

# Life Cycle Assessment of a building at an Educational Institution

*A Dissertation*

*Submitted in partial fulfillment of the requirement*

*For the award of degree of*

*Masters of Technology in Environmental Science and Technology*



**Submitted by: Under the supervision of**  
**Aditya Kanwar Mr K.S. Babu**  
**Roll No. 301101009 (Assistant Professor, SEE)**

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**School of Energy and Environment**  
**THAPAR UNIVERSITY**  
**PATIALA-147004**  
**INDIA**  
**July, 2015**



## DECLARATION


I hereby declare that the work presented in the dissertation entitled **Life Cycle Assessment of a Building at an Educational Instituton** in partial fulfillment of the requirement for the award of the degree of Master of Technology in Environmental Science and Technology, is an authentic record of my own work during a period of six months from January 2015 to June 2015, under the guidance of Mr. K. S. Babu, Assistant Professor, School of Energy and Environment, Thapar University, Patiala. The report has not been submitted for the award of any other degree or certificate in this or any other University.

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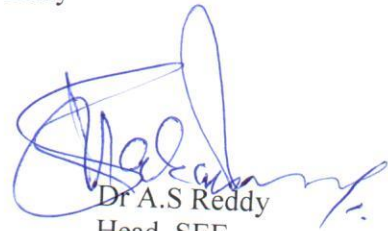
  
Aditya Kanwar  
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## CERTIFICATE

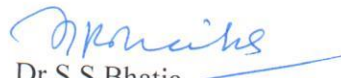
This is to certify that the dissertation entitled **Life Cycle Assessment of a Building at an Educational Institution** submitted by Aditya Kanwar in partial fulfillment of the requirement for the award of the degree of Masters of Technology in Environmental Science and Technology to Thapar University, Patiala, is a record of student's own work carried out by her under my supervision and guidance. The report has not been submitted for the award of any other degree or certificate in this or any other University

  
15/7/2015

Mr K.S Babu  
Assistant Professor, SEE  
Thapar University  
Patiala



Dr A.S Reddy  
Head, SEE  
Thapar University  
Patiala

  
Dr S.S Bhatia  
Dean, Academic Affairs  
Thapar University  
Patiala

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## **Abstract**

This study quantifies the Green House Gas (GHG) emission throughout the life span of the Tan Building located at Thapar University, Patiala, India. The methodology involves quantifying both primary energy consumption as well as GHG emissions throughout service life of 75 years. A comprehensive Life Cycle Assessment is carried out both manually and by using GaBi 6 Software to determine environmental effects of the structure. The life span is divided into three phases. The study shows that steel, cement and bricks are major GHG emissions contributor during construction phase. Overall, operation phase uses 64% of the primary energy of the building. Further, Energy saving techniques are discussed for reduction of Carbon Footprint during both Operation and Construction phase.

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# Chapter 1

## Introduction

### 1.1. Construction sector and Green House Gas (GHG) emissions

Urbanization and increasing population in cities have burdened the environment in metropolitan cities. Research from the past years indicates that these changes in global climate are increasing rapidly and will continue with time (Hulme et al., 2002; IPCC, 2011). Large amount of people migrating to cities have forced the construction sector to grow rapidly which has affected the environment in cities particularly air and water and by 2030 the number of people living in cities will reach 60-65%

and it is estimated that the urban population in India would rise to 590 million by 2030 and these people migrating to cities would need more houses and infrastructure to live. Buildings account for more than 30% of electricity consumption in India being second only to industries. The total built space would increase five fold from 2005 to 2030 and by then more than 60% of the commercial building area and space would be air conditioned (McKinsey & Company, 2009).

Construction sector is now a major contributor to Global GHG Emissions and hence a reduction in these emissions leads to significant reduction in overall global GHG Emissions. Hence there is a dire need to modify and improve construction practices to achieve maximum efficiency by using minimum of resources and thus reducing the global pressure being put on the environment by the construction sector. Building uses energy throughout its lifespan i.e. from cradle to grave. The building sector accounts for 40% of the primary energy consumption and 36% of the energy related to CO<sub>2</sub> emissions in the industrialized countries (IPCC, 2011b). There is significant influence of building sector over the total natural resource consumption and on the emissions released, along with the other associated environmental impacts. Building consumes 40% of the stone, sand and gravels, 25% of wood, 40% of energy from fossil fuels; and 16% of water globally every year in the world (Arena & Rosa, 2003). During operation phase of the building, a lot of electrical energy is consumed by lighting and electrical appliances and by heating and cooling appliances. Over 40% of the total energy

gy used in a building is consumed by heating, ventilation and air-conditioning systems (Little, 1999).

As most of the energy in buildings is consumed by buildings for heating and cooling purposes, there is a great need to minimize the energy consumption by buildings so that the environmental impact can be reduced. But before going into the reduction of building energy consumption, the primary thing is to obtain the quantitative values of environmental impacts associated with building's entire life cycle i.e. GHG emissions, input-output material flow, energy consumption, etc.

## **1.2. The Concept of Life Cycle Assessment (LCA)**

In a world where resources are scarce and population is increasing rapidly, the societies are realizing that the modern day lifestyle and conveniences have a serious impact on the environment and hence it is important to analyze and find ways to reduce mankind's environmental burden. Given its official name in 1991, Life Cycle Assessment (LCA) examines the full spectrum of processes associated with a product from beginning to end of its life. International Organization for Standardization (ISO) defines the life cycle of a product as including "raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal" (ISO 14040:2006). LCA is one of the well-known tools for analyzing the environmental impacts by a product through its entire life. It is applicable for all the stages of building and finding out the important alterations to maximize the performance of building (Horne et al., 2009).

The assessment in general includes examination of inflows and outflows associated with a product throughout its lifespan. These flows are organized into a series of phases in a product's life cycle like extraction, manufacturing, transportation. LCA is not just about collecting data, it is also about interpreting that data.

LCA may be performed by industries, government policymakers, or private research operations for a number of purposes. It can be applied to virtually any product, material, or structure. Depending on where boundaries are drawn and what the researcher's ultimate goals are, significant gaps or manipulations in a product's life cycle may be found in the LCA, and the variability between separate LCAs of similar products can be astonishing. Figure 1.1 illustrates a very basic methodology to conduct LCA.

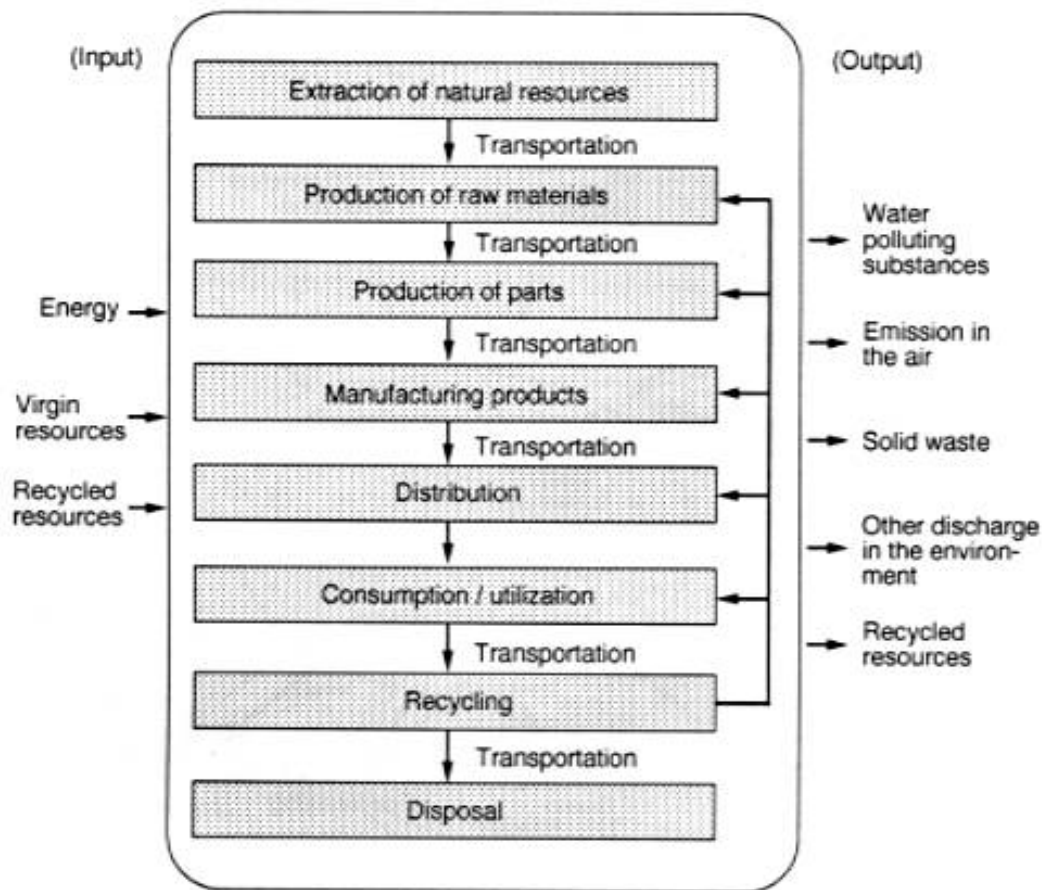


Fig1.1 Basic Methodology of LCA

(Source: [http://www.env.go.jp/en/wpaper/1998/images/09\\_1.jpg](http://www.env.go.jp/en/wpaper/1998/images/09_1.jpg))

### 1.3. LCA and Buildings

Life Cycle Assessment can prove to be an effective indicator to recognize to which extent a building can be termed as a “green building” (Dammann et al., 2006). LCA is an effective tool to estimate a carbon footprint of a building. It is vital to calculate the embodied energy of structures and determine ways to diminish this energy. This can be accomplished by altering the structural system of the building to use environmental friendly construction materials and locally available materials.

LCA is an essential tool to help civil, structural and environmental engineers understand how they can contribute to lowering the embodied energy of any building. It provides us with huge potential of improving and lessons learned from LCA are significant. Construction materials like steel are highly recyclable but come with high energy requirements. Construction materials such as concrete, masonry and bricks are more difficult to recycle and contribute largely to total material consumption.

Buildings can be categorized according to their usage i.e. residential and non-residential buildings. Residential buildings can be categorized into individual houses, like in societies and apartments. Non-Residential buildings are those which are used for commercial purpose i.e. school, university, office industry etc. The classification of buildings is shown in figure 1.2

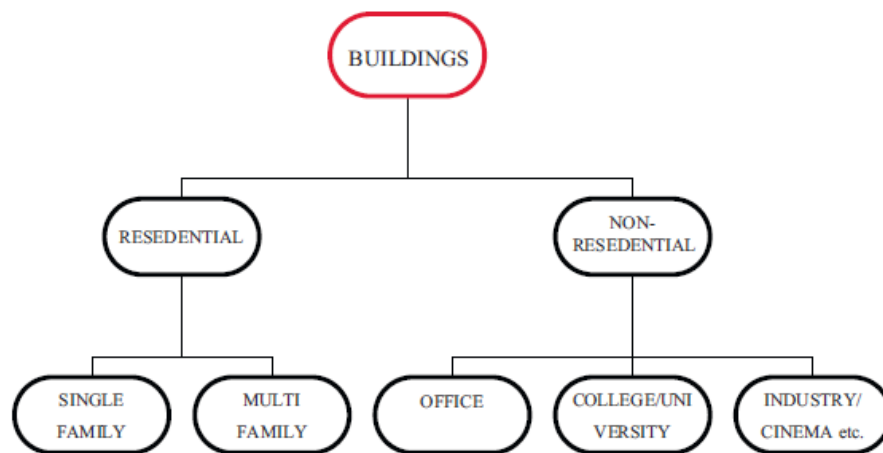


Fig 1.2: Classification of Buildings

The study has been done for TAN Building located at Thapar University, Patiala. LCA technique is used to calculate carbon footprint of the building in a lifespan of 75 years. The building has three floors and analysis is done for the whole building and the primary energy consumption and GHG emission contribution are included. The necessary calculations are performed at construction, operational and maintenance phases separately.

## **1.4.Objectives**

- To calculate the GHG emissions throughout the lifecycle of the building and hence calculate the Carbon Footprint of the building using LCA and Gabi6 (LCA software)
- To determine the impact of each material and lifecycle phase on the total carbon footprint of the structure.
- To reduce the carbon footprint of the structure by using more environmental friendly materials and suggesting some renewable energy techniques that can be used to reduce environmental impact of buildings that would be constructed in future at university

## **Chapter 2**

### **Review of Literature**

The information collected on lifecycle assessment, emission quantification during construction operation and maintenance from research journals, e-resources is presented below:

**Reddy et al., (2004)**, address certain issues concerning embodied energy in buildings and its effect on environment and sustainability of currently used methods of construction. Construction industry contributes 22% of the total GHG into the atmosphere. Currently available energy-intensive materials and building technologies have a huge burden of future demand. Alternative building technologies developed by ASTRA are energy efficient as well as the embodied energy of buildings constructed using this technology is less than half of the energy of conventional buildings. The need is to switch over to the use of energy efficient building materials and technologies and invent methods and mechanisms to utilize industrial wastes. Recycle and reuse of building wastes for the manufacture of building materials and products for the sustainable construction practices should be promoted.

**Dammann et al., (2006)**, investigated to what extent a consensus on environmental indicators as ‘a common language for green building’ can be reached among core groups in Danish building sector and what such indicators look like. Four different technological frames were used to identify four different perceptions of environmental indicators.

Environmental indicators for buildings have the potential to serve as a means of making the environmental impacts (and possibly benefits) of buildings visible to all relevant actors. In addition, indicators facilitate the consideration and management of an array of environmental issues in the relevant decision-making situations.

**Liu & Yang, (2010)**, discussed the importance of sustainable technologies for sustainable low carbon buildings. The study combines natural technology with building technology to create a kind of sustainable low carbon building that is cheap and convenient conforming to a situation in China. The study highlighted factors that affect the emissions after building is used, i.e. dimensions, style, function and life of the building. Amongst materials, locally available materials were given preference and use of solar energy chimney and passive solar housing was encouraged. Economizing the air conditioning by studying the plan and spaced design is also an important factor and can help reduce emissions to a great extent.

**Martinez et al., (2011)** showed the results of applying the Lifecycle assessment (LCA) methodology in some actual construction residential buildings built by several researchers from the School of Architecture of Seville. The objective was to analyze the significance of using different construction techniques and building materials.

The three dwellings were named C-1, C-2, and C-

3 respectively. The impact assessment results show that (except “Ecotoxicity of freshwater”, in which C-2 dwelling has done better due to used disposal scenario for metals), C-

1 dwelling is the one that gets the best result in almost all impact categories. This shows that optimization of building materials reduces the negative impact on the environment. C-

1 dwelling is the one with the least amount of resources consumed.

C-

3 dwelling gets more negative results for almost every impact categories. This result is a direct consequence of the high amount of resources that has been used in the construction and also because of some building materials used.

Selection of building materials and systems can reduce, considerably, environmental impacts. Thus C-

2 dwelling, despite having the worst building type from the viewpoint of resource optimization, achieves the best results in impact categories due to the environmental friendly nature of its building materials and components

**Yan et al., (2011)** discuss measures to construct and develop the Low-carbon building during its whole course of planning, layout and design, build and construction, and operation period, thus we can control and reduce the building carbon footprint, and form the healthy cycle sustainable development model. The study presents that the development of low-carbon building is a systematic project and the low carbon material and energy saving equipment are of essential significance for controlling the main stage of carbon emission and ensuring low-carbon quality.

**Frazoni et al., (2011)**, explained the role of selection of building materials in achieving “green” tag for the building both at early design stage as well as at working plan stage.

Working plan stage is more important but engineers and architects in charge of this stage often lack evaluation tools that can help them to select better materials. In this study, the critical aspects of defining “green building materials” are discussed and overviewed with attention particularly on the working plan stage and the application of such tools are discussed with reference to Italian market. It is observed that the architects and engineers are presently nearly left alone while selecting commercially available environmental friendly building materials. The aspects of environmental impact and contribution to indoor air quality should be always jointly considered and applied evaluation tools should be either improved or modified

**Tangetal.,(2011)**, presented a study on development of low carbon buildings based on life cycle assessment and did a research on the status of low carbon technologies in building area and the necessity and importance of reducing carbon emissions throughout the lifespan of the structure were discussed. A low-carbon assessment model was constructed and the difficulties and challenges faced in its development were identified, effective ways were implemented and provided a theoretical basis for the healthy and rapid development of low-carbon buildings. The key carbon reduction incentive policies should be based on the actual situation and reflect the different characteristics flexibly, which is able to adjust and adapt with changes in factors such as public awareness of reduction carbon emissions, low carbon investment and effect of policy implementation, low-carbon technologies to activate the positive role of economic lever combined with different stages of low-carbon building market.

