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RESEARCH ARTICLE

COMPARATIVE PERFORMANCE ASSESSMENT OF ECO- FRIENDLY BUILDINGS AND CONVENTIONAL BUILDINGS OF KATHMANDU VALLEY

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ABSTRACT

Environment needs protection against ill effects of rapid construction. the performance assessment of existing eco- friendly buildings inside Kathmandu Valley by taking both eco- friendly and conventional buildings for case study and by comparing the obtained performance data of both type of buildings. This study is also an initial attempt to find out the new technologies and to observe the building materials that are being used in the existing eco- friendly buildings. Some new techniques and materials were also found to be used during the case study of Hama Steel complex. In unit area, embodied energy produced by Paudel residence was found to be 21.85% more than the embodied energy produced by Mato Ghar. Also, Paudel residence produced 11% of Carbon more than that of Mato Ghar. The calculation of U-Value of surfaces of eco- friendly buildings were found to be noticeably lesser than that of conventional buildings which means eco- friendly buildings have better thermal insulation than conventional ones. Also, 10%-15% additional building costs was found in both eco- friendly buildings whereas the operation and maintenance costs of those buildings were nearly 50% lesser than the conventional buildings. In terms of various parameters, the results show that the performance of existing Eco- friendly buildings of Kathmandu Valley is better in comparison to the conventional buildings. More eco- friendly building materials are introduced in such buildings producing less harm to environment.

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INTRODUCTION

Conventional building refers to a building built according to the common practice of a specific country in a specific period (Santori, 2007). In Nepal, the conventional building method has almost transformed from traditional mud and wood houses to cement concrete buildings. So, it is comprehensible that in today's context, Reinforced Cement Concrete (RCC) building construction is the conventional building construction, most specifically inside Kathmandu Valley. Rapid urbanization growth inside the valley has certainly increased number of concrete buildings which lead to the production of huge amount of carbon emissions and embodied energy during manufacture of the building materials that are being used in construction of these concrete buildings. Hence, the carbon footprint that are being obtained with the construction of these concrete buildings are causing environmental degradation which is one of the major ongoing issues of Kathmandu Valley. The haphazard increasing urbanization is a major concern of the city in which alternative building construction method Should be definitely explored. The Eco-Friendly Building Construction which is mainly focused on sustainability and Energy Efficiency could become the best alternative solution to balance such scenario (https://sustainabledevelopment.un.org/content/documents/challenges_and_way_forward_in_the_urban_sector_web.pdf). Eco- friendly buildings are constructed focusing primarily for the betterment of environmental resources with the combination of suitable construction techniques and materials. There are relatively very few Eco Friendly buildings inside the city that are designed and constructed in an energy efficient manner by using natural building materials along with other different green building features. The research studies has almost proved that Eco-Friendly buildings are the best solutions for today's world which are not only energy efficient and sustainable but are also comfortable and healthy for the occupants. But, only international research results are not enough to prove the betterment of Eco- Friendly buildings over the conventional buildings. There might be also several negative aspects of such buildings in local context. So, it is better to have a performance assessment of the existing green buildings along with the conventional buildings of similar nature and compare. The analysis and conclusion obtained by the comparison could help the designers, builders and clients to choose the right building

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technology and materials in today's timeframe. It might also help the policy makers to make certain policy about the green buildings if they are found to be convenient after the study.

Statement of the problem

Eco- Eco- friendly building design practices are relatively new concept and the history of such building only goes back a few decades. In around 1970s, due to the energy crisis, eco-friendly building moved from research to reality (Stone, 2011). In Nepal, design and construction of green buildings are still considered to be not so common and most of the customers/builders are not aware about the effectiveness and performance of those kind of buildings. Since this building concept is becoming widely popular in international building construction field, it definitely could be applicable in context of our building industries too. Therefore to acquire good knowledge and to find out the applicability of such buildings in local context, the comparative performance assessment should be done in detail. Although, many Non-Government Organizations (NGOs) and International Non-Government Organizations (INGOs) are running programs for the awareness and construction of green houses in local level, but again the majority of people are unknown about the fact of the importance of energy efficiency nor do they feel any responsibility for the issues of environmental degradation. In Kathmandu valley, there are some remarkable buildings which are built by following the methods and techniques of eco friendliness, though the outputs of the buildings are yet not analyzed broadly. Hence, the comparative performance assessment of existing eco- friendly buildings and conventional buildings could help people to understand more about the outputs of eco- friendly buildings in more practical manner.

Research Objectives

The major objective of this study is find out the performance difference between eco-friendly building and conventional building in context of Kathmandu Valley. The other specific research objectives are to compare the environmental, economic and social performance between the eco-friendly and conventional buildings, to identify the building materials that are being used in the existing eco-friendly buildings inside Kathmandu Valley.

Limitation of the Study

The study was limited in the buildings of Kathmandu Valley which were only specified by the building owners as eco-friendly building. Traditional buildings were not taken for the case study as eco-friendly buildings. Social measures were limited within the focus group discussion with occupants.

Literature review

Literatures were reviewed related with the building materials and techniques of both eco-friendly and conventional buildings, their performances, features and specialties for the comparison of the performances of both types of buildings.

Conventional Buildings

"Conventional Building" refers to a building built according to the common practice of a specific country in a specific period (Santori, 2007). These buildings are designed and constructed with common methods and techniques. Conventional Building Construction refers to the traditional method of construction where the construction knowledge is passed from one generation to the other and where new technologies and materials are barely utilized (Heng, 2017). The major building materials used in conventional buildings are concrete, brick, wood, stone, glass etc.

Eco- Friendly Buildings

Eco- friendly building which is also known as Green building or sustainable building refers to both a structure and the using of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition (Kukreja, 2016). Many research have shown that it benefits humans, the community, the environment, and a builder's bottom line. It is about tailoring a building and its site to the local climate, site conditions, culture and community, in order to reduce resource consumption while enhancing quality of life (Karolides, 2002). The main strategies to achieve a green building includes reduced energy consumption, water conservation and recycling waste (Hasegawa, 2003). Numbers of study have analyzed that eco- friendly buildings save running cost, increase comfort and create healthier environments for people to live and work, using improved indoor air quality, natural daylight, and thermal comfort. Energy use by depleting natural resources as well as CO_2 emissions is one of our most important environmental impacts. Volatile energy markets, rising energy costs and increasing environmental awareness about issues such as global warming make energy efficiency and conservation a high priority (Riddell *et al*., n.d).

Eco- Friendly Building Materials

Eco- Friendly building materials are those that provide appropriate service and life span, with minimum maintenance, while minimizing the extraction of raw materials, the pollution from and energy consumed by manufacturing and use, and that have the maximum potential of reuse or resource recovery (Haghighat and Kim, 2009). The search of environmentally building materials represents response from the building sector intended to reduce the environmental cost of making and using the building. Such building materials may come from traditional sources, such as earth and stone material, they may also come from existing industrial processes, found by life cycle analysis to be the most environmentally benign, or they may come from new processes or raw material inputs such as industrial waste or the waste stream of an industry.

