Energy Efficient Building in Kathmandu Valley – A Case Study of Passive and Contemporary Residential Building

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Abstract: In Nepal, energy consumption by residential building accounts for 89% of the total national energy consumption [3]. The increasing urbanization and modern lifestyle has further enhanced the energy consumption in the building sectors. Building energy efficiency is the first step toward achieving sustainability in buildings. Energy efficiency helps control rising energy costs, reduce environmental footprints and increase the value and competitiveness of buildings. It helps to find out the most efficient way to use the energy, identifying the potential savings and also reducing environmental impacts. This research has focused on the measure of building energy audit in contemporary residential buildings of Kathmandu valley. Energy consumption data would provide the initial baseline for the energy use pattern in residences of Nepal, mainly focusing in Kathmandu valley. Furthermore it has also focused on opportunities and challenges of energy reduction methods and technologies for optimum building energy use in household sector. The final output will be derived by calculating the total energy saved through improved energy performance of building.

Keywords: energy efficiency, energy audit, energy consumption.

1. Introduction

Energy efficiency has become one of the growing issues all over the world. Energy use in buildings currently account for about 32% of the global total final energy consumption in the world. In terms of primary energy consumption, buildings represent around 40% in most countries and 65% of the total electric consumption [1]. In Nepal, the energy consumption by residential buildings accounts for 89% of the total energy consumption of national consumption [3]. The recent CBS data shows that the number of individual household in Nepal is 54,23,297 with population growth rate of 1.3 per annum and average household size of 4.88 which is an indication for the rise of energy usage in the future in the buildings sector [2].

The residential sector consumed almost 89% of the total energy consumption of Nepal in 2008/09. Biomass resources are the major fuel used in this sector. Recently renewable sources like biogas and electricity from micro hydro and solar homes systems are substituting conventional fuels used mainly for cooking and lighting [3].

The increasing urbanization and modern lifestyle has further enhanced the energy consumption in the building sectors. Besides that, the energy consumption is increased due to the poor thermal construction of the residential buildings that does not refer climate and does not fulfill the comfort limit of the occupants in the residence. This is a vital sign for the change in our consumption pattern via building energy efficient buildings.

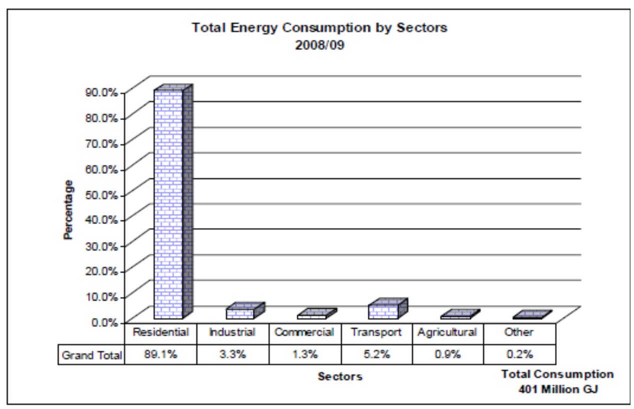

Figure 1 Sectoral energy consumption
Source: [3]

The use of energy efficient buildings accounts for a large share of the total end use energy. This includes energy used for controlling the climate in buildings and for the buildings themselves, but also energy used for appliances, lighting and other installed equipment.

Given the long lifespan of most buildings, the relative energy efficiency of new buildings will influence energy consumption for many years. Energy efficient improvements can reduce the demand for and costs of cooling and heating systems.

Building energy efficiency is the first step toward achieving sustainability in buildings and organizations. Energy efficiency helps control rising energy costs, reduce environmental footprints, and increase the value and competitiveness of buildings. Sustainability is all about using the resources of today efficiently, in a manner that meets our own needs, but doesn't compromise the ability of others to meet their own needs in the future.

2. Methodology

This study is a qualitative research in which data are collected in the field. The research has been carried out step by step. The process of research methodology is divided into three stages. The first stage begins with the literature review aimed to raise the research questions and develops the research. It is followed by preliminary study of energy situation in residential buildings ending in selection of field study areas. Based on the variable identified, a study starts in the field. The second stage begins with mainly the field study with qualitative surveys of energy use and performance of contemporary residential buildings. The questionnaires are designed, tested and developed for qualitative surveys for field. This stage contains collection of data, followed by data coding, error checking and tabulation. The third part contains data analysis, followed by testing and triangulation, aiming to draw the final conclusions and recommendation and directions for future research. All the data collected household questionnaire survey from field was analyzed statistically with the help of computer software.

