Environmental Impact Assessment of a Residential Unit:

A Comparative Study

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A thesis submitted in partial fulfilment of

the requirements for the degree of

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This is to certify that the
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has been accepted towards the partial fulfilment

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THESIS ACCEPTANCE CERTIFICATE

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This thesis is dedicated to my parents, my advisor and my brothers

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Above all, I would like to thank ﷲ عزوجلwho always helped me throughout my life and to get through this degree and thesis.

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ABSTRACT

The world is facing the worst environmental issues like never before. Environmental adversaries across the globe have compelled the world to pay attention to reduce the environmental impacts. Urbanization is happening at an unprecedented scale all over the world. This study is an endeavor for measuring the environmental effects of the residential sector which represents a major chunk of urbanization. Research results based on LCA technique measured environmental impacts of a single residential unit. Environmental impact assessment showed various factors which are contributing to environmental degradation. It made the identification of factors easy which has the highest contribution, particulate matter formation in this case. Further analysis at the process level helped in identifying the process which is the root cause for highest environmental impacts, use phase of the building in this study, and improving that process will lower the impacts on environment. EIA is an excellent decision support system to make environmentally sensitive decisions which are vital in achieving sustainable development in the construction industry.

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LIST OF ABBREVIATIONS

AIA	American Institute of Architects
BIM	Building Information Modeling
EIA	Environmental Impact Assessment
LCA	Life Cycle Analysis
LCIA	Life Cycle Impact Assessment
OECD	Organization for Economic Co-operation and Development
KWh	Kilo Watt Hour
LCI	Life Cycle Inventory
LCCA	Life Cycle Cost Analysis
LCEA	Life Cycle Energy Analysis
GHG	Green House Gases
LEED	Leadership in Energy and Environmental Design
NREL	National Renewable Energy Laboratory
USGBC	U.S. Green Building Council
ISO	International Organization for Standardization
HAP	Hourly Analysis Program
RCC	Reinforced Cement Concrete
UNO	United Nations Organization

Chapter 1

INTRODUCTION

1.1 General

The construction industry is very diverse and vast in nature and, its history is parallel to human history. Evolution of construction industry is in progress from the very first day and it is evident that form the basic needs of shelter to the sophisticated and complex projects no one can deny its importance and almost eleven major industries run in tandem with the construction industry. A major chunk of the natural and human resource is attached with it and wherever the construction project is, that will disturb the natural habitat.

It is now proved that construction process has a huge impact on the environment (Jo et al., 2009; Zuo et al., 2012). Buildings, dams, infrastructure projects and all sorts of other construction activities consume natural resources and add a major share in greenhouse gases. Construction waste is also a major problem and a lot of research is available on it for example in China where a lot of mega projects were completed in last decade and still, there is no stop. For China, construction waste contributes to the 40% of countries waste and building stock of China contributes 25% of GHG and 30% of total energy consumption (Wang et al., 2010).

In the light of above and many challenges related to the construction industry and predicted by the World Business Council for Sustainable Development in his document named as *Vision 2050* and also says that buildings role is crucial in this respect. As construction projects have usually a life of almost 50 years and environmental impacts are not only associated with construction phase but also the whole life cycle of building and for sustainable development life cycle approach incorporation is necessary (Heeren et al., 2013; Lee et al., 2009; Mahlia et al., 2011; Sharma et al., 2011; Tae et al., 2011). Sustainable development includes many emerging ideas having far reaching effects and takes the construction process in its retrospect (Ardente et al., 2011; Cucchiella & D'Adamo, 2012; Dixit et al., 2013; Pacheco et al., 2012).

To incorporate the ideas of sustainable development in construction use of modern tools can't be overlooked as sustainable developments bring more stakeholders to the projects so there must be a tool which can serve the purpose of multi-objective decision tool. BIM has vast application in construction and proved to be useful. Manning and Messner (2008) used BIM in health care project and found BIM to be used as a multi objective decision tool, detailed information analysis, and collaboration. It is reported in the literature that 3-D simulations of BIM can provide an interesting insight and can give more logical sequencing and conflict identification (Oliveira, 2009). Many add-ons are available for performing the different analysis. LCA can also be applied via BIM. According to Porwal and Hewage (2013) benefits of BIM can be maximized by integration of stakeholders and parties involved in the process. So, with the help of BIM, using that as a tool LCA of buildings a better solution can be provided for the optimum design of the building which will cover the material selection process as well.

1.2 Problem Statement

Urbanization is a core issue for the modern world and it is worse when we consider this along with more imminent global threats like climate change. The residential sector is a major contributor in urbanization and by addressing its negative impacts is an excellent opportunity to prevent any further harm and a quick approach for achieving the sustainable development in the residential sector.

1.3 Research Objectives

a. To carry out environmental impact assessment of a residential unit.
b. To identify and improve the process which is having the highest impact based on EIA results.
c. To validate the results of the improved process.

Chapter 2

LITERATURE REVIEW

2.1 Urbanization and Carbon Emissions

Urbanization is a global phenomenon and we can define it as the number of people living in the urban areas or the movement of people from the rural area to the urban area resulting in the physical expansion in both horizontal and vertical direction. So, it is predicted that by 2050, 64.1% and 85.9% of the developing and developed world countries will be urbanized, respectively (Science Daily, 2014). UNPD (2014) predicts that this enormous urbanization phenomenon will affect the economic growth, resources, law and order situation, energy use and carbon emissions and by 2020 in developing countries urbanization will pass 50%. This report is clearly depicting the true picture that there is a dire need of sustainable development to survive and to provide the coming generations a better and safe future. According to the Busch and Kennan (2013) urbanization can have a negative and positive impact on the environment and big cities/metropolitans can be used as to combat the rising carbon emissions by sustainable development and advised three different ways to for this

- Excessive use of cars and buses must be abandoned instead encourage biking, walking and public transit.
- Low building energy use per person.
- Conserving forestland and other green spaces which store carbon.

The scope of this thesis is related to the buildings and we are more focused towards housing sector as this is a major consumer of energy throughout its life cycle which will be discussed later in detail encompassing all its factors and methods to reduce it. In large metropolitan cities around the world, there is a stiff competition for space and greater demand means less space for offices houses and which results in the less lightning heating and cooling demands which result ultimately in lower per-person carbon emission where as in developing countries per person carbon emissions are greater as shown in Figure 2.1.

Awareness regarding sustainability is growing and according to the rating reported by the Environmental Leader (2013) Sweden is considered to be the most sustainable country in the world but there are many objections on this and some consider it true as well but it depends on how one defines and quantifies the sustainability. According to the source mentioned above Australia, Switzerland, Denmark and Norway round out the top five. The United Kingdom ranks sixth, followed by Canada, Finland, USA, and Netherlands.

Environmental Leader (2013) defines the carbon emissions as the measure of the GHG caused by the business, society or individual. American Institute of Architect (AIA) issued a report in November 2014 and it is observed that since 2012 most of the building's design are in accordance with the AIA target for the 60% carbon reductions in buildings.

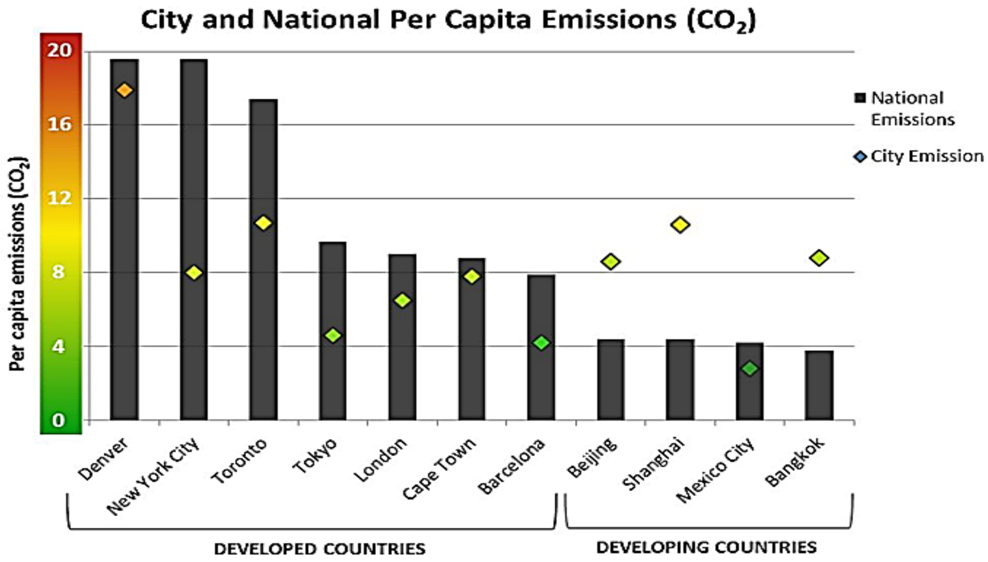

Figure 2.1: City and nations per capita emissions

In order to deal with the carbon emissions and methods to reduce it first, we have to look at the data which can provide us the categorical contribution of carbon emissions globally.

According to the CDIAC (2014) and Global Carbon Project (2014) latest results reveals that there is an increase of carbon emission by 2.3% (highest in human history) due to the burning of fossil fuel and cement production, the life line of any construction projects. The graphical representation is shown in Figure 2.2.

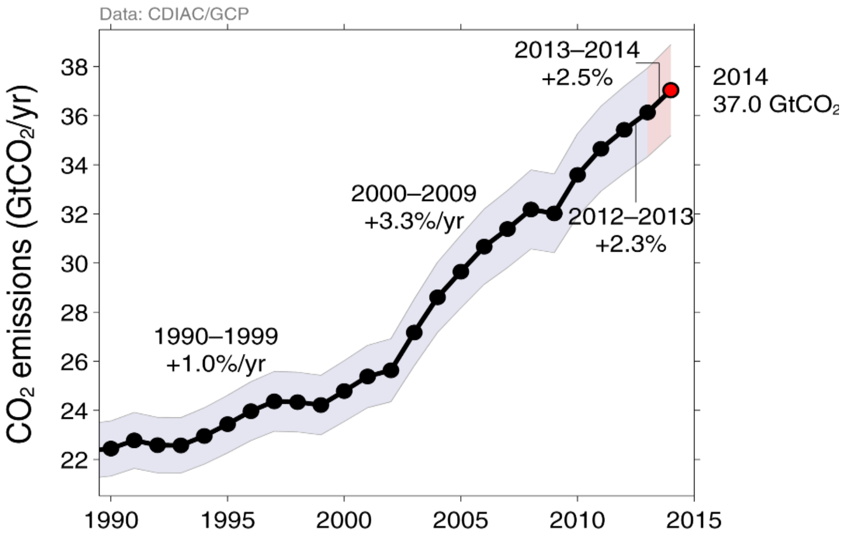

Figure 2.2: Carbon emissions due to fossil fuel use and cement production

Top fossil fuel emitters are USA 14%, China 28%, EU28 10%, and India 7% cover the 58% of global emissions whereas cement contribution in global emissions is 6% (CDIAC, 2014; Global Carbon Project, 2014).