Eco- Friendly Building Components

Eco- Friendly buildings incorporate principles of energy and resource efficiency. It deals with practical applications of waste reduction, pollution prevention, good indoor air quality, natural light to promote occupant health and productivity. It is also focused on transportation efficiency in design and construction, during use and reuse. All the components of eco- friendly building lead to sustainability. Figure below shows the overall life cycle of a sustainable building that enhanced the eco-friendly building components. Environmental Protection Agency (EPA) of USA defines eco- friendly building as: Eco-Friendly building (also known as green construction or sustainable building) as the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from sitting to design, construction, operation, maintenance, renovation and deconstruction (Brebbia and Zubir, 2015). There are several methods which can be used to achieve sustainability in buildings. There are six main relevant features widely used

1. Site and surroundings
2. Energy efficiency and renewable energy use
3. Water consumption
4. Indoor environmental quality
5. Materials use and management
6. Integrated design approach

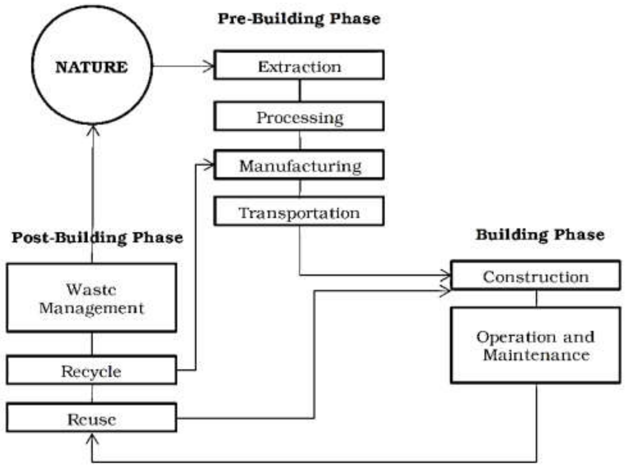

Figure 1. The sustainable building life cycle (Kim and Rigdon, 1998)

Performance Parameters of Eco- Friendly Buildings

This study considered eco- friendly building construction in the context of sustainable development. A building consists of four major phases as design; construction; operation and maintenance; and demolition. As given in figure, sustainable building means changing the process that cause pollution, non-renewable resource usage into usage of resource-efficient products and processes beneficial for environment and society during the phases of pre-building, building and post-building. The building processes should be analyzed in each of these three phases so that a better understanding of how a building's design, construction, operation and disposal can affect the larger ecosystem (Brebbia and Zubir, 2015). Hence as shown in figure 2.2, the parameters of green building performance can be further classified into environmental, economic and social measures.

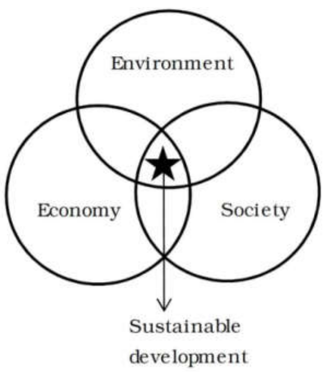

Figure 2. Triple bottom line of sustainable development (Parkin *et al*., 2003)

Environmental Measures

Environmental measures of an eco- friendly building includes embodied energy and carbon emission of the building during construction phase, energy consumption during operational phase and recycling/ reuse of the materials during dismantle phase. It is believed that the embodied energy and carbon emission produced in eco- friendly buildings are lesser than that of the conventional buildings. Researches also state that eco- friendly buildings consume less energy during operation time period. The internal built environment of the green buildings are also believed to be more satisfactory. Therefore, to find out the environmental performance, following measure calculations can be done:

Embodied Energy and Carbon Emission of Building Materials

The embodied energy is the energy consumed by all the processes associated with the production of a product from the acquisition of natural resources to the product delivery. This includes the mining and manufacturing of materials and equipment, the transport of materials and the administrative functions. Typically, embodied energy is measured as a quantity of non-renewable energy per unit of building material, component or system. Every building is a complex combination of many processed materials, each of which contributes to the building's total embodied energy. Generally, focus has been on understanding energy use during the operational period of the building (use phase). Measure of embodied energy are the associated with environmental implications of resource depletion, greenhouse gases, environmental degradation and reduction of biodiversity. As a rule of thumb, embodied energy is a reasonable indicator of the overall environmental impact of building materials, assemblies or systems (Kumar *et al*., 2012).

S.No.	Material	Embodied Energy (MJ/kg)	CO_2 emission (kg / kg)
1	Aggregate	0.10	0.005
2	Concrete	0.95	0.13
3	Brick	3.00	0.22
4	Soil	0.45	0.023
5	Glass	15.00	0.85
6	Aluminum	155.00	0.24
7	Steel	24.40	1.77
8	Plastics	80.50	
9	Timber	8.50	0.46
10	Lime	5.50	0.74
11	Cement	4.60	0.83
12	Sand	0.10	0.005
13	Ceramics	10.00	0.65

Figure 3. Embodied Energy per unit mass and CO_2 emission of Building Materials (Hammond and Jones, 2008)

Embodied energy per unit mass of materials used in building varies enormously and is tabulated as:

Calculation of Embodied Energy and Emitted Carbon

The calculation of embodied energy and emissions has been calculated as follows:

Embodied Energy= Quantity of Material * Embodied Energy Coefficient
CO2 Emission (MT) = Quantity of Material * Carbon Emission Coefficient (Utama and Gheewala, 2009)

U- Value of Surfaces of a building

Thermal transmittance, also known as U-value, is the rate of transfer of heat through a structure (which can be a single material or a composite), divided by the difference in temperature across that structure. The units of measurement are W/m²K. The better-insulated a structure is, the lower the U-value will be. Workmanship and installation standards can strongly affect the thermal transmittance. If insulation is fitted poorly, with gaps and cold bridges, then the thermal transmittance can be considerably higher than desired. Thermal transmittance takes heat loss due to conduction, convection and radiation into account (Lymath, 2015).

U-Value Calculator

To calculate the u-value of a particular part of the building construction, a little knowledge about each element of the construction is needed.

Thermal Resistance (R)

U-values are calculated from the thermal resistances of the parts making up a particular part of the structure. Transmission of heat is opposed in varying amounts dependent on material and surface. Thermal Resistance is defined as a measure of the opposition to heat transfer offered by a particular component in a building element (Lymath, 2015). In order to calculate thermal resistance, the thickness of the material and the Thermal Conductivity (K) value must be known. These values can be found in the Metric Handbook, or the Architects Pocket Book,

Where

R= Thermal Resistance (m2K/W)
d= Thickness of material (in Meters)
k= Thermal conductivity of the material (W/m K)

The value of thermal resistance (R) must be known in order to calculate the u-value. If standard products are specified it is often easy to find the resistance values for these elements. Sometimes it is worth having a look at specific manufacturers' websites for these details.

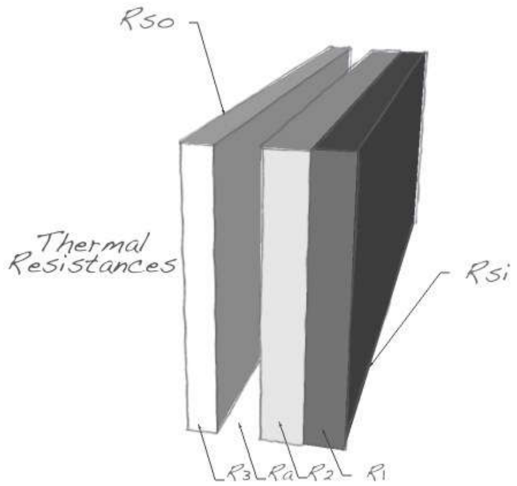

Figure 4. Calculation of U- Value (McMullan, 2007)

Total Resistance (Rt)
= Rsi+ R1+ R2+ Ra+ R3+ Rso
Where R1, R2 and R3 are the thermal resistance value of different layers of a surface and Ra is the air gap.

Value of Rsi and Rso

Rso is the outside surface resistance, and Rsi is the inside surface resistance of a building and their values in normal temperature are given as:

	RsiInside Surface	RsoOutside Surface
Roof/Ceiling	0.10	0.04
Wall	0.12	0.06
Floor	0.14	0.04

(McMullan, 2007)

Therefore, the final U- Value= 1/ Rt
BREEAM standards of U- value:
Roof: 0.16 W/m2 K, Wall: 0.2 W/m2 K, Floor: 0.22 W/m2 K

(Lymath, 2015).

S.No	Materials	Thermal Conductivity (K)
1	Plywood	0.12
2	Brick	0.65
3	Clay Tile	0.6
4	Cement Concrete	0.65
5	Cement Plaster	0.5
6	Clay Roof Tile	0.95
7	PVC	0.19
8	Styrofoam	0.033
9	Glass Wool	0.04
10	Bamboo	0.025
11	Ceramic Tile	0.72

Figure 6. Value of Thermal Conductivity of Building Materials (Baden-Powell *et al.*, 2011)

The other environmental measures include the energy consumption during operation and maintenance phase.

