Environmental Performance of a Green Educational Building: Case Study of U.S. Pakistan Center for Advanced Studies in Energy

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Session 2018-20

Supervised by

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Thesis Acceptance Certificate

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Dedication

Dedicated to those who inspired, instilled passion, and stood by as pillars of strength.

Through passion I gain strength

Through strength I gain power

Through power I gain victory

Through victory my chains are broke

Acknowledgment

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Abstract

Architects and designers are working towards minimizing the impact buildings have on environment over last twenty years. In spite of the fact that many architects claim their buildings are environment friendly, the claims cannot be justified unless a Life Cycle Analysis is conducted since evaluating the impact of building on the eco-system is difficult otherwise. The two major parts of the theoretical basis of the proposed scheme are the concept of sustainability of the building and methods of assessing the building. The objective of this report is to evaluate and comparing the possible ecological impact of office buildings through their life cycle, from extracting raw materials to end of life. The study also shows how to apply the life cycle assessment of a singular material to diverse and complex systems.

In order to accomplish the goal of the study, a single-case method of life cycle assessment was used to determine which stage of the life cycle (manufacturing, construction, consumption, maintenance, and dismantling) made the most contribution to the overall impact. The main installation system (foundation, frame, wall, floor, roof) of a building will have an impact on the environment during its life cycle. One typical new educational building was used as a case study in Islamabad and an optimized LCA method based on energy consumption inventories, material input and output, and the assessment of environmental impact. In addition, analysis has been conducted in this study as well for assessing the operational performance of this building.

This study shows that the operating phase of a building during its 60-year life cycle has the greatest impact on the following impact categories (90+% of the total impact): global warming potential, overall energy consumption (fossil fuel), and acidification potential & the possibility of health effects on the respiratory system. The production stage holds the greatest impact in the following impact categories: the most significant on the potential for depletion of ozone with 87% of the total impact or eutrophication-65% of the total impact. In terms of building assembly systems, this study has shown that wall systems contribute the most to the impacts mentioned as follows, respiratory potential (57%), acidification (40%), global warming (26%) and smoke potential (35%). The structural system comprises of the most contribution to the overall energy consumption (31%) & the eutrophication category (56%). The building's roof system of also partakes in impacting substantially, second to buildings, on utilization of energy

(27%) and global warming (17%). It stands right after the walls causing 29% of potential smog.

Studies and research conducted in the future can replicate the same classification technique on other types of building and construction methods (such as wood, concrete and so on) in order to apply life cycle assessment more widely in design & operation of buildings. This is especially vital in the maintenance phase of replacing certain systems. Today, there is a need for higher availability, standardization, and quality of life cycle assessment data in order to be more widely used in building planning and construction.

Keywords: Life cycle assessment, Sustainability, ATHENA impact factor, ISO 14040 Environment Management, Life cycle stages and building groups

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1. **Environmental Profiling of Green Educational Building Using Life Cycle Assessment**

   Proceedings of the 1st International Conference on Energy, Power and Environment (University of Gujrat, Gujrat)

   Authors: Talha Bin Farooq, Muhammad Bilal Sajid

CHAPTER 1

Introduction

1.1 Outline of the Study:

This study contains an executive summary, along with six detailed chapters and a bibliography. The first chapter is devoted to the importance of the research question and ends with explaining the research's main objectives, scope, and limitations. Background, history, descriptive methodology, and how it applies to products and architecture are discussed in Chapter 2. Chapter number 3 provides a broad investigation and categorization of the priorly done LCA research on the architecture and gives a condensed argument on the necessity of this research. Chapter 4 introduces a research methodology that uses several case studies and life cycle assessments as tools to calculate the environmental impact of these events over a 60-year life cycle. Chapter 5 describes the characteristics of the three design options and describes the procedures followed to accomplish them. The conclusion is discussed in Chapter 6. It presents arguments that support the fact that the data used is legit, valid, and reliable, and ends with the importance of research and courses of future research.

1.2 Apprehensions of Pakistan and the U.S. Regarding Sustainability

Out of the many causes of the exhaustion of natural resources & undesirable outcomes such as poisonous waste, global warming, air pollution, water pollution, and many other terrible outcomes, one of the main causes is the Construction and Building Industry[1]. Not only in the United States but globally as well. Although the conventional mindset of getting limitless resources continues to be dominant within the U.S., the awareness of ecological and environmental effects is developing, and plenty of projects looking to cope with sustainability apprehensions are gaining momentum.

One of the many purposes the building industry is centered on for sustainable green development is the massive capacity for saving energy & natural resources and reducing the amount of waste in landfills. Another very important reason is to choose the most suitable materials and construction methods for indoor climate. There is an urgent need for guidelines based on not only national but also international legislation. These two are very influential for development and the basis of research. Therefore, in addition to economic and productivity principles of sustainability, the construction industry needs to regard environmental performance as one of its guiding principles.

Studies conducted in recent years show that the building sector plays a huge part in the effect of human activities on the environment [2], [3]. Environmental impacts that construction and the maintenance of the buildings instigate are multifaceted. Among the significant impacts is Climate Change, which is set off by energy consumption in these activities. With the escalation in the usage of fossil fuels, climate change has become an urgent issue, considering that a link has been found that relates greenhouse gases to their impact on global temperature. In warmer climates, this may increase the melting of glaciers. In addition, environmental releases change the water cycle, leading to extreme effects of climate change and wind and flooding. One of the consequences may be population displacement, with huge economic consequences.