2.2 Sustainable Development and Life Cycle Assessment

Li and Huang (2013) consider that study related to energy performance on the building has increased over the time and energy performance of the building is the prime target for all stake holders because of their adverse impacts on the environment. Sustainable development is a comprehensive approach and it encompasses many parameters which in isolation cannot fulfill the purpose of the sustainable development but in combination.

Sustainability is the most talked but least understood word. People's perception and aspects to deal with this thing have blurred the idea of sustainability. Most of the people think that it is just the green building, yes, it is, but just one part of it and essence of sustainability is the preservation of the environment, efficient use of resources, stable economic growth, poverty eradication and continual social progress as shown in Figure 2.3.

Figure 2.3: Sustainable development overview

Sustainable construction involves issues such as the design and management of buildings; materials performance; construction technology and processes; energy and resource efficiency in building, operation and maintenance; robust products and technologies; long-term monitoring; adherence to ethical standards; socially-viable environments; stakeholder participation; occupational health and safety and working conditions; innovative financing models; improvement to existing contextual conditions; interdependencies of landscape, infrastructure, urban fabric and architecture; flexibility in building use, function and change; and the dissemination of knowledge in related academic, technical and social contexts (Holcim Foundation, 2015).

According to OECD (2014) building construction sector has the largest potential because half of the population is living in urban areas and consume 40% of the world energy throughout its life cycle incorporating raw material production, construction, operation and maintenance and decommissioning. According to

Asdrubali (2009), greenhouses techniques can be very effective in reducing the energy demands saving fossil fuels and reduction in GHG also with that usage of sustainable material can have far reaching effect as less energy is required for their production as compared to the conventional ones.

According to Chou and Bui (2014), precise measurement of heating and cooling loads is a challenging task because of many influencing factors mentioned by researchers whereas heating and cooling loads are the measure of energy added or removed from a particular space to provide comfort for the habitat. Wan et al. (2011) and Parasonis et al. (2012) have identified many parameters for optimum building design like orientation, climate, surface area, wall area, roof area and relative compactness. All these factors can be grouped into two main categories physical properties and meteorological conditions which again are highly dependent on each other, control over these parameters individually is not as effective as we need an integrated approach incorporating all the parameters and considering all the phases of construction and for this life cycle assessment is considered to be the best techniques so far and it can also be used as a decision-making tool which is actually the scope of this thesis, an integrated approach of all parameters and their life cycle impact assessment.

Buildings structure and their parameters as mentioned above for the sustainable development coupled with the uniqueness, complexity, wide range of materials/components, long life of operation and maintenance have made this technically complex and uncertain. Life cycle assessment is vital for the quantification of environmental impact and energy demand during the entire life span of the building Zabalza Bribián et al. (2009). Life cycle assessment has various stages which cover the whole life of a product, assembly or component and it can be further sub divided into many components and processes. Standard life cycle analysis framework is shown in Figure 2.4.

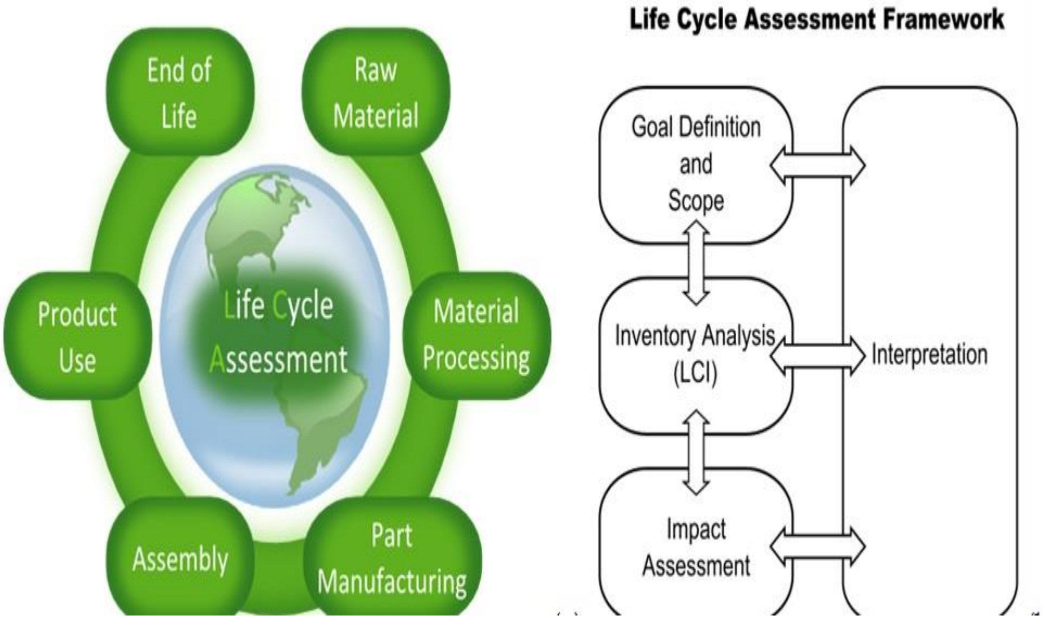

Figure 2.4: IS0 14040 frame work for the LCA

Energy demand in their life cycle can be classified into two types, direct and indirect. Indirect energy is used in the production of raw material and technical installation whereas direct energy is consumed while construction, renovation, demolition and usage of the facility. Life cycle assessment methods are not new but for construction, its usage started a decade ago. LCA knowledge is fragmented and can be found in many national and international journals and it is an authenticated approach. Many methods and procedures are developed for it and have a wide industrial application. The main advantage and reason for its popularity is its systematic and comprehensive approach to measure the environmental impacts of different products, procedures, and services over their life cycle. It can be very useful for selection, evaluation, and optimization of construction processes. Frame work stages of LCA according to ISO are shown in Table 2.1.

Table 2.1: ISO 14040 frame work fragmentation.

Frame work Stages	Establishes
Goal and scope definition	Functional units, system boundaries and quality criteria for inventory data
Life cycle inventory formation	Information on physical material and energy flows in life cycle
Life cycle impact assessment	Calculation of impact on various aspects of environment
Interpretation	Interpretation of the results obtained from the above stages

The concept of life cycle was developed mainly in the 70s and 80s. The main focus was the quantification of energy used, as part of the standard 14000 series International Organization for Standardization (ISO) has included 14040 series focusing on establishing methodologies for LCA (European Committee for Standardization). These distinctive stages will form the complete LCA. According to Ortiz et al. (2009); Sharma et al. (2011); Singh et al. (2010) and European commission of standardization from early 1990s it's been used to assess the product development but now it's widely used in objective evaluation of construction process but in recent past literature there are not much traces of this used as a decision tool, very few people have used it. Life cycle assessment can be done on many stages.

Following are the completely different classification found in literature Ortiz et al. (2009) LCA application for product selection

- LCA application for system process/system evaluation
- LCA tools and data base to the construction industry
- LCA methodological application related to the construction industry

2.3 Environmental Impact Assessment Studies

In Sweden, Jönsson et al. (1997) compared the environmental evaluation of three different material from their production and found solid wood flooring to be the best among three different (linoleum, vinyl flooring, and solid wood flooring) options.

According to Scheuer et al. (2003) it is very challenging to quantify the actual process of construction and demolition environmental effects as there is very less information available regarding production and manufacturing of materials. Nässén et al. (2012) compared the concrete and wooden frame structures the cost related to the CO_2, material, and energy as well as their carbon emissions. Gustavsson and Joelsson (2010) shows that for production primary energy use is around 60% for low energy houses and for conventional houses, it is 45% and all this is related to the variations in conventional houses and energy supply system. Energy efficient buildings are designed for the better efficiency, for better heating and cooling to lower the energy loads. A study carried out by Peuportier et al. (2013) concludes that occupants behavior strongly influence the performance of buildings. Embodied energy related issues are very critical in life cycle assessment and sufficient research is available on it. Construction types effect the content of embodied energy and different studies showed this e.g. Aye et al. (2012); Gong et al. (2012); Gustavsson and Joelsson (2010); Huberman and Pearlmutter (2008). Findings of these researchers show that in the transportation of concrete wood and steel frame works CO_2 emissions are 11%,12%, and 8% respectively.

Guggemos and Horvath (2006)proposed an augmented hybrid process based LCA model. Actually, this was a case study in which they analyzed the environmental effects of construction phase in construction and were of opinion at the end that if use phase is significantly larger than the construction phase, construction phase effects will be almost irrelevant as compared to use phase. This case study was for commercial buildings of California. However, construction phase environmental effects will have significance when we take all the processes at once for our research. Koroneos and Dompros (2007) suggested the use of low sulfur fuels to reduce the environmental impact of research on the brick production process in Greece by using eco indicator 95 aggregation method. Construction, use, and disposal phases were not included in the LCA boundaries for this research. Ximenes and Grant (2013) quantified the impacts of a wood product in Australia for flooring and result was to replace all the floor and sub floor products with timber floor for best results.

Van den Heede and De Belie (2012) published their results about the impacts of traditional and green concrete and apart from that they concluded that the variance in the results of the LCA is highly influenced by defining the system boundaries, functional units, inventory data, and choice of impact assessment method while applying ISO 14040.

To evaluate the environmental impacts of houses focusing on the direct and indirect environmental impact Citherlet and Defaux (2007) studied three different houses in Switzerland and conceded that direct environmental impact can be reduced by the use of better insulation and renewable energy sources. Guggemos and Horvath (2005) conducted the study in which they used two methods, one is process based LCA and EIO-LCA, compared two frame structures of concrete and steel and ultimately conclude that concrete structure has more energy emissions and associated use because of the longer time of installations.

