UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Sede Amministrativa: **Università degli Studi di Padova**

Dipartimento di: **Territorio e Sistemi Agro-Forestali (TESAF)**

_____

SCUOLA DI DOTTORATO DI RICERCA IN: **Territorio, Ambiente, Risorse e Salute**

CICLO: **XXVIII**

TITOLO TESI:

SUSTAINABILITY ASSESSMENT OF BUILDING SYSTEM IN HIMALAYAN REGION

Direttore della Scuola: **Ch.mo Prof. Mario Aristide Lenzi**

Supervisore: **Prof. Raffaele Cavalli**

Dottoranda: **Silu Bhochhibhoya**

To my Parents & Sagun

Summary

Sustainability has become a global concern these days in order to reduce the environmental impact from the human activities (Passer, Kreiner, and Maydl 2012). Building sector stocks the emission from the energy consumed during the construction and operational phase until the demolition of the building (Scheuer, Keoleian, and Reppe 2003). It is important to quantify the environmental performance of the buildings in order to observe the potential environmental impacts and their influence on sustainable development (Sonnemann, Castells, and Schuhmacher 2003; Passer, Kreiner, and Maydl 2012).

This research work analyzed the environmental and economic impacts of building technologies and its efficiency in Himalayan region of Nepal through greenhouse gas (GHG) accounting in order to reduce the emission in the particular region. In the Himalayan touristic region of the Sagarmatha National Park and Buffer Zone (SNPBZ), the construction of modern buildings is growing fast, due to the increasing tourist flow. To satisfy the needs of the increasing tourist population, the traditional building design is modified, by replacing wood and stone masonry with reinforced concrete structure. Hence, the study on assessment of the environmental and the economic impact in the building system is important which gives an overall picture of the emission situation and helps identify the major emission sources and potential areas of improvement.

This research focuses on:

- The Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) of the Himalayan building with a functional unit of ***"One guest per night stay"*** to assess the environmental and economic impact of three existing types of building in the Himalayan region of Nepal on a life-cycle perspective. This motivates constructor, hotel owners, and tourist to choose the best eco-efficient building in the Park. The main aim of the study is to assess the environmental and economic

impact of commercial buildings located in the Himalayan region of Nepal, from a life-cycle perspective.

▪ The research also presents the comprehensive overview of life cycle prospective both on environmental and economic aspect including physical and technical parameters such as energy consumption, thermal conductivity and size, over the entire hotel sector in the Park to accomplish building sustainability and promote the use of sustainable construction practice.

▪ The global warming potential of the building in the prospect of the Himalayan region with functional unit *"construction and occupation"* to compare the building in environmental and energy aspect in three different building types. This chapter concerns a study on the environmental assessment of buildings in Sagarmatha National Park (SNP), the Himalayan region of Nepal, where the high tourist flow encourages rapid development of the modern buildings.

▪ The Life Cycle Assessment of the Himalayan building with a functional unit of *"1 m² wall"* to assess the environmental impact of building materials in prospect to the Himalayan building. This allows construction and hotel owners for decision making on constructing the environmentally friendly building. It provides a comparative life cycle assessment in terms of Global Warming Potential (GWP) of different wall materials used in traditional, semi-modern and modern types of buildings in Sagarmatha National Park and Buffer Zone (SNPBZ).

▪ The broad overview of environmental and economic impacts in the entire commercial sector of the park using statistic methods. It allows constructor, hotel owner or even tourist to choose the best eco-efficient building in the Park.

- The potential of GHG emission reduction in terms of household behavioural changes in the Himalayan region. It gives an overview of possible reduction of energy consumption in the Park, through the behavioral change on the consumption, which ultimately reduces the GHG emission in household level for the sustainable consumption.

The study consists of the life cycle assessment (LCA) and life cycle costing (LCC) of three building types: traditional, semi-modern and modern. The life-cycle stages under analysis include raw material acquisition, manufacturing, construction, operation, maintenance, and materials replacement. The result on LCA and LCC on the building types shows that the modern building has the highest global warming potential ($kgCO_{2\text{-}eq}$) as well as the highest costs over 50 years of building lifespan. This is due to the use of the commercial materials that has to be manufactured and transported into the construction site instead of the traditional materials, which is available in the Park itself. Moreover, the operational stage is responsible for the largest share of environmental impacts and costs, which are related to energy use for different household activities. Furthermore, a breakdown of the building components shows that the roof and wall of the building are the largest contributors to the production-related environmental impacts. The findings suggest that the main improvement opportunities in the building sector lie on the reduction of impacts in the operational stages and on the choice of materials for wall and roof.

The study on the potential of GHG emission reduction in terms of the household behavioural changes in the Himalayan region shows that 6,094 t of $CO_{2\text{-}eq}$ per year can be reduced by following simple measures like keeping lid while cooking, using a pressure cooker for cooking, turning off the lights when not needed, reducing watching television etc. The reduction of $CO_{2\text{-}eq}$ emission in the region can also be achieved by encouraging the use of energy-saving activities like the efficient cooking and heating stoves and efficient light bulbs and use of a solar cooker for cooking also help to reduce the $CO_{2\text{-}eq}$ emission in the region. This study shows that the use of the bio-insulation made of local material can reduce the emission by 19% of the total emission.

On the basis of LCA and LCC results, it is concluded that the energy efficient building with the use of local materials in combination with proper insulation and renewable energy is the recommended option for sustainable building design in the Himalayan region. Energy-efficient technologies including cooking stoves, heating stove, light bulb and use of renewable energy have the major positive impact on the CO_{2-eq} emission and should be encouraged in the Park. Sustainable building with the low energy consumption, high efficiency, and innovation in building construction, such as passive house should be promoted.

It is also revealed that the reduction of GHGs can be easily done with simple behavior changes without any compromises in daily household activities that should be encouraged in the Park. Information sharing and awareness program to the local people have to be conducted in this sector for effective results on GHG reduction. The results of this study will help to design the target-based policies related to behavioral changes in the household level to perceive the sustainable energy building that needs to be developed and implemented to reduce the local level GHG emission.

Astratto

Il settore delle costruzioni fornisce un contributo notevole agli impatti ambientali globali, in particolare attraverso le emissioni date dal consumo di energia durante le varie fasi del ciclo di vita, dalla realizzazione fino alla demolizione. Per questo motivo è importante quantificare le prestazioni ambientali degli edifici, al fine di individuare i potenziali impatti ambientali e la loro influenza sullo sviluppo sostenibile.

Questo lavoro di ricerca analizza gli impatti ambientali ed economici degli edifici nella regione himalayana del Nepal, attraverso la quantificazione dei gas a effetto serra (GHG) al fine di ridurre le emissioni in quella particolare area. Nella regione turistica himalayana del Sagarmatha National Park and Buffer Zone (SNPBZ), la costruzione di edifici moderni è in rapida espansione per far fronte al crescente flusso turistico. Per soddisfare le esigenze della popolazione turistica, il tradizionale design costruttivo degli edifici viene spesso modificato, sostituendo il legno e la muratura in pietra con strutture in cemento. Lo studio dell'impatto ambientale ed economico del sistema costruttivo è pertanto molto importante in quanto fornisce un quadro complessivo del livello di emissioni e aiuta a identificare le principali fonti delle stesse e i potenziali margini di miglioramento.

Lo studio consiste nell'applicazione di due metodologie di analisi, Life Cycle Assesment (LCA) and Life Cycle Costing (LCC), a tre tipologie edilizie: tradizionali, semi-moderne e moderne. Le fasi del ciclo di vita analizzate includono l'acquisizione delle materie prime, la fabbricazione, la costruzione, l'utilizzo e la manutenzione dell'edificio, la sostituzione dei materiali. Il risultato delle analisi LCA e LCC sulle tipologie edilizie mostra che l'edificio moderno con una durata di vita pari a 50 anni ha il più alto potenziale di riscaldamento globale ($kgCO_{2-eq}$), così come i costi più alti.. Ciò è dovuto all'uso dei materiali commerciali, che devono essere fabbricati e trasportati nel cantiere, invece dei materiali tradizionali, che sono disponibili nel Parco stesso. La fase di utilizzo dell'edifico è responsabile per la quota maggiore degli impatti e dei costi ambientali, in particolare per il consumo di energia dato dalle diverse attività domestiche. La ripartizione dei componenti edilizi dimostra che il tetto e le pareti degli edifici sono i maggiori

contributori degli impatti ambientali legati alla produzione. I risultati suggeriscono che le principali potenzialità di miglioramento nel settore delle costruzioni consistono nella riduzione degli impatti nelle fasi utilizzo dell'edificio e sulla scelta dei materiali per le pareti ed il tetto.

Lo studio sulla potenziale riduzione delle emissioni di gas serra attraverso cambiamenti comportamentali nelle attività domestiche nella regione himalayana mostra che 6.094 t di CO_{2-eq} per anno possono essere ridotte seguendo semplici misure, come tenere il coperchio durante la cottura, utilizzare una pentola a pressione per la cottura, spegnere le luci quando non servono, limitare l'uso della televisione ecc. Questo studio mostra anche che l'uso di bio-isolante fatto con materiale locale può ridurre le emissioni del 19% sul totale.

Sulla base dei risultati delle analisi LCC e LCA, si conclude che edifici ad elevata efficienza energetica realizzati mediante l'uso di materiali locali, in combinazione con un adeguato isolamento e l'utilizzo di fonti energetiche rinnovabili rappresentano le opzioni consigliate per la progettazione di un'edilizia sostenibile nella regione himalayana. Tecnologie ad alta efficienza energetica, tra cui fornelli, stufe, lampadine e l'uso di energie rinnovabili hanno il maggiore impatto positivo sulla riduzione delle emissioni di CO_{2-eq} e dovrebbero essere incoraggiati nel Parco. Edifici sostenibili con basso consumo energetico, alta efficienza e innovazione nei sistemi costruttivi, come la casa passiva, dovrebbe essere promossi.

Acknowledgement

I owe my deep gratitude to my family who provided me perpetual love and support, who are always there to encourage and motivate me. I am very thankful to **Mr. Shital Kumar Gupta** for his continuous moral support, guidance and endowing me with the much-needed assurance for the successful completion of the thesis work. I heartily acknowledge all my friends who were always there to encourage and motivate me for the successful completion of the project.

Silu Bhochhibhoya

Table of Contents

CHAPTER THREE

COMPREHENSIVE OVERVIEW OF LIFE CYCLE PROSPECTIVE OF COMMERCIAL BUILDING IN SAGARMATHA NATIONAL PARK AND

CHAPTER FOUR

LIFE CYCLE ASSESSMENT OF BUILDING WALL MATERIALS

List of Figures

List of Tables

List of Abbreviation

°C	Degree Celsius
ANOVA	Analysis of variance
AP	Acidification Potential
CFC	Chlorofluorocarbon
CGI	Corrugated Galvanized Iron
CH_4	Methane
CML	Institute of Environmental Science
CO_{2-eq}	Carbon dioxide equivalent
D	End-of-life Cots
EP	Eutrophication Potential
EV-K2-CNR	Ev-K2-CNR Committee
FU	Functional Unit
GHG	Greenhouse gas
GWP	Global Warming Potential
HH	Household
HVAC	Heating, Ventilation and Air Conditioning
IC	Investment Costs
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardization Organization
Kg	kilogram
kWh	Kilo Watt hour
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Inventory Assessment
LPG	Liquid Petroleum Gas
M	meter
m a.s.l.	meter above sea level
M&RC	Maintenance and Replacement Costs
m/s	Meter per second
N_2O	Nitrous oxide
NIST	National Institute of Standards and Technology
NMVOC	Non-methane volatile organic compound
O	Operational Costs
ODP	Ozone Depletion Potential
PM	Particulate Matter
POCP	Photochemical Ozone Creation Potential
SETAC	Society for Environmental Toxicology and Chemistry
SNPBZ	Sagarmatha National Park and Buffer Zone

SO$_2$	Sulphur dioxide	
SPCC	Sagarmatha Pollution Control Committee	
SPSS	Statistical Package for the Social Sciences	
t	Tonnes	
TV	Television	
UNEP	United Nations Environment Program	
VAT	Value added Tax	
VDC	Village Development Committee	
W	Watt	

CHAPTER ONE

1.1 General Introduction

1.1.1 Building and environment

The building industry is one of the largest consumers in terms of nature resources, and one of the largest producers of pollution (Vijayan and Kumar 2005). The building sector accounts for a substantial amount of energy consumption which makes a considerable contribution to the worldwide environmental impacts (Scheuer et al. For instance, the building sector is responsible for 30% of global annual greenhouse gas emissions and consumes up to 40% of all energy (UNEP 2009). Lowering energy intensity and environmental impacts of the building is increasingly becoming a priority. Since the building are long-term investments associated with environmental impacts over their entire life span (Cole 2000), the design of the sustainable, low-impact buildings is a key issue in the building sector (Ferreira et al. 2015). The main objectives of the sustainable design are to prevent environmental degradation caused by the facilities and infrastructure throughout the life cycle and to create the healthy structures, environment friendly, comfortable, safe and productive building environment (WBDG Sustainable Committee 2014).

Buildings have significant and complex impacts both in their construction and operational phase. It uses the resources such as energy, raw materials, water, etc. and generates potentially harmful atmospheric emissions and polluted water during its life span. Building owners, designers, and builders face a challenge to develop a new and renovated facilities that allows people to live in a healthy environment and improved social, economic and environmental conditions for present and future generations (WBDG Sustainable Committee 2014; Ortiz et al. 2009).

Thus, it is important to quantify the environmental performance of the building in order to observe the potential environmental impacts and their influence on sustainable development (Passer et al. 2012). To assess the sustainability of the building, it is significant to consider their entire life cycle and to evaluate the environmental impacts associated with the extraction, production and transportation phases by identifying and quantifying the energy and materials used and the waste released to the environment (Pittet 2010; Sonnemann 2003). In this regard, life cycle based methodologies on building assessment tool are required such as Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) (Moschetti et al. 2015a).

The application of the global methodology such as LCA and LCC is adopted to support environmentally and economically concerned decision-making in the building sector. (Gustavsson 2006; Zabalza et al.2011; Passer et al. 2012).

1.1.2   Application of LCA in building sector

The LCA methods for the assessment of the environmental performance of the buildings have been developed since the early 1990s (Passer et al. 2012). The International Standardization Organization (ISO) prepared the first standard that addresses the specific issues and aspects of the sustainability relevant to the building and the construction works. Currently, the application of the LCA also includes the analysis of the economic performance of the buildings (Braganca 2012).

LCA for the buildings provides the quantitative and comparative values of the environmental impacts of various building technologies (Singh et al. 2011). LCA is used for quantifying the emission, energy and material consumption of a building system in different life cycle phases starting from the acquisition of raw material, product manufacturing assembling and disassembly (UNI EN ISO 14040 2006; UNI EN ISO 14044 2006; Consoli et al. 1993).

The Society for Environmental Toxicology and Chemistry (SETAC) reported that executing an LCA at the building level implies an assumption of its performance and includes all the necessary material, energy and transportation processes. Applying LCA in the building sector has become a distinct working area within LCA practices (Khasreen et al. 2009). This is due to the complexity of buildings, typically relative

long life span, uncertain changes undergo in its form and function during its life span. On top of that, many environmental impacts of a building occur during its operation.

It is widely recognized in the field of Building Sustainability Assessment that the LCA is a preferred method for evaluating the environmental pressure caused by the materials, construction element and by the whole life-cycle of the building (Braganca 2012). Several initiatives for harmonization and standardization of methodological development and LCA practice in the building industry have taken at a national and international level.

There are two distinguish approaches mentioned by Erlandsson and Borg (2003) for LCA at the building level: a bottom-up approach focusing on building material selection and top-down approach that considers the entire building as a starting point for further improvements.

Application of LCA in the building sector

Type of User	Stage of the Process	Purpose of LCA Use
Consultants advising municipalities, urban designers	Preliminary Phases	Setting targets at Municipal level Defining zones where residential/office building is encouraged or prohibited Setting targets for development areas
Property Developers & clients	Preliminary Phases	Choosing the building site Sizing the project Setting environmental targets in a programme
Architects	Early design (Sketch) and detailed design in collaboration with engineers. Design of a renovation project	Comparing design options (Comparing/ orientation, technical choices)
Engineers/Consultants	Early design in collaboration with architects, and detailed design Design of a renovation project	Comparing design options (geometry, technical choices)

The key milestone accomplished in the LCA within the building sector by Ortiz et al. (2008) for the period of 2000-2007., revealed that LCA of the full building life cycle as a process varies on the functional unit was chosen and different construction techniques. Many case studies were focused on the specific part of the buildings life cycle and few dealt with the whole life span. Most of these case studies have higher environmental loads n the operation phase due to the higher energy required for the heating, ventilation and air conditioning (HVAC), recognised as the greatest environmental challenge facing the built environment. The main focus of all assessments is promoting better thermal insulation, replacing materials with less environmental burdens and supporting the application of renewable energies.

1.1.3 Definition and aspects of life cycle assessment (LCA)

LCA is a technique to evaluate the environmental impact of products or activities, starting from the extraction of raw materials, manufacturing, production, use and finishing with the final disposal, i.e. from cradle to grave (Sonnemann 2006; Fava 2006), which helps to identify and evaluate opportunities to affect the environmental improvement. Life cycle assessment (LCA) is an effective method to evaluate the environmental behaviours of products in a life cycle from cradle to grave (Jensen et al. 1997).

ISO 14044:2006 claimed that LCA can help decision-makers select the product or process that results in the least impact to the environment. It helps in identifying opportunities to improve the environmental performance of products at various points in their life cycle. It also helps in selecting of relevant indicators of environmental performance, and marketing (e.g. implementing an eco-labelling scheme, making an environmental claim, or producing an environmental product declaration. According to the International Standard ISO 14040 and 14044, LCA includes four phases in an LCA study shown in Fig.1. 1.
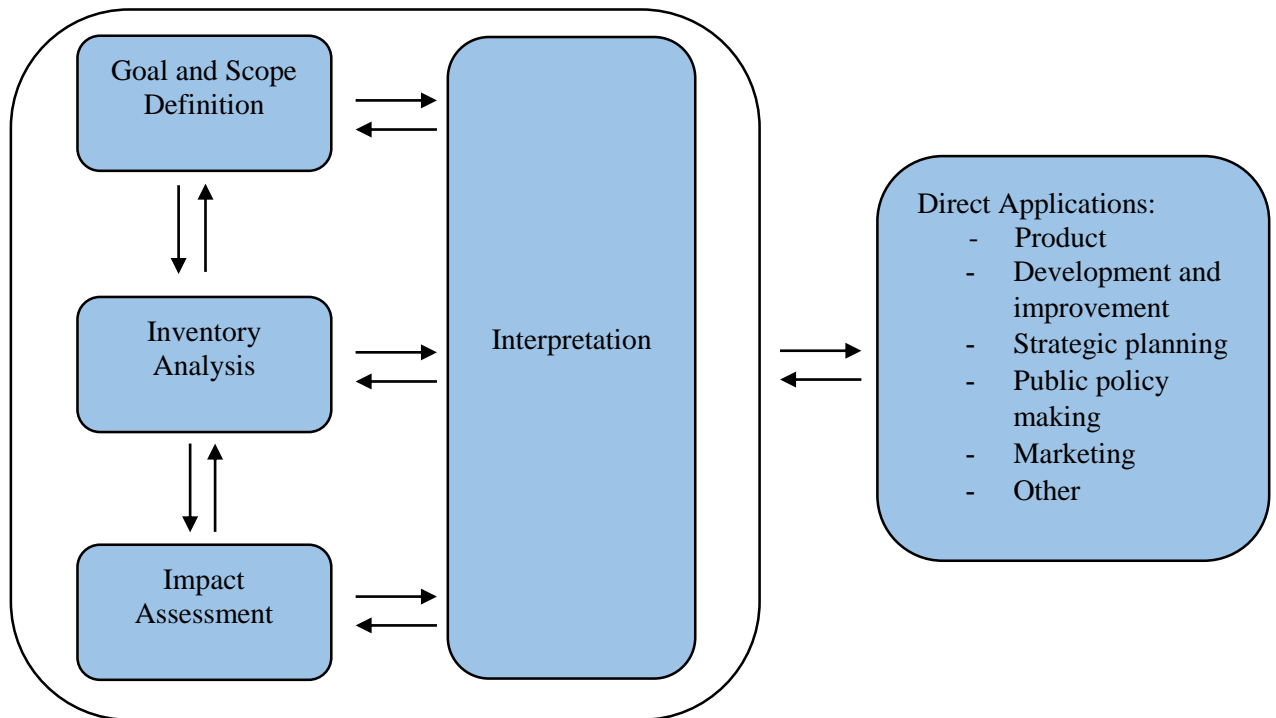
Fig.1. 1: Framework of LCA   (Based on ISO 14040, 2006)

1.1.3.1   Goal and scope definition

The goal and scope definition is a guide that ensures the LCA is performed consistently (Pre-sustainability). The goal and scope include the functional unit, which defines what precisely is being studied and quantifies that enables alternative goods, or services, to be compared and analysed; the system boundaries; assumptions and limitation; methodological choices, the impact categories chosen. The system's function and functional unit are key elements of the LCA analysis. The primary purpose of a functional unit is to provide a reference to which the input and outputs are related.

1.1.3.2   Life cycle inventory analysis

The life cycle inventory analysis phase (LCI phase) is the second phase of LCA study (ISO 14044:2006). LCI involves the collection, description and verification of data, as well as the modelling of the product system. In this phase, all inputs and outputs of the system are identified. Materials and energy used are quantified in inputs and, the

products and by-products generated and the environmental release in terms of emissions and wastes as outputs. It includes information on all of the environmental inputs and outputs associated with product or service i.e. material and energy requirements, as well as emissions and wastes.

1.1.3.3   Life cycle impact assessment

The life cycle impact assessment phase (LCIA) is the third phase of the LCA study. This phase of the LCA methodology is the systematic assessment of impacts, i.e., determining the potential contribution of the product to the environmental impact categories such as Global warming, Acidification etc. The assessment of the environmental impact categories is defined as a technical process, quantitative and/or qualitative, to characterize and assess the effects of the flows identified in the previous phase (Braganca et al. 2010, Braganca and Mateus 2012).

According to ISO 14040, LCIA is divided into two required steps: Classification and characterization and two optional i.e. normalization and aggregation. The classification step comprises the distribution of the results in the LCI phase to different impact categories that are relevant for the purpose of analysis. For example, the emission of CO_2 and CH_4 contributes to Global Warming so are assigned to this impact category, while emission of SO_2 and NH_3 are attributed to the impact category Acidification. Whereas, the characterization phase study the relative contribution of each LCI results in the value indicated of each environmental impact categories (European Commision - Joint Research Centre - Institute for Environment and Sustainability 2010). In other words, the different characterization factors associated with each emission and with the different types of impact categories

The normalization is used for simplifying the interpretation of the results. It enables the comparison between different types of environmental impact categories as all the impacts are converted into the same unit. The aggregation allows the determination of global indicators and involves assigning a weight to each category of environmental impact

The last stage, Interpretation phase is often considered the most important. At this phase, the given obtained results are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition. The findings of a LCA analysis, the processes and materials that contribute most to the impacts of a product are conducted sensitivity and uncertainty analysis.

Sensitivity analysis evaluates the influence of the most important assumptions have on the results. The principle of sensitivity analysis is to change the assumption and recalculate the LCA. With this type of analysis, we will get a better understanding of how different assumptions affect the result (Mark et al. 2013). The uncertainties of the data can be expressed as a range or standard deviation, using a statistical method, such as Monte Carlo technique, which can calculate data uncertainty on the results of LCA.

1.1.4 Life Cycle Costing (LCC)

The National Institute of Standards and Technology (NIST) Handbook 135, 1995 edition define LCC as "the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system" over a period of time (Sieglinde 1996). Life cycle cost is the economical method for evaluating and comparing different building designs, both in terms of initial costs and future operational cost (Ristimäki et al. 2013). Buildings are long- term investment associate with environmental impacts over its life span (Raymond 2000). By applying LCC in early design phase, decision makers are able to understand the cost during the life cycle for different design strategies (Ristimäki et al. 2013).

LCC is used to evaluate the cost performance of a building throughout its life cycle, including acquisition, development, operation, management, repair, disposal and decommissioning (Davis Langdon Management Consulting 2006a). In the International Standard ISO 15686-5 standard, Life Cycle Costing is defined as a methodology for systematic economic evaluation of life-cycle costs over a period of analysis, as defined in the agreed scope. The use of LCC in the early design phase

allow decision makers to able to obtain a deeper understanding of costs during the life cycle of different design strategies (Ristimäki et al. 2013). It is used to optimise product performance and lifetime cost of ownership (Henn 1993). Aye, et al. (2000) state that LCC is used for analysing a range of property and construction options for a building (Aye et al. 2000).

$$LCC = IC + O + M\&RC + DC$$

1.1.4.1 Investment cost

The initial cost that may include capital investment costs for land acquisition, construction and for the equipment needed to operate a facility (WBDG Sustainable Committee 2014).

1.1.4.2 Operation cost

The cost at this stage comprises consumer or user operations of the product in the field throughout its life cycle (Asiedu and Gu 1998) Most of these costs are related to building utilities and custodial services (Mearig et al. 1999). Operation costs are the most significant portion of the LCC and yet are the most difficult to predict (Asiedu and Gu 1998). All the annual operation costs are to be discounted to their present value prior to the life cycle cost analysis.

1.1.4.3 Maintenance and replacement cost

This is the third step of life cycle cost analysis that includes all the future maintenance and replacement costs of the alternative. Maintenance refers to the costs incurred to keep building system running properly (Environmental Stewardship Committee 2002). Maintenance costs consist of preventive maintenance and repair costs. Preventive maintenance costs are routine and scheduled activity intended to keep a system running at its best. While, repair costs are an unanticipated expenditure that is required to maintain the building.

Maintenance and replacement costs are anticipated expenditures to major building system components that are required to maintain the operation of a facility (Mearig et al. 1999). These costs incurred the cost of building material that has been replaced

completely. All the maintenance and replacement are to be discounted to their present value prior to the life cycle cost analysis.

1.1.4.4 *End-of-life costs*

This is the last step of life cycle costing analysis, which also include two distinct types: residual value and demolition. Residual value is the net worth of a building or building system at the end of the life span. Usually, it is assumed that all buildings have zero residual value at the end of the study life. Demolition cost is assigned to the new project on a site ((Environmental Stewardship Committee 2002).

1.1.5 Fundamental concepts of life cycle cost

Since LCC take into account future costs, the time-value of money needs to be accounted for the analysis (Fabrycky and Blanchard 2000; Korpi 2008). So, it is important to discount the future cash flows into the present value especially if the life of the building is long. Moreover, many LCC methods (Fabrycky and Blanchard 2000; Woodward 1997; Korpi 2008) take also inflation into account.

1.1.5.1 *Inflation rate*

The inflation rate is the rate of increase in the prices of goods and services and represents changes in the purchasing power of money. Inflation rate reduces the value or purchasing power of money over time. It is a result of the gradual increase in the cost of goods and services due to economic activity (Environmental Stewardship Committee 2002). Inflation rate reduces the value or purchasing power of money over time. It is a result of the gradual increase in the cost of good and service due to economic activity.

1.1.5.2 *The discount rate*

The discount rate represents the real value of money over time. In order to add and compare cash flows that are incurred at a different time during the lifespan, they have to be made time-equivalent. To make cash flows time-equivalent, the LCC method converts them to present values by discounting them to a common point in time.They must be discounted back to their present value through the appropriate equations.

Most goods and services do not have prices that change at exactly the same rate as inflation. On average over time, however, the rate of change for established commodities is close to the rate of inflation. Like discount rates, escalation rates are adjusted to remove the effects of inflation (Environmental Stewardship Committee 2002).

1.1.6   Application of LCC in building sectors

The LCC provide a financial/economic evaluation of sustainability impacts that have a widely agreed and readily calculated monetary value

The use of LCC can provide a financial/economic evaluation of alternative options identified in LCA assessment. To select cost effective options, then making a final decision in the light of a process of LCA carried out on those options only.

1.2   Background

With growing consequences of climate change globally, concerns on emission control of GHGs are rising in both developed and developing countries. Moreover, the impact of climate change is not experienced equally throughout the world. Developing countries are considered to be particularly susceptible to climate change due to their limited capacity to cope with hazards associated with changes in climate. Montemayour (2012) revealed that the most dangerous threat in the remote settlement in the mountain rage is the rapid melting of its glaciers caused by progressive increases in mean annual temperature. The scientist claimed that the effects of climate change are more severe in rural mountain communities because with limited livelihood options, adaptive capacity, poor access to services, and inequitable access to productive assets (Gentle and Maraseni, 2012). The study has shown that the warming trend in the Himalayan region is greater than the global average (Montemayour, 2012).

The government of Nepal is planning to implement a policy to attract more tourists in the near future. Although these initiatives will bring new income opportunities for the

local communities, they will also contribute to a fast growing in buildings that could worsen the already critical situation in terms of environmental pollution (Salerno et al. 2010; Manfredi et al. 2010), especially keeping into account the ongoing replacement of traditional wood and stone masonry with concrete structures. To satisfy the needs of this increased population, a large amount of energy supply is needed. Where possible, the energy is supplied from the combination of traditional energy sources (firewood and animal dung) and commercial sources (kerosene, LPG and electricity).

Pandit (2013), revealed that the Himalayas are warming faster than other mountain ranges, and the increased use of reinforced concrete in building construction, replacing the traditional wood and stone masonry there, is likely to create a heat-island effect and thus add to regional warming.

In that condition, assessment on environmental impacts of building technologies/systems has a greater importance. Scientists have claimed the importance of assessing the entire life cycle of building to evaluate the environmental impacts associate with production, process, transportation, or activity by identifying and quantifying energy and materials used and wastes released to the environment. Life Cycle Assessment (LCA) is a technique to evaluate the environmental impact of products or activities, starting from extraction of raw materials, manufacturing, production, use and finishing with the final disposal, i.e. from cradle to grave (Sonnemann et al. 2003; Fava 2006), which helps to identify and evaluate opportunities to affect the environmental improvement.

Environmental impacts of building materials production and construction processes vary according to the regions and countries (Pittet et al. 2010). Developing countries, compared to highly industrialized/developed nations, have generally less efficient processes that consume more energy and generate an environmental impacts for producing same materials (Buchanan and Honey 1994; Emmanuel 2004; Asif et al. 2007; Pittet et al. 2010).

This research work observed the environmental impacts of building technologies and its efficiency in high Mountains of Nepal through GHG accounting in order to reduce

the emission in that region. Hence, the study on assessment of the environment in building system is important which gives and overall picture of emission situation and helps identify major emission sources and potential areas of improvement.

1.2.1 Study site

Sagarmatha National Park and Buffer Zone (SNPBZ), in the Eastern Development Region, is an attractive tourist destination because of its bountiful natural beauty enhanced by highest peak, Mount Everest, in the world.The park lies within an area of 1148 km^2, which is located between 27° 30' 19" – 27° 06' 45" N latitude and 86° 30' 53" – 86° 99' 08" E longitude (Figure 1.3). It ranges in elevation from 2845 m at Jorsalle to 8848 m a.s.l. at the summit of Mount Everest. The mean temperature of the coldest month, January, is -0.4°C. Some 56% of years' experience a tropical regime (summer rain), 35% are bixeric (two dry periods) and 1% are trixeric (three dry periods) or irregular.

The conservation of natural ecosystem and management of environmental conditions in Sagarmatha National Park (SNP) is of global significance. The stringent regulations of SNP, the creation of its buffer zone (BZ) and increased tourist industries have been putting a lot of social, environmental and economic stresses on the inhabitants of three VDCs of Solukhumbu District; namely Chaurikharka, Namche and Khumjung. Since the establishment of Sagarmatha National Park (SNP), with its strict regulations on resource use, people living inside the park have used the forest for timber, fuel-wood, leaf litter, etc. Moreover, most of the 30 000 tourists, who visit SNP yearly use forest directly (meals, showers, heat) and indirectly (tourists' porters burn fuel-wood to cook, lodges are constructed). Due to heavy pressure on the forest area from local people, SNP residents, and tourists, degradation is visible and increasing.

This park is divided into different climate zones because of the rising altitude (Fig.1. 2). They include a forested lower zone (alpine scrub), an intermediated one that includes the upper limit of vegetation growth, and the Arctic zone where no plants can grow. The indigenous Sherpa population is about 2500, mainly Buddhists, whose economy is based on tourism and agriculture (United Nation 2011).
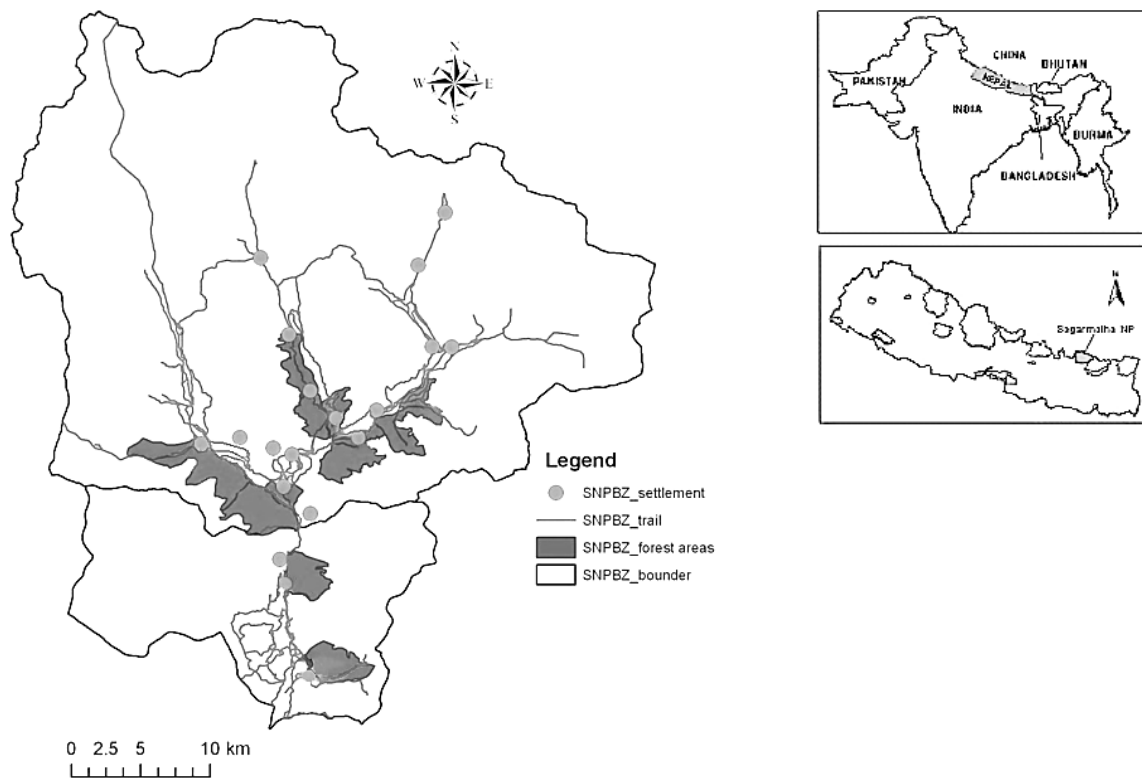
Fig.1. 2: Location of SNPBZ and climate zones

Fuel-wood has been identified as the major source of energy for the majority of people in SNPBZ, which is not produced adequately to meet the increasing demands of tourist and the local population in the region at present. On the other hand, thinning of forest mass in Pharak area due to increased extraction has to be addressed. There is a need to develop alternative energy sources to ensure the sustainable use of natural resources. Therefore, it is proposed to carry out the research to identify both the expansion of alternative energy sources at present in the SNP and BZ and the development of new alternative energy sources.

In the case of cooking and heating stoves, according to Sulpya and Bhadra (1991), the efficiency of the cooking stove is 16.1 % in Namche, SNPBZ. Increasing the efficiency of the stove both on cooking and heating system could decrease the consumption of energy.

1.2.2 Buildings in SNPBZ

Locally available materials are abundantly used particularly on the roof and the wall construction. Due to the cold climate in the region, houses are built facing south-east to receive the early morning sun and to continue receiving it until late in the afternoon.

Materials involved in construction for the traditional building are mainly be categorized into wood, stone and mud. Whereas, modernization of the building is increasing that use imported construction material i.e. cement and insulation like glass wool and polystyrene, to attract the tourist. The choice of the building materials mainly depends on cost, availability and appearance. However, these days, people are concerned on the environmental suitability of material, which is another important factor (Asif et al. 2004).

The construction is mainly wood for the internal support structure, stone or soil for the envelope, according to different installation techniques: compressed clay or sun-baked mud bricks (Sestini 1998); dry stone masonry of 70-80 cm thick. As for the floor, timber joists are disposed perpendicularly to the main girders, overlaid by floorboards; the roof is characterized by the same structural scheme, except for the specific inclination of the pitched room. Windows have a timber frame and 3-4 mm thick single glass; the openings are exposed to The South-East in order to maximize the light in the house (Sestini et al. 1978) (Fig.1. 3).
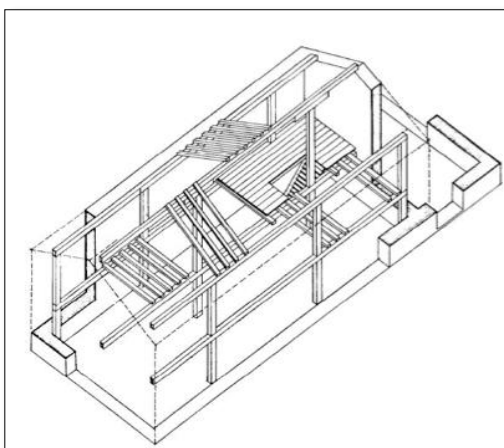
Fig.1. 3a: Typical building layout   *Fig.1. 3b: Building construction*

1.2.3 Building materials

1.2.3.1 Wood

Wood has been the traditional building material, widely used for different applications in construction such as for framing, flooring, roofing and walling. Himalaya Birch Silver (*Betula utilis* D. Don) and Himalayan hemlock (*Tsuga dumosa* D. Don Eichler) are generally used for the building construction in the park. The woods for the construction are usually brought from the Chaurikharka. The wood processing for the plank, joist and framing for the construction are done in the construction – site itself (Fig.1. 4).

Fig.1. 4: On-site wood processing

1.2.3.2 Kamero (White soil)

Soil as a construction material has been extensively used since the 20th century. Many types of research these days have been carried out to adapted modern technologies to the soil (Morel et al. 2001). The soil is abundantly accessible in the region. It is used as a binding material as well as insulation. In traditional building type, 2-3 inches of mud plaster has been used externally in masonry stonewall (Fig.1. 5).