Particularly, after the environmental management system standard, ISO 14001, was established in 2001, The environmental protection designs have grasped the attention of many organizations. With the U.S. economy transitioning to a service type, investment in commercial buildings, especially offices, is expected to lead to significant growth. The ecological design of a building refers to the subject or knowledge of the life cycle of a building [4]. This life cycle knowledge also provides an opportunity to optimize the requirements of investors on both sides. It helps design decisions, particularly in the initial stages. Spreading awareness about the environment also helps to reduce the impact on the environment.

1.3 Effect of Building Industry on Environment & Economy

Globally, the construction and building sector showing an increase in emissions and energy use. In 2018, building construction and operations accounted for the greatest share of global final energy use (36%) and energy-related $CO2$ emissions (39%) [5].

Amongst the largest Industries of the U.S. economy is the construction Industry. Construction spending was estimated to be $1524.2 billion in April 2021 [6]. In the first four months of this year, total spending on the construction industry amounted to $452.3 billion [6].

Buildings account for the wealth of more than 50% of the total of the United States. In 2020, the total amount of new construction and maintenance was about 1469 billion U.S. dollars [6], account for 7% of GDP, and 7.41 million people were employed [7]. Buildings are responsible for one-third of global CO2 emissions. The building and construction sector accounts for 40% of the total electricity consumed in the U.S. [8].

The construction sector in Pakistan adds up to 380 billion PKR in GDP. 36.38% population resides in urban areas. Housing demand in Pakistan is growing due to the 2.4% of growth rate of the population [9].

The United States has many specific country problems. The country has a diverse climate, and traditional construction techniques vary from region to region. From North Sub-Arctic to desert and subtropical, winter is severely cold, summer is hot, and the climate fluctuates greatly. Because of this diversity and the legal dominance of each state in governing construction practices, building codes vary in each state. The United States has more than 5.9 million buildings and a floor area of 97,016 million square feet[10].

In the United States, buildings account for more than 30% of total energy. The consumption, as mentioned earlier, of energy accounts for approximately one-fourth of the total U.S. carbon emissions and is the main factor leading to climate change. Water pollution. Although the impact today is serious, sustainability trends have grown substantially recently, and the water and air are cleaner than decades ago.

Currently, households have a share of 45% in electricity consumption in Pakistan. Total electricity units sold in Pakistan in March-2020 were 2.3 million kWh, which was 5.3% greater than the same month of last year [11].

Commercial buildings play a considerable part in natural resource depletion and other adverse ecological effects. The adverse effects are Air pollution, water pollution, toxic chemicals production, hazardous waste generation.

1.4 Eco-Friendly Design

In recent years, a globally increase has been observed in the understanding of the sustainability. With the continuous growth in this movement, it's becoming clear that non-renewable resources are being exhausted at an inefficient and alarming rate. Sustainable development attempts to assist the current generation in meeting their requirements without jeopardizing future generations' while satisfying their own needs [12]. Public attention has been focused on various measures to lessen environmental damage, including reusing obsolete components in new products, reducing the usage of packaging, recycling municipal solid waste, and so on.

The public has perceived the construction industry as a significant source of pollution and a substantial energy and raw resources user. As a result of pressure imposed by pressure groups, the industry began to use these resources and energy responsibly, harmlessly disposing of trash, cleaning out the manufacturing processes & recycling products after consumption and garbage, among other things. Businesses have started to use environmental management practices and concepts as a business standard to limit their ecological consequences. Environmental management concepts and practices have become the standard, and a means for businesses to limit their environmental effect. The World Organization for Standardization ISO has developed environmental management and standards due to the international community's efforts. ISO 14000, a series of standards, was issued in September 1996. These new standards have become critical for organizations that wish to conduct business on a global scale. The United States government began promoting sustainability initiatives more than a decade ago. For instance, the federal procurement standard of 1995 in the U.S. makes it mandatory for contractors to implement sustainable practices if they want to be in business with the government. The federal contractors must comply with the reporting requirements of the Toxic Release Inventory (TRI). The federal government also endorses The US EPA's Energy Star Program, which focuses on cutting back on energy consumption by computers and peripherals. These practices now require that computers purchased at the federal level have an Energy Star rating. The federal government has approved the EPA Energy Star Computer and Peripheral Equipment Energy Efficiency Program. It is a primary requirement that computers being purchased at the federal level have an Energy Star rating.

New efforts for "prevention of pollution" and "design for the environment" have reached the core of sustainable development. Both provide several tools and techniques that will help society cope with environmental challenges, including reducing waste generation and emissions and shortening the product life cycle as early as possible in the product's entire life cycle. Tools and techniques are required in the design phase to reduce waste generation and make the products sustainable. Even though great work has been done towards preventing pollution, creating sustainable designs, and research conducted in industrial ecology. There is still an absence of critical literature, effective methodologies, and useful tools. To assist the designers in understanding the environmental impact of their decisions better, indicators and tools are a requirement. There is a grim need for methods to measure Environmental Performance so the sustainability of products and processes can be measured, and an Industry-wide benchmark can be set.

1.5 Problem Statement

The daily decisions significantly impact the environment, and the architects have yet to realize that. In recent years, architects have started to focus on reducing the effect of buildings on the environment that they have designed. Despite claims architects make that their buildings are eco-friendly, it cannot be proved until LCA is conducted. Compared with other products, buildings are more difficult to evaluate from an ecological perspective because they are large and have a complicated model material. The limited service-life of its components makes the simulation a dynamic process. In addition, the manufacturing process of buildings is not as standardized as most consumer products. Each building has a unique design and a complex operational phase, such as limited information on the impact of the materials or process included in construction and demolition. It causes the analysis to become more difficult. Understand building energy efficiency strategies, and even less understand the impact of upstream (mining, production, transportation) and downstream (demolition, disposal) of buildings. Life cycle assessment is a comprehensive method used to analyze the impact of a product on the environment throughout its life (from creation to completion). The concept of LCA moved from domestic consumption or commercial products to materials and components used in building. L.C. analysis of all existing buildings is very important to determine and evaluate how key design systems (foundation, frame, wall, floor, roof) affect the environmental performance of the building.