Fay et al. (2000) carried out a comprehensive study and briefly discussed some theoretical issues related to the life cycle energy analysis by using an Australian model and in that they concluded that LCCA and LCEA results urge us to prioritize things over the whole life cycle. Choices must be justified in terms of their energy and cost. Radhi and Sharples (2013) carried out research on measuring the environmental impacts of facade material and studied five different scenarios. Later reported that best way to reduce the CO_2 is to control the emissions from concrete blocks as they covered the most of the façade of the building. Bilec et al. (2006) used a hybrid process based LCA model for the construction process and found that transportation of material has the largest impact among all factors considered like on-site water and electricity consumption, construction, equipment maintenance and production.

Similarly Muga et al. (2008) conducted a study and concluded that a built up roof and green roof for a building behaves differently in use and construction phase with respect to the emitted pollutants, given that green roof emits more pollutants in construction phase (material acquisition stage) but on use phase its pays back and overall impact in life cycle by using EIO-LCA it is evident that pollutants emitted by build up roofs are greater than green roofs by 46%. Studies related to the cost effectiveness and their payback periods are quite interesting and shows that not all the time it is true that environmental effect will keep the cost minimum most of the time they are not cost effective. Praditsmanont and Chungpaibulpatana (2008) conducted a case study based research and found that payback period of increased thickness is three to five years.

Researchers have carried out an extensive research but all the researchers have a different approach and dealing the different aspects of buildings but all believe that along with other factors building envelope, climatic conditions and study period effect financial benefit regarding building efficiency. Literature depicts that very few studies are there which provide an integrated design approach resulting the best optimize the solution. Von (2003) finds out that cost of obtaining the LEED certification for a building can be offset in 40-years study period in terms of energy saving and upfront cost can go as high as 250%. Energy performance of a building can't be measured from its LEED certification and literature shows that LEED certified buildings saves energy around 18%-39%, in comparison to the non-LEED buildings. Building that are not LEED certified use more energy per square feet (Newsham et al., 2009). Levinson and Akbari (2010) conducted research on 236 cities of US and four types of houses and determines that US saves \$0.356/m^2 annually across the US from the cool roofs. Cetiner and Özkan (2005) finds out after simulations on different glass facade designs that single facade design is more efficient than double facade as double facade is a costly solution. Kneifel (2010) concluded in research that on average 20-30% reduction in energy can be achieved by using the conventional methods.

There are several studies which are carried out to focus the energy performance and energy loads of the building and at NREL (National Renewable Energy Laboratory) many researchers have published articles based on energy simulations for whole building.(Griffith et al., 2007) devised a methodology with research on US commercial buildings and found that energy performance simulations is a data driven process and set of buildings types and location is necessary to represent building stock. However, life cycle economic and environmental indicators were not considered in this research. The emphasis of performing whole building design approach was devised by Torcellini et al. (2006) in his research for performance of buildings.

It is evident and well known that the use phase of the building is most critical and have contributions of 80-85% in energy use so this part must be well addressed and even at the cost of less gains in other stages (Ramesh et al., 2010; Richman et al., 2009; Sharma et al., 2011; Shu-hua et al., 2010). Norman et al. (2006)Carried out a research and proved that choice of functional unit is very important for the understanding of urban density effects and in their study, they chose two functional units

- Living area
- No of people living in an area (per capita concept).

Different data sets were used and for transportation GHG estimated they rely on Kennedy (2002) report for Greater Toronto area. Results of study showed that brick, concrete, windows and dry wall contribute more towards the GHG emissions, embodied energies and combined effect of all these contribute almost 60-70% of embodied energy. Proietti et al. (2013) conducted study to evaluate the combine effect of passive techniques and modern technology that concluded that energy saving measures can provide the significant effect on the reduction of environmental impact and that modern technology do not always provide positive effects although there are many factors involved in this and this need more debate but for a review purposes we are writing only the bottom line conclusion. Similar study was carried by Thiel et al. (2013) and Monahan and Powell (2011) but later study has more focus on embodied energy.

Kofoworola and Gheewala (2008) research showed that steel and concrete have huge impact related to the material and energies in use phase accounts for 52% of the energy use. Research was carried out for an office building in Thailand and LCA was used to access the impacts.

After a comprehensive literature study, it is evident that it is not easy to compare the different studies on LCA as every study has different boundaries, climatic conditions and local regulations so we have to look every study according to the research parameters and conditions defined by relevant researchers. Buyle et al. (2013) and Cabeza et al. (2014) concluded that most important phases of LCA are scope, topology of building, functional units, system boundaries and location.

After the survey of 60 LCA cases from the 9 different countries Sartori and Hestnes (2007) showed that design of low energy buildings can increase the embodied energy but can be useful in terms of total energy demand throughout the life cycle and there exists a linear relationship between the operating and total energy of building. According to Matar et al. (2010) sustainable construction is a new concept which brings together the concepts of construction and sustainability and widens the scope of the sustainability just to be known as green buildings. Sustainable development concept in research and its adoption in real construction projects in very popular and many organizations such as U.S. Green Building Council (USGBC) and building research establishment have developed the rating system to encourage this and to serve as a guide for the professionals working in this field. In spite of its popularity and its advantages but still there are many obstacles for its widespread adoption and various studies revealed that. Sustainable construction brings more players, complex construction methods, stakeholder of varying nature, new goals and objectives that requires quick information sharing, better collaboration and effective decision making which will lead the team towards common goal which is optimization of building system. Researchers decisive in believe that integrated design approach is better for the meeting goals of sustainable development and for this multi criteria decision tools can't be forgotten (Pulaski et al., 2006; Raphael, 2011).

2.4 Integrated Design Approach and Use of BIM

Integrated project design is the best practice for sustainable construction to reduce time and this has the capacity to introduce new trends as this system has much flexibility as compared to other systems (Hellmund et al., 2008). Most critical step during the design stage of project is the material and component selection of sustainable projects. Basbagill et al. (2013) emphasizes on its importance because sustainable projects have a limited choice regarding the selection of components and materials as not all the martial and components are economical and efficient.

Research of Bunz et al. (2006) conducted study on the LCA as a decision making tool, their research proposed that in design and material selection whole life cycle of the building must be kept in mind. Their research compares the responses from Europe, USA and Asia. Basbagill et al. (2013) emphasis that decisions made during the design stage have a critical impact.

Construction industry has benefitted from the technological advancements in information and communication for the user friendly and transparent support system for various purposes (Christiansson et al., 2010). As sustainable development encompasses many areas, its influence circle is very similar in sustainable construction and we have to look at the different aspects of project like environmental impacts, money, time for construction and energy absorption. It is the ICT which according to the Verbeeck and Hens (2010) provide tools which facilitates the decision making as a whole and not at an individual level which cause unexpected results but this doesn't deny the importance of the individual evaluation because sometimes we need individual behavior of the components for specific design purposes.

Building information modelling is an advanced form of the ICT. It allows working and collaboration among the different parties working on projects. In construction industry ICT is used for various purposes but major purposes are

- Communication
- Information gathering and retrieval
- Processing information and computing for analysis

BIM is also used to support sustainable aspects of projects such as life cycle analysis (Wang et al., 2011).Royal Institute of British Architects (RIBA) has devised a process for construction and that is known as *RIBA work stage* which is used for construction purposes but denied the importance of life cycle assessment. Loh et al. (2009) with the help of BIM proposed that at the early stage of the design (such as material selection and conceptual design) life cycle assessment can be inserted as a sub process of RIBA with environment consideration. Additional information regarding the benefits of BIM is discussed in the many researches e.g. (Azhar, 2011; Azhar et al., 2008; Teicholz et al., 2011).

Chapter 3

METHODOLOGY

According to the American Institute of Architects (AIA) buildings designed using the integrated design process are the best designed, more efficient and environmentally sustainable as different departments work together from project conception to achieve certain targets which otherwise are not possible. In integrated design approach, a team from the outset of a project is able to consider the building and its components as a whole system and ultimately a better engineered, low cost and efficient building. Sustainability isn’t just the environmentally viable solution but it is multi objective in nature and construction industry is one which is in dire need of sustainability.

The scope of this thesis is to carry out the environmental impact assessment of the residential unit and to identify which factor is contributing the most in a whole life cycle. In this study, it is a house model. The reason to select housing sector is in the light of urbanization, as it is fast growing and happening globally. Our solution will be more aligned with current practices and to provide improvements in those factors. The best thing is that all these techniques can be applied to any construction work as we know the basic components and materials are more or less same.

The whole idea of environmental impact assessment is that it not only incorporates the idea of life cycle analysis but also to get control over each and every component of building construction with a number of alternatives and a better decision support system for decision making.

Methodological framework for this study is given below in Fig 3.1

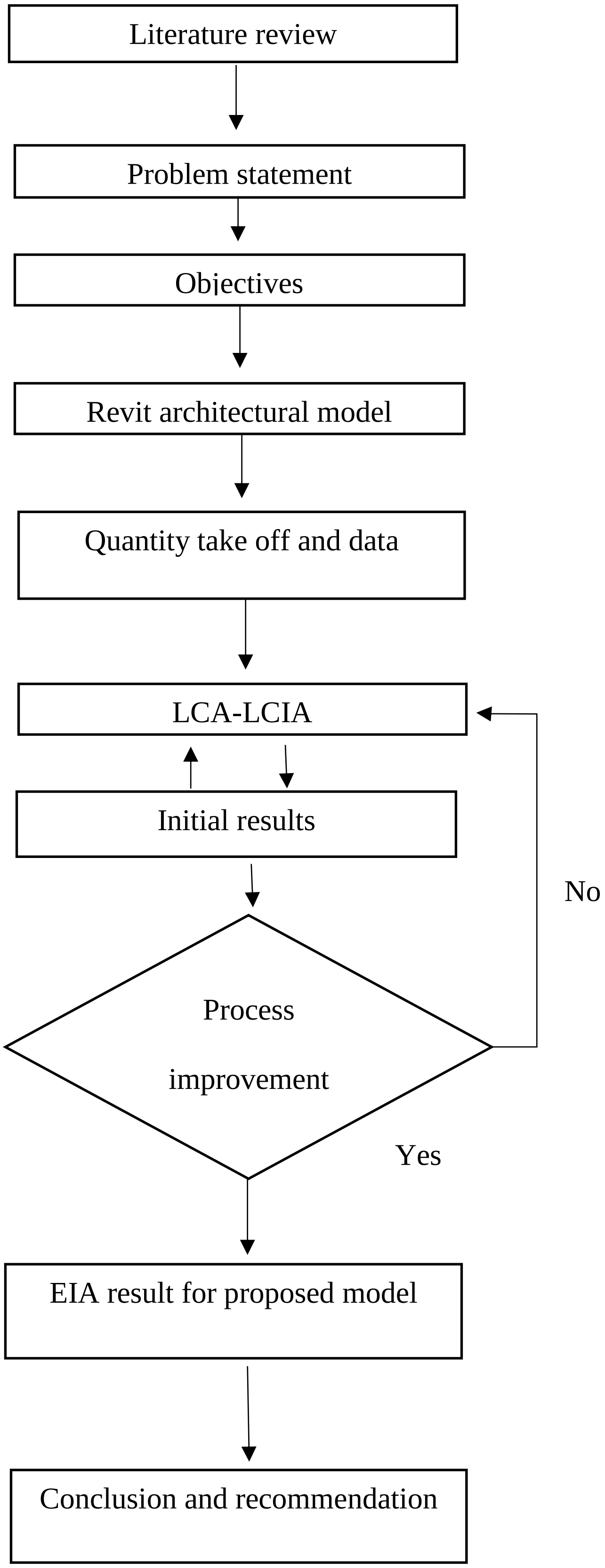

Figure 3.1: Methodological frame work

3.1 Life Cycle Analysis

Life cycle assessment is the most important part of our work as the results from this analysis will be used to assess which component is contributing the most. Life cycle assessment will be carried out according to the standard method discussed in ISO 14040 and 14044. According to the ISO standards, LCA includes four steps,