The main purpose of research is to discover the energy consumption in contemporary residential buildings. At the very first, the reference buildings will be identified and finalized for the data. The reference buildings studied shall be contemporary two and half storey residential building of Kathmandu valley. The family size consists of 4 to 6 family members. Such buildings are mostly newly built in the valley. So the housing sectors will be chosen for the case study. The planning, material and technology of these buildings shall be analyzed. The detail of energy use pattern for lighting, cooking, heating and cooling shall be carried out. In this sense, the main research focuses to field study with monitoring energy consumption of different residences per year. It contains evaluation of energy use of buildings with field data, sample analysis, followed by discussion and aiming to draw the results and conclusions. The qualitative method adopted as household questionnaire survey of energy use by the residents of different buildings of Kathmandu valley. The objective of qualitative household questionnaire survey is to study the energy scenario of local people in residential building. The analysis, discussion and results are further compared and draw the conclusion in this study.

3. Sample Size Calculation

The sample size for this research has been determined with the help of sample size calculation software. The population size has been taken from national report 2011. The total population size of Kathmandu valley is 25,17,023 that include population of Lalitpur, Bhaktapur and Kathmandu [2]. The confidence level is 95% and confidence interval taken is 9.5%. The sample size determined is 107.

Sample Size Calculation					
Confidence level	95%	95%	95%	95%	95%
Confidence Interval	6%	9.75%	7%	9.50%	9.60%
Population Size	2517023	2517023	2517023	2517023	2517023
Sample Size	267	102	196	107	105

4. Energy Efficiency Measures

Energy efficiency in building can be attained through three main factors:

- Reduce heating, cooling demand
- Utilize renewable energy sources
- Increase efficiency of heating and cooling equipment

Heating and cooling demand in a building are influenced by orientation, building envelope, thermal mass, natural ventilation and sun shading. Using renewable sources for operational phase of building contributes significantly in whole energy efficiency scenario. For instance use of solar thermal for hot water and space heating and cooling. Photovoltaic for electricity and heat pumps. Efficient appliances for heating and lighting increases energy efficiency in buildings.

5. Case Study

5.1. Investigated Contemporary residential building

The reference building for the study has been divided into two types. The first one is contemporary residential building normally built in the valley which is also a general permissible building to built according to building bye-law of Kathmandu valley i.e. two and half storey building. The reference buildings are taken from Civil Homes, Phase III, and Binayak Colony. For the study, 38 houses of Civil homes and 35 homes of Binayak Colony were selected. The rest of 34 houses were selected from contemporary houses in Kathmandu valley. The common characteristic of this building is that it is built in area of 3 anna to 8 anna, built with RCC structure, bricks and cement mortar for a family size of 4-6 people.

Figure 2: Civil Homes, Phase III

Figure 3: Binayak Colony

5.1.1. Civil homes, Phase III, Sunakothi

The building is rectangular in shape. The ground floor has living room with dinning space, kitchen and common toilet. The first floor has either two or three bedrooms varying from house area. The second floor has puja room and open terrace. The windows are made of wooden frame with single glazed glass of 6mm. The windows cover nearly 8% of total floor area. The walls are usually 9" thick at the exterior of the house and 5" thick at the inner partition. The walls are built from brick and cement mortar. Sun dried brick are used for both interior and exterior walls. Both exterior and interior walls have cement plaster after brick wall with 2 coats of paints outside. The roofs are flat and has terraces finished with floor tile above the RCC floor.

5.1.2. Binayak Colony, Bhainsepati

The building is rectangular in shape. The ground floor has living room with dinning space, kitchen and common toilet. The first floor has either two or three bedrooms varying from house area. The second floor has puja room and open terrace. The windows are made of aluminium frame with single glazed glass of 6mm. The windows cover nearly 8% of total floor area. The walls are usually 9" thick at the exterior of the house and 5" thick at the inner partition. The walls are built from brick and cement mortar. Sun dried brick are used for both interior and exterior walls. Both exterior and interior walls have cement plaster after brick wall with 2 coats of paints outside. The roofs are flat and have been finished with floor tile above the RCC floor.

5.1.3. Other Contemporary buildings

The buildings are mostly rectangular in shape. The other features of building are similar to houses of Civil homes and Binayak Colony.

Table 1: Calculation of U-value of Contemporary building

Calculation of U-value of Contemporary Building (W/m2K)	
Brick Wall (230mm thick burnt brick)	1.93
Concrete Roof (110mm)	2.87
Window (Single Glazed)	5
Energy Consumption per year (kwh/year)	1337.48

5.2. Investigated energy efficient residential building

The study of energy efficient building has been limited to the study of Mato Ghar of Buddhanilkantha. Since there are no other passive building existing in Kathmandu particularly the residences, the study of energy efficient building has to be limited to single case study. The building has been taken only as the reference and study of other passive solar techniques in the building rather than its direct comparison with contemporary building in its energy consumption.

Mato Ghar Buddhanilkantha:

Figure 4: Mato ghar of Buddhanilkantha

Mato Ghar of Buddhanilkantha is single storey residential building. It is built in an area of 2000 sq. ft. The main feature of this building is it has been designed and constructed with passive solar techniques. Mud is the main component of this building and thus has been named as "Mato Ghar". It also has other passive solar technology integrated in the building like solar photovoltaic panel and solar water heater. It also has floor heating through solar water heating but has not been used yet.