Copious research has been conducted in the last two decades regarding the buildings' ecological impact, but in-depth studies are very few. The previous studies are based on single-cased buildings, but there are no complete phase life cycles and only a few environmental impact categories. Such studies are also centered on basic data about the building or parts of the entire building, e.g., building materials or embodied energy, etc. Others are done at the smaller level of material or product rather than the building level. More emphasis is placed on estimating energy usage and carbon dioxide emissions without considering other environmental impacts: depletion of the ozone layer, global warming, smog formation, acidification of soil, and eutrophication. That emphasis contributes greatly to solving current climate change issues such as ozone depletion, acid rain, etc., and potential respiratory effects. However, there are very few studies and research examining the entire life-cycle of a building or considering all environmental effects at each stage.

This research bridges the gap as mentioned earlier by comprehensively monitoring & quantifying all the environmental impacts at all stages of the life of a building. Not only that, but this study also considers eight types of impact at each stage and calculates the percentage contribution of the main building installation systems (foundation, frame, wall, floor, and roof) to the environmental impact of the entire building, and provides the necessary information, including the design process. It also presents a complete picture of how the building analyzes its environmental impact.

1.6 Objectives of the Research

This research aims to calculate and assess the environmental impact of educational buildings with a service lifespan of more than 60 years. Another goal is to determine which of the stages of a building's life cycle and the assembly systems of a building participate significantly in the environmental impacts. The expectations from this research are to produce critical abstract as well as practical and educational results. Following are the goals of the research:

- Assessment of operational performance of a green educational building
- Apply a single-material life cycle assessment model to complex systems like long-lived (60 years) buildings.
- Determine the contribution of life cycle phases of individual buildings to the overall impact and use some strategies to mitigate the impact at the said phases.
- Estimate the influence of each basic building component (foundation, structure, floor, walls, and ceiling) on all the effects on the environment in terms of energy consumption, materials, and environmental emissions throughout the life cycle.

- Choose more environment-friendly raw materials and other components in the initial stages of planning and upkeep of the building. For instance, materials with low energy consumption and low environmental impact should be chosen. It does better than the uncertified buildings.

To achieve the goals mentioned earlier, this study reviewed the degree of environmental impact throughout the life cycle and examined their impact on selecting materials and components.

1.7 Queries Addressed in this Research

Through this research the following queries are addressed:

- During the entire life cycle, what is the connection between environmental pollution and consumption of energy?
- Which stage of the building's life cycle has the greatest impact on the environment?
- In what ways can we quantify the sustainability of buildings based upon the actual performance rather than a set of prescribed standards, as in the current rating system (BREEAM, LEED)?
- Will the choice of building materials in their life cycle have different environmental impacts?
- Which building assembly system (foundation, structure, wall, floor, and roof) has the greatest impact on the life cycle and the share of each system in the cumulative environmental impact?
- How do you achieve an architectural design that has low adverse environmental consequences?

1.8 Scope of the Study

The research focuses on calculating the environmental impact and energy consumption at different stages of the building's life cycle, including installation and use. The research focuses on the ecological part of sustainable development, including resource economy and ecosystem protection. It can be quantified in terms of energy and mass flow using life cycle assessment methods.

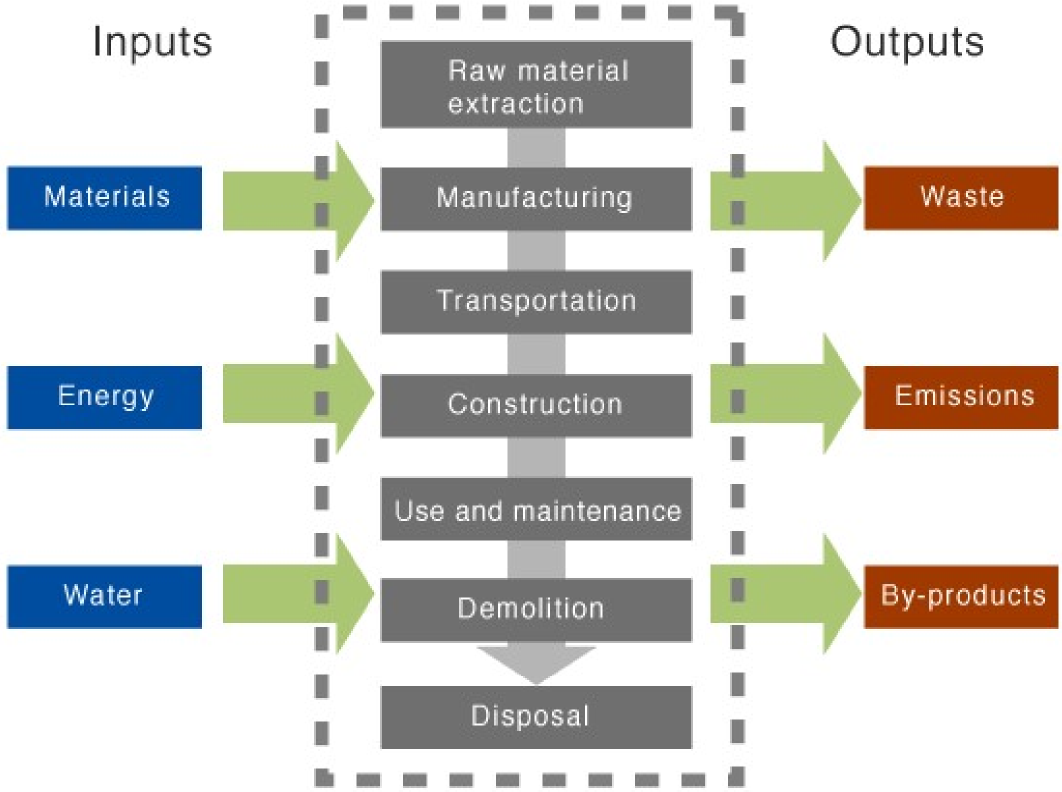

Figure 1.1: Lifecycle of a building and it inputs and outputs (Adapted from [13])