a. Goal and scope definition
b. Life cycle inventory
c. Life cycle impact analysis
d. Interpretation of results

3.2 Goal and Scope Definition

Goal and scope part of the LCA is used to describe an overall purpose of the study and clearly stating the scope of the study as LCA is a very vast technique so one has to clearly define scope so that the purpose of the study doesn't get swayed by the absence of scope.

The goal of this study is to measure the environmental impacts of a residential unit to find out the factors or processes which contribute the most to the whole building life cycle analysis and to reduce the impact of that factors or processes.

The scope of the project is that the LCA will be used to carry out EIA taking the life of building as fifty years. LCA will be carried out on simapro software.

3.2.1 BIM model

BIM model of the house has been developed in Autodesk Revit software. Material quantity data take off was carried out from BIM including all the areas, dimensions and other properties required for this study. Revit BIM model picture is shown in Figure 3.2.

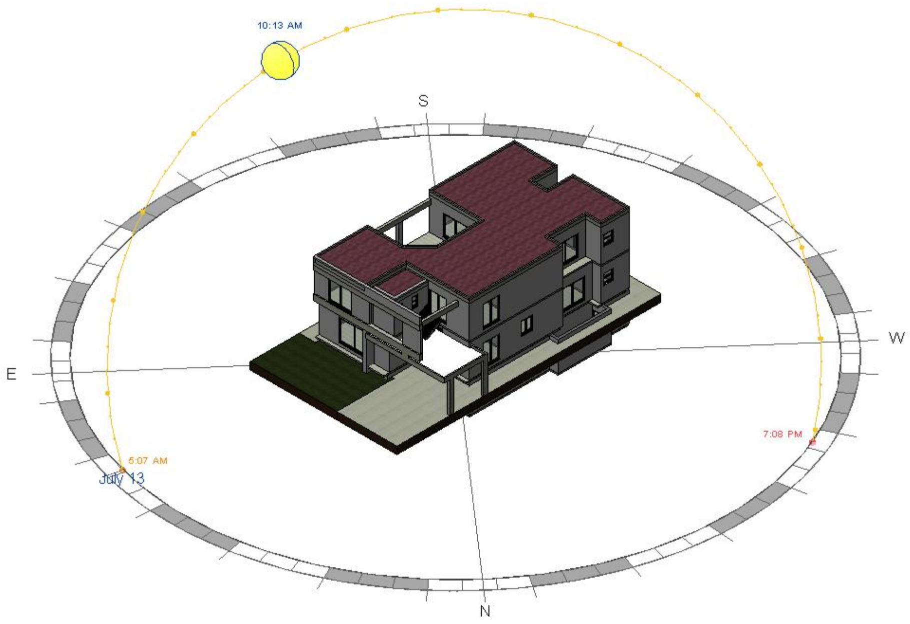

Figure 3.2: Architectural model in Autodesk Revit architecture

General information regarding the project is shown in Table 3.1

Table 3.1: General information of residential unit

Location	Phase 6 DHA Lahore
Total plot area	4500 ft^2
Total covered area	7300 ft^2
Orientation	North-East
Ceiling height	3.2m

Total material quantity take-off is shown in Table 3.2. Wastage amount is also included in this quantity take off

Table 3.2: Total material quantity take off

Total Quantity Take off		
Process	**Quantity**	**Unit**
Excavation	692	m^3
Brick Work	103828	Bricks
Plastering	30383	sq.ft
Painting Area	30383	Sq.ft
Flooring Area	7300.62	Sq.ft
RCC Total	219.92	m^3
Glass	1356	Sq.ft
Wood	1332	Sq.ft

Eco-invent data base will be used for the input materials in Simapro.

3.2.2 Functional unit

The functional unit is defined as the value to which we refer our input and output values. In current study, it is taken as m^2. All values refer this on a unit level but in process development, we inserted values in Kg. The reason for taking the amount in mass is to specify the waste type at the process development stage in the simapro, otherwise waste calculation will not be incorporated in the life cycle analysis.

3.3 System Boundaries

System boundaries determine which process are included in the LCA study. The building is broken down into the process units encompassing all material, components, and elements that constitute the building. System boundary for the complete life cycle of this study is *'Cradle to Grave'*.

System boundaries strongly influence the input, output and the results of the study as all the inputs depend upon the system boundaries of the project.

This study comprises of three distinct phases.

a. Construction phase
b. Use phase
c. End of life or Waste scenario.

3.3.1 Construction phase

This phase deals with the material used for the construction and their complete data regarding extraction of material from the natural resources, transportation of that material to the manufacturing facility and energy used in making a ready to market product. One aspect needs to be noted carefully that how much-recycled material is being added in the production of that material and that amount has to be specified in the simapro analysis in avoided products tab. Eco-invent data base is used for all construction materials.

3.3.2 Building construction

This phase deals with the building construction related processes and consider all the processes involved in the transportation of material from the production facility to the actual assembly of the construction. Input comprise of data regarding transportation of material and energy used in the assembling the unit process. Frame work of this phase is shown in Figure 3.3.

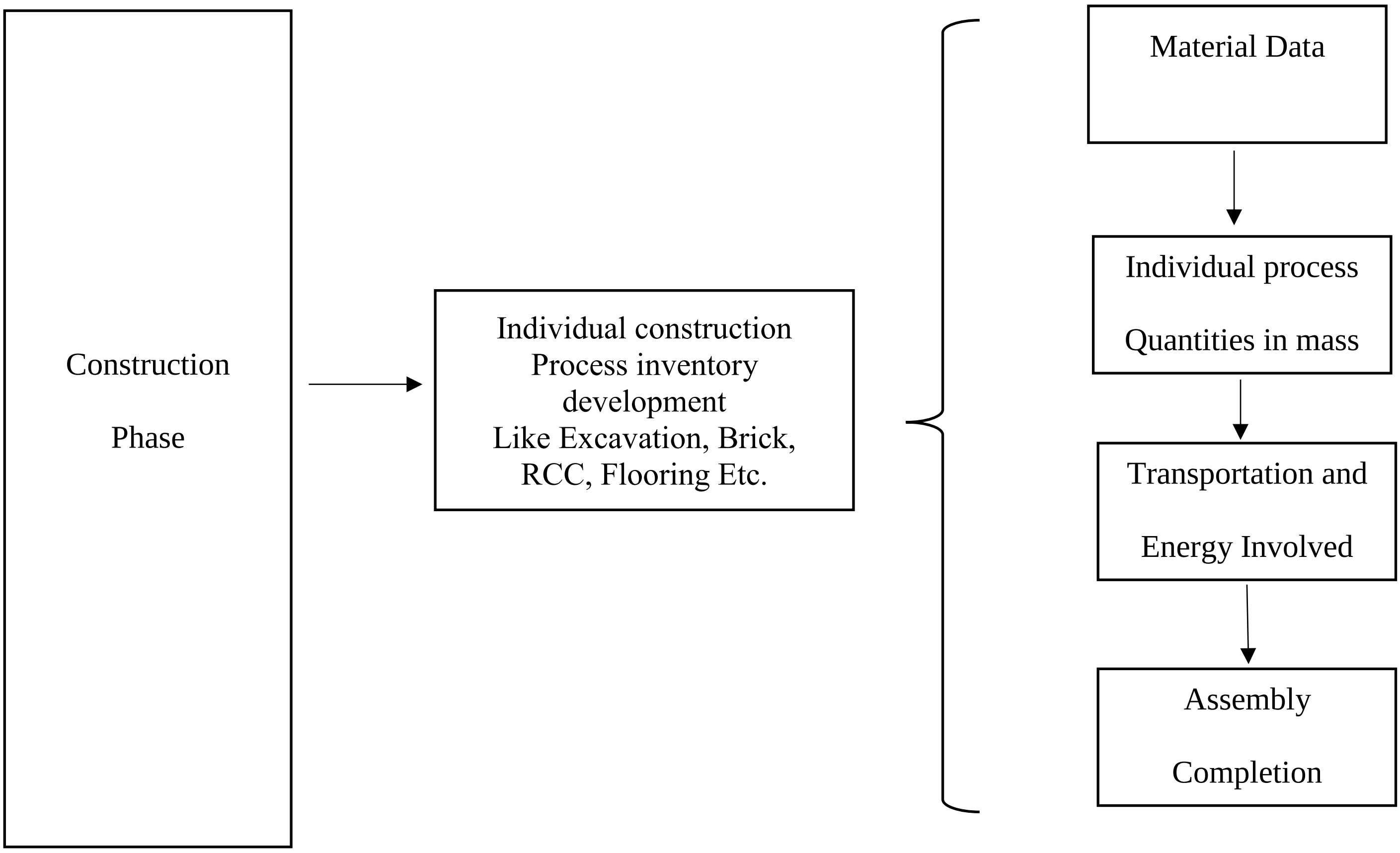

Figure 3.3: LCA system boundary for the construction Phase

3.3.3 Use phase

All activities related to the use of building are included in this phase. This phase includes all operating energy for heating, cooling, lighting and powering appliances. LCA system boundary frame work for use phase is shown in Figure 3.4.