#### **BoWU&Wei-**

**huaZENG,(2011)**, brought forward the research tool of carbon footprint to formulate the development of low carbon city planning in a better way. By computing method of carbon footprint, all kinds of carbon footprint and the capacity of carbon sink of a city, in Beijing Shijingshan District, were calculated and analyzed. The results show clearly that the carbon footprint of the city was relatively large, especially the production carbon footprint had reached 17,008,722 ton and that of life had reached 2144.33 ton. To minimize the carbon footprint, the industrial structures should be modified and improved, the carbon sink resources should be expanded, new energy conservation technology

ys should be developed and the existing sources of renewable energy should be encouraged and low carbon buildings, transport with low footprints should be developed in future.

**Tangetal.,(2011)**, did a research about the status of low carbon technologies in building area, and discussed the necessity and importance of reducing carbon emissions in the full life cycle of building. A low carbon assessment model of a building was constructed, the development of low carbon construction law field was explored and the difficulties and challenges faced in the development were identified. It was concluded that to improve the level of low carbon technologies, to increase effort to promote low carbon construction, to strengthen carbon management, implementing low carbon incentive policy is necessary.

**Bei et al.,(2011)**, discussed the importance of low carbon structures and buildings at a time when the deterioration of climate and environment has threatened the human survival seriously. The architectural design should be aimed at controlling and improving the harmful effects of climate and environment through design methods and technologies that create an environment with low energy consumption, economic, healthy and comfortable. Developing the low carbon building will become the focus attention of the whole society. It is of significant to establish the resource-saving and environment-friendly society.

**Bignozzietal.,(2011)**, conducted a study on sustainable cements for green buildings by partially replacing clinker content with non-hazardous waste. It is important that these selected waste has an almost constant composition and available in large amount throughout the territory. Other routes to make cement production sustainable involved different approaches. For example, the alternative fuels use (e.g.: discarded tyres) is becoming popular in cement kilns. Various physical, mechanical and chemical properties were tested. Loss on ignition, Insoluble residue, sulphate and chloride content were checked and all results were within Italian specifications. Thermal and electrical efficiency of cement plant can be improved with the aim to avoid energy loss and large consume of fossil fuels.

**Guardiglietal.,(2011)** compared the environmental impact of wooden and reinforced concrete structures by Life Cycle assessment methods and inferred that the estimated environmental impact

of wood buildings on human health, resources and ecosystem quality is generally smaller than a typical concrete structure but at the same time overuse of wood threatens the quality of the ecosystem. LCA can be used successfully to make decisions in sustainable building construction and design.

Cost analysis indicates that wood structures resulted in more convenient (17%) and bigger savings can be obtained by speeding up the construction. According to the LCA approach, overall wood structures are environmentally less harmful than concrete ones.

**Patle et al., (2011)**, presented energy minimization and cost minimization techniques ultimately leading to reduction in overall impact of the building on environment and pushing it towards green building category. The study revealed that fly ash bricks are 2.86% cheaper than clay bricks and Pozzolana Portland cement (PPC) gives 11.43% less cost than ordinary Portland cement (OPC) and both these products contain appreciable amount of fly ash making it an alternative solution to solid waste management problem as well as cost reduction technique.

It has also been calculated that carbon emissions from fly ash bricks is 81.36% less as compared to clay bricks and PPC has 32.58% lesser carbon emissions as compared to OPC for the designed green building at VNIT campus,

Nagpur. Application of recycled steel is recommended which reduces significant carbon emissions as compared to fresh steel. It has been estimated that carbon emission from recycled steel is 81.98% less as compared to fresh steel. Replacing fluorescent tube lights with CFL resulted in the saving of 41.06% cost of installations as well as operation for a year, in turn savings in carbon emission has been estimated as 41.18%. Wherein, for peak summer season use of evaporating coolers is recommended as compared to air conditioner that resulted in 64.11% cost saving as well as 85.14% savings in carbon emissions.

**Huet al., (2011)**, analyzed a residential building in China for carbon emissions throughout its life cycle. The research introduces Life Cycle Carbon Emissions (LCCE)

Model to analyze carbon dioxide emissions of urban buildings system based on the principle of LCA. Sources of CO<sub>2</sub> emissions during the whole life cycle of urban buildings system, which are industrial process emissions, energy consumption emissions, fugitive emissions and land footprint emissions were identified. It was observed that GHG emissions during the life cycle of residential building

Buildings majorly came from energy consumption and land footprint. Buildings of masonry-concrete architectural structure created more GHG emission than steel-concrete structure with the same area. The results show that steel-concrete structural building contributes 315.79 tonnes equivalent carbon dioxide per 100 square meters and masonry-concrete architectural style contributes 329.61 tonnes per 100 square meters. Most emissions come from energy consumption and land footprint, accounting for 78–83% and 13–20% of the total emissions respectively. This further can be reduced by promoting the recycling of constructive materials, transformation of patterns of citizen's consumption and improvement of building floor area effective utilization of natural energy and ecologically friendly building materials according to the characteristics of local urban development.

**Kanagaraj et al., (2011)**, provide a means for improving energy related decision making during design phase of the structure. To bridge the gap between architects, environmentalists and engineers, a comprehensive design process titled 'Integrated Energy Efficient Building Design Process' (IEBDP) is suggested. It provides a framework based on the theory that facilitates the integration of various different parameters of energy efficient alternatives selection process. Analytical Hierarchy Process (AHP), a multi-attributed decision-making technique is used to resolve conflicts amongst diverging design goals. The proposed IEBDP framework was then used to design an office building, taken as a case study, in the composite climate of New Delhi, India. It was found that considerable energy savings could be achieved by following the IEBDP process. The various designs were evaluated in terms of strategies adopted, the level of exploration as well as design integration, in order to validate the applicability and use of the IEBDP framework. Results indicate that the IEBDP process can aid designers in developing optimal energy efficient designs.

**Wang et al., (2011)**, developed a life cycle GHG (equivalent CO<sub>2</sub>) emission computation model for a urban residential building and discussed the quantitative analysis on carbon emission. The results show that the largest CO<sub>2</sub> emission is in the phase of operation and maintenance of residential building. The average heat transfer coefficients of exterior enclosures were higher as compared to developed countries. If these coefficients are to be lowered down to Europe

an standard of similar climate areas as Beijing, the CO<sub>2</sub> emission will decrease by 20%. If the lighting power decreases to 6 W/m<sup>2</sup> from 0.7 W/m<sup>2</sup>, the CO<sub>2</sub> emission can be drop about 3%. Reducing the average heat transfer coefficient of exterior enclosures of residential building will increase the initial construction cost and total investment.

The average service life of residential building in China at present is much less than 50 years and a lot of that is only 30 years or even less. Comparing that in European and American, it is generally 70 years or even more. According to the computational result in next section, the annual CO<sub>2</sub> emission of unit building area is higher by 14% for T=30 years, meanwhile is lower by 6% compared with the benchmark of T=50 years.

**Varun et al., (2012)**, quantified the significant environmental effects of mechanical engineering block of NIT, Hamirpur which is a three storey building. The building has a floor area of 3960 m<sup>2</sup> and a projected service life of 50 years. The total energy usage for different phases i.e. construction, operation and maintenance is calculated. The construction phase consumes about 10,512,410.8 MJ of primary energy which is around 40% of the total energy requirement. The energy usage for operation phase was calculated to be maximum and it has been found out to be around 59% of total energy usage. Most of the use energy is required for heating/cooling, computer usage and operating of heavy machinery in the building. During the operational phase almost all the life-cycle elements causes significant impacts. In maintenance phase the energy usage is around 210,248.22 MJ which is less than 1% of total energy usage. The total life cycle GHG emissions contributed by the MED building are 1764.82 ton CO<sub>2</sub> eq. The operation phase consumes maximum about 59% of total life cycle GHG emissions. The life cycle GHG emissions per unit area are around 0.45 ton CO<sub>2</sub> eq/m<sup>2</sup> 50 year. Construction of second floor has the biggest share in the GHG emissions i.e. about 25% of total GHG emissions. This is due to high large amount of steel and aluminum used in the construction. During the construction phase, RCC framework and steel are the highest contributor of total GHG emissions for all three floors. Two life cycle phases viz. construction and operation seem to be more significant in all impact categories (energy and emissions).

**Rao et al., (2013)**, conducted a survey and analysis to understand the impact of lifestyle on carbon footprint and found out that the carbon footprint of urban population was higher than those living in rural areas due to lifestyle and standard of living. The average carbon footprint in rural areas is estimated to be 0.85 tonnes carbon dioxide equivalents per capita per year and in urban areas it is 2.5 tonnes carbon dioxide equivalents per capita per year. Among all the sources, cooking fuel (36%) is the biggest contributor to the rural carbon footprint whereas in the urban areas, electricity (33%) and travel (35%) are the major contributors. Long distance travel (including Air Travel) and high percentage of personal vehicle usage in the urban areas result in much higher carbon footprint as compared to the rural areas. The rural carbon footprint will go down by 250 kg of carbon dioxide equivalents per capita per year (~30%) if we assume the firewood to be carbon dioxide neutral.

This study can be helpful in designing a transparent carbon calculator which will be specific for Indian situations and locations.

**Vataliset al., (2013)**, investigated the sustainability components affecting decisions for green building projects. 32 participants were surveyed based on a questionnaire that assessed nine sustainability components. Energy efficiency and renewable energy is considered of high priority followed by the reduction of toxic materials, indoor pollution and water saving. The results showed that the people should and want to live in an environment that is designed and incorporated a) energy efficiency and renewable energy, b) with reduction of toxic materials c) without indoor pollution, d) water saving, e) with trust in environmentally innovative projects f) in waste minimization and pollution prevention, g) reuse of friendly building materials.

**Yiing et al., (2013)**, conducted a study to check the accessibility of green buildings in Malaysia. Malaysia has both Universal Design (UD) and Green Building Design (GBD) and Green Building Index (GBI) is a way to further reinforcement of agenda of GBD although is not mandatory. For more than forty years, SD has dominated the global environmental discourse and guiding ecosystem protection. The accessibility was checked using creating similar situations as persons with disability (e.g. blindfold). Ketha Low Energy Office (LEO) in Putrajaya and PTM Green Energy Office (

GEO) in Bangi are are two green certified government office buildings, located in non-residential existing building (NREB) category and non-residential new construction (NRNC) category, respectively and The Ministry of Women, Family and Community Development (KPKWM) in Putrajaya is a non-green certified building, were chosen according to the consideration of UD and accessibility of PD during preconstruction stage. The results showed that KPKWM building (score of 65 of 90) provides better accessibility to building users, followed by LEO (score of 51 of 90) and GEO (score of 44 of 90). This means, the majority of the facilities provided in the KPKWM meets 75% of the requirements while less than 50% for the facilities in GEO building. Future studies were recommended to perform a qualitative research using case studies by interviewing disabled persons including those with sensory impairment in terms of using green-certified buildings, from the perspective of employment.

**Kennedy et al., (2013)**, draw upon a small, limited set of six cities that have conducted recent, repeat GHG inventories for the period 2004-2009. These six cities are reducing their per capita consumption by 0.27 ton CO<sub>2</sub> equivalents/capita/year. Some of the changes are attributed to change in source of power generated, consumer tending to move towards more energy and fuel efficient products as well as vehicles and mode of transport but still there is a further scope of reduction in GHG emissions. Cities can not take all the credit for reducing their emissions; they work within a multi-level governance context. If, however, cities recognize their role as the control points and gateways between nations in a globalized economy then the emissions from international flights leaving city airports should be included.

**Dula et al., (2013)**, suggested GHG emission reduction techniques in cities with a wider perspective of finding out the coincidences of common local priorities and climate change mitigation policy. Strong urban policy and its implementation have become a necessity and still most of urban policies are weak and fragmented. For example, there are separate policies for various air pollutant reduction even though the activities and sources of many of these pollutants are essentially the same. This has resulted in weakened enforcement and co-

ordination failures of air pollution control policy. Cities account for 75% of global energy consumption and up to 80% of global GHG emissions. With rapid growth in population, expansion of middle class in urbanized areas and availability of cheap vehicles such as Tata Nano and Bajaj RE60 in India, the demand for energy and emissions is expected to grow massively.

**Joshi and Pathak, (2013)**, found the benefits and barriers to the energy efficient buildings (EEB) and decentralized energy (DE) in India. It was found that building sector has a huge potential to act as secondary power source in India. Architectural reforms and use of advanced energy efficient technology can help reduce the demand. Renewable DE can be used to produce energy required for on-

site use which has lower cost of installation compared to conventional centralized power plants and transmission losses are reduced significantly. Moreover, it reduces the GHG emissions due to use of clean power and due to environmentally conscious building material, the embodied carbon content is also reduced. One of the major barriers to the sustainable growth of India is the energy crisis.

India faces transmission losses of more than 32% (in 2010) as compared to global average of 15% because of inefficient transmission network and location of power generation sites at very far distances from the end use sites. Also, the rapidly growing building sector is responsible for at least 30-40% of energy usage and this demand is growing annually at 11-12%, which is almost twice global average of 5-6%.

**Lazarus et al., (2013)**, discussed a core framework and scenario for deep GHG reductions at the city scale and presented a scenario that represents one of many possible mitigation pathways and serves to illuminate the depth of potential GHG reductions that could move a city towards becoming carbon neutral. These strategies include developing alternative transportation modes, lower building energy use, and developing energy-efficient vehicles infrastructure, increasing recycling, composting and waste reduction. Results of four mitigation scenarios suggest that the aggressive implementation of a full suite of emissions-reducing strategies could reduce Seattle's per capita core-scope GHG emissions by 34% in 2020 and 91% in 2050. Separating the emissions sources in a city a

According to the core, expanded production, and consumption perspectives allows for flexibility and enable this framework to be adapted for communities with differing local characteristics.

**Moncaster et al., (2013),** described the method used by a new design decision tool, Embodied Carbon & Energy of Buildings (ECEB), to calculate the whole life embodied energy and carbon of buildings as recommended by UK government. The method described provides an estimate of the whole life, 'cradle to grave' embodied energy instead of the earlier widely followed 'Cradle to Gate' embodied energy at the early stages of design. ECEB includes also the carbon and energy impacts of the material. The study has further shown that an analysis of whole life embodied energy and carbon of buildings within the UK is considerably restricted by the lack of data and it is now the responsibility of industries to complete the relevant data with standardization.

**Mathure et al., (2013),** presented the potential impact of Energy Conservation Building Code (ECBC) of India that is applicable on buildings having more than 100 kW connected load or 120 kVA contract demand and analyzed six different types of buildings in Jaipur using calibrated simulation models to estimate energy saving potential. Energy saving potential ranges from 17% to 42% and by implementing the advanced features of ECBC, these savings can be further increased. Government offices and private offices together consume more than half of city's total energy. The energy saving potential with ECBC is in the range of 44 kWh/m<sup>2</sup>/year in Government buildings as lowest effect, whereas in case of the private office, it is estimated to be 128 kWh/m<sup>2</sup>/year.

For hotels, envelope and HVAC are major concern area. HVAC efficiency is most rewarding in the buildings which operate 24 hours. Using these estimates and the trend of increase in commercial building energy consumption, the potential of energy saving in the city of Jaipur has been identified as 12,475 MWh/y in the next five years.

**Bakisi et al., (2013),** in a study on the city of Barcelona analyses the transformations from a traditional agglomeration to a twenty-first century metropolis. The reason for choosing Barcelona for the study was due to its apparent desire, reflected by its current policies regarding urban planning making it one of the leading metrop-

olises in Europe. The main components of smart city strategies such as Smart districts, e-services and the Barcelona Smart City model were explored. The results of the case study analysis indicate that Barcelona has been effectively implementing the Smart City strategy with an aim to be a Smart City model for the world.