Fig.1. 5: Mud plastered traditional building

1.2.3.3 Stone

Dry stone masonry is abundantly used in all building types in SNPBZ. The sandstone is widely been used for the construction. The stone for the masonry work are obtained usually from the riverbed as shown in Fig.1. 6a. The stones are further cut down (Figure 1.6b) into required measurement by chisel and hammer. To achieve a clean sharp finish, carving and moulding of the stone is done.

Fig.1. 6 a: People extracting stone   Fig.1. 6b: 1A person carving stone

1.2.3.4 Glass wool

Modernization of building accesses the commercial material like glass wool as insulation. The material is imported either from China or India.

1.2.3.5 Cement

Cement in other-hand has gradually been used in new building construction in the region. The material is particularly used as binding purpose. It is transported from the industry nearby the capital city and then cargo it to the Lukla.

1.2.4 Energy resources in sampling sites

1.2.4.1 Fuel wood

Among different energy resources, the major ones in study area include fuel wood, kerosene, LPG, animal dung, solar and hydropower, in which the fuel wood is dominant energy resource. Temperate, sub alpine and alpine forests of SNPBZ serve

as a major source of fuel wood for a people living near SNPBZ. The main forest species of the Park area include:

- Blue pine *(Pinus wallichiana)*,

- Fir *(Abies spectablilis)*,

- Fir-juniper *(Juniperus recurva)*,

- Birch – rhododendron *(Betula utilis, Rhododendron campanulatum and R. campylocarpum)*,

- Shrub *(Juniperus spp., Rhododendron anthopodon, R. lepidotum)*.

The local settlements between the Park and the Buffer Zone areas utilize the forest for firewood, fodder, non-timber forest products and grazing their livestock. Plantation program and other nature conservation activities were promoted by the Himalayan Trust in different locations of the Park, (especially Khumjung and the Namche). Six fenced plantation areas in Namche and surrounding areas were found during the course of study. To preserve the forest, Forest User Committee allow the collection of fuelwood by 2 persons per household twice a year for 15 days each (Franco et al. 2010).

1.2.1.1 *Animal excrete*

It is especially cow dung when dried (*guitha*) is used as one of the major source of energy (for burning) in most of the region in Nepal. Along with cow dung, dried dung of other species is used as an energy source in the study area. As illustrated, 6368.41 tons (CEE, 1999) of animal dung is collected in the study area, which founds different application in different place of Pharak, and SNP area. In Chaurikharka (Pharak region), animal waste is used for composting while in SNP region, due to the involvement of people in trekking/porter and expansion of trek area, dung finds a form of cake which is sold for about Rs. 200-300 (1.8 – 2.7 €) per bhari 1 bhari = 45 kg).

1.2.1.2 *Hydropower plants*

 Hydropower Plants are capable of producing a substantial amount of electrical energy that could be advantageously used for substituting conventional sources of energy (commercial and traditional sources of energy) in SNPBZ. Several hydropower sites

could be developed to address the energy need in SNPBZ. It already hosts hydropower plants with a capacity ranging from a few kW to 630 kW. Local peoples' aspiration in Namche is to build larger scale hydropower plants, however, SNPBZ regulations restrict such large-scale projects.

Currently, four hydropower stations supply electricity to Upper Khumbu region namely; Khumbu Bijuli Company (630 kW), Tengboche Micro-hydropower Plant (22 kW), Pangboche Micro-hydropower Plant (15 kW) and Phortse Micro-hydropower Plant (60 kW). Lower Khumbu, has Ghatte Khola Micro-hydropower Plant and several pico-hydropower plants.

1.2.1.3 Solar PV and Solar Thermal plants

Sun radiation is another major source of renewable energy. Maturing technology provides an ample opportunity for solar electrification and other solar technologies in a country like Nepal. In the study area, the meteorological station installed by EV-K2-CNR in Namche reported that the global radiation is about 155.8 W/m^2 in 6 hr for a total sunshine hour.

Solar energy has been traditionally used for drying agricultural commodities, clothes and fuel wood. With an increase in tourist inflow, solar photovoltaic and solar water heater has been introduced in SNPBZ region. Along with these technologies introduced, Solar Passive house provides an option for reducing the energy demand for space heating which in turn reduces the dependence on SNP forest for energy. Along with the promotion of nature conservation, use of these technologies substantially reduces the health hazard caused by indoor pollution.

1.2.1.4 Wind power

The Wind is another open source for harvesting an ample amount of energy from the Mother Nature. The data from Namche meteorological station reveal the monthly average wind velocity of the area of about 4.2 m/s ranging from 3.29 m/s to 5.22 m/s with the standard deviation of 0.7. The data reveals the theoretical potential of wind energy for 10 m height is 4.6 kW. The spot measurement of wind velocity at different location of Namche reveals the average wind velocity of 6.05 m/s ranging from 5.4

m/s to 10.8 m/s, which provides an average theoretical potential of 8.085 kW. The data reveals the fact that the standard deviation of 2.66 providing a power output for the region ranging from 6.26kW – 12.08kW.

1.2.1.5   *Kerosene and Petroleum Liquid Gas (LPG)*

Kerosene and LPG are one of the major commercial energy sources in the study area. To fulfil the increasing energy demand and to reduce the pressure in the study area three kerosene depots were found in SNPBZ, in Syangboche, Dole and Pheriche. The stock of kerosene for the depots is maintained at 2500 liters for slack seasons and 4500 litres for the main trekking season in Syangboche. About 18000 liters of kerosene are sold every year. Along with kerosene, Bottle gas (LPG) is circulated in the study area, from Phakding to Everest Base Camp in about 1000 cylinders per year. [Mr. Lhakpa Nimbu Sherpa, businessman (LPG)]

According to Mr. Kapidra Rai, Programme Manager, SPPC has 100 LPG Cylinders and out of this number they send 40 to Lukla. The number, which they send to Lukla, is not sufficient for the users so the local shops also supply the gas and the kerosene.

1.2.5   Research aim and objectives

The main aim of this research is to study the environmentally sustainable building assessment with the integration of environmental and economic impacts of the Himalayan buildings. Based on the assessment, the study aims to support on selecting of technologies and materials to minimize the environmental and economic burden of future construction projects in the Himalayan region. Specifically, it is envisaged that this research will promote environmental sustainability in the Himalayan building sectors.

To fulfil the main aim of the research, there are several specific objectives

> I.   Investigate literature review on sustainable building assessment
>
> II.   Highlight the environmental impacts of construction activities with a focus on the impact of construction materials throughout their life cycle and suggest strategies for sustainable construction implementation.

III.   Estimate the building operation for the period of 50 years of building lifespan. The detailed study on energy consumption pattern and its emission for household activities in the Park.

IV.   Investigate the life cycle cost of commercial buildings that incurred construction, operational and replacement cost in the region

V.   To observe the comprehensive overview of environmental and economic burdens in the commercial building sectors of the region based on different sustainable indicators using statistical methods.

VI.   Recommend the best practice to reduce the GHG emission from the building sector in the region. Investigate the potential of greenhouse gas emission reduction in terms of household behavioural changes. On the other hand, examine the bio-insulation made of local materials in the region.

1.2.6   Rational of the research

The most common, interrelated factors that exacerbate global environmental problem are population growth, climate change and building activity consequences on changing the earth environment. Sagarmatha National Park and Buffer Zone is the home of Mt. Everest, 35,000 of tourist visit the place every year. With increasing population, the construction of modern buildings with reinforced concrete structure design is growing fast. These modern buildings are built by using imported construction materials, which has to be transported from the capital city by airfreight. Such materials have a larger environmental burden from a life cycle perspective than a traditional building. On the top of this, a large amount of energy supply is needed to satisfy the needs of increased tourist population. Where possible, the energy is supplied from the combination of traditional energy sources (firewood and animal dung) and commercial sources (kerosene, LPG and electricity). Pandit (2013), revealed that the Himalayas are warming faster than other mountain ranges, and the increased use of reinforced concrete in building construction, replacing the traditional wood and stone masonry there, is likely to create a heat-island effect and thus add to regional warming.

Climate change is becoming one of the major threats in the Himalayan region like Sagarmatha National Park and Buffer Zone area. Montemayour (2012) revealed that the most dangerous threat in the remote settlement in the mountain rage is the rapid melting of its glaciers caused by progressive increases in mean annual temperature. The scientist claimed that the effects of climate change are more severe in rural mountain communities because with limited livelihood options, adaptive capacity, poor access to services, and inequitable access to productive assets (Gentle and Maraseni 2012). The study has shown that the warming trend in the Himalayan region is greater than the global average (Montemayour 2012). The increasing temperature in the Himalayas creating serious impacts on the countries glacial lakes, which are the main source of Nepal's fresh water resources. This situation is particularly serious in the fragile Himalayan ecosystem, which could raise the threat of glacier-lake outburst floods (Nema et al. 2012) as well as facing large scale in forest decline (Prasad et al. 2001; Stevens 2003; Nepal 2008).

The situation of mountains are certainly on perilous, thus, should be given the prime importance on GHG emission control. The principal goal of the study is to develop information that can be used to mitigate climate change by reducing greenhouse gas emissions

The construction and operation of buildings account for significant energy consumption and the consequential amount of greenhouse gas emissions. Developing countries, compared to highly industrialized/developed nations, have generally less efficient processes that consume more energy and generate an environmental impact for producing same materials (Buchanan and Honey 1994; Emmanuel 2004; Asif et al. 2007; Pittet et al. 2010). In that condition, assessment on environmental impacts of building technologies/systems has a greater importance. Scientists have claimed the importance of assessing the entire life cycle of building to evaluate the environmental impacts associate with production, process, transportation, or activity by identifying and quantifying energy and materials used and wastes released to the environment.

To better understand the environmental and economic performance of buildings in developing countries, such as the Himalayan region, a specific study has been

performed. Moreover, understanding of LCA and LCC of building sector in the region in order to identify major emission sources and potential area to reduce the local GHG emission is not investigated yet. This study explores the different energy related activities and identifies key behaviours to reduce energy consumption and GHG emissions.

1.2.7 Limitations of the study

    I.   Lack of data on building sector for developing countries is the main limitation. However, primary data collected in the site as well as an eco-invent database for {RoW}*(Rest of the World)*, are used to assess the result. The buildings are chosen as representative but there may be variability across the various buildings in the park.

    II.   Record on actual energy usage through instrumentation is hard to obtain therefore this research relies on lodge owner's estimation.

    III. CO_2 emission from energy use was estimated by an emission factor of greenhouse gas from literature. The instrumental analysis could not have be done on the field.

1.2.8 Research questions

The main research questions for this research aim to address are:

    I.   Which kind of building is more environmental friendly? Which life-cycle stage comprises an environmental impact in this study?

    II.   Which building is most cost effective?

    III.   What are the characteristics of buildings in the Park?

    IV.   What is the distribution of environmental performance across the building? Is there any significant different of environmental performance between the buildings types?

    V.   What are the relevant the best practice to reduce the GHG emission from the building sector in the region?

1.2.9 Organization of the thesis

This thesis comprises of seven chapters shown in Fig.1. 7 and the specific chapter descriptions are as follows:

<u>Chapter One</u>

This chapter provides background information of the research. It explains why and how this research is significant to the building sector in Himalayan region. It presents the aims and objectives, with underlying research questions followed by study limitations.

<u>Chapter Two</u>

This chapter presents the comparative Life Cycle Assessment and Life Cycle Cost of three existing typical Buildings. This chapter reports on an integrated assessment method combining LCA with LCC within the building sector context, in particular by looking at the unique situation of buildings in the Himalayan region. The study aims at filling this gap by providing new information on Himalayan buildings and their life cycle.

The content and structure of this chapter is based on given paper.

Bhochhibhoya S., Pizzol M., Achten W., Maskey R.K., Zanetti M., Cavalli R. (2015), *"Comparative Life Cycle Assessment and Life Cycle Costing of Three Himalayan Building"*. Manuscript submitted in International Journal of Life Cycle Assessment *(In review)*

<u>Chapter Three</u>

This chapter presents the comprehensive picture of life cycle prospective both on environmental and economic aspect, with the addition of physical and technical parameters such as energy consumption, thermal conductivity and size, over the entire hotel sector in the Park to accomplish building sustainability and promote the use of sustainable construction practice.

The content and structure of this chapter is based on given paper:

Bhochhibhoya S., Pizzol M., Marinello F., Maskey R.K., Zanetti M., Cavalli R. (2016) "Comprehensive picture of life cycle prospective over the entire hotel sector in the Park" Manuscript submitted in Building and Environment *(In review)*

Chapter Four

This chapter presents the environmental performance of building materials in a perspective from the Himalayas. It provides a comparative life cycle assessment of different wall materials used in existing buildings in Sagarmatha National Park and Buffer Zone.

The content and structure of this chapter is based on given paper:

Bhochhibhoya S., Zanetti M., Pierobon F., Gatto, P., Maskey R.K and Cavalli R. (2015), *"Global warming and building materials: A prospective from the Himalayas".* Manuscript submitted in Mountain Research and Development Journal *(In review)*

Chapter Five

This chapter gives a broad overview of environmental impacts in whole buildings. It allows constructer, hotel owner or even tourist to choose the best eco-efficient hotel in the Park.

The content and structure of this chapter is based on given paper:

Bhochhibhoya S. and Cavalli R. (2015), *"Global Warming and Himalayan Building"* A chapter submitted to the book Life-cycle approaches to Sustainable Regional Development *(In press)*

Chapter Six

This chapter is devoted exclusively on reducing GHG emission through household behaviour change and bio-insulation made of local material.

The content and structure of this chapter is based on given paper:

Bhochhibhoya S., Gupta S.K., Marinello F., Zanetti M., Maseky R.K., Cavalli R. (2015), *"The potential of GHG emission reduction in terms of household behavioral changes in the Himalayan region"*. Manuscript submitted in Kathmandu University Journal of Science, Engineering and Technology *(In review)*

<u>Chapter Seven</u>

This chapter summarized overall achievement of this thesis and provides directions for further research based on findings of the study.

Chapter One

Background information, develop research aims and objectives, research questions and the method adopted

Chapter Two

Comparative Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) of three Himalayan Buildings

Chapter Three

Comprehensive picture of life cycle prospective over the entire hotel sector in the Park

Chapter Four

Comparative study on life cycle assessment of building wall in existing buildings of the Park

Chapter Five

Overview of environmental impacts in whole building sector of the Park

Chapter Six

Potential GHG reduction through behaviour changes and Bio-insulation made of local materials

Chapter Seven

Summarization of overall achievement of this thesis and provides direction of future study

Fig.1. 7: Thesis organization

Comparative life cycle assessment and life cycle costing of three Himalayan building types

Abstract

The main aim of the study is to assess the environmental and economic impact of commercial buildings located in the Himalayan region of Nepal, from a life-cycle perspective. The assessment should support decision-making in technology and material selection for minimal environmental and economic burden in future construction projects.

The study consists of the life cycle assessment and life cycle costing of three building types: traditional, semi-modern and modern. The life-cycle stages under analysis include raw material acquisition, manufacturing, construction, operation, and maintenance and materials replacement. The study is performed using a consequential inventory modeling approach and includes a sensitivity analysis focusing on the lifespan of buildings, occupancy rate, and discount and inflation rates. The functional unit was considered as the "*Stay of one guest for one night*" and the time horizon is 50 years of building lifespan. Both primary and secondary data were used in the life cycle inventory.

The modern building has the highest global warming potential [kg $CO_{2\text{-eq}}$] as well as highest costs over 50 years of building lifespan. This is due to the use of commercial materials instead of traditional materials. The results also show that the operational stage is responsible for the largest share of environmental impacts and costs, which are related to energy use for different household activities. Furthermore, a breakdown of the building components shows that the roof and wall of the building are the largest contributors to

the production- related environmental impact. The findings suggest that the main improvement opportunities in the building sector lie in the reduction of impacts in the operational stages and in the choice of materials for wall and roof.

Keywords: Sustainability, Environmental impact, Construction Materials, Economic Impact, Net Present Value

2.1 Introduction

The building sector makes a considerable contribution to global environmental impacts (Scheuer et al. 2003). For instance, the building sector is responsible for 30% of global annual greenhouse gas emissions and consumes up to 40% of all energy (UNEP 2009). To assess the sustainability of long- term investments as buildings it is important to consider their entire life cycle and to evaluate the environmental impacts associated with the raw material extraction, the production, transport stages involved, etc., as well as the final disposal of the materials (Pittet et al. 2012; Sonnemann et al. 2003; Raymond 2000; Ferreira et al. 2015). Although the choice of the building materials mainly depends on their cost, availability and appearance, the environmental suitability of materials is becoming increasingly an important choice element (Asif 2007). A comprehensive evaluation of buildings' life cycle should include a quantification of both their environmental and economic performance (Gu et al. 2008). Previous authors have stressed how combining environmental and economic aspects can strengthen sustainability assessment of buildings (Rathcliffe and Stubbs 2005). In this context, the use of decision support tools such as Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) for sustainability assessment is particularly appropriate.

Ristimäki et al. (2013) describe how implementing LCC and LCA analysis in an early building design stage allows identifying the best economic and environmental design alternatives to develop sustainable urban areas. In particular, the use of LCC in the early design stage allows decision makers to obtain a deeper understanding of long-term design strategies (Ristimäki et al. 2013), and to optimise product efficiency and lifetime cost of ownership (Gluch and Baumann 2003). Moschetti et al. (2015) develop an overall

methodology regarding buildings' environmental impacts, energy output, and global costs for a complete building sustainability evaluation. Brown et al. (2011) show how life cycle management approaches, where LCA and LCC are integrated, help in establishing sustainability in the design of resorts. Other studies have also tried to combine LCA with LCC to support environmentally-concerned decision-making in the building sector (Brown et al. 2011; Davis Langdon Management Consulting 2006b; Gu et al. 2008). Despite the many studies on LCA of buildings, little is known about the impact of building in developing countries, where modern construction method are slowly replacing traditional ones.

In the Himalayan touristic region of the Sagarmatha National Park (SNP), the construction of modern buildings is growing fast, due to the increasing tourist flow. To satisfy the needs of the increasing tourist population, traditional building design is modified, and reinforced concrete structure replace traditional wood and stone masonry. The modern building is built by using imported construction materials, which have to be transported from the capital city, Kathmandu by air transport due to the complex terrain orography that makes difficult the road transport. Commercial materials are likely to have a larger environmental burden from a life-cycle perspective than the traditional materials. On top of this large amount of energy supply is needed to satisfy the needs of this increased tourist population, where possible, the energy is supplied from the combination of traditional energy sources (firewood and animal dung) and commercial sources (kerosene, LPG and electricity). In this context, the assessment of environmental and economic impacts of different building types is of great importance.

This chapter reports on an integrated assessment method combining LCA with LCC within the building sector context, in particular by looking at the unique situation of buildings in the Himalayan region. Information about the environmental impact of building materials is currently very limited in developing countries and especially for Himalayan region, one among the most vulnerable areas in the world with regard to the hazards associated to climate change (Pouliotte et al. 2009; Gentle and Maraseni 2012; Pandit 2013). The chapter aims at filling this gap by providing new information on

Himalayan buildings and their life cycle. The scope of the study is limited to examining the environmental and economic performance of three different types of buildings in the Himalayan region of the Sagarmatha National Park Buffer Zone (SNPBZ). Based on this assessment the study aims to support the selection of technologies and materials to minimize the environmental and economic burden of future construction projects in this region.

2.2 Materials and Methods

2.2.1 Building types in the Himalayas

As a consequence of higher altitude and cold weather, the buildings in the Himalayas are constructed and designed to meet the human demands in a cold environment (Little and Hanna 1978). Due to the cold climate in the region, houses are built facing south-east to receive the early morning sun and to continue receiving it until late in the afternoon (Pokharel and Parajuli 2000). Due to the difficult terrain, movement of people and materials over long distances is rather difficult, therefore, local materials and skills are used in great extent (Pokharel and Parajuli 2000). The materials adopted in the construction of the traditional building are mainly wood, stone and mud, which are locally available and used for e.g. roof and walls construction.

The modern and semi-modern buildings are built by using mainly imported construction materials i.e. cement and insulation materials like glass wool and polystyrene which have to be transported from the capital city, Kathmandu by airfreight. Such materials are likely to have a larger environmental burden from a life-cycle perspective from production till its end use. However, locally available materials like stone and wood are also used for the construction of this kind of building. The Park authority has enacted a regulation that allows the use of 30 m^3 of wood timbers per construction of one new building. Supplementary wood timbers are brought from Jiri, the hilly region of Nepal, which is located at 51 km aerial distance from the Park. These materials are mostly transported by helicopter from Jiri to the Park.

2.2.2 Building types addressed in the study

In the context of the tourist presence in this region, the study focused on the commercial building types present in the area. More specifically, the study focused on buildings that only have the commercial purpose of lodging. Three different existing building types, typical of current Himalayan Sherpa architecture and building typologies were chosen as case study for this analysis and described below:

Fig. 2. 1Modern building   *Fig. 2. 2 Semi-modern building*   *Fig. 2. 3 Traditional building*

a. **Modern type**: to enhance the tourism in the national park area, the modern cemented houses (Fig. 2. *1*) are designed using imported construction materials for insulation like glass-wool and polystyrene. Interestingly, nowadays all the modern houses (latest built) are being equipped with the latest efficient lighting arrangement with sensors.

b. **Semi-modern type**: this type of buildings is a combination of local and modern technologies with limited insulation (Fig. 2. 2). It is the modification of traditional houses into modern ones.

c. **Traditional type**: these follow the ancestral house design typically known as "Sherpa House". In the construction of these types of houses, locally available materials are abundantly used particularly on the roof and the wall construction. For example, locally available wood is used as a beam in the roofs whereas locally available wooden planks, dry stones and mud plasters are used in walls (FiFig. 2. 3).

Primary data on building size, building materials and energy consumption were collected through questionnaires in Sagarmatha National Park during the month of March/April, in 2014 Three buildings were selected with three different patterns based on material used

and architecture design: traditional, semi-modern and modern that are representative to all the existing buildings in the Park

As the commercial materials were imported from the Kathmandu, the questionnaires on the source of materials, type of vehicle used from the manufacturer to the retailer, and transportation distance covered were undertaken from the retailers in Kathmandu. General features of the three building types are summarized in Table 2. 1

Table 2. 1 Characteristics of the three buildings types considered in the study

Type	Traditional	Semi-modern	Modern
Location	Namche	Namche	Namche
Elevation (m)	3800	3800	3800
Operational season	7 months	7 months	7 months
Net area (m^2)	210	244	301
Gross volume (m^3)	1953	2868	3897
Construction method	Load bearing	Load bearing	Reinforced concrete
No. of floor	3	4	3
No. of beds	17	33	34
Occupancy assumption (in % of rooms occupied)	80	80	80
Guests per night stay	14	26	27
External walls	Mud plaster inner and outer side of dry stone, with wooden plank in internal wall	Cement pointing in dry stone, with wooden plank in internal wall	Cement pointing in dry stone, with insulating materials in space, wooden plank in internal wall
Insulation	Mud plaster	Polystyrenes	Glass wool/ polystyrenes
Windows	Wooden frame with single glazed glass	Wooden frame with single glazed glass	Wooden frame with double glazed glass, with 4mm thick each, and air space of 6 mm
Roofing	Galvanized sheets	Galvanized sheets	Galvanized sheets
Floor	Wooden plank	Wooden plank	Wooden plank
Door	Wooden	Wooden	Wooden
Heating system	Metal heating chimney	Metal heating chimney	Metal heating chimney + Electric heater

2.2.3 Life Cycle Assessment (LCA)

In this study, a cradle to gate LCA from construction till replacement stage was performed using a consequential inventory modeling approach and sensitivity analysis focusing on specific parameters. The SimaPro 8 software was used for the calculations.

2.2.3.1 Goal and scope definition

The goal of the study was to evaluate the life-cycle environmental impacts of the three building types: traditional, semi-modern and modern. The scope of the study included the following life cycle stages: raw materials acquisition and manufacture, building construction, building operation, building maintenance and material replacement (Fig. 2. 4). The end-of-life of the building was not taken into account due to the limited information on building demolition, waste transportation, and different waste treatment processes. The functional unit (FU) was considered as the "stay of one guest for one night". This allows comparing environmental and economic aspects of the three different types of buildings in SNP. The building lifetime was set to 50 years as this is the average age of buildings in SNPBZ.

Construction stage

Building material production

Raw materials extraction

Transportation of raw material to the manufacture site

Manufacturing of building materials

Building construction

Transportation of building materials to the construction site

Building construction

Operation stage

Building operation
(cooking, space heating, lighitng, heating water, power applicances)

Replacement and Maintenance stage

Maintenance of building through painting, cleaning

Replacement of building materials and assemblies

End-of-life stage

Building demolition

Transportation of the demolished materials

Reuse

Recycling

Disposal

Incineration

Stages

Excluded from system boundary

Flows

Sub-Stages

System boundary

Fig. 2. 4: LCA system boundaries.

2.2.3.2 Life cycle inventory

Both primary and secondary data were used in the life cycle inventory. Primary data on the quantity of material used in each type of buildings, transportation distances and the use means of transport, energy consumption for different household activities were collected in the field. Data on energy consumption during building operation were collected through questionnaires with the owners of selected three buildings. Direct measurements of the buildings size and dimensions were also carried out to quantify the volumes of different building components (e.g. wall, doors) and then calculate the amount of building materials used. Measurement of room dimensions (height, length, width), wall thickness, type of material used, measurement of doors and windows and its numbers, and measurement of the whole building (length and breadth) were undertaken. The ecoinvent database v.3 (Frischknecht et al. 2007; Weidema et al. 2013; Frischknecht et al. 2004) has been utilized to model the manufacturing process of the material used and their associated emissions.

I. *Construction stage*

The construction stage in this study includes the collection of raw materials by resource extraction; processing of the raw materials to building products; transportation of the products to the construction site; till the assembly of the products in a construction site. The type and quantities of material used for the construction of three buildings are given in Table 2. 2 and detailed information is given in Appendix 1. The data were collected from the fieldwork. Measurements of the buildings on-site, direct observations, interviewing the concern people like experts, contractors and local people were done. The weight is calculated based on the measured volume of the materials in the buildings and on their density.

In addition, transportation means and distance covered from manufacturing site to the construction site was estimated for each construction material. To obtain the environmental impact from transportation, the total weight (tonnes) of construction materials were multiplied by the total distance covered (km).

Table 2. 2: Life cycle inventory of the buildings

Enclosure	Materials	Weight (kg) Modern	Semi-modern	Traditional
Wall	Wooden plank	1842.80	1394.46	752.76
	Plywood	116.23	79.43	30.86
	Glass-wool	176.03	0.00	0.00
	Mud	8095.16	4963.00	8408.28
	Stone	443407.32	271845.07	115145.29
	Polystyrene	204.98	0.00	0.00
	Enamel	46.05	36.26	14.93
	Ordinary nails	8.53	6.72	2.77
	Cement	328.03	194.84	72.50
Roof	Wooden joist	6567.48	2226.29	2230.01
	Corrugated galvanized iron	834.91	282.35	281.41
	Roofing nails	9.84	3.33	3.32
Window	Wooden frame	371.28	227.91	81.11
	Glass	1221.68	432.51	204.53
Door	Wooden door	98.54	84.65	102.04
	Plywood door	4.76	4.53	1.76
Floor	Wooden joist	5661.65	3500.52	1410.44
	Wooden plank	7045.70	4356.27	1755.23
Ceiling	Wooden joist	5661.65	3500.52	1410.44
	Plywood	36.43	22.53	9.08
Ladder	Wood	56.26	72.34	56.26
Corridor	Wooden plank	1677.47	737.35	823.76
	Wooden joist	460.03	170.61	201.63
Pillar	Cement	251.94	0	0
	Sand	1084.75	0	0
	Iron rod	256.00	0	0

II. *Operational stage*

The operational stage is included to account for the impact generated by the energy consumption of different household activities such as cooking, space heating, water heating, lighting and the use of other electrical appliance during the building lifetime. The energy consumption of commercial buildings has significant seasonal variation. The tourist season was taken into consideration since higher amounts of energy are consumed in this period.

The energy consumption for different household activities was estimated with questionnaires administered to the lodge owner in these three buildings. The emission factor for the different fuel types was taken from literature (Bhattacharya and Salam 2002).The use of traditional fuels (fuel-wood and cow dung), commercial fuels (kerosene and LPG), and electricity were quantified. Table 2. 3 reports the amount of energy used for different household activities in selected three buildings.

Table 2. 3: Energy consumption pattern in three buildings

Building Type	Building Activities	Fuelwood (kWh/day *person)	Kerosene (kWh/day *person)	LPG (kWh/day *person)	Dung (kWh/day *person)	Electricity (kWh/day *person)	Solar PV (kWh/day *person)	Total
Modern	Cooking	-	8.09	0.67	-	0.27	-	9.03
	Lighting	-	-	-	-	0.09	-	0.09
	Space heating	2.36	-	-	-	0.73	-	3.09
	Heating water	-	-	-	-	0.08	-	0.08
	Electrical appl.	-	-	-	-	0.003	-	0.00
	TOTAL							**12.29**
Semi modern	Cooking	2.59	1.92	0.73	-	0.15	-	5.40
	Lighting	-	-	-	-	0.06	0.45	0.51
	Space heating	3.24	-	-	-	-	-	3.24
	Heating water	-	-	-	-	0.06	-	0.06
	Electrical appl.	-	-	-	-	0.01	-	0.01
	TOTAL							**9.21**
Traditional	Cooking	9.43	-	0.48	-	0.31	-	10.22
	Lighting	-	-	-	-	0.02	-	0.02
	Space heating	9.42	-	-	-	-	-	9.43
	Heating water	-	-	-	-	0.11	-	0.11
	Electrical appl.	-	-	-	-	0.01	-	0.01
	TOTAL							**19.79**

III. *Maintenance and Replacement stage*

This stage accounts for the impact associated with the replacement of building materials and the building maintenance during the 50 years life span. The rate of maintenance was estimated based on the questionnaire responses given by the lodge owner, whereas the

rate of replacement of building materials was calculated based on the materials expected lifetime. Maintenance activities include enamelling every 10 years. For the replacements of plywood wall and polystyrene: twice in 50 years; for plywood door, ceiling, glass-wool, mud, wooden plank for the wall, and Corrugated Galvanized Iron (CGI) sheet: once in 50 years (ATD Home Inspection 2015). Details are given in Appendix 2.

2.2.3.3 Impact assessment and interpretation

The three impact assessment methods IPCC 2013, CML 2001 and ReCiPe were chosen for the impact assessment of the three building types. Six impact categories were included in the analysis: Global warming potential (GWP), Ozone Depletion Potential (ODP), Eutrophication Potential (EP), Acidification Potential (AP), Photochemical Ozone Creation Potential (POCP), Particulate matter formation (PM). These are the most important and common environmental indicators applied in building sectors at global (GWP, ODP), regional (AP, POCP) and local scale (EP, PM) as indicated by(Khasreen et al. 2009). PM is considered in the study as it has a significant influence on the effects on human health.

2.3 Life Cycle Costing (LCC)

Life cycle costing was applied to compare different building designs both in terms of initial costs and expected future operational cost (Ristimäki et al. 2013). In this study, initial costs are all the costs incurred in the construction of the building, whereas future costs are costs for the building's operation and maintenance and replacement over a 50 years life span. In order to accurately combine initial expenses with future expenses, the present value of all expenses was determined (Mearig et al. 1999). LCC analysis approach developed by the SMART SPP consortium (Seebach et al. 2011) was used in this study (1). The present value of all the costs including construction costs, operational costs, maintenance and replacement costs in 50 years of building lifetime has been studied.

$$LCC = Co + \sum_{t=0}^{T} \frac{Ct}{(1+i-j)t} \qquad (1)$$

Where,

C_0 = initial cost;

C_t = present value of all recurring costs (operation costs, maintenance and replacement costs) at year t;

t = year of cash flow;

i = discount rate;

j= inflation rate

Discount rate and inflation rate were chosen in order to actualize the future price in the initial price. It is used to discount and transform future cash flows (such as future operation, replacement, disposal costs) into present value costs. The Central Bank discount rate of Nepal is 6% and the Inflation rate is 10% in the fiscal year 2013.

An escalation rate was also taken in account to indicate the relative price changes over time (Kirk and Dell'Isola 1995). This rate accounts for the increase in future costs over time. The escalation rate was applied on energy cost and material cost, labour cost for maintenance, and replacement costs. We used escalation rates obtained from the interviews with the retailers as well as web search. The escalation rate for kerosene is 4% and 2 % for LPG (Nepal Oil Corporation Limited 2015). From the interview with retailers, it was found that escalation rate for enamel is 6%, wooden plank 3%, glass wool 1 %, polystyrene 1%, plywood 9%, CGI 8% and nail by 2 %. However, the labour cost for transportation is increased by 5% every year

Construction costs are the sum of the costs for building construction materials, transportation of materials from retailer to the building site by vehicles, and labor. Construction costs are evaluated based on the cost of each material in retailer shop including VAT, in addition of transportation cost from retailer shop, which is mainly, based on a flight from Kathmandu to Lukla. Further, the materials are transported to the construction site from Lukla airport manually, which is counted as labor cost for transportation.

Operational costs include the energy cost associated with building operation activities such as cooking, space heating, lighting, heating water and use of other electrical

appliances. The costs of energy were estimated by an interview in the retailer shop in SNPBZ. Costs associated with building operation are discounted to present value.

Maintenance and replacement costs include the cost of painting (material and transportation cost) that is applied in the interval of every 10 years and the costs of materials that are substituted during the period of 50 years. Costs associated with maintenance and replacements are discounted to present value.

2.3 Results

2.3.1 Global warming potential of Himalayan buildings

Results for the Global Warming Potential (GWP) impact produced by one guest per night in the three building types are reported in Table 2.4. Among the three building types, the stay of one guest per day in the modern building shows the highest GWP impact: GWP of a modern building is almost the double of the semi-modern GWP and 18% higher than GWP produced by the guest in the traditional building. The operation phase is the largest contributor to the GWP in the three building types (98%), whereas both the building construction and the replacement stage represent about 1% of the total impact. Since these three buildings are hotels and lodges, thus high amount energy consumed for different household activities like for cooking, space heating, heating water etc., to fulfill the need of the tourist. Thus, GWP associated with energy consumption in the operational stage is higher during the period of 50 years.

Table 2. 4: GWP of three building types

Building types/ Phases	Construction (GWP kg $CO_{2\text{-}eq}$/person.day)	Operation (GWP kg $CO_{2\text{-}eq}$/person.day)	Replacement (GWP kg $CO_{2\text{-}eq}$/person.day)	Total (GWP kg $CO_{2\text{-}eq}$/person.day)
Modern	0.12	10.28	0.14	10.53
Semi-modern	0.04	5.20	0.08	5.32
Traditional	0.07	8.73	0.13	8.93

The variation of the results is due to the energy performance and construction materials used in three buildings. It is important to note that the modern building is constructed mostly with commercial materials such as cement, plywood, glass-wool, polystyrene,

glass which are brought to the Park through various means of transportation. On the other hand, the net area of the modern building is usually bigger than rest of the building types. Thus, the GWP of the modern building is significantly higher than that of the traditional and semi-modern building.

2.3.1.1 Construction stage

Fig. 2. 5 show the results of the GWP impact associated with the main building components: wall, roof, window, door, ceiling, floor, ladder and columns. The walls and roof construction produce the highest amount of $CO_{2\text{-eq}}$ /person.day, followed by the ceiling, the floor and the window construction. The total GWP of roof and wall for the modern building is approximately 0.08 kg $CO_{2\text{-eq}}$, 0.03 kg $CO_{2\text{-eq}}$ for semi-modern and 0.045 kg $CO_{2\text{-eq}}$ for traditional buildings.
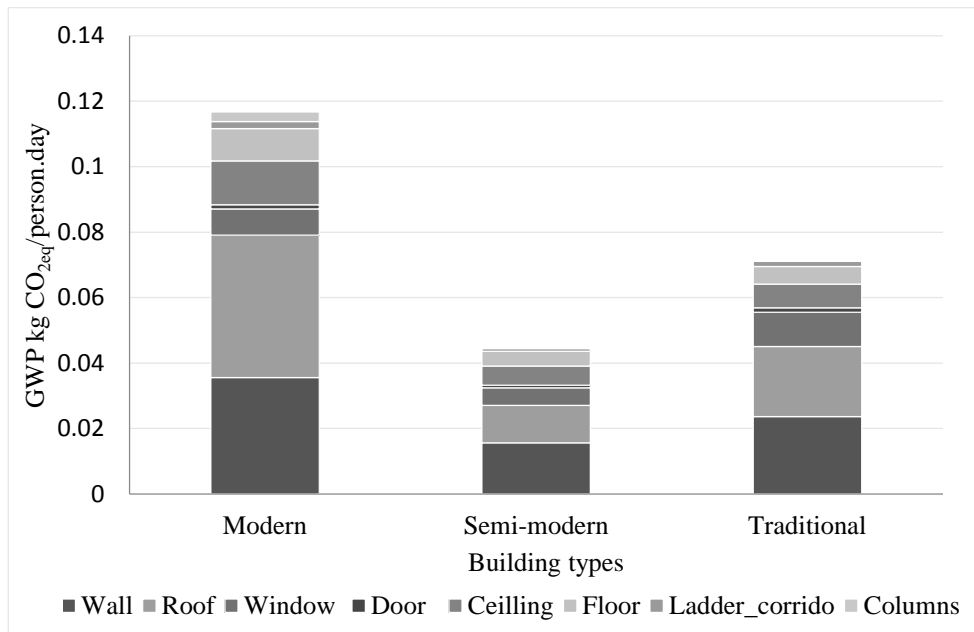
Fig. 2. 5: GWP of different building components

These results seem realistic because the building component that covers a larger area, as wall and roof, uses more materials, and ultimately has a larger environmental impact.