1.9 Limitations of the study

i. The life cycle assessment contains neither market mechanisms nor secondary effects on technological development; it only focuses on the physical properties of industrial activities.

ii. The issues involved in this study are limited to the total effect of the building's entire life cycle on the environment, including resource consumption, energy consumption, production, construction, operation, maintenance, and harmful environmental releases to air, water, and land during these processes

iii. The contents of this study are limited to data from the U.S. and a few figures from Canada

iv. Life Cycle Costing is excluded from the scope of this study since it considers the different types of costs and does not include impacts on the environment This study only discusses the effect of material energy and consumption of energy by operations on the environment since they are the substantial components of the overall environmental impact.

v. This study aims to conduct LCA analysis to determine impacts on the environment so better alternatives for material can be chosen. This study is conducted on an existing database hence generation of new data is beyond the scope of this study.

Summary

This chapter gives the brief introduction to the comprehensiveness of the building sector and its potential to reduce the harm associated with the environment. Further objective, scope and limitations are presented in this chapter.

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CHAPTER 2

LIFE CYCLE ASSESSMENT (LCA)

Life Cycle Assessment (LCA) includes the comprehensive assessment of the impacts on the environment of a product, process, or activity, considering the product's entire life cycle or process from the extraction of the raw materials to disposal. As an effort towards Green Designing, there is a requirement of selecting designs, raw materials, tools & techniques, recycle & reuse strategies, and waste management which needs a cautious approach towards resource & energy consumption along with the environmental impacts related to each design substitute

2.1 History & Background of LCA

In 1969, the Coca-Cola Company financed a study comparing resource utilization to environmental emissions from beverage packaging. At the same time, Europe also developed a similar inventory method, which was later called "life cycle assessment." In 1972, Ian Boosted analyzed the overall energy consumption in manufacturing many beverage containers, plastic, glass, aluminum & steel types in the U.K. In the following years, he consolidated this study to make it more appropriate for applying to various materials in a handbook he published called "The Industrial Energy Analysis" in 1979 [1]. Primarily, the efficient consumption of energy used to be more important than the generation of waste and environmental releases. There was not much difference between how the inventories evolve and how they account for the cumulative effects. But after the oil crisis, the importance of energy issues became less important. However, interest and research in life cycle assessment continue.

Even though development speed has slowed down, the methodology has begun to consolidate and approach maturity. In 1995, the life cycle assessment community was confident that the new tool had a promising future. There are a large number of LCA software that is currently available in the market. The assessment process itself raises awareness of the environmental impact and promotes efforts towards improvement. For example, AT&T develops in-house Life Cycle Analysis tools [2] for its product line. The government agencies, EPA also provide general guidance for life cycle assessment [3]. Life cycle assessment standards have entered the eco-label system, such as the German environmental management standards Blue Angel and ISO 14000 [4]. Practical applications of the SETAC [5] method include simplifying life cycle assessment by drawing a line, limiting to only a few interested manufacturers under consideration in the process starting with raw material and ending with waste disposal. Simplified life cycle assessments appear in well-reputed magazines even; Consumer Reports, for example, talks about the environmental impact of various sorts of chemicals and product packaging.

LCA-based assessment is a new and innovative method for assessing the environmental impacts for the building and construction industry. It is particularly developed for the construction industry, aiming to include the advantages of LCA and overcome the shortcomings of the eco-labeling system as a holistic method. The assessment based on LCA has been well developed conceptually, but its application is in construction. Assessment based on LCA has become a promising method because of its integration in weighing applications and solutions. Based on industry standards, regional weights, international standards, and unified assessment levels (such as GB Tool), all of these will strengthen the further development of LCA. Although LEED [6] has achieved more achievements in the national qualification program than any other tool, it must become a convention in the process of construction on which professionals can depend. LEED is not only a milestone, but it is also critical in this work because it defines most of the green and sustainable building area and also involves an extensive range of stakeholders. However, LEED itself isn't a reliable tool for assessing the sustainability of the construction industry. Therefore, the use of life cycle assessment in the construction process is much more complicated. LCA-based assessments provide an attractive guideline for the development of environmental assessment tools.

2.2 Single Material Life Cycle

The Life cycle of a single material identifies by SETAC [5] has [6] phases which are discussed as follows

Phase 1: Procurement of Raw material This phase involves all the activities to get the raw material and energy, from extraction to transportation to the manufacturing facility.

Phase 2: Manufacturing the process in which material and energy are taken as an input and are converted into the final product for consumption is called manufacturing

Figure 2.1: Product life cycle (Adapted from [5])

Phase 3: Distribution and Transportation When in the final form, the product is then dispatched to the final consumers

Phase 4: Use and Maintenance The end consumers use the product over its life span. During use, the product may require maintenance as well.

Phase 5: Recycle: When the product has spent its useful life and reached its form as scrap, it can be recycled in closed or open-loop cycles.

Phase 6: Waste Management This is the final phase in a product's life cycle when it has served its objective and is returned to the environment as waste or scrape.