**Weibenberger et al., (2014)**, presented the historical development and background of Life Cycle Assessment (LCA) and nearly zero energy buildings in Germany. According to European Union guidelines (2010/31/EU), starting in 2021 new buildings must achieve the nearly zero-energy standards therefore the ecological optimization of construction and disposal of nearly zero-energy buildings is the crucial next step. In order to confront the main challenges of the building sector, limited resources as well as the energy-efficiency and a sustainable building stock, a life cycle view is required. The current applied life cycle assessment methodology began in the 1970s in the packaging industry. Around the turn of the millennium this calculation method was standardized into an international series of standards. Today the ISO 14040 and ISO 14044 are the only internationally standardized methods for assessing potential environmental impacts. In addition, the LCA approach and limitations are common.

**Buyle et al., (2014)**, conducted a screening LCA of a flat apartment in Belgium according to attributional (ALCA) as well as consequential (CLCA) approach. The main objective was to compare the results of the approaches rather than doing detailed LCA. The main difference in both approaches is data collection. ALCA uses averaged data at a certain point in time and it is assumed that all processes are unlinked and do not interact with each other and future projections are done on market mixes. CLCA looks at the marginal changes under the system under study, i.e. it looks only at the processes that are actually affected by the system. The overall results show that there is a shift of impacts per building stage. At use phase, CLCA assigns a lower impact (8%) to electrical consumption and reward recycling and it generates negative impact for the end of the life. Finally, to enhance a sustainable society it is needed that policy is focused on the entire life cycle of buildings instead of merely on energy efficiency.

**Kapuretal.,(2014)**,discussedparametersofupgradingexisting building into green building.

Energyefficiencyupgradesrepresentthemostcosteffectivewaytomeetgrowingenergydemands.Studieshaveshownthatenergy-efficientandcertifiedgreenbuildingsmerithighermarketvalues,greaterrentsandhigheroccupancies.Afterunderstandingthedynamics,costfactorisalsoconsideredandcostbenefitanalysisisdoneforunderstandingtheincreaseincapitalcost,paybackperiodandbenefitsofgreenbuildings .Atenpointprogramforapproachingthegreeningofexistingbuildings,focusedontheactivitiesofdecisionmakersamongpropertyowners,buildingandfacilitymanagers.Long-terminvestmentsinenergyefficiencyandwatersavingsaretheeconomicdriversforgreeningexistingbuildings.

**Biswas,(2014)**,employed‘miningouse’approachtconductlifecycleassessmentandenergyanalysisoftheEngineeringPavilion(building216)atCurtinUniversityWesternAustralia.ThelifecycleGHGmissionsandembodiedenergyofbuilding216are14,229CO<sub>2</sub>and172TJrespectively.Theusagestageproduces63%lessGHGmissions thantheUniversity’s average,duetoimplementationofanenergyefficientBuildingManagementSystem(BMS).Therestudyidentifiesthe‘hotspots’,orthestagesinproductionandoperationofbuilding216thatcontributesheavilyinGHGmissions.IntroductionofBMSreducedtheembodiedenergyconsumptionoflifecycleofbuildingby20%lessthantheuniversity’s average.Theresearchestimates thatthereisapotentialforsavingaround60%carbonfootprintassociatedwithBuilding216.However,useofrevisedcementformulationsandrecycledaluminumandsteelusewhereverpossiblecanfurtherreduceGHGmissionsbyaround7%

**Palaniappanetal.,(2014)**,presentedthelifecycleenergyuseofaresidentialbuildingofSouthIndiaincludingtheon-siteconstructionprocess.Buildingconsistsoffourblocksand96apartmenttypehomeshaving112.14squaremetersusablefloorareaperhome.Intermsoftotalweightcement,coarseandfineaggregatesarefoundtobemostsignificant.Embodiedenergyduetobuildingmaterialsisintherangeof 8.1–

10.8GJ/m<sup>2</sup>. The two most significant materials are cement and all forms of steel and iron. Cement represents 28–32% of energy due to construction materials. All forms of steel and iron represent 38–40% of embodied energy of materials. Analysis by building component indicates that structural frame, building envelope and finishing work represent 74%, 8% and 13% of total embodied energy of materials. The average operational energy used by the end-user is found to be 320kWh per home per month based on 1852 samples gathered over a period of 2 years. In terms of primary energy, this corresponds to 116kWh/m<sup>2</sup>/year (0.42GJ/m<sup>2</sup>/year). It is concluded that the construction energy is as important as operational energy in case of three scenarios: (a) residential buildings with partial or no air-conditioning, (b) the energy efficiency of operational phase reaches 50–75% of operational energy of a conventional case and (c) reduced building service life period.

**Mangano et al., (2014)**, provides with a comprehensive understanding of the concept of Smart City (SC) through pertinent application domains namely: natural resources and energy, economy, people, transport and mobility, living and buildings. This study explores the possibility of how that various economic, urban, demographic and geographical variables might have influenced the planning approach to create a smarter city and explores current trends in shaping smarter cities. The results revealed that there is no unique global definition of SC, and that the current trends and evolution patterns of any individual SC depend to a great extent on the local context factors. City policymakers are therefore urged to understand these factors in order to shape appropriate strategies for their Smart Cities.

**Kamalet al., (2014)**, conducted a study of achieving environmental sustainability through renewable energy technologies in all building structures. The search for available renewable energy sources, technologies to harness them and their economic and environmental assessment have become very important. Building materials such as steel and cement with high intensities of embodied energy are required to create the skeletal framework and lay the foundation for their long-lasting structures. The growing global pressure to reduce carbon footprint and concerns for creating sustainable habitats, have also greatly ignited the quest to deliver

innovative solutions and emerging trends in all building designs. Around 35% of the renewable energy contribution is from wind energy, which by the virtue of height is the plus point of tall buildings and high level of wind speeds in the mainstream of atmospheric boundary layer can benefit all buildings.

**Bulle et al., (2014),** presented

a life cycle carbon and life cycle cost assessment of energy efficient retrofit measures (ERMs) to the building envelope and heating system of four existing schools which represent school archetypes built in the UK between the year 1870-1995. The basis of energy efficiency assessment was energy simulation models of the existing structures. The regression equation formulated with the help of energy models has a coefficient of determination of 95–

97%. This equation can be used in predicting life cycle carbon saving within the tested range of ERMs

, and also within the range of the other building features included as independent variables. The regression equation calculated carbon savings will be close to energy model simulated savings.

The study also shows that it is vital to create scenarios to understand the energy-use implications of different design interventions and retrofit measures in combination. The simple approach of modeling each retrofit measure individually is useful to understand its independent impact but not adequate for determining the effectiveness of multiple retrofits together.

**Biswal et al., (2014),** suggested innovation to reduce carbon footprint that is interfering with the climate and causing climate change in Indian context. Availability of appropriate technologies and robust collaborative processes for decision making among multiple stakeholders limit the capacity for mitigation of climate change. Schools should act as a bridge between public and the knowledge producers. Strategies such as Reducing Food Prints, Saving Energy Movement, Green Habits, Value Inculcation Enhancing Awareness through social media network, All India Coordinated Projects/Publications, Encouraging Science Communication at School Level, Documentation of Success Stories, Community Participation which are proposed which could be implemented in India as part of a broader strategy of action for future carbon emissions and encourage economic development are discussed.

**Ali et al., (2015)**, conducted an environmental life cycle impact assessment of a residential building in Egypt using Simapro v8.1 and using ISO 14040 standards for the analysis. The final results and analysis indicate that the use stage, which has the highest share of energy, is also the main contributor to all the other environmental impacts and contribute 71.9% to total effect. The main categories which have the biggest share are respiratory inorganics, global warming and non-renewable energy. Solutions were suggested to minimize the adverse environmental impacts of buildings such as reducing operating energy consumption, selecting sustainable building materials and increasing use of renewable energy during operating phase.

**Praseeda et al., (2015)**, investigated embodied energy (EE) of different building materials from life cycle standpoint and various methods for their quantification are identified. EE assessment can be carried out by using Input-output analysis (I/O), process analysis and hybrid analysis. Unavailable data, lack of product specific data, high variability of energy tariffs and commodities are salient drawbacks of I/O method. I/O method is reported unsuitable for EE assessment in Indian perspective. Hence a new process based framework was eventually adopted for EE assessment.

Aluminium coils were found to have the highest EE amongst basic materials followed by steel, glass and cement. And amongst masonry units, burnt clay bricks have high EE (1.2–4.05 MJ/kg) followed by concrete blocks (0.17–0.25 MJ/kg) and laterite stone blocks (0.007 MJ/kg). EE of concrete blocks is sensitive to the cement content used in the block manufacture. EE of aggregate is very low at 0.04 MJ/kg, whereas ceramic floor tile has a high EE value at 10.63 MJ/kg. Study also implies that it is impractical to arrive at a single value hence the best way to represent EE values are by a range.

## **Chapter 3**

### **Materials and Methodologies**

This chapter deals with the resources employed, Materials used and methodologies adopted during the study.

#### **3.1 Description of the Building**

##### **3.1.1 Location:**

The building chosen for the study is a relatively new building known as 'TAN Building' constructed inside Thapar University, Patiala, India. Thapar University was founded in 1956 as Thapar College of Engineering and Technology and TAN Building is a recent building of the University and has been in operation since the last two years. The building was planned as well as built in a single phase and the structure has a floor area of nearly 4000m<sup>2</sup>. It is a three-storey building and has the rooms majorly utilized for academic purposes.

##### **3.1.2 Structural Features**

The structure is aesthetically appealing due to vitrified tile floor work along with marble and kota stone tiling at some minor places. The main construction components used are considered and it is evident that cement mortar, reinforced concrete cement framework, glass, timber, brick masonry, aluminum, steel, kota stone, ceramic and vitrified tiles are main components employed in the construction.

Other significant specifications of building are:

Structure: Reinforced Cement Concrete Framework

Masonry: Both stone and Brick masonry

Flooring: Cement concrete flooring with kota stone, vitrified tiles (mainly), marble and ceramic tiles used at various locations.

Door and Windows: Aluminum frames have been used and doors have wooden chowkhat and mainly ply wood, teak wood and timber along with some ivory cost wood at some places

Roof: Steel framed structure

### 3.2 Electricity Scenario

To calculate the operational energy of the structure that is the power required to run the electrical appliances, machinery, pumps and the HVAC (Heating, Ventilation and Air conditioning) requirement, there is a need to consider the current electricity scenario of India. This enables accurate and efficient calculations of GHG emissions released during operation phase. The current Electricity Scenario of India is shown in Tables 3.1 and 3.2.

SECTOR	MW	PERCENTAGE SHARE
STATE SECTOR	96,963	36.2
CENTRAL SECTOR	72,521	27.1
PRIVATE SECTOR	98,153	36.7
TOTAL	2,67,637	

Table 3.1: Electricity Scenario (Sector wise) in India (Installed capacity as on 31/3/2015)

Table 3.2: GHG Emission contribution

TYPE OF FUEL	MW	% SHARE	GHG EMISSIONS (GCO <sub>2</sub> eq/kwhe)
TOTAL THERMAL	188,898	70.6	
COAL	164,636	61.5	1005
GAS	23,062	8.6	543
OIL	1,200	0.4	650
HYDRO (RENEWABLE)	41,267	15.4	41
NUCLEAR	5,780	2.2	25
RES** (MNRE)	31,692	11.8	35
<b>TOTAL</b>	<b>2,67,637</b>		

\*\*Renewable Energy Sources (RES) include SHP, BG, BP, U&I and Wind Energy

SHP=Small Hydro Project, BG=Biomass Gasifier, BP=Biomass Power,

U&I=Urban&Industrial Waste Power, RES=Renewable Energy Source

It is worth mentioning that Thapar University, Patiala draws its power requirement from National Grid

### 3.3 Life Cycle Assessment

LCA is one of the well-

known tools used for the quantitative assessment of a material used, environmental impact of products used and energy flows. It follows a systematic approach to assess the impact of each process, material and product.

LCA is the most appropriate framework for the identification, quantification, and evaluation of the inputs, outputs and the potential environmental impacts throughout its lifecycle. Basically there are three types of LCA methodology that is process based LCA, input-output LCA and hybrid LCA (Bullard & Herendeen, 1975; Facanha & Horvath, 2006; Guinea, 2002; Heijungs & Suh, 2002; Kofoworola & Gheewala, 2008; Suh & Huppes, 2005). In a process based LCA, the user outlines all processes associated with all life-cycle phases of a product, and associates inputs and outputs with each process, by which total environmental load energy can be determined. There are four stages of Life Cycle Assessment. The methodology of the study is illustrated in Figure 3.1

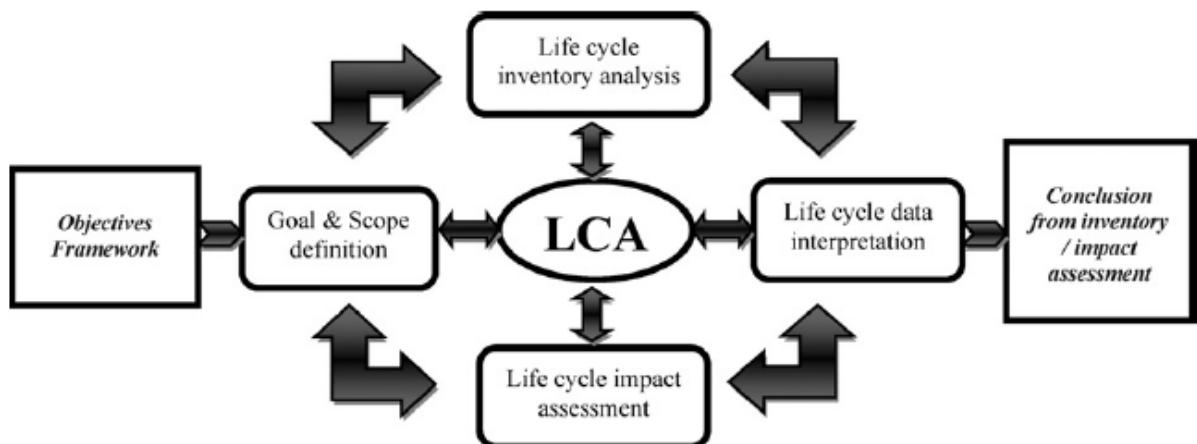


Fig3.1:MethodologyofLCAanalysis(Source:Varunetal.,2012)

### **3.3.1 Goal and Scope Definition**

The goal and scope definition of an LCA determines the significance of the study. System boundaries are defined and a quality criterion for inventory analysis is setup. Life Cycle assessment deals with the building life cycle and materials used during construction. Indoor air quality data, furniture details and individual emissions due to people entering and leaving the building are out of the system boundaries.

The life span of the building consists of three phases: Construction, Operation and maintenance. It is assumed that no structural modifications are done to the structure. The life span of the building is considered as 75 years. Painting and other minor maintenance including minor structural changes are included in maintenance phase. The maintenance energy value is taken as 5% of the total life cycle energy of the structure.

### **3.3.2 Life Cycle Inventory Analysis (LCI)**

According to EPA, a life cycle inventory is a process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, process, or activity. In the life cycle inventory phase of an LCA, the relevant data is collected and further organized.

Without an LCI, no basis exists to evaluate comparative environmental impacts or potential improvements. The level of accuracy and detail of the data collected is reflected throughout the remain

der of the LCA process. Lifecycle inventory analyses can be used in various ways. They can assist a n organization in comparing products or processes and considering environmental factors in material selection. In addition, inventory analyses can be used in policy-making, by helping the government develop regulations regarding resource use and environment al emissions. An inventory analysis produces a list containing the quantities of pollutants released to the environment and the amount of energy and material consumed. The results can be segregated by lifecycle stage, media (air, water, and land), specific processes, or any combination thereof.

For Buildings and structures, the plan of the building and visual inspection help to collect the raw data and inventory analysis is done during all three phases of lifespan of building. Using the consumption chart and abstract of quantities, a list of number of materials and their quantities is prepared. The data is then compiled using embodied energy coefficients of all different types of materials and primary energy of the structure during the construction phase is established. The values of coefficients are taken from Indian Literature, Inventory of carbon emissions (ICE) database published by University of Bath UK and other standardized databases.

### **3.3.2.1 Embodied Energy**

Embodied energy (EE) of building materials constitutes the total energy expenditure for manufacture of building materials including that for raw material extraction and associated transportation. EE assessment of building material reveals the extent of energy consumed and associated greenhouse gas emissions in their manufacture.