2.3.1.2 Operational stage

The GWP emission from one guest stay per night in the modern building is higher than the other types of buildings (Fig. 2. 6). The GWP of cooking in a modern building is 8.671 kg CO_{2-eq} person day while the space heating is responsible for 1.498 kg CO_{2-eq} person day. The variation of the results depends on the type and quantity of the energy source (Table 2. 3). Kerosene and LPG, used for cooking activities, have the highest emission intensity, with the consumption of 8.09 kWh and 0.67 kWh per person per day respectively. Firewood of 2.36 kWh and 0.73 kWh of electricity are used for space heating per person per day.
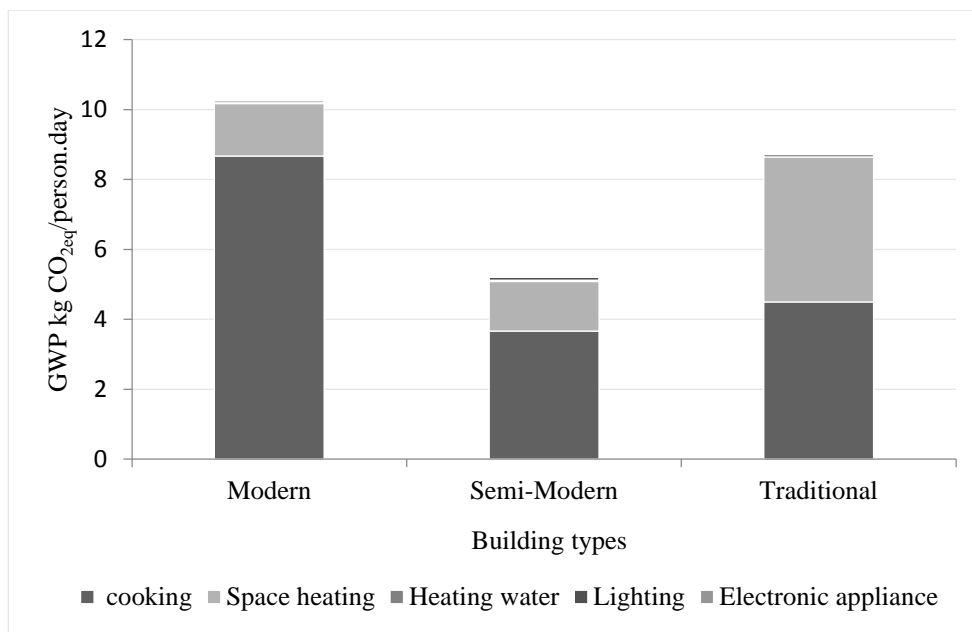
Fig. 2. 6: Operational stages on three different building types

The semi-modern building shows to have the best environmental performance during the operational stage, with approximately half the impact of the modern buildings. The semi-modern building used a large amount of wood and kerosene as energy sources for household activities (Table 2. 3): 48% of firewood, 36 % of kerosene and 16% of LPG and electricity.

In the traditional building, GWP emissions produced during the operational stage are 74% higher than those of semi-modern building. Firewood is the major energy source in traditional building and is used for producing 90% of total energy, whereas in the semi-modern building the use of firewood covers the 63% of energy demand with 3.3 times less wood than in the traditional building (Table 2. 3). The lower energy needs are tied to a more efficient insulation material of the semi-modern building (polystyrene) compared to the traditional one (mud plaster).

2.3.1.3 Replacement stage

Similarly to the construction stage, the main contributors to the total environmental impact of the replacement stage are the walls and roof components of the building (Fig. 2. 7). Walls contribute 48% of the total GWP while the roof contributes 40% in the modern building. On the other hand, the roof contributes the major environmental impacts in the semi-modern and traditional building that contributes 53% and 59% respectively.
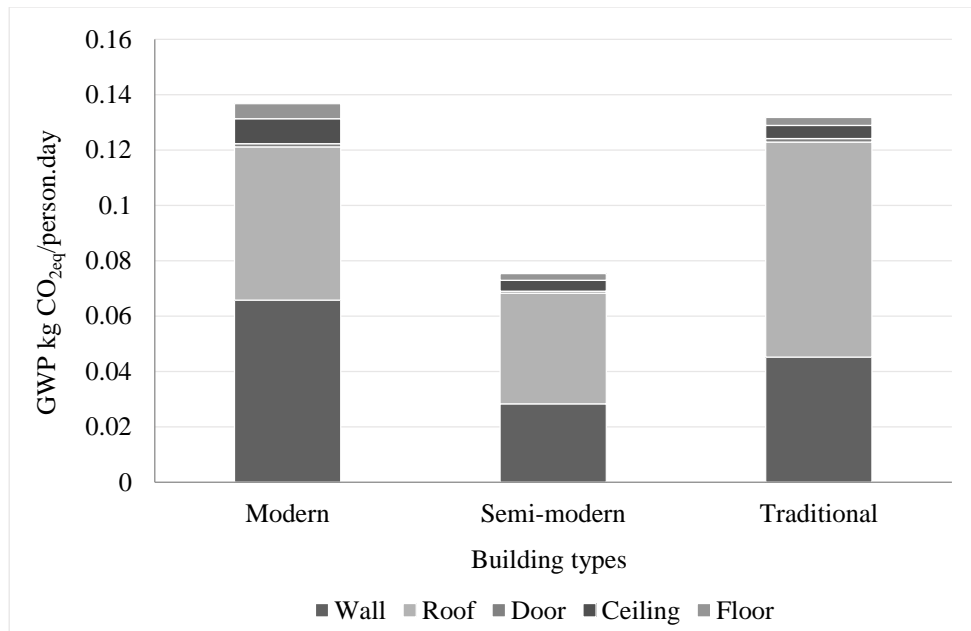
Fig. 2. 7: Replacement stages on three building types

CML and ReCiPe methods have also been used for calculating the emissions associated to the chosen impact categories. The results are reported in Table 2. 5. Both methods give the same values of GWP, ODP, POCP, AP, EP and PM. The GWP has already been

mentioned above. The result on other impact categories shows that the modern building has the highest environmental impacts. The variation of the results is mainly based on energy performance and construction technique (Passer, Kreiner, and Maydl 2012). The operational stage in all the building types has the high environmental impacts due to the high amount of energy needed.

The results for EP are dominated by the operational stage and the construction phase for all building types. The EP value of the modern building is ten times higher than semi-modern building and similar to EP of traditional building. The calculated AP value of the modern building is still higher than those of semi-modern and traditional buildings, but the less emissive building in terms of AP is the traditional one with 0.01 kg SO_{2eq}. The emissions are mainly from the operational stage and the production of construction materials. Also for the impact categories POCP, ODP and PM the construction and operation stage are the most important.

Table 2. 5: Life cycle impact categories indicators of the buildings.

Impact category		Modern			Semi-modern			Traditional		
		CS	OS	RS	CS	OS	RS	CS	OS	RS
ODP	kg CFC_{-11} eq	9.9E-09	6.2E-06	9.7E-09	3.8E-09	1.9E-06	5.6E-09	6.0E-09	5.2E-07	9.8E-09
POCP	kg $C_2H_{4\ eq}$	7.9E-05	3.7E-03	9.0E-05	3.6E-05	1.4E-03	4.8E-05	5.0E-05	9.6E-04	8.1E-05
AP	kg $SO_{2\ eq}$	8.4E-04	5.9E-02	9.7E-04	3.4E-04	2.0E-02	5.1E-04	5.4E-04	1.0E-02	8.9E-04
EP	kg PO_{4eq}	1.7E-03	1.5E-02	2.0E-03	4.7E-04	5.7E-03	1.4E-03	8.5E-04	5.0E-03	2.6E-03
PM	kgPM_{10eq}	6.1E-04	1.7E-02	7.0E-04	2.2E-04	5.7E-03	4.0E-04	3.5E-04	4.0E-03	7.2E-04

*CS= Construction Stage; OS=Operational Stage; RS=Replacement Stage

2.3.2   LCC analysis results

The cost of three building types during its lifespan is shown in Table 2. 6. As in the case of LCA results, the LCC results show that the modern building contributes the highest life cycle cost over a period of 50 years of lifespan of the building. In this case, semi-modern comes second with 3 times lower cost than modern building. Traditional building has the least LCC which is almost 5 times lesser than that of modern buildings since

traditional building relies on the local products in terms of building product as well as energy, which is comparably lesser cost that of a commercial product.

Table 2. 6: Life cycle cost of different building types during its life span

Building types/ Phases	Construction (€/person.day)	Operation (€/person.day)	Replacement (€/person.day)	Total
Modern	0.15	18.46	1.30	19.91
Semi-modern	0.05	5.73	0.55	6.33
Traditional	0.08	3.38	0.82	4.28

The construction cost concurred with the relatively small percentage of global cost in all building types that contribute only 1% because the cost is associated to the use of the building by a guest. While, the operation cost contributes around 90% in modern and semi- modern building and 79% in the traditional building. Replacement cost, on the other hand, contributes around 8% of total cost in modern and semi-modern buildings and 19% in the traditional building.

2.3.3 Sensitivity analysis

The LCA and LCC modeling of the study are based on multiple assumptions that may have an effect on the results. So sensitivity analysis was undertaken to determine overall uncertainties. A lifetime of the buildings, the percentage in occupancy of a room in the buildings, and discount and inflation rate were considered as key parameters in terms of uncertainty. The sensitivity of LCA and LCC results with respect to these parameters was then investigated. Fig. 2. 8 summarize the results of the sensitivity analysis.

Discount and inflation rates are continuously changing, depending on the interest rate set by the commercial bank of Nepal (Adhikari 1987) and fluctuation in the overall price levels of goods and services of the country (World Bank 2015). The sensitivity analysis evaluated a decrease discount and inflation rate from 6% and 10% to 3% and 5%

respectively. The results show that all the environmental and economic impacts decrease in the operational and replacement phase of all building types.

The lifetime of the building was initially estimated to be 50 years. However, this may vary depending on the degree of operation, maintenance. Thus, results were calculated for a lifetime of 25 and 100 years respectively. The changes in a lifetime have a substantial overall effect on the environmental and economic impact. The sensitivity analysis of 25 years of building lifetime shows that all the potential impacts on both environment and economic in construction, and replacement stage of different building types increases. Concerning the replacement stage, the economic impact of modern and semi-modern buildings is higher than an environmental one, conversely the replacement phase in traditional building shows a lower economic impact compared to the environmental one. In operational phase, no change was observed in all three building types as energy consumption in building operation remains the same per guest in a day.
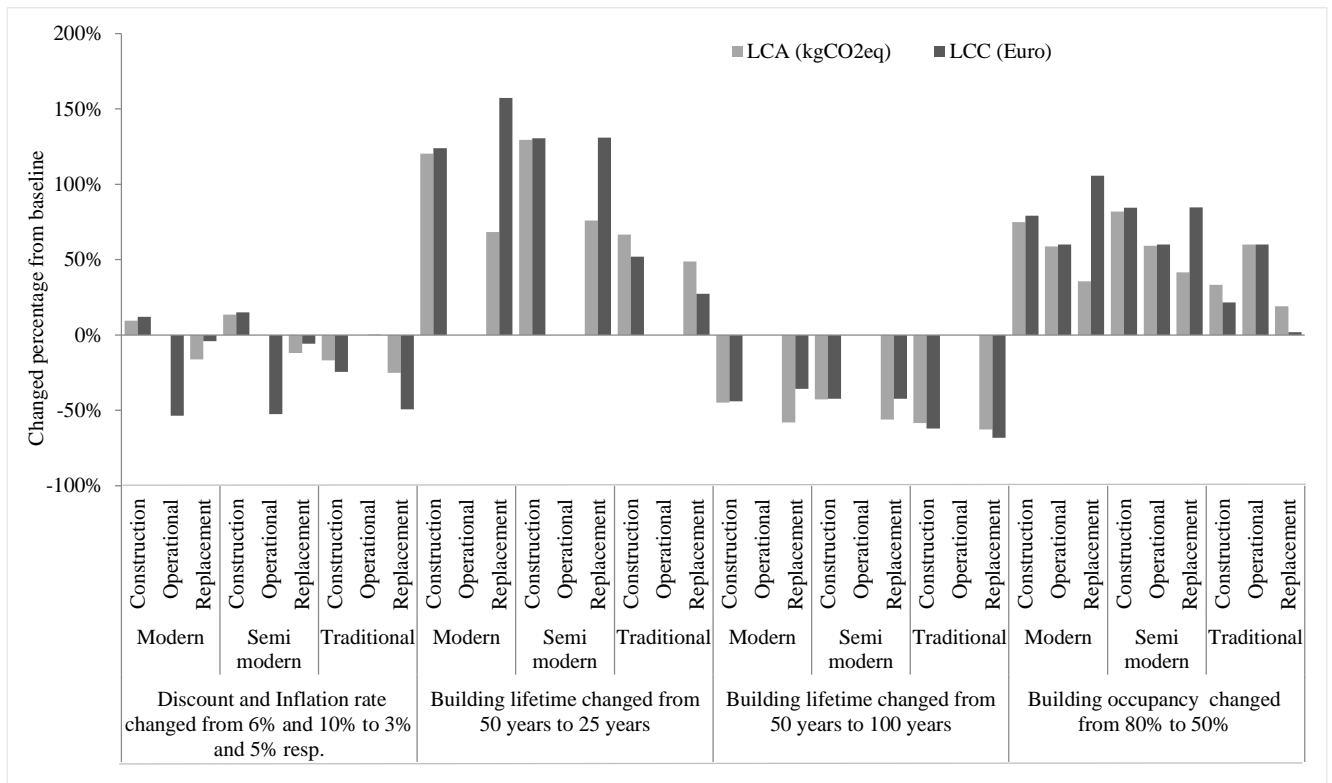
Fig. 2. 8: Sensitivity analysis of building system

On the contrary, all the potential environmental impacts and economic value decreases with the increase of lifespan of the building into 100 years. There is no change in operational phase in this case also, as energy consumption in building operation remains the same per guest in a day. Furthermore, the increase of the lifetime causes a decrease of the differences between the impacts both economic and environmental between the different types of buildings.

The change in the percentage of room occupancy in the buildings from 80% to 50% shows that all the impact categories on the environment and economic increases in three buildings. The share of impacts increases per person as decreasing the occupancy of the building.

2.4 Discussion

The aim of this study was to evaluate both the environmental and economic life cycle impact of three existing building types in the Himalaya in order to give a valuable overview for decision making in future buildings construction projects.

The study showed that the operational stage is the hot spot (approximately 90% of total GWP). This value confirms the results of other studies showing that the impact of operation to be in the range of 80-90% (Asdrubali, Baldassarri, and Fthenakis 2013). The study done by Cuéllar-Franca and Azapagic (2012) shows that the use stage contributes to 90% of GWP in the UK residential buildings. Comparably, the study done by Ortiz et al. (2009) concluded that the highest environmental impact in a dwelling located in Sweden is the operation stage with 85 % of GWP. However, results of these case studies vary according to the assumptions made. Results may also depend on which household activities are included in the analysis and on the functional unit chosen. The study done by (Ristimäki et al. 2013) accounted for heating and cooling of the buildings, plus heating water and lighting in the operational stage, whereas other studies (Asdrubali et al. 2013; Cuéllar-Franca and Azapagic 2012) included all the household activities such as cooking, space heating, lighting, water heating and electrical appliances.

The result in the breakdown of the building components signifies that the wall and roof are responsible for the largest share of the total environmental impact of the construction stage. The study done by (Zhang et al. 2014) also gives the similar overview with the highest environmental impact on the wall and roof.

The LCA study requires a significant amount of data and the outcome depends on quality, accessibility and accuracy of this input data (Ristimäki et al. 2013). However, there is the lack of data on the building sector for developing countries. The primary data collected in the site, as well as ecoinvent database, were used to assess the result. The buildings are chosen as representative, but there may be variability across the various building in the Park. The result on LCA and LCC of three buildings might not give the comprehensive picture of the whole Park. Thus, buildings from different elevation, village and villagers have to be randomly chosen for the analysis for the overall picture of the whole Park.

Three representative buildings were studied to give a detailed insight of building in terms of LCA and LCC, but even with these results it is difficult to generalize the findings of the study to the buildings for whole Park, and this should be the focus of further research.

Estimated long-term energy consumption and cost for 50 years is questionable matter. As the efficiency of the stove, type of energy source and its cost has been changing, thus it is difficult to predict type and amount of energy source and its cost for future. For the future price estimation, escalation rate of energy price has been used for the long-term price increment. It should be noted that these future price estimations are influenced by the political situation of the country.

GWP impact category has been chosen to express and compare the impact of three buildings. GWP is generally regarded as a major indicator in LCA studies (Knauf Marcus 2015). GWP or "greenhouse effect" leads to climate change, which is currently one of the significant global environmental issues and moreover, the situation of mountains are certainly on perilous due to global warming, thus the prime importance has been given GHG emission to set the mitigation target/ to mitigate climate change by reducing greenhouse gas emissions. Improving building sector and restraining carbon emission

have a significant impact on energy conservation and global climate change (Chen et al. 2011; Ristimäki et al. 2013).

2.5 Conclusions

LCA and LCC were performed to assess the environmental and economic impacts of three existing buildings in the Himalayas. Results show that modern building accounts the highest GWP and the cost over the period of 50 years as commercial materials are mostly used which accounts the highest environmental impact and high material cost. Building with local materials is, therefore, a more environmentally friendly option than building with other equivalent commercial materials because of the lower impact associated with the production of this material and the lower need for transportation (Morel et al. 2001).

The obtained results show that operational stage is responsible for high environmental impacts and high operational cost, which are related to energy use for different household activities. The main improvement opportunities in the building sector perspective to Himalayan region lie in the reduction of impacts in the operational stage.

On the basis of LCA and LCC results, it is concluded that the energy efficient building with the use of local materials with proper insulation and renewable energy is the recommended option for sustainable building design in Himalayan region. Well-insulated energy – efficient building construction method could reduce greenhouse gas emission and improve the quality of lives of local people as this helps to reduce the heating needs through fire-wood, dung and other burnable fuels. Energy-efficient technologies including cooking stoves, heating stove, light bulb and use of renewable energy should be encouraged in the Park. Sustainable building with low energy consumption, high efficiency and innovation in building construction (Zabalza et al 2009), such as passive house should be promoted. It is recommended that the government and environmental agencies should improve the construction codes and relevant environmental policies to incentive sustainable building construction practices in the country.

Further study on LCA and LCC of building sector in all three Village Development Committee (VDC) of the Park is needed to give a more comprehensive picture on life cycle prospective both on environmental and economic aspect, which would accomplish building sustainability and promote the use of sustainable construction practice.

Supplementary Information

Appendix 1

Parameters used to quantify the amount of building materials

Building Components		Thickness (m)	Density	Modern	Semi modern	Traditional
				Volume (m³)		
Wall	Wooden plank	0.05	670.00	2.75	2.08	1.12
	Plywood	0.01	6.18	18.81	12.85	4.99
	Glasswool	0.05	32.00	5.50	0.00	0.00
	Mud	T=0.05 SM, M=0.01	1906.00	4.25	2.60	4.41
	Stone	T=0.55 SM,M=0.5	2610.00	169.89	104.16	44.12
	Polystyrene	0.02	28.00	7.32	0.00	0.00
	Enamel	-	1090.00	0.04	0.03	0.01
	Ordinary nails		1.08	7.87	0.85	0.35
	Cement	0.01	2162.00	0.15	0.09	0.03
Roof	Wooden joist	0.09	670.00	9.80	3.32	3.33
	CGI`		4.71	177.26	59.95	59.75
	Roofing nails		3.64	2.70	1.23	1.23
Window	Wooden frame		0.55	670.00	0.34	0.12
	Glass	0.04	10.00	122.17	43.25	20.45
Door	Wooden door	0.10	670.00	0.15	0.13	0.15
	Plywood door		0.77	6.18	0.73	0.28
Floor	Wooden joist	0.09	670.00	8.45	5.22	2.11
	Wooden plank	0.05	670.00	10.52	6.50	2.62
Ceiling	Wooden joist	0.09	670.00	8.45	5.22	2.11
	Plywood	0.01	6.18	5.90	3.65	1.47
Ladder	Wood	0.05	670.00	0.08	0.11	0.08
Corridor	Wooden plank	0.05	670.00	2.50	1.10	1.23
	Wooden joist	0.09	670.00	0.69	0.25	0.30
Pillar	Cement		2162.00	0.12	0.00	0.00
	Sand		1550.00	0.70	0.00	0.00
	Rod		7850.00	0.03	0.00	0.00

Appendix 2

Replacement intervals during the period of 50 years

Materials	Typical replacement intervals (years)	Number of replacement over 50 years
CGI	30	1
Roofing Nail	30	1
Wooden plank	100+	-
Wooden Window	50	-
Plywood wall	15-30	2
Plywood door	15-30	1
Plywood ceiling	15-30	1
Glass wool	25-30	1
Polystyrene	10-15	2
Stone	100+	-

Sensitivity analysis of different parameters

LCA Parameters	Unit	Modern			Semi-Modern			Traditional		
		CS	OS	M&RS	CS	OS	M&RS	CS	OS	M&RS
25 years										
Global warming (GWP100a)	kg CO2 eq	2.5E-01	1.0E+01	2.3E-01	1.0E-01	5.2E+00	1.3E-01	1.2E-01	8.7E+00	2.0E-01
Ozone layer depletion (ODP)	kg CFC-11 eq	2.1E-08	6.2E-06	1.7E-08	8.5E-09	1.9E-06	1.0E-08	1.0E-08	5.2E-07	1.6E-08
Photochemical oxidation	kg C2H4 eq	1.7E-04	3.7E-03	1.5E-04	8.0E-05	1.4E-03	8.0E-05	8.2E-05	9.6E-04	1.1E-04
Acidification	kg SO2 eq	1.9E-03	5.9E-02	1.6E-03	7.8E-04	2.0E-02	9.1E-04	8.9E-04	1.0E-02	1.3E-03
Eutrophication	kg PO4--- eq	3.5E-03	1.5E-02	3.9E-03	9.8E-04	5.7E-03	2.7E-03	1.6E-03	5.0E-03	5.0E-03
Particulate matter formation	kg PM10 eq	1.3E-03	1.7E-02	1.2E-03	5.1E-04	5.7E-03	7.4E-04	6.0E-04	4.0E-03	1.2E-03
100 years										
Global warming (GWP100a)	kg CO2 eq	6.3E-02	1.0E+01	5.7E-02	2.5E-02	5.2E+00	3.3E-02	2.9E-02	8.7E+00	4.9E-02
Ozone layer depletion (ODP)	kg CFC-11 eq	5.4E-09	6.2E-06	4.3E-09	2.1E-09	1.9E-06	2.6E-09	2.6E-09	5.2E-07	4.0E-09
Photochemical oxidation	kg C2H4 eq	4.3E-05	3.7E-03	3.6E-05	2.0E-05	1.4E-03	2.0E-05	2.0E-05	9.6E-04	2.8E-05
Acidification	kg SO2 eq	4.6E-04	5.9E-02	4.0E-04	2.0E-04	2.0E-02	2.3E-04	2.2E-04	1.0E-02	3.1E-04
Eutrophication	kg PO4--- eq	8.8E-04	1.5E-02	9.8E-04	2.4E-04	5.7E-03	6.8E-04	4.0E-04	5.0E-03	1.3E-03
Particulate matter formation	kg PM10 eq	3.3E-04	1.7E-02	3.0E-04	1.3E-04	5.7E-03	1.8E-04	1.5E-04	4.0E-03	2.9E-04
50% occupancy										
Global warming (GWP100a)	kg CO2 eq	2.0E-01	1.6E+01	1.8E-01	8.0E-02	8.3E+00	1.1E-01	9.4E-02	1.4E+01	1.6E-01
Ozone layer depletion (ODP)	kg CFC-11 eq	1.7E-08	1.0E-05	1.4E-08	6.8E-09	3.1E-06	8.2E-09	8.2E-09	8.3E-07	1.3E-08
Photochemical oxidation	kg C2H4 eq	1.4E-04	5.9E-03	1.2E-04	6.4E-05	2.2E-03	6.4E-05	6.5E-05	1.5E-03	8.8E-05
Acidification	kg SO2 eq	1.5E-03	9.5E-02	1.3E-03	6.3E-04	3.1E-02	7.3E-04	7.1E-04	1.7E-02	1.0E-03
Eutrophication	kg PO4--- eq	2.8E-03	2.4E-02	3.1E-03	7.8E-04	9.1E-03	2.2E-03	1.3E-03	8.0E-03	4.0E-03
Photochemical oxidant formation	kg NMVOC	1.6E-03	6.2E-02	1.3E-03	7.1E-04	2.3E-02	7.3E-04	7.4E-04	1.9E-02	9.8E-04
Discount and Inflation rate										
Global warming (GWP100a)	kg CO2 eq	1.3E-01	1.0E+01	1.1E-01	5.0E-02	5.2E+00	6.6E-02	5.9E-02	8.7E+00	9.8E-02
Ozone layer depletion (ODP)	kg CFC-11 eq	1.1E-08	6.2E-06	8.6E-09	4.3E-09	1.9E-06	5.1E-09	5.1E-09	5.2E-07	7.9E-09
Photochemical oxidation	kg C2H4 eq	8.7E-05	3.7E-03	7.3E-05	4.0E-05	1.4E-03	4.0E-05	4.1E-05	9.6E-04	5.5E-05

Acidification	kg SO2 eq	9.3E-04	5.9E-02	7.9E-04	3.9E-04	2.0E-02	4.5E-04	4.4E-04	1.0E-02	6.3E-04
Eutrophication	kg PO4--- eq	1.8E-03	1.5E-02	2.0E-03	4.9E-04	5.7E-03	1.4E-03	8.0E-04	5.0E-03	2.5E-03
Particulate matter formation	kg PM10 eq	6.7E-04	1.7E-02	6.0E-04	2.6E-04	5.7E-03	3.7E-04	3.0E-04	4.0E-03	5.8E-04
LCC										
25 years	Economic	3.3E-01	1.2E-01	3.4E+00	1.2E-01	5.7E+00	1.3E+00	1.1E-01	3.4E+00	1.0E+00
100 years	Economic	8.0E-02	1.8E+01	8.4E-01	3.0E-02	5.7E+00	3.2E-01	3.0E-02	3.4E+00	2.6E-01
50% occupancy	Economic	2.6E-01	3.0E+01	2.7E+00	9.0E-02	9.2E+00	1.0E+00	9.0E-02	5.4E+00	8.3E-01
Discount & Inflation	Economic	1.6E-01	8.6E+00	1.3E+00	6.0E-02	2.7E+00	5.2E-01	6.0E-02	3.4E+00	4.1E-01

*CS= Construction stage, OS= Operational stage, M&RS= Maintenance and Replacement

CHAPTER THREE

Comprehensive overview of life cycle prospective of commercial building in Sagarmatha National Park and Buffer Zone

Abstract

This chapter presents the broad overview on the Himalayan building performance for the entire hotel sector in Sagarmatha National Park and Buffer Zone. The performance of the buildings is analysed based on three criteria: environmental, economic, physical and technical. This study consists of the life cycle assessment, life cycle costing, thermal efficiency, number of guest, energy consumption, area of buildings of three building types: traditional, semi-modern and modern. Results show that traditional building accounts the highest GWP and the cost over the period of 50 years of building lifespan. Operational stage is responsible for high environmental impact (97% of total GWP) and operational cost (by 90%) that are associated with energy consumption in different household activities. The use of insulating materials in the wall of modern building, the energy consumption for space heating has reduced the heat demand in the room (36.80 W/m^3). The correlation matrix shows that there is a strong correlation between environmental and economic impact with the amount of energy consumed for the household activities. On the contrary, number of guest and building size are negatively correlated with environment and economic impacts. It proves that the main improvement opportunities in the building sector perspective to Himalayan region lie in the reduction

of impacts in the operational stage. It reports that to achieve the sustainable building, low energy consumption, high building efficiency and renewable energy need to be promoted.

3.1 Introduction

The building industry is one of the largest consumers in terms of nature resources, and one of the largest producers of pollution (Vijayan and Kumar 2005). The building sector accounts for a substantial amount of energy consumption which makes a considerable contribution to the worldwide environmental impacts (Scheuer et al. 2003). For instance, the building sector is responsible for 30% of global annual greenhouse gas emissions and consumes up to 40% of all energy (UNEP 2009, IPCC 2001). Lowering energy intensity and environmental impacts of the building is increasingly becoming a priority. Buildings are represent long- term investments and have associated with environmental impacts over their entire life span (Cole 2000). It is therefore, important to design sustainable buildings with low environmental impact (Ferreira et al. 2015,. Proietti et al. 2013) further said that improving sustainability of buildings is necessary to develop awareness toward the environment and resources used.

Thus, it is important to quantify the environmental performance of the building in order to observe the potential environmental impacts and their influence on sustainable development (Passer et al. 2012). To assess the sustainability of the building, it is significant to consider their entire life cycle and to evaluate the environmental impacts associated with the extraction, production and transportation phases by identifying and quantifying the energy and materials used and the waste released to the environment (Pittet 2010; Sonnemann 2003). In this regard, life cycle based methodologies on building assessment tool are required such as Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) (Moschetti et al. 2015a). This tool could help in the decision-making when selecting the best technology and material availability and minimizing the

environmental impact of the building (Petersen and Solberg 2005; Gustavsson and Sarthe 2006; Zabalza et al 2011; Passer et al. 2012).

Environmental impacts of building materials production and construction processes vary according to the regions and countries (Pittet et al. 2010). Developing countries, compared to highly industrialized/developed nations, have generally less efficient processes that consume more energy and generate more environmental impacts for producing same materials (Buchanan and Honey 1994; Emmanuel 2004; Asif et al. 2007; Pittet et al. 2010). High levels of pollution from the building industry are the result of the energy consumed during the extraction, manufacturing and transportation of materials (Morel et al. 2001), leading to unsustainable outcomes. Furthermore, the energy used for material production and process, transportation means and distances travelled are very different, with potential consequences on the overall environmental impacts (Pittet and Kotak 2010; Cole 1999; Huberman and Pearlmutter 2008; Pearlmutter 2007). Moreover, developing countries are considered to be particularly susceptible to climate change due to their limited capacity to cope with hazards associated with changes in climate. Montemayour (2012) revealed that the most dangerous threat in the remote settlement in the mountain rage is the rapid melting of its glaciers caused by progressive increases in mean annual temperature.

Information about the environmental impact of the building is currently very limited in developing countries, although they represent the most vulnerable areas on the world to the hazards associated with climate change (Pouliotte et al. 2009; Gentle and Maraseni 2012; Pandit 2013). Therefore, it is important to understand the environmental and economic performance of buildings in the Himalayan region of Nepal in order to minimize the environmental and economic burden of future construction projects in the region. This chapter aims at filling this gap by providing new information about Himalayan buildings and their life impacts, on a life cycle perspective.

In this study, the performance of three different types of Himalayan buildings are analysed considering environmental, economic and technical criteria (Table 3. 1). The

purpose of the study to illustrate how different types of buildings performs according to these criteria.

Table 3. 1: Some indicators in three criteria

Environmental criteria	Economic criteria	Technical criteria
Energy consumption	Material cost	Thermal efficiency
Construction impact	Labour cost	Area per square
Operational impact	Operation cost	No of guest (person/m2)
Maintenance		Occupancy
GWP emission (other emission indicators)		

This study takes the case of the Sagarmatha National Park and Buffer Zone of Nepal (SNPBZ) as point of departure. This is a renowned touristic area attracting about 30,000 tourists each year (Census 2014). The government of Nepal is planning to implement a policy to attract more tourists in the near future (Salerno et al. 2010). Although these initiatives will bring new income opportunities for the local communities, they will also contribute to a fast growing in buildings that could worsen the already critical situation in terms of environmental pollution (Salerno et al. 2010; Manfredi et al. 2010), especially taking into account the ongoing replacement of traditional wood and stone masonry with concrete structures. Besides, the increase in population due to the presence of tourists leads to the increase in energy demand. In the park, energy is supplied from the combination of traditional and locally available sources (firewood and animal dung) and commercial sources (kerosene, LPG, and electricity) that need to be transported to the park over long distances, with both environmental and economic costs associated with. Since appropriate choice of construction materials, improvements in thermal efficiency, and proper use of space could reduce the needs for materials, energy, and transport in the park, the assessment of the life-cycle environmental impacts of buildings in the park from has a greater importance.

Life Cycle Assessment (LCA) for the buildings provides the quantitative and comparative values of the environmental impacts of various building technologies (Singh et al. 2011). LCA is used for quantifying the emission, energy and material consumption of a building system in different life cycle phases starting from the acquisition of raw material, product manufacturing assembling and disassembly (UNI EN ISO 14040 2006; UNI EN ISO 14044 2006; Consoli et al. 1993). It is widely recognized in the field of Building Sustainability Assessment that the LCA is a preferred method for evaluating the environmental pressure caused by the materials, construction element and by whole life-cycle of the building (Braganca 2012).

Differently from previous studies on the LCA of buildings in developing countries (Ozolins et al. 2010; Pittet et al. 2012), and from a previous study of LCA of Himalayan buildings (Chapter Two), which has focused on the detailed analysis of few selected buildings, this study aims at providing a more broad picture of the environmental impacts of buildings in the entire park, by determining performance indicators for a large number of buildings and comparing across them.

3.2 Materials and Methods

3.2.1 Study Area and typical building types

Sagarmatha National Park and Buffer Zone (SNPBZ), in the Eastern Development Region, is an attractive tourist destination because of its bountiful natural beauty enhanced by the highest peak in the world: Mount Everest,.The park lies within an area of 1148 km^2, which is located between 27° 30' 19" – 27° 06' 45" N latitude and 86° 30' 53" – 86° 99' 08"E longitude. It ranges in elevation from 2845 m at Jorsalle to 8848 m a.s.l. at the summit of Mount Everest. The mean temperature of the coldest month, January, is -0.4°C. The park is divided into three village development committees (VDCs): Namche, Khumjung as core areas in the north and Chaurikharka as a buffer zone in the south of the park. The zones that include a forested lower zone, a zone of alpine scrub, the upper alpine zone includes upper limit of vegetation growth, and the Arctic zone where no plants can grow.

The traditional type of building that follows the ancestral house design typically known as "Sherpa house". Materials involved in construction for traditional building are mainly wood, stone and mud. These locally available materials are abundantly used particularly on the roof and the wall construction. Due to the cold climate in the region, houses are built facing south-east to receive the early morning sun and to continue receiving it until late in the afternoon.

Modern buildings are built mainly for touristic purposes, primarily use imported construction materials such as cement and glass wool and polystyrene sheets. Such materials have to be transported from capital city, Kathmandu by airfreight due to the complex orography. These materials are likely to have high environmental burden from a life cycle perspective from production till its end use.

Semi-modern type of buildings are the partial transformation of traditional into modern, with limited or no insulation material besides wooden planks, dry stones and less amount of cement and mud as plaster.

The choice of the building materials mainly depends on cost, availability and appearance. The construction are mainly wood for internal support structure, stone or soil for envelope, according to different installation techniques: compressed clay or sun-baked mud bricks (Sestini 1998); dry stone masonry of 70-80 cm thick. As for floor, timber joists are disposed perpendicularly to the main girders, overlaid by floorboards; the roof is characterized by the same structural scheme, except for the specific inclination of the pitched room. Windows have a timber frame and 3-4 mm thick single glass; the openings are exposed to South-east in order to maximize the light in the house (Sestini et al. 1978).

3.2.2   Data Collection

3.2.2.1 Selection of sampling houses

Primary data for forty-five buildings located in nine different settlements of the Park were collected. Proportions of sampling houses were selected based on the total number of

available different types of households. The total numbers of existing and sampling household in ten different settlements are given in Table 3. 2 and Fig 3. 1.

Table 3. 2: Total existing and sampled commercial building in the surveyed villages

	Traditional	Semi-modern	Modern	Total
Existing building	34	79	37	150
Sampled building	9	17	19	45
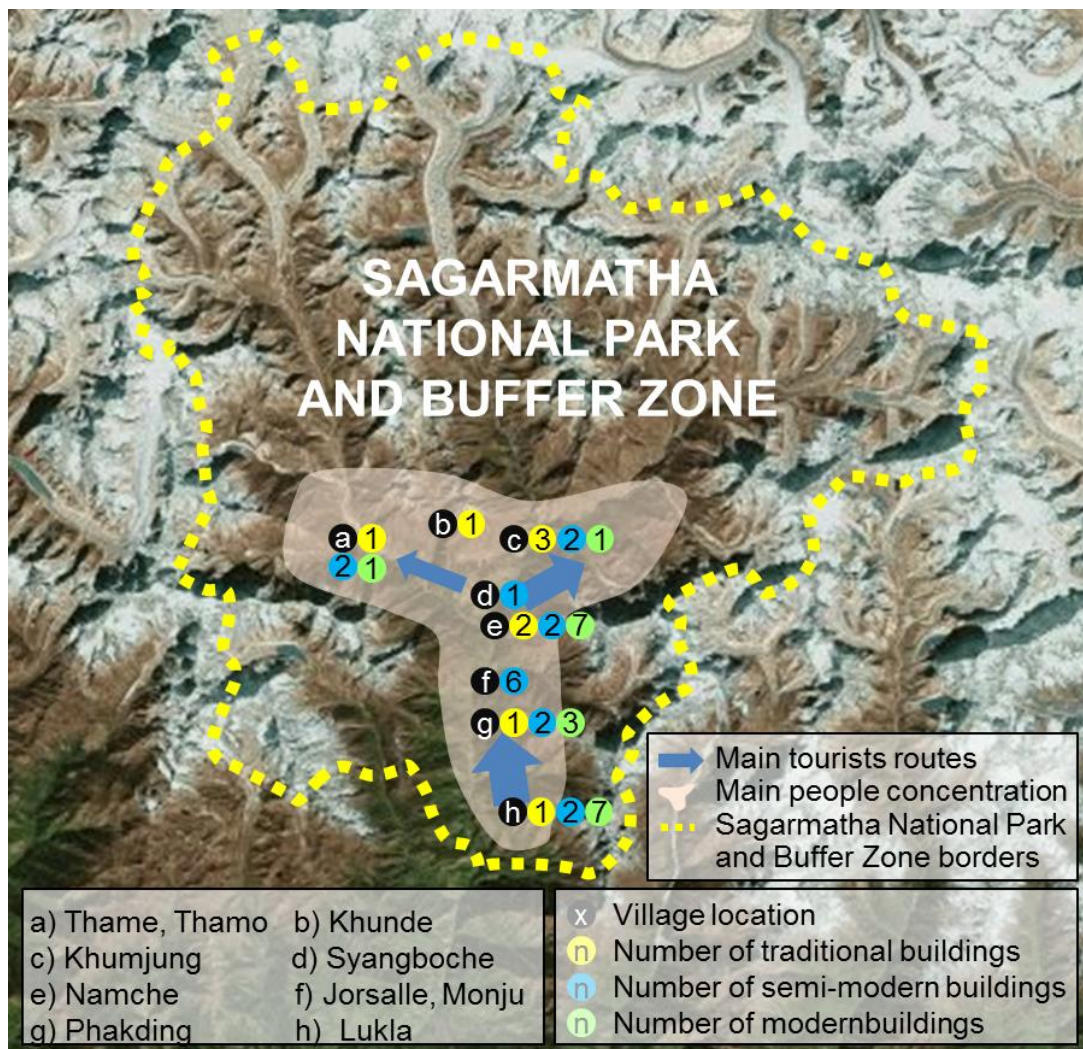
Fig 3. 1: Sampling site in Sagarmatha National Park and Buffer Zone

3.2.2.2 *Preparation of questionnaires*

Questionnaire was prepared in LCA standard, that includes material used in existing building, material source, quantities used, transportation distance and means, energy used for processing and transportation. The questionnaires for retailers of building materials were also prepared. For the efficacy, this questionnaire was revised with the help of the Project Supervisor and prior to the actual survey; trial survey was carried out in small town of Nepal, Banepa.