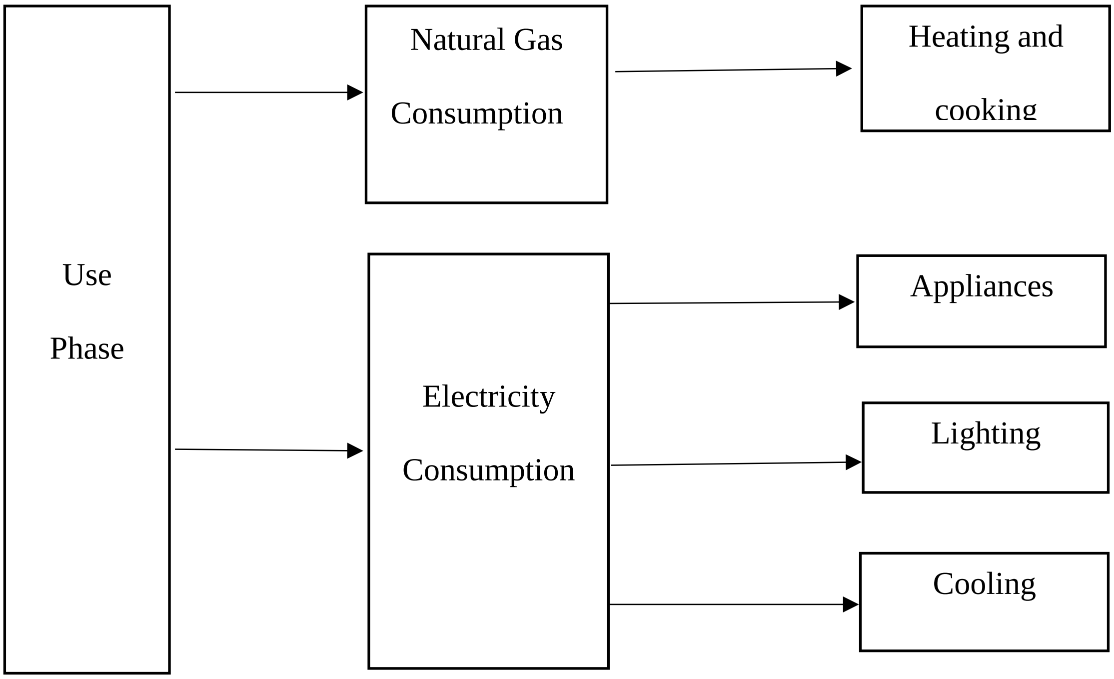

Figure 3.4: LCA system boundary for the use phase of the building

3.3.3.1 HAP energy modelling

Hourly Analysis Program (HAP) is used for the energy simulations to quantify the energy consumption in the use phase of the building. In HAP, we input data related to weather, space dimensions, exposure surfaces and appliance and lighting load.

3.3.3.2 Weather input data

The first model that we simulated in HAP is known as a Base model or scenario 1. In this case, the weather data we used is shown in Table 3.3

Table 3.3: Weather input data for the scenario 1

Weather Data	
Latitude	31.5
longitude	72.5
Elevation	712 ft.
Summer design DB	115 F
Summer coincident WB	84 F
Summer daily range	36 F
Winter design DB	37.9 F
Winter coincident WB	30 F
Atmospheric clearance number	0.9
Average ground reflectance	0.1
Soil conductivity	0.75

Values for the Atmospheric Clearance number, Average ground reflectance, and soil conductivity were taken from the HVAC design consultants.

3.3.3.3 Space input data

In order to carry out energy modeling we have to define each space individually in HAP and for that, we need complete data of that space. In our case, we have taken values from the BIM model as far as the information regarding the building geometry is concerned. Detailed information is given in Table 3.4.

Table 3.4: Individual space information for base model

Spaces	General				Overhead Lightening				Task Lighting	Walls. Windows, Doors				Roof, Skylight				Partition				
First Floor level	Name	Floor Area	Avg Ceiling Height	Building Weight	Fixture Type	Wattage	ES, TL	Ballast Multiplier	Wattage	Exposure	Wall Gross Area	Windows	Doors	Exposure	Roof Gross Area	Roof slope	Skylight Quantity	Area	Unconditioned space Max Temp	Ambient at space Max Temp	Unconditioned Space Min Temp	Ambient at Space Min Temp
Room 6	Room 6	251.76	10.5	70	Recessed vented	112	4,1	1	5	SE	173.67	0		H	251.76	0	0	117.9	105	115	86	93
										EN	187.16	1 Area 56 (8*7)				0	0					
										SW	125.16					0	0					
Room 4	Room 4	297.11	10.5	70	Recessed vented	152	3,2	1	10	SE	196.035	0				0	0		105	115	86	93
										EN	167.16	1 Area 56 (8*7)		H	297.11	0	0	141.2				
Room 5	Room 5	199.13	10.5	70	Recessed vented	88	2,1	1	5	NW	135.66	1 Area 56 (8*7)		H	199.13	0	0	135.9				
Lounge 3	Lounge 3	317.66	10.5	70	Recessed vented	200	5,2	1	0	NW	167.16	0				0	0		105	115	86	93
								1		SE	71.25	1 Area 71.25(9.5*7.5)		H	317.66	0	0	166.5				
																0	0					
Wash Room 5	Wash Room 5	72.32	10.5	70	Recessed vented	48	2,0	1	0							0	0		105	115	86	93
Wash Room 6	Wash Room 6	101.8	10.5	70	Recessed vented	48	2,0	1	0							0	0		105	115	86	93
Wash Room 7	Wash Room 7	137.22	10.5	70	Recessed vented	72	3,0	1	0							0	0		105	115	86	93
Open Space +Lobby	Open Space +Lobby	297.3	10.5	70	Recessed vented	152	3,2	1	10							0	0		105	115	86	93
Ground Floor level																						
Drawing room	Drawing room	226.3	10.5	70	Recessed vented	200	5,2	1	10	SE	156.19			Ground floor so nothing is exposed		0	0		105	115	86	93
										EN	167.16	1 Area 72(10*7.5)				0	0	95.72				
																0	0					
Lounge 2	Lounge 2	523.22	10.5	70	Recessed vented	224	6,2	1	10	SE	219.66	1 Area 75(10*7.5)				0	0	74	105	115	86	93
																		114.9				
																		118.4				
Kitchen	Kitchen	123.69	10.5	70	Recessed vented	152	3,2	1	0	NW	166.22	1 Area (4*4.5)				0	0					
Master Bed Room	Bed Room 2	317.01	10.5	70	Recessed vented	176	4,2	1	15	SE	209.16	1 Area 56 (8*7)				0	0	141.2	105	115	86	93
																0	0					
Bed Room 3	Bed Room 3	239.03	10.5	70	Recessed vented	112	4,1	1	10	NW	135.66	1 Area 56 (8*7)				0	0	56.91	105	115	86	93
																0	0	185.5				
Wardrobe	Wardrobe	110.88	10.5	70	Recessed vented	72	3,0	1	0							0	0		105	115	86	93

Spaces	General				Overhead Lightening				Task Lighting	Walls. Windows, Doors				Roof, Skylight				Partition				
First Floor level	**Name**	**Floor Area**	**Avg Ceiling Height**	**Building Weight**	**Fixture Type**	**Wattage**	**ES, TL**	**Ballast Multiplier**	**Wattage**	**Exposure**	**Wall Gross Area**	**Windows**	**Doors**	**Exposure**	**Roof Gross Area**	**Roof slope**	**Skylight Quantity**	**Area**	**Unconditioned space Max Temp**	**Ambient at space Max Temp**	**Unconditioned Space Min Temp**	**Ambient at Space Min Temp**
Wash Room 3	Wash Room 3	88.76	10.5	70	Recessed vented	88	2,1	1	0							0	0		105	115	86	93
Store Room 3	Store Room	69.48	10.5	70	Recessed vented	72	3,0	1	0							0	0		105	115	86	93
Wash Room 4	Wash Room 4	38.32	10.5	70	Recessed vented	48	2,0	1	0							0	0		105	115	86	93
Kitchen	Kitchen	124	10.5	70	Recessed vented	136	4,1	1	0													
lobby	lobby	296.24	10.5	70	Recessed vented	152	3,2	1	0							0	0		105	115	86	93
Basement Floor Level																						
										Nothing is exposed of Basement				Nothing is exposed of Basement								
Lounge 1	Lounge 1	599.7	11	70	Recessed vented	312	8,3	1	0							0	0		105	115	86	93
																0	0					
Bed Room 1	Bed Room 1	234.28	11	70	Recessed vented	136	4,1	1	10							0	0		105	115	86	93
																0	0					
Living Room 1	Living Room 1	307.8	11	70	Recessed vented	176	4,2	1	10							0	0		105	115	86	93
																0	0					
Servant Room 1	Servant Room 1	136.37	11	70	Recessed vented	112	4,1	1	0							0	0		105	115	86	93
Servant Room 2	Servant Room 2	78.51	11	70	Recessed vented	88	2,1	1	0							0	0		105	115	86	93
Wash Room 1	Wash Room 1	43.88	11	70	Recessed vented	48	2,0	1	0							0	0		105	115	86	93
Wash Room 2	Wash Room 2	78.36	11	70	Recessed vented	72	3,0	1	0							0	0		105	115	86	93
Store	Store	80	11	70	Recessed vented	98	4,0	1	0													

Appliances and lighting wattage consumption was collected from available online manuals and market. Detailed information regarding appliance and lighting is given in Table 3.5.