There have been extensive efforts in the last few decades towards assessment of EE for a wide variety of building materials. Most studies lack consensus on the assessment method and comprehensive assessment framework. Further, the EE values from various studies differ widely consequent to differences in study area, energy assessment in terms of primary to end use energy, industrial characteristics such as raw material procurement, production technology and data characteristics which emphasize the need for region specific database for embodied energy assessment of building materials.

EEassessment can be carried out using process analysis, Input-Output analysis and Hybrid analysis. Input-Output method of analysis is supposed to encompass the energy spent in upstream and downstream activities. Several assumptions underlie Input-Output method adopted for EE analysis. Detailed investigations on Indian input-output transaction tables have found them unviable for EE assessment of building materials in the Indian context.

Unreliable data, lack of product specific data, high variability of energy and commodity tariffs across the country and out-of-date Input-Output tables on time represent salient drawbacks associated with Input-Output method. The Input-Output Transaction Tables for India are more than a decade old and also, it is difficult to access authentic Input-Output data Tables in many countries. These reasons render the Input-Output method unsuitable for EE assessment in the Indian context. A new process analysis based framework was eventually adopted for EE values. In the present study, process based LCA is followed over the process whether it is embodied energy assessment or impact assessment due to other factors. The methodology of process based assessment of embodied energies is shown in fig 3.2.

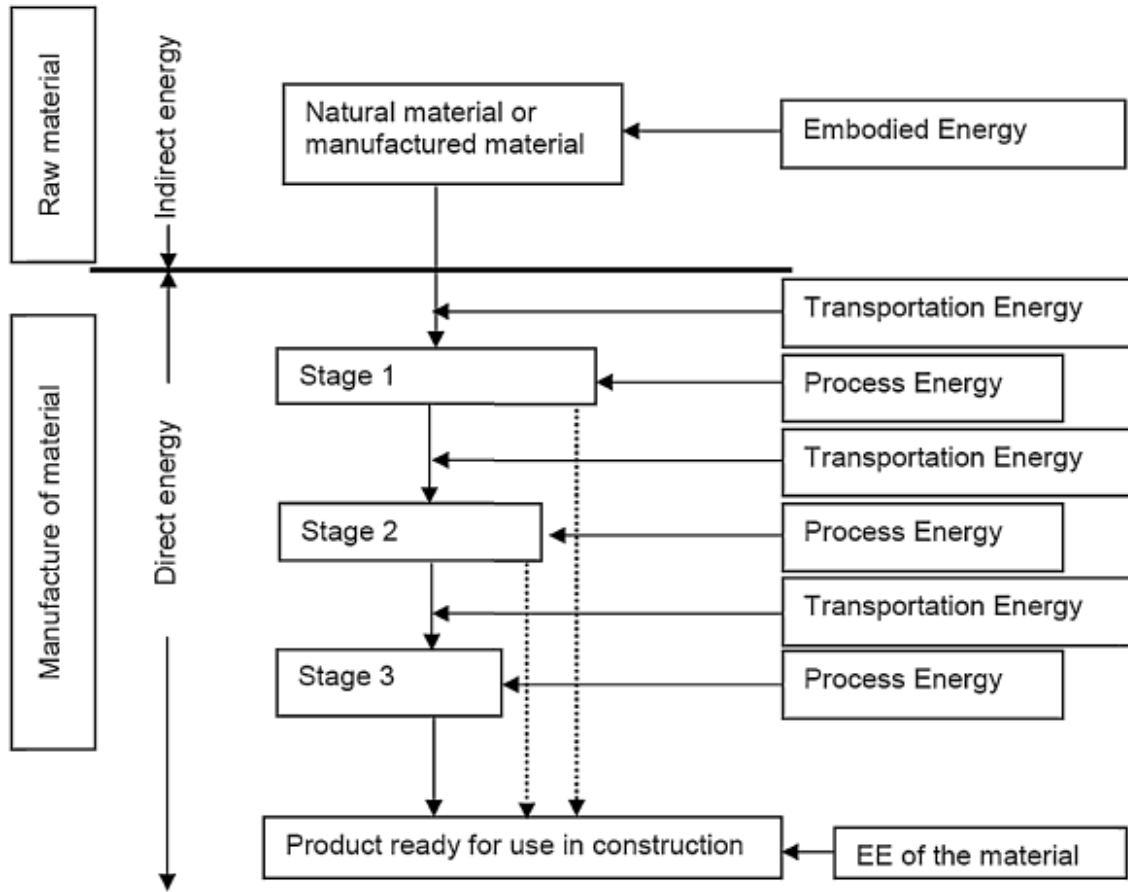


Fig3.2 Methodology of process based assessment of embodied energy (Source: Praseeda et al., 20

15)

### 3.3.3 Life Cycle Impact Analysis (LCIA)

The Life Cycle Impact Assessment (LCIA) phase of an LCA is the assessment of potential human health and environmental impacts of the environmental resources and discharges during the LCI. A life cycle impact assessment tries to establish a linkage between the product or process and its burden in environmental impacts (For example, What are the consequences of 7,600 tons of carbon dioxide or 20,000 tons of methane emissions released into the atmosphere? Which one is worse? What are their likely impacts on global warming?). An important distinction exists between life cycle impact assessment (LCIA) and other types of impact analysis. LCIA does not necessarily attempt to enumerate any specific actual impacts related with a prod

uct, process, or activity. Instead, it seeks to establish a relation between a system and potential impacts.

The models used within LCIA are often consequent and easy versions of more sophisticated models. These cut-down models are suitable for relative comparison of the potential to cause any environmental or anthropogenic change, but cannot indicate complete risk or real damage to human health or environment. Risk assessments are concentrated on a single chemical at a very specific location. In the case of a traditional risk assessment, it is thinkable to conduct very detailed modeling of the predicted impacts of the chemical on the population exposed and even to predict the probability of the population being impacted by the discharge. In the case of LCIA, hundreds of chemical emissions (and our stressors) which are occurring at various locations are evaluated for their potential impacts in multiple impact categories. Hence LCIA proves to be a handy tool when the scope is well defined.

The key concept in this section is that of stressors. A stressor is a set of situations that may lead to an impact (For example, if a creation or process is emitting greenhouse gases, the growth of greenhouse gases in the atmosphere may contribute to global warming). An LCIA provides a orderly procedure for categorizing and characterizing these types of environmental effects.

#### Key Steps of a Life Cycle Impact Assessment:

The following steps comprise a life cycle impact assessment.

- I. Selection and Definition of Impact Categories- recognizing relevant environmental impact categories (e.g., global warming, acidification, terrestrial toxicity).
- II. Classification- conveying LCI results to the impact categories (e.g., classifying carbon dioxide emissions to global warming).
- III. Characterization- modeling LCI impacts within impact categories using science-based conversion factors (e.g., modeling the potential impact of carbon dioxide and methane on global warming).

- IV. Normalization-  
uttering potential impacts in ways that can be compared (e.g. comparing the global warming effect of carbon dioxide and methane for the two options).
- V. Grouping-  
arranging or ranking the indicators (e.g. sorting the indicators by location: local, regional, and global).
- VI. Weighting-emphasizing the most significant probable impacts.
- VII. Evaluating and Reporting LCIA Outcomes-  
gaining a better understanding of the dependability of the LCIA results.

### **3.3.4 Life Cycle Data Interpretation**

Lifecycle data interpretation is a step by step procedure to identify, quantify, check, and analyze information from the results of the LCI and the LCIA, and communicate them effectively. Lifecycle interpretation is the last phase of the LC A process.

ISO has defined the following two objectives of lifecycle interpretation:

- I. Analyze results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the LCA, and to report the results of the lifecycle interpretation in a transparent manner.
- II. Provide a readily understandable, complete, and consistent presentation of the results of a nLCA study, in accordance with the goal and scope of the study. (ISO 1998b). This step mainly involves comparing the suggested alternatives by interpreting the results.

While conducting the Lifecycle inventory and Lifecycle impact assessment, it is necessary to make assumptions, engineering estimates, and decisions based on the values and the values of involve stakeholders. Each of these decisions must be included and communicated within the final result to clearly and comprehensively explain conclusions drawn from the data.

### **3.4 Embodied Energy Assessment (for Databases)**

The Inventory of carbon and energy (ICEV 2.0) database is a widely accepted database which is possible due to efforts of Sustainable Energy Research Team (SERT), Bath University U.K.

The database follows “Cradle to Gate” approach for Embodied Energy calculations and precision is maintained throughout EE assessment. Material profiling is done in order to maintain the standards of results. Material profiling usually consists of four sections that is Database Statistics, Best values of Embodied energy and carbon, Scatter graph and fuels split and embodied carbon split and Material properties.

The database is improvised and modified over the years with changing construction practices. All possible energy inputs are taken into consideration to ensure accuracy in embodied energy values. The necessary boundary conditions to be adopted during the calculations are represented in Table 3.3.

Type of Energy	Boundary treatment
Delivered energy	All delivered energy is transformed into primary energy equivalent
Primary energy	Default method, drew back to the 'cradle'.
Primary electricity	Included, totaled as energy content of the electricity (rather than the opportunity cost of energy).
Renewable energy (inc. electricity)	Included.
Calorific Value (CV)/Heating value of fossil fuel energy	Default values are Higher Heating Values (HHV) or Gross Calorific Values (GCV), both are like metrics.
Calorific value of organic fuels	Included when used as a fuel, excluded when used as a feedstock, e.g. timber or wood chips. When used as a fuel, the calorific value of the wood is included, but when used as a feedstock, the calorific value of the wood is excluded.
Feedstock energy	Fossil fuel derived feedstocks are included in the assessment, but identified separately. For example, petrochemicals used as feedstocks in the manufacture of plastics are included. See above category for organic feedstock treatment.
Carbon sequestration and biogenic carbon storage	Excluded, but ICE users may wish to modify the data themselves to include these effects.
Fuel related carbon dioxide emissions	All fuel related carbon dioxide emissions which are attributable to the product are included.
Process carbon dioxide emissions	Included; for example CO <sub>2</sub> emissions from the calcination of limestone in cement clinker manufacture are counted.
Other greenhouse gas emissions	The newest version of the ICE database (2.0) has been expanded to include data for GHGs. The main summary tables show the data in CO <sub>2</sub> only and for the GHGs in CO <sub>2</sub> e.
Transport	Included within specified boundaries, i.e. typically cradle-to-gate.

Table 3.3: Relationship of Type of Energy and Boundary Conditions in Embodied energy

### 3.4.1 Material Profiling

This section contains the step by step procedure followed to obtain the values in Inventory of carbon emissions version 2.0 – a database used for the study. The database has been developed by Sustainable Energy research team of University of Bath, UK.

### 3.4.1.1 Database Statistics (Table 3.4)

The materials were broken into sub categories, which reflect how the data is stored within the database. Most materials have a General category and are broken down into more specific forms, for example Iron general, Iron Extrusion. Each of the sub categories are further broken according to recycled/virgin content of the metal

These are simple statistics from database. These include no of records which represent the sample size that was used to select this data. Additional statistics include maximum and minimum values of EE and Standard deviation to maintain openness in the inventory. The boundaries are predefined as seen in the previous section

Material Profile: Example						
Embodied Energy (EE) ICE-Database statistics MJ/Kg						
Main Materials	No of Record	Average EE	Standard deviation	Minimum EE	Maximum EE	Comments on the database statistics
Material						
Sub Material category						
100% Recycled						
50% Recycled						
Other Specification						
Unspecified						
Virgin						

**3.4.1.2 Selected(or 'best')valuesofembodiedenergyandcarbon (Table 3.5)**

The values of embodied energy are presented here, although this example is only for products that are recyclable which are mostly metals. General values can be used if unsure what to apply. Primary is mainly for virgin material and secondary for recycled materials

Embodied carbon is shown her. Again the same distinguish between primary and secondary materials have been used

The low to high range of EE is written here and hence an idea can be drawn about the range in which the value might exist

<b>SelectedEmbodiedEnergyandCarbonCoefficientsandAssociatedData</b>									
<b>Materials</b>	<b>EmbodiedEnergy-MJ/Kg</b>			<b>EmbodiedCarbon-MJ/Kg</b>			<b>Boundaries</b>	<b>BestEERange-MJ/Kg</b>	
	UKTypical	Primary	Secondary	UKTypical	Primary	Secondary		LowEE	HighEE
GeneralMaterial									
CastProducts									
Extruded									
Rolled									
Comments									

**3.4.1.3:ScattergraphandfuelsplitandEmbodiedCarbonSplit (Table 3.6)**

There is a scatter graph for each materials. The scatter graph plots the year of data versus the value of embodied energy for each point in the database. This maintains the transparency of inventory data and it can be seen that whether the real value is affected by one or two values

Where possible the historical embodied carbon per unit fuel was calculated as an index of 1990 data. This section does not appear on all profiles

The fuel split is shown here along with the fraction of embodied energy used from source. In cases where it was not possible to get a fuel breakdown,

**ScattergraphandfuelsplitandEmbodiedCarbonSplit**

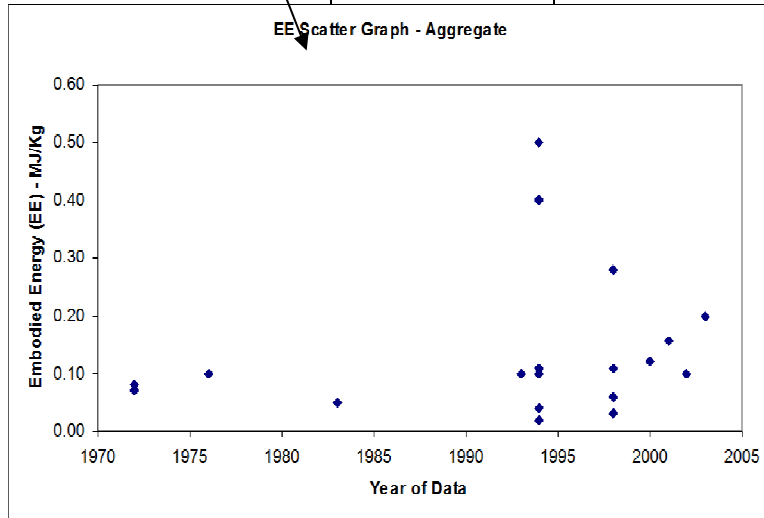
**MaterialScatterGraph**

**EmbodiedEnergyandEmbodiedCarbonSplit**

**EnergySource**

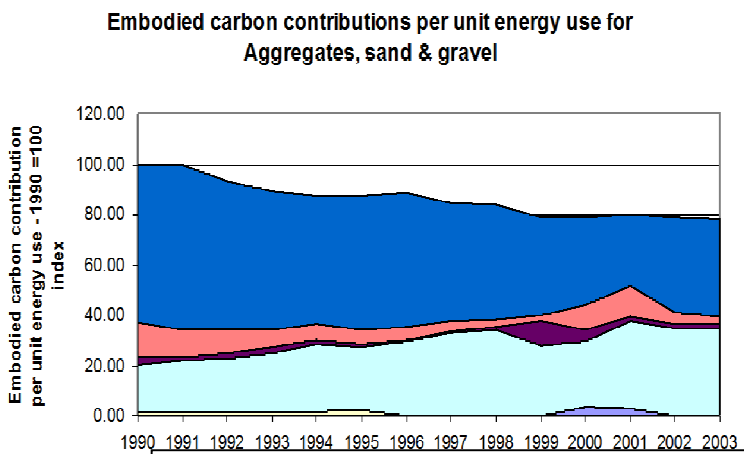
**%ofembodiedenergyfromenergysource**

**%ofembodiedcarbonfromsource**




Comments:

**Historical embodied carbon per unit fuel use:**



(Table 3.7)

Data extracted from the most recent CIBSE guide is presented here. The list of materials here was in many cases more specific then there is data available on embodied energy. But it is possible to estimate the appropriate embodied energy from the most similar material in the inventory

Material	Condition	ThermalConductivity	Density	SpecificHeat	ThermalDiffusivity
Material		230	2700	880	9.68013E-05
MaterialGalvanized		45	7680	420	1.39509E-05

### 3.5 GaBi6 – A Software for LCA

- GaBi6 is the next generation products sustainability solution with a dominant Life Cycle Assessment engine. GaBi6 models each element of a product or organization from a lifecycle perspective, preparing businesses to make the best informed decisions on the manufacture and lifecycle of any product.