Building Form and use:

The building is rectangular in shape and all the room has been arranged linearly along east west direction. All the living spaces have been placed on the southern side while other utility rooms have been placed towards north. The living room, bed rooms are placed in south and kitchen, toilets, laundry and study room has been placed towards north.

The windows are made of double glazed aluminium panel with air cavity. The windows cover nearly 10% of total floor area. The windows provide clear lighting inside the building as well as insulate the outer noise to certain amount. The overhangs have been projected from roof so as to provide shade in summer and allow winter sun inside the room.

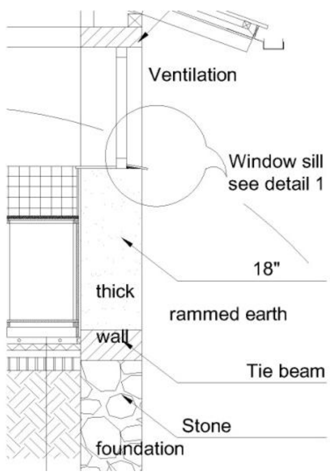

Figure 5: wall section of Mato Ghar

The wall is made of rammed earth. The walls are 18" thick at the exterior and interior partition of the house. The walls are reinforced at different level to resist the seismic forces. The walls are plastered with mud to give smooth texture externally and internally. The south facing walls have big windows to allow sun inside the building for lighting and heating while north facing walls have small windows to resist cold wind.

It has two way slope roof. The roof has insulation of 2" thick styro foam. the external layer of roof consists of 24 Guage hulas red, under it lies 2"X2" pinewood purlin, radiated aluminium sheet, 2" thick Styro foam insulation, 12 flatten bamboo and bamboo rafters. There is a gap between external layer and purlin which allows the heated air to rise above.

Table 2 Calculation of U-value of Passive building

Calculation of U-value of Passive Building (W/m2k)	
Rammed earth (18"thick)	0.37
Double Glazed window	3.06
Insulated roof	0.2
Energy Consumption per year (kwh/year)	274.8

6. Data Analysis

From the household survey in residential sectors following results have been found.

6.1. Energy use for cooking

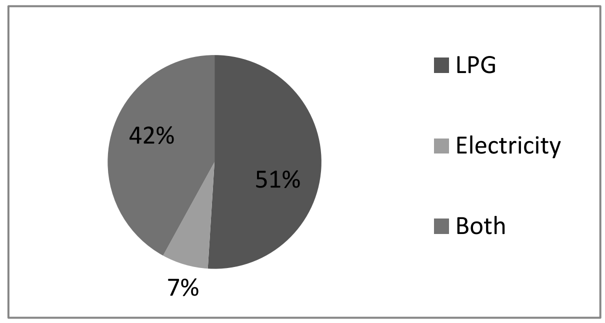

Figure 6: Energy use for cooking

In residential sector, most of the houses use LPG, i.e. 51% of the household used it for their cooking purpose. The use of electricity has been nominal which is only 7%. While most residences use both electricity and LPG for cooking, which accounts almost 42%. It was found that the use of electricity has been limited to use of rice cooker only. While there is no use of kerosene, wood and briquette found to be used for cooking.

6.2. Energy use for room heating in winter

It is found out that 82% consume energy for room heating and only 18% don't use any energy form for room heating in winter. Most of the residence uses LPG heater and electric heater in winter for room heating. 39% use LPG heater and electric heater, 12% use kerosene heater for room heating, 9% uses AC and 1% use firewood. For energy efficiency of building, instead of using non renewable energy like LPG heater, kerosene heater, it is better to switch to renewable source of energy like electricity and electric heaters. For more energy efficiency, designing a building as passive solar building can help to reduce the energy consumption in heating to zero.