3.2.2.3 *Data acquisition*

The survey was carried out during peak tourist season in the month of May/April 2014. Data on building size, building materials used in each type of buildings, transportation distance of building material from retailer to construction site, means of transport and energy consumption for different household activities of three building types were collected. Measurement of room dimensions, doors and windows and its numbers, wall thickness, type of material used, measurement of whole building were undertaken.

Furthermore, data on construction costs, operation cost, maintenance and replacement cost of the building were collected. Construction cost includes material cost and transportation cost. Operational cost includes the energy cost associated with building operation such as cooking, space heating, lighting, heating water and use of other electrical appliances. Maintenance and replacement costs includes the cost of painting that are applied in the interval of 10 years and the cost of materials that are replaced during the life span of the buildings.

The survey was also undertaken with retailers of building material in capital city, Kathmandu to assess data on source of materials, type of vehicle used, and transportation distance covered from manufacturer to retailers, customers and vehicle they used to carry the materials.

3.2.2.4   *Data analysis*

The primary data collected in the field were further processes to calculate the building-specific carbon footprint, life cycle costs, and thermal transmittance, and then statistical testing was performed to identify significant differences between building types. For the analysis of environment assessment of the building, Life Cycle Assessment (LCA) tools were applied. Both primary and secondary data were used in the life cycle inventory. The Ecoinvent database v.3 were used for modelling the manufacturing process of the material used. LCA applied to building materials provides the quantitative and comparative values of the environmental impacts of various building technologies (Singh et al. 2011; Zabalda et al. 2011; Takano et al. 2015). LCA in this study is used for quantifying the emission, energy and material consumption of a building system in the construction phase of life cycle from the acquisition of raw material, product manufacturing, transportation, and assembling (UNI EN ISO 14040 2006; UNI EN ISO 14044 2006; Consoli et al. 1993). The detailed calculation is given in Chapter Two.

For the economic assessment of building, Life cycle costing was applied. The present value of all the cost comprised in construction costs, operational, maintenance and replacement costs during the life span of 50 years were studied. A detailed description of integration of LCA and LCC and its methodology were given in our previous study (Chapter Two).

To measure of heat demand of heating room, thermal transmittance (U-value) was used. So as to calculate the thermal efficiency of the heating room, data on room dimensions (height, length breadth), wall thickness, number of doors and windows, insulation material type, inside and outside temperature of the room were used. For further analysis in energy requirement inside a room was set 20°C as a standard that will keep a room in comfortable temperature. The detailed calculation is given in (Bhochhibhoya 2008)

To get a broad overview of the building performance on the entire hotel sector in the Park, statistical analysis was performed. Buildings are expected to have variable performance, but it is not clear if different building types perform significantly different from a

statistical point of view. Analysis of variance (ANOVA) test was therefore applied to investigate the difference in different parameters (environment, economic, thermal efficiency) across the building types. Correlation analysis between buildings parameters were further analyzed by factor analysis. Factor analysis is a multivariate statistical technique for examine the interrelationship (or correlations) among a large number of variables (Hair et al. 2009). The same approach was utilized in the work of Fahy (2002) on sustainability. Multivariate statistical analysis allows relations between observed variables to be pointed out. The analysis was performed on the *Statistical Package for the Social Sciences* (SPSS), version 16.

3.3 Results and Discussion

3.3.1 Overview of buildings' performance

Environmental criteria: Table 3. 3 shows a broad overview of various parameters on entire hotel sector of the Park. Results show that Life cycle assessment with the functional unit of "one guest stay per night" on traditional building show the highest global warming potential (GWP) impact. GWP of traditional building is almost the double of the modern buildings, and 0.6 times higher than of semi-modern building. The largest share of GWP is responsible for operational stages, which are related to energy use for different household activities. In traditional building, GWP during the operational stage is 7.76 GWPkgCO$_{2\text{-eq}}$/person.night, which is 76% higher than that of modern building and 35% higher than that of semi-modern building. In traditional building, the energy consumption for household activities consists of 12.15 kWh/person night.

Construction stage includes GWP associate with the collection of raw materials by resource extraction; processing of the raw materials to the building products, transportation of the products to the construction site and the assembly of the products in a construction site. The GWP on construction stage is higher in Modern building due to the use of commercial material, which has to be transported from the capital city. On the other hand, modern building occupies the larger area (597.92 m^2) that needs more building material, which ultimately produces larger environmental impact.

Maintenance and replacement stage accounts for the impact associated with the maintenance and replacement of building materials during the 50 years of building life span. The result shows that traditional building contributes higher GWP (0.15 GWPkgCO$_{2\text{-eq}}$/person.night), which is 60% times higher than modern building and 30% times higher than of semi-modern building.

Table 3. 3: Building performance in various building parameters

Criteria	Paramters	Modern	Semi-modern	Traditional
Environmental criteria	LCA_construction (GWPkgCO$_{2\text{-eq}}$/person.night))	**0.12±0.13(25)** **(0.03 - 0.54)**	0.08±0.04(16) (0.03-0.54)	0.09±0.03(4) (0.06-0.12)
	LCA_operation (GWPkgCO$_{2\text{-eq}}$/person.night)	4.41±2.28(25) (1.21 - 10.28)	5.73±3.23(16) (2.13-13.25)	**7.76±2.35(4)** **(5.67-10.63)**
	LCA_maintenace & replacement (GWPkgCO$_{2\text{-eq}}$/person.night)	0.09±0.05(25) (0.03 - 0.22)	0.11±0.05(16) (0.04-0.19)	**0.15±0.05(4)** **(0.10-0.22)**
	LCA_total (GWPkgCO$_{2\text{-eq}}$/person.night)	4.61±2.29(25) (1.31 - 10.48)	5.92±3.27(16) (2.22-13.45)	**8.54±3.21(4)** **(6.01-12.95)**
Economic criteria	LCC_construction (Euro/person.night)	**0.09±0.05(25)** **(0.03 - 0.24)**	0.07±0.04(16) (0.03-0.16)	0.08±0.03(4) (0.05-0.11)
	LCC_operation (Euro/person.night)	4.99±3.84(25) (1.21 - 18.46)	5.34±3.84(16) (1.48-13.01)	**8.04±6.46(4)** **(2.83-16.70)**
	LCC_maintenance & replacment (Euro/person.night)	0.66±0.41(25) (0.20 - 1.75)	0.55±0.27(16) (0.19-1.05)	**0.68±0.19(4)** **(0.44-0.85)**
	LCC_total (Euro/person.night)	5.74±3.91(25) (1.54 - 19.43)	5.97±3.87(16) (3.87-13.75)	**8.81±6.46(4)** **(3.80-17.40)**
Physical and Technical criteria	Energy consumption (kWh/person.night)	7.39±4.97(25) (1.68 - 22.49)	10.06±7.43(16) (1.47-25.94)	**14.78±5.99(4)** **(7.60-19.83)**
	Thermal efficiency (Watt/m3)	36.80±5.49(25) (25.23-45.11)	**48.21±8.38(16)** **(39.13-61.40)**	47.25±4.36(4) (41.24-53.37)
	No.of tourist/year	**845.76±385.14(25)** **(240-1680)**	498.00±268.18(16) (240-1200)	318.00±119.80(4) (192-432)
	Area_m²	**597.92±239.99(25)** **(227.95-1052.11)**	325.76±157.12(16) (159.35-760.25)	303.75±199.26(4) (160.95-649.67)

Mean±Standard deviation (n) (minimum – maximum)

Economic criteria: The life cycle cost of three building types during the lifespan of 50 years shows that traditional building contributes the highest cost over the period of 50

years, which is 53% higher than that of modern building and 47% higher than of semi-modern building. Operation cost is responsible for higher life cycle cost on traditional building, as large amount of energy is consumed in different household activities. Construction and replacement cost concurred relatively less cost in all building type.

Physical and technical criteria: Energy consumption for different household activities is higher in traditional building (14.78 kWh/person.night), which is two times higher than that of modern and 1.5 times higher than that of semi-modern building. It is important to consider that traditional building also host the guest from modern building and semi-modern building for the lunch. Stove in SNPBZ is found to have efficiency of just 11.6 % (Sulpya 1991), that results in 88.4 % heat waste.

Regarding the thermal efficiency of the building, this study estimates that semi-modern buildings are less efficient as it demands more heat (48.21 Watt/m^3) to keep the room warm. The material used and thickness of the wall is less efficient in this houses as compared to modern and traditional buildings since the local people tries to modify the building structure and material used. The heat demand is therefore high in this building. In contrast traditional and modern building have high resistance offered by the wall material, therefore, reduce the heat loss from the room and resulting in a lower consumption of energy for the space heating.

Technology has greatly influenced the modern building construction method. Use of imported insulating material in the wall and the modern glass technology has reduced the energy consumption for space heating in the modern building in the study area as compared to traditional and semi modern modified houses, which results in less energy demand in these houses.

It is estimated that modern building host more guests (846 person/year) compare to semi-modern and traditional buildings. In terms of building size, the modern building is bigger in size (with an average of 597.9 m^2), compared to semi-modern, which has average area of 325.8 m^2 area and traditional building with 303.8 m^2 area.

3.3.2 Differences across the buildings, results of ANOVA test

The result of the ANOVA test show highlights a significant difference on GWP per guest stay per night between the building types (Table 3.4). It is also estimated that GWP on operational stage has significant difference between the buildings. However, there is no significant different found on construction, maintenance and replacement stages.

Life cycle cost per "guest stay per night" is lower in the case of modern building but this is a tendency, which is not significantly proved by the ANOVA test due to the high variability and lower number of traditional buildings.

It is significantly verified in the case of thermal efficiency and the size of the building.

Table 3. 4: Performance of various parameters across the buildings

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
LCA_construction (GWPkgCO$_{2\text{-eq}}$/person.night)	Between Groups	.013	2	.007	.597	.555
	Within Groups	.460	42	.011		
	Total	.473	44			
LCA_operation (GWPkgCO$_{2\text{-eq}}$/person.night)	Between Groups	46.397	2	23.198	3.273	**.048**
	Within Groups	297.716	42	7.088		
	Total	344.113	44			
LCA_maintenace & replacement (GWPkgCO$_{2\text{-eq}}$/person.night)	Between Groups	.016	2	.008	2.941	.064
	Within Groups	.117	42	.003		
	Total	.134	44			
LCA_total (GWPkgCO$_{2\text{-eq}}$/person.night)	Between Groups	59.269	2	29.634	3.925	**.027**
	Within Groups	317.112	42	7.550		
	Total	376.381	44			
LCC_construction (Euro/person.night)	Between Groups	.001	2	.001	.280	.757
	Within Groups	.092	42	.002		
	Total	.093	44			
LCC_operation (Euro/person.night)	Between Groups	32.346	2	16.173	.970	.387
	Within Groups	700.081	42	16.669		
	Total	732.427	44			
LCC_maintenance & replacment (Euro/person.night)	Between Groups	.127	2	.063	.513	.603
	Within Groups	5.196	42	.124		
	Total	5.322	44			
LCC_total (Euro/person.night)	Between Groups	33.012	2	16.506	.967	.389
	Within Groups	716.892	42	17.069		
	Total	749.904	44			
	Between Groups	216.670	2	108.335	2.977	.062

Energy consumption (kWh/person.night)	Within Groups	1528.255	42	36.387		
	Total	1744.925	44			
Thermal efficiency (kWh/m^3)	Between Groups	1409.956	2	704.978	15.982	**.000**
	Within Groups	1852.665	42	44.111		
	Total	3262.621	44			
Number of tourist	Between Groups	1740032.640	2	870016.320	7.805	**.001**
	Within Groups	4681906.560	42	111473.966		
	Total	6421939.200	44			
Area (m2)	Between Groups	997162.370	2	498581.185	11.885	**.000**
	Within Groups	1761945.247	42	41951.077		
	Total	2759107.617	44			

3.3.3 Correlation between different building parameters

This study was performed to investigate the correlation/ dependence between multiple variables at the same time. Pearson correlation analysis method were selected to measures the linear dependence between two variables. Table 3. 5 shows the result containing the correlation coefficients between each building parameter and the others. The values in the bold shown in the Table 3. 5 represent statistically significant correlation between the two variables. When Pearson's r-value is close to 1, it means there is a strong correlation between two variables. This means the changes in one variable are strongly correlated with changes in the secondr variable.

The results show that LCA per "stay of one guest per night stay" is strongly correlated with operation stage as Pearson's r value is 0.99. Similarly, the result on LCA (GWPkgCO$_{2\text{-eq}}$/person.night) is correlated with LCC per guest per night stay as well as operation cost and energy consumption. This indicates that the operation stage associate with energy consumption in different household activities is highly responsible for largest share of environmental and economic impacts.

Similarly, life cycle cost per one guest per night stay in a commercial building has a strong correlation with operation cost, which is responsible for larger share of economic impact. Additionally, LCC is highly correlated with GWP in operational stage, LCA, energy consumption.

On the other hand, thermal conductivity of the building is negatively correlated with its size. The Pearson's r value is -0.478 between thermal conductivity and building size. This means that smaller the size of the building, the higher will be the thermal conductivity and vice-versa.

Likewise, the number of guests is negatively correlated with LCA, LCC and operation, maintenance and replacement stages. The higher is the number of guests, the lower is the environmental and economic impact per guest night stay. This happens because the share of impacts increases with an increase in the number of guest. However, the number of guest is strongly correlated with the size of the building. The larger is the size of the building, the higher is the number of guests. Thus, the size of the building also has negative correlation with the environmental and economic impacts.

Table 3. 5: Correlation matrix of different building parameters

Variables	LCA_construction (GWPkgCO$_2$eq/person.night)	LCA_operation (GWPkgCO$_2$eq/person.night)	LCA_maintenace & replacement (GWPkgCO$_2$eq/person.night)	LCA_total (GWPkgCO$_2$eq/person.night)	LCC_construction (Euro/person.night)	LCC_operation (Euro/person.night)	LCC_maintenance & replacment (Euro/person.night)	LCC_total (Euro/person.night)	Energy consumption (kWh/person.night)	Thermal efficiency (kWh/m^3)	No. of guest (assumed that 80% of hotel are occupied)	Area (m^2)
LCA_Building Construction	**1**	-0.046	0.075	-0.013	0.148	-0.011	0.115	0.000	-0.029	-0.160	0.226	0.142
LCA_Building Operation	-0.046	**1**	**0.358**	**0.994**	0.267	**0.722**	0.227	**0.736**	**0.891**	-0.050	**-0.447**	-0.272
LCA_Building Replacement	0.075	**0.358**	**1**	**0.367**	**0.851**	0.101	**0.855**	0.182	**0.391**	-0.027	**-0.840**	**-0.572**
LCA total	-0.013	**0.994**	**0.367**	**1**	0.271	**0.738**	0.237	**0.753**	**0.887**	-0.045	**-0.447**	-0.278
LCC_Building Construction	0.148	0.267	**0.851**	0.271	**1**	0.092	**0.965**	0.184	**0.311**	-0.276	**-0.618**	-0.294
LCC_Building Operation	-0.011	**0.722**	0.101	**0.738**	0.092	**1**	0.070	**0.996**	**0.410**	-0.097	-0.144	0.018
LCC_Building Replacement	0.115	0.227	**0.855**	0.237	**0.965**	0.070	**1**	0.164	0.268	-0.246	**-0.630**	-0.290
LCC Total	0.000	**0.736**	0.182	**0.753**	0.184	**0.996**	0.164	**1**	**0.431**	-0.120	-0.203	-0.010
Energy consumption (kWh/person.night)	-0.029	**0.891**	**0.391**	**0.887**	**0.311**	**0.410**	0.268	**0.431**	**1**	-0.020	**-0.481**	**-0.332**
Thermal efficiency (kWh/m^3)	-0.160	-0.050	-0.027	-0.045	-0.276	-0.097	-0.246	-0.120	-0.020	**1**	-0.222	**-0.478**
No. of guest (assumed that 80% of hotel are occupied)	0.226	**-0.447**	**-0.840**	**-0.447**	**-0.618**	-0.144	**-0.630**	-0.203	**-0.481**	-0.222	**1**	**0.760**
Area (m^2)	0.142	-0.272	**-0.572**	-0.278	-0.294	0.018	-0.290	-0.010	**-0.332**	**-0.478**	**0.760**	**1**
Values in bold are different from 0 with a significance level alpha=0.05												

3.4 Conclusions

The main goal of this study was to get a comprehensive picture of life cycle prospective both on environmental and economic aspect, with addition of physical and technical parameters such as energy consumption, thermal conductivity and size, over the entire hotel sector in the Park to accomplish building sustainability and promote the use of sustainable construction practice. Results show that traditional building accounts the highest GWP and the cost over the period of 50 years of building lifespan. Operational stage is responsible for high environmental impact (97% of total GWP) and operational cost (by 90%) that are associated with energy consumption in different household activities. These values confirm other studies showing the impact of operation to be in the range of 80-90% (Asdrubali et al. 2013; Cuéllar-Franca and Azapagic 2012; Ortiz et al. 2009).

It is important to note that the traditional buildings host a lower number of guests compared to modern and semi-modern buildings. The share of impacts decreases with lower number of guests. Thus, the impact is higher in the case of traditional buildings. The other reason could be a larger use of firewood and cattle dung for cooking and space heating. Stove in SNPBZ is found to have an efficiency of just 16% (Sulpya 1991), that results in 84% of heat waste. The main improvement opportunities in the Himalayan buildings lie in a reduction of impacts in the operational stages. This can be achievable by using more efficient stove, heating stove, light bulb and use of renewable energy.

The construction stage contributes only 1% of the total GWP and 2% by maintenance and replacement stage in all building types. Although construction, maintenance and replacement stage are less responsible for environmental and economic impacts, there is still room for improvement in these stages. As highlighted in a previous study, it can be concluded that the construction of energy efficient buildings implementing local materials with proper insulation and use of renewable energy is a recommendable option for sustainable building design in Himalayan region.

With the implementation of insulating materials (glasswool and polystyrene) in the wall of modern buildings, the energy consumption for space heating has reduced the heat (36.80 W/m³), which ultimately reduces the energy consumption and its

emission. Traditional building with thick wall and small opening of door and windows have been found to be thermally efficient, more than that of semi-modern building which implement less or even no insulation.

Since the different insulating materials have different thermal conductivities, there will be slight variations in the U value and thus with their performance. Owner's selection of insulation material determines the amount of heat loss and thus the energy demand for heating. They are therefore having a choice of using expensive glass wool or locally available mud plaster and cheap polystyrene, reducing heat demand by 23% and 19.6% respectively (Bhochhibhoya 2008). Initial investments in insulation could save unnecessary future expenses in energy. The installation of insulation using locally available resource has least payback period than using other resources available for insulation.

The correlation of different parameters on commercial sector of building in the Park shows that there is a strong correlation between environmental and economic impact with the amount of energy consumed for the household activities. On the contrary, number of guest and building size is negatively correlated with environment and economic impacts. This reveals that the main improvement opportunities in the building sector perspective to Himalayan region lie in the reduction of impacts in the operational stage.

In order to optimize the buildings under the LCA perspective, Asdrubali et al. (2013) claimed that it is important to account buildings envelope solution (insulation materials and type and width of masonry), facilities and promotion of renewable energy. Furthermore, Zabalza et al. (2009) said that for the promotion of sustainable buildings with low energy consumption and high building efficiency, in addition to promote the use of renewable energy and equipment with high energy efficiency, priority must be given to bio-construction and bio-climatic eco-design, the use of low impact, natural, recyclable material available in the local area. Therefore, it is important to carry out detail studies on the alternatives to optimize the building sustainability.

.

CHAPTER FOUR

Life cycle assessment of building wall materials perspective from Himalayan buildings

Abstract

This chapter provides a comparative life cycle assessment in terms of Global Warming Potential (GWP) of different wall materials used in traditional, semi-modern and modern types of buildings in Sagarmatha National Park and Buffer Zone (SNPBZ) in Nepal. The three building systems differ for the wall materials used, since the traditional building type is made of local materials, mainly wood and stones, while the semi-modern and modern building types use different amounts of commercial materials, such as cement and glass wool. The building systems have been analysed and compared considering as functional unit 1 m^2 of wall in all the building types.

The study shows that the traditional building type releases about one fourth (1064.36 g $CO_{2-eq}m^{-2}$) of the greenhouse gas emissions released by the semi-modern building type (4013.02 g $CO_{2-eq}m^{-2}$) and less than one fifth of the greenhouse gas emissions released by the modern building type (5626.34 g $CO_{2-eq}m^{-2}$). It has been recognized that if local materials, as wood, are used in building construction, the emissions from production processes and transportation could be dramatically reduced.

Keywords: Sustainability, Life Cycle assessment, Building materials, Sagarmatha National Park

4.1 Introduction

The growing threat of climate change is raising concerns on the control of the GHG emission in both developed and developing countries. Developing countries are particularly susceptible to climate change (Pouliotte et al. 2009; Gentle et al. 2012; Pandit 2013), because of their limited capacity to cope with the hazards associated with changes in climate (Olmos 2001, UNFCC 2007). Even within developing countries, some communities may be more vulnerable than others. For example, the effects of climate change are usually more severe in rural areas, often characterized by limited livelihood options, poor access to service and inequitable access to productive assets (Shrestha et al. 2012, Ortiz-Montemayor 2012, Gentle and Maraseni 2012). Within rural areas, mountainous ones are probably the most exposed to hazardous processes, including climate change, because of their higher ecological complexity, both environmental and economic (Luthe et al. 2011; Delay et al. 2015). At the same time, thanks to the extensive presence of natural ecosystems and land-use types, mountainous areas are essential providers of public services such as biodiversity, water, recreation, carbon (Viviroli et al. 2007; Glass et al. 2013; European Environmental Agency 2010; Grêt-Regamey et al. 2008). Therefore, any change in these fragile ecosystems must be carefully considered, as their value extends much beyond the local scale, up to the national or international societal one. For their pivotal role in global environmental conservation, mountainous areas are core in the research agenda for sustainable development ever since Rio 1992 (Preston 1997; Messerli 2010; Gurung et al. 2012). From another perspective, mountainous areas are also interesting because their continuous exposure to a variety of natural and economic hazards over different times and scales has allowed their communities to develop specific adaptation strategies often embedded on local traditional knowledge. Thus, they could be a good laboratory to study how the introduction of new technologies can impact on local and general environmental sustainability and, in general, on local communities livelihood patterns (Gurung et al. 2012; Gardner and Dekens 2007; Barua et al. 2013 Weyerhaeuser and Nowrojee, 2014).

The Himalayan region is a paradigmatic example of the value of mountain areas as global resources, but also of the many possible threats arising from global and local drivers (Ramakrishnan 2001). Although not the most important, increasing human population growth accompanied by expansion in buildings (Battha 2003) is a source of local change. Thus, to satisfy needs and thermal comfort of the increased population, buildings in the Himalayan region are modified into reinforced concrete building, displacing traditional wood and stone masonry. This may create a heat-island effect and thus add to regional warming (Pandit 2013). The building sector makes a considerable contribution to worldwide environmental impacts (Scheuer et al. 2003; Pittet 2010), since it shares 20-30 % of the global carbon footprint (McKinsey and Company, 2009). At global level, the building construction consumes 24% of the raw materials extracted from the lithosphere (Zabalda et al. 2011). High levels of pollution from the building industry are the result of the energy consumed during the extraction, processing and transportation of materials (Morel et al. 2001), leading to unsustainable outcomes.

To assess how buildings can contribute to overall sustainable development in mountainous areas, it is important to consider their entire life cycle and to evaluate the environmental impacts associated with the extraction, production, and transportation phases identifying and quantifying the energy and materials used and the waste released to the environment (Pittet and Kotak 2010; Sonnemann et al. 2003). The interest in documenting the environmental impact of building materials and processes is increasing in developed countries, aiming to reduce their energy consumption for the operation and processing (Pittet and Kotak 2010; Cole 1999), but information in this field is still very scanty. Due to the lower efficiency generally encountered in smaller size manufacturing plants, developing countries may produce larger environmental impacts per unit of material produced (Pittet and Kotak 2010; Buchanan and Honey 1994; Asif et al. 2007; Fava 2006). Furthermore, the energy used for material production and process, transportation means and distances travelled are very different, with potential consequences on the overall environmental impacts (Pittet and Kotak 2010; Cole 1999; Huberman and Pearlmutter 2008; Pearlmutter 2007).

To better understand the environmental performance of building materials in developing countries, specific studies have to be performed. This study was carried out in Himalayan region of Nepal, renowned touristic area, which attracts about 30,000 tourists each year (Census 2014). The government of Nepal is planning to implement a policy to attract more tourists in the near future. Although these initiatives will bring new income opportunities for the local communities, they will also contribute to a fast growing in buildings that could worsen the already critical situation in terms of environmental pollution (Salerno et al 2010; Manfredi et al 2010), especially keeping into account the ongoing replacement of traditional wood and stone masonry with concrete structures. In Himalayan regions, wood, as some other building materials, is found nearby the houses, whereas other materials are transported through aircraft from the main cities due to the difficult road connection. In such situation, Life Cycle Assessment (LCA) could help in the decision-making when selecting the best technology and material availability and minimizing the environmental impact of the building activity on the mountainous environment (Petersen and Solberg 2005; Gustavsson and Sarthe 2006; Zabalza et al. 2011; Passer et al. 2012).

In this context, this chapter provides a comparative LCA of the building materials used in typical houses built in mountainous region in Nepal. The purpose of the study is twofold: (i) to identify the major emission sources during the life span of materials used in wall of the building in prospect of Himalaya and (ii) to understand the potential actions to reduce the local greenhouse gas emission and ultimately contribute towards a more sustainable development of such a unique global resource. The LCA methodology has been used for assessing the global warming potential (GWP) of building materials utilized in three different building types throughout their life cycle.

4.1.1 Study site

The study area is located in Sagarmatha National Park and its Buffer Zone (SNPBZ), in Nepal. SNPBZ lie in the Northeastern regions of Solu-Khumbu District of Sagarmatha Zone in Nepal. The park is situated between 27° 30' 19'' - 27° 06' 45'' N latitude and 86° 30' 53" - 86° 99' 08" E longitude. The altitude ranges from 2800 m to 8848 m above mean sea level. The Park lies within an area of 1,148 km² that

comprises 69% of the park while 28% is grazing land and the remaining 3% is forested (Stevens 2003).The park is divided into three village development committees (VDCs): Namche, Khumjung as core areas in the north and Chaurikharka as a buffer zone in the south of the park. The zones that include a forested lower zone, a zone of alpine scrub, the upper alpine zone includes upper limit of vegetation growth, and the Arctic zone where no plants can grow.

The sources of economic activities in the park are tourism and agriculture. It is a popular tourist destination enhanced by the highest peaks of the world that can be reached only by airplane or on foot.

4.2 Materials and Methods

4.2.1 Building types and materials

The wall of the three types of buildings: traditional, semi-modern and modern has been studied. Traditional buildings, known as *Sherpa* Houses (Fig. 4. 1), which follow their ancestral house design practice with thick wall are built mainly using timber, stone and mud. Semi-modern type of buildings (Fig. 4. 2) is the partial transformation of traditional into modern, with limited insulation material besides wooden planks, dry stones and a less amount of cement and mud as plaster. Modern buildings (Fig. 4. 3), built mainly for touristic purposes, primarily use imported construction materials such as cement and glass wool.
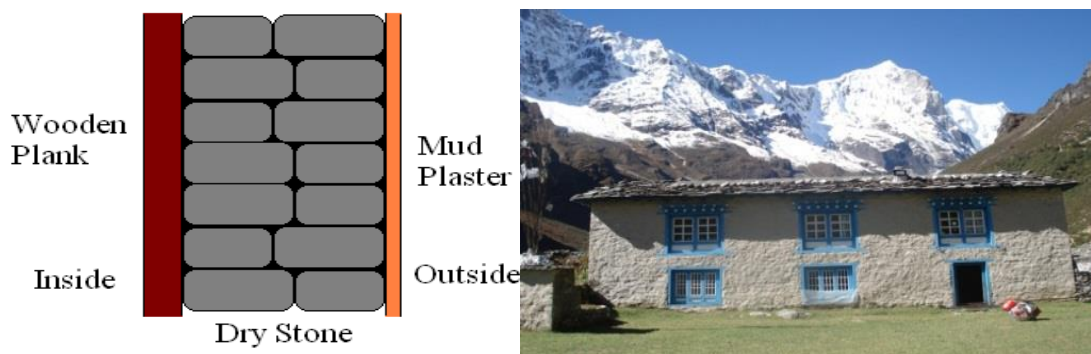
(a) Wall-cross section   (b) Exterior appearance

Fig. 4. 1: Traditional building type

(a) Wall-cross section   (b) Exterior appearance

Fig. 4. 2: Semi-modern building type
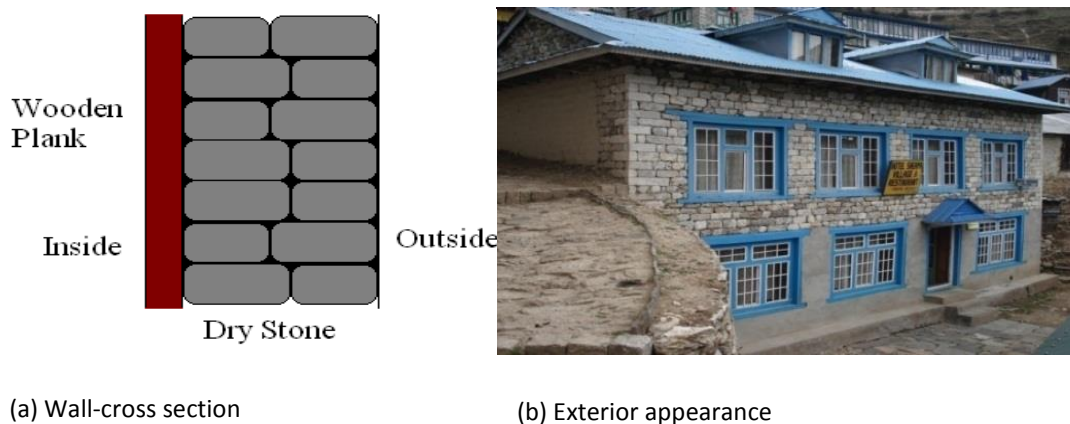
(a) Wall-cross section;   (b) Exterior appearance
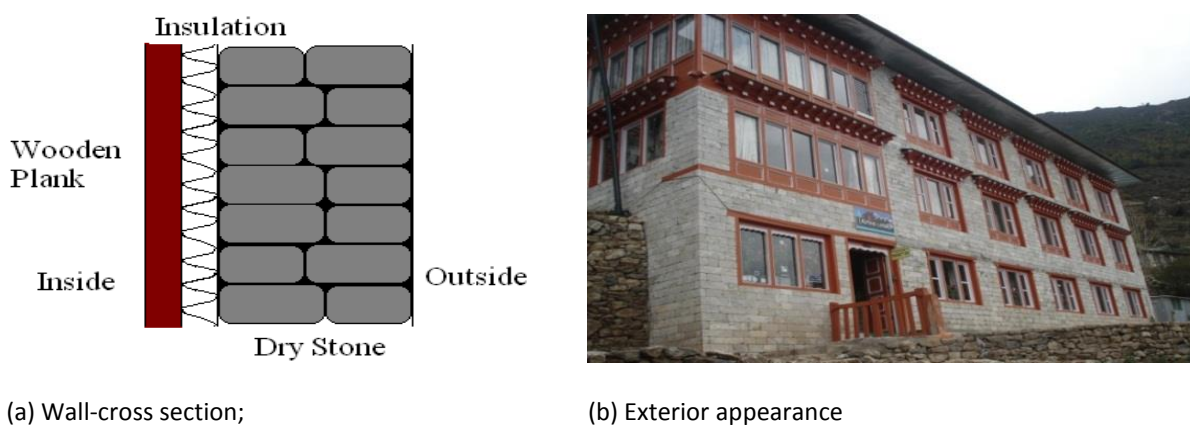
Fig. 4. 3: Modern building type

The construction materials are mainly timber for internal support structure, stone or soil for envelope, according to different installation techniques: compressed clay or sun-baked mud bricks (Sestini 1998) and 0.7-0.8 m thick dry stone masonry.

Pine (*Pinus wallichiana)* and fir (*Abies spectabilis*) wood timbers are generally used for building construction in the Park (Stevens 2003). The Park authority has enacted a regulation that allows the use of 30 m^3 of wood timbers per construction of one new building. Royalty has to be paid to the Park for the extraction of the allocated wood timber from the forested area. Supplementary wood timbers are brought from Jiri, the hilly region of Nepal, which is located at 51 km aerial distance from the Park. These materials are mostly transported by helicopter from Jiri to the Park. In the semi-modern and modern building wall, 50% of wooden planks are assumed to come from

Jiri and 50% from the Park, while in the traditional building, 100% of wooden planks come from the Park.

Beside wood, white mud, locally known as *Kamero*, is abundantly available in the Park. *Kamero* as a binding and insulation materials has been extensively used since 20th century and research has been carried out to adapt modern technologies to use it as building material (Morel et al. 2001). In traditional building type, 0.05 m thick mud plaster is used externally in masonry stonewall.

Another locally available material used in all type of building wall in the Park is dry stone. The stones for the masonry work are obtained usually from the cropland and/or riverbed. To achieve a clean sharp finishing, carving and molding of the stone are done manually with the help of chisel and saw.

Some commercial materials like glass wool and polystyrene for insulation, respectively used in modern and semi-modern building, and cement for binding have been gradually adopted for modern buildings in the Park. The glass wool and polystyrene are imported either from China or India, whereas cement and other construction materials are transported from the industries located nearby Kathmandu.

4.2.2 Life cycle assessment of buildings materials

LCA applied to building materials provides the quantitative and comparative values of the environmental impacts of various building technologies (Singh et al. 2011; Zabalda Bribián et al. 2011; Takano et al. 2015). LCA in this study is used for quantifying the emission, energy and material consumption of a building system in the construction phase of life cycle from the acquisition of raw material, product manufacturing, transportation, and assembling (UNI EN ISO 14040 2006; UNI EN ISO 14044 2006; Consoli et al. 1993).

The functional unit considered is "*1 m^2 of wall*" (Cole 1999) in all-building types. Disposal and waste products are not taken into account with the consideration that the waste products are negligible since they are reused for the construction. The life expectancy of the building is difficult to predict in the region, as the age of existing buildings varies significantly.

Since LCA is a data-intensive method, the preparation of data for the building assessment according to the standard is a fundamental step (Takano et al. 2015). The data used in the model are both primary and secondary data: the quantity of material and the energy necessary to built 1 m^2 of wall has been collected. Secondary data have been utilized for the emission factors provided by Ecoinvent database (Frischknecht et al. 2005) internationally recognized by the scientific community to be one of the most complete database to perform LCA studies. The energy and materials used for production of equipment, tools and infrastructures are not incorporated within the system boundaries. Ninety-one buildings located in nine different settlements of the Park have been studied. The data have been collected through a field survey, interviewing the local people from different households in SNPBZ. The survey has also been undertaken with retailers of building material in Kathmandu. The questionnaire has been prepared in LCA standard, that includes material used in existing building, material source, quantities used, transportation distance and means, energy used for processing and transportation. The different processes for the material acquisition, transportation and energy used are described (Appendix S1). The average data has been used to build the LCA model (Appendix S2).

GaBi 6.0 software has been used to perform the LCA of buildings in SNPBZ, to generate the emissions factors and to analyse the relative contribution of the various material processes to emissions. GaBi 6.0 is a software package developed by PE International designed for analysing the environmental impact of products and services over their whole life cycle. The global warming impact category (GWP) has been chosen to express and compare the impacts of the different processes related to the different wall type production. GWP is generally regarded as a major indicator in LCA studies (Knauf 2015). The GWP or "greenhouse effect" produces an increase of temperature in the lower atmosphere that can lead to climate and environmental changes. No matter where the contributing substances are emitted, they contribute to the same phenomenon and GWP impact category is therefore considered to be global. The GWP is expressed in terms of carbon dioxide equivalents ($CO_{2\text{-eq}}$). This means that the effect of the greenhouse gas emissions on global warming is referred to the CO_2 by multiplying the concentrations of each greenhouse gas by its global warming potential. The time frame for the assessment is 100 years, as recommended by the

Kyoto Protocol (1997) and IPCC (2013). The relative contribution of each process to global warming has been calculated utilizing the CML 2001 – Apr. 2013 method incorporated within GaBi and developed by the Institute of Environmental Sciences (CML) of Leiden University (The Netherlands). CML 2001 is an impact assessment method that has been utilized due to its broad international acceptance and common application in building sector (Ortiz et al. 2009; Filimonau et al. 2011).

4.3 Results and Discussion

4.3.1   GWP of wall

The assessment of the environmental impact of the three different building types has shown that the traditional building type, constructed from locally available materials shows the least emissions (Fig. 4. 4). The Global Warming Potential (GWP) of wall from the traditional building type is of 1064.37 g CO_{2-eq} m^{-2} in which the contribution is equally distributed between the alkyd paint used on the wood surface (512.18 g CO_{2-eq} m^{-2}) and the chainsaw used to cut the planks coming from the trees felled by hand in the local park (522.18 g CO_{2-eq} m^{-2}). Locally available wooden plank and other materials such as mud and dry stone less or do not contribute to CO_{2-eq} emissions due to the manual processing and transportation. In the specific case, mud and dry stone are produces manually, and for wooden planks manufacturing, trees are felled using a jack-saw and a large amount of their GWP gases emission is due to the use of the alkyd resin and the chainsaw to cut the log into planks.
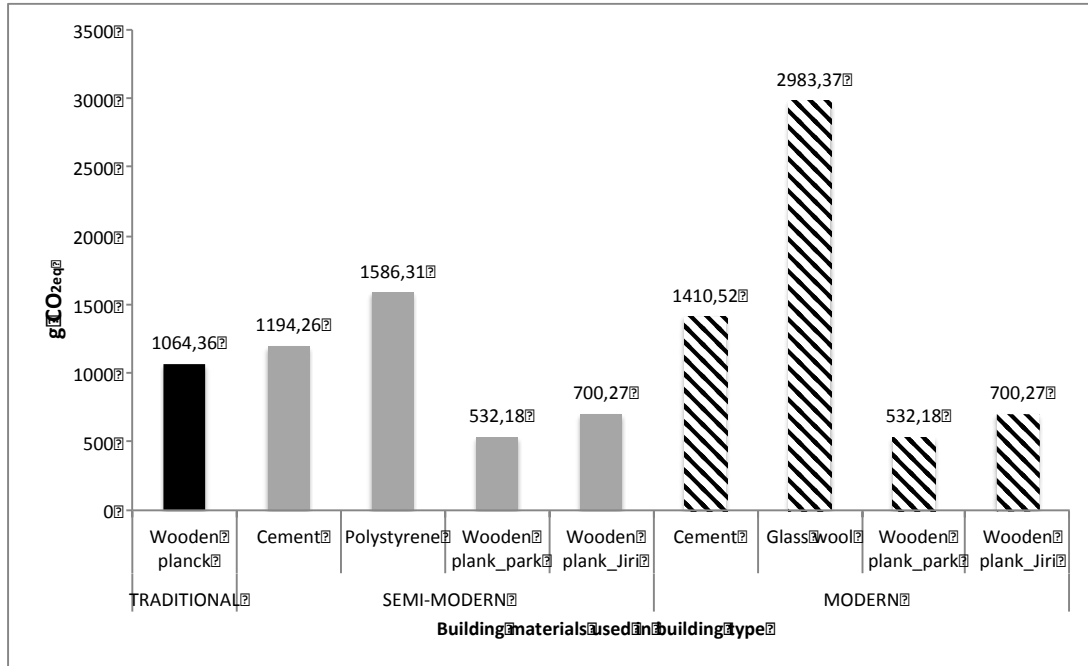
Fig. 4. 4: Global Warming Potential (GWP) of materials needed to built 1 m² of wall of the three building types in the Park

The GWP of wall from the modern building type is five time higher than the traditional building and consists of 5626.34 g $CO_{2\text{-eq}}$ m^{-2}. Modern building wall includes commercial materials produced in China (glass wool) or in other part of Nepal (cement) and transported using different means in SNPBZ. Glass wool insulation panel manufacturing and transport processes contribute for more than 50% of emissions (2983.37 g $CO_{2\text{-eq}}$ m^{-2}) while cement production and transport processes produce 1410.52 g $CO_{2\text{-eq}}$ m^{-2} (Fig. 4. 4). Moreover, in the modern building manufacturing, wooden planks come from two different sites: 50% come from Local Park and 50% come from Jiri, located at 51 km from SNPBZ and transported by helicopter and lorry (Appendix S2). In this case the total contribution of wooden planks (Local Park + Jiri) to global warming is slightly higher (1232.45 g $CO_{2\text{-eq}}$ m^{-2}) than wood used in traditional building (1064.37 g $CO_{2\text{-eq}}$ m^{-2}).