- It also delivers an easily accessible and constantly revitalized content database that specifies the costs, energy and environmental impact of obtaining and refining every raw material or treated component of a manufactured article. Moreover, it looks at the effect on the environment offering alternative possibilities for manufacturing, distribution, recyclability, pollution and sustainability.
- GaBi6 makes it stress-free for companies to carry out Life Cycle Assessments (LCA) in order to defend their most precious asset; their brand. It also empowers them to provide more sustainable yet efficient products that better satisfy consumer hopes.

### **3.5.1 Applications of Gabi6**

#### **Life Cycle Assessment**

- Design for Environment: evolving products that meet environmental guidelines
- Eco-efficiency: decreasing material, energy and resource consumption in the most cost-effective manner
- Eco-design: evolving products with reduced environmental footprint such as fewer GHG releases, reduced water intake and waste
- Efficient value chains: improving efficiency of value chain e.g. R&D, design, production, suppliers, distribution

#### **Life Cycle Costing**

- Cost reduction: planning and optimizing products and processes for cost reduction.

#### **Life Cycle Reporting**

- Sustainable Product Marketing: products sustainability tags & claims, Environmental Product Declarations (EPDs).

- Sustainability Reporting: environmental communication & products sustainability reporting.
- LCA knowledge sharing: reporting and examination for internal departments, management and supply chain.

### **Life Cycle Working Environment**

- Responsible manufacturing: developing manufacturing procedures that address social responsibilities.

### **3.5.2 Advantages**

GaBi6 helps supply add sustainable products & shrink operational costs for any organization & supply chain. By using GaBi6 to boost sustainability decision-making and LCA projects, businesses can form sustainable brands, which buyers increasingly prefer. Businesses achieve consumer trust through calculated and verifiable information to verify their sustainability labelling and communications. Additionally, giving clients insight into a product's sustainable characteristics across its lifecycle will help a brand accomplish market leadership.

Quantifying the life-cycle impact of a product will also aid a company to assess its supply chain to identify product kinds with the highest impacts; the drivers behind the product's energy expenditure, carbon footprint, waste and water footprint; and the hotspots where sustainability efforts can be focused. Organizations can set objectives and Key Performance Indicators (KPIs) for products sustainability, building a more sustainable portfolio.

### **3.6 Bentley's STAAD.Pro**

STAAD.Pro is the structural engineering professional's choice for steel, concrete, timber, aluminum, and cold-

formed steel design of virtually any structure including culverts, petrochemical plants, tunnels, bridges, piles, and much more through its flexible modeling environment, advanced features, and fluent data collaboration.

STAAD.Pro permits structural engineers to investigate and propose virtually any type of structure through its malleable modeling environment, innovative features and fluent data association. Flexible modeling is delivered by a state-of-the-art graphical environment and the design ropes over 70 international codes and over 20 U.S. codes in 7 languages. An array of advanced structural analysis and design features are included such as nuclear certification for 10 CFR Part 50, 10 CFR 21, ASME NQA-1-2000, time history and pushover analysis and cable (linear and non-linear) analysis.

Efficiencies are multiplied through the ability to uphold and modernize current workflows with fluent data collaboration. STAAD.Pro assimilates with other Bentley products such as STAAD.foundation and ProSteel and OpenSTAAD is provided for integration with third party programs. Other salient features of STAAD.Pro include

### **Enhanced Advanced Analysis Capabilities**

- i. Advanced Cable Analysis: Nonlinear analysis capabilities for cable structures
- ii. Missing Mass: Enhanced dynamic provisions
- iii. Cloud analysis encoded with Bentley CONNECT (Beta)

### **Design Codes**

- ✓ AISC 360-10 Torsion design
- ✓ Eurocode National Annexes. Additional country selections added to concrete as well as steel designs
- ✓ New Colombian seismic loading
- ✓ IS:456 superior beam designs for column effects.

### **Post Processing**

- RAMConnectionmodule.Rationalizedtoutilizethecurrentengineotherwiseaccessibleasastandaloneapplication.

### **Databases**

- Brazilian,modernizedandnowcomprisingpublishedplategirdersections
- SteeljoistUPTissuedbySJI.

## **Chapter4-ResultsandDiscussions**

This Chapter deals with the analysis carried out and the results obtained during the analysis of the Tan building at Thapar University, Patiala.

### **4.1STAAD.ProAnalysis**

Table 4.1 shows Basic details of the structure

Name of the Building	TAN
Structure Type	SPACEFRAME
Number of Nodes	5487
Number of Elements	1276
Number of Plates	4728
No of Basic Load Cases	4
Number of Combination Load Cases	19

Table 2: Loads and Load combinations used for analysis (According to Indian Standards)

Load combination	Type	Name
1	Primary	Seismic load
2	Primary	Seismic I load
3	Primary	Dead load
4	Primary	Live load
5	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
6	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
7	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
8	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
9	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
10	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
11	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
12	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
13	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
14	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
15	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
16	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
17	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
18	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES
19	Combination	GENERATED INDIAN CODE GENERAL STRUCTURES