Building Rating (BR) system for Eco- Friendly/ Green Buildings

Another key element of green buildings is the certification systems or rating tools to examine the performance of the building and to improve the green building process and strategies. These rating systems are refined over time in response to improvement in technology, knowledge and market advancements. Examples of rating systems including, BREEAM (Building Research Establishment's Environmental Assessment Method), developed in the United Kingdom, in 1990, CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), developed in Japan, in 2001, LEED (Leadership in Energy and Environmental Design), developed in United States, in 1998. All these rating tools provide sharing the experience of the sector and so lead to accelerate the green building movement. In several countries, there are good numbers of Green building rating system that certifies the buildings as eco- friendly / Green building. A rating system can be defined as a set of prerequisites and requirements that a project team must fulfill in order to receive certification. This rating system offers different levels that signify how many prerequisites and requirements a project team fulfilled (Grihaindia, 2007). Such BR systems have their own tools and evaluation grades for the certification which are interrelated with the eco- friendly characters.

Building Code

Nepal Building Code (NBC)

NBC is designed with Mandatory Rules of Thumb (MRT) for reinforced concrete buildings with masonry infill and reinforced concrete building without masonry infill (DUDBC and NBC-202, 1994). This MRT addresses the particular requirements of those RC-framed buildings which have become very common with owner-builders, who even undertake the construction of this type of building without employing professional designers. However, the users of this MRT are required to comply with certain restrictions with respect to building configuration, layout and overall height and size. These codes include general requirements for column size, beam size, outer wall, partition, reinforcement detailing, slab detailing *et al* for houses (DUDBC and NBC-202, 1994). After the devastating earthquake of 25th April, 2015; the design and construction are being monitored strictly by the concerned municipalities focusing more in structural stability. The building code still doesn't mention any rules, regulations or policies about the sustainable/green houses in NBC205, 2013 even after the amendment of NBC -202, 1994.

Traditional Housing inside Kathmandu Valley

Kathmandu valley has traditional architecture which was developed with mud architecture as that of the ancient architecture of the world. The materials used for those types of buildings are sundried brick, burnt brick, mud mortar, mud plaster, clay tile, timber and stone. The thick load bearing wall of 450 to 600 mm with built with multilayer of Burnt Red brick (pakkiapa), Sun dried brick (kachi apa) and mud plaster placed from outside to inside in external walls. These building constructed were sustainable (Bajaracharya, 2013). It's been around 40 years that reinforced concrete came into practice. We can find buildings with reinforced concrete frames and unreinforced brick masonry infill in cement mortar within Kathmandu valley (Bajaracharya, 2013). The thickness of the infill wall is 230 mm or 115 mm and the column size is predominantly 230 mm x 230 mm. The prevalent practices in most urban areas for the construction of residential and commercial complexes generally falls under this category. These buildings are not structurally designed and their construction is not supervised by engineers. This category also includes buildings that have architectural drawing prepared by engineers (Bajaracharya, 2013).

Scenario of Conventional Construction in Kathmandu Valley

The building construction in Kathmandu valley that we find these days is reinforced concrete frames. The vertical space created by reinforced concrete (RC) beams and columns are usually filled in by walls referred to as masonry infill wall or panels. The walls are usually of fired bricks in cement mortar and also aluminum and wood are used for door and windows. These walls are built after the frame is constructed and used as cladding or as partition. One of the main reasons in using masonry infill is economy and ease of construction, because it used locally available materials and labor skill (Shrestha, 2008). Brick is widely used for the construction of building in Nepal as it is the most common and preferred construction materials. The registered brick kilns in Nepal are 429 but according to Federation of Nepalese Brick Industries (FNBI), there are more than 700 brick kilns in the country. The available brick kilns in Nepal produce almost 3.2 billion bricks per year. The local brick weight in Kathmandu valley is 2.03 kg and that outside Kathmandu valley is 2.79 kg (Manandhar and Dangol, 2013).

Scenario of Eco- Friendly Building Construction inside Kathmandu Valley

Kathmandu Valley is well popular for its increasing urbanization along with concrete infrastructures mushrooming all around the city. Eco- Friendly Buildings are not so familiar between the customers here neither they are well aware about the environmental issues. There are very few buildings in Kathmandu that are in process of being certified and rated as Environmentally Friendly building by LEED. There is no any local rating system that measures the features of such buildings and also there are no specific rules and policies to follow for construction of such kind of houses. As the environmental impacts of buildings has become more apparent, now the planners in the country have started discussing the concept of green homes to create healthier and more resource-efficient models of construction, renovation, operation, maintenance and demolition. The maze of unmanaged infrastructure development has not only put pressure on natural resources such as water, soil and energy sources, but has also contributed to the increase in the emissions of harmful greenhouse gases over the years. It is estimated that an additional one million houses will be required in the decade of 2011 to shelter the growing urban population in the valley (Shahi, 2013). While the average urban population growth rate of the country stands at around 6 percent since 1970s, the Kathmandu Valley continues to sustain a fast pace of population growth at about 4.3 percent per year (Shahi, 2013). Inside the valley and in other parts of the country, construction of Eco- Friendly/ Sustainable houses are being increased more in humanitarian projects of INGOs and NGOs rather than in the private or public buildings. UN- Habitat, Nepal has recently completed its one of the project "Green Homes: Promoting Sustainable Housing in Nepal." The approaches of this project were working in Partnership with stakeholders, the government, municipalities, SMEs, and consumers, pursuing holistic and systemic approach to ensure the promotion of sustainable housing systems as a whole and not just of a particular technology, promoting SMEs to mainstream the green products and services. Similarly, the major activities done during the projects were assisting government in preparing policy frameworks to promote sustainable housing, Supporting three selected municipalities in promoting Green Homes, Stimulating demand for Green Homes components by strengthening supply chain, bridging SMEs and consumers through awareness building and promotional activities, building capacity of SMEs and creating green jobs for the urban poor, developing voluntary Green Labeling System. There are also some few consultants that are working in sustainable design inside the valley such as Tecinter Interface, Thamel; Mathema and Partners, Sanepa; Prabal Thapa, Archiects, Hattisar; Innovative Createers Pvt. Ltd, Jyatha, Thamel; Hemendra Bohra, Mato Ghar Builders; Nripal Adhikari, ABARI. Beside the non-government projects, the Government of Nepal has also started to initiate the promotion of environment friendly concept in the buildings and surrounding periphery. On October 9, 2013, the

Government endorsed a new initiative called the EFLG Frame Work, through the Ministry of Federal Affairs and Local Development. Environment Friendly Local Governance Program (EFLGP); has been implemented in 14 Districts, 54 Municipalities and 60 VDCs with goal to develop climate adaptive and environmental friendly rural and urban communities through environment sensitive local governance to contribute in poverty reduction. (Interview with Chakra Pani Sharma, Director, EFLGP, Hattisar, Kathmandu). The program has been started with simpler form focusing outside the valley for now with simple techniques rather than focusing on the whole building form. Currently, the program is motivating to maintain the energy of house by installing solar panels and by using LED bulbs for lighting. As according to Mr. Sharma, the guidelines for the green building houses will also be introduced in future which is currently in its planning phase. Though the concept of eco- friendly buildings is relatively new to the country and its people to work on, neighboring countries India and China have already excelled themselves towards the sustainable path. India, which got its first certified green building in 2003, has the second highest number of green buildings per square foot after the United States. Similarly, China in its 12th five-year plan (2011-2015) has pledged to ensure all new buildings reduce energy use by 65 percent and have one-third of all new buildings green by 2020. Other countries like Japan and Singapore have also pledged to go for green and energy-efficient buildings in the coming years (Shahi, 2013).

MATERIALS AND METHODS

This chapter discusses the methodology used in this research. Problems were identified and research objectives were set based on problems. Various literatures were reviewed related with the research.

Study Area and Site Selection

Kathmandu Valley was taken as the study area for this research which is highly populated with dense settlement and rapidly increasing urbanization. This city is also considered as one of the most polluted city in the world. Also, the major problem that people are facing in this city are the frequent energy crisis. As according to the study, around 28% of electricity produced in Nepal in the year 2005, was consumed in the Kathmandu Valley alone (Shakya *et al*., 2015). The recent data shows that the number of individual household in Nepal is 54,23,297 with population growth rate of 1.35 per annum and average household size of 4.88 (CBS, 2011). The urbanization rate of the country is 3.62%. Meanwhile, Kathmandu valley has most huge demographic profile. The population growth rate of the valley is 4.35%, making it one of the highest growing urban agglomerate is South Asia (Shakya *et al*., 2015). These are the indicators which show the necessities and importance of the environmental friendly buildings in the city which would provide balance between the energy needed and whole life cycle of the building.

