtures use were assumed based on observance of lifestyle of people of Kathmandu. Energy simulation was run using Design Builder software. The total energy consumed for lighting, appliances and HVAC were respectively 1344 kWh, 4689 kWh and 13,494 kWh.

The reference design was then modified based on the recommendations drawn in the previous chapter. The area of the proposed housing was almost same. The assumptions for electricity and HVAC use were also kept same so as to compare the energy reduction due to passive solar design and energy efficient fixtures. The energy simulation results showed that the total energy for lighting, appliances and HVAC were respectively 862 kWh, 4689 kWh and 2965 kWh. The total energy consumption was 8516 kWh. From the energy comparison, it was concluded that the energy efficient fixtures can reduce 35% of the lighting energy. Similarly, the passive solar design can reduce the energy for heating and cooling of housing by 78% and the total energy consumption can be reduced by 56%.

Similarly, a solution of water management within a housing unit was also proposed in the research. In a housing case in Kathmandu, rain water harvesting would be a good option because of plenty of rainfall, easy in installation and efficient management. The period for which the water to be harvested was assumed for 30 days. Calculation showed that the total water needed to be harvested for 30 days was 12000 liters. For this 240 mm of rainfall is required to fill the tank.

CHAPTER 9
CONCLUSION

9.1 Conclusion

This research was conducted in one of the real housing projects in Kathmandu with an objective of finding how much energy can be reduced if passive solar design strategies are applied to the same housing unit. The research was limited to single housing unit design and not the entire housing complex, and also not in a planning level. All the passive design principles and the sustainability principles were adopted in the design, e.g., orientation of building, opening design for solar radiation and natural ventilation, shading, overhangs, vegetation and landscaping. The building's thermal performance was also increased by using low U-value materials for building envelope. Similarly, energy efficient fixtures were used for lighting. Using Design Builder software, simulation of energy consumption was run and the reduction in energy for HVAC and lighting was 78% and 35% respectively. The remaining energy was supplied using PV system. Similarly, rain water harvesting was also proposed in addition to city supply for household water use. The research result showed that rainwater could be harvested for at least a period of four months.

9.2 Recommendations for Further Research

This research was based upon the recommendations drawn from the study of climate and vernacular architecture of Kathmandu and applied to one housing unit. Sustainable housing incorporates wide range of built environment. So there are still several areas where further research can be done for sustainable housing design in the context of Kathmandu. Some of the recommendations for future study are discussed in the following paragraphs:

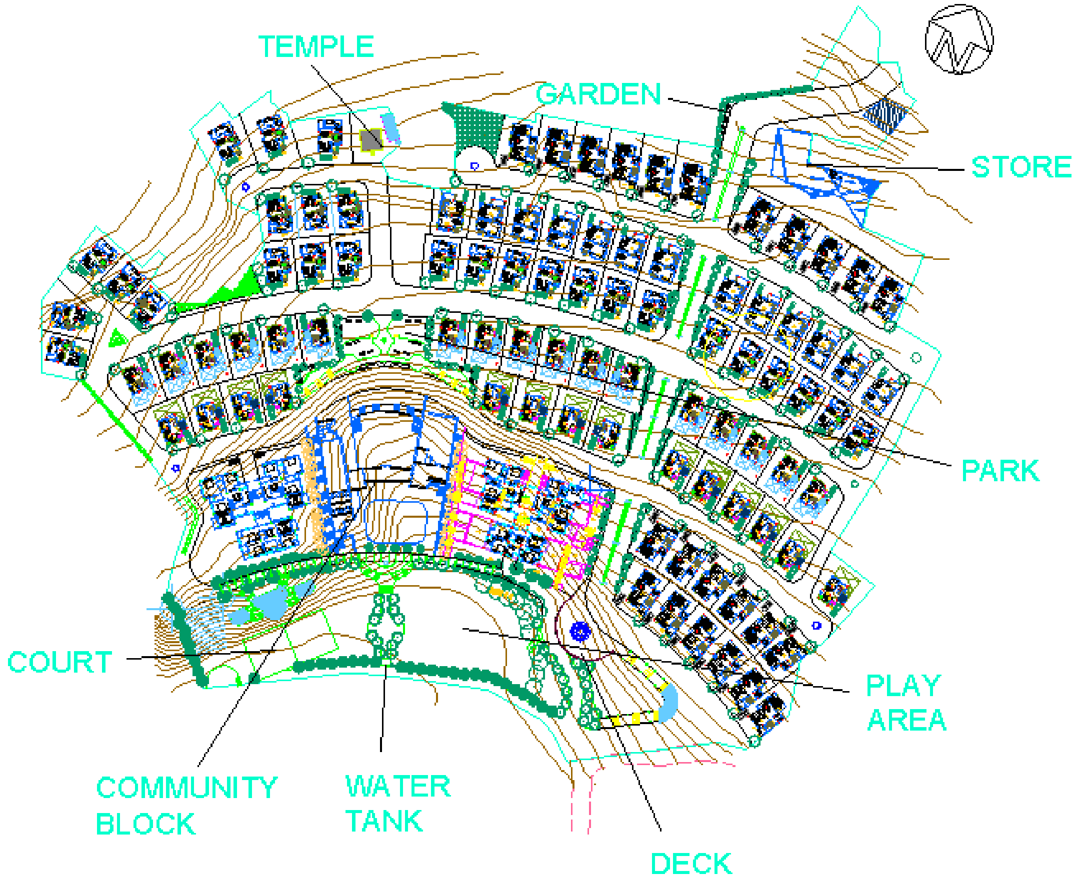
This research was conducted to analyze the heating and cooling load with light wall with insulation. Heating and cooling energy consumption with the construction of heavy thermal mass can be simulated to see if significant energy load can be reduced for HVAC.

Lifecycle analysis of building and cost is also important part of sustainable construction. Future research can be done to see if overall lifecycle of building significantly changes or not.

Maintaining the quality of indoor environment may be an area in which future study can be done. Similarly, significant amount of waste is generated during construction and operation of housing. For this, waste management can be another area of further research.

This research focuses on the design of a single housing unit of the entire housing complex. There are other phases of sustainable housing development where further research can be done such as in planning, development, maintenance and deconstruction. Similarly, Socio-cultural sustainability of community living or housing can be another area of future research.

APPENDIX: MASTER PLAN OFHOUSING



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Prakash's research interests are in the field of green construction and sustainable built environment. He looks forward to using his knowledge and research skill in the sustainable development. He is U.S. Green Building Council LEED Accredited Professional (LEED- AP).