2.3 Life Cycle of the Entire Building

The Life cycle of building consists of the following phases:

2.3.1 Phase 1: Extraction/ Manufacturing of Building Material

The life cycle of most construction products begins with the mining of raw materials such as iron ore and wood. It is the beginning of life-cycle inventory data development, showing the energy consumption per component of resource and releases to air, water, and land. In addition to resource extraction, mining, or mining, these recycling stages also involve the transportation of raw materials to defined mining and production the boundary between the factory or the factory's gate. One main difficulty out of the many in evaluating the environmental impact of extraction of resource, which is one of the many environmental impacts that people are concerned about, for instance, the impact on quality of water, soil stability, biodiversity, etc. Periodic or existing research is just a passing mention at this point.

The stage which usually makes up the largest proportion of embodied energy and emissions associated with the life cycle of a building product is manufacturing. Manufacturing begins with the raw resources and other materials being delivered at the manufacturing facility and delivers products to the retailer.

Figure 2.2: Building Life Cycle (Adapted from [6])

2.3.2 Phase 2: Transportation of Material to the Construction Site

The material is then relocated to the site of construction for use. Average transport distances to the construction sites are used in the life cycle assessment process.

2.3.3 Phase 3: Construction of the Building

This phase is similar to the additional production step in which singular components, products, and sub-assemblies are brought together to produce the entire building. Construction phases start with moving all the materials and products required for assembling to the construction site from the distribution centers. This phase can be significant in energy consumption and various other environmental impacts as it can generate significant amounts of waste. The construction phase also incorporates the usage of energy in machinery and the transportation of the material and machinery. The on-site construction phase involves transporting equipment to and from the construction site, concrete formwork, and temporary heating and ventilation.

2.3.4 Phase 4: Use and Maintenance of Building

During this phase, the building is underuse, and maintenance of the building is done over the period. Not only functions such as heating, cooling, lighting, and water consumption must be considered, but also the introduction of new products such as paint, dyes, flooring, and further interior fittings. A building can be rebuilt or reconfigured (a form of reuse) multiple times during its lifespan, with a few modifications to the layout of the interior and perhaps adding more products or systems. During the stage of maintenance in the life-cycle of the building, some of the parts of the building may be changed.

2.3.5 Phase 5: Demolition or Erosion of Building

Demolition is the final stage of a building, and recycling is the final stage of the material that makes up the building. At this stage, drift energy in various structural systems is inspected under different climatic conditions. We Assume that building materials are reused and recycle 100%. Recycling is a particularly challenging area for constructing life cycle assessments. For the buildings being designed now, it involves long-term practices and future loads, so it is quite unpredictable because most of the environment related to recycling and reuse Factors are usually recycled reused. Transportation is the cost to pay for the next use of the product (closed-loop recycling). The focus is mainly related to the environmental impact of landfills or incineration.

2.4 Life Cycle Assessment Approaches

The three types of life cycle assessments are

- Process-based LCA
- Economic input-output analysis based LCA (EIO-LCA)
- Hybrid LCA

Process-based LCA and EIO-LCA are the two major types. The third type is a mixture of both of these approaches called the Hybrid LCA.

2.4.1 Process-Based Life Cycle

SETAC is Society for Environmental Toxicology & Chemistry originally came up with the LCA, which was basically process-based. This methodology was made official by International Organization for Standards in ISO 14040 [7] [8].

LCA analyzes different ways of causing environmental damage. We can get a balanced view by using this approach about

a) direct or local effects (e.g., human toxicity, smog formation)
b) long-term or global concerns (e.g., global warming, depletion of non-renewable energy)

Methodology:

Process-based life cycle assessment is conducted in four steps [2]:

- Goal
- Definition
- Scope
- Boundaries of the process

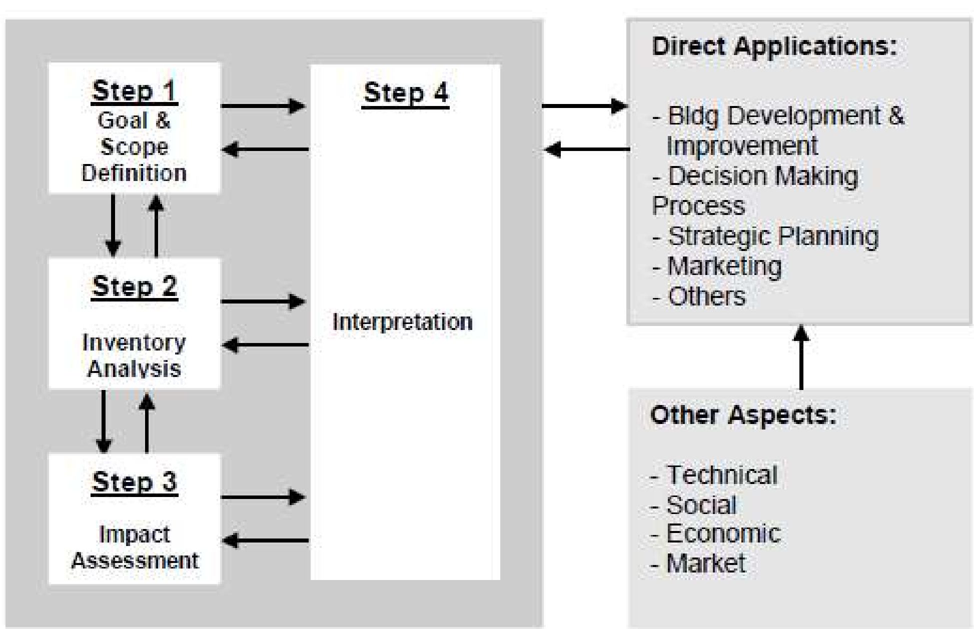

Figure 2.3: Framework of life cycle analysis (Adapted from [12])