For this research, two buildings: Ama Ghar, Godavari and Mato Ghar, Budanilakantha of Kathmandu Valley were taken that are considered as environment friendly buildings and for the comparative study, two similar conventional buildings: Happy Home, Godavari and Residence Building of Mrs Paudel, were taken. "Hama Steel", which is in process of certification of LEED is taken as a case study to illustrate the building and its features in detail.

Figure 7. Aama Ghar

Figure 8. Happy Home

Figure 9. Mato Ghar

Data Collection

Primary data collection were done through the case selection, two numbers of focus group discussion with the occupants. Various data recorded to compare the performance assessment of the buildings with theoretical validation include calculation of U- value, embodied energy and CO_2 emission during construction. Similarly, cost estimation of eco-friendly features of the green buildings, Operational and maintenance cost of both types of buildings were also done.

Figure 10. Paudel Residence

For social measure, interviews were taken with the respective owners and two focus group discussions were done with other occupants of the houses where the discussions were done about the performance of their buildings in terms of thermal comfort and satisfaction. For the findings of this objective, focused group discussion was done with the occupants of the case studied buildings. For the first Case Study of an eco- friendly building, Ama Ghar; 10 participants took part in the focus group:

- 4 men and 6 women
- 2 men were 30-40 years old; 2 boys were 12-14 years old; 4 girls were 8-18 years old; 2 women were 40-50 years old
- 4 were the staff members of the institution and 6 were the children living in the institution.

Similarly, 10 participants were involved in the focus group discussion during case study visit of a conventional building, Happy Home where there were:

- 3 men and 7 women
- 2 men were 25-35 years old, 1 man was 18 years old, 2 women were 30-40 years old and 5 girls were 14-18 years old
- 4 people were staff members and the rest were children living in that institution

Also, Interview in semi structured manner was taken to the occupants of both the houses of Mato Ghar and Paudel Residence to find out their perceived satisfaction and comfort from the buildings. In both houses, a nuclear family with 4 occupants were found, so the questions were asked to all four of them. Similarly, the use of materials during construction of existing eco-friendly buildings were listed down by the observation in the case studies and their workability was analyzed with comfort level of the occupants and also was compared with the literature review. The effectiveness of such materials in case of human comfort was analyzed by focus group discussion with the occupants about the natural heating/ cooling effect, insulation inside the building spaces. FGD was done in Ama Ghar and Happy Home, where as in Mato Ghar and Paudel residence; interviews with the occupants were done. Besides this, observations of the buildings during the case studies were also done for both kind of buildings. The observations included site area, building orientations (Passive solar technique), construction techniques being used and types of lighting and fixtures used.

Data Processing and Analysis

The processing was carried out comprising editing, classifying and tabulation of collected data for easy analysis. The quantitative data from surveys and interviews were further demonstrated in pie charts and bar graphs. The further analysis were done comparing the obtained data from the buildings.

RESULTS AND DISCUSSION

This part consists of results and discussion after processing and analyzing the data which were obtained from primary and secondary sources.

Observation during Case Study Visit

During site visit of the buildings, the following features were observed:

(a) Ama Ghar, Godavari and Happy Home, Godavari

Ama Ghar consists of various green features including the planning, construction technique, building materials, passive and active solar energy, bio gas and wastewater management, rain water harvesting and green spaces. Happy Home is constructed in conventional method with frame structure system which consists 2 wings of buildings and are 2- storied. The building does not consist any of the green features, though there is plenty green spaces in the site area. The production of vegetables and fruits in the site area help to reduce expenses in the kitchen. Livestock farming is also being done in the periphery with limited number of cows and horses. Other than that, the building and its periphery are completely conventional. The building materials used in both the wings are similar; the external façade is of exposed brick, ceramic tile is used for flooring whereas paintings are done in internal walls. All the opening frames are made up of timber with single glazed glass panels.

b) Mato Ghar, Budhanilakantha and Paudel Residence, Dhapasi

Mato Ghar is a residential building which is wholly constructed by the concept of rammed earth technology. The house owner; Mr. Hemendra Bohra, who studied environmental engineering at Harvard University is the main person behind the concept of this Rammed Earth green building. Ar. Prabal Thapa and his team enhanced the concept in the design form. Mr. Bohra further led the construction phase; he also currently works as a builder in his own company, "Mato Ghar Builders." The building is constructed in load bearing system where the building materials used, are complete environment friendly and are also influenced by traditional building method. Paudel residential building of Mrs. Sapana Khati Paudel is constructed in conventional method with frame structure system including all the conventional building materials. There are not any features in the building which are focused on utilizing the renewable energy sources. For electricity and water, regular supply from the Nepal Electricity Authority (NEA) and Nepal Drinking water Authority (NDA) are used. Various Electric devices are also used by the occupants for the thermal comfort during summer and winter. Inverter is used for the backup of the electricity. The green space around the building also looks insufficient; though the building occupies 30% of the total land, more use of interlocking blocks in the site area have decreased the green spaces.

(c) Hama Steel (Ameer Bhawan), Kamaladi

Hama Steel Complex is considered as the iconic green building inside Kathmandu Valley which has been listed in Leadership in Energy and Environmental Design (LEED) with platinum certification. Ar. Bibhuti Man Singh, Structure Er. Durga Prasadh Shrestha and their team are the lead planners of this project along with the client, "Hama Steel PVT. LTD." The technical people involved in the design of this building are widely known as the sustainable designers of Nepal. The building design and construction have followed the guidelines of LEED focusing on maximum use of renewable energy sources resulting sustainability and adaptability with energy efficient features. The major topics of a green building have been effectively addressed and performed in the design, construction and operation of this building that include sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design and regional priority. In this project, certain experiments are done including building materials and other various features which are innovative and of course, environment friendly. Therefore, the main reason to choose this building as one of the case study is to demonstrate its green building features that are relatively new in construction industry of Nepal. Some of the major green features of this building are passive solar energy, active solar energy, Variable Refrigerant Volume (VRV) and Cristopia Heating Ventilation Air Conditioning (HVAC) System, wind turbine, green roof, parking ventilation based on CO2 levels and others. Further detail demonstration of green building features of this complex will be done in results and analysis chapter.

Performance Assessment of the Buildings

Environmental, economic and social measures were taken for findings of this objective.

Environmental Parameter

For this, the total estimated embodied energy, emitted carbon of structure and super structure of the buildings during construction and U- Value of different surfaces of the buildings were calculated and hence compared.

Calculation of Embodied Energy and Carbon Emission

Since, the building materials used in Ama Ghar are conventional and are not different than the building materials used in Happy Home; it wouldn't give any sense to calculate the energies and compare them. In case of Mato Ghar, various green building materials are used for construction of the building with traditional approach and therefore the estimated values were calculated and compared with conventional residence house of Mrs. Paudel. The total built up area of Mato Ghar is 2500 Sq.ft. and the Paudel residence's total floor area is 3683.33 Sq.ft. A two and half stories Paudel residence has 1436.10 Sq.ft of ground floor area, 1466.22 Sq.Ft in first floor and has 788 Sq.ft of floor area in second floor. A total of 371,473.55 MJ embodied energy was obtained while construction of structure and sub structure of Mato Ghar while in Paudel residence; 508,240 MJ embodied energy was produced. Similarly, 49,062.51 kg of carbon was emitted in Mato Ghar and 53609.3 kg of carbon was emitted in Paudel residence.

The obtained data and comparison illustrate that Mato Ghar, an eco- friendly home; emitted less carbon and also less embodied energy was produced during construction in compared to the conventional house of Mrs. Paudel. When converted into unit Area, embodied energy of Mato Ghar is 143.828 MJ where as that of Paudel Residence is 187.06 MJ which means Paudel Residence produced 40.885 MJ more embodied energy per unit area in compare to the Mato ghar. Similarly, Mato Ghar emitted 17.89 Kg carbon per square feet whereas Paudel residence emit 20.11 Kg carbon per square feet. This leads to 2.227 kg of more carbon emission per unit area in Paudel Residence in compare to Mato Ghar. Hence, this analysis shows that existing green houses are making positive impacts in environment producing less embodied energy and carbon footprint during construction phase.