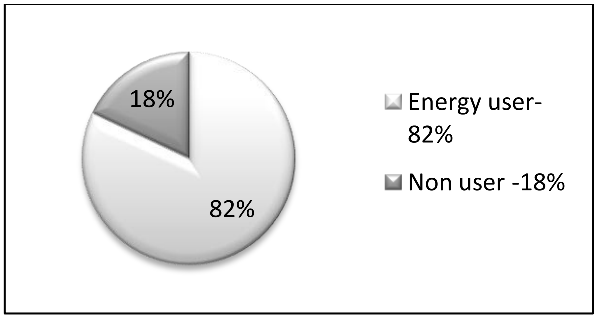

Figure 7: Energy user for room heating in winter

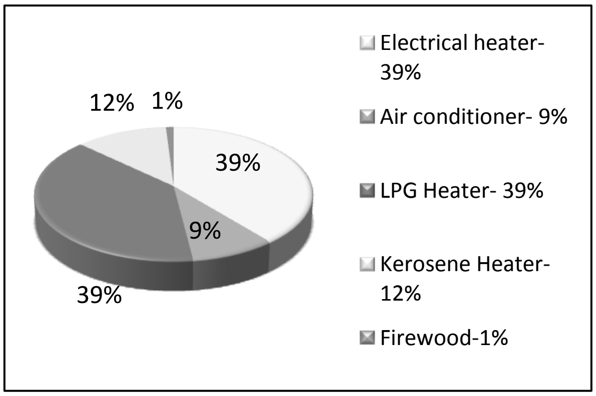

Figure 8: Energy use for room heating in winter

6.3. Energy use for room cooling in summer

For room cooling in summer, about 59% consumed energy for room cooling and 41% use natural ventilation. Most of the residences use an electric fan. 85% uses electric fan for room cooling and 15% use AC. The energy efficiency can be gained through less use of electric fan for room cooling and using existing natural ventilation in building. For this, building has to be designed according to wind direction in such a way that maximum natural ventilation passes through the building and consumes less energy for cooling.

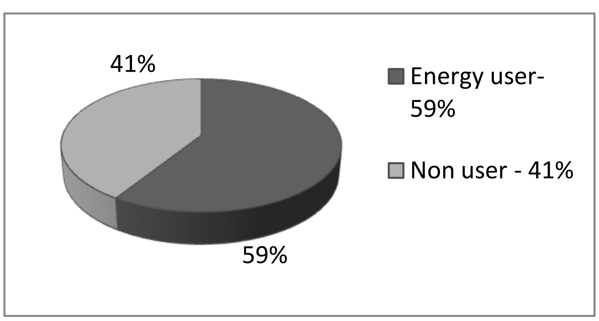

Figure 9: Energy use for cooling in summer

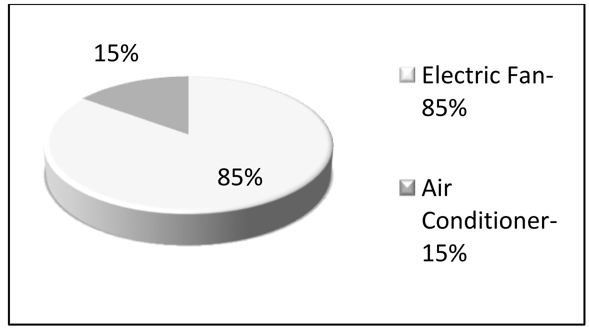

Figure 10 Energy use for room cooling in summer

6.4. Energy use for water heating for shower

About 72% use Solar water heater for water heating for shower, 20% use gas gyser, and 4% use electric coil and 4% use other measures such as boiling through LPG and use of water without heating. The percentage use of solar water heater has been high in this figure is because Binayak Colony has solar water heater installed in every house. The solar water heater is one of the renewable energy source measures for saving energy for water heating.

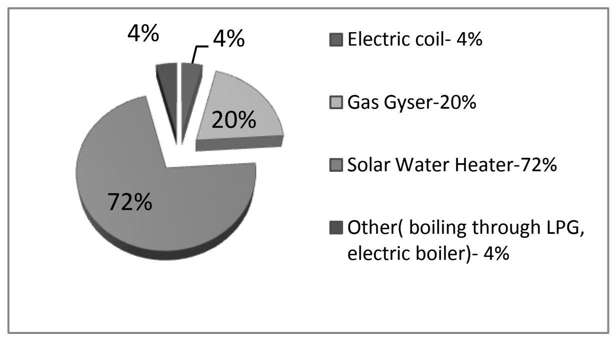

Figure 11: Energy use for water heating for shower

6.5. Electricity use for water pump

Most of the residences uses pump less than 3 hours/week for water pumping. On the survey, it was found that in Binayak colony water is allowed to flow in residences through gravity flow and thus the people don't have to use pump.

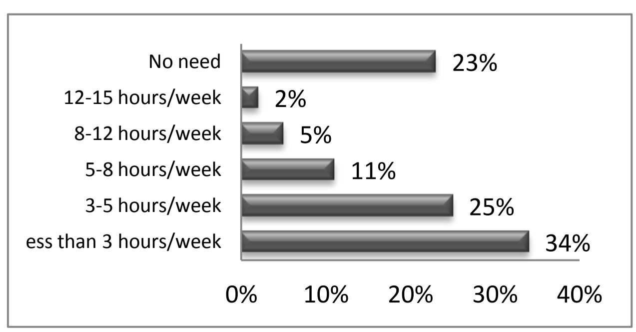

Figure 12: Energy use for water pumping

6.6. About rain water harvesting

About 81% of the household don't have rain water harvesting system. Only 19% of the household have rain water harvesting in their homes. Despite the sufficient availability of rain water in the valley, due to lack of knowledge and information, most of residences doesn't harvest rainwater.