Table 3.5: Appliances and lighting wattage, brand and model numbers

Scenario 1		
Electrical equipment	**Brand**	**Wattage**
Energy saver	Philips	24
Task light	Crest CR-LGS-SL	5
Tube light	Philips	40
Fan	Royal fan	120
Exhaust Fan	Royal fan	35
Sandwich maker	Philips HD2393	820
Toaster	ANEX AG3017	870
Laser jet printer	HP LaserJet Pro M402dn	591
Dry Iron	Philips	1200
Hair dryer	Philips (BDH 004)	1800
Electric shaver	Philips (9000 Series)	9
LED TV	Samsung (32" HD Flat TV J4003 Series 4)	48
Laptop	HP	120
Hair Straightener	Burn (Stain Hair 3)	140
Meat mincer	Molineux (Hv8)	1700
Microwave oven	23L Haier (HGN-2390EGT)	900
Food processor	Kenwood (FP-735)	1000
Juicer all in one	Haier HJE-1024	500
Refrigerator	Orient Zero Bazel series	170
Water dispenser	Orient -OWD533	100

3.3.3.4 Windows

Windows are an important component of the building and play a vital role in thermal comfort, illuminance, and aesthetics of the building. In HAP energy modeling, one needs to put information of windows and one has an option either to put detailed information on its characteristics, like solar heat gain coefficient

(SHGC), transmissivity, reflectivity, and absorption or just put the values for overall shading coefficient and U-value along with sizing. For the base model, we have inserted the values of overall shading coefficient and U-values directly with the dimension of windows. Windows used in the base model are single glazed. U-value and shading coefficient is given below.

U-value = 0.910 BTU/hr/ft^2/F

Shading coefficient =0.82

Glass manufacturer of windows is Ghani glass Pvt. Ltd. Values are taken from the manufacturer.

3.3.3.5 Wall and roof

These are important components of the building envelope and provide thermal and acoustical comfort to the occupants. Exposed wall and roof area is very important in HAP energy modeling along with thermal resistance values. While defining the HAP defining material for wall and roof is important as based on those materials HAP will calculate the overall U-value. HAP has a data base for the most common materials used in construction if the desired material is not there one can edit the existing data or can add completely new data set for the material. In the base model, there is no insulation for roofs and walls in base model. Overall U-values for roof and walls are given below

Over all U-value for Wall = 0.356 BTU/hr/ft^2/F

Over all U-value for Partition walls = 0.425 BTU/hr/ft^2/F

Over all U-value for Roof = 0.095 BTU/hr/ft^2/F

3.4 End of Life

This system boundary deals with the processes related to the demolition of the building and transportation of them to the recycling or dumping place. LCA system boundary for the End of life phase is shown in Figure 3.5.

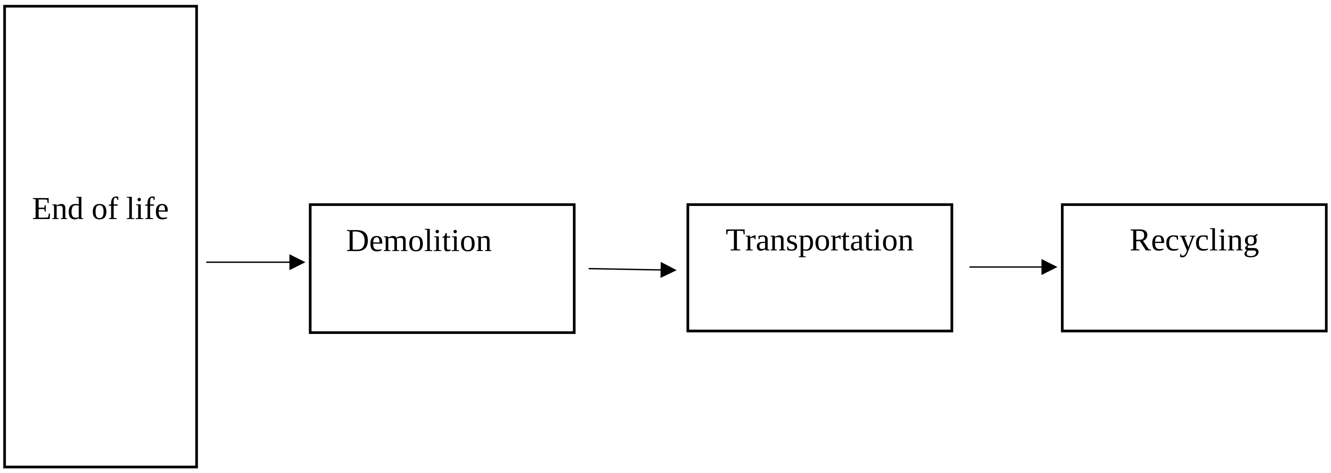

Figure 3.5: LCA system boundary for the End of life phase

End of life scenario distribution is shown in Table 3.6.

Table 3.6: End of life scenario

Description	Recycling Percentage
Steel	100% recycled
Inert waste	100% land filled
Municipal waste	50% recycled, 50 % land filled
Glass	100% recycled
Waste concrete (Without rebar)	60% reused rest land filled
Wood	50 % recycled, 50% burnt

Percentages used for the end of life scenarios are taken from contractors.

3.5 Inventory Analysis

Inventory analysis comprises of all the data required for the LCA to be carried out and distinctive inventory of each process needs to be developed. The inventory contains all input and output data of all the processes based on the functional unit and each process has to be defined separately and mention of waste type is necessary. Eco-invent data base is being used for the input and output values of the project processes, and their mass quantifications are project specific along with the distance of transportation. Total amount of inventory data that will be used at the product stage development is shown in Table 3.7.

Table 3.7: Inventory processes amount in mass unit

Description	Quantity	Unit
Brick wall	450	Ton
RCC	547	Ton
Wood	0.92	Ton
Glass	1.8	Ton
Plaster and Paint	65	Ton
Flooring	10.7	Ton

Distances for the transportation of material are taken from the material suppliers and distance for some materials like ceramic tiles are taken from the market distance to the construction site. Reason for taking the materials from the market is that we want to neglect the infrastructure related emissions. In actual material suppliers at the city level provide materials for small scale projects like residential so we have neglected the transportation emissions for very large distances.

3.6 Life Cycle Impact Analysis

Life cycle impact assessment is the part of life cycle analysis where we combine all the processes and carryout impact assessment based on the method selected for the evaluation. In this study method used for evaluation is ReCiPe Midpoint I V1.13/World ReCiPe I.

In this study end of life phase doesn’t include the impacts regarding the reproduction (making new materials from recycling process) as they are secondary goods and out of the scope of this research. Analysis performed based on the methodology and three stages mentioned above will generate results and analysis will be performed on Simapro and conclusions will be drawn from those results.

Chapter 4

RESULTS AND PROCESS IMPROVEMENT

4.1 Preliminary Environmental Impact Assessment Results

Based on the developed inventory in simapro, LCIA was carried out to evaluate the environmental impact assessment by selecting the ReCiPe Midpoint (I) V1.13 World Recipe I method. In this method, we have excluded the long-term emissions. LCIA normalization result for base model is shown in Fig 4.1.

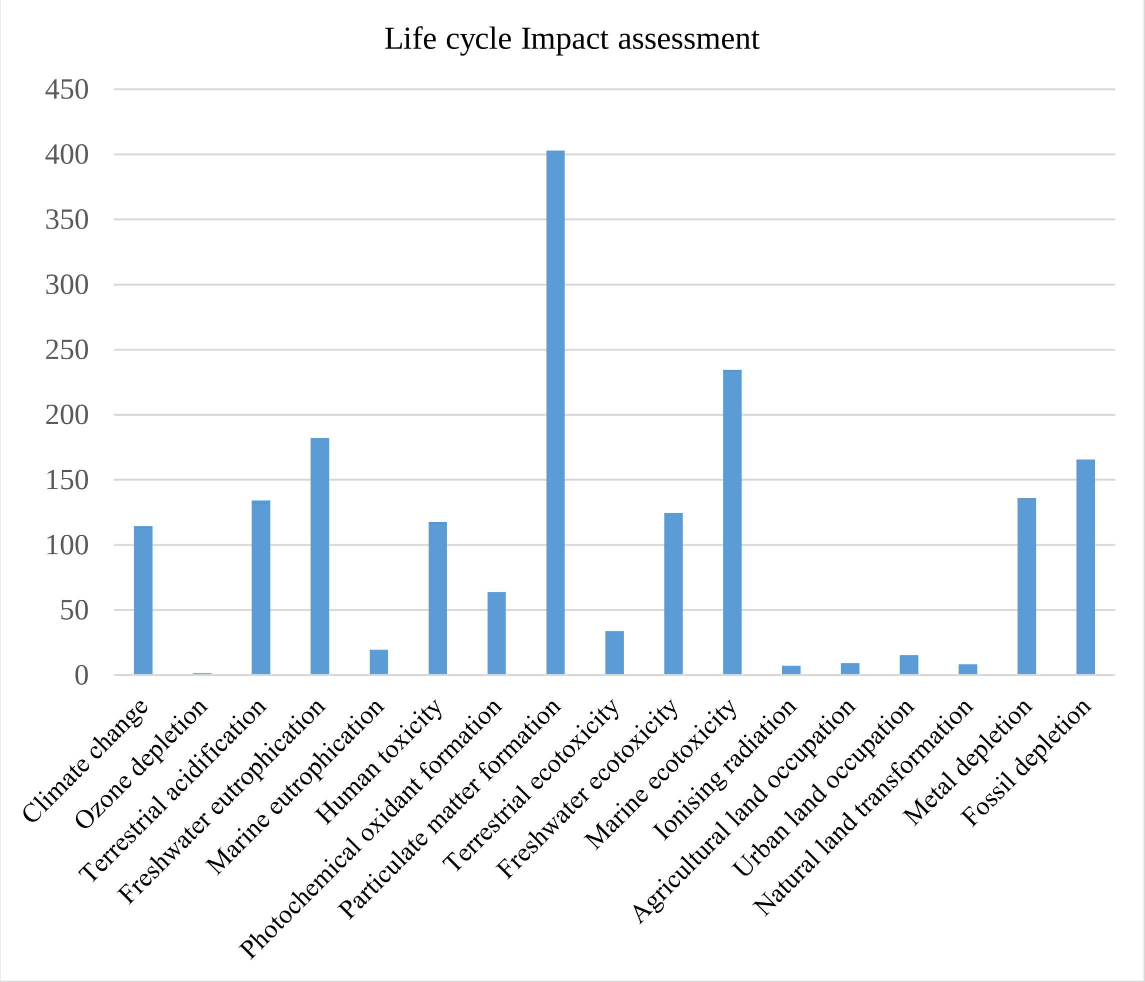

Figure 4.1: LCIA of base model (normalization values)

Initial results of environmental impact assessment of a residential unit (base model) revealed that most contribution in the environmental degradation is from the particulate matter formation and its normalization value is 403.

Now we have to evaluate each and individual process to see that which process is contributing to this particulate matter formation. LCIA results of each process are given in Fig 4.2.