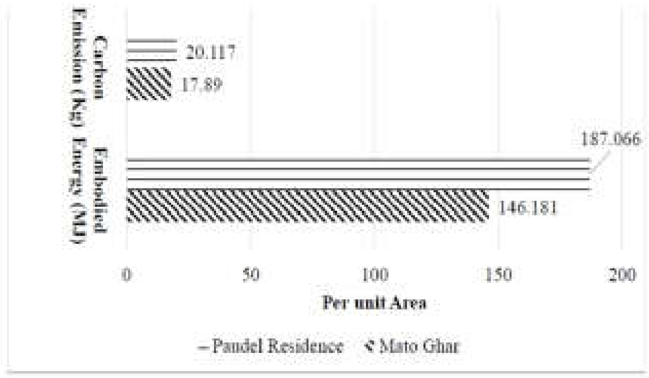

Figure 11. Comparative Study of calculation of Embodied Energy and Carbon Emission of Mato Ghar & Paudel Residence

The other environmental measure for this objective was the calculation of U- Value of different surfaces of green and conventional buildings and their comparative analysis was done. The calculated U- Value of wall of Ama ghar and Happy home was 1.37 and 1.68 respectively. The building techniques and materials of both buildings are same, the only difference is the thickness of brick wall, where Ama Ghar has 14" thickness and Happy home has 9" thickness. Due to this, the U- Value obtained of Ama Ghar is slightly lower than that of Happy Home. So, technically, the wall with lesser U- Value acts as good insulator means wall of Ama ghar has slightly better insulation than the wall of Happy home. 2.216 and 2.574 are the respective U- Values of floors of Ama Ghar and Happy home and are almost similar. So, the insulation properties of both the houses are same. Similarly, the U-Value of roofs of Ama Ghar and Happy home were found to be 1.86 and 3.56. Clay tiles are used for the roofing in the Ama Ghar where as Happy home has conventional reinforced concrete ceiling. The values obtained explain that the roof insulation of Ama ghar is better than Happy home since its U- value is lesser than that of Happy home. The obtained U- Value of walls of Mato Ghar and Paudel residence were 0.76 and 1.73 which clearly shows that the thermal insulation of walls of Mato Ghar is better than that of Paudel residence. Mato Ghar consists of Double pane windows which is said to be very effective for thermal insulation. This window is used in Mato Ghar instead of regular single pane windows, that's why the calculation of U- Value of the windows of both houses were done and compared to see whether it is applied practically or not. From the calculation, it is clear that the double pane window provides far better insulation in compare to single pane window where the value of double pane window was found to be quite lesser than single pane window. 2.79 and 5.6 were the calculated U- Value of Mato Ghar and Paudel residence. The obtained U- Value of floors of Mato Ghar and Paudel Residence were 0.5 and 1.8 respectively, which also explain that thermal insulation of floors of Mato Ghar is better than that of Paudel Residence. Similarly, U- Value of roofs of Mato Ghar was found to be lesser than Paudel Residence where the value was 0.3 and Paudel Residence had U- Value of 3.06. The obtained value clearly states that the thermal insulation of roofs of Mato ghar is definitely better than the thermal insulation of Paudel residence.

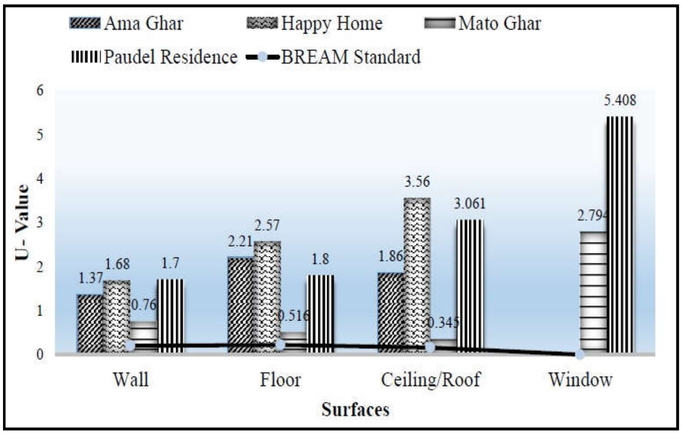

Figure 12. Comparative Study of Calculation of U-Values of different surfaces of the Case Studied buildings

The final results from illustration of above obtained U- Value of surfaces of the buildings show that the thermal insulation of Ama Ghar and Happy home are comparatively similar, since there are no special green building materials used in Ama Ghar. But, in case of Mato Ghar and Paudel Residence, the result is vice versa. Mato Ghar has reintroduced the traditional building materials which is purely environment friendly and sustainable at the same time and effectiveness of use of those materials could be undoubtedly seen in the U- Value of surfaces thus obtained. Hence, the above measures and the comparative analysis done afterwards gave fruitful output for this research objective.

Economic Parameter

Eco- Friendly buildings are said to be energy efficient which not only help to use the renewable energy sources but also save the certain monthly operational and maintenance cost. So, economic parameters are also chosen to demonstrate the effectiveness of existing green buildings. For this, the monthly O&M cost of both type of buildings that are related to energy use and green building feature costs in the overall building construction were listed down and were further comparison analysis between the two types of building was done.

Estimated Calculation of O & M Cost and Comparison

In Ama Ghar, the total average monthly O& M cost was estimated as Rs 28,692.00 where there are 53 numbers of occupants. Similarly, in Happy home; the total average monthly O & M cost was estimated as Rs.83,480.00 with 100 occupants. It shows that the O & M cost of Happy home is noticeably high. Though the number of occupiers of Happy home is more but having same nature of occupiers with exact same function, applying unit formulae; a person living in Happy home is paying Rs 293.34 than the one who is living in Ama Ghar which is 35.25% higher.

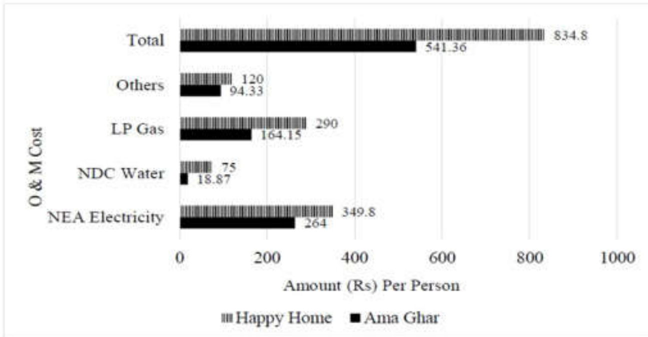

Figure 13. Comparative Study of estimated Calculation of O& M Cost of Happy Home and Ama Ghar

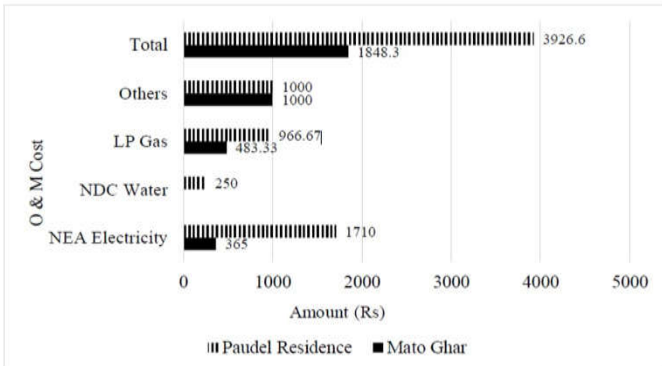

Figure 14. Comparative Study of estimated Calculation of O& M Cost of Paudel Residence and Mato Ghar

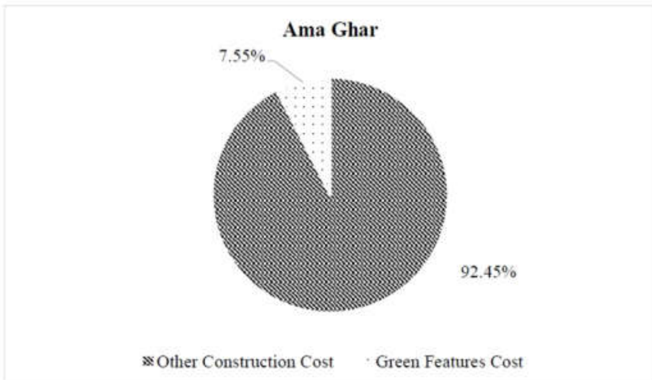

Figure 15. Estimated extra cost for Green Building Features of Ama Ghar

Similarly, the estimated O&M cost of Mato Ghar and Paudel Residence were Rs 1563.3 and Rs 3656.76 having four occupants in both the houses and both being used for residential purpose. The difference of Rs 2093.43 was occurred which means Paudel Residence pay approximately 57.2 % more for operation and maintenance of the house with compared to Mato Ghar. Hence, the above obtained data and analysis show that the running cost of the green buildings are definitely lesser than the running cost of conventional buildings. As per the result, green building pay 53% less amount for monthly O&M.