Similarly, the global warming potential of wall from the semi-modern building type consists of 4013.02 g $CO_{2\text{-eq}}$ m^{-2}, where the largest emissive component is the polystyrene used as an insulation (1586.31 g $CO_{2\text{-eq}}$ m^{-2}) that is manufactured in India. The amount of cement used for 1m² of semi-modern building wall is lower compared to that of modern building (2.75 kg instead of 3.24 kg – Appendix S2), thus cement is

the third contributor material to the emissions account of GWP (1194.26 g CO_{2-eq} m^2), but very close to wooden planks emissions, in semi-modern building (Fig. 4. 4).

These results are coherent with other studies conducted on this topic. Comparing to other construction materials, as concrete, bricks and steel, construction of wooden materials have a lower GWP because the balance in equivalent carbon dioxide emissions is almost neutral (Buchanan and Levine 1999; Zabalza et al. 2011), since the CO_{2-eq} can be offset by the activity of absorption of trees. Particularly, the already low impact related to the wooden planks production could be reduced by 48% by avoiding the use of the alkyd resin and further limiting the importation of wooden planks from Jiri.

The results of the wall technologies comparison reported by Pittet and Kotak (2010) also indicates that, in order to substantially reduce the energy consumption and the related CO_{2-eq} emissions, technologies such as earth walls (adobe and cob), wattle, daub and stone walls making limited use of cement or lime mortar and plaster should be encouraged. The study about the environmental sustainability of different materials in Sri Lanka (Emmanuel 2004) has found that wattle and daub (local material) are the most environmentally suitable wall materials among other wall materials such as brick, cement masonry unit, cabook and rubble. The study of Asif et al. (2007) reveals that concrete and mortar are responsible for 99% of the total CO_{2-eq} emission of the home construction, mainly due to its production process. Hence, building with local materials is environmentally better than with other equivalent commercial materials also because the amount of transported materials decreases and consequently their environmental impact (Morel et al. 2001).

The wall of semi-modern and modern building types, on the other hand, constituted of commercial material, such as glass wool, polystyrene and cements result in considerably high CO_{2-eq} emission mainly from production phase and transportation. As far as the GWP impact of insulation material is concerned, the results have shown that the conventional materials with a high level of industrial processes are the largest contributors. Comparing the CO_{2-eq} emitted by different types of insulation materials, Zabalza et al. (2011) showed that insulation of natural origin as cellulose fibre and sheep's wool emitted respectively 75% and 98% less than conventional insulation as

EPS foam slab. Also the use of kenaf - fibres insulation boards involves a significant reduction of environmental impacts derived from the use of synthetic insulating materials (Ardente et al. 2008). It is remarkable to think that finding alternatives in natural and local available materials, the emissions could be at least halved.

Another important result is related to the transportation of the commercial building materials from the manufacturer to the end users. Transport contributes to significantly increase $CO_{2\text{-eq}}$ emissions. The materials such as glass wool and polystyrene are transported from China and India to the capital city Kathmandu by lorry, which are again transported to the Park by aircraft. Other commercial building materials such as cement or wooden plank are also transferred from cities to the Park by aircraft.

To propose strategies for the reduction of GWP, it is useful to understand which process contributes the most to the emissions related to each material and what chemicals are involved.

Table 4. 1: Greenhouse gases (GHG) emissions and type in the three different Nepali buildings

Impact Categories	Traditional g $CO_{2\text{-eq}}$	Semi-modern g $CO_{2\text{-eq}}$	Modern g $CO_{2\text{-eq}}$
Emissions to air (tot)	1064.37	4013.02	5626.34
Inorganic emissions to air (tot)	989.48	3601.26	5335.33
Carbon dioxide	833.10	3375.30	4999.52
Carbon dioxide (biotic)	5.95	65.21	153.87
Nitrous oxide (laughing gas)	146.59	156.12	173.41
Sulphur hexafluoride	3.83	4.62	8.54
Organic emissions to air (group VOC) (tot)	74.89	411.76	291.01
Group NMVOC to air	0.77	4.13	9.53
Methane	73.85	406.41	277.85
Methane (biotic)	0.27	1.23	3.63

As reported in Table 4. 1, the chemical that is by far the most emitted during manufacturing of all the building types is carbon dioxide (CO_2), followed by nitrous oxide (N_2O) in traditional building, and methane (CH_4) in semi-modern and modern buildings. It should be noted that while the amount of fossil CO_2 increased six-fold passing from traditional to modern building, the amount of NO_2 does not have the

same trend, increasing by 20%. Regarding CH_4, the semi-modern building shows the highest emission due to the insulation material manufacturing process.

The details about the amount and type of gas emitted in the different manufacturing and transportation processes of each material to produce $1m^2$ of wall of traditional, semi-modern and modern building are reported in Appendix S4. The percentage of CO_2 emitted from processes, respect to the total greenhouse gas emissions, varies between 80% (wooden planks and polystyrene) to 97% (cement). CO_2 represents the 93% of the emissions of the glass wool processes.

The transportation means of wooden planks form Jiri contribute to increasing the emissions. The increment is of 168.08 g CO_{2-eq} m^{-2}, mainly due to CO_2 emissions (97%). Except for cement, where transportation has a higher impact than manufacturing, generally the material production is the phase with the highest emission. This is particularly true in the case of insulation materials: polystyrene, used in semi-modern building wall, and glass wool used in modern building wall. Polystyrene and glass wool manufacturing emitted respectively almost three times and five times more than wooden planks production, i.e. 1527.62 and 2521.70 g CO_{2-eq} m^{-2} versus 552.18 g CO_{2-eq} m^{-2} needed to cut the wooden plank. In the case of polystyrene three quarters of the greenhouse gases emitted are CO_2 and the rest is mainly CH_4. The polystyrene and glass wool manufacturing process produced respectively 302.78 g CO_{2-eq} m^{-2} and 159.14 g CO_{2-eq} m^{-2} of CH_4. Glass wool transportation processes also emitted more than the polystyrene one because a larger amount of glass wool is needed for modern building insulation: 1.63 kg m^{-2} of glass wool versus 0.36 kg m^{-2} of polystyrene in the semi-modern building (Appendix S2).

As a result, the wall of the modern building produces higher environmental impact from the production of its wall compared to semi-modern and traditional building wall. However, the modern building that uses heavy insulation are more thermally efficient that demand 13 W/m^3 of heat to keep the room warm. Use of insulation materials such as glass wool in the wall reduces the energy consumption for space heating as compared to traditional and semi-modern building. Traditional building, having a thick wall that uses local materials, demands 16.6 W/m^3 of energy for space heating while semi-modern demands 17.44 W/m^3.

The wall of three existing building consists of different materials, thus the environmental impact from different type of buildings differs. If roof is taken into account, corrugate galvanized sheet (CGI), wooden joist and roofing nails materials are mainly used in all types of building. GWP from roof is the same in all building types in which 99% of the emissions is from the CGI sheet.

Since the CO_{2-eq} is the main gas emitted during the life cycle of considered materials, through the promotion of wood utilization and a sustainable forest management, CO_{2-eq} emissions could be offset. Wood and wood products contain stored carbon that is released to the atmosphere only when wood is burnt or degraded by the organisms (Buchanan and Levine 1999). As a renewable material, the harvested wood in forest can be replaced in a relatively short time through the carbon absorption in forest. By saving a part of the biomass increment, a sustainable forest management can aim at offsetting the emissions of the whole supply chain (Pierobon et al. 2015). So there are trade-offs between sequestering carbon stocks in forests and the climatic benefits obtained by sustainable forest harvesting and using wood products to displace fossil carbon emissions (Pingoud et al. 2010). In this case, if park regulations allow to cut 30 m^3, considering a wood density of 670 kg m^{-3}, and if 70% of the harvested wood is used to produce wooden planks, then this corresponds to 14 t of wood available for building. Assuming a carbon content of 50% of the total biomass (IPCC 2006), 7 tons of carbon is stored in the total available woody biomass. Contrarily to the carbon in biomass for bioenergy that it is released during combustion, the carbon storage in wood used as building material will be stored for the entire building lifespan that in this context is greater than 100 years.

4.4 Conclusions

In this study a life cycle assessment of building materials used in Nepali buildings of SNPBZ has been performed to evaluate the contribute of each material to the overall impact of 1 m^2 of wall building systems in terms of GWP. The study has outlined that the semi-modern and modern building walls that use commercial materials, like cement, polystyrene and glass wool, and that are progressively replacing the traditional building type, which on the contrary uses locally available materials, have

impacts on global warming from 4 to 5 times higher. Although the production of GWP is high in modern building, the wall of the building is thermally efficient compared to semi-modern and traditional buildings. Even if the environmental impact of modern building construction is higher, the higher thermal efficiency helps to reduce the energy consumption for space heating and consequently reduce the GWP during modern building utilization.

The study also has demonstrated the possible areas to reduce the CO_{2-eq} emission during the life span of building materials. The analysis has indicated that high amount of CO_{2-eq} is produced during the production and transportation of the materials, especially the insulation material. This suggests that CO_{2-eq} can be reduced by adopting traditional manufacturing techniques and local materials available in the Park and which have high value in terms of environmental protection. Among the local available materials, the use of wood associated to sustainable forest management practices that have an impact on carbon stocks in biomass and on the annual supply of wood products, should be encouraged.

In an overall perspective, the study can be embedded in the general debate on sustainable mountainous development, especially on the role that communities' knowledge can play in it. Although traditional knowledge and locally-developed bottom-up solutions are often proposed in juxtaposition with top-down technologically-based ones, the results of the study show that both traditional building types and modern ones can contribute, although in different ways, towards a more sustainable use of environmental resources. Appropriate solutions thus require a balanced mix across tradition and modernity, which cannot be generalised but need to be locally defined in order to cater for the high specificity and delicate equilibrium of mountainous ecosystems.

Glass wool fibers → Manufacturing — Glass wool → Transportation — Glass wool → Transportation — Glass wool → Transportation — Glass wool
Electricity → Machine
Diesel → Lorry
Diesel → Van
Diesel → Aircarft
Glass wool

Oil → Manufacturing — Polystyrene → Transportation — Polystyrene → Transportation — Polystyrene → Transportation — Polystyrene
Electricity → Machine
Diesel → Lorry
Diesel → Van
Diesel → Aircarft
Polystyrene

Limestone → Limestone — Gravel → Manufacturing — Cement → Transportation — Cement → Transportation — Cement → Transportation
Diesel → Manual
Electricity → Machine
Diesel → Lorry
Diesel → Van
Diesel → Aircraft
Cement

River bank → Stone Quarry — Stones → Transportation — Stones → Cutting — Blocks → Assemble
Manual
Manual
Manual
Manual
Stone

Forest → Tree felling — Felled tree → Transportation — Felled tree → Cutting — Plank → Transportation — Plank → Alkyd coating — Plank → Assemble
Manual
Manual
Power sawing
Helicopter
Manual
Manual
Electricity
Diesel
Wooden Plank

Hills → Mud Quarry — Mud → Transportation — Mud → Mud mixutre
Manual
Manual
Manual
Mud

Modern Building
Semi-modern Building
Traditional Building

Appendix S2

Material	Origin	Quantity (kg)	Transportation distance (km)	Means of transportation
Wooden plank (density: 670 kg/m³)	National Park Forest (SNPBZ)	34.04 (T, SM, M)	5 (National Park Forest)	Manual
	Jiri		15 51.02 (Jiri)	Lorry 3.5-16t + Helicopter
Stone (density: 2610 kg/m³)	River bank/Cropland (SNPBZ)	T = 1456.38 SM = 1192.77 M = 1325.88	1	Manual
Mud (density: 1906 kg/m³)	Hills/Cropland (SNPBZ)	T = 96.82 SM = 24.20	3	Manual
Cement (density: 2162 kg/m³)	Jagdamba Cement Factory, Nepal	SM = 2.75 M = 3.24	10 (mine to plant)	Tractor
			290 (Bhairahwa to KTM)	Lorry 3.5-16 t
			10 (KTM retailer to KTM airport)	Van < 3,5 t
			136 (KTM to Lukla)	Cargo aircraft
Glass wool (density: 30 kg/m³)	China	M = 1.63	999 (China to KTM)	Lorry >16 t
			10 (KTM retailer to KTM airport)	Van < 3.5 t
			136 (KTM to Lukla)	Cargo aircraft
Polystyrene foam (density: 30 kg/m³)	India	SM = 0.36	886 (India to KTM)	Lorry >16 t
			10 (KTM retailer to KTM airport)	Van < 3.5 t
			136 (KTM to Lukla)	Cargo aircraft
Alkyd resin (density 1090 kg/m³)	Asian Paint Nepal	0.14 (T, SM, M)	82 (Hetauda to KTM)	Truck
			10 (KTM retailer to KTM airport)	Van < 3.5 t
			136 (KTM to Lukla)	Cargo aircraft

(T=Traditional building, SM= Semi-Modern building, M= Modern building, KTM = Kathmandu)

Appendix S3

		Emissions to air	Carbon dioxide	Carbon dioxide (biotic)	Nitrous oxide	Sulphur hexafluoride	Group NMVOC to air	Methane	Methane (biotic)
WOODEN PLANK from PARK		g CO$_{2eq}$	g CO$_{2eq}$	g CO$_{2eq}$	g CO$_{2eq}$	g CO$_{2eq}$	g CO$_{2eq}$	g CO$_{2eq}$	g CO$_{2eq}$
Alkyd resin treatment	manufacturing	490.20	361.78	4.38	90.11	0.27	0.56	32.90	0.21
	aircraf	20.34	19.98	0.02	0.06	0.00	0.00	0.27	0.0008
	lorry >16t	1.49	1.41	0.00	0.01	0.00	0.01	0.05	0.0001
	van <3.5t	0.15	0.02	0.01	0.03	0.00	0.00	0.08	0.0006
Plank	power sawing	552.18	449.90	1.53	56.38	3.56	0.19	40.56	0.06
	Total	1064.37	833.10	5.95	146.59	3.83	0.77	73.85	0.27
WOODEN PLANK from JIRI									
Alkyd resin treatment	manufacturing	245.10	180.89	2.19	45.05	0.13	0.28	16.45	0.10
	aircraft	10.17	9.99	0.01	0.03	0.00	0.00	0.14	0.00
	lorry >16t	0.74	0.71	0.00	0.01	0.00	0.00	0.03	0.00
	van <3.5	0.07	0.01	0.01	0.01	0.00	0.00	0.04	0.00
Plank	power sawing	276.09	224.95	0.76	28.19	1.78	0.10	20.28	0.03
	helicopter	102.30	100.83	0.08	0.07	0.01	0.01	1.30	0.00
	lorry 3.5-16t	65.78	61.76	0.24	1.14	0.02	0.46	2.16	0.01
	Total	700.27	579.15	3.29	74.50	1.94	0.85	40.39	0.15
POLYSTYRENE									
	manufacturing	1527.67	1207.40	13.68	1.75	0.48	0.83	302.78	0.76
	aircraft	53.89	52.92	0.05	0.17	0.005	0.01	0.72	0.00
	lorry >16	4.35	4.13	0.01	0.04	0.001	0.02	0.15	0.0004
	van <3.5t	0.40	0.06	0.04	0.07	0.004	0.01	0.21	0.0015
	Total	1586.31	1264.51	13.78	2.02	0.48	0.88	303.86	0.77
GLASS WOOL									
	manufacturing	2521.70	2241.86	93.25	15.16	4.27	4.92	159.14	3.10
	lorry>16t	216.76	205.90	0.58	1.92	0.04	0.88	7.40	0.02
	van<3.5t	1.78	0.27	0.17	0.31	0.02	0.06	0.95	0.01
	aircraft	243.13	238.78	0.25	0.77	0.02	0.06	3.24	0.01
	Total	2983.37	2686.80	94.25	18.17	4.35	5.92	170.74	3.14
CEMENT_SM									
	manufacturing	566.39	510.59	43.40	0.86	0.15	0.17	11.09	0.12
	tractor and trailer	8.83	7.89	0.33	0.07	0.00	0.22	0.31	0.00
	aircraft	410.66	403.32	0.41	1.30	0.04	0.10	5.47	0.02
	lorry 3.5-16t	205.20	192.66	0.74	3.54	0.06	1.42	6.74	0.03
	van <3.5t	3.19	0.63	0.29	0.53	0.03	0.10	1.60	0.01
	Total	1194.26	1115.09	45.17	6.30	0.28	2.01	25.23	0.18
CEMENT_M									
	manufacturing	668.96	603.06	51.26	1.01	0.18	0.20	13.10	0.14
	tractor and trailer	10.40	9.30	0.39	0.08	0.00	0.26	0.37	0.00
	aircraft	485.03	476.36	0.49	1.54	0.04	0.12	6.47	0.02
	lorry 3.5-16t	242.36	227.56	0.87	4.18	0.07	1.68	7.97	0.03
	van <3.5t	3.77	0.75	0.34	0.63	0.03	0.12	1.90	0.01
	Total	1410.52	1317.02	53.35	7.44	0.33	2.38	29.80	0.21

Life cycle assessment of building in prospect of Himalayan region

Abstract

This chapter concerns a study on the environmental assessment of buildings in Sagarmatha National Park (SNP), Himalayan region of Nepal, where the high tourist flow encourages rapid development of modern buildings. The study calculates the life-cycle environmental impacts (CO_{2-eq} emissions) of several typical commercial buildings in SNP: traditional, semi-modern and modern. The study covers the cradle–to–gate life-cycle of the building. The functional unit defines as "construction and occupation" over 50 years of life span. The results show that traditional buildings using local materials are the most environmentally friendly, producing the least CO_{2-eq} emissions over their lifetime.

Keywords: Life cycle assessment, building sector, construction materials, carbon footprint, Nepal, Sagamartha National Park

5.1 Introduction

Sustainability has become a global concern these days to reduce the environmental impact from human activities. Building sector make a considerable contribution to worldwide substantial environmental impacts (Scheuer et al. 2003), since it shares 20-30% of the global carbon footprint (McKinsey and Company 2009). Building sector stocks the emission from the energy consumed during construction, operational phase until the demolition. It is important to quantify the environmental performance of

buildings in order to observed the potential environmental impacts and their influence on sustainable development (Passer et al. 2012).

To assess the sustainability of buildings it is significant to consider their entire life cycle and to evaluate the environmental impacts associated with the extraction, production, and transportation phases identifying and quantifying the energy and materials used and the waste released to the environment (Pittet 2010; Sonnemann 2003)

The application of global methodology such as Life Cycle Assessment (LCA) is adopted to assess the environmental impact of building over their life span. This tool could help in the decision-making when selecting the best technology and material availability and minimizing the environmental impact of the building (Gustavsson 2006; Zabalza et al. 2011; Passer et al. 2012).

In every country, the building sector is a major contributor emissions as well as a huge user of natural resources and energy (Asif et al. 2007; Fan and Zhang 2001). Environmental impacts on production processes of the building materials vary according to the regions and countries (Buchanan and Honey 1994; Pandit 2013). Due to the lower efficiency generally encountered in smaller size manufacturing plants, developing countries may produce larger environmental impacts per unit of material produced (Pittet et al. 2012; Cole 1999; Huberman 2008; Pearlmutter 2007). Furthermore, the input for material production and the transportation means and distances travelled are very different, with potential consequences on the overall environmental impacts (Pittet and Kotak 2010; Cole 1999; Huberman and Pearlmutter 2008; Pearlmutter 2007).

Information about the environmental impact of building materials is, on the contrary, very limited in developing countries, although they represent the most vulnerable areas on the world to the hazards associated with climate change (Pouliotte et al. 2009; Gentle and Maraseni 2012; Pandit 2013).

To better understand the environmental performance of buildings in developing countries, such as the Himalayan region, a specific study has been performed. This study was carried out in Sagarmatha National Park (SNP) of Nepal, renowned touristic

area, which attracts about 30,000 tourists each year (Census 2014). The government of Nepal is planning to implement the policy to attract more tourists in the near future and this fact will contribute to a fast growing in buildings construction, that could worsen the already critical situation in terms of environmental pollution (Salerno et al. 2010; Manfredi et al. 2010). Due to the high tourist flow and to the planned policy to attract more tourists, the lodge owners are modifying their traditional building made of local materials into concertized modern building. Building materials for the modern house are mostly transported from the capital city via aircraft due to the difficult road connection. On the other hand, majority of the building materials used for the traditional building, are found nearby the Park. In such situation, Life Cycle Assessment (LCA) could help in the decision-making when selecting the best technology and material availability and minimizing the environmental impact of the building (Petersen and Solberg 2005; Gustavsson and Sarthe 2006; Zabalza et al. 2011; Passer et al. 2012).

This study aims to better understanding of the LCA of existing building types in Sagarmatha National Park. There are mainly three types of building pattern available in such Himalayan region: traditional, semi-modern and modern. Traditional buildings, known as Sherpa Houses, which follow their ancestral wisdom in building them, mainly use timber, stone and mud. Semi-modern type of buildings which are the partial transformation of traditional into modern, with the limited or no insulation material besides wooden planks, dry stones and less amount of cement and mud as plaster. Modern buildings, built for touristic purposes, primarily use imported construction materials such as cement and glass wool and polystyrene sheets.

5.2 Materials and Methods

Life Cycle Assessment for building material provides the quantitative and comparative values of the environmental impacts of various building technologies (Singh et al. 2011). This LCA study follows the ISO 14040/44 methodology that addresses the environmental aspects and potential environmental impacts through a product's life cycle. The LCA modelling has been carried out in GaBi V 6.0 and the

CML 2001 – Apr. 2013 method has been used for the assessment of environmental impact.

5.2.1 Goal and scope definition

The goal of the study is to estimate the life-cycle environmental impacts of typical commercial building in Sagarmatha National Park: traditional, semi-modern and modern. The study examines the cradle–to–gate life cycle of the building that includes acquisition, manufacture, construction, operational, maintenance and replacement phase. The end-of-life of the building materials is not taken into account because the life expectancy of the building is difficult to predict in the region, as the age of existing buildings varies significantly. The end-of-life phase include the impact related to demolition of the building transportation of the waste to the treatment site and different treatment process.

The functional unit was considered as the *"construction and occupation"* referring to (Cuéllar-Franca and Azapagic 2012), over 50 years of life span. This supports on comparing the building in environmental and energy aspect in three different types of buildings in SNP.

The construction phase in this study refers to the impact associate with collection of raw materials by resource extraction; processing of the raw materials to building products; transportation of the products to the construction site; assembly of the products. The operation phase is related to the impact caused by energy consumption in different household activities such as cooking, space heating, water heating, lighting and other electrical appliance. Maintenance and replacement phase includes the impact associate with replaced building materials and maintenance during 50 years of life span. The life of the building materials has been anticipated by referring (ATD 2015).

5.2.2 The inventory analysis phase

The life cycle inventory analysis addresses the collection and summarization of data according to the standard on the building materials and energy use in this study. The data used in the model are both primary and secondary data. Eco-invent database has

been utilized for the emission factors as a secondary data in the study. The data have been collected through investigating the inventory reports, direct observations and measurement, and interviewing the concern people like contractors and local people

5.2.3 Impact Assessment and interpretation of results

This phase focuses on how the product affects the environment using both qualitative and quantitative approach to know how raw materials use, energy generation, and air emission effect on the environment. The global warming potential warming impact category (GWP) has been chosen to express and compare the impacts of different processes related to the different materials used in the buildings in SNP. GWP is generally regarded as a major indicator in LCA studies (Knauf 2015). The GWP is expressed in terms of carbon dioxide equivalents (CO_{2-eq}). The time frame for the assessment is 100 years, as recommended by Kyoto Protocol (1997) and Intergovernmental Panel on Climate Change (2013).

5.3 Result and Discussion

Global warming potential of three different building types during its life span is presented in Fig. 5. 1. The results show that the highest environmental impacts during building's life span takes place during the operational phase that accounts approximately 53% (88t CO_{2-eq}) of total life cycle impact, while construction phase was approximately 21% (35t CO_{2-eq}) and replacement phase accounted for approximately 25% (41t CO_{2eq}) in case of modern building. Furthermore, the semi-modern building accounts 65% (97t CO_{2-eq}) during the operational phase; construction phase represented 14% (21t CO_{2-eq}), and the replacement 20% (30t CO_{2-eq}). In case of traditional building, GWP shows the least emission as they are constructed mainly from local materials (stone, mud, wooden plank) and only few commercial materials (CGI sheets, enamel, plywood). However, the emission from operation phase is high with 57% (56t CO_{2-eq}) of total emissions, construction phase accounts 17% (17t CO_{2-eq}) and replacement with 26% (25t CO_{2-eq}).
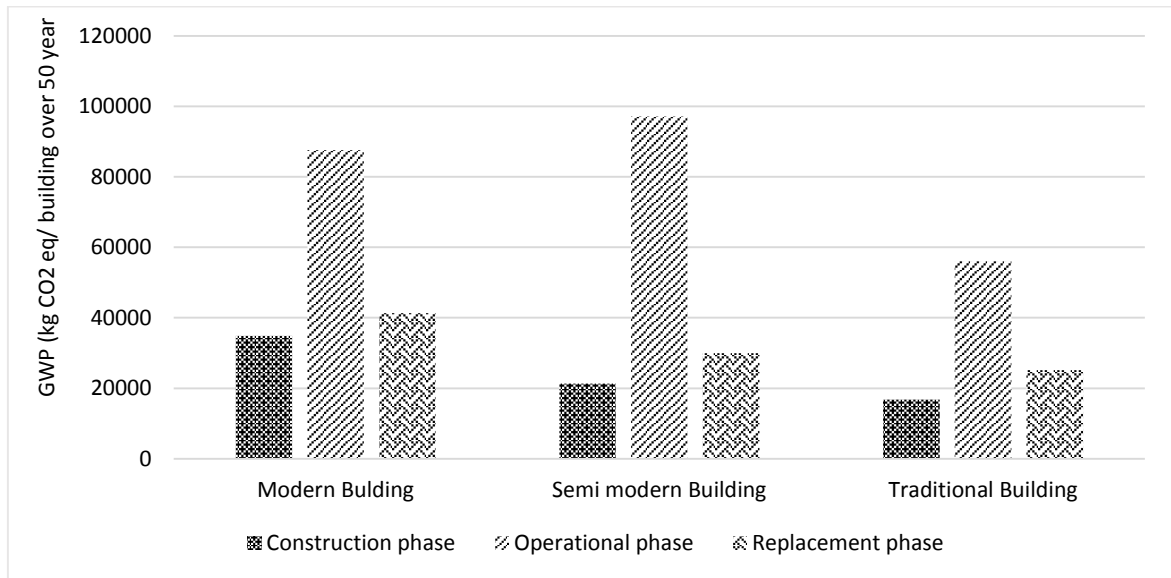
Fig. 5. 1: Comparison of global warming potential in different life-cycle phase of buildings

Emissions from different sectors in each phase of buildings were also analysed. The GWP from the plant, during the manufacturing of the materials for construction and replacement phase, is the highest among other medium that accounts approximately 85% of total GWP. Transportation of materials by lorry and aircraft accounts 14% of total GWP.

A breakdown of the total environment impacts from different materials from each building during the life span is presented in Fig. 5. 2. The result shows that among all material used, CGI sheets and plywood in construction and replacement phase are the main contributors in all types of buildings. CGI sheets account highest impact: 22t CO_{2-eq} for modern building, 7t CO_{2-eq} for semi-modern and traditional building. Plywood occupies the second position on the rank of environmental impact that accounts 8t CO_{2-eq} for modern building, 12t CO_{2-eq} for semi-modern and for traditional 8t CO_{2-eq}. So, if the concern is to reduce the environmental impacts of the buildings in Himalayan region like Sagarmatha National Park, then the attention should be focused on finding alternatives for roof and wall envelope.
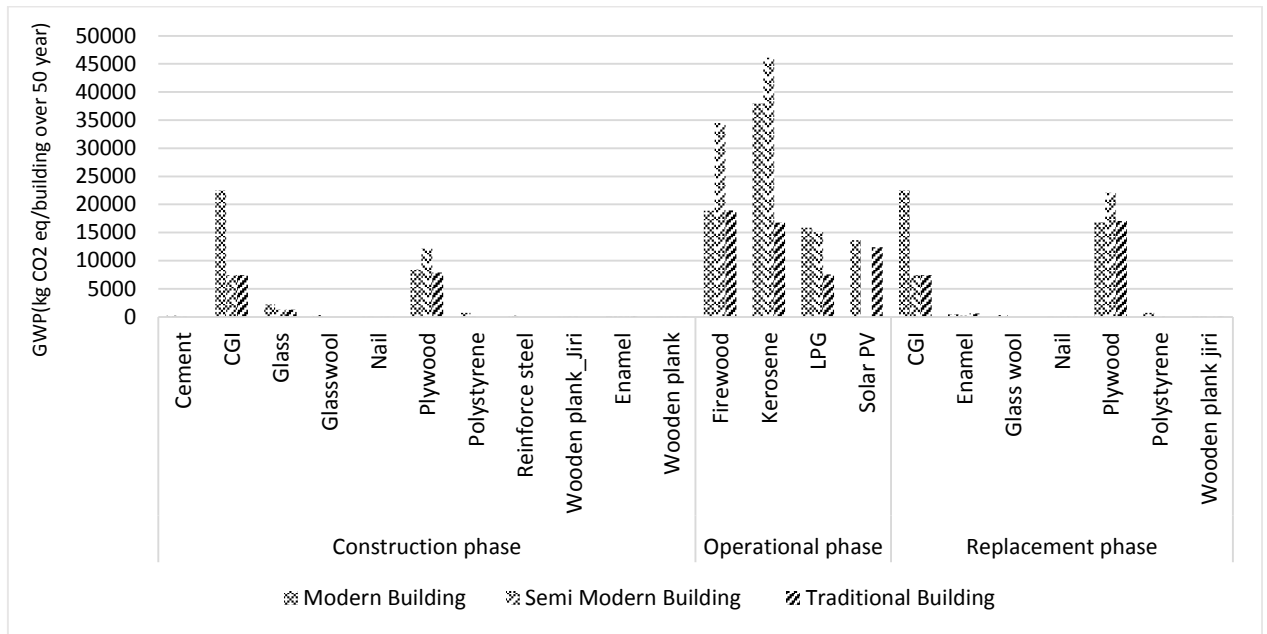
Fig. 5. 2: Global warming potential of different materials in different phase of building life cycle

As mentioned before, the operation phase is by far the highest contributor to the total GWP: the modern building generates 86t $CO_{2\text{-eq}}$ over, while semi modern produces 96t $CO_{2\text{-eq}}$ and the traditional building 56t $CO_{2\text{-eq}}$ over 50 years. The result shows that the kerosene and firewood are the main contributors in the operational phase, contributing to the total energy used respectively: 44% kerosene and 22% firewood in modern building, 48% kerosene and 36% firewood in semi-modern, 30% kerosene and 34% firewood in traditional building.

Likewise in the construction phase, CGI sheet and plywood are the major contributor of GWP also in replacement phase. During the period of 50 years, CGI sheet is replaced once and twice in case of plywood. CGI sheet accounts approximately 55 % and plywood 41% in modern building, 25% and 74% in semi-modern building, and 30% and 68% in traditional building. Therefore, the study shows that local material are more environmental sustainable among other commercial materials like CGI sheet and plywood.

Traditional buildings follow their ancestral Sherpa house, which has more social values that is made of local materials like stone, mud, and wooden plank. However, the modern building is constructed from commercial materials like cement, glass wool, polystyrene etc. To attract more tourists in their lodge, lodger owner has

modified their traditional into modern architecture design. Thus, modern buildings are more costly for its construction compare to traditional building.

The relative contribution of the main greenhouse gases to global warming in the three different buildings shows that the carbon dioxide is the main contributor (>90%) in all-building types. The contribution of nitrous oxide to global warming is 1% in all-building types. However, contribution of methane is 5% in modern building, 4% in semi-modern and 3% in traditional building. Non-methane volatile organic compounds (NMVOC) lesser extend to the total emission in the three type of building.

5.4 Conclusions

The total GWP over the lifetime of 50 years is 164t CO_{2-eq} for modern building, 148t CO_{2-eq} for semi modern building and 98t CO_{2-eq} for traditional building. For all the three types of building, operational phase accounts the highest environmental impacts during their life span, which are related to the energy use. The main improvement opportunities in the building sector perspective to Himalayan region lie in the reduction of impacts in the operational phase. Studies revealed that the energy saving and the emission reduction in household can be achieved by behavioral changes on energy use and by implementing product's innovations like energy efficient light, increasing efficiency of the stove (O'Neill 1999; Streimikiene and Ciegis 2010).

The study has outlined that the modern and semi-modern building types that used mostly commercial materials have impacts on global warming by 4 to 5 times higher than the traditional building which basically used locally available materials.

The study also reveals that CGI and plywood have higher CO_{2-eq} compare to other materials. So, for the reduction of environmental impacts of the buildings in Himalayas, then the attention should be focused on finding alternatives for roof and wall envelope. Locally available materials are more environmentally friendly, among that the use of wood associated to a sustainable forest management practices, should be encouraged

Building with local materials is more environmentally friendly than with other equivalent commercial materials because of impact associate with production of these

material and its transportation (Morel et al. 2001). In this perspective use of wood and wood products could be the best alternatives. The energy efficient building with the use of local materials is highly recommended for the sustainable building design in Himalayan region.

CHAPTER SIX

Study on potential reduction of GHG emission: In terms of household behavioral changes in the Himalayan region

Abstract

The rising human population both local and tourist in the Himalayan region increases the significant amount of energy consumption and its GHG emission is affecting local impact in the region. Thus, the energy conservation is important for environmental protection and sustainable energy consumption in these areas.

This chapter gives an overview of possible reduction of energy consumption in highly touristic Himalayan region: Sagarmatha National Park, through the behavioral change on the consumption, which ultimately reduce the GHG emission in household level for the sustainable consumption. Questionnaire survey on the energy consumption pattern for tourist season and off-tourist season were performed in different building types in this region. The GHG emission from each energy sources was calculated by its associated emission factor. Based on the literature review, analysis of GHG emission reduction from the households behavioral changes were performed. The study found that 6,094 tons of $CO_{2\text{-eq}}$ can be reduced from the household behavioral changes without compromising the comfort.

Keywords: Household energy conservation, Sustainable consumption, Energy saving, GHG emission, Emission reduction, Sagarmatha National Park and Buffer Zone

6.1 Introduction

Energy is the single most important resource capable of sustaining life on the earth. Energy not only influences the economic growth but also the cause of important life threatening outcomes (Mariam 2002). Statistics published by The International Energy Outlook 2014 (U.S. Energy Information Administration 2014) indicate that the global energy demand may rise by roughly 56 % over the next 25 years. Such ever-increasing demand could place significant damage to world environmental health by CO_2, CH_4, CO, SO_2, NO_x effluent gas emissions and increase global warming (Omer 2008). Intergovernmental Panel on Climate Change (IPCC, 2007) projects that CO_2 emission from energy use increases by 45 to 110 % if fossil fuels continue dominating energy production through 2030, with up to three-quarters of future emission increases coming from developing countries. Furthermore, IPCC (2007) assessment reports have clearly mentioned that the global climate is changing as a result of increasing anthropogenic activities. Man-made emissions accounted for an estimated 69 % of loss of ice from glaciers from 1991-2010 (Doyle 2014). IPCC (2007) warns that failure to act to reduce greenhouse gas emissions now will lead to costly risks to the society, the economy and the earth.

Global climate change mitigation depends greatly on reducing energy consumption, switching to low-carbon fuels and controlling emission of non-CO_2 Greenhouse Gases (GHG) (Karlsson and Moshfegh 2006; IPCC 2007). Managing energy is about providing savings, savings that can reduce greenhouse gas emissions and operational cost of energy systems (Ryan and Campbell 2012). Streimikiene and Volochovic (2011) stated that increase in energy efficiency and reducing fossil fuel consumption would result in better environment as well as financial saving. Studies (Abrahamse et al. 2005; Steg 2008; Streimikiene and Ciegis 2010) revealed that the energy saving and GHG emission reduction in household can be achieved by two following methods: by behavioral changes and by implementing product's innovations. Streimikiene (2015) cited that individual behavior has significant impact on environmental impacts and further mentioned that individual choice of product and lifestyle have direct and indirect impact on energy saving and GHG emission reduction (Abrahamse et al. 2007; Benders et al. 2006; Streimikiene 2015). IPCC

(2007b) has also specified that the change in lifestyle and behavior patterns can contribute to climate change mitigation. Vringer et al. (1995) found that by using energy efficient product and shifting consumption towards lower energy intensity, the energy requirement is reduced by 9 %. Other studies found that with large but tolerable change in lifestyle, 30 % of CO_2 in US household can be reduced (Timothy 2008; Girod and de Haan P 2009). Furthermore, shifting consumption toward lower GHG intensity is an important strategy for reducing the GHG emission of household (IPCC 2007a; Girod and de Haan P 2009). Switzerland reduces GHG emission by 5-17 tons of CO_{2-eq} per capita per year from heating, electricity use, car use and travel by aircraft (Streimikiene and Volochovic 2011). In Netherlands, the 27 % reduction of total annual GHG emission in country can be achieved by applying product and behavioral innovation (Joosen 2001). Another study (Gardner and Stern 2002) shows that household can saved 27 % of energy by curtailment behaviors. User's behavior on energy saving depends on the grade of information, motivation and responsibility (Steg 2008; Streimikiene and Ciegis 2010), while product innovations are related with increasing energy efficiency and renewable energy technologies (Streimikiene and Ciegis 2010). It is certain that behavioral change in terms of sustainable energy consumption is an important factor in reducing greenhouse gas emission and combating climate change (Gentle and Maraseni 2012; Gaigalis and Skema 2014; Markowitz and Doppelt 2009; Tsantopoulos et al. 2014).