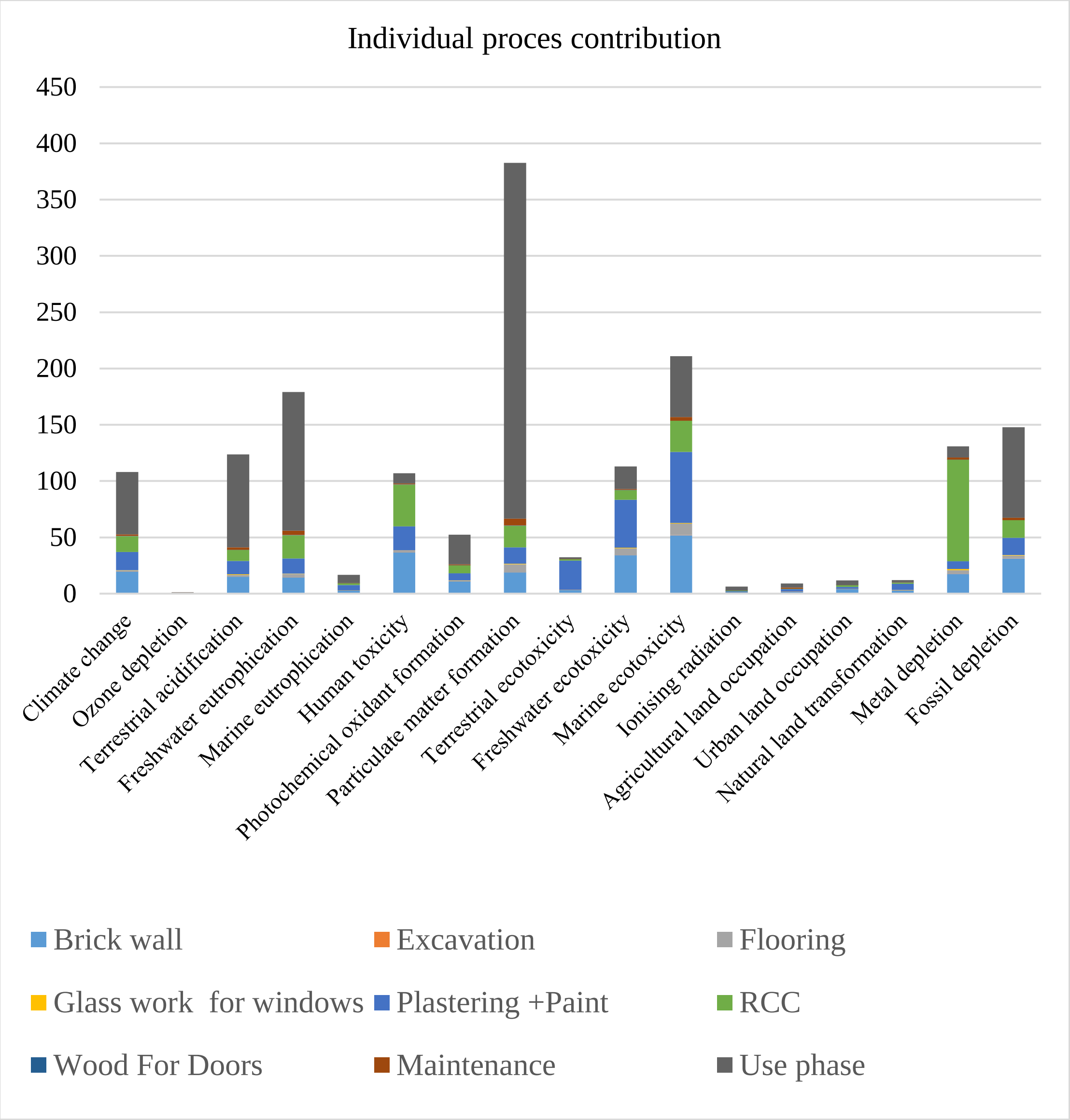

Figure 4.2: Individual process contribution (normalization values)

LCIA of individual processes made it easy to identify which individual process is having a large impact in particulate formation and that is the use phase of the building.

4.2 Use Phase Process Improvement

In the light of LCIA of whole building and LCIA of the individual processes, it is identified that use phase is consuming the most of the energy and this needs to be improved. To improve the use phase energy consumption process, we will perform energy modeling to improve the energy consumption in use phase of the building.

4.3 HAP Modeling for Proposed Model

HAP energy modeling for the proposed model will be performed, aimed at reducing the energy consumption by reducing the cooling demand of the building (Envelope Improvement), using energy efficient appliances and lighting without compromising the quality and functionality. Theproposed model is denoted as Scenario 2. The whole idea behind these proposed changes is to lower the wattage consumption by using efficient appliances and lighting devices coupled with reduced demand of cooling load.

4.3.1 Weather input data

Weather data will remain the same for proposed and base model.

4.3.2 Space input data proposed model

As it is already being discussed in base model that space definition is an important phase of the building and contains all the data regarding the modeling. Space input data for proposed model is shown in Table 4.1.

Table 4.1: Space input data for scenario 2

Spaces	General				Overhead Lightening				Task Lighting	Walls. Windows, Doors				Roof, Skylight				Partition				
First Floor level	Name	Floor Area	Avg Ceiling Height	Building Weight	Fixture Type	Wattage	ES, TL	Ballast Multiplier	Wattage	Exposure	Wall Gross Area	Windows	Doors	Exposure	Roof Gross Area	Roof slope	Skylight Quantity	Area	Unconditioned space Max Temp	Ambient at space Max Temp	Unconditioned Space Min Temp	Ambient at Space Min Temp
Room 6	Room 6	251.76	10.5	70	Recessed vented	65	4,1	1	2.5	SE	173.67	0		H	251.76	0	0	117.9	105	115	86	93
										EN	187.16	1 Area 56 (8*7)				0	0					
										SW	125.16					0	0					
Room 4	Room 4	297.11	10.5	70	Recessed vented	91	3,2	1	5	SE	196.035	0				0	0		105	115	86	93
										EN	167.16	1 Area 56 (8*7)		H	297.11	0	0	141.2				
Room 5	Room 5	199.13	10.5	70	Recessed vented	52	2,1	1	2.5	NW	135.66	1 Area 56 (8*7)		H	199.13	0	0	135.9				
Lounge 3	Lounge 3	317.66	10.5	70	Recessed vented	91	5,2	1	0	NW	167.16	0				0	0		105	115	86	93
								1		SE	71.25	1 Area 71.25(9.5*7.5)		H	317.66	0	0	166.5				
																0	0					
Wash Room 5	Wash Room 5	72.32	10.5	70	Recessed vented	26	2,0	1	0							0	0		105	115	86	93
Wash Room 6	Wash Room 6	101.8	10.5	70	Recessed vented	26	2,0	1	0							0	0		105	115	86	93
Wash Room 7	Wash Room 7	137.22	10.5	70	Recessed vented	39	3,0	1	0							0	0		105	115	86	93
Open Space +Lobby	Open Space +Lobby	297.3	10.5	70	Recessed vented	91	3,2	1	5							0	0		105	115	86	93
																0	0					
																0	0					
Ground Floor level																0	0					
Drawing room	Drawing room	226.3	10.5	70	Recessed vented	117	5,2	1	5	SE	156.19			Ground floor so nothing is exposed		0	0		105	115	86	93
										EN	167.16	1 Area 72(10*7.5)				0	0	95.72				
																0	0					
Lounge 2	Lounge 2	523.22	10.5	70	Recessed vented	130	6,2	1	5	SE	219.66	1 Area 75(10*7.5)				0	0	74	105	115	86	93
																0	0	114.9				
																0	0	118.4				
Kitchen	Kitchen	123.69	10.5	70	Recessed vented	91	3,2	1	0	NW	166.22	1 Area (4*4.5)				0	0					
Master Bed Room	Bed Room 2	317.01	10.5	70	Recessed vented	104	4,2	1	7.5	SE	209.16	1 Area 56 (8*7)				0	0	141.2	105	115	86	93
																0	0					
Bed Room 3	Bed Room 3	239.03	10.5	70	Recessed vented	65	4,1	1	5	NW	135.66	1 Area 56 (8*7)				0	0	56.91	105	115	86	93
																0	0	185.5				
Wardrobe	Wardrobe	110.88	10.5	70	Recessed vented	39	3,0	1	0							0	0		105	115	86	93
Wash Room 3	Wash Room 3	88.76	10.5	70	Recessed vented	52	2,1	1	0							0	0		105	115	86	93

Spaces	General				Overhead Lightening				Task Lighting	Walls. Windows, Doors				Roof, Skylight				Partition				
First Floor level	Name	Floor Area	Avg Ceiling Height	Building Weight	Fixture Type	Wattage	ES, TL	Ballast Multiplier	Wattage	Exposure	Wall Gross Area	Windows	Doors	Exposure	Roof Gross Area	Roof slope	Skylight Quantity	Area	Unconditioned space Max Temp	Ambient at space Max Temp	Unconditioned Space Min Temp	Ambient at Space Min Temp
Store Room 3	Store Room	69.48	10.5	70	Recessed vented	39	3,0	1	0							0	0		105	115	86	93
Wash Room 4	Wash Room 4	38.32	10.5	70	Recessed vented	26	2,0	1	0							0	0		105	115	86	93
Kitchen	Kitchen	124	10.5	70	Recessed vented	78	4,1	1	0													
lobby	lobby	296.24	10.5	70	Recessed vented	91	3,2	1	0							0	0		105	115	86	93
										Nothing is exposed of Basement				Nothing is exposed of Basement		0	0					
Lounge 1	Lounge 1	599.7	11	70	Recessed vented	182	8,3	1	0							0	0		105	115	86	93
																0	0					
Bed Room 1	Bed Room 1	234.28	11	70	Recessed vented	92	4,1	1	5							0	0		105	115	86	93
																0	0					
Living Room 1	Living Room 1	307.8	11	70	Recessed vented	104	4,2	1	5							0	0		105	115	86	93
																0	0					
Servant Room 1	Servant Room 1	136.37	11	70	Recessed vented	65	4,1	1	0							0	0		105	115	86	93
Servant Room 2	Servant Room 2	78.51	11	70	Recessed vented	52	2,1	1	0							0	0		105	115	86	93
Wash Room 1	Wash Room 1	43.88	11	70	Recessed vented	26	2,0	1	0							0	0		105	115	86	93
Wash Room 2	Wash Room 2	78.36	11	70	Recessed vented	39	3,0	1	0							0	0		105	115	86	93
Store	Store	80	11	70	Recessed vented	52	4,0	1	0													

4.3.3 Proposed model changes

Changes made in base model are aimed at reducing the total wattage demand of the house. In this study, we are not only using the appliances and lighting those are energy efficient but changing the hotspots in envelope to improve the energy performance at the same time.