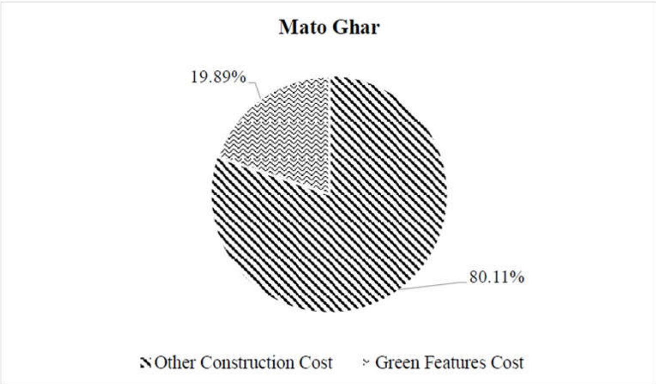

Figure 16. Estimated extra cost for Green Building Features of Ama Ghar

Additional Cost of Green Buildings

As according to the Market rate and owner's information, the total building cost of Ama Ghar was Rs 4,00,00,000.00 where Rs 40,19,750.00 was the cost of green features of the building including PV panels, waste water treatment, bio gas and rain water harvesting. This shows that 7.55% of total cost of the building project included the green features of the building beside the regular construction of the building. Also, the total building cost of Mato Ghar as per the market rate and the owner's information; the total building construction cost was Rs 1,00,00,000.00 including the green building features. The total expenditure for the green features of this building was estimated as Rs 19,88,900.00 which is 19.89% of the total cost.

Social Parameter

In general, occupants of Ama Ghar were satisfied with the performance level of the building which includes thermal comfort, lighting (includes day light), acoustic and health. As according to the discussion, the participants said that the rooms are:

- Cold during summer and normal during winter
- Bright and don't need artificial light during day time
- Well ventilated

The occupants of were satisfied with the day lighting and the ventilation. They were also happy with the room temperature in both summer and winter as they don't use any mechanical devices. They felt healthier within indoor environment of the building. The participants complained that one of the staff room of the building is having seepage problem which is making the room colder. Apart from this, participators felt positive and satisfied with the building performance level till date.

During the discussion, the participants of Happy Home had an average view regarding to performance level of the Happy Home building. They felt that their rooms are:

- Normal during summer and cold during winter
- Bright and don't need artificial light during day time
- Well ventilated

Participants also explained that they use electric heater during winter for heating system but don't use any mechanical devices during summer. They are thoroughly satisfied with the day lighting and ventilation but feel colder in winter. Though it's a conventional building, the participated occupants felt themselves healthier living inside the building and its surrounding area. In first case study i.e. Ama Ghar and Happy Home; result with the measured data, their comparative analysis and further analysis show that the features of eco-friendly building (Ama Ghar) seem to be effective in environmental and economic point of view. But, due to the use of limited conventional building materials, the building fails to give required thermal comfort that is stated in the principles of an eco- friendly building. Though, none of the mechanical devices were used by the building occupants of Ama Ghar, the calculated U- Value obtained from both the houses are similar which means thermal insulation of the surfaces of both buildings have same properties. Hence, based on the result, it was analyzed that the effectiveness of Ama Ghar is recommendable but it still doesn't carry completeness of green building properties. In second case study, the situation is different. Here, Mato ghar succeeded to stand as a complete green building fulfilling all the principles. All indicators resulted that the effectiveness of this house is practically proved. The use of traditional building materials merging up with some new technique and materials have made the house environmentally, economically and socially more effective and beneficial in compare to the conventional houses. The occupants of Mato Ghar were found to be completely happy and satisfied with the internal built environment of the house. Since the construction of the house and the building materials used are almost completely environment friendly; the house is providing expected thermal comfort without use of any mechanical devices. Summer or winter, the occupants feel comfortable in room temperature inside the house. Also, the occupants are strongly satisfied with the day light and acoustic performance of the house. Similarly, the occupants of the residence house of Mrs. Paudel are also satisfied with the thermal comfort inside the house in summer. But, in winter they feel cold while staying inside the rooms and therefore they use electric/ gas heaters to make the room temperature comfortable. The occupants are also satisfied with the day lighting and acoustic performance of the building. Occupants of both houses seem to be satisfied with the performance of the buildings. They feel comfortable living in the indoor built environment of their respective houses. Occupiers of residence of Mrs. Paudel complaint about the unfavorable room temperature during winter; other than that, they are completely satisfied and feel comfortable in their conventional house. The result by interviewing with occupants of all 4 buildings, about the perceived satisfaction and comfort shows that the occupiers staying in eco- friendly buildings are comparatively more satisfied and comfortable than the occupiers of conventional buildings. But the result doesn't show much difference in the comfort level and health of occupiers of both type of buildings.

Building Materials in existing Eco- Friendly Buildings

The building materials that were used in the 3 case studied green buildings are listed and described as follows:

(a) Building Materials used in Ama Ghar

In Ama Ghar, there were no special building materials used in the structure of the building. All the materials used are the conventional ones. From the structure, sub structure, civil and finishing of the building; conventional building materials are used. Regular PPC and OPC are used for the cement concrete, RCC is done for super structure, and fired burnt bricks are used in both the external and internal wall. Since the walls are brick exposed both externally and internally, nonuse of plaster works and paint in the wall reduced the harmfulness in the environment and in overall cost as well. The openings are of aluminum frame with singe glazed glass panels whereas the main entry door is of timber frame and panel. The floorings are of mixed types which include clay tile flooring, laminated wood flooring and screeding. Jhingati tiles are used in the slope roofs supported with timber rafters and iron frame tie beams and struts. For lighting fixtures, LED lights which consume less energy and have longer life time. In sanitary fixtures, normal fixtures are used which are easily available in the market. With thorough observation of the building and interview with administrative officer Mr. Bhesh Nepali, the result for the building materials used in the buildings show that all the building materials used are conventional and no green materials are used in this building.

(b) Building Materials used in Mato Ghar

Mato Ghar is one of the few buildings inside Kathmandu Valley which represents the true features of Environment friendly house. It is a merge form of traditional and modern building technology. Building owner Mr. Hemendra Bohra, who is also a builder was the master mind behind the construction of this house. He researched about the rammed earth houses of Mustang region and being influenced with the techniques of those houses, Mr. Bohra decided to use the technology in his own residence building merging with the modern means and materials. The main building material of this house is rammed earth, but there are other various green building materials with some few conventional materials. The major building materials found in the Mato Ghar during the observation were rammed earth, sun dried brick, stone, bamboo, Styrofoam, glass wool, linseed oil etc.

Figure 17. Rammed Earth used in the Mato Ghar

(c) Hama Steel Complex

As already mentioned, Hama Steel complex is one of the very few buildings which is on process of getting the LEED certification. The building consists various features for making it energy efficient which includes the use of environment friendly building materials. One of the many reasons to take this building as a case study is to illustrate the building materials that are used in this building. The main structure of the building is frame structure and is constructed in conventional method using RCC but the use of green concrete and other various green building materials have reduced the overall carbon emission production and embodied energy while constructing the building.