2.4.2 EIO-LCA

EIO-LCA stands for the economic input/output-based Life Cycle Assessment. The 1997 "Input-Output Matrix" of the U.S. included 491 different sectors. This type of data, along with the resource consumption, wastes & emission to trail various economic operations, requirement of resources, and required environmental releases missions regarding a certain product/service [9]. EIO-LCA data is gathered from a publicly accessible database of resource utilization, environmental emissions, and waste generation. Then the data of the individual economic sectors is used in combination with the economic inflows and outflows for evaluating the environmental impact. It means that all resources and emissions that are directly or indirectly (in the supply chain) caused by product manufacturing or service provision can be considered

Comparison of the Two Models

The first two life cycle assessment methods have their advantages and disadvantages. Process-based life cycle assessment can perform in-depth analysis of a procedure at a certain point. Still, it is subjective every so often when identifying the process to be taken. In addition, local conditions and inventory overtime details may not match other estimated conditions. It can limit the accuracy of the study. In contrast, EIO-LCA avoids the majority of the subjective issues that affect process LCA. It is used because of data over-aggregation since it gives an aggregate score for the majority of the products & processes.

2.4.1 Hybrid Model

This model was introduced to benefit from the pros of both the formerly mentioned processes. Hybrid LCA uses EIO LCA's all-inclusiveness of emissions by the supply chain to deal with the need for process assessment of all processes in the supply chain and uses process-based assessment to overcome inaccurate life cycle analysis when EIO LCA is too aggregated to specify the purpose. Bilek et al. [10] published an overview of the existing hybrid model and its use in construction.

2.5 International Standards for LCA

The International Organization for Standardization's LCA series of standards ISO 14040 (1997) was published in Geneva at the end of the 1990s to develop the environmental management standard ISO 14000 further. ISO 14040 defines the principles, framework, and method standards for the implementation of environmental management. It discusses the four steps, namely:

Step one: definition of objectives, scope, and status analysis

Step two: general introduction structure

Step three: impact assessment

Step four: interpretation

Table 2.1: Results of EIO-LCA electricity production and distribution [9]

Sector Code		Total Economic ($million)	Value Added ($million)	CO (mt)	NOx (mt)	PM10 (mt)	GWP (MTCO2E)	CO2 (MTCO2E)	Total Energy (TJ)
	Total for all sectors	1.73	1	5.54	25.7	1.34	10600	10100	100
221100	Power Generation and supply	1.01	0.63	2.66	24.31	1.14	9979.53	9793.6	96.01
211000	Oil and gas extraction	0.1	0.04	0.16	0.07	0	104.44	16.77	0.39
212100	Coal Mining	0.08	0.04	0	0	0.06	245.28	15.38	0.39
486000	Pipeline Transportation	0.03	0.01	0.21	0.01	0	35.08	28.82	0.4
482000	Rail Transportation	0.03	0.02	0.09	0.79	0.02	86.38	82.33	1.14
420000	Wholesale trade	0.03	0.02	0.17	0.02	0	7.89	0.75	0.01
533000	Lessors of nonfinancial intangible assets	0.02	0.02	0	0	0	0.27	0.09	0
324110	Petroleum refineries	0.02	0	0.01	0.01	0	30.07	14.87	0.29
336120	Heavy duty track manufacturing	$1.x10^{-6}$	0.00	0.1	0	0.01	$1x10^{-4}$	$1x10^{-4}$	$3x10^{-6}$
…..									
339111	Lab apparatus and furniture manufacturing	$1.x10^{-6}$	0.01	0.00	0.01	0.1	$4x10^{-5}$	$3x10^{-5}$	$1.x10^{-6}$

2.5.1 Objectives and Scope of the study

Step one of L.C. Analysis is to determine the purpose and scope of the research. The research objective includes the reasons for the research and the expected applications and target groups of the results. The elements in the life cycle assessment discussed are the system boundaries, functional Unit, the system's function, impact assessment types of methodology, interpretations, requirements and quality of data, underlying assumptions, and limitations.

- **System Boundary**

The system boundary determines which standard processes are included in the life cycle assessment study. System limits are determined partly based on subjective decisions made during scoping when the limits were set initially. The following constraints can be considered:

The boundary between nature and the system. The life cycle generally starts with the energy and raw materials extraction from nature. The final stage usually involves the production of waste and heat. For example, geography is a vital factor in most life cycle assessment research. Infrastructure such as power generation, transportation systems, and waste management vary from region to region. Timespan: Not only have to set limits on space, but you also set limits on time. Life cycle assessment is to assess current impacts and predict future scenarios. The deadline depends on the technology used, the life span of the contaminants, etc.

- **Unit of Function**

It is the measure of the function of the system under study. Functional Unit represents a frame of reference that can allocate inputs and outputs to compare two different important systems. For instance, Unit of the function of a paint shop can be a unit of area (ft2) over ten years. It makes it possible to compare the impact on the environment of different coating systems with that same Unit.

- **Data Quality Requirements**

The data being used for the analysis should be reliable and accurate as the reliability and accuracy of the LCA analysis depends upon the quality of the data.

2.5.2 Life Cycle Impact Assessment (LCIA)

LCIA determines the importance of probable effects on the environment based on the outcome of LCI and associating inflows and outflows with impacts on the environment. It contains a series of category indicators, impact categories, and models of characterization. Life cycle assessment. The ISO 14040 assumes that LCIA comprises of the steps mentioned below:

- Classification
- Characterization
- Valuation
- Grouping
- Weighting
- Data quality analysis

2.5.3 Life Cycle Inventory Analysis

LCI includes every stage of recovering and managing data. The data is verified and then is assigned to a function block that can summarize the consequences. LCI also calculates the inputs and outputs of material and energy within the system. Raw energy and materials are consumed in all aspects. Environmental emissions, solid and water waste are all discharged. Examples of production are the depletion of resources (such as materials and energy), the emission of pollutants, and the emission of chemical or physical loads (such as substances, heat). Collecting data is the most resource-intensive part of life cycle assessment. Reusing data from other studies can make things easier. However, this needs to be done very carefully so that the data is representative.