#### 4.1.1 3D Rendered View of TAN Building

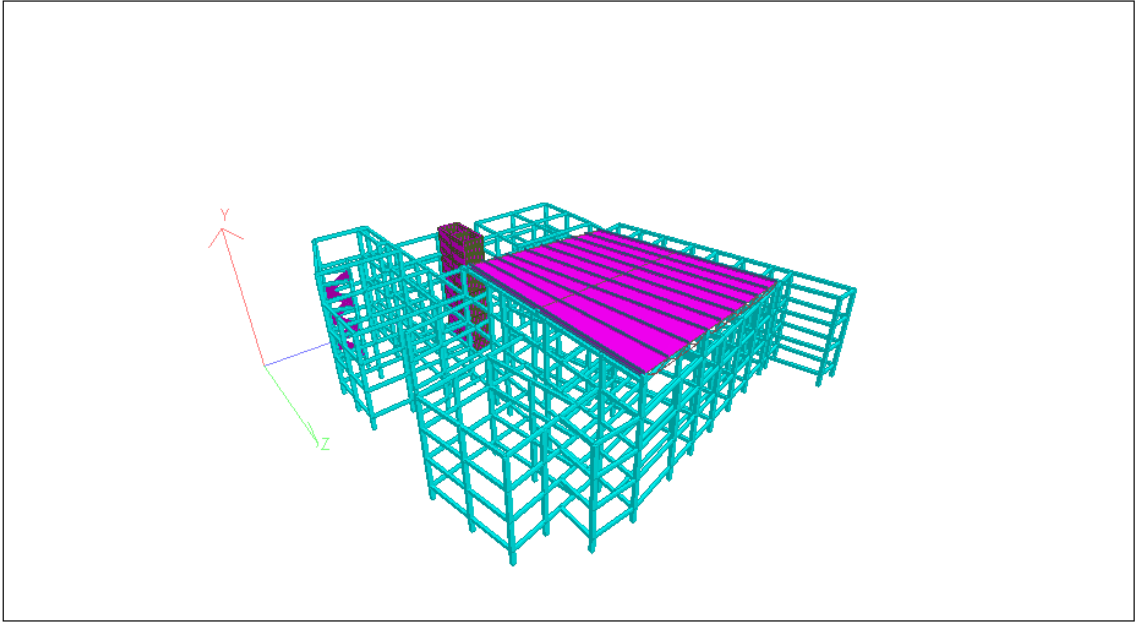


Fig 4.1(a)Frontview

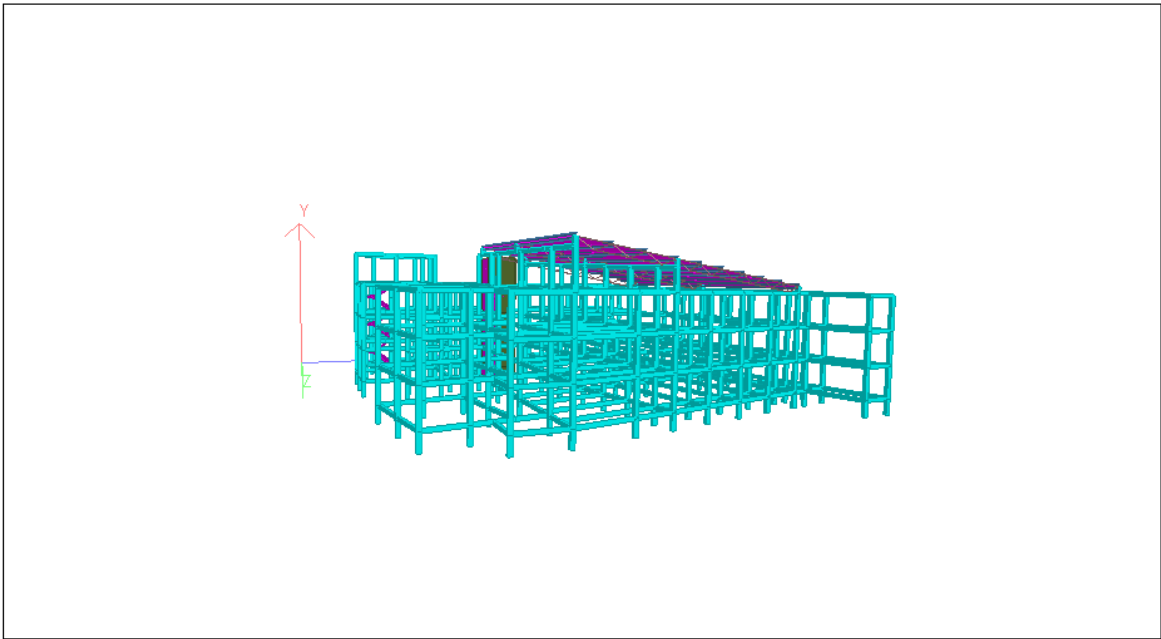


Fig 4.1 (b) SideView

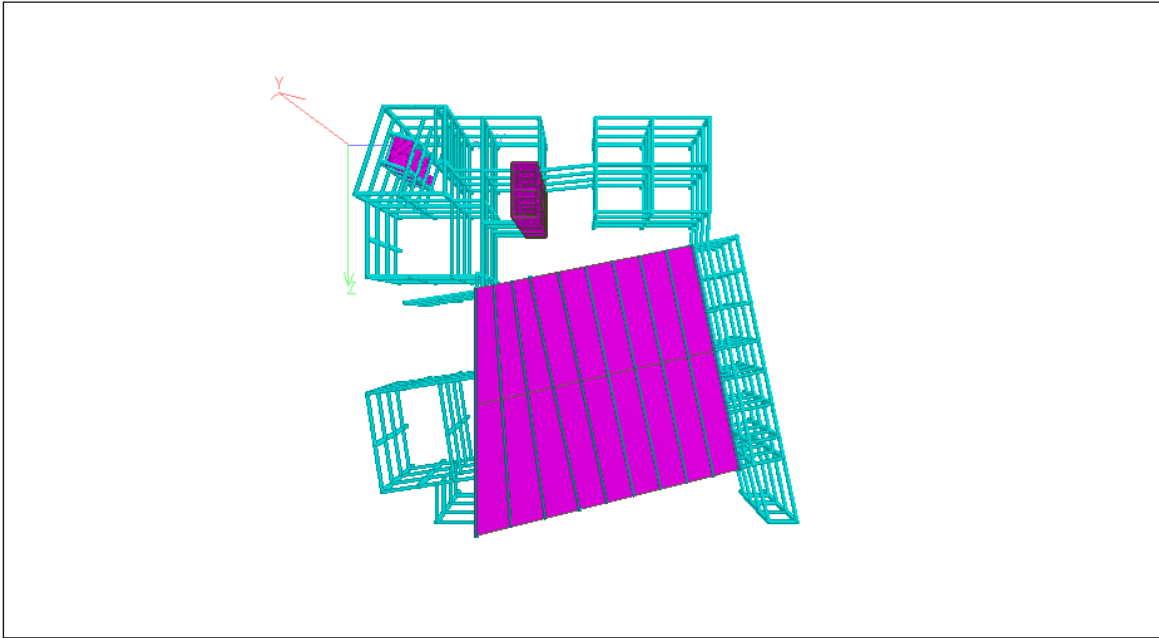


Fig 4.1(c) Topview

#### 4.1.2 Seismic Parameters and Seismic Load calculations

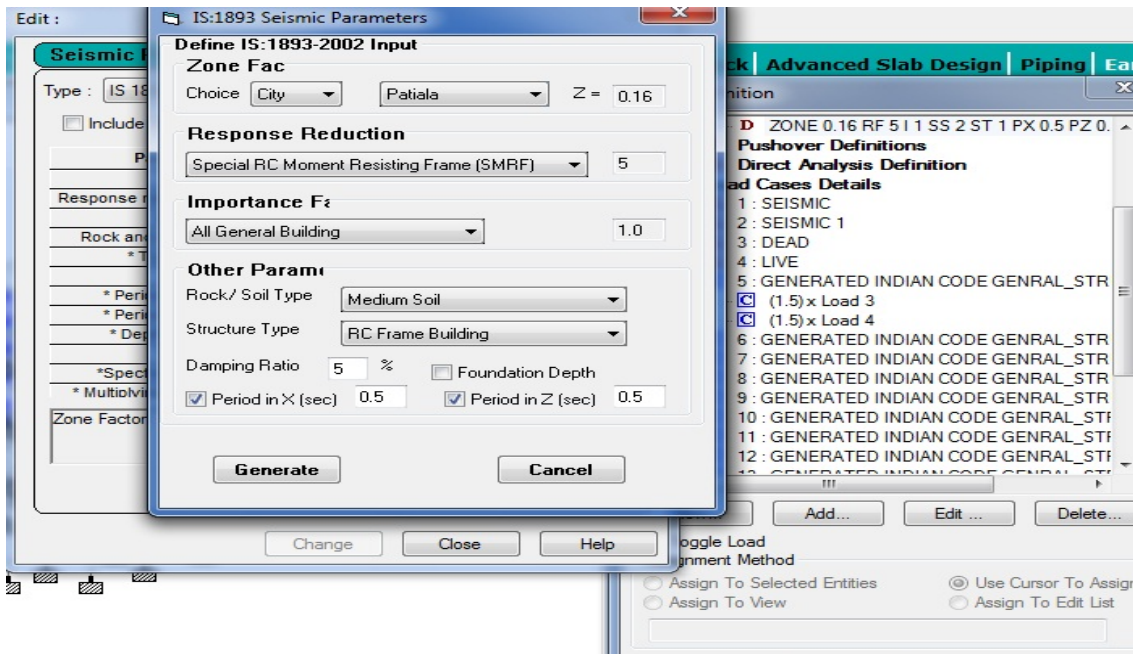


Fig 4.1(d) Seismic Calculations

### 4.1.3 Deadload and Live load Calculations assigned

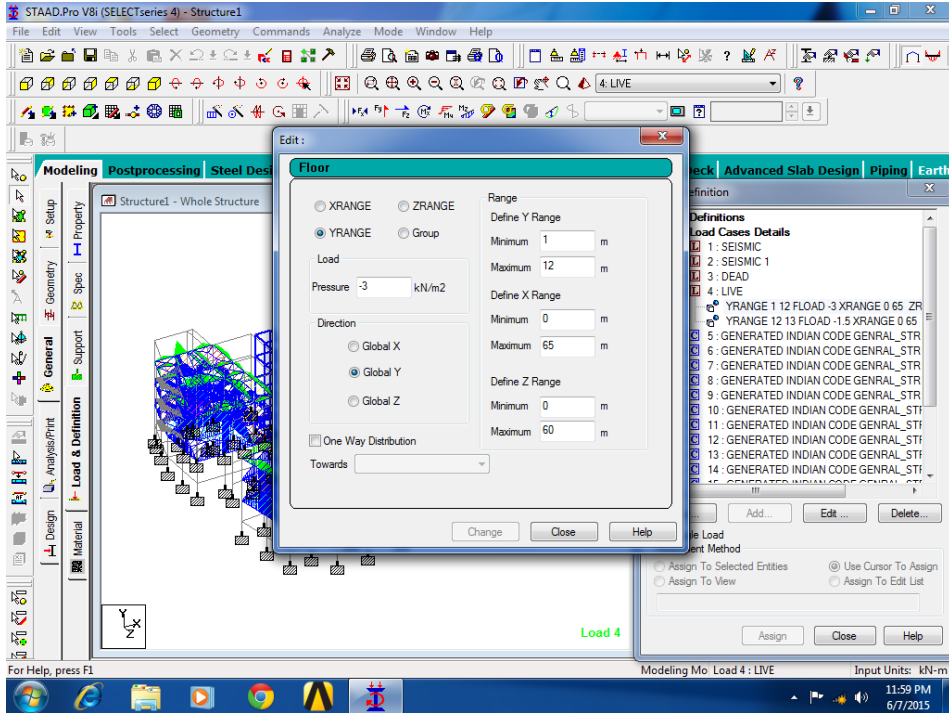


Fig 4.1(e) Dead load & Live load Calculation

### 4.1.4 Beam and column Detailing

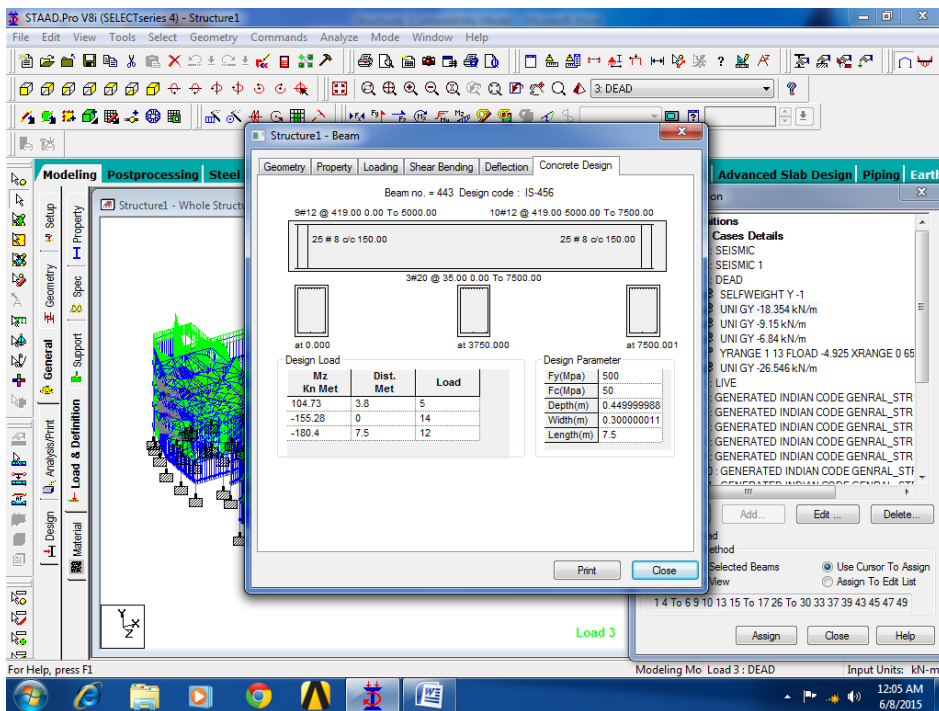


Fig 4.1(f) Beam Detailing

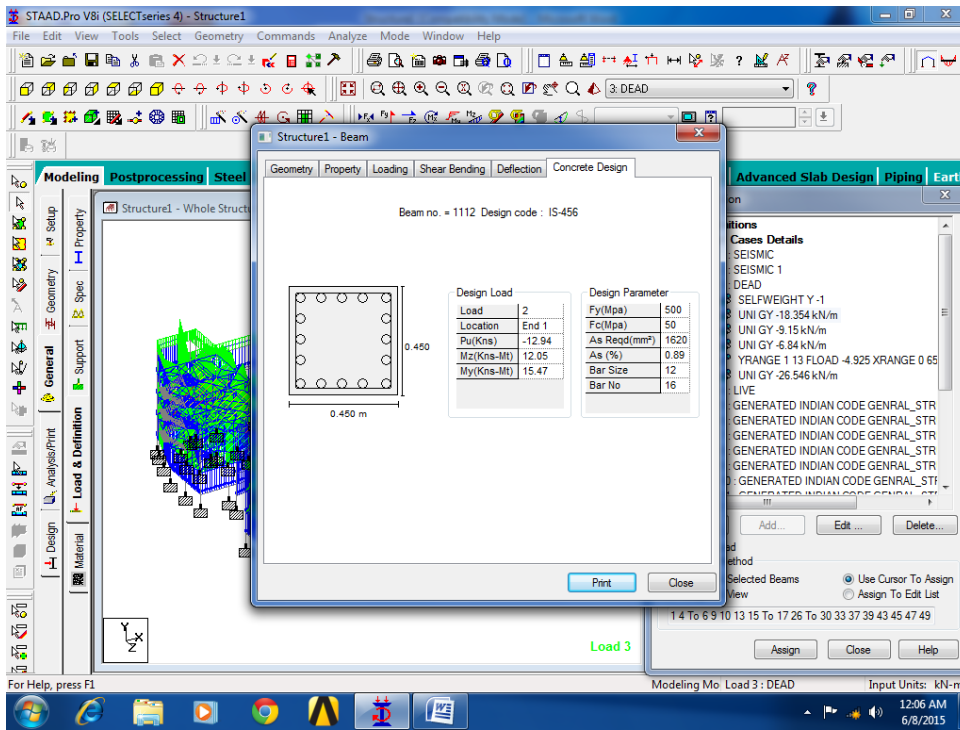
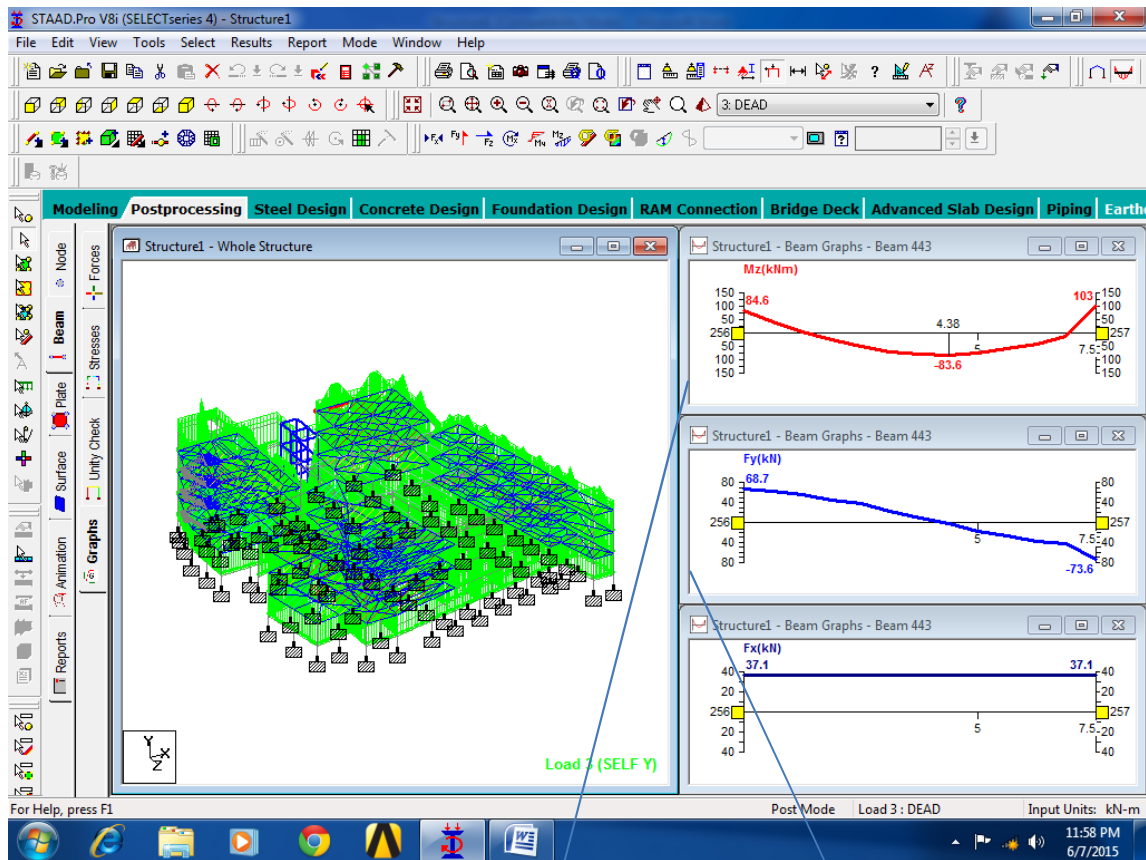


Fig 4.1(g) Column Detailing

By using this the number of reinforcements and size of each reinforced bar can be calculated anywhere within a particular beam and column

#### 4.1.5 Shear Force and Bending Moment Diagram for the structural elements



Bending Moment diagram

Shear force Diagram

Fig 4.1(h) Shear force and Bending Moment Diagram

By using this method the amount of shear stress and bending moment at a particular point of an element can be calculated. (Unit weight of concrete of 25 kN/cum and Unit weight of brick wall 19 kN/cum)

4.1.63D Stress Contour Diagram

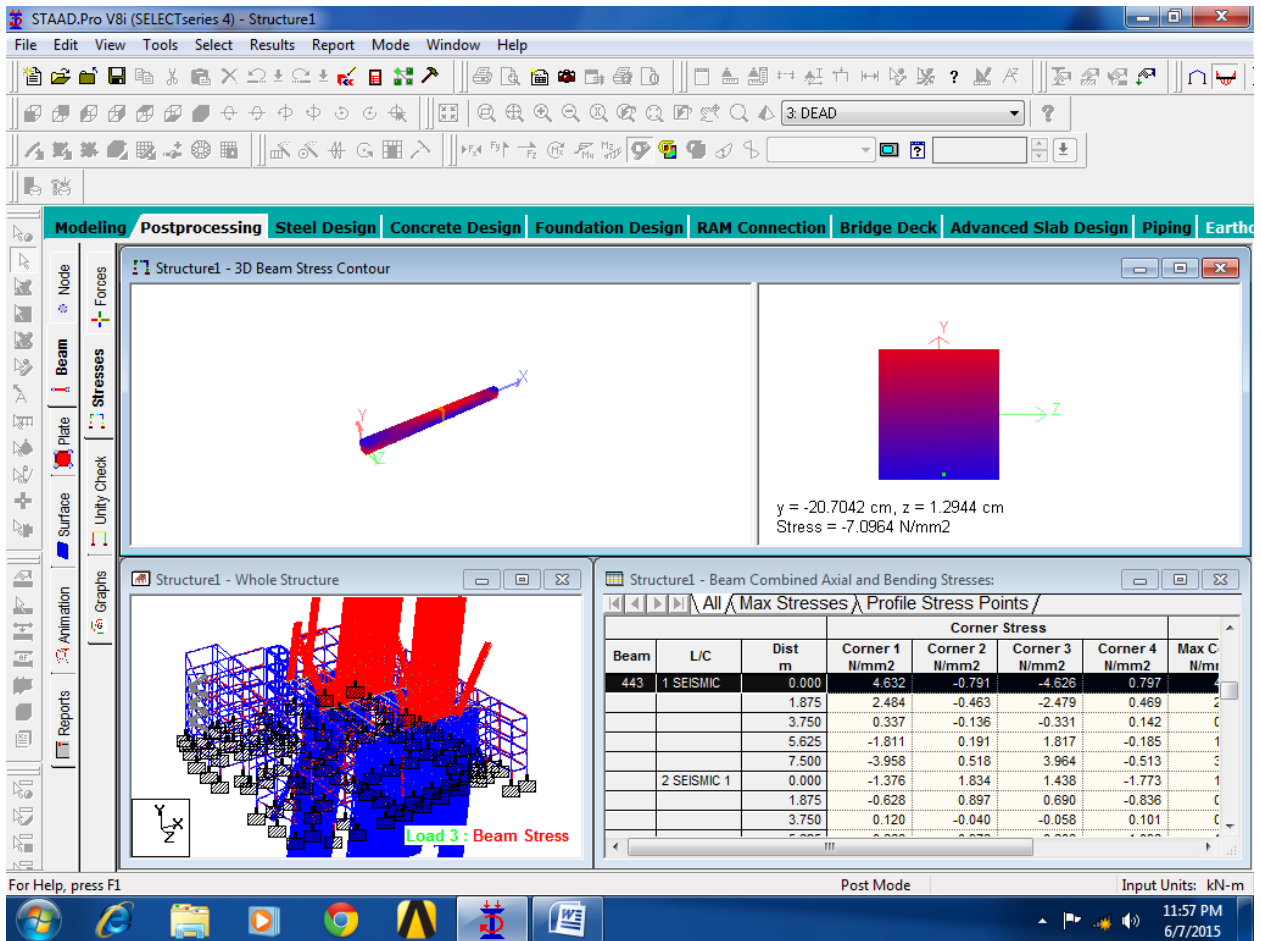


Fig 4.1(i) 3D Stress Contour Diagram

By using this Method, exact values of tensile and compressive stresses at a particular point of any structural element can be calculated. Red and Blue colors are indicators of compression and Tension

## 4.2 Carbon Footprint Calculations

Table 4.2.1 Quantities of Materials Used for Construction

<b>1.</b>	<b>Basic Materials used for various construction purposes</b>	Quantity of Material	Units	Conversion Factor	Conversion Factor(KG)	<b>Final Value (KG)</b>
	Bricks	803894	Nos	NA	2.9	2331293.6
	Cement	22011	Bags	NA	50	1100550
	Sand(fine aggregate)	2218.27	cum	NA	1800	3992886
	Bajri(coarse aggregate)(20M M)	2699.12	cum	NA	2240	6046028.8
<b>2.</b>	<b>Stone usage and Tile Work</b>					
	P.O.P covering(10mm) to protect tiles	3369.94	sqm	0.01	2500	84248.5
	Bitumen on roofs	3301.34	Kg	NA		3301.34
	Dholpur Tiles 25mm thick	137.99	sqm	0.025	2360	8141.41
	Coloured Granite stone tiles(20mm)	826.52	sqm	0.02	2750	45458.6
	Kota stone tile flooring 20-30 mm	65	sqm	0.025	2600	4225
	Kota stone tiles 20 mm	6.2	sqm	0.02	2500	310
	Gypsum/lafarz false ceiling(12.5mm)	1560.35	sqm	0.0125	2500	48760
	Marble stone flooring with 18 mm thick marble stone	202.64	sqm	0.018	2700	9848.304
	Vitrified floor tiles of Size 600 x 600 mm (thickness 10mm)	3978.2	sqm	0.01	2000	79564

	Anti skid floor Tiles(10mm)	588.59	sqm	0.01	2200	5622.98
<b>3.</b>	<b>Metal &amp; other material used for construction</b>					
	Aluminium	6901	KG	NA	NA	6901
	Steel	428632.06	KG	NA	NA	428632.06
	Glass sheets	353.6	sqm	0.055	2500	48620
	Glass	591.71	KG	NA		591.71
	Resin Bonded Glass Wool(50mm)	2056.47	sqm	0.05	24	2467.764
<b>4.</b>	Acrylic paint(exterior)	6219.65	sqm	NA	NA	6219.62
	Plastic emulsion paint(interior)	13292.92	sqm	NA	NA	13292.92
<b>5.</b>	<b>Wood used</b>					
	12 mm commercial plywood	106.97	sqm	0.012	900	1155.276
	Teak wood	168.32	sqm	0.003	900	454.464
	Miranda wood	11334.23	sqm	0.003	900	30602.42
	3mm plywood	1374.08	sqm	0.003	900	3710.016
	Additional wood	619	kg	NA		619

## Calculation of Carbon Footprint Using IS, Databases and Indian literature

Carbon footprint of the structure during construction phase can be calculating embodied energy and final GHG emissions during construction period.