Figure 18. Flattened Bamboo used in roofing

The detail description of the building materials used in Hama Steel complex are given as follows:

Eco- Friendly Features

Planning, Construction Technique and Building Materials

From beginning phase of this project, both consultant and client were indisputable about the green building concept and were also well aware about the LEED certification process and its requirements. The concept, design and planning were strictly focused in the green features, most specifically in planning for construction of the building minimizing harmfulness to the environment as far as possible and making the complex, energy and resource efficient. The use of different green building materials that are relatively new in the market, makes the building more prior and is also getting good attention from researchers, designers, builders and media too. As according to Durga Prasadh Shrestha who was involved in the project, construction of the complex was done keeping in mind about the LEED certification guide lines following the requirements: sustainable site, materials and resources, water efficiency, energy and atmosphere, indoor environment quality, innovation in operation and regional priority. During the case study too, the building environment was found to be satisfactory to meet these criteria. Based on the LEED criteria with the involvement of expert technical personals, Hama Steel Complex has been in operation from four months, but some interior works are still running. So, for complete demonstration of this building, few more months are needed.The major specific green building materials used in the complex are described as follows:

Use of Fly Ash in Concrete

In this building, instead of using the conventional type of concrete, the use of fly ash is done in the concrete which is a by-product produced during the operation of coal-fired power plants. More than 20% of OPC is replaced by Fly ash and 2%-5% micro silica. Due to the utilization of fly ash as a part replacement of cement as a mineral admixture in concrete has saved on cement and hence the emission of CO_2 is also reduced. Er. Shrestha also explained that due to the use of good quality fly ash in concrete, remarkable improvement in durability of concrete has been observed. The proportion of fly ash in the cement are different as per the nature of the structure.

Fiber Cement Board

Fiber cement board is used for the wall structure of the building replaced by the fired burnt clay bricks. It is the composition of cement and cellulose fibers which is a plant extract as reinforcement with ½” thickness. This replacement of the board with the brick helps to reduce a lot of carbon emission and embodied energy, since the board has comparatively very low carbon emission rate and embodied energy. In compared to the brick, it is also less heavy and hence makes the total building weight lighter. It is time efficient too which is a prefabricated product and are installed in the site in lesser time.

Floor Insulation

Special kind of insulation is being used in the flooring for the apartments. The rubber insulation layers of approximately 1” height are placed below the laminated flooring which make the floor weight less heavier, environment friendly and act as very good insulator.

Steel Structure and Double Pane Windows

More use of steel can be seen in the exterior part of the building, especially in the staircase area and the balconies which comparatively reduce the production of embodied energy and carbon emission. Similarly, double pane windows are used as the window panels for thermal comfort and to make the building energy efficient.

Light Weight Concrete

Very few amount of OPC is used with huge quantity of granular foam for making cement concrete and is poured in between the fiber cement boards to form the wall. This light weight concrete is not only energy efficient but is also very good for sound insulation. Hence, the use of some building materials in this complex help to maintain the guidelines of LEED and also they are definitely new or not conventional kind of materials in the building market of Nepal, which means the scope of such materials are high too. The other green building featured of Hama Steel complex are described as follows:

Active Solar Energy and Wind Turbine

PV panels are placed in the terrace in huge numbers to acquire the sunlight and convert it into electricity for different uses. Approximately, the total panels have the capacity of 30 KW energy production per day. A wind turbine is also placed in top of the building to convert the kinetic energy produced by the air to electrical power. Wind turbine practice in buildings is not so common in our country, so this installation might also help for future scope of use of this technique. The maximum use of renewable energy is one of the major objectives of green buildings and hence this complex follows the rule by installing these devices for the maximum utilization of renewable energy resources.

Passive Solar Energy

The building orientation is designed to capture the daylight as much as possible facing the most usable rooms towards south. Sky lighting is also provided for the health club space which helps to enter the day light in the huge hall and also reduce the energy of the building.

VRV HVAC System

VRV (Variable Refrigerant Volume) has been used in the building for heating and cooling around the interior spaces. The basic idea of this system is that a large outdoor unit servesmultiple indoor units. Each indoor unit uses an LEV (electronic liquid expansion valve) to control its refrigerant supply to match the demand of the space it serves. The outdoor unit also varies its output to match the communal demands of the indoor units it serves. Thus, at any point in a system there will be a variable volume of refrigerant flowing. Various strategies are used to vary the output of the outdoor units including: modulating fan/s, heat exchanger valved in sections, variable speed inverter drive compressor/s, multiple compressors, twin or multiple modular outdoor units. This system contains mixed mode operation that leads to energy savings as both ends of the thermodynamic cycle are delivering useful heat exchange. In mixed mode the energy consumption is dictated by the larger demand, heating or cooling, and the lesser demand, cooling or heating is delivered free. VRV/VRF is a proven technology which can play a large part in helping integrated building services design to achieve high energy efficiency.

Sewage Treatment Plant

Sewage treatment plant is also another especial feature of this high rised building. The process of this system is as same as described earlier in the green building features of Ama Ghar. The process leads three different treatments: Primary, Secondary and Tertiary. Primary treatment involves the sedimentation of waste water and sludge and their primary treatment in septic tanks. This unit treats black water and organic solids to produce 5m3 of bio gas per day. In Secondary unit, both black and grey water is treated in a chambered Anaerobic Baffled Reactor (ABR). The ABR reduces biological and chemical oxygen demand by anaerobic digestion inside the chambers. The final unit involves aerobic/ anaerobic treatment inside Horizontally Planted Gravel Filters (HPGF) that reduces colors and odors. Hence treated water is used for flushing of toilets and gardening, thus decreasing the use of fresh water.

Rain Water Harvesting

Rain water harvesting is proceed in the building for water management. Kathmandu Valley is well known for the shortage of water in spring. So, to overcome this problem and to not depend completely on the regular drinking water supply of Nepal drinking water authority, this feature has been made for the building occupiers.

Parking Ventilation Based on CO_2 Levels

The building has double basement with ventilation based on appropriate CO_2 level. There is always chance of having high level of CO_2 more in basement because of absence of air circulation and also due to the number of vehicles but in this building, sufficient ventilation are provided which balance the level of CO_2.

Green Roof/ Hydroponics & Vertical Farming

Green roofs concept is also one of the attractive feature of this building where some of the parts of terrace floor has already been vegetated by green grasses, where as some parts are still on process; since the building is still not completely operated and many internal construction are still going on. Therefore, the whole green design of this building has yet to be seen. Hydroponics i.e. a subset of hydroculture, is a method of growing plants using mineral nutrient solutions, in water, without soil. Terrestrial plants may be grown with their roots in the mineral solution only, or in an inert medium, such as perlite or gravel. This kind of farming is also one of the concept involved in green roof.