1.1.1 Analysis of LCA's result

The analysis or interpretation stage aims to evaluate the results and draw conclusions and recommendations based on the determined research purpose and scope. The LCI and LCIA results are summarized and presented as a complete research description. The analysis of life cycle assessment or life cycle assessment includes three main elements: Identify important issues arising from the life cycle assessment and life cycle assessment stages; Assessment of results, including checking completeness, sensitivity and consistency; and the last step is conclusions and recommendations.

Table 2.2: Commonly used impact categories [11]

Env'l Impact Category	Scale	Relevant LCI Data (i.e., classification)	Common Characterization Factor	Description of Characterization Factor
Global Warming	Global	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Bromide (CH_3Br)	Global Warming Potential	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials can be 50, 100, or 500-year potentials.
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons Methyl Bromide (CH_3Br)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Acidification	Regional Local	Sulfur Oxides (SOx) Nitrogen Oxides (NOx) Hydrochloric Acid (HCL) Hydrofluoric Acid (HF) Ammonia (NH_4)	Acidification Potential	Converts LCI data to hydrogen (H+) ion equivalents.
Eutrophication	Local	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates Ammonia (NH_4)	Eutrophication Potential	Converts LCI data to phosphate (PO_4) or to Nitrogen (N) ion equivalents.
Photochemical Smog	Local	Non-methane hydrocarbon (NMHC)	Photochemical Oxidant Creation Potential	Converts LCI data to ethane (C_2H_6) equivalents.
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC_{50}	Converts LC_{50} data to equivalents.
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC_{50}	Converts LC_{50} data to equivalents.
Human Health	Global Regional Local	Total releases to air, water, and soil.	LC_{50}	Converts LC_{50} data to equivalents.
Resource Depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used	Resource Depletion Potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve.
Land Use	Global Regional Local	Quantity disposed of in a landfill	Solid Waste	Converts mass of solid waste into volume using an estimated density.

2.6 Components of Energy Used in LCA

The main energy components used in LCA are obtained from the output of energy models such as eQuest or BLAST.

The first component is the operational energy, which is basically the predicted amount of energy used in a building during its operation in one meteorological year.

Another component is "Embodied Energy." The energy needed to manufacture products, including all the processes related, namely; mining, manufacturing, and transportation, is known as Embodied Energy. Grey energy calculation has two components: the initial implicit energy and the cyclic energy part (caused by maintenance and replacement). As measures are taken to reduce working energy, it becomes more and more important to understand the specific energy needs.

Summary

This chapter gives the brief description about the life cycle assessment, phases, and types. Further described that international standard ISO 14040 was developed to define the principles, framework, and method standards for the implementation of environmental management.

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CHAPTER 3

Practices and Studies Regarding Environmental Assessment of Buildings

3.1 Assessment tools for the Environmental Impact of Buildings

The three general techniques used for the building environmental assessment are as follows:

1. Rating System (R.S.)
2. Environmental Impact Assessment (EIA)
3. Life Cycle Assessment (LCA)

This chapter will discuss the three types, briefly overviewing all the essential aspects of these assessment tools.

3.1.1 Rating System

The rating system works because credit is awarded to the building designs for the standards design has met. The building is awarded a label or a certificate when the building reaches the criteria of earning a certain amount of credit. This criterion is set with "expert consensus" as it varies from one rating system to another. However, this system has a limitation as the criteria may not be molded according to each building's frame of reference. Let us take, for instance, the criteria for recycled or reused is 50%. Meeting this criterion awards the same amount of credit across the U.S., but it can have very different effects on the environment in the various states of the U.S. However, it should be recognized that the rating system is a powerful tool in education, public image, and even marketing and encourages people to consider the impact of buildings on the environment. The use and dissemination of the results led to a rapid increase in end users. Examples of the rating systems are LEED in the United States [1] and BREEAM in the United States.

3.1.2 Environmental Impact Assessment

In the 1960s, environmental impact assessment was used as an integral component in rational decision-making; it included technical assessments that have led to impartial decisions. In 1969, EIA became a law in the U.S. National Environmental Policy Act

(NEPA). Environmental impact assessment checks an item's impact on the environment. The International Association for Impact Assessment (IAIA) defines environmental impact assessment as "the process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other significant impacts of development proposals before major decisions and commitments are made. ISO issued a standard that explained the steps involved in EIA known as Standard 14011. The steps discussed are [2], [3],[4]

Identify the context

Forecast the impacts

Evaluate the Impact

Minimize the Impact

The main focus of the tool's application is the Precautionary Principle. According to this principle, the decision-maker checks the complete set of different outcomes before implementing the decision. EIA is used in various types of projects, mainly large projects like highways, dams, industrial facilities, power plants, etc. One of the main disadvantages of EIA is that it is too general and requires extensive analysis. The environmental impact assessment implemented today is used more to aid decision-making than a decision-making tool.

3.1.3 Life Cycle Assessment

Life Cycle Assessment is the most scientifically valid method for the measurement of environmental impacts. The mass-energy balance method forms the basis of this system, and the analysis structure remains the same throughout. The advantages of this system are that LCA is thorough, and the scope is broad, but the flaw to this system is its monotonous framework. Since LCA uses different models, results from each model may vary. For example, the result yielded from the process-based model will be different from the one yielded from EIO-LCA. So appropriate professional judgment, data collection, and availability are essential to limit its scope.