Table 4.2.2 Primary Embodied Energy of TAN building (LCIA results)

<b>1.</b>	<b>Basic Materials used for various construction purposes</b>	<b>Final Value (KG)</b>	<b>Embodied Energy Coefficient (MJ/kg)</b>	<b>Embodied Energy(MJ)</b>
	Bricks	2331293.6	<b>3.00</b>	6993881
	Cement	1100550	<b>5.5</b>	6053025
	Sand(fine aggregate)	3992886	<b>0.081</b>	323423.8
	Bajri(coarse aggregate)(20MM)	6046028.8	<b>0.083</b>	501820.4
<b>2.</b>	<b>Stone usage and Tile Work</b>			
	P.O.P covering(10mm) to protect tiles	84248.5	<b>1.8</b>	151647.3
	Bitumen on roofs	3301.34	<b>51</b>	168368.3
	Dholpur Tiles 25mm thick	8141.41	<b>12.00</b>	97696.92
	Coloured Granite stone tiles(20mm)	45458.6	<b>7.5</b>	340939.5
	Kota stone tile flooring 20-30 mm	4225	<b>1.5</b>	6337.5
	kota stone tiles 20 mm	310	<b>1.45</b>	449.5
	Gypsum/lafarz false ceiling(12.5mm)	48760	<b>1.95</b>	95082
	Marble stone flooring with 18 mm thick marble stone	9848.304	<b>2.5</b>	24620.76
	vitrified floor tiles of Size 600 x 600 mm( thickness 10mm)	79564	<b>9.00</b>	716076
	Anti skid floor Tiles(10mm)	5622.98	<b>4.2</b>	23616.52

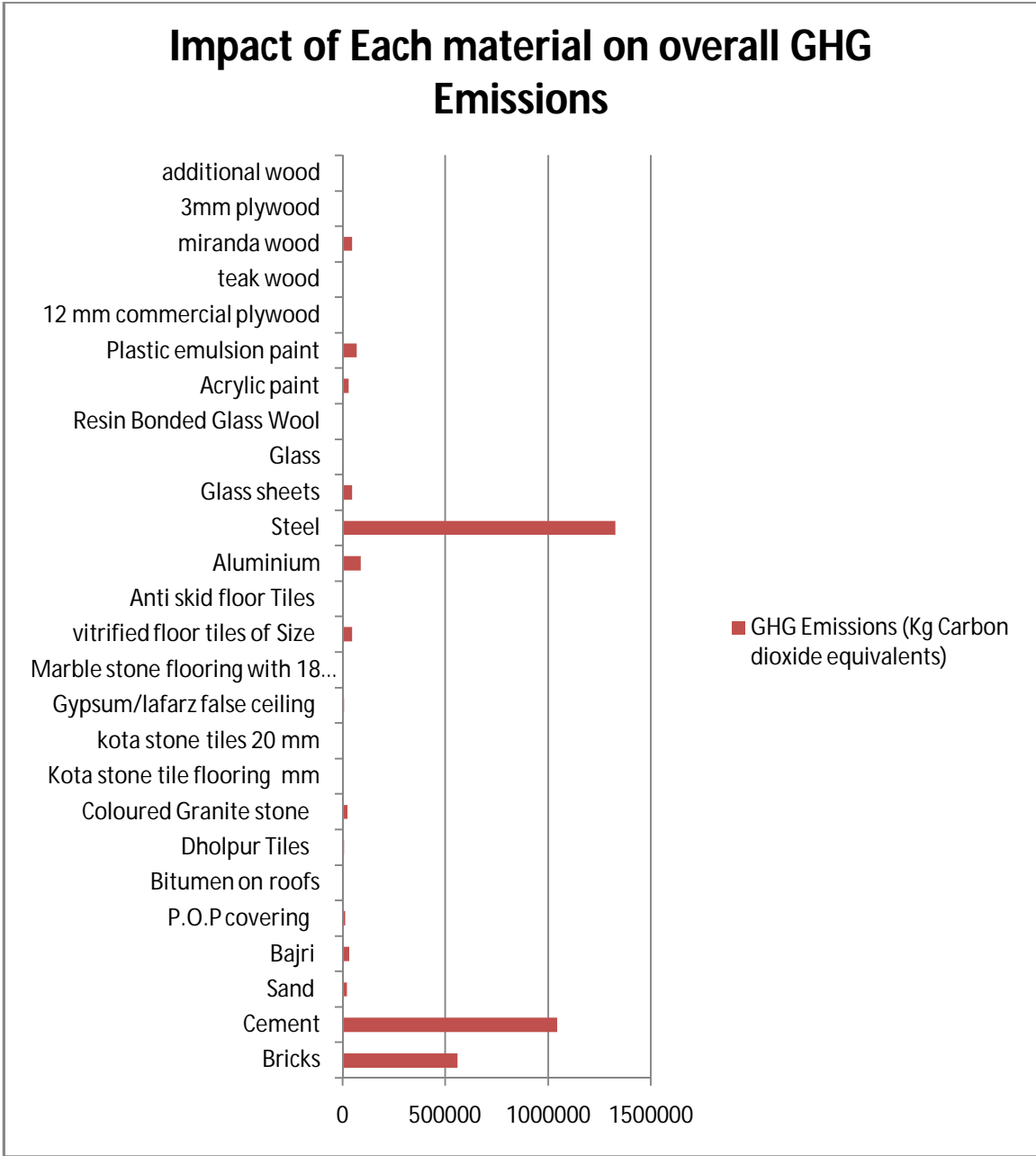
<b>3.</b>	<b>Metal &amp; other material used for construction</b>			
	Aluminium	6901	<b>218</b>	1504418
	Steel	428632.06	<b>35.40</b>	15173575
	Glass sheets	48620	<b>15.00</b>	729300
	Glass	591.71	<b>15.00</b>	8875.65
	Resin Bonded Glass Wool(50mm)	2467.764	<b>28.00</b>	69097.39
<b>4.</b>	<b>Paints(Sqm)</b>			
	Acrylic paint(exterior)	6219.65	<b>65.1</b>	404899.2
	Plastic emulsion paint(interior)	13292.92	<b>77.2</b>	1026213
<b>5.</b>	<b>Wood used</b>			
	12 mm commercial plywood	1155.276	<b>14.4</b>	16635.97
	Teak wood	454.464	<b>27.00</b>	12270.53
	Miranda wood	30602.42	<b>23.00</b>	703855.7
	3mm plywood	3710.016	<b>15.00</b>	55650.24
	Additional wood	619	<b>12.00</b>	7428
	Total in mJ			<b>35,209,203</b>

#### 4.2.1 GHG Emissions during Construction Phase

Table 4.2.3 GHG emissions from Construction Phase

<b>1.</b>	<b>Basic Materials used for various construction purposes</b>	<b>Final Value (KG)</b>	<b>GHG emissions Coefficient (Kg CO2 equivalents/ Kg)</b>	<b>GHG Emissions (Kg CO2 equivalents)</b>
	Bricks	233129 3.6	<b>0.24</b>	559510.5
	Cement	110055 0	<b>0.95</b>	1045523
	Sand (fine aggregate)	399288 6	<b>0.0051</b>	20363.72
	Bajri (coarse aggregate) (20mm)	604602 8.8	<b>0.0052</b>	31439.35
<b>2.</b>	<b>Stone used and Tile Work</b>			
	P.O.P covering(10mm) to protect tiles	84248.5	<b>0.12</b>	10109.82
	Bitumen on roofs	3301.34	<b>0.55</b>	1815.737
	Dholpur Tiles 25mm thick	8141.41	<b>0.78</b>	6350.3
	Coloured Granite stone tiles(20mm)	45458.6	<b>0.48</b>	21820.13
	Kota stone tile flooring (20-30 mm)	4225	<b>0.09</b>	380.25
	Kota stone tiles 20 mm	310	<b>0.087</b>	26.97
	Gypsum/lafarz false ceiling(12.5mm)	48760	<b>0.13</b>	6338.8
	Marble stone flooring with 18 mm thick marble stone	9848.30 4	<b>0.187</b>	1841.633
	Vitrified floor tiles of Size 600 x 600 mm(thickness 10mm)	79564	<b>0.55</b>	43760.2
	Anti skid floor Tiles(10mm)	5622.98	<b>0.32</b>	1799.354

<b>3.</b>	<b>Metal &amp; other material used for construction</b>			
	Aluminium	6901	<b>12.79</b>	88263.79
	Steel	428632. 06	<b>2.89</b>	1328759.386
	Glass sheets	48620	<b>0.91</b>	44244.2
	Glass	591.71	<b>0.91</b>	538.4561
	Resin Bonded Glass Wool(50mm)	2467.76 4	<b>1.55</b>	3825.034
<b>4</b>	<b>Paints</b>			
	Acrylic paint(exterior)	164509 7.4	<b>2.1</b>	28610.39
	Plastic emulsion paint(interior)	321024 0.1	<b>2.3</b>	66464.6
<b>5.</b>	<b>Wood used</b>			
	12 mm commercial plywood	1155.27 6	<b>1.0788</b>	1246.312
	Teak wood	454.464	<b>1.56</b>	708.9638
	Miranda wood	30602.4 2	<b>1.44</b>	44373.509
	3mm plywood	3710.01 6	<b>1.08</b>	3190.614
	Additional wood	619	<b>0.75</b>	464.25
	Total (in kg)			3361769.269
	Total in tons of CO2 equivalents			<b>3361.769</b>



**Fig 4.2.1 GHG emissions during Construction Phase (Material Wise)**

#### 4.2.2GHG Emissions Due to Operation Phase

Operation phase GHG emissions can be calculated by collecting information from electricity bills and associated emissions can be found out by considering electricity scenario of India. Table 4.2.4 shows the consumption of electricity from September 2013- September 2014.

Table 4.2.4 Electricity Consumption of Tan Building(kWhe)

Month	Meter Reading	A.C
Sep-13	4547	4091
Oct-13	3331	10583
Nov-13	2166	857
Dec-13	1285	858
Jan-14	2529	0
Feb-14	2090	0
Mar-14	1930	674
Apr-14	2717	2626
May-14	1531	2481
Jun-14	446	0
Jul-14	2139	16771
Aug-14	2958	26896
Total	31269	76517
<b>Total(1 year)</b>		<b>107,786</b>
<b>Cumulative (75 years)</b>		<b>8,083,950</b>

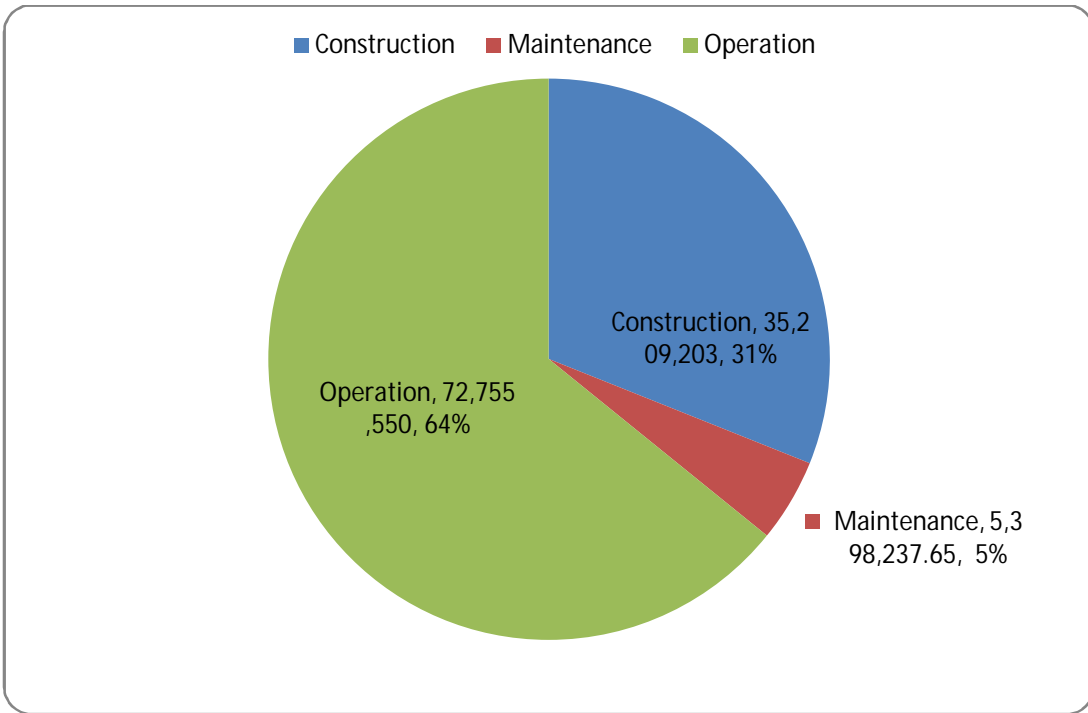
The life span of the building is considered as 75 years. Tan building Consumes 107,786 kWhe in one year and hence total life cycle energy consumption is 8.08 GWhe. By considering the average emission coefficient to 0.4, the actual amount of energy spent to obtain electrical energy can be calculated. In this case the value after calculation is 20,209,875 kWh. The associated GHG emissions are shown in Table 4.2.5.

Table 4.2.5 GHG emissions during Operation Phase

Source	% share	GHG EMISSIONS (gCO <sub>2</sub> eq/kwhe)	Emissions for Life Span of Tan Building (in Tons)
Coal	61.5	1005	4996.48
Gas	8.6	543	377.50
Oil	0.4	650	21.01
Hydro	15.4	41	51.04
Nuclear	2.2	25	4.44
Renewable Sources	11.8	35	33.38
<b>Total in Tonnes</b>			<b>5483.85</b>

Table 4.2.6 Energy share of each phase in terms of primary energy

S.No.	Name of Phase	Primary Energy Consumption(mJ)	Percentage Share
1	Construction	35,209,203	31.05
2	Maintenance	5,398,237.65	5% (fixed)
3	Operation	72,755,550	63.95
	<b>Total</b>	<b>113,362,990</b>	



**Fig 4.2.2 Primary Energy Consumption (Phase Wise)**

### 4.3 Carbon Footprint Calculation Using GABI 6

Table 4.3.1 Construction and Operation Phase GHG emissions

<b>1.</b>	<b>Basic Materials used for various construction purposes</b>	<u>Final Value</u> <u>(KG)</u>	<b>GHG emissions Coefficient (Kg CO<sub>2</sub> equivalents/Kg)</b>	<b>GHG Emissions (Kg CO<sub>2</sub> equivalents)</b>
	Bricks	2331293.6	<b>0.21</b>	489571.7
	Cement	1100550	<b>0.9</b>	990495
	Sand(fine aggregate)	3992886	<b>0.00257</b>	10261.72
	Bajri(coarse aggregate)(20MM)	4588504	<b>0.0034</b>	15600.91
<b>2.</b>	<b>Stone used and Tile Work</b>			
	P.O.P covering(10mm) to protect tiles	84248.5	<b>0.16</b>	13479.76
	Bitumen on roofs	3301.34	<b>0.406</b>	1340.344
	Dholpur Tiles 25mm thick	8141.41	<b>0.755</b>	6146.765
	Coloured Granite stone tiles(20mm)	45458.6	<b>0.5</b>	22729.3
	Kota stone tile flooring 20-30 mm	4225	<b>0.11</b>	464.75
	Kota stone tiles 20 mm	310	<b>0.092</b>	28.52
	Gypsum/lafarz false ceiling(12.5mm)	48760	<b>0.11</b>	5363.6
	Marble stone flooring with 18 mm thick marble stone	9848.304	<b>0.127</b>	1250.735
	Vitrified floor tiles of Size 600 x 600 mm( thickness 10mm)	79564	<b>0.51</b>	40577.64
	Anti skid floor Tiles(10mm)	5622.98	<b>0.36</b>	2024.273

<b>3.</b>	<b>Metal &amp; other material used for construction</b>			
	Aluminium	6901	<b>9.01</b>	62178.01
	Steel	428632.06	<b>2.28</b>	977281.1
	Glass sheets	48620	<b>0.903</b>	43903.86
	Glass	591.71	<b>1.13</b>	668.6323
	Resin Bonded Glass Wool(50mm)	2467.764	<b>1.93</b>	4762.785
<b>4</b>	<b>Paints(In sqm)</b>		<b>Per square meter</b>	
	Acrylic paint(exterior)	6219.65	<b>4.34</b>	26993.28
	Plastic emulsion paint(interior)	13292.92	<b>5.2</b>	69123.18
<b>5.</b>	<b>Wood used</b>			
	12 mm commercial plywood	1155.276	<b>0.84</b>	970.4318
	Teak wood	454.464	<b>1.3</b>	590.8032
	Miranda wood	30602.42	<b>1.5</b>	45903.63
	3mm plywood	3710.016	<b>0.834</b>	3094.153
	Additional wood	619	<b>0.81</b>	501.39
	Total in Kg (construction)			2835306
	<b>Total in Tonnes</b>			<b>2835.306</b>
	<b>Operational Energy in Tonnes</b>	8,083,950 kWh	<b>0.71</b>	<b>5730.60</b>