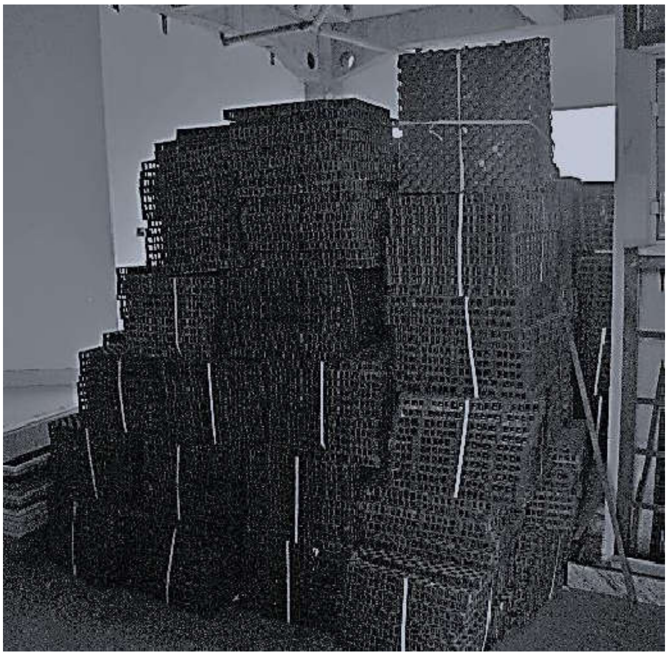

Figure 19. Rubber Insulation

Figure 20. Large openings with double pane in apartment room

Figure 21. Light Weight Concrete used to fill up the cavity wall

Figure 22. PV Panels and Wind Turbine

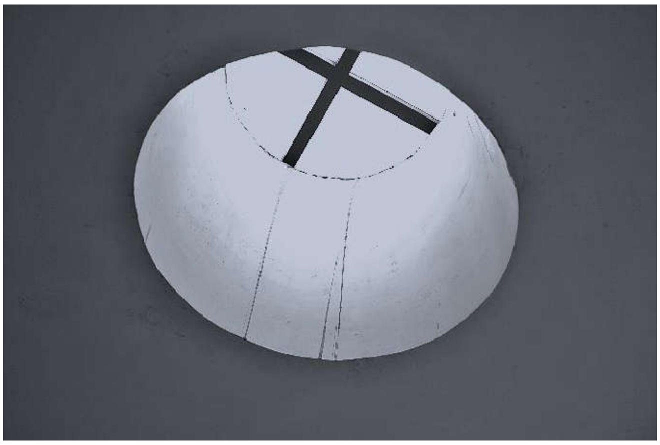

Figure 23. Providing Skylight in health club

Figure 24. Outdoor Unit of VRV HVAC System

Figure 25. Parking Ventilation based on CO2 level

Figure 26. Green Roof Concept

Energy efficient lighting techniques, water efficient fixtures, solar water heating system etc. are other green building features of the complex. After doing case study of the building and by taking interview with experts related to this project, the building is found to be one of the project which is following the green building movement and could withstand as one of the best example of sustainable green building in near future.

Conclusions and Recommendations

This chapter includes the findings, conclusions and recommendations after doing the case studies, collecting data and comparing them.

Findings

Comparative Performance assessment was done between green buildings and conventional buildings on basis of environmental, economic and social measures. For environmental measure, estimated calculation of embodied energy and carbon emission of Mato Ghar and Paudel Residence were done where Mato Ghar produced 3,65,452 MJ of embodied energy and 44,727 kg of carbon during construction phase in building area of 2500 Sq.ft. whereas Paudel residence produced 6,39,037 MJ of embodied energy and 74, 098 Kg of Carbon during construction phase. When converted into unit area, embodied energy produced by Paudel residence was found to be 40.885 MJ more than the embodied energy produced by Mato Ghar. Also, Paudel residence produced 2.27 Kg of Carbon more than that of Mato Ghar. Estimated calculation of U- value of surfaces of the buildings were also done to compare the performance assessment. The calculated U- Value of wall of Ama ghar and Happy home was 1.37 and 1.68 respectively. The building techniques and materials of both buildings are same, the only difference is the thickness of brick wall, where Ama Ghar has 14" thickness and Happy home has 9" thickness. 2.216 and 2.574 are the respective U- Values of floors of Ama Ghar and Happy home which are almost similar. Similarly, the U-Value of roofs of Ama Ghar and Happy home were found to be 1.86 and 3.56. The obtained U- Value of walls of Mato Ghar and Paudel residence were 0.76 and 1.73.The value of double pane window was found to be quite lesser than single pane window. 2.79 and 5.6 were the calculated U- Value of windows. The obtained U- Value of floors of Mato Ghar and Paudel Residence were 0.5 and 1.8 respectively. Similarly, U- Value of floors of Mato Ghar was found to be lesser than Paudel Residence where the value was 0.3 and Paudel Residence had U- Value of 3.06. For the economic measures, the estimated O & M costs of both type of buildings were calculated. In Ama Ghar, the total average monthly O& M cost was estimated as Rs 28,692.00 where there are 53 numbers of occupants. Similarly, in Happy home; the total average monthly O & M cost was estimated as Rs.83480.00 with 100 occupants. Applying unit formulae; a person living in Happy home is paying Rs 293.34more than the one who is living in Ama Ghar which is 35.25% higher. The estimated O&M cost of Mato Ghar and Paudel Residence were Rs 1563.3 and Rs 3656. 76 having four occupants in both the houses and both being used for residential purpose. The difference of Rs 2093.46 was occurred which means Paudel Residence pay approximately 57.2 % more for operation and maintenance of the house in comparison to Mato Ghar. Also, estimated additional costs of the green buildings were calculated where total building cost of Ama Ghar was Rs 4,00,00,000.00 where Rs 30,19,750.00 was the cost of green features of the building including PV panels, waste water treatment, bio gas and rain water harvesting. This shows that 7.55% of total cost of the building project included the green features of the building beside the regular construction of the building. Similarly, the total building cost of Mato Ghar as per the market rate and the owner's information; the total building construction cost was Rs 1,00,00,000.00 including the green building features. The total expenditure for the green features of this building was estimated as Rs 19,88,900.00 which is 19.89% of the total cost. For social measures, focus group discussion was done with the occupants of the buildings and was found that the occupants of eco- friendly buildings were more satisfied than that of conventional buildings on basis of thermal comfort and health satisfaction level. During the case study of five different buildings, many interesting building materials were also found to be used in eco- friendly buildings which include rammed earth, linseed oil, bamboo, Styrofoam, sun dried brick, fibre cement board, floor insulation materials, fly ash, double pane windows and light weight concrete.

Conclusion

The main goal of this study is to find out the effectiveness of those existing eco- friendly buildings in practical manner. Along with this, the research objectives also aim to explore eco- friendly building materials that are being used in such buildings, finding the merits and demerits of eco- friendly buildings in surrounding context. Four case studies were done in this research; two eco- friendly buildings (Ama Ghar, Mato Ghar) and two conventional buildings (Happy Home and Paudel Residence) were taken for the study. The study area were chosen as per their similar functions so that it would be reliable to do comparative study between the buildings. To find out the answer of the research questions, various qualitative and quantitative analysis were done. For environmental measures, estimated calculation of U- Value were done in all the four buildings for the environmental measure, where data was compared afterwards. The result of comparison of Ama Ghar and Happy home showed not much difference in both buildings due to the use of similar building technique and materials. But the data obtained from Mato Ghar and Paudel residence were noticeably different where U- Value of surfaces of Mato Ghar was much lower. The use of proper building materials and insulating techniques lead this result. Similarly, Embodied Energy and Carbon Emission of Mato Ghar was found to be lesser than that of Paudel Residence with tentatively equal built up area. In Ama Ghar, it was all constructed with conventional building materials, so there was similar production of energies as that of Happy Home. For economic measures, O& M costs and additional buildings cost were calculated. The running costs of both eco- friendly buildings were found to be 50% lesser than the conventional ones and also, eco- friendly buildings were found to have nearly 10%-20% additional cost in total project cost. For social measures, focus group discussion was done with the occupants of the Ama Ghar and Happy home. By FGD, it was found that occupants of eco- friendly buildings were more comfortable and satisfied with the internal built environment. Another case study was done in one of the very well-known eco- friendly high rise building “Hama Steel”, which is on process of getting the LEED certification. Different types of new building materials were found in the building during the observation which are readily used in regular construction market. Different other features were also found in the building which are definitely energy efficient and nature friendly. Expert interviews were taken along with the comparative performance assessment analysis for illustrating the merits and demerits of eco- friendly building construction in Nepal from which major issues of economy, market, education, awareness and society were found to be involved.

In a conclusion, the collected data and their analysis proved that the existing Eco- friendly buildings inside Kathmandu Valley perform well in compare to the conventional buildings on basis of economic, environmental and social measures. But, use of building materials are still limited to the same conventional ones in many of the eco- friendly houses although the other eco- friendly features are being explored more in those projects. The conclusion also motivates to design and construct eco-friendly buildings as they fulfill today’s needs of energy without harming environment and help to build better and healthier tomorrow making a balance relationship with nature.

Recommendations

Based on the foregoing results of the study, the following are recommended for design and construction of eco- friendly buildings in Kathmandu Valley and throughout the country:

1. Further research could be done in performance assessment of traditional buildings of Kathmandu Valley which impose eco-friendly building features.
2. More research and study should be done in the use of locally available materials and traditional techniques to make the building cost not only cheaper but also energy efficient and this would also support to reduce the dependency in foreign lands to bring the building materials which would certainly increase the sustainability of local construction market.
3. Eco-friendly ideas should be popularized at mass level by demonstrating real life cases.
4. Mandatory inclusion of eco-friendly technologies in commercial, industrial and educational buildings should be done to accelerate green building movements in Nepal.
5. Formation of local green building rating system should also be done to promote the green building culture.

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