4.3.4 Appliances and lighting

Energy efficient lighting and appliances have been advised for the proposed model without compromising the functionality and quality. Percentage difference between the wattage of appliances and lighting for both the scenarios is shown in Table 4.2

Table 4.2: Appliances and lighting comparison of both scenarios

Appliances	Scenario 1 wattage	Scenario 2 wattage	% Difference (reduction)
Energy saver	24	13	-46%
Task light	5	2.5	-50%
Tube light	40	26	-35%
Fan	120	50	-58%
Exhaust Fan	35	26	-26%
Sandwich maker	820	700	-15%
Toaster	870	800	-8%
Laser jet printer	591	400	-32%
Dry Iron	1200	1000	-17%
Hair dryer	1800	1600	-11%
Electric shaver	9	5.4	-40%
LED TV	48	37	-23%
Laptop	120	90	-25%
Hair Straightener	140	90	-36%
Meat mincer	1700	1600	-6%
Microwave oven	900	800	-11%
Food processor	1000	750	-25%
Juicer all in one	500	350	-30%
Refrigerator	170	130	-24%
Water dispenser	100	80	-20%

Appliances and lighting wattage values were obtained from available online manuals and market.

4.3.5 Windows, walls and roof insulation

In order to improve the envelope of the base model, few changes have been made to improve the thermal performance of the building. Jumbolon is used for the better insulation of walls and roof. Material properties of Jumbolon are shown in Table 4.3

Table 4.3: Jumbolon material properties

Description	**Properties**	**Unit**
Cell structure	Close very fine	-
Density	Kg/m^3	32-40
Thermal conductivity	BTU in/ft^2.hr.F	0.19
Bending strength	N/cm^2	52
Coefficient of linear expansion	mm/mk	0.07

With the use of jumbolon U-value for roof and walls improved and the values of overall U-value for wall and roof is as follows;

Over all U-value of wall for proposed model = 0.114 BTU/hr/ft^2/F

Over all U-value of roof for proposed model = 0.066 BTU/hr/ft^2/F

Material properties for jumbolon are taken from the manufacturer.

Double glazed windows are used for the proposed model and the overall U-value and Shading coefficient values are given as follows.

U-value of Double glazed window = 0.334 BTU/hr/ft^2/F

Shading Coefficient of double glazed windows = 0.114

Data for the double-glazed window is taken from the manufacturer online data sheet.

In this case, double-glazed windows contain argon gas between the gap (12mm) of two glasses. Glass thickness is 6mma and the gap between glasses is 12mm. Percentage improvement results for proposed model by individual components are given in Table 4.4.

Table 4.4: Percentage improvement in each category

Description	**Percentage (%) reduction**
Lighting	44.70%
Cooling	24.88%
Appliances	16.98%

Here is another comparison table which depicts the reduction in operation cost and cooling load demand. Comparison is given in Table 4.5.

Table 4.5: Cooling load and cost comparison between two scenarios

Description	**Scenario 1**	**Scenario 2**	**Units**
Total coil load	11.7	8.6	Tons
Non-HVAC components	1.162	0.902	$\$/ft^2$
Annual Cost HVAC	1068	802	$
Cost per floor	0.188	0.141	$\$/ft^2$

Envelope energy transmission improvement comparison table is shown in Table 4.6.

Table 4.6: Envelope changes result comparison

Description	Scenario 1	Scenario 2	Units (Sensible)
Windows transmission	11630	5124	BTU/hr
Roof transmission	3514	1895	BTU/hr
Wall Transmission	17191	5353	BTU/hr
Floor Transmission	540	375	BTU/hr

Based on the comparison results for both the scenarios it is evident that use phase process has improved. Now with the improved energy consumption we have to perform the EIA to see how much reduction in the particulate matter formation we have achieved.

4.4 Environmental Impact Assessment Final Results

Environmental impact assessment of scenario 2 is the result of this research and a complete life cycle impact assessment of both the scenarios is shown in Figure 4.3.

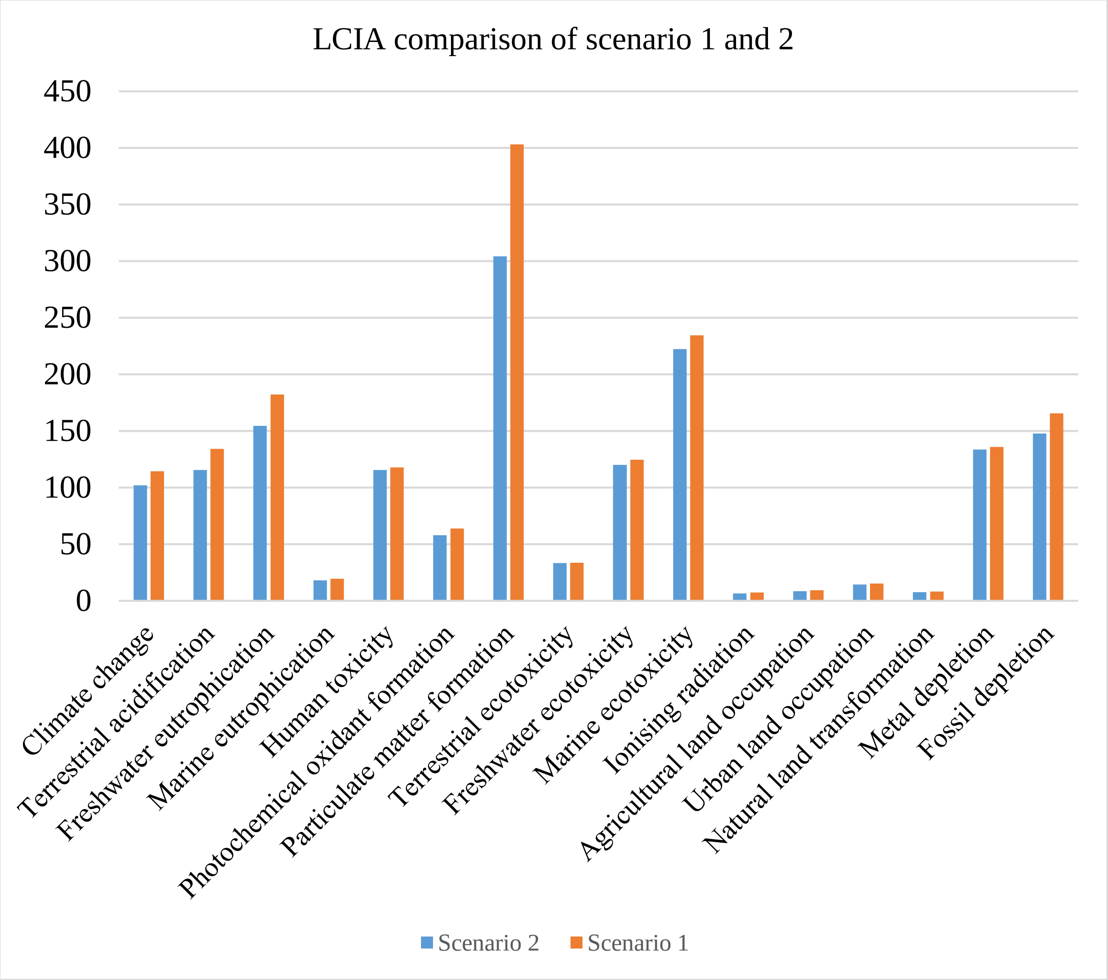

Figure 4.3: Comparison of LCIA of both scenarios

The method used for the life cycle analysis is ReCiPe Midpoint (I) V1.13 World Recipe I. Result of environmental impact assessment of a residential unit (base model) which reveals that most contribution in the environmental degradation is from the particulate matter formation and its total score on normalization is 403. Particular matter contribution investigation led to the use phase of the building and use phase process has been improved.

After the process improvement which is use phase energy consumption, in this case, a significant drop in the value of particulate formation can be seen in the above-given graph. It is now reduced to 311 from the previous value which was 403.As this study is a complete life cycle impact assessment and complete construction process has been taken into consideration so by improving one process can effect another process. In the above given graph, values in some impact categories are higher than the scenario 1 due to the reason that materials have increased, as we have added insulation in the exposed walls, roofs and improved the thermal resistance of windows with double glazed windows, and we are having the effects of those materials complete life cycle in the final results. In order to obtain optimal solutions for the complete building, EIA iterations are very important, as in a complex system like construction we have to deal with multiple variables and keep things in acceptable limits.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Sustainable development is the need of the hour and it is due to the fact that human race is facing the environmental issues at an unprecedented scale. Pakistan as a developing country is in dire need of sustainable development in construction as it is having a boom in construction projects all across its length and breadth. This study targets one of the major chunk of the construction projects i.e. residential sector. Urbanization is happening rapidly so it is imperative to reduce the environmental impacts related to residential sector construction. Following conclusions are drawn from the study

- EIA proved to be a quick and reliable tool for the identification of major contributors.
- EIA provided an excellent opportunity to identify and improve processes.
- Improving each process can lead to the optimum solutions based on EIA iterations.
- EIA is best tool for taking environmentally sensitive decisions.

EIA is a time consuming and lengthy process to carryout. It is highly dependent upon the availability of the data as construction processes are very diverse in nature yet very useful in environmentally sensitive decision making. This study is related to one unit of residential sector and aiming at reducing the one factor which stands first in impact category, but by doing this at every process and improving overall construction industry will have an enormous positive impact. Based on the conclusion of this study following are the recommendations to be considered for future research work,

- Process improvement at the industry level is imperative to improve the overall supply chain of the construction industry as basic materials and processes are similar to a large extent.
- Certain acceptable values of impacts need to be set as a baseline for decision making as the processes are complex and improvement in one can effect another.
- Cleaner energy production is vital to further reduce the impacts related to energy.
- Research at pre-consumer level will shift the industry towards green chemistry and production processes.

As concluded in this study that energy consumption matters the most so there is a huge opportunity for research on the clean energy production potential, process improvement at pre-and post-consumer level. Residential sector consumes most of the energy from the national grid and if houses have potential to produce clean energy and reduce burden on the grid this can lead to more sustainable living and energy production.

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