## 4.4 Comparing Results obtained by using Gabi 6 Results and Manual Calculations

### 4.4.1 Individual Material wise GHG emission comparison during Construction Phase

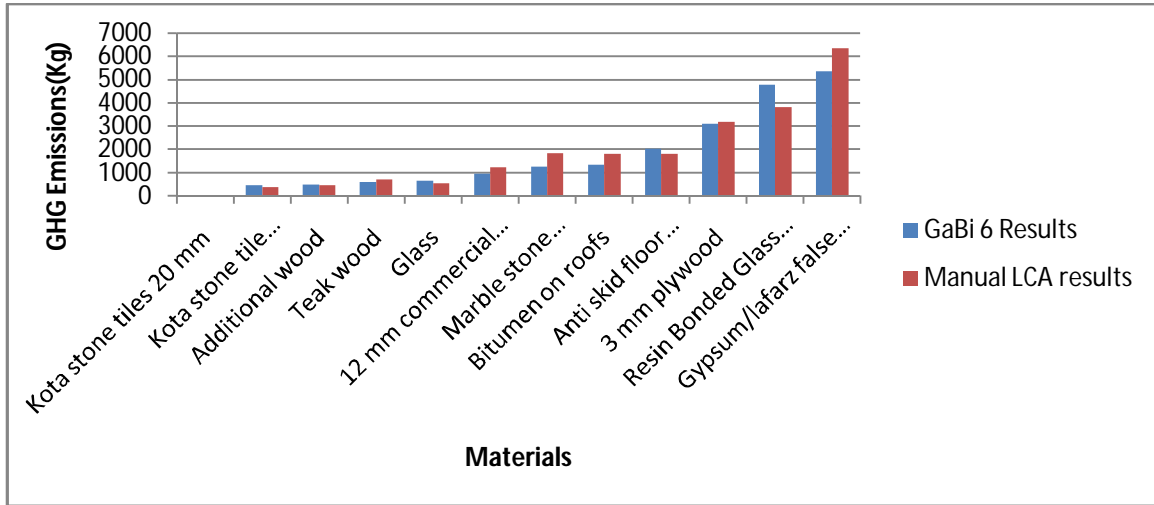


Fig 4.4.1 (a) Comparison of construction phase GHG emissions

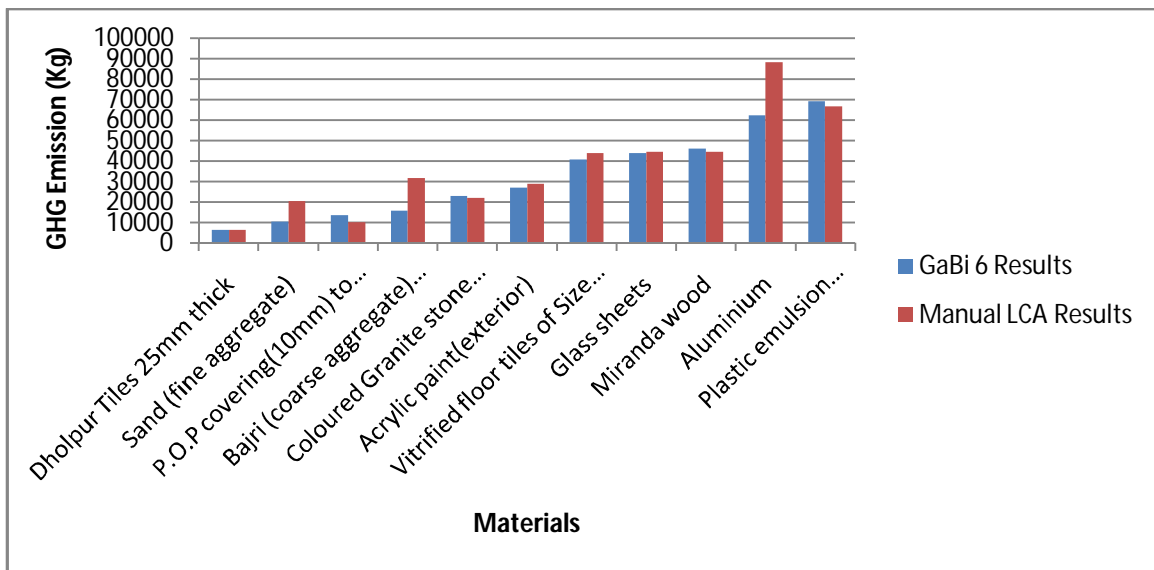


Fig 4.4.1 (b) Comparison of construction phase GHG emissions

#### 4.4.1.1 Comparing Major Contributors during Construction Phase

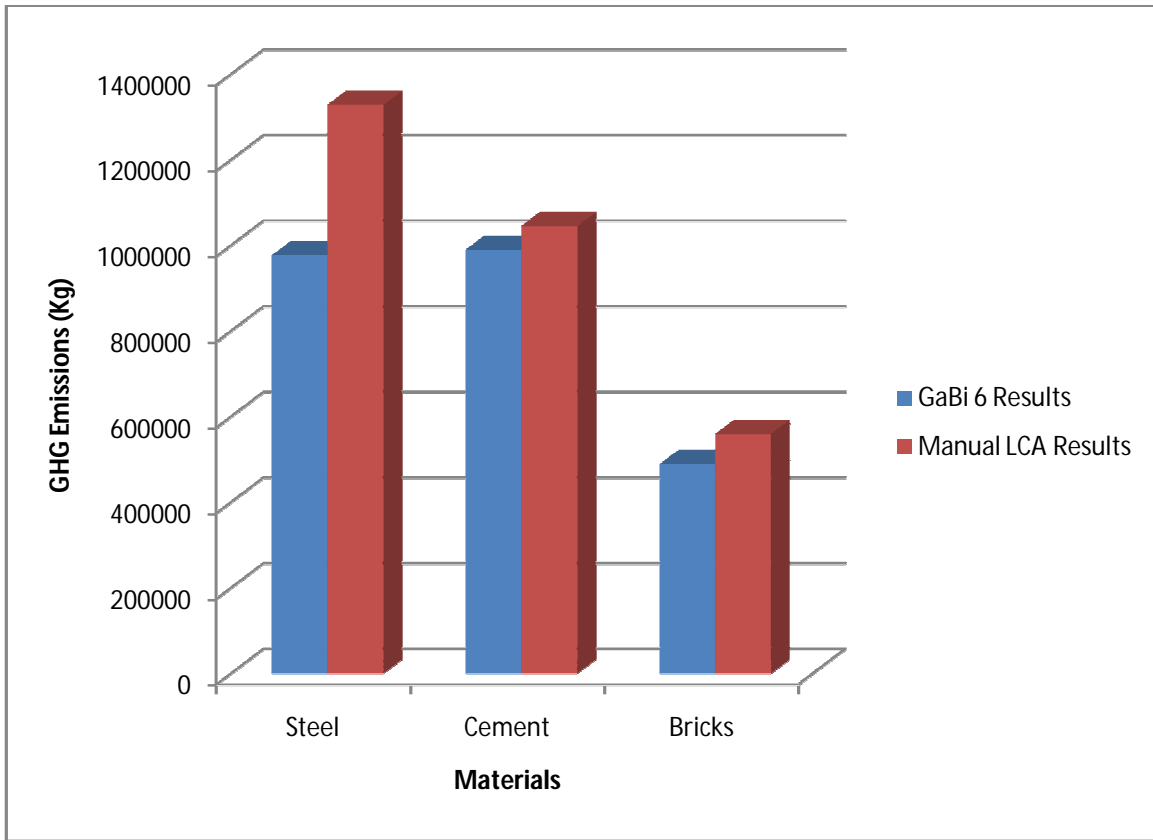


Fig 4.4.3 Major GHG Emission Contributors

#### 4.4.2 Comparing phase wise GHG Emissions (in tons) obtained using both methodologies

S.No	Methodology Used	Construction	Operation	Maintenance	Total
1.	Gabi 6	2835.306	5730.60	428.29	8994.2013
2.	Manual LCA	3361.769	5483.85	442.280	9287.899
	% Inconsistency	<b>15.6603</b>	<b>4.49958</b>	<b>3.163155</b>	<b>3.162154</b>

Table 4.4.1 Phase Wise Inconsistency

Phase-wise Calculations are illustrated below in Fig 4.4.4

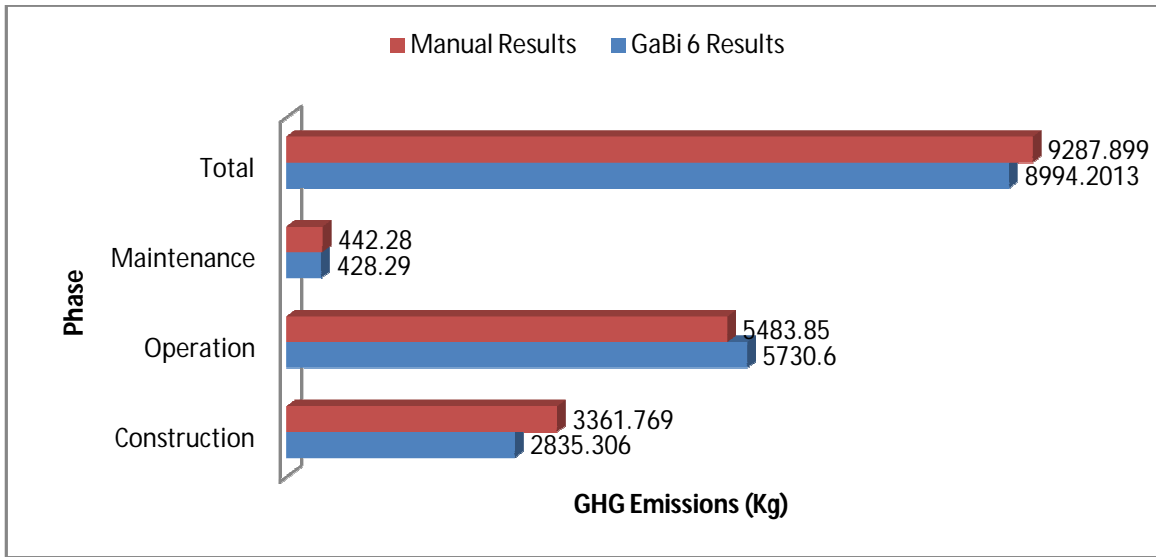


Fig 4.4.4 Phase wise GHG Emissions in both Methodologies

#### 4.5 Potential Savings

- There are 520 Linear C.F.L'S of 15W and 825 Linear C.F.L'S of 65 W installed in corridors and Classrooms/Auditoriums respectively. Replacement by LED can save at least 10% electricity
- Recycled steel, Fly ash bricks and Cement containing fly ash can be used to minimize construction phase GHG Emissions up to 55%.

Table 4.5.1 Potential Savings During Construction Phase

S.No.	1	2	3	4
Material Used	Bricks	Steel	Cement	Aluminum
GHG Emissions (Kg)	559510.5	1328759.386	1045523	88263.79
Material Replaced	Fly Ash bricks	Recycled Steel	Cement with Optimum Fly ash	Recycled aluminum
GHG Emissions (Kg)	373007	201457.1	682341	12490.81
<b>% Reduction</b>	<b>33.33</b>	<b>84.38%</b>	<b>34.73</b>	<b>85.84</b>

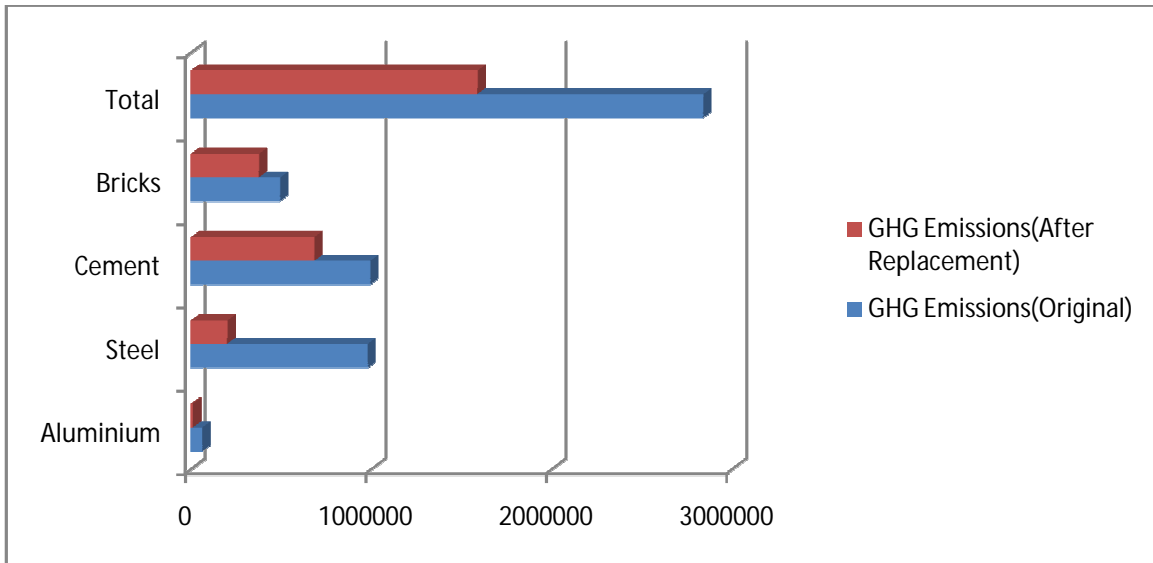


Fig 4.5.1 Reduction in GHG Emissions By using Eco Friendly Materials

- Installing Solar Panels along with solar Pumps can also reduce electricity consumption and carbon footprint by at least 5%.
- It has been proved and verified by various studies that setting up Air conditioner's temperature at 26 degrees Celsius can lead to a reduction of about 5-10% in overall electricity consumption.

#### 4.6 Future Scope of the Study

- Furniture and indoor air quality can be taken into account for future studies.
- HVAC and other requirements can be further reduced.
- Reduction after actual replacement via LED in case of lighting and solar panels can also be calculated.

#### 4.7 A comparison with Previous Similar Studies Conducted

S.No	Year	Specification of Building	Place	Type	Life Time	Floor Area	GHG Emissions (CO <sub>2</sub> eq Tons/sqm 50/75 years)	
1	2001	Malmo	Sweden	R	50	700	1.30	
2	2001	Helsingborg	Sweden	R	50	1160	1.35	
3	2001	Vaxjo	Sweden	R	50	1190	1.51	
4	2001	Stockholm	Sweden	R	50	1520	1.40	
5	2003	School Building	Mendoza, Argentina	C	50	NA	34,000	
6	2003	University Of Michigan	Michigan, USA	C	75	7300	18.49	
7	2005	Steel Framed	Midwestern US	R	50	4400	NA	
9	2006	Low density Building	Toronto, Canada	R	50	NA	5.365	
10	2006	High density Building	Toronto, Canada	R	50	NA	3.885	
11	2006	High-End	South Finland, Europe	C	50	4400	3.01	
12	2008	Office Building	Thailand	C	50	60,000	0.93	
13	2009	Via Garrone Building	Turin, Italy	R	50	6110	3.34	
14	2012	NIT, Hamirpur	India	C	50	3960	0.45	
15	<b>2015</b>	<b>Current</b>	<b>Patiala, India</b>	<b>C</b>	<b>75</b>	<b>3690</b>	<b>Manual</b>	<b>GaBi</b>
							<b>2.517</b>	<b>2.437</b>

## Chapter 5

### Conclusions

- The Life Cycle Assessment clearly indicates that the operation phase uses most of the primary energy delivered to the building(64%) with most power consumed by HVAC.
- The study concludes that the Carbon footprint/GHG emissions calculated by both manual LCA and GaBi 6 have inconsistency of less than 5%. (3.162%)
- It is clear that steel, cement and Brickwork are the main contributors to GHG emissions during construction phase with aluminum, paints and woodwork and tiles playing a minor role
- The GHG emissions can be reduced up to 55% during construction phase by replacing certain materials by more environmental friendly materials and during operation phase by replacing CFL's by LED's, by using solar panels and via controlled air conditioning

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