Nepal is being a country vulnerable to the impacts on climate change due to its fragile mountain ecosystem, weak geological condition and diverse nature of climate (Mirjam 2010; Dixit 2010) and is more susceptible due to their limited capacity to cope with hazards associated with changes in climate (UNFCCC 2007). Rising populations, income levels, and energy use are leading to rapid greenhouse gas emission in developing countries (Chandler et al. 2002). Climate change mitigation in developing countries is not the goal, but rather an outgrowth of effort driven by economy, security and local environmental concern (Chandler et al. 2002). GHG emission reduction potential for the building in developing countries fall into three categories: efficient light, improved cooking stoves and efficient electric appliance (IPCC 2007a).

Household consumption greatly depends on the geographical region, climate, income, building appliances, energy type and, as indicated above, user's behavior (Benders et al. 2006; Aubin et al. 2003). In Nepal, energy consumption in the residential sector constitutes of 89 % in total energy consumption in 2008/09 Water and Energy Commission Secretariat (WECS 2010). It is estimated that only about 20% of rural areas of Nepal have reliable access to electricity. There are still 16.5 million rural Nepalese, about 62% of the country's total population of 26.6 million, that have never used electricity in their homes (Poudel 2013). Firewood is the major fuel used in this sector, supplied by 86 % of the total energy requirement of the sector, 12 % from the commercial source and only 1% by alternative energy resources (WECS 2010). About 52 % of the urban energy is used for cooking purpose followed by other household activities (WECS 2010). Firewood is the principle source of energy for cooking, spacing heating, water boiling, animal feeding, etc. (Rijal 1999). The rise in human population and the uncontrolled growth of tourism in the Himalayan region increase significant amount of energy consumption, which subsequently increases the GHG emission and also creates a greater pressure in forest, resulting in their heavy depletion (Nepal 2008; Salerno et al. 2010). This situation is particularly serious in the fragile Himalayan ecosystem, which could raise the threat of glacier-lake outburst floods (Nema et al. 2012) as well as facing large scale in forest decline (Prasad et al. 2001; Stevens 2003; Nepal 2008). Thus, energy conservation is significantly important not only for reducing emissions but also for forest conservation. Therefore, it is necessary to design strategies for energy-efficient buildings that reduce the energy load in building sector. In this context, the framework for GHG emission reduction was design for Sagarmatha National Park, the most famous tourist Himalayan region of Nepal. This study explores the different energy related activities and identifies key behaviors to reduce energy consumption and GHG emissions.

6.2 Methods

6.2.1   Data collection

The data on energy consumption were collected through the questionnaire survey, interviewing the local people from different households in the park. Based on altitudinal variation, main tourist route and availability of different household types,

nine pertinent sites were chosen. The selections of household in the park were done based on the uses of the household that are categorized into: commercial, residential and institutional. Commercial type of building mainly includes lodges and shops, whereas residential type of building includes resident houses used only for shelter and finally institutional building type includes schools, bank and police stations.

The questionnaire was surveyed by random structure sampling method and about 50% of sampling was done in each settlement. Field survey was carried out during tourist season in the months of March/April 2014. The data for off-tourist season were also collected during the survey. Ninety-one buildings located in the chosen nine different settlements of the park were surveyed. In each sampled building, primary data on (i) type of energy consumption, (ii) amount of energy consumption and (iii) time spent for specific activity were recorded. Secondary data on potential practices of GHG emission reduction in household were also obtained from related bibliography. The data obtained from different technique were processed into statistical software SPSS version 21.

6.2.2   Assessment of greenhouse gas emission reduction potential

Various review articles on GHG reduction potential from behavioral change were consulted. The approach followed by Streimikiene and Volochovic (2011) for assessing GHG emission reduction through behavioural change were studied and applied for this study. The main aim of our study in Sagarmatha National Park and Buffer Zone is similar to Streimikiene and Volochovic study in Lithuania (2011), which is to reduce CO_2 emission each year in household sector by behavioural change and at no cost. The method used in the study done in Lithuania was replicable in our study since the GHG reduction potential was evaluated in scenario basis in both warm and cold year period. While in our study, for the assessment of GHG emission reduction through behavioural changes in the park, both tourist season and off-tourist season were taken into account.

The assessment of greenhouse gases emission from the household energy consumption was calculated by using following equation (Jina et al. 2006):

$$EG_i = \sum_{k=1}^{n} AF_{ik} \times C_{ik} \ (k = 1,2,3 \ldots \ldots n) \qquad (1.1)$$

Where, EG_i is the amount of the ith GHG ($kgCO_{2\text{-}eq}$) from household energy consumption(kg); AF_{ik} is the amount of the kth fuel, which corresponds to the emission of the ith gas(kg); and C_{ik} is the emission factor for the ith gas of the kth type of fuel (kg/kWh). The emission factor used for GHG assessment are based on (Bhattacharya and Salam 2002).

The algorithm applied to assess the GHG emission reduction potential is given in (1.2) (Streimikiene and Volochovic 2011):

$$E_{1s} = G_{1s}D_sP \qquad (1.2)$$

Where, E_{1S} is GHG emissions in households during tourist season for the baseline scenario; G_{1S} is the daily GHG emissions per capita; D_S is the duration of energy consumption and P is the population size.

GHG emission reduction scenario was evaluated by (Streimikiene and Volochovic 2011):

$$E_{2s} = G_{2s}D_sP \qquad (1.3)$$

Where, E_{2S} is the GHG emissions in households during tourist season for baseline reduction scenario; G_{2S} is the daily GHG emissions per capita in reduction scenario; D_S is the duration of energy consumption and P is the population size.

The GHG emission reduction scenario in household during tourist season is given by (Streimikiene and Volochovic 2011):

$$M_s = E_{1s} - E_{2s} \qquad (1.4)$$

Where, M_S is the GHG emissions during tourist season in the park. For the off-season period, the total GHG emission reduction scenario M_o in household is given by (Streimikiene and Volochovic 2011):

$$M_o = E_{1o} - E_{2o} \qquad (1.5)$$

Where E_{1o} is the GHG emissions in households during the off-tourist season for baseline scenario and E_{2o} is the GHG emissions in households during the off-tourist season for baseline reduction scenario

The total GHG emission G in households throughout the year is given by (1.6) (Streimikiene and Volochovic 2011):

$$G = M_s + M_o \qquad\qquad (1.6)$$

Where, G is the total potential annual GHG emissions reduction in household by energy saving through behavioural changes; M_S is the GHG emissions during tourist season in the park and M_o is the total GHG emission reduction scenario in household.

6.2.3   Potential practices for energy saving and GHG reductions in SNPBZ

Due to the high tourist influx, energy consumption has been increased in SNPBZ producing high amount of Green House Gas (GHG) emission. Thus, it is necessary to conserve the household energy by improving energy efficiency and reducing energy demand that are considered most promising, fastest, cheapest and safest means to mitigate climate change (Sorrell 2015). The most relevant practices for energy saving in SNPBZ are listed in Table 6. 1.

Table 6. 1: The most relevant practices saving options in SNPBZ

Saving Options	Fuel type Saved	Average saving (kWh/HH/day)	Description	References
Reducing fuel for space heating	Firewood	152	Firewood consumption for space heating is higher than needed to keep the room in comfortable temperature (20ºC)	(Bhochhibhoya S 2008)
Using energy efficient light bulb	Electricity	$R = 5.62 \pm 3.47$ $C = 17.91 \pm 16.53$ $I = 7.16 \pm 3.5$	Using efficient LED bulb of 3.5W for rooms and 8.5 for major places like kitchen, dinning	*
Lowering lighting time	Electricity	$R = 4.29 \pm 2.45$ $C = 12.42 \pm 10.86$ $I = 5.61 \pm 3.35$	Lowering the lighting time from 5hrs to 3 hrs	*
Using Pressure Cooker	Firewood; R and C LPG; I	$R = 10.24$ $C = 92.23$ $I = 4.5$	Using pressure cooker for cooking rice, beans, *dal*, potatoes	(Petroleum Conservation Research Association 2014)
Keeping lid on cooking vessels	LPG	4.2	Keeping lid on cooking vessels	(Petroleum Conservation Research Association 2014)
Solar Cooker	Firewood	1153	9 kg of firewood can be save per day by using solar cooker for boiling water, cooking rice, dal, potatoes	(Ligtenberg A 2007)
Increasing the efficiency of stoves (from 16 to 35)%	Firewood	333		(Bhattacharya et al. 1999) (CRTN (Centre for Rural Technology Nepal) 2005)
Reducing watching TV		$R = 4.13 \pm .88$ $C = 3.99 \pm .933$ $I = 4.8 \pm 1.03$	Reducing hour for watching TV from average 5 to 3 hrs	*

*R= Residential, C= Commercial, I= Institutional   * Information collected from Field Survey*

Keeping lid on cooking vessels, switching off the light when not needed, using pressure cooker are some very simple easy behavioural changes which brings huge difference in energy consumption and its emission.

Furthermore, maintenance of cooking and heating stove and use of briquette or wood chips may also reduce the consumption of energy in the park.

6.3 Results

6.3.1 Energy consumption pattern in Sagarmatha National Park

The monthly record of energy consumption during tourist season in different household activities is given in Table 6. 2. The study shows that the highest amount of energy is consumed by the commercial sector (9,102 kWh) in comparison to the residential (4,556 kWh) and institutional sector (571 kWh) per household. The high flow of tourist in lodges increases the energy consumption in commercial sector. Due to high heterogeneity of data on energy consumption, the mean value and standard deviation of the data comes closer.

Table 6. 2: Energy consumption per household (HH) per month during tourist seasons in different building types

Building Type	Description	Firewood (kWh/HH/ month)	Electricity (kWh/HH/ month)	Kerosene (kWh/HH/ month)	LPG (kWh/HH /month)	Dung (kWh/HH/ month)	Solar PV (kWh/HH/ month)	Total (kWh/HH/ month)
Residential	Cooking	1,354 ± 925	59 ± 25	-	93 ± 61	487 ± 408	-	1,993
	Space heating	1,025 ± 388	105 ± 17	-	-	1,158 ± 681	-	2,288
	Heating Water	118 ± 23	25 ± 7	-	-	-	-	143
	Lighting	-	11 ± 7	10 ± 0	-	-	7 ±5	28
	Entertainment		5 ± 2					5
	Total	2,497	205	10	93	1,645	7	4,457
Commercial	Cooking	1,876 ± 1,094	121 ± 54	1,375 ± 1,189	600 ± 548	291 ± 0		4,263
	Space heating	2,960 ± 1,118	333 ± 166	-	-	1,284 ± 1219	-	4,577
	Heating Water	156 ± 26	45 ± 0	-	-	-	-	201
	Lighting	-	36 ± 30	10 ± 0	-	-	10 ±2	56
	Entertainment		5 ± 4					5
	Total	4,992	540	1,385	600	1,575	10	9,102
Institute	Cooking	-	199 ± 121	-	216 ± 163	-	-	415
	Space heating	-	100 ± 17	-	-	-	-	100
	Heating Water	-	34 ± 13	-	-	-	-	34
	Lighting	-	15 ± 8	-	-	-	-	15
	Entertainment	-	7 ± 2	-	-	-	-	7
	Total	-	355	-	216	-	-	571

Values shown are mean ± Standard deviation

Higher amount of energy is used for cooking (1,993 kWh) and space heating (2,288 kWh) per household in residential building. Whereas in commercial building 4,263 kWh of energy is used for cooking and 4,577 kWh in space heating per household. While, in institutional sector, 415 kWh of energy is consumed for cooking especially for making tea and 100 kWh is used for space heating.

Firewood from the forests still remains the main source of energy mainly in residential (2,497 kWh) and commercial building (4,992 kWh) per household. Kerosene and LPG are another major energy source for cooking purposes in all building types. Animal dung has also been used for space heating and cooking in residential and commercial buildings. Electricity from micro-hydropower subsidises the certain amount of fuel consumption, which has been mainly used for cooking, heating, boiling water, entertainment and for lighting purpose in the park. It was estimated that 50 % of sampled household used firewood for cooking, space heating and water boiling. Similarly, 45% of respondent lodges used kerosene for cooking purposes, 70 % of respondent lodges used LPG and 94 % of lodges used electricity.

Relative to the tourist season, energy consumption is less in off-season (Table 6. 3). However, the firewood consumption remains the same for cooking and space heating. During this season, only some workers in the lodge remained in the park. Most of the local Sherpa people returned to Kathmandu to escape from the harsh weather during this period.

Table 6. 3: Energy consumption per household (HH) per month during off-seasons in different building type

Building Types	Description	Firewood (kWh/HH/month)	Electricity (kWh/HH/month)	Kerosene (kWh/HH/month)	LPG (kWh/HH/month)	Dung (kWh/HH/month)	Solar (kWh/HH/month)	Total (kWh/HH/month)
Residential	Cooking	1,375 ± 938	-	-	98 ± 61	4 ± 2	-	1477
	Space heating	577± 325	105 ± 17	-	-	-	-	682
	Heating Water	-	18 ± 4	-	-	-	-	18
	Lighting	-	8 ± 5	10 ± 0	-	-	7 ±5	25
	Entertainment	-	7 ± 2	-	-	-	-	7
	Total	1,952	138	10	98	4	7	2,209
Commercial	Cooking	431 ±405	-	205 ± 239	34 ±28	6 ± 1	-	676
	Space heating	2,776 ± 1293	93 ± 17	-	-	-	-	2869
	Heating Water	180 ± 175	45 ± 0	-	-	-	-	225
	Lighting	-	9 ± 8	10 ± 0	-	-	10 ±2	29
	Entertainment	-	8 ± 3	-	-	-	-	8
	Total	3,387	155	215	34	6	10	3,807
Institute	Cooking	-	199 ± 121	-	216 ± 163	-	-	415
	Space heating	-	100 ± 17	-	-	-	-	100
	Heating Water	-	34 ± 13	-	-	-	-	34
	Lighting	-	15 ± 8	-	-	-	-	15
	Entertainment	-	9 ± 3	-	-	-	-	9
	Total	-	357	-	216	-	-	573

Values shown are mean ± Standard deviation

Similar to the tourist-season, the highest amount of energy is consumed by the commercial sector (3,807 kWh per household) in comparison to the residential (2,107 kWh per household) and institutional sector (573 kWh per household).

Due to the harsh winter, significant amount of firewood is used for space heating (2,869 kWh) compare to cooking (676 kWh) in the off-tourist season.

5.1.1   Greenhouse gases emission reduction potential in SNPBZ

Table 6. 4 gives an overview of energy consumption and its associate emissions, and scenario for energy saving and GHG reduction. Based on the information provided on Table 6. 2 and Table 6. 3 regarding energy consumption for season and off-season, the coefficient of GHGs emission were calculated by Eq. (1.6) and its associate emission factor. The application of the possible potential practices for energy saving given in Table 6. 1 provides the reduction scenario of energy consumption and emission shown in Table 6. 4.

Table 6. 4 gives the clear overview of total energy consumption in different household activities in both tourist and off-tourist season. Further, shows the total reduced amount of energy consumption by the given behaviour changes in Table 6.4. The total amount of GHG emission is calculated based on total energy consumption and the emission factor.

The result shows that 39 % of GHG emission can be reduced by given behaviour changes in residential and institutional, whereas 29% in commercial building. Due to high-energy consumption, percentage reduction may be slightly lesser than rest of other buildings.

The reduction of the energy by cooking is higher compare to other activities, mostly due to the increase in stove efficiency from 16 to 35%.

Table 6. 4: Energy consumption and GHGs emission scenario (S= season, O=Off-season)

Building type	Description	Reduction Possibilities	Fuel Type	Total consumption (kWh/HH/month)		Amount Reduced (kWh/HH/month)		$CO_{2\text{-}eq}$ emission (kg/HH/month)		Reduced $CO_{2\text{-}eq}$ (kg/HH/month)	
				S	O	S	O	S	O	S	O
Residential	Cooking	Using Pressure Cooker Increasing the efficiency of stoves	Firewood	1,354	1,375	607	628	522	530	234	242
		Solar Cooker	Dung	487	6	487	4	189	2	-	2
		Lid on cooking vessels	LPG	93	98	89	93	52	55	50	53
			Electricity	59							
	Space heating	Reducing fuel	Firewood	1,025	577	1,608	425	395	223	308	164
			Dung	1,158		1,108		449		371	
			Electricity	105	105						
	Boiling Water	Solar Cooker	Firewood	118		118		45		45	
			Electricity	25	18		18				
	Entertainment	Reducing watching TV	Electricity	5	7	1	3				
	Lighting	Using efficient bulb Lowering lighting time	Electricity	11	8	6	4				
			Kerosene	10	10	10	10	4	4	4	4
			Solar	7	7						
								1,657	813	1,012	465
Commercial	Cooking	Using Pressure Cooker Increasing the efficiency of stoves	Firewood	1,876	431	1,047	160	723	166	404	108
		Solar Cooker	Dung	291	6	291	6	113	2	113	2
		Lid on cooking vessels	LPG	600	34	596	23	339	15	336	13
			Kerosene	1,375	205			531	79		
			Electricity	121							
	Space heating	Reducing fuel	Firewood	2,960	206	2,808	54	1,171	79	1,082	21
			Dung	1,284		1,132		498		439	
			Electricity	333	93						
	Boiling Water	Solar Cooker	Firewood	156		156		60		60	
			Electricity	45	45						
	Entertainment	Reducing watching TV	Electricity	5	8	1	3				
	Lighting	Using efficient bulb Lowering lighting time	Electricity	36	9	18 24	4				
			Kerosene	10	10			4	4	4	4
			Solar	10							
								3,438	346	2,435	148
Institutional	Cooking	Using Pressure Cooker Lid on cooking vessels Solar Cooker	LPG	216		216	132	132	122	122	75	75
			Electricity	199							
	Space heating	Reducing fuel	Electricity	100	100						
	Boiling Water	Solar Cooker	Electricity	34	34						
	Entertainment	Reducing watching TV	Electricity	7	9	5					
	Lighting	Using efficient bulb Lowering lighting time	Electricity	15	15	7 6					
								122	122	75	75

The total GHG emission during tourist season and off-season in three different building types given in Table 6. 5 were calculated according to Eq.(1. 2) and Eq. (1. 3).

Table 6. 5: Assessment of total GHG emission and its reduced amount

Building Type	Tourist Season GHG emission ($kgCO_{2\text{-}eq}$ /HH/month)	Duration (month)	Total number of household	Total GHG emission ($kgCO_{2\text{-}eq}$)	Off-season GHG emission ($kgCO_{2eq}$ /HH/month)	Duration (month)	Total number of household	Total GHG emission (kg CO_{2eq})
Residential	1,657	7	644	7,469,756	813	5	644	2,617,860
Commercial	3,438	7	256	6,160,896	346	5	256	442,880
Institutional	122	7	17	14,518	122	5	17	10,370
Total				13,645,170				3,071,110
Reduced amount								
Residential	1,012	7	644	4,562,096	464	5	644	1,494,080
Commercial	2,434	7	256	4,361,728	148	5	256	189,440
Institutional	75	7	17	8,925	75	5	17	6,375
Total				8,932,749				1,689,895

The total GHG emission in the Park during the tourist-season is 13,646,062 kg (13,646 t) of $CO_{2\text{-}eq}$, and the reduced amount of total GHG emission is 8,934,087 kg (8934 t) of $CO_{2\text{-}eq}$. By using Eq. (1.4) the total GHG emission reduction in the Park during tourist season is evaluated.

$$M_s = (13,645,170 - 8,932,749)kgCO_{2\text{-}eq}$$
$$= 4,712,421 \text{ kgCO}_{2eq} = 4712 \text{ tCO}_{2\text{-}eq}$$

Similarly, for off-tourist season, the GHG emission reduction is evaluated according to Eq. (1.5). The total GHG emission in the Park during the off-season is 3,071,841 kg (3,072 t) of $CO_{2\text{-}eq}$ and the reduced GHG emission is 8,934,087 kg (8934 t) of $CO_{2\text{-}eq}$.

$$M_o = (3,071,110 - 1,689,895) \text{ kgCO}_{2\text{-}eq}$$
$$= 1,381,215 \text{ kgCO}_{2\text{-}eq} = 1,381 \text{ tCO}_{2\text{-}eq}$$

The total possible GHG emission reduction in different household from the given behaviour change and energy saving is evaluated according to Eq. (1.6):

$$G = (4,712,421 + 1,381,215) \text{ kgCO}_{2\text{-}eq}$$

$$= 6,093,636 \text{ kgCO}_{2\text{-eq}} = 6,094 \text{ tCO}_{2\text{-eq}}$$

The total amount of GHGs emission that can be reduced by simple behaviour changes mentioned in Table 6. 1 on the household activities in the park is 6,094 tons of $CO_{2\text{-eq}}$ per year.

6.4 Discussion

The study has examined that the GHGs reduction potential from behaviour change in household level to reduce the energy consumption that ultimately reduces the GHG emission. The present study shows that the annual GHG emission in household level in the Park is 16,718 $tCO_{2\text{-eq}}$. From simple behavioural changes in household activities in the Park, the approximate amount of 6,094 t of GHGs emission can be reduced annually. Some of the relevant measures taken in account are increasing the efficiency of the stoves, using pressure cooker, keeping a lid while cooking, using solar cooker, reducing watching television, and using efficient bulb for lighting. The study was performed both for tourist season and off-tourist season. This study can also be applied to other regions of Nepal, moreover, can supplement some options related to transportation, use of technologies like washing machine, and use of computer etc. that have an access to road and some more household technologies.

The per capita reduction of GHG emission by given behaviour changes accounts 0.169 tons $CO_{2\text{-eq}}$ annually in the Park. Comparably, the study done in Lithuania (Streimikiene and Volochovic 2011) indicates 1.855 $tCO_{2\text{-eq}}$ per capita GHG emission reduces from household behaviour changes annually during warm and cold season. While in Switzerland (Streimikiene and Volochovic 2011), the estimated potential of GHG emission is 5-17 $tCO_{2\text{-eq}}$ per capita per year. Depending on the geographical region and mechanism or techniques of behaviour changes, the rate of GHG reduction differs, however, it is demonstrated that large amount of emission can be reduced through behaviour changes.

There are more other options for the behaviour changes, which can have a significant reduction of GHG emissions. However, the option should be simple, easier, quicker and more convenient that may help to reduce the cognitive overload that could facilitate more effective decision making regards to energy consumption (Frederiks et

al. 2015; Osbaldiston and Schott 2012; Steg and Vlek 2009). The study found that giving limited choice to the people may be more desirable and may even perform better (Frederiks et al. 2015). Campaigns and education programs regarding behavioural strategies should focus with simple communicating messages that all the people can quickly and easily understand (Iyengar et al. 2000). The results of this study can help to design the target based policies related to behaviour changes in household level to perceive sustainable energy efficient building that need to be developed and implemented to reduce the local level GHG emission. The study also found that the reduction of impact can also be done with the sustainable ecotourism in the Park (Salerno et al. 2010).

The targets of sustainable energy consumption can be related to reduction of energy intensity, increase in energy efficiency (Jan 2012), use of renewable energy (Gautam, Baral, and Herat 2009; Nepal 2012; Surendra et al. 2011), that have direct impact on GHG emission reduction (Huang and Lo 2011). Table 6.1 gives an overview that solar cooker save more energy compare to other options. Timilsina et al. (2000) also indicated that solar power should be highly encouraged in national policy level since it can reduce national GHG emission and other hand it contributes to national GDP growth. Use of 'real-time monitor' or 'energy cost indicator' might help to reduce the energy in household level (Allen et al. 2006). The attention should also be given in the energy performance of the building, which is still poor in terms of building envelope, installed heating system and electrical appliance such as type of lighting and refrigerator used. Therefore, emphasis should be given to energy efficient building and renewable energy sources that can embed sustainable energy development strategy of the region. The effective policies needs to deployed to achieve the sustainable energy efficient building in the country, while contributing improve level of comfort and lower energy bills for citizens (Gaigalis and Skema 2014).

6.5 Conclusions

Climate change is becoming one of the major threats in the Himalayan region like Sagarmatha National Park and Buffer Zone. Ice melting and increasing rate of glacier lake formation are among the most directly visible signals of the global warming due

to increased greenhouse gases emission. Increasing energy uses with increasing tourists in SNPBZ have contributed more greenhouse gases emission such as carbon dioxide (CO_2) and methane (CH_4).

Initiation of climate change mitigation in local level should be started from individuals. Simple change in life style without compromising the comfort, the huge amount of energy can be saved which ultimately have positive impact on climate change. Many environmental problems are related to human behavior which consequently may be reduced through behavior changes (Abrahamse et al. 2005).

The study estimates that the GHGs emission can be reduced by 6,094 $tCO_{2\text{-eq}}$ per year by some simple measures like keeping lid while cooking, using pressure cooker, turning off the light, reducing watching television and energy saving activities like increasing/using the efficient stove and bulb, using solar cooker. It is indicated that the reduction of GHGs can be easily done without any compromises in daily household activities. Information sharing and awareness program to the local people has to be done in this sector for effective results on GHG reduction. The results of this study will help to design the target based policies related to behaviour changes in household level to perceive sustainable energy building that need to be developed and implemented to reduce the local level GHG emission.

Study on potential reduction of GHG emission: In terms of bio-insulation in the Himalayan region

6.6 Introduction

Energy conservation can be done by reducing the amount of energy loss. Buildings in the high altitude regions can be built using this principal. Using insulation tiles in the walls can reduce the amount of heat loss from the room. The cold weather in the high altitude regions demands high amount of energy for room heating. If the buildings were poorly insulated, a great deal of heat will escape aggravating already poor supply of energy. In order to reduce the amount of energy wastage, there is a need to insulate the buildings properly. Furthermore, Zabalza et al. (2009) said that for the promotion of sustainable buildings with low energy consumption and high building efficiency, in addition to promote the use of renewable energy and equipment with high energy efficiency, priority must be given to bio-construction and bio-climatic eco-design, the use of low impact, natural, recyclable material available in the local area.

The insulation tile made up of locally available material like white soil *(Kamero),* cow dung and waste product like paper, plastic, wooden grains were tested in two different methods; Thermo-Box method and Lee's method. Their thermal conductivity and transmittance were measured and a comparison was done. This chapter mainly deals the efficiency of insulation tiles as well as the method used.

6.7 Method and Materials

6.7.1 Determination of thermal conductivity of insulation tile by thermo-box method

The research was conducted in Centre for Excellence in Production and Transportation of Electrical Energy, Research Unit, Kathmandu University under the supervision of Prof. Dr. Ramesh Kumar Maskey.

The insulation Tile made up of locally available materials like *Kamero* (white soil), cow dung and waste product like plastic, paper, wooden grain, rice husk may be the

effective thermal insulation. Thus, to test the thermal transmittance (U- value) of insulation tiles, the preparation of the tile are describe below.

I.   *Collection:* Collection of locally available raw materials.

II. *Preparation:* Mixing of the raw material (Fig. 6. 1) usually in one part fresh dung, two parts insulating material (viz; plastic, paper, wood pieces instead of commercial insulation products) and four parts *kamero*. However, the composition can be varied according to the desired property of the insulating material.

III. *Manufacture:* Production of tiles using commercially available machines were used. The produced tiles are of dimensions (9" X 9" X 2") which can be increased for quicker production.

IV. *Finishing:* Laying of surface finish for additional strength and look and drying of the tiles for compaction shown in .Fig. 6. 1

Fig. 6. 1: Preparation of material

Fig. 6. 2: Insulation tile

Fig. 6. 3: Testing of the insulation tile in hot box.

6.7.2 Determination of the coefficient of thermal conductivity by Lee's method

This research was conducted in Department of Natural Science, Kathmandu University Nepal.

6.7.2.1 Procedure:

Steam is passed from the inlet of the cylindrical until steady state is reached. The steady state temperature $\Theta1$ and $\Theta2$ at T1 and T2 respectively are noted. Then the cylindrical vessel and the metallic disc is brought into direct contact until the disc's temperature is about 10°C above the steady temperature indicated at T2. It is then allowed to cool and temperature is noted in an interval of 30seconds till its temperature falls to about 10°C below $\Theta2$. A graph is plotted between temperature and time.

If M is the mass of the metallic disc, s the specific heat of its material, then rate of cooling at $\theta2$ is equal to $Ms\frac{d\theta}{dt}$. Where: $\frac{d\theta}{dt}$ is the rate of fall of temperature at $\theta2$.

Therefore,

$$K\frac{\pi r2(\theta1 - \theta2)}{d} = Ms\frac{d\theta}{dt}$$

Or,
$$K = \frac{Msd}{\pi r2\ (\theta1 - \theta2)}\frac{d\theta}{dt}$$

Where,
K=coefficient of thermal conductivity
M=Mass of the metallic body (gm)
s=Specific heat of the metal (cal/gm°C)
d=Thickness of the disc (cm)
r=Radius of the disc (cm)
D=Diameter of the disc (cm)
$\Theta1$=Temperature in thermometer T1
$\Theta2$=Temperature in thermometer T2
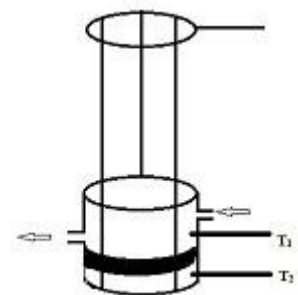
Fig. 6. 4: Setup of sampling tile in Lee's method

6.7.2.2 Testing of insulation tiles

The insulation tile then tested in the Thermo-Box designed and developed at Centre for Excellence in Production and Transportation of Electrical Energy, Kathmandu University (CEPTE/KU), Nepal. The top view of the box is shown in Fig. 6. 5. The Thermo-Box was designed in such way that cooling system is automatically controlled in outer box to maintain the prescribed lower temperature. On the other hand an automatically controlled 400W heater was placed inside the Thermo Box.
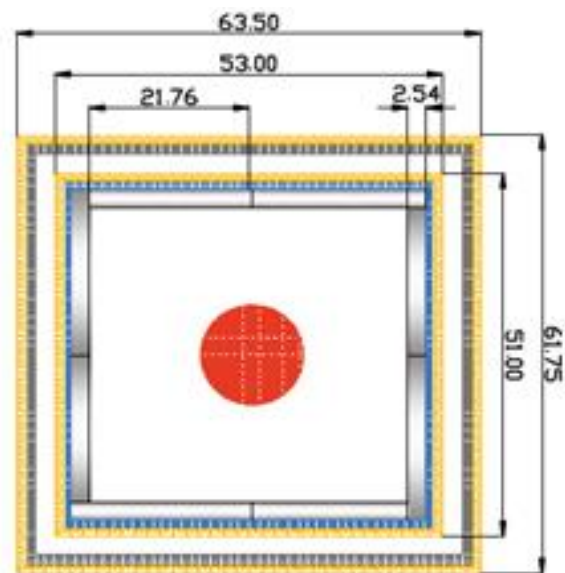
Fig. 6. 5: Top view of thermo box

All dimensions are in cm

The insulation tiles were then sandwiched between inner and outer boxes. Styrofoam with the known thermal conductivity was tested for the reference values.

The controlled temperatures inside and outside boxes with correspond to ambient temperature were noted. Thermal conductivity of the insulation tile was calculated with the temperature difference between inner and outer temperatures of the boxes. The working formula for calculating thermal conductivity (K) is given by:

$$K = \frac{Q \times L}{A \times \Delta T}$$

Where,

Q = amount of heat flowing through surface in unit time (Watt)

 L = thickness of the tile (m)

A = area of the tile (m^2)

ΔT= temperature gradient (Kelvin)

Further, Thermal Resistance of the insulating tile was calculated with known value of thermal conductivity and thickness of tile.

$$R = \frac{L}{K} \text{ (m}^2\text{K/W)}$$

Thermal Transmittance (U- value) is the reciprocal of R-Value which can be calculated as:

$$U = \frac{1}{R} \text{ (W/m}^2\text{K)}$$

6.7.2.3   *Measuring heat demand of existing building*

Heat demands of existing buildings in SNP were measured. The sampling households were categorized based on Traditional, Semi-modern and Modern type. Proportions of sampling houses were selected based on the total number of available different types of households. Twenty percent of buildings were sampled in each settlement.

To calculate the heat demand, measurement of room dimensions (height, length, and breadth), wall thickness, number of doors and windows, used insulation material type,

inside and outside of the room temperatures were measured and documented. For keeping inside room in comfortable condition 20°C was considered.

6.8 Results

6.8.1 Thermal Efficiency of Insulation Tiles

Insulation tiles made up of different local materials like white soil (*kamero*), cow dung, rice husks, wooden grains and waste products like paper and plastics were tested in Thermo-Box. Table 6. 6 shows the thermal conductivity of these tiles.

Table 6. 6: Thermal Conductivity of Tiles

Types of insulating material	Thickness (m)	Thermal Conductivity by Box Method (W/mK)	Thermal Conductivity by Lee's Method (W/mK)
Empty box	0.025	1.023	
Styrofoam	0.032	0.078	0.091
Option 1(Kamero, Wooden grain, cow dung)	0.025	0.092	0.165
Option 7 (Kamero, Wooden grain, plastic thread, cow dung)	0.032	0.075	0.208
Option 2(Kamero, Rice husk, cow dung)	0.025	0.094	0.151
Option 10 (Kamero, Tile powder, cow dung)	0.025	0.096	0.140
Option 13 (Kamero, paper pulp, cow dung)	0.032	0.075	0.236
Option 11 (Kamero, paper pulp, cow dung, baking powder)	0.025	0.089	0.255

The thermal conductivity of option 13 tile made up of *Kamero*, paper pulp and cow dung with thickness 0.032 meter was found to be 0.07 W/mK which is better than other tiles. The second ranks accounts Option 7 with Kamero, wooden grain, plastic thread and cow dung with the thermal conductivity 0.075 W/mK in 0.032 m. For the reference commercial Styrofoam was tested which has a thermal conductivity of 1.023 W/mK.

6.8.2 Retaining temperature

The average temperature in the hot box with the insulation tiles increases drastically within few minutes and the tempearute loss in a slow rate. The temperature remains

in the confortable zone i.e around 20^0C for longer period of time as shown in Fig. 6. 6.
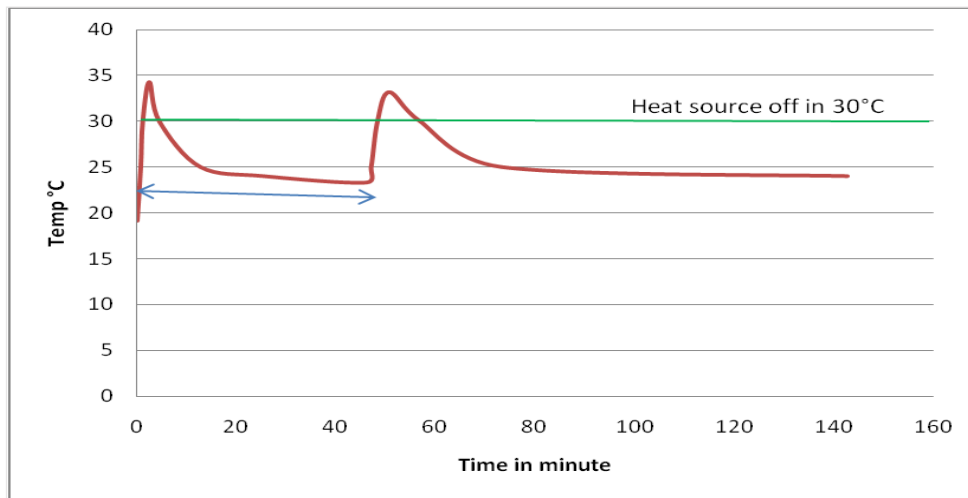
Fig. 6. 6: Retained temperature

The graph indicates that half hour of heat source remains for four hours in comfortable temperature. Thus, less amount of heat energy is enough to keep the room warm for the longer period of time.

6.8.3   Comparison of Insulation Materials

The comparison of the insulation tiles was done with commercial insulation materials like glass-wool, polystyrene, wooden planks etc in terms of thermal efficiency and cost shown in Fig. 6. 7. The graph shows that the insulation tiles prepared from locally available materials, reused waste products could be both economically as well as environmentally sound.
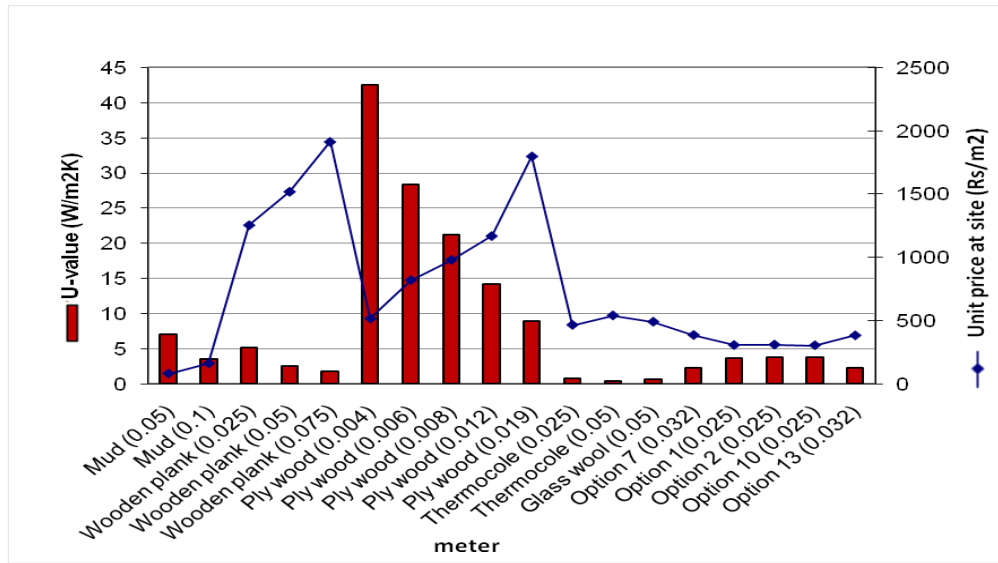
Fig. 6. 7: Comparison of U-value and price of different insulation materials

The best option for better insulation in building in high altitude could also be done using energy model prepared to stimulate the management scenarios.