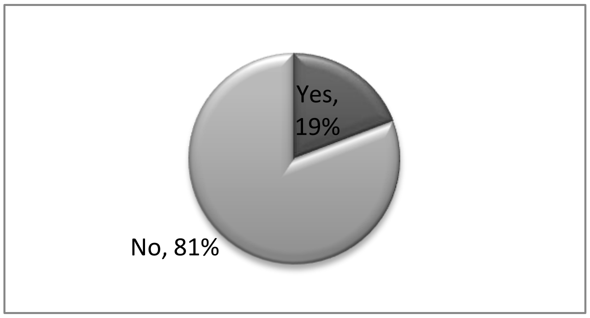

Figure 13: Rain water harvesting in homes

6.7. Installation of renewable sources of energy

About 66% of the household have renewable sources of energy. Among those who have installed renewable energy in their house, 26% have solar water heater, 8% have solar PV, 34% have both solar water heater and solar PV installed. The use of renewable source of energy is growing in the valley and only 2/3 of household are acquainted with the renewable energy sources. There's a lot of potential of renewable energy penetration in the household sector.

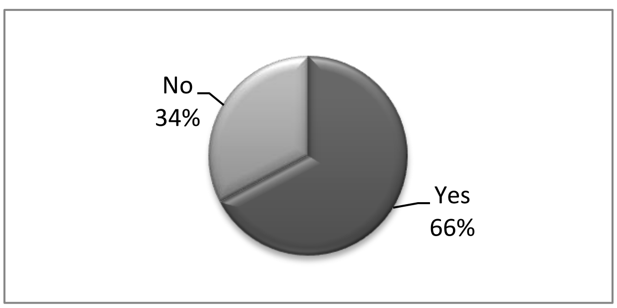

Figure 14: Installation of renewable sources of energy

6.8. Backup during load shedding

Load shedding has become the usual problem of Kathmandu valley. To provide the backup during loadshedding, 61% of the household uses inverter, 30% uses solar inverter and 6% uses torch, 2% use generator and 1% use others sources such as candles. Only 1/3 of household has solar inverter which is renewable source of energy. The use of inverter has also helped in raising the electricity consumption in the household. Hence to reduce this energy consumption during load shedding, solar PV inverters are recommended to use rather than inverter.

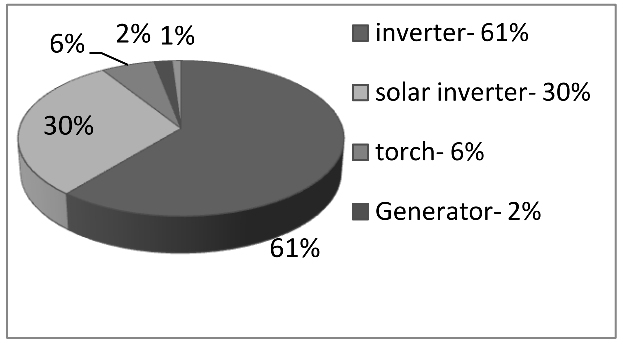

Figure 15: Backup used during load shedding

6.9. Uses of inverter

The inverter has been used mainly for lighting, then television, computer and laptops and some use for using fan and other appliances such as mobile charging.

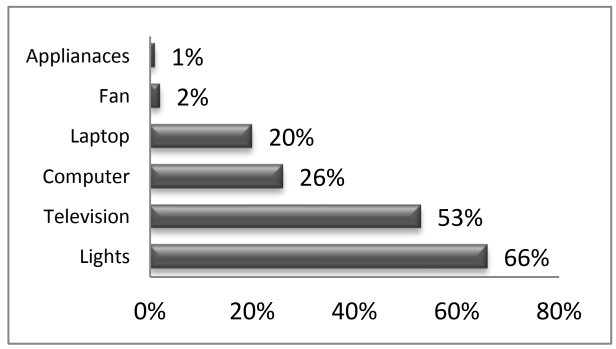

Figure 16: Uses of inverter

6.10. Electricity bill per month

Most of the household pay their monthly bill of electricity Nrs. 1000-3000 which is about 2% of their monthly income. About 52% household pay their bills of Nrs.1000-3000, 40% pay their electricity bill less than 1000 rupees and 6% of household pay within Nrs. 3000-5000 and 2% of household pay more than Nrs.5000.

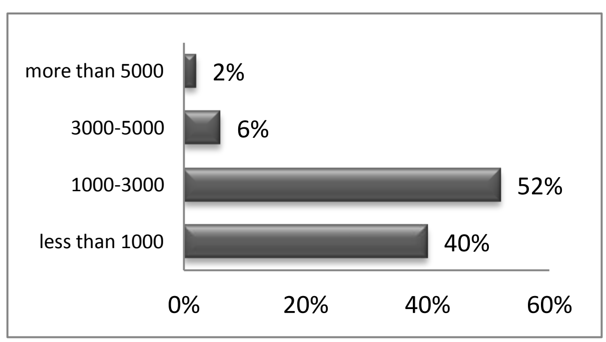

Figure 17: Electricity bill per month

6.11. *Waste Disposal*

Most of the household have their waster disposed privately. About 35% dispose waste privately, 32% disposes waste to municipal, 22% have mix way of disposing waste and 11% use composting method to dispose waste. In mix way of disposing, the waste is disposed by composting method for degradable material and for non degradable material they either dispose it to municipal or privately.