3.2 Advancement in the Environmental Assessment Tools:

Since EIA is almost obsolete, in this section, the progress in Rating System and LCA will be discussed. Before the release of BREEAM (Building Research Establishment Environmental Assessment Method) in 1990, there wasn't any effort made regarding objective and method for comprehensive assessment tools. Putting a sustainability label can increase the actual market value of the building while improving its environmental performance. It has promoted the transformation of the market and construction industry. Over the years, the number of environmental rating methods for buildings used worldwide has increased rapidly.

The progress in sustainable plans & environment assessment tools for buildings initially focused on building a wide array of prevailing information and considerations in a practical framework. In 1999, for instance, Kim [5] studied the impact of architectural design on the environment in a report named "Introduction to Sustainable Design" and explores the green architecture principle to mitigate the effects as mentioned above. The architectural assessment uses different phases (before construction, during construction, and after construction) to explore the theories and beliefs of resource economics, draw up plans for the life cycle, and consider the design. This study has also discussed sustainable materials and products, shortage issues, high-cost mining, and strict regulations on unsustainable resource use and waste management.

Although these assessment tests were not perceived as mandatory rather voluntary, however, we can see how the building industry is taking initiatives to become green and sustainable by the increasing popularity of these assessment tools. On the other hand, market-based tools are mostly used by the public sector to set the benchmark for new facilities

The "Green Building Movement" to promote sustainable building designs has pushed the architects to use such an environmental tool, consequently increasing their demand. For example, the Leadership in Energy and Environmental Design (LEED) rating system aims to reduce the environmental impact of products by the point system. For instance, a reward is awarded for using recyclable ingredients or materials procured from the local market. Another example is the rewarding use of material with low volatile organic compound (VOC) content. Similar to LEED, the point system does not always consider the actual situation. For example, recycled paint from the local area may contain many VOCs. The focus is on the need for truly productivity-oriented tools. These kinds of tools can highlight areas where LEED could not provide the reliable material option

Even though The Life Cycle Energy Analysis (LCEA) offers a more comprehensive performance overview ever since the 1970s, it was not included in mainstream environmental discussions at that time. The research of Kohler [6] gave people a more Thorough, diligent, and comprehensive interpretation of the impact of a building throughout its life. Life Cycle Assessment (LCA) is now widely regarded in environmental research as the sole legal basis for comparing alternative materials, components, elements, services, and entire buildings. Eco Effect (Sweden), ENVEST (United Kingdom), BEES (United States), and ATHENA (Canada) all meet the strict requirements of life cycle assessment. The main LCA estimation methods usually require large amounts of data. Collecting and maintaining data over a long period may incur huge costs and significant alterations in material manufacturing processes. Some of these tools are designed to make them easier to use during the designing of the building. However, this approach may make the assessment tools rigid towards new design elements.

With the development in information technology, people are increasingly looking for "indicators" to evaluate and compare the environmental performance at all levels, from construction to the country's progress in achieving green development. 2003 publication of Gann et al. [7] suggested that "a new performance measurement culture has been set in motion to spread in the British construction sector," especially in the manufacturing process. The Design Quality Index (DQI) was developed for evaluating a large number of matters, which shows that people are interested in evaluating the performance of the entire building while taking into account all the factors and aspects that go beyond the current interest in environmental assessment.

3.3 Analysis of Energy and Material used in buildings

In an investigation conducted by Honey and Buchanan in 1994 [8], the scientists investigated the amount of energy needed to construct a specific building from fossil fuels and the consequent carbon dioxide emission to the environment. Afterward, a comparison of energy and CO2 release requirement was made for various kinds of traditional architecture. Switching from traditional concrete or steel structures to wood structures, although small change, resulted in a substantial reduction in energy consumption and waste generation.

In a study conducted by Cole in 1999 [9] effects of green substitutes were analyzed by studying the consumption of energy and harmful releases from various alternatives; wood, steel, and concrete at the construction site. The purpose of this study was to find out the significance of proportionate changes to total Initial Embodied Energy and CFCs emissions by using different alternatives

In recent times, studies have started to adopt the Full Life Cycle approach; nonetheless, all of the impacts were not factored in a while using this approach for comparing domestic buildings. Adalbert (2000) [10] conducted the study in which the seven residential buildings constructed in the 1990s were chosen, and their energy consumption and impact were investigated in the course of their life cycle. As a result of this study, it was found that only 10 to 20 percent of the overall impact resulted from the manufacturing phase, whereas 70 to 90 percent of the overall adverse impact on the environment resulted from the usage phase of the building.

The majority of the studies investigating the environmental impact of architecture portray this matter in quantitative terms rather than a broader spectrum. A study showed that most of the environmental impact resulted from the usage of the building [11]. On the contrary, another study suggested that the impact assessment of residential buildings should focus on large of the material assemblies used, and the impact of other materials should be ignored [12]. Similarly, another study does not include the impact water consumption causes as it is trivial compared to the energy and material consumption.

A study also discusses various tools that help assess the environmental impact of architecture as in-depth guiding principles. Furthermore, other common tools like EIA, MIPS, and Embodied Energy Model are also used [12],[13].

Many studies and research also discuss the limitations on the scope of L.C. analysis. Reijnders [14] sheds light on the fact that only impact caused by material and operations can be discussed because of the scale and lifespan of the buildings.

3.4 Studies on LCA with limited Impact Categories

Although discussing the entire life cycle of a building, numerous studies only base their analysis on a few indicators. Most of the time, these indicators are the CO2 emission or primary energy consumption. According to Thormark (2000) [15], out of total energy consumption, primary energy makes up approx. 85%, assuming 50 years life span of the building. In another study, Thormark states that the impact of material used in "Low-Energy Buildings" is much more substantial. The impacts, as mentioned above, make