6.8.4 Potential for reducing greenhouse gas

The existing energy demand and supply along with the energy demand after using proper insulation like wooden plank, mud plastering and polystyrene shows that the CO_{2-eq} emission can be reduced by 19%, while reducing present energy consumption. It also indicates potentiality for reducing CO_{2-eq} by 38% while maintaining the energy supply to the demand limit after use of proper insulation.

6.9 Conclusions

Locally available materials and waste product could be used as building insulation for energy efficient technology. Energy efficient building could be one of the significant technologies to reduce the greenhouse gas emission at local level.

CHAPTER SEVEN

Conclusions

This chapter summarized overall achievement of this thesis and provides directions for further research based on findings of the study. The primary aim of this research is performed to study the environmental sustainable building assessment with the integration of environmental and economic impact of the Himalayan buildings has been achieved.

LCA and LCC were performed to assess the environmental and economic impacts of three existing building types in the Himalayas. The life-cycle stages under analysis include raw material acquisition, manufacturing, construction, operation, and maintenance and materials replacement. The functional unit was considered as the "*Stay of one guest for one night*" and the time horizon is 50 years of building lifespan. The result indicates that modern building accounts the highest GWP and the cost over the period of 50 years as commercial materials are mostly used which accounts the highest environmental impact and high material cost. The obtained results show that operational stage is responsible for high environmental impacts and high operational cost, which are related to energy use for different household activities. The main improvement opportunities in the building sector perspective to Himalayan region lie in the reduction of impacts in the operational stage. Furthermore, a breakdown of the building components shows that the roof and wall of the building are the largest contributors to the production- related environmental impact. The findings suggest that the main improvement opportunities in the building sector lie in the reduction of impacts in the operational stages and in the choice of materials for wall and roof.

The comprehensive picture of life cycle prospective over the entire hotel sector in the Park has also been performed. This study also indicates that operational stage is responsible for high environmental (97% of total GWP) and economic impacts (by 90%) that are associated with energy consumption in different household activities. The construction stage contributes only 1% of total GWP and 2% by maintenance and replacement stage in all building types. On the contrary to the previous study, this research estimates that the traditional building accounts the highest GWP and the cost over the period of 50 years of building life span. This may be due to the hosting less number of guests that share more impacts. The other reason could be use of more firewood and cattle dung for cooking and space heating. Stove in SNPBZ is found to have efficiency of just 16 % (Sulpya, 1991), that results in 84% % heat waste. The main improvement opportunities in the Himalayan buildings lie in the reduction of impacts in the operational stages. This can be achievable by using more efficient stove, heating stove, light bulb and use of renewable energy.

The study on life cycle assessment of building materials used in Himalayan buildings were further performed to evaluate the contribution of each material to the overall impact of 1 m^2 of wall building systems. This study provides comparative life cycle assessment of different wall materials used in existing buildings in SNPBZ. The study has outlined that the wall of semi-modern and modern building that use commercial materials, like cement, polystyrene and glass wool, and that are progressively replacing the traditional building type, which on the contrary uses locally available materials, have impacts on global warming from 4 to 5 times higher. Although the production of GWP is high in modern building, the wall of the building is thermally efficient compared to semi-modern and traditional buildings. Even if the environmental impact of modern building construction is higher, the higher thermal efficiency helps to reduce the energy consumption for space heating and consequently reduce the GWP during modern building utilization. It has been recognized that if local materials, as wood, are used in building construction, the emissions from production processes and transportation could be dramatically reduced.

The study also critically examined the potential practices to reduce the GHG emission from the building section in the region. The investigation was performed the potential

of greenhouse gas emission reduction in terms of household behavioural changes as well as examine the bio-insulation made of local materials in the region. The study estimates that the GHGs emission can be reduced by 6,094 tCO_{2-eq} per year by some simple measures like keeping lid while cooking, using pressure cooker, turning off the light, reducing watching television and energy saving activities like increasing/using the efficient stove and bulb, using solar cooker. Information sharing and awareness program to the local people has to be done in this sector for effective results on GHG reduction. The results of this study will help to design the target based policies related to behaviour changes in household level to perceive sustainable energy building that need to be developed and implemented to reduce the local level GHG emission.

For the promotion of sustainable buildings with low energy consumption and high building efficiency, in addition to promote the use of renewable energy and equipment with high energy efficiency, priority must be given to bio-construction and bio-climatic eco-design, the use of low impact, natural, recyclable material available in the local area (Zabalza Bribián et al. 2009). The study found that locally available material such as white soil (*Kamero)*, cattle dung, wooden grain and waste product like paper pulp, plastic thread, could be efficient building insulation in the region. However, the detail study on bio-insulation is necessary to extend for the real field implications that are simple, replicable, easily available and cost-effectiveness, environmental compatible.

The research in the sustainable building assessment with the integration of environmental and economic impact of the Himalayan buildings was the prime objective and the findings in this research can be further extended and modified to accomplish the ultimate goal of promoting and improving sustainable practices in construction and operation of the building. The research, whilst completed at this stage, has opened up opportunities for further research in many other areas of the country.

References

Abrahamse, Wokje, Linda Steg, Charles Vlek, and Talib Rothengatter. 2005. "A Review of Intervention Studies Aimed at Household Energy Conservation." *Journal of Environmental Psychology* 25 (3): 273–91. doi:10.1016/j.jenvp.2005.08.002.

Abrahamse, Wokje, Linda Steg, Charles Vlek, and Talib Rothengatter. 2007. "The Effect of Tailored Information, Goal Setting, and Tailored Feedback on Household Energy Use, Energy-Related Behaviors, and Behavioral Antecedents." *Journal of Environmental Psychology* 27 (4): 265–76. doi:10.1016/j.jenvp.2007.08.002.

Adhikari, Ramesh. 1987. "Estimation of Economic Discount Rate for Practical Project Appraisal: The Case of Nepal." *Project Appraisal* 2 (2): 113–22. doi:10.1080/02688867.1987.9726610.

Allen, Daisy, Kathryn Janda, and Oberlin College. 2006. "The Effects of Household Characteristics and Energy Use Consciousness on the Effectiveness of Real-Time Energy Use Feedback : A Pilot Study Continuous Feedback : The Next Step In Residential Energy Conservation ?" *Buildings*, 1–12. http://www.eci.ox.ac.uk/publications/downloads/janda06aceee.pdf.

Asdrubali, Francesco, Catia Baldassarri, and Vasilis Fthenakis. 2013. "Life Cycle Analysis in the Construction Sector: Guiding the Optimization of Conventional Italian Buildings." *Energy and Buildings* 64 (September): 73–89. doi:10.1016/j.enbuild.2013.04.018.

Asiedu, Y, and P Gu. 1998. "Product Life Cycle Cost Analysis : State of the Art Review," 883–908.

Asif, M., T. Muneer, and R. Kelley. 2007. "Life Cycle Assessment: A Case Study of a Dwelling Home in Scotland." *Building and Environment* 42 (3): 1391–94. doi:10.1016/j.buildenv.2005.11.023.

ATD. 2015. "AVERAGE LIFE SPAN OF HOMES, APPLIANCES, AND MECHANICALS." http://www.atdhomeinspection.com/advice/average-product-life/.

ATD Home Inspection. 2015. "Average Life Span of Homes, Applicances, and Mechanicals." http://www.atdhomeinspection.com/advice/average-product-life.

Aubin, Pierre, Genevieve Auger, and Claude Perreault. 2003. "Climate Change and Greenhouse Gas Awareness Study." Canada: Ottawa. http://www.c-ciarn.uoguelph.ca/documents/clima_e.pdf.

Aye, Lu, Nick Bamford, Bill Charters, and Jon Robinson. 2000. "Environmentally Sustainable Development: A Life-Cycle Costing Approach for a Commercial Office Building in Melbourne, Australia." *Construction Management and Economics*. doi:10.1080/014461900446885.

Benders, René M.J., Rixt Kok, Henri C. Moll, Gerwin Wiersma, and Klaas Jan Noorman. 2006. "New Approaches for Household Energy conservation—In Search of Personal Household Energy Budgets and Energy Reduction Options." *Energy Policy* 34 (18): 3612–22. doi:10.1016/j.enpol.2005.08.005.

Bhattacharya, S.C., R.A. Attalage, M. Augustus Leon, G.Q. Amur, P.A. Salam, and C. Thanawat. 1999. "Potential of Biomass Fuel Conservation in Selected Asian Countries." *Energy Conversion and Management* 40 (11): 1141–62. doi:10.1016/S0196-8904(99)00002-3.

Bhattacharya SC and Salam AP. 2002. "Low Greenhouse Gas Biomass Options for Cooking in the Developing Countries." *Biomass and Bioenergy* 22: 305–17.

Bhochhibhoya S. 2008. "Impact of Household Energy-Use on Climate Change in Sagarmatha National Park." Kathmandu University.

Braganca Luis, Mateus Ricardo. 2012. *Life Cycle Analysis of Buildings. Environmental Impact of Building Elements*. 1st ed. Portugal: iiSBE Portugal.

Brown, Kristin Lee, Daniel Clayton Greer, and Ben Schwegler. 2011. "Life Cycle M Anagement Approach to the Design of Large-Scale R Esorts." *Towards Life Cycle Sustainability Management*. doi:10.1007/978-94-007-1899-9_22.

Buchanan A, Honey B. 1994. "Energy and Carbon Dioxide Implications of Building Construction." *Energy and Building* 20: 205–17.

Census. 2014. "Monthly Tourist Record at Jorsalle, SNPBZ."

Chandler, William, Roberto Schaeffer, Zhou Dadi, Sukla PR, Fernando Tudela, Ogunlade Davidson, and Sema Alpan-Atamer. 2002. "Climate Change Mitigation in Developing Countries." *Photovoltaics Bulletin*. doi:10.1016/S1473-8325(02)01227-0.

Chen, G.Q., H. Chen, Z.M. Chen, Bo Zhang, L. Shao, S. Guo, S.Y. Zhou, and M.M. Jiang. 2011. "Low-Carbon Building Assessment and Multi-Scale Input–output Analysis." *Communications in Nonlinear Science and Numerical Simulation* 16 (1): 583–95. doi:10.1016/j.cnsns.2010.02.026.

Cole RJ. 1999. "Energy and Greenhouse Gas Emissions Associated with the Construction of Alternative Structural Systems." *Building and Environment* 34: 335–48.

Consoli F, Allen D, Boustead I, Fava J, Franklin, W, Jensen A, De Oude, N, Parrish R, Perrimann R, Postlethwaite D, Quay B, Seguin J, Vigon B. 1993. "Guidelines for Life-Cycle Assessment: A 'Code of Practice.'"

CRTN (Centre for Rural Technology Nepal). 2005. "National Energy Situation Survey Report, Nepal-Focus on Renewable Energy and Poverty Reduction." Kathmandu, Nepal.

Cuéllar-Franca, Rosa M., and Adisa Azapagic. 2012. "Environmental Impacts of the UK Residential Sector: Life Cycle Assessment of Houses." *Building and Environment* 54: 86–99. doi:10.1016/j.buildenv.2012.02.005.

Davis Langdon Management Consulting. 2006a. "Literature Review of Life Cycle Costing (LCC) and Life Cycle Assessment (LCA)." *Draft Literature Review for LCC Methodology Project*.

Davis Langdon Management Consulting 2006b. "Literature Review of Life Cycle Costing (LCC) and Life Cycle Assessment (LCA)." *Management*.

Dixit, Ajaya. 2010. "Climate Change in Nepal: Impacts and Adaptive Strategies." http://www.wri.org/our-work/project/world-resources-report/climate-change-nepal-impacts-and-adaptive-strategies.

Doyle A. 2014. "Man-Made Warming Becomes Main Cause of Glacier Retreat, Study Says." *Reuters*. New York, USA. http://uk.reuters.com/article/2014/08/14/us-climatechange-glaciers-idUKKBN0GE1XL20140814.

Environmental Stewardship Committee. 2002. "Guidelines for Life Cycle Cost Analysis."

Erlandsson, Martin, and Mathias Borg. 2003. "Generic LCA-Methodology Applicable for Buildings, Constructions and Operation Services - Today Practice and Development Needs." *Building and Environment*. doi:10.1016/S0360-1323(03)00031-3.

European Commision - Joint Research Centre - Institute for Environment and Sustainability. 2010. *ILCD Handbook: International Reference Life Cycle Data System*. Edited by 24708 EN. Luxembourg. First. Publication Office of the European Union. doi:10.2788/38479.

Fabrycky, Wolter J, and Benjamin S Blanchard. 2000. "8.13 Life-Cycle Costing 5."

Fahy, John. 2002. "A Resource-Based Analysis of Sustainable Competitive Advantage in a Global Environment." *International Business Review* 11 (1): 57–77. doi:10.1016/S0969-5931(01)00047-6.

Fan, Cheng-Wei, and Junfeng (Jim) Zhang. 2001. "Characterization of Emissions from Portable Household Combustion Devices: Particle Size Distributions, Emission Rates and Factors, and Potential Exposures." *Atmospheric Environment* 35 (7): 1281–90. doi:10.1016/S1352-2310(00)00399-X.

Fava JA. 2006. "Will the Next 10 Years Be as Productive in Advancing Lifecycle Approaches as the Last 15 Years." *The International Journal of Lifecycle Assessment* 11: 6–8.

Ferreira, J., M. Duarte Pinheiro, and J. de Brito. 2015. "Economic and Environmental Savings of Structural Buildings Refurbishment with Demolition and Reconstruction-A Portuguese Benchmarking." *Journal of Building Engineering* 3 (July): 114–26. doi:10.1016/j.jobe.2015.07.001.

Filimonau V, Dickinsc J, Robbins D, Mark AJ. 2011. "Reviewing the Carbon Footprint Analysis of Hotels: Life Cycle Energy Analysis (LCEA) as a Holistic Method for Carbon Impact Appraisal of Tourist Accommodation." *Journal of Cleaner Production* 19: 1917–30.

Frederiks, Elisha R., Karen Stenner, and Elizabeth V. Hobman. 2015. "Household Energy Use: Applying Behavioural Economics to Understand Consumer Decision-Making and Behaviour." *Renewable and Sustainable Energy Reviews* 41 (January): 1385–94. doi:10.1016/j.rser.2014.09.026.

Frischknecht, Rolf, Niels Jungbluth Editors, Hans-jörg Althaus, Gabor Doka, Roberto Dones, Thomas Heck, Stefanie Hellweg, et al. 2007. "Overview and Methodology Ecoinvent Report No. 1," no. 1: 77. http://www.ecoinvent.org/fileadmin/documents/en/01_OverviewAndMethodology.pdf.

Frischknecht, Rolf, Niels Jungbluth, Hans-Jörg Althaus, Gabor Doka, Roberto Dones, Thomas Heck, Stefanie Hellweg, et al. 2004. "The Ecoinvent Database: Overview and Methodological Framework (7 Pp)." *The International Journal of Life Cycle Assessment* 10 (1): 3–9. doi:10.1065/lca2004.10.181.1.

Gaigalis, Vygandas, and Romualdas Skema. 2014. "Analysis of Fuel and Energy Transition in Lithuanian Households Sector and Its Sustainable Development in Compliance with the EU Policy." *Renewable and Sustainable Energy Reviews* 37 (September): 273–87. doi:10.1016/j.rser.2014.05.031.

Gardner, Gerald T., and Paul C Stern. 2002. *Environmental Problems and Human Behaviour*. 2nd . Pearson Custom Publishing.

Gautam, Rajeeb, Sumit Baral, and Sunil Herat. 2009. "Biogas as a Sustainable Energy Source in Nepal: Present Status and Future Challenges." *Renewable*

and Sustainable Energy Reviews 13 (1): 248–52.
doi:10.1016/j.rser.2007.07.006.

Gentle, Popular, and Tek Narayan Maraseni. 2012. "Climate Change, Poverty and Livelihoods: Adaptation Practices by Rural Mountain Communities in Nepal." *Environmental Science & Policy* 21 (August). Elsevier Ltd: 24–34. doi:10.1016/j.envsci.2012.03.007.

Girod B, and de Haan P. 2009. "Mental Rebound Rebound Research Report." Zürich, IED-Institute for Environmental Decisions. http://e-collection.library.ethz.ch/eserv/eth:2118/eth-2118-01.pdf?pid=eth:2118&dsID=eth-2118-01.pdf.

Gluch, Pernilla, and Henrikke Baumann. 2003. "The Life Cycle Costing (LCC) Approach : A Conceptual Discussion of Its Usefulness for Environmental Decision-Making." *Building and Environment* 39: 571–80. doi:10.1016/j.buildenv.2003.10.008.

Gu, Lijing, Borong Lin, Yingxin Zhu, Daojin Gu, Mingxing Huang, and Jiazi Gai. 2008. "Integrated Assessment Method for Building Life Cycle Environmental and Economic Performance." *Building Simulation* 1: 169–77. doi:10.1007/s12273-008-8414-3.

Gustavsson L, Sathre R. 2006. "Variability in Energy and Carbon Dioxide Balances of Wood and Concrete Building Materials." *Building and Environmental* 41: 940–51.

Hair J.F., Anderson R.E., Tatham R.L., and Black W.C. 2009. *Multivariate Data Analysis, Upper Saddle River*. 7th ed. Upper Saddle River: Prentice Hall.

Henn CL. 1993. "The New Economics of Life Cycle Thinking." *IEEE*.

Huang, Hui-Fen, and Shang-Lien Lo. 2011. "Review and Classify the GHGs-Related Indicators." *Renewable and Sustainable Energy Reviews* 15 (1): 594–602. doi:10.1016/j.rser.2010.07.023.

Huberman N, Pearlmutter D. 2008. "A Life-Cycle Energy Analysis of Building Materials in the Negev Desert." *Energy and Building* 40: 837–48.

Intergovernmental Panel on Climate Change. 2013. "Climate Change 2013: The Physical Science Basis." *Intergovernmental Panel on Climate Change*. doi:10.1038/446727a.

IPCC. 2007a. "Climate Change 2007: Working Group III: Mitigation of Climate Change." http://www.ipcc.ch/publications_and_data/ar4/wg3/en/tssts-ts-6-2-mitigation-technologies.html.

IPCC 2007b. "Finding of the IPCC Fourth Assessment Report: Climate Change Mitigation. IPCC Highlights Series." http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/IPCC-WGIII-UCS-summary-72dpi.pdf.

Iyengar, Sheena S, Mark R Lepper, and S Iyengar. 2000. "When Choice Is Demotivating: Can One Desire Too Much of a Good Thing?" *Journal of Personality and Social Psychology* 79 (6): 995–1006. doi:10.1037//0022-3514.79.6.995.

Jan, Inayatullah. 2012. "What Makes People Adopt Improved Cookstoves? Empirical Evidence from Rural Northwest Pakistan." *Renewable and Sustainable Energy Reviews* 16 (5). Elsevier Ltd: 3200–3205. doi:10.1016/j.rser.2012.02.038.

Jina, Yinlong, Xiao Mab, Y Xining Chenb, Ibin Chenga, Enis Barisc, and Majid Ezzatid. 2006. "Exposure to Indoor Air Pollution from Household Energy Use in Rural China: The Interactions of Technology, Behavior, and Knowledge in Health Risk Management." *Social Science and Medicine* 62: 3161–76.

Joosen S, Blok K. 2001. "Economic Evaluation of Carbon Dioxide Emission Reduction in the Household and Service Sectors in the EU, Bottom-up Analysis." Utrecht.

Karlsson JF and Moshfegh B. 2006. "Energy Demand and Indoor Climate in a Low Energy Building-Changed Control Strategies and Boundary Conditions." *Energy and Building* 38 (4): 315–26.

Khasreen, Mohamad Monkiz, Phillip F. G. Banfill, and Gillian F. Menzies. 2009. "Life-Cycle Assessment and the Environmental Impact of Buildings: A Review." *Sustainability* 1 (3): 674–701. doi:10.3390/su1030674.

Kirk SJ, and Dell'Isola AJ. 1995. *Life Cycle Costing for Design Professionals*. New York: Mc Graw-Hill.

Knauf Marcus. 2015. "Applying Opportunity Costs to Correctly Interpret Resource Efficiency in LCA Studies and Environmental Product Declarations." *European Journal of Wood and Wood Products* 73: 251–57.

Korpi, Eric. 2008. *Life Cycle Costing : A Review of Published Case Studies. Managerial Auditing Journal*. Vol. 23. doi:http://dx.doi.org/10.1108/02686900810857703.

Ligtenberg A. 2007. "Integrated Strategies to Solar Cooking/ Water Pasteurization, That Include Other Sustainable Technologies That Advance MDG's Nepal." In *International Wrerce Conference "Renewable Energy For Our Future."*

Jakarta, Indonesia.

Little, M. a., and J. M. Hanna. 1977. "Cold Responses of High Altitude Populations." *International Journal of Biometeorology* 21 (2): 123–34. doi:10.1007/BF01553706.

Little M.A, and Hanna J.M. 1978. *Responses of High-Altitude Populations to Cold and Other Stresses*. Edited by The Biology of High-Altitude Peoples Paul T. Baker. 1st ed. Cambrigdge: The syndics of Cambridge University Press . https://books.google.de/books?id=hdI9AAAAIAAJ&printsec=frontcover#v=onepage&q&f=false.

Manfredi, E C, B Flury, G Viviano, S Thakuri, S N Khanal, P K Jha, R K Maskey, et al. 2010. "Solid Waste and Water Quality Management Models for Sagarmatha National Park and Buffer Zone, Nepal Implementation of a Participatory Modeling Framework." *Mountain Research and Development* 30 (2): 127–42. doi:10.1659/mrd-journal-d-10-00028.1.

Mariam, Yohannes. 2002. "The Implication of Incorporating Environmental Costs in Utility Rate Setting." *Munich Personal RePEC Archive*. https://mpra.ub.uni-muenchen.de/id/eprint/412.

Mark, Goedkoop, Oele Michiel, Leijting Jorrit, Ponsioen Tommie, and Meijer Ellen. 2013. "Introduction to LCA with SimaPro Colophon," no. November.

Markowitz, Ezra M, and Bob Doppelt. 2009. "Reducing Greenhouse Gas Emissions Through Behavioral Change." *Climate Leadership Initiative, Institute for a Sustainable Environment*.

McKinsey and Company. 2009. "Pathways to a Low-Carbon Economy. Version 2 of the Global Greenhouse Gas Abatement Cost Curve."

Mearig, Tim, Nathan Coffee, and Michael Morgan. 1999. "Life Cycle Cost Analysis Handbook."

Mirjam Macchi, ICIMOD. 2010. "Mountains of the World – Ecosystem Services in a Time of Global and Climate Change." Kathmandu. http://www.alpconv.org/en/ClimatePortal/multimedialibrary/Documents/icimod-mountains_of_the_world_-_ecosystem_services_in_a_time_of_global_and_climate_change.pdf.

Morel, J.C, a Mesbah, M Oggero, and P Walker. 2001. "Building Houses with Local Materials: Means to Drastically Reduce the Environmental Impact of Construction." *Building and Environment* 36 (10): 1119–26. doi:10.1016/S0360-1323(00)00054-8.

Morel JC, Mesbah A, Oggero M, Walker P. 2001. "Building Houses with Local Materials: Means to Drastically Reduce the Environmental Impact of Construction." *Building and Environment* 36: 1119–26.

Moschetti, Roberta, Livio Mazzarella, and Natasa Nord. 2015a. "An Overall Methodology to Define Reference Values for Building Sustainability Parameters." *Energy and Buildings* 88 (February): 413–27. doi:10.1016/j.enbuild.2014.11.071.

Moschetti, Roberta, Livio Mazzarella, and Natasa Nord. 2015b. "An Overall Methodology to Define Reference Values for Building Sustainability Parameters." *Energy and Buildings* 88 (February). Elsevier Ltd: 413–27. doi:10.1016/j.enbuild.2014.11.071.

Nema, Pragya, Sameer Nema, and Priyanka Roy. 2012. "An Overview of Global Climate Changing in Current Scenario and Mitigation Action." *Renewable and Sustainable Energy Reviews* 16 (4). Elsevier Ltd: 2329–36. doi:10.1016/j.rser.2012.01.044.

Nepal Oil Corporation Limited. 2015. "Retail Selling Price Based on Kathmandu."

Nepal, Rabindra. 2012. "Roles and Potentials of Renewable Energy in Less-Developed Economies: The Case of Nepal." *Renewable and Sustainable Energy Reviews* 16 (4). Elsevier Ltd: 2200–2206. doi:10.1016/j.rser.2012.01.047.

Nepal S. 2008. "Tourism- Induced Rural Energy Consumption in the Annapurna Region of Nepal." *Tourism Management* 29: 89–100.

O'Neill J, Spash CL. 1999. "Conceptions of Value in Environmental Decision-Making. ." *Environmental Values* . Cambridge, UK. http://www.clivespash.org/eve/prb4-edu.pdf.

Omer, Abdeen Mustafa. 2008. "Energy, Environment and Sustainable Development." *Renewable and Sustainable Energy Reviews* 12 (9): 2265–2300. doi:10.1016/j.rser.2007.05.001.

Ortiz O, Castells F, Sonnemann G. 2009. "Sustainability in the Construction Industry: A Review of Recent Developments Based on LCA." *Construction and Building Materials* 23 (1): 28–39.

Ortiz, Oscar, Francesc Castells, and Guido Sonnemann. 2008. "Sustainability in the Construction Industry: A Review of Recent Developments Based on LCA." *Construction and Building Materials* 23: 28–39. doi:10.1016/j.conbuildmat.2007.11.012.

Ortiz, Oscar, Francesc Castells, and Guido Sonnemann. 2009. "Sustainability in the Construction Industry: A Review of Recent Developments Based on LCA." *Construction and Building Materials* 23 (1): 28–39. doi:10.1016/j.conbuildmat.2007.11.012.

Osbaldiston, R., and J. P. Schott. 2012. "Environmental Sustainability and Behavioral Science: Meta-Analysis of Proenvironmental Behavior Experiments." *Environment and Behavior*. doi:10.1177/0013916511402673.

Ozolins, Peter Charles, Humberto L Rodriguez-camilloni, Lawrence S Grossman, James R Jones, Josiah S Tlou, and Peter Charles Ozolins. 2010. "Assessing Sustainability in Developing Country Contexts : The Applicability of Green Building Rating Systems to Building Design and Construction in Madagascar and Tanzania," no. April.

Pandit MK. 2013. "The Himalayas Must Be Protected." *International Weekely Journal of Science* 501: 283.

Passer A, Kreiner H, Maydl P. 2012. "Assessment of the Environmental Performance of Buildings: A Critical Evaluation of the Influence of Technical Building Equipment on Residential Buildings." *International Journal of LCA* 17: 1116–30. http://download.springer.com/static/pdf/159/art%253A10.1007%252Fs11367-012-0435-6.pdf?auth66=1421751518_19cc647973feb0e154e509e1914df74f&ext=.pdf.

Passer, Alexander, Helmuth Kreiner, and Peter Maydl. 2012. "Assessment of the Environmental Performance of Buildings: A Critical Evaluation of the Influence of Technical Building Equipment on Residential Buildings." *The International Journal of Life Cycle Assessment* 17 (9): 1116–30. doi:10.1007/s11367-012-0435-6.

Pearlmutter D. 2007. "Alternative Materials for Desert Buildings: A Comparative Life Cycle Energy Analysis." *Build Research and Information* 32 (2): 144–55.

Petroleum Conservation Research Association. 2014. "Make Gas & Kerosene Last Longer." *Petroleum Conservation Research Association*. http://www.pcra.org/english/domestic/lastLong.htm.

Pittet, Daniel, K.S. Jagadish, Tejas Kotak, Kiran Vaghela, Pratik Zaveri, Sareshwala Humaira, and Gohel Jayesh. 2012. *Environmental Impact of Building Technologies: A Comparative Study in Kutch District, Gujarat State, India. Techonologies and Innovations for Development*. 1st ed. Springer Paris. doi:10.1007/978-2-8178-0268-8_9.

Pokharel M.R., and Parajuli B.K. 2000. *Retrofitting Tradtional Buildigns by Passive Solar Concepts in Jumla and Solukhubu*. Edited by Asha K. Thaku Greta Mary Rana, Dharma R. Maharjan. 1st ed. Kathmandu: International Centre for Integrated Mountain Development. http://lib.icimod.org/record/23584/files/c_attachment_245_2100.pdf.

Poudel, Ram C. 2013. "Quantitative Decision Parameters of Rural Electrification Planning: A Review Based on a Pilot Project in Rural Nepal." *Renewable and Sustainable Energy Reviews* 25. Elsevier: 291–300. doi:10.1016/j.rser.2013.04.032.

Pouliotte, Jennifer, Barry Smit, and Lisa Westerhoff. 2009. "Adaptation and Development: Livelihoods and Climate Change in Subarnabad, Bangladesh." *Climate and Development* 1 (1): 31–46. doi:10.3763/cdev.2009.0001.

Prasad, Rakesh, Sameer Maithel, and Asim Mirza. 2001. "Renewable Energy Technologies for Fuelwood Conservation in the Indian Himalayan Region." *Sustainable Development* 9 (2): 103–8. doi:10.1002/sd.160.

Proietti, Stefania, Paolo Sdringola, Umberto Desideri, Francesco Zepparelli, Francesco Masciarelli, and Francesco Castellani. 2013. "Life Cycle Assessment of a Passive House in a Seismic Temperate Zone." *Energy and Buildings* 64 (September): 463–72. doi:10.1016/j.enbuild.2013.05.013.

Rathcliffe J, and Stubbs M. 2005. *Urban Planning and Real Estate Development*. 2nd ed. The Natural and Built Environment Series,Taylor and Francis.

Raymond J Cole, Eva Sterner. 2000. "Reconciling Theory and Practice of Life-Cycle Costing." *Building Research and Information* 28: 368–75. http://pure.ltu.se/portal/files/154780/LTU-DT-0209-SE.pdf#page=150.

Rijal, K. 1999. "Energy Use in Mountain Areas, Trends and Patterns in China, India, Nepal and Pakistan." Kathmandu, Nepal.

Ristimäki, Miro, Antti Säynäjoki, Jukka Heinonen, and Seppo Junnila. 2013. "Combining Life Cycle Costing and Life Cycle Assessment for an Analysis of a New Residential District Energy System Design." *Energy* 63 (December): 168–79. doi:10.1016/j.energy.2013.10.030.

Ryan, Lisa, and Nina Campbell. 2012. "Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements." *International Energy Agency*. https://www.iea.org/publications/insights/insightpublications/Spreading_the_Net.pdf.

Salerno, Franco, Emanuele Cuccillato, Paolo Caroli, Birendra Bajracharya, E C Manfredi, Gaetano Viviano, Sudeep Thakuri, et al. 2010. "Experience With a

Hard and Soft Participatory Modeling Framework for Social-Ecological System Management in Mount Everest (Nepal) and K2 (Pakistan) Protected Areas." *Mountain Research and Development*. doi:10.1659/MRD-JOURNAL-D-10-00014.1.

Salerno, Franco, Gaetano Viviano, Sudeep Thakuri, Bastian Flury, Ramesh Kumar Maskey, Sanjay Nath Khanal, Dinesh Bhuju, et al. 2010. "Energy, Forest, and Indoor Air Pollution Models for Sagarmatha National Park and Buffer Zone, Nepal." *Mountain Research and Development* 30 (2): 113–26. doi:10.1659/MRD-JOURNAL-D-10-00027.1.

Scheuer, Chris, Gregory A Keoleian, and Peter Reppe. 2003. "Life Cycle Energy and Environmental Performance of a New University Building: Modeling Challenges and Design Implications." *Energy and Buildings* 35 (10): 1049–64. doi:10.1016/S0378-7788(03)00066-5.

Seebach Dominik, Adell Aure, and Tepper Philip. 2011. "ENG_SMART_SPP_LCC_CO2_tool_v2." The SMART SPP consortium, c/o ICLEI-Local Governments for Sustainability.

Sestini V. 1998. "La Terra Cruda, Tradizioni E Tecnologie Nel Patrimonio Architettonico Himalayano (The Raw Earth, Traditions and Technologies in the Himalayan Architectural Heritage)." *Costruire in Laterizio* 64: 271–77.

Sieglinde K. Fuller, Stephen R. Petersen. 1996. *Life-Cycle Costing Manual for the Federal Energy Management Program*. 1995th ed. National Institute of Standards and Technology Handbook 135. http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf.

Singh, Amanjeet, George Berghorn, Satish Joshi, Matt Syal, and M Asce. 2011. "Review of Life-Cycle Assessment Applications in Building Construction," no. March: 15–23. doi:10.1061/(ASCE)AE.1943-5568.0000026.

Sonnemann, Guido. 2006. "Life Cycle Management in Developing Countries : State of the Art and Outlook" 1 (1): 123–26.

Sonnemann, Guido, Francesc Castells, and G Schuhmacher. 2003. *Integrated Life–Cycle and Risk Assessment for Industrial Processes. Advanced Methods in Resource and Waste Management Series*. Edited by Boca Raton. Volume 2. Advanced Methods in Reserouce and Waste Management, Lewis Publishers.

Sorrell, Steve. 2015. "Reducing Energy Demand: A Review of Issues, Challenges and Approaches." *Renewable and Sustainable Energy Reviews* 47 (July): 74–82. doi:10.1016/j.rser.2015.03.002.

Steg L. 2008. "Promoting Household Energy Conservation." *Energy Policy* 36:

4449–53.

Steg, Linda, and Charles Vlek. 2009. "Encouraging pro-Environmental Behaviour: An Integrative Review and Research Agenda." *Journal of Environmental Psychology* 29 (3): 309–17. doi:10.1016/j.jenvp.2008.10.004.

Stevens S. 2003. "Toursim and Deforestation in the Mt Everest Region of Nepal." *The Geographical Journal* 169: 255–77.

Streimikiene, Dalia. 2015. "Assessment of Reasonably Achievable GHG Emission Reduction Target in Lithuanian Households." *Renewable and Sustainable Energy Reviews* 52 (December): 460–67. doi:10.1016/j.rser.2015.07.111.

Streimikiene, Dalia, and Remigijus Ciegis. 2010. "Life Style Changes: Significant Contribution to GHG Emission Reduction Efforts." In *In: Filho WL, Editor. Universities for Climatechange. Berlin: Springer-Verlag*, edited by Walter Leal Filho, 167–77. Springer Berlin Heidelberg. doi:10.1007/978-3-642-10751-1_14.

Streimikiene, Dalia, and Andzej Volochovic. 2011. "The Impact of Household Behavioral Changes on GHG Emission Reduction in Lithuania." *Renewable and Sustainable Energy Reviews* 15 (8): 4118–24. doi:10.1016/j.rser.2011.07.027.

Surendra, K. C., Samir Kumar Khanal, Prachand Shrestha, and Buddhi Lamsal. 2011. "Current Status of Renewable Energy in Nepal: Opportunities and Challenges." *Renewable and Sustainable Energy Reviews* 15 (8). Elsevier Ltd: 4107–17. doi:10.1016/j.rser.2011.07.022.

Timilsina, Govinda R., Thierry Lefevre, and Sameer Shrestha. 2000. "Financing Solar Thermal Technologies under DSM Programs: An Innovative Approach to Promote Renewable Energy." *International Journal of Energy Research* 24 (6): 503–10. doi:10.1002/(SICI)1099-114X(200005)24:6<503::AID-ER599>3.0.CO;2-R.

Timothy Gutowski, Amanda Taplett, Anna Allen, Amy Banzaert, Rob Cirinciore, Christopher, Barry Cleaver, Stacy Figueredo, Susan Fredholm, Betar Gallant, Alissa Jones, Jonathan Krones, Tim Kudrowitz, Cynthia Lin, Alfredo Morales, David Quinn, Megan Roberts, Robert Scaringe, and and Malima Wolf Studley, Sittha Sukkasi, Mika Tomczak, Jessica Vechakul. 2008. "Environmental Life Style Analysis (ELSA)." In *IEEE International Symposium on Electronics and the Environment*. San Francisco, USA.

Tsantopoulos, Georgios, Garyfallos Arabatzis, and Stilianos Tampakis. 2014. "Public Attitudes towards Photovoltaic Developments: Case Study from

Greece." *Energy Policy* 71 (August): 94–106. doi:10.1016/j.enpol.2014.03.025.

U.S. Energy Information Administration. 2014. "International Energy Outlook 2014: World Petroleum and Other Liquid Fuels With Projections to 2040." doi:DOE/EIA-0484(2014).

UNEP. 2009. "Buildings and Climate Change: A Summary for Decision-Makers." *United Nations Environmental Programme, Sustainable Buildings and Climate Initiative*. 15 Rue de Milan, 75441 Paris CEDEX 09, France. doi:ISBN: 987-92-807-3064-7 DTI/1240/PA.

UNFCCC. 2007. "Climate change:Imapct, Vulnerability and Adaptation in Developing Countries." Bonn, Germany. http://unfccc.int/resource/docs/publications/impacts.pdf.

UNI EN ISO 14040. 2006. Environmental management - Life cycle assessment - Principles and framework, issued 2006.

UNI EN ISO 14044. 2006. Environmental management Life cycle assessment Requirements and guideline, issued 2006.

Vijayan, Abhilash, and Ashok Kumar. 2005. "A Review of Tools to Assess the Sustainability in Building Construction." *Environmental Progress*. doi:10.1002/ep.10065.

Vringer K, Blok K. 1995. "The Direct and Indirect Energy Requirement of Households of Household in the Netherlands." *Energy Policy* 23 (10): 893–902.

WBDG Sustainable Committee. 2014. "Sustainable." https://www.wbdg.org/design/sustainable.php.

WECS (Water and Energy Commission Secretariat). 2010. "Energy Sector Synopsis Report 2010." Kathmandu, Nepal. http://www.wecs.gov.np/pdf/snyopsis.pdf.

Weidema, BP, C Bauer, R Hischier, C Mutel, T Nemecek, J Reinhard, CO Vadenbo, and G Wernet. 2013. "Swiss Centre for Life Cycle Inventories Overview and Methodology (final)(v3)" 3.

Wilson Charlie, Hadi Dowlatabadi. 2007. "Models of Decision Making and Residential Energy Use." *Environment and Resources* 32: 169–203.

Woodward, David G. 1997. "Life Cycle Costing--Theory , Information Acquisition and Application" 15 (6): 335–44.

World Bank. 2015. "Inflation, Consumer Prices (annual %)." *World Bank Group*. http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG/countries/NP?display=graph.

Zabalza Bribián I, Capilla AV, Usón AA. 2011. "Life Cycle Assessment of Building Materials: Comparative Analysis of Energy and Environmental Impacts and Evaluation of the Eco-Efficiency Improvement." *Building and Environment* 46: 1133–40.

Zabalza Bribián, Ignacio, Alfonso Aranda Usón, and Sabina Scarpellini. 2009. "Life Cycle Assessment in Buildings: State-of-the-Art and Simplified LCA Methodology as a Complement for Building Certification." *Building and Environment* 44 (12): 2510–20. doi:10.1016/j.buildenv.2009.05.001.