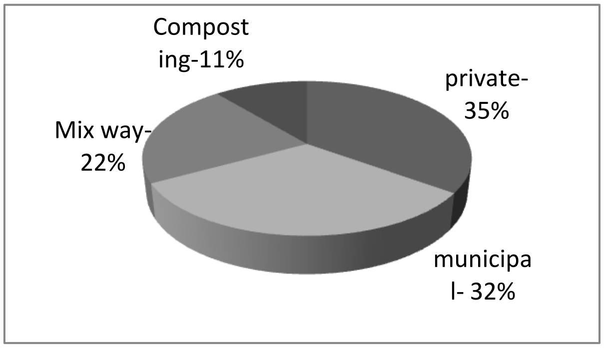

Figure 18: Waste disposal system

6.12. *Cost for transportation*

Non renewable energy such as fossil fuel has been consumed in the household sector in large amount as petrol for transportation. About 7% of the monthly income is spent in transportation. About 29% spent Nrs. 3000-5000, 16% spent Nrs. 5000-10000, 31% spent Nrs. 1000-3000 and 11% spent above Nrs. 10000 in transportation or in fossil fuel. Those who spent above Nrs. 10000 spent about 10% of their monthly income in non renewable energy.

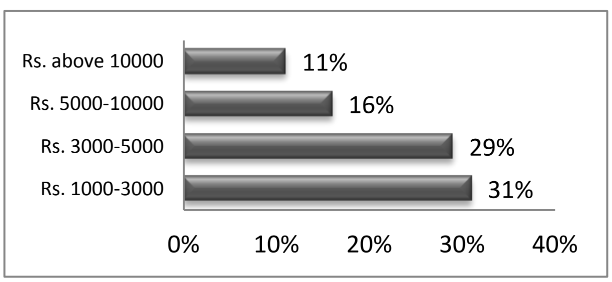

Figure 19: Cost for transportation

6.13. *Average energy consumption per household*

From the household survey, the average energy consumption per household per day was found out. The electricity is highly consumed for room heating for winter i.e. 1.41 KWh per day. The various electronic equipment such as refrigerator, iron, oven, vaccum cleaner, etc. consumes about 0.73KWh. Electric fan and AC consumes about 0.56KWh which is less than equipment used in household. The average lighting consumes about 0.48KWh and TV consumes about 0.11KWh. The average energy consumption per household is 3.3KWh. The energy efficiency can be attained through reducing the heating demand of the building, using energy efficiency equipments and lighting and through installation of renewable energy. The heating demand of building can be reduced through passive solar technologies and energy efficient equipments. The cooling demand can be reduced through passive design of building. While the use of energy efficient devices can helps to reduce the energy consumption in equipments.

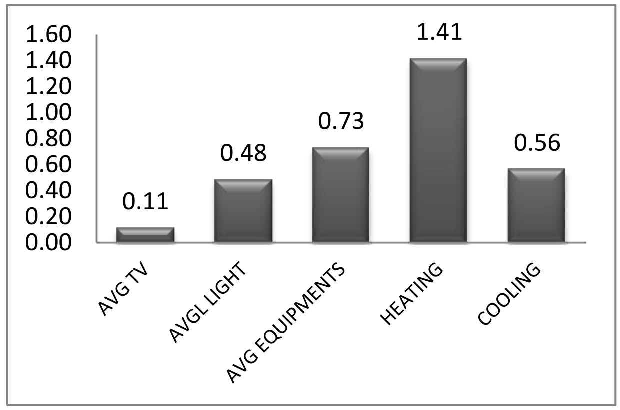

Figure 20: Average energy consumption per household

6.14. *Average energy consumption per household in lighting*

Lighting consumes less than half KWh energy per day in household. About 50% of the household use tube light. Only 37% use CFL Lights, 12% still use incandescent bulb and 1% use Led Light. CFL light is found to be used only in housing community. The other residence buildings around the valley still uses tube light for most lighting. The use of LED light is found to be very nominal in houses primarily due to its high cost and lack of its information.

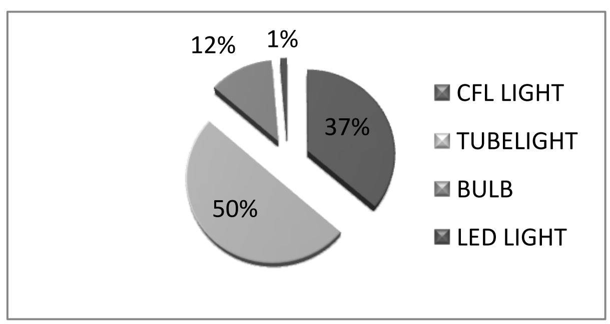

Figure 21: Average energy consumption in lighting

6.15. *Cost of electricity per month per household*

The average cost of electricity per month is Nrs.887.62. The yearly cost is Nrs. 6997.15 and daily cost is Nrs. 29.59.

6.16. *Cost of energy for 10 years of referenced buildings*

The cost for energy is nearly three times higher in contemporary building than in passive building at present and for next 10 years. The daily cost of energy for contemporary building is Nrs. 19.17 while for passive building it is just Nrs. 6.77. The energy consumption for passive building for lighting and other equipments is nearly half than contemporary building. Whereas, there is no need for any energy for heating and cooling because of its passive solar design. The passive solar design helps in saving 60% of its total energy consumption for heating and cooling.

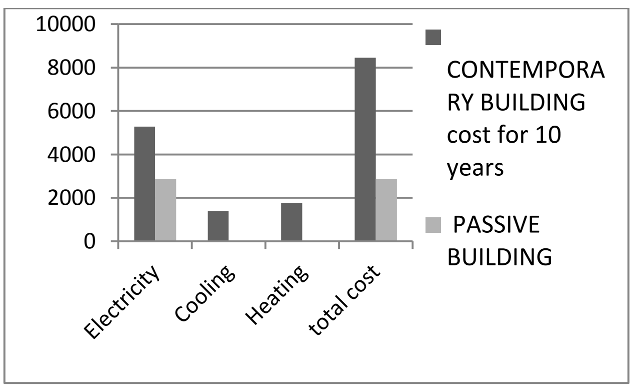

Figure 22 Comparative energy cost for 10 years

7. Heating Demand Analysis

For the heating demand analysis, three scenarios have been assumed as base case scenario and improved case scenario I and II. The base case scenario represents the present scenario of building in Kathmandu Valley. The other two scenarios represent the change of Base case scenario for analysis of heating loss from building.

1. Base Case

From the study of referenced building, the base case scenario has been generated. The base scenario represent the residential building in Kathmandu valley which are constructed with RCC, cement, concrete, burnt brick, sand and use of either wooden windows and door or aluminium door and windows. The heating and energy demand has been shown in table 1. Likewise, the heating and energy demand of passive building studied has also been shown in table 2.

The U-value of contemporary residential building is comparatively higher than passive building. This results in the higher energy demand in the summer and winter time in contemporary residential building. The energy consumption is nearly 4 times higher in contemporary building than in passive building since it doesn't have to use any devices to adjust with the climate in any season.

Table 3: Calculation of U-value, Improved scenario I

Calculation of U-value of improved contemporary building(W/m2k)	
Cavity Brick wall (230mm brick wall+ 50mm cavity+110mmsun dried brick)	0.71
Concrete roof with air cavity(floor finish+ wooden plank+air cavity+ rcc slab)	0.67
Double glazed window	3.06

2. Improved Case I

In this case, the buildings are intervened with energy efficiency measures known. Here the heating demand of building is examined from the U-value calculation of improved building material and construction. Instead of single leaf wall structure, the heat loss can be minimized through cavity wall construction. Single glazed window has been replaced by double glazed window and insulation has been provided in the roof. Table 3 shows that heat loss through wall can be minimized about 38% than in the base case. Similarly, insulation in roof can also provide about nearly 47% saving in heat loss compared to base case. While changing the window from single glazed to double glazed can save about 38% reduction in heat loss.

3. Improved Case II

Here the heating demand of building is examined from the U-value calculation of improved building material and construction. Instead of single leaf wall structure, the heat loss can be minimized through cavity wall construction along with sundried brick in inner leaf. Single glazed window has been replaced by double glazed window and insulation has been provided in the roof. Table 3 shows that heat loss through wall can be minimized about 60% than in the base case. Similarly, insulation in roof can also provide about nearly 76% saving in heat loss compared to base case. While changing the window from single glazed to double glazed can save about 38% reduction in heat loss.

Table 4: Calculation of U value, Improved case scenario II

Calculation of U-value of improved contemporary building (W/m2k)	
Cavity Burnt Brick wall (230mm brick wall+ 50mm cavity+110mm brick)	1.18
Concrete roof with air cavity(floor finish+ wooden plank+air cavity+insulation+ rcc slab)	1.5
Double glazed window	3.06

Table 5: Comparison Table of U-Value

U-Value				
	Contemporary building	Passive building	Improve case I	Improved case II
Brick wall	1.93	0.37	1.18	0.71
Concrete roof	2.87	0.2	1.5	0.67
Window	5	3.06	3.06	3.06

The Comparison of U-value of contemporary, passive building and improved cases shows that the overall U-value of Passive building is lesser than all other cases. It implies that passive building has comfortable environment during both winter and summer. Since orientation and site of building can't be varied to any parameters, but improvement in its building envelope, energy consumption can be reduced.

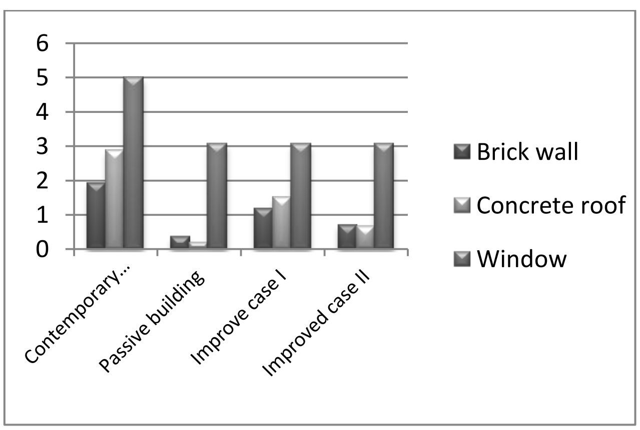

Figure 23: Comparison of U-value

8. Results and Discussion

This research has focused on study of energy consumption pattern of contemporary residential buildings in Kathmandu valley. From the research carried out following results have been found:

1. Heating and cooling consumes 60% of total energy consumption in contemporary building.
2. The contemporary building consumes 3 times more energy than the passive building.
3. The cost for transportation, i.e. cost for non renewable energy, petrol account for 7% of the total income which is more than cost for total monthly electricity bill.
4. The cooking energy is highly dependent on LPG with use of electricity only for rice cooking.
5. The energy cost for equipment use is higher than for lighting use.
6. The average energy consumption is high for heating which is 1.21 KWh per day. Other electronic equipments such as refrigeration, oven, vacuum cleaner, etc. consumes 0.73 KWh energy per day. While cooling consumes 0.56 KWh and lighting consumes less than half KWh per day i.e. 0.48 KWh.
7. The comparative U-value of building envelope of passive building is lesser than Improved case I and II.
8. The cavity wall construction can minimize 38% heat loss than 9" thick wall.
9. The cavity wall with sun burnt brick outside and sundried brick inside can minimizes 60% heat loss through walls.
10. Double glazed window can reduce heat loss to 38% than single glazed window.
11. Similarly concrete roof with cavity can save47% heat loss while insulation along with cavity can save about 76% heat loss than concrete roof without insulation.

This research is limited to study of contemporary residential building in Kathmandu valley as the required passive or energy efficient building is not available here. The study of energy efficient building in Kathmandu valley has to be limited to study of only one passive building of Kathmandu valley, Mato ghar of Buddhanilkantha. This research has not attempted to carry the direct comparison between the contemporary and passive building but tends to analyze the consumption pattern and behavior of contemporary and passive building. The study of passive building been taken just for the reference study and to study possible best used techniques that can be applied to contemporary building for energy efficiency. Beside it, this research has focused on energy efficiency through thermal performance of building materials only, the water efficiency and waste management have not been considered.

9. Conclusion and recommendations

Energy efficiency in building has become the growing issue for researcher all over the world. Construction of passive solar building could significantly reduce the heating and cooling energy demand as shown by energy calculation of Passive building in the case study. The improvement in contemporary building can be achieved through improvement in building envelope such as walls, roof and windows. The improvement of wall by cavity wall and roofing by insulation can reduced the energy consumption significantly. Improvement in glazing of window is must for increasing efficiency.

The following recommendations are drawn from this research.

Criteria	Contemporary building	Passive Building	Remarks for Improved contemporary building
Site	Rectangular in shape	Elongated in shape	Can be varied
Orientation	Vary with site	Oriented along east west direction at 10° inclination to axis	Preferred along east-west direction
Building form	Rectangular	Rectangular	Rectangular
Wall	9" thick brick wall	18"thick rammed earth	wall with low U-value
Windows	Single glazed	Double glazed	Double glazed
Roof	Flat rcc slab	Insulated slope roof	Insulated roof
Floor	5" thick Rcc slab	Insulated 4" thick cob floor	insulated floor
Energy consumption per day	3.29 KWh	0.76 KWh	
Energy cost per year	Nrs. 6997.15	Nrs. 2473.2	

For the general construction of wall, cavity wall with sundried brick in the inner leaf is recommended as it has lower u-value i.e. 0.71 W/m2k than the cavity wall with burnt brick at inner and outer leaf.

This U-value is based on traditional building of Kathmandu valley as user feels it more comfortable.

Double glazed window of U-value 3.06 W/m^2k is recommended to use. Beside thermal insulation it also provides sound insulation.

The roof should be insulated with air cavity in between so as to allow air to flow in between. Air being the good insulator, along with other insulating material it provides great insulation. The roof with U-value of 0.67 W/m2k is recommended to use.

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