Zabalza Bribián, Ignacio, Antonio Valero Capilla, and Alfonso Aranda Usón. 2011. "Life Cycle Assessment of Building Materials: Comparative Analysis of Energy and Environmental Impacts and Evaluation of the Eco-Efficiency Improvement Potential." *Building and Environment* 46 (5). Elsevier Ltd: 1133–40. doi:10.1016/j.buildenv.2010.12.002.

Zhang, Weiqian, Shen Tan, Yizhong Lei, and Shoubing Wang. 2014. "Life Cycle Assessment of a Single-Family Residential Building in Canada: A Case Study." *Building Simulation* 7: 429–38. doi:10.1007/s12273-013-0159-y.

Annex 1: Questionaires

Q.No.   Basic Information

GPS Point: Datum WGS84 N ……º…'……." E …...º……'….." Altitude (m):

Location:

1. Identifying Household

Name of Place/ House no.	
Type	Household (HH) / Office / Institution / Business
Date of Interview	......./……./……. Time: (a.m./p.m.)
Name of interviewer	

2. Informant's background

	Educational status			
	Occupation			
	Religion			
	Ethnic group			
	Family type and number (Valid only for HH)			
	How long your half yearly income can sustain your family expenditure (Valid only for HH)	> 12 months	> 6 months	> 3 months

3. Building Information

	Building Type	1 Traditional 2. Semi-modern 3.Modern
	Storey and no. of room	
	Position of building	
	Kitchen and dinning	1. Attached 2. Separate
	Ktichen and dinning with main building	1. Attached 2. Separate

4. Wall Information
a. Consumption base materials used in SNPBZ to produce 1m ^{2} wall block

Material Used	Unit of measure	Quantity
Wooden planks		
Dry Stone		
Plaster (Cement/ Mud)		

Cement blocks/ Stone		
Glasswool		
Polystyrene		

* Please specify the unit of measure used and draw a cross section of wall below

b. Origin of material

Materials	Resources	Source*:	Distance in km from the source
Dry Stone	Rock		
Mud	White Mica Clay (Kamero)		
Wooden Plank			

c. Data for commercial materials

Material	Quantity of material bought	Type of vehicle (eg truck, articulated lorry etc.) from retailers	Amount you pay for vehicle	Amount you pay in airport
Insulation				
Cement				
Enamel				

d. Data for Natural resources

Materials	Quantity	Energy Used
Wooden Plank		
Tree felling		
Transport		
Drying		
Processing		
Mud plastering		

Processing ...		

5. Tourist Information

No. of Tourist visit per month/season	
Duration of stay	
Meal	1. Breakfast 2. Lunch 3. Dinner

6. Fuel Types and Users (Household / Office / Business)

Using the fuel list below, what types of fuel do you use for the following purposes?
(List in order of importance using numbers shown below)

Wood =1 Dung = 2 Agricultural residues = 3 Other residues = 4 Charcoal = 5	Kerosene (Paraffin) = 6 Bottled gas (LPG) = 7 Solar cooker = 8 Solar electric (solar PV) = 9 Grid electricity = 10	Batteries = 11 Wax candle = 12 Pico Hydro = 13 Water Mill (IWM/TWM) = 14 Other = 15

Purpose	Fuel Priority								
/month	First priority	Qty	Cost	Second Priority	Qty	Cost	Third priority	Qty	Cost
Cooking (including drinks)									
Lighting									
Space heating									
Heating water for Drinking/ Bathing / Bed warming / Washing									
Beer brewing									
Cooking food/drink for selling (excluding beer)									
Cooking animal feed									
Grinding grains									
If fuel is used for another type of household task, please specify task (s)	Task 1: Task 2:								

7. Getting Fuel: Buying and Gathering

Fuels	Source	Distance in km from the source
Fire wood		
Cow dung		
Kerosene		
LPG		
Grid Electricity		
Batteries		
Wax Candles		
Briquette		

How do you get fire-wood or dung?	1- all gathered 2- mostly gathered	3- mostly bought 4- all bought
If you use the following fuels, how much do you pay for it per month? Wood Charcoal Kerosene (paraffin) Bottled gas Grid electricity Batteries Wax candles Others	Qty / month	NRs. / month
Total (in NRs.)		
What are the reasons for buying fuel? (more than one reason can be selected) 1. Scarcity of fire-wood and dung for gathering 2. Faster than gathering it 3. Cleaner for cooking 4. Other reason (please specify)		
If you or your family gather fuel, how often is it gathered? 1- every week 2- every month 3- Twice in a year 4- Specific time(mention)	Qty / month in summer	Qty / month in winter
Collection Labour charge		
If you gather fuel, for how long will it be sufficient (in months)?		
If you gather fuel, for how long do you take to gather?		

If you gather fuel, do you experience any problems when gathering it? If any, write the problems?		

8. Electricity Use Pattern

List the electrical equipment and tools			Number of equipment	Wattage	Time of the day use (period) e.g./ 6 -7 AM / PM		
			(-)	(W)	Morning	Day	Evening
a) Light bulbs	IL	60 W					
		100 W					
	FL	20 W					
		40 W					
	CFL	< 10 W					
		> 10 W					
	WLED	1 W					
b) Toaster							
c) Bakery Oven							
d) Rice cooker							
e) Water heater							
f) Fan							
g) Room heater / air conditioning							
h) Pumping							
i) TV							
j) Audio/Video/Overhead							
k) Saw mill							
l) Grinder/coffee/wheat							
m) Mixture							
n) Coffee maker							
o) Washing machine							
p) Dish washer							
q) Refrigerator							
r) Battery charger							
s) Other specify							
Total							
Is it sufficient for them			Yes / no				
If no then what type of other energy use you want to add							

Mention any other information regarding electricity use pattern				
How much are you paying for electricity per month?				

9. Stoves (*Chulo*)

Type of stove (If multiple stoves are found to be used tick them according to priority)	For Cooking			Space Heating		
	L (m)	B (m)	H (m)	L (m)	B (m)	H (m)
1. Three-stone or two-stone fire						
2. Shielded mud fire or mud stove (including chimney stove)						
3. Ceramic stove (made of fired clay)						
4. Metal stove one pot / two pots / three pots / Nepal made or foreign made						
5. Briquette stove						
6. kerosene stove						
7.Gas stove						
8. Solar cooker						
9. Grid-powered electric stove						
10. Other type of stove						
Smoke Extraction Pipe Chimney / Hood Chimney / Pipe Chimney with water heating provision						

10. Indoor pollution

In what ways do you feel that smoke from the fire affects (a) your health, and (b) health of your children, if at all		
Symptoms	Member	Mild/High
Eyes		
Cough		
Chest illness		
Headache		
Shortness of breath		
Do you Smoke?	(Yes/No)Quantity……..	

2. Questionnaire for Retailers

Q.No.

Basic Information

Name of the shop	
Location	
Date of Interview	......./......./....... Time:
Name of interviewer	

Shop Information

Type of shop	1. Whole Seller 2. Retailer
Items sold	
Customers	

Data on Items Purchased

Items	From	Quantity	Cost

Data on the Vehicle Used to Transport Materials

Items	Distance Covered	Type of vehicle (eg truck, articulated lorry etc.)	Load capacity (eg 28 tons)

Total household and sampling number.

VDC	Villages	Building Types	Commercial		Institutional		Residential		Total Existing HH	Total Sampled HH
			Sample	Existing	Sample	Existing	Sample	Existing		
Chaurikharka	Lukla	Traditional	1	6	0	0	5	63	74	6
		Semi-modern	2	30	1	9	2	27	69	5
		Modern	7	12	0	0	3	6	21	10
	Total								**164**	**21**
	Phakding	Traditional	1	5	1	1	3	28	38	5
		Semi-modern	2	12	0	0	2	36	50	4
		Modern	2	2	0	0	0	0	2	2
	Total								**90**	**11**
	Monju	Traditional					1			1
		Semi-modern								1
		Modern	1							
	Jorsalle	Traditional							0	0
		Semi-modern	6	6					6	6
		Modern							0	0
	Total								**6**	**6**
Namche	Namche	Traditional	2	9	0	0	3	52	64	5
		Semi-modern	2	16	1	7	2	30	56	5
		Modern	7	20	0	0	3	7	30	10
	Total								**150**	**20**

	Syangboche	Traditional							0	0
		Semi-modern	1	4	1	1			6	2
		Modern							0	0
	Total								**6**	**2**
	Thame	Traditional	1				1		1	2
		Semi-modern	1				1		1	2
		Modern	1						0	1
	Total								2	**5**
	Thamo	Traditional					1		1	1
		Semi-modern	1						0	1
		Modern							0	0
	Total								1	**2**
Khumjung	Khunde	Traditional	1	4	0	0	1	49	54	2
		Semi-modern	0	0	1	1	1	17	20	2
		Modern	0	0	0	0	1	2	3	1
	Total								**77**	**5**
	Khumjung	Traditional	3	8	1	1	10	160	180	14
		Semi-modern	2	9	1	1	2	41	54	5
		Modern	1	1		0	1	2	4	2
	Total								**238**	**21**
										95

Life Cycle Inventory on <u>construction stage</u> of modern building

	Product/Substance		Type	46_wall_Consstruction [mud]	46_wall_Construction [wooden plank]	46_wall_Construction [enamel]	46_wall_Construction [nail]	46_wall_Construction [dry stone]	46_wall_Construction [polystrene]	46_wall_Construction [glass wool]	46_wall_Construction [plywood]	46_wall_Construction [wall]	46_roof_Construction [nail]	46_roof_Construction [CGI sheet]
			Unit	kg	m3	kg	kg	kg	kg	kg	m3	p	kg	m2
			reference flo	7.214,09	3,04	46,05	8,53	395.147,57	163,99	176,03	13,67	1,00	9,84	224,82
Compartme	Product/Substance	Sub-compartr	Category Type	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material	_Himalayan_46 Material
	46_wall_Consstruction [mud]		kg											7.214,09
	46_wall_Construction [wooden plank]		m3											3,04
	46_wall_Construction [enamel]		kg											46,05
	46_wall_Construction [nail]		kg											8,53
	46_wall_Construction [dry stone]		kg											395.147,57
	46_wall_Construction [polystrene]		kg											163,99
	46_wall_Construction [glass wool]		kg											176,03
	46_wall_Construction [plywood]		m3											13,67
	46_wall_Construction [wall]		p											
	46_roof_Construction [nail]		kg											
	46_roof_Construction [CGI sheet]		m2											
	46_roof_Construction [wooden joist jiri]		m3											
	46_roof_Construction [roof]		p											
	46_window_Construction [wooden frame]		m3											
	46_window_Construction [window glass]		m2											
	46_window_Construction [window]		p											
	46_door_Construction [wooden]		m3											
	46_door_Construction [plywood]		m3											
	46_door_Construction [door]		p											
	46_columns/beams_Construction [steel rod]		kg											
	46_columns/beams_Construction [cement]		kg											
	46_columns/beams_Construction [sand]		kg											
	46_columns/beams_Construction [column/beam]		p											
	46_floor_Construction [wooden plank]		m3											
	46_floor_Construction [wooden joist]		m3											
	46_floor_Construction [floor]		p											
	46_ceiling_Construction [wooden joist]		m3											
	46_ceiling_Construction [plywood]		m3											
	46_ceiling_Construction [ceiling]		p											
	46_ladder_Construction [wooden plank]		m3											
	46_corridor_Construction [wooden plank]		m3											
	46_corridor_Construction [wooden joist]		m3											
	46_ladder_corridor_Construction [ladder corridor]		p											
	46_building_Construction [building]		p											

Life Cycle Inventory on <u>construction stage</u> of modern building

	Compartme	Product/Substance		Sub-compartr	Product Type	46_roof_Construction [wooden joist jiri]	46_roof_Construction [roof]	46_window_Construction [wooden frame]	46_window_Construction [window glass]	46_window_Construction [window]	46_door_Construction [wooden]	46_door_Construction [plywood]	46_door_Construction [door]	46_columns/beams_Construction [steel rod]	46_columns/beams_Construction [cement]	46_columns/beams_Construction [sand]
1																
2					Unit	m3	p	m3	m2	p	m3	m3	p	kg	kg	kg
3					eference flc	10,82	1,00	0,53	71,68	1,00	0,16	0,55	1,00	256,00	251,94	1.084,75
4																
5					Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
6						Material	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material
7		46_wall_Consstruction [mud]			kg											
8		46_wall_Construction [wooden plank]			m3											
9		46_wall_Construction [enamel]			kg											
10		46_wall_Construction [nail]			kg											
11		46_wall_Construction [dry stone]			kg											
12		46_wall_Construction [polystrene]			kg											
13		46_wall_Construction [glass wool]			kg											
14		46_wall_Construction [plywood]			m3											
15		46_wall_Construction [wall]			p											
16		46_roof_Construction [nail]			kg		9,84									
17		46_roof_Construction [CGI sheet]			m2		224,82									
18		46_roof_Construction [wooden joist jiri]			m3		10,82									
19		46_roof_Construction [roof]			p											
20		46_window_Construction [wooden frame]			m3				0,53							
21		46_window_Construction [window glass]			m2				71,68							
22		46_window_Construction [window]			p											
23		46_door_Construction [wooden]			m3							0,16				
24		46_door_Construction [plywood]			m3							0,55				
25		46_door_Construction [door]			p											
26		46_columns/beams_Construction [steel rod]			kg											
27		46_columns/beams_Construction [cement]			kg											
28		46_columns/beams_Construction [sand]			kg											
29		46_columns/beams_Construction [column/beam]			p											
30		46_floor_Construction [wooden plank]			m3											
31		46_floor_Construction [wooden joist]			m3											
32		46_floor_Construction [floor]			p											
33		46_ceiling_Construction [wooden joist]			m3											
34		46_ceiling_Construction [plywood]			m3											
35		46_ceilling_Construction [ceiling]			p											
36		46_ladder_Construction [wooden plank]			m3											
37		46_corridor_Construction [wooden plank]			m3											
38		46_corridor_Construction [wooden joist]			m3											
39		46_ladder_corridor_Construction [ladder corridor]			p											
40		46_building_Construction [building]			p											

Life Cycle Inventory on <u>construction stage</u> of modern building

			Product	46_columns/beams_Construction [column/beam]	46_floor_Construction [wooden plank]	46_floor_Construction [wooden joist]	46_floor_Construction [floor]	46_ceiling_Construction [wooden joist]	46_ceiling_Construction [plywood]	46_ceilling_Construction [ceiling]	46_ladder_Construction [wooden plank]	46_corridor_Construction [wooden plank]	46_corridor_Construction [wooden joist]	46_ladder_corridor_Construction [ladder corridor]	46_building_Construction [building]
			Unit	p	m3	m3	p	m3	m3	p	m3	m3	m3	p	p
			reference flo	1,00	9,97	8,01	1,00	8,01	4,52	1,00	0,09	2,76	0,76	1,00	1,00
			Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
Compartme	Product/Substance	Sub-compartr	Type	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material
	46_wall_Consstruction [mud]		kg												
	46_wall_Construction [wooden plank]		m3												
	46_wall_Construction [enamel]		kg												
	46_wall_Construction [nail]		kg												
	46_wall_Construction [dry stone]		kg												
	46_wall_Construction [polystrene]		kg												
	46_wall_Construction [glass wool]		kg												
	46_wall_Construction [plywood]		m3												
	46_wall_Construction [wall]		p												1,00
	46_roof_Construction [nail]		kg												
	46_roof_Construction [CGI sheet]		m2												
	46_roof_Construction [wooden joist jiri]		m3												
	46_roof_Construction [roof]		p												1,00
	46_window_Construction [wooden frame]		m3												
	46_window_Construction [window glass]		m2												
	46_window_Construction [window]		p												1,00
	46_door_Construction [wooden]		m3												
	46_door_Construction [plywood]		m3												
	46_door_Construction [door]		p												1,00
	46_columns/beams_Construction [steel rod]		kg	256,00											
	46_columns/beams_Construction [cement]		kg	251,94											
	46_columns/beams_Construction [sand]		kg	1.084,75											
	46_columns/beams_Construction [column/beam]		p												1,00
	46_floor_Construction [wooden plank]		m3				9,97								
	46_floor_Construction [wooden joist]		m3				8,01								
	46_floor_Construction [floor]		p												1,00
	46_ceiling_Construction [wooden joist]		m3							8,01					
	46_ceiling_Construction [plywood]		m3							4,52					
	46_ceilling_Construction [ceiling]		p												1,00
	46_ladder_Construction [wooden plank]		m3											0,09	
	46_corridor_Construction [wooden plank]		m3											2,76	
	46_corridor_Construction [wooden joist]		m3											0,76	
	46_ladder_corridor_Construction [ladder corridor]		p												1,00
	46_building_Construction [building]		p												

Life Cycle Inventory on construction stage of modern building

	Product/Substance	Sub-comp	Type	46_roof_Construction [wooden joist jiri]	46_roof_Construction [roof]	46_window_Construction [wooden frame]	46_window_Construction [window glass]	46_window_Construction [window]	46_door_Construction [wooden]	46_door_Construction [plywood]	46_door_Construction [door]	46_columns/beams_Construction [steel rod]	46_columns/beams_Construction [cement]	46_columns/beams_Construction [sand]
	Unit			m3	p	m3	m2	p	m3	m3	p	kg	kg	kg
	reference flow			10,82	1,00	0,53	71,68	1,00	0,16	0,55	1,00	256,00	251,94	1.084,75
	Category			_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
Compartme	Product/Substance	Sub-compartr	Type	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material
	Sawnwood, softwood, air dried, planed {RoW}| market for	Conseq,		m3	-		0,53			0,16					
	Electricity, low voltage {RoW}| market for	Conseq, U		kWh	151,98		13,40			13,40					
	Power sawing, without catalytic converter {RoW}| processing	Conseq, U		hr	10,00		2,00			2,00					
	Alkyd resin, long oil, without solvent, in 70% white spirit solution state {GLO}| mark		kg											
	Transport, freight, lorry, unspecified {GLO}| market for	Conseq, U		tkm	98,51			117,31			0,85		70,31	73,06	
	Transport, freight, light commercial vehicle {GLO}| market for	Conseq, U		tkm				10,20			0,06		2,56	2,52	
	Transport, freight, aircraft {GLO}| market for	Conseq, U		tkm				138,73			0,52		34,82	34,26	
	Transport, helicopter {GLO}| market for	Conseq, U		hr	0,50										
	Limestone, unprocessed {RoW}| limestone quarry operation	Conseq, U		kg											
	Cement mortar {GLO}| market for	Conseq, U		kg										251,94	
	Transport, tractor and trailer, agricultural {GLO}| market for	Conseq, U		tkm											
	Polystyrene foam slab {GLO}| market for	Conseq, U		kg											
	Glass wool mat {GLO}| market for	Conseq, U		kg											
	Plywood, for indoor use {RoW}| market for	Conseq, U		m3							0,55				
	Steel, unalloyed {GLO}| market for	Conseq, U		kg											
	Tin plated chromium steel sheet, 2 mm {GLO}| market for	Conseq, U		m2											
	Glazing, double, U<1.1 W/m2K {GLO}| market for	Conseq, U		m2				71,68							
	Reinforcing steel {GLO}| market for	Conseq, U		kg									256,00		
	Bundle, energy wood, measured as dry mass {RoW}| softwood forestry, pine, susta		kg											
	Kerosene {RoW}| market for	Conseq, U		kg											
	Liquefied petroleum gas {RoW}| market for	Conseq, U		kg											
	Solid manure loading and spreading, by hydraulic loader and spreader {RoW}| proce		kg											
	Electricity, low voltage {RoW}| electricity production, photovoltaic, 3kWp flat-roof i		kWh											
Air	carbon dioxide		kg											
Air	methane		kg											
Air	Nitrous oxide		kg											
Raw	water		kg											
Raw	Sand		kg											1.084,75
Raw	Clay, unspecific		kg											
Economic	material cost		EUR2003	2.998,71		34,81	102,01		10,74	470,57		192,84	37,49	
Economic	transportation (van+aircraft)		EUR2003	7.329,31			1.185,84			4,43		297,60	292,88	
Economic	transportation (labor)		EUR2003	610,78		29,70	94,87		9,16	0,35		1.190,40	1.171,53	10,09

Life Cycle Inventory on <u>construction stage</u> of modern building

				AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
	A	B	C	D											
1				Product	46_columns/beams_Construction [column/beam]	46_floor_Construction [wooden plank]	46_floor_Construction [wooden joist]	46_floor_Construction [floor]	46_ceiling_Construction [wooden joist]	46_ceiling_Construction [plywood]	46_ceiling_Construction [ceiling]	46_ladder_Construction [wooden plank]	46_corridor_Construction [wooden plank]	46_corridor_Construction [wooden joist]	46_ladder_corridor_Construction [ladder corridor]	46_building_Construction [building]
2				Unit	p	m3	m3	p	m3	m3	p	m3	m3	m3	p	p
3				eference flc	1,00	9,97	8,01	1,00	8,01	4,52	1,00	0,09	2,76	0,76	1,00	1,00
4																
5				Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
6	Compartme	Product/Substance	Sub-compartr	Type	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material	Material
65		Sawnwood, softwood, air dried, planed {RoW}| market for	Conseq,	m3		9,97	8,01		8,01			0,09	2,76	0,76		
66		Electricity, low voltage {RoW}| market for	Conseq, U	kWh		60,32	60,32		60,32			20,11	33,51	20,11		
67		Power sawing, without catalytic converter {RoW}| processing	Conseq, U	hr		9,00	9,00		9,00			3,00	5,00	3,00		
68		Alkyd resin, long oil, without solvent, in 70% white spirit solution state {GLO}| mark	kg												
69		Transport, freight, lorry, unspecified {GLO}| market for	Conseq, U	tkm						6,95						
70		Transport, freight, light commercial vehicle {GLO}| market for	Conseq, U	tkm						0,47						
71		Transport, freight, aircraft {GLO}| market for	Conseq, U	tkm						4,26						
72		Transport, helicopter {GLO}| market for	Conseq, U	hr												
73		Limestone, unprocessed {RoW}| limestone quarry operation	Conseq, U	kg												
74		Cement mortar {GLO}| market for	Conseq, U	kg												
75		Transport, tractor and trailer, agricultural {GLO}| market for	Conseq, U	tkm												
76		Polystyrene foam slab {GLO}| market for	Conseq, U	kg												
77		Glass wool mat {GLO}| market for	Conseq, U	kg												
78		Plywood, for indoor use {RoW}| market for	Conseq, U	m3						4,52						
79		Steel, unalloyed {GLO}| market for	Conseq, U	kg												
80		Tin plated chromium steel sheet, 2 mm {GLO}| market for	Conseq, U	m2												
81		Glazing, double, U<1.1 W/m2K {GLO}| market for	Conseq, U	m2												
82		Reinforcing steel {GLO}| market for	Conseq, U	kg												
83		Bundle, energy wood, measured as dry mass {RoW}| softwood forestry, pine, susta	kg												
84		Kerosene {RoW}| market for	Conseq, U	kg												
85		Liquefied petroleum gas {RoW}| market for	Conseq, U	kg												
86		Solid manure loading and spreading, by hydraulic loader and spreader {RoW}| proce	kg												
87		Electricity, low voltage {RoW}| electricity production, photovoltaic, 3kWp flat-roof i	kWh												
88	Air	carbon dioxide		kg												
89	Air	methane		kg												
90	Air	Nitrous oxide		kg												
91	Raw	water		kg												
92	Raw	Sand		kg												
93	Raw	Clay, unspecific		kg												
94	Economic	material cost		EUR2003		659,80	530,19		530,19	3.866,50		6,13	182,84	50,14		
95	Economic	transportation (van+aircraft)		EUR2003						36,39						
96	Economic	transportation (labor)		EUR2003		139,83	112,36		112,36	2,91		1,30	38,75	42,78		

Life Cycle Inventory on <u>operation stage</u> of modern building

	A	B	C	D	AM	AN	AO	AP	AQ	AR
1				Product	46_building_Operation, energy used per person.day kWh/person.day [cooking]	46_building_Operation, energy used per person.day kWh/person.day [space heating]	46_building_operation, energy used per person.day kWh/person.day [heating water]	46_building_Operation, energy used per person.day kWh/person.day [lighting]	46_building_Operation, energy used per person.day kWh/person.day [electronic appliance]	46_building_Operation [building]
2				Unit	kWh	kWh	kWh	kWh	kWh	p
3				eference flo	6,37	2,18	0,06	0,06	0,00	1,00
4										
5				Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
6	Compartme	Product/Substance	Sub-compartr	Type	Material	Material	Material	Material	Material	Material
I1		46_building_Operation, energy used per person.day kWh/person.day [cooking]		kWh						6,37
I2		46_building_Operation, energy used per person.day kWh/person.day [space heatin;		kWh						2,18
I3		46_building_operation, energy used per person.day kWh/person.day [heating water		kWh						0,06
I4		46_building_Operation, energy used per person.day kWh/person.day [lighting]		kWh						0,06
I5		46_building_Operation, energy used per person.day kWh/person.day [electronic ap		kWh						0,00
I6		46_building_Operation [building]		p						

Life Cycle Inventory on <u>operation stage</u> of modern building

	A	B	C	D	AM	AN	AO	AP	AQ	AR
1				Product	46_building_Operation, energy used per person.day kWh/person.day [cooking]	46_building_Operation, energy used per person.day kWh/person.day [space heating]	46_building_operation, energy used per person.day kWh/person.day [heating water]	46_building_Operation, energy used per person.day kWh/person.day [lighting]	46_building_Operation, energy used per person.day kWh/person.day [electronic appliance]	46_building_Operation [building]
2				Unit	kWh	kWh	kWh	kWh	kWh	p
3				eference flc	6,37	2,18	0,06	0,06	0,00	1,00
4										
5				Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
6	Compartme	Product/Substance	Sub-compartr	Type	Material	Material	Material	Material	Material	Material
65		Sawnwood, softwood, air dried, planed {RoW}| market for	Conseq,		m3					
66		Electricity, low voltage {RoW}| market for	Conseq, U		kWh	0,19	0,51	0,06	0,06	0,00	
67		Power sawing, without catalytic converter {RoW}| processing	Conseq, U		hr						
68		Alkyd resin, long oil, without solvent, in 70% white spirit solution state {GLO}| marke		kg						
69		Transport, freight, lorry, unspecified {GLO}| market for	Conseq, U		tkm						
70		Transport, freight, light commercial vehicle {GLO}| market for	Conseq, U		tkm	0,04					
71		Transport, freight, aircraft {GLO}| market for	Conseq, U		tkm						
72		Transport, helicopter {GLO}| market for	Conseq, U		hr						
73		Limestone, unprocessed {RoW}| limestone quarry operation	Conseq, U		kg						
74		Cement mortar {GLO}| market for	Conseq, U		kg						
75		Transport, tractor and trailer, agricultural {GLO}| market for	Conseq, U		tkm	0,03					
76		Polystyrene foam slab {GLO}| market for	Conseq, U		kg						
77		Glass wool mat {GLO}| market for	Conseq, U		kg						
78		Plywood, for indoor use {RoW}| market for	Conseq, U		m3						
79		Steel, unalloyed {GLO}| market for	Conseq, U		kg						
80		Tin plated chromium steel sheet, 2 mm {GLO}| market for	Conseq, U		m2						
81		Glazing, double, U<1.1 W/m2K {GLO}| market for	Conseq, U		m2						
82		Reinforcing steel {GLO}| market for	Conseq, U		kg						
83		Bundle, energy wood, measured as dry mass {RoW}| softwood forestry, pine, susta		kg	-	1,67	-			
84		Kerosene {RoW}| market for	Conseq, U		kg	5,71				-	
85		Liquefied petroleum gas {RoW}| market for	Conseq, U		kg	0,48					
86		Solid manure loading and spreading, by hydraulic loader and spreader {RoW}| proce		kg	-	-				
87		Electricity, low voltage {RoW}| electricity production, photovoltaic, 3kWp flat-roof i		kWh					-	
88	Air	carbon dioxide		kg	3,37	0,60	-	-	-	
89	Air	methane		kg	0,00	0,00	-	-	-	
90	Air	Nitrous oxide		kg	0,00	0,00	-	-	-	
91	Raw	water		kg						
92	Raw	Sand		kg						
93	Raw	Clay, unspecific		kg						
94	Economic	material cost		EUR2003	12,59	0,40	0,02	0,02	0,00	
95	Economic	transportation (van+aircraft)		EUR2003						
96	Economic	transportation (labor)		EUR2003						

Life Cycle Inventory on <u>maintenance and replacement stage</u> of modern building

	Product/Substance	Sub-compartm	Type	46_wall_Maintenances [enamel coating]	46_wall_Replacement [replacing wooden plank]	46_wall_Replacement [replacing plywood]	46_wall_Replacement [mud]	46_wall_Replacement [replacing Glasswool]	46_wall_Replacement [replacing polystrene]	46_wall_Replacement [wall]	46_roof_Replacement [replacing CGI sheet]	46_roof_Replacement [replacing Nails]
			Product									
			Unit	kg	m3	m3	kg	kg	kg	p	m2	kg
			eference flc	184,19	3,04	27,35	7.214,09	176,03	327,97	1,00	290,98	9,84
			Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
Compartme	Product/Substance	Sub-compartm	Type	Material	Material	Material	Material	Material	Material	Material	Material	Material
	46_wall_Maintenances [enamel coating]		kg							327,97		
	46_wall_Replacement [replacing wooden plank]		m3							3,04		
	46_wall_Replacement [replacing plywood]		m3							27,35		
	46_wall_Replacement [mud]		kg							7.214,09		
	46_wall_Replacement [replacing Glasswool]		kg							176,03		
	46_wall_Replacement [replacing polystrene]		kg							327,97		
	46_wall_Replacement [wall]		p									
	46_roof_Replacement [replacing CGI sheet]		m2									
	46_roof_Replacement [replacing Nails]		kg									
	46_roof_Replacement [roof]		p									
	46_door_Replacement [replacing plywood]		m3									
	46_door_Replacement [door]		p									
	46_ceiling_Replacement [replacing plywood]		m3									
	46_ceiling_Replacement [ceiling]		p									
	46_floor_Replacement [replacing wooden plank]		m3									
	46_floor_Replacement [floor]		p									
	46_building_Replacement [building]		p									
	46_Life Cycle [FU = 1 night, 1 guest accomodation]		day									

Life Cycle Inventory on <u>maintenance and replacement stage</u> of modern building

Compartme	Product/Substance	Sub-compartr	Type	46_roof_Replacement [roof]	46_door_Replacement [replacing plywood]	46_door_Replacement [door]	46_ceiling_Replacement [replacing plywood]	46_ceiling_Replacement [ceiling]	46_floor_Replacement [replacing wooden plank]	46_floor_Replacement [floor]	46_building_Replacement [building]	46_Life Cycle [FU = 1 night, 1 guest accomodation]
			Unit	p	m3	p	m3	p	m3	p	p	day
			reference flo	1,00	0,55	1,00	4,52	1,00	9,97	1,00	1,00	1,00
			Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
				Material	Material	Material	Material	Material	Material	Material	Material	Material
	46_wall_Maintenances [enamel coating]		kg									
	46_wall_Replacement [replacing wooden plank]		m3									
	46_wall_Replacement [replacing plywood]		m3									
	46_wall_Replacement [mud]		kg									
	46_wall_Replacement [replacing Glasswool]		kg									
	46_wall_Replacement [replacing polystrene]		kg									
	46_wall_Replacement [wall]		p								1,00	
	46_roof_Replacement [replacing CGI sheet]		m2	290,98								
	46_roof_Replacement [replacing Nails]		kg	9,84								
	46_roof_Replacement [roof]		p								1,00	
	46_door_Replacement [replacing plywood]		m3		0,55							
	46_door_Replacement [door]		p								1,00	
	46_ceiling_Replacement [replacing plywood]		m3				4,52					
	46_ceiling_Replacement [ceiling]		p								1,00	
	46_floor_Replacement [replacing wooden plank]		m3						9,97			
	46_floor_Replacement [floor]		p								1,00	
	46_building_Replacement [building]		p									0,0000020425
	46_Life Cycle [FU = 1 night, 1 guest accomodation]		day									

Life Cycle Inventory on <u>maintenance and replacement stage</u> of modern building

Compartment	Product/Substance	Sub-compartment	Type	46_wall_Maintenances [enamel coating]	46_wall_Replacement [replacing wooden plank]	46_wall_Replacement [replacing plywood]	46_wall_Replacement [mud]	46_wall_Replacement [replacing Glasswool]	46_wall_Replacement [replacing polystrene]	46_wall_Replacement [wall]	46_roof_Replacement [replacing CGI sheet]	46_roof_Replacement [replacing Nails]
			Unit	kg	m3	m3	kg	kg	kg	p	m2	kg
			reference flow	184,19	3,04	27,35	7.214,09	176,03	327,97	1,00	290,98	9,84
			Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
			Type	Material	Material	Material	Material	Material	Material	Material	Material	Material
	Sawnwood, softwood, air dried, planed {RoW}| market for	Conseq,		m3		3,04							
	Electricity, low voltage {RoW}| market for	Conseq, U		kWh		91,19							
	Power sawing, without catalytic converter {RoW}| processing	Conseq, U		hr		6,00							
	Alkyd resin, long oil, without solvent, in 70% white spirit solution state {GLO}| mark		kg	184,19								
	Transport, freight, lorry, unspecified {GLO}| market for	Conseq, U		tkm	15,10		42,07		175,85	6,56		96,01	2,72
	Transport, freight, light commercial vehicle {GLO}| market for	Conseq, U		tkm	1,84		2,84		1,76	3,28		8,35	0,10
	Transport, freight, aircraft {GLO}| market for	Conseq, U		tkm	25,05		25,77		23,94	44,60		113,55	1,34
	Transport, helicopter {GLO}| market for	Conseq, U		hr									
	Limestone, unprocessed {RoW}| limestone quarry operation	Conseq, U		kg									
	Cement mortar {GLO}| market for	Conseq, U		kg									
	Transport, tractor and trailer, agricultural {GLO}| market for	Conseq, U		tkm									
	Polystyrene foam slab {GLO}| market for	Conseq, U		kg						327,97			
	Glass wool mat {GLO}| market for	Conseq, U		kg					176,03				
	Plywood, for indoor use {RoW}| market for	Conseq, U		m3			27,35						
	Steel, unalloyed {GLO}| market for	Conseq, U		kg									9,84
	Tin plated chromium steel sheet, 2 mm {GLO}| market for	Conseq, U		m2								290,98	
	Glazing, double, U<1.1 W/m2K {GLO}| market for	Conseq, U		m2									
	Reinforcing steel {GLO}| market for	Conseq, U		kg									
	Bundle, energy wood, measured as dry mass {RoW}| softwood forestry, pine, susta		kg									
	Kerosene {RoW}| market for	Conseq, U		kg									
	Liquefied petroleum gas {RoW}| market for	Conseq, U		kg									
	Solid manure loading and spreading, by hydraulic loader and spreader {RoW}| proce		kg									
	Electricity, low voltage {RoW}| electricity production, photovoltaic, 3kWp flat-roof i		kWh									
Air	carbon dioxide		kg									
Air	methane		kg									
Air	Nitrous oxide		kg									
Raw	water		kg									
Raw	Sand		kg									
Raw	Clay, unspecific		kg				7.214,09					
Economic	material cost		EUR2003	19.184,64	4.888,37	197.927,65		598,19	16.490,83		29.444,87	56,39
Economic	transportation (van+aircraft)		EUR2003	890,19	7.318,06	276,35		728,17	1.282,66		4.374,07	52,45
Economic	transportation (labor)		EUR2003	253,50	399,98	56,41	630,40	153,82	282,79		1.141,99	13,45

Life Cycle Inventory on <u>maintenance and replacement stage</u> of modern building

Compartment	Product/Substance	Sub-compartment	Type	46_roof_Replacement [roof]	46_door_Replacement [replacing plywood]	46_door_Replacement [door]	46_ceiling_Replacement [replacing plywood]	46_ceiling_Replacement [ceiling]	46_floor_Replacement [replacing wooden plank]	46_floor_Replacement [floor]	46_building_Replacement [building]	46_Life Cycle [FU = 1 night, 1 guest accomodation]
			Unit	p	m3	p	m3	p	m3	p	p	day
			reference flo	1,00	0,55	1,00	4,52	1,00	9,97	1,00	1,00	1,00
			Category	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46	_Himalayan_46
			Type	Material	Material	Material	Material	Material	Material	Material	Material	Material
	Sawnwood, softwood, air dried, planed {RoW}| market for	Conseq,		m3						9,97			
	Electricity, low voltage {RoW}| market for	Conseq, U		kWh						60,32			
	Power sawing, without catalytic converter {RoW}| processing	Conseq, U		hr						9,00			
	Alkyd resin, long oil, without solvent, in 70% white spirit solution state {GLO}| mark·		kg									
	Transport, freight, lorry, unspecified {GLO}| market for	Conseq, U		tkm		0,85		6,95					
	Transport, freight, light commercial vehicle {GLO}| market for	Conseq, U		tkm		0,06		0,47					
	Transport, freight, aircraft {GLO}| market for	Conseq, U		tkm		0,52		4,26					
	Transport, helicopter {GLO}| market for	Conseq, U		hr									
	Limestone, unprocessed {RoW}| limestone quarry operation	Conseq, U		kg									
	Cement mortar {GLO}| market for	Conseq, U		kg									
	Transport, tractor and trailer, agricultural {GLO}| market for	Conseq, U		tkm									
	Polystyrene foam slab {GLO}| market for	Conseq, U		kg									
	Glass wool mat {GLO}| market for	Conseq, U		kg									
	Plywood, for indoor use {RoW}| market for	Conseq, U		m3		0,55		4,52					
	Steel, unalloyed {GLO}| market for	Conseq, U		kg									
	Tin plated chromium steel sheet, 2 mm {GLO}| market for	Conseq, U		m2									
	Glazing, double, U<1.1 W/m2K {GLO}| market for	Conseq, U		m2									
	Reinforcing steel {GLO}| market for	Conseq, U		kg									
	Bundle, energy wood, measured as dry mass {RoW}| softwood forestry, pine, susta		kg									
	Kerosene {RoW}| market for	Conseq, U		kg									
	Liquefied petroleum gas {RoW}| market for	Conseq, U		kg									
	Solid manure loading and spreading, by hydraulic loader and spreader {RoW}| proce		kg									
	Electricity, low voltage {RoW}| electricity production, photovoltaic, 3kWp flat-roof i		kWh									
Air	carbon dioxide		kg									
Air	methane		kg									
Air	Nitrous oxide		kg									
Raw	water		kg									
Raw	Sand		kg									
Raw	Clay, unspecific		kg									
Economic	material cost		EUR2003		11.259,22		92.512,37		16.057,18			
Economic	transportation (van+aircraft)		EUR2003		15,76		129,48		24.038,16			
Economic	transportation (labor)		EUR2003		3,33		27,35		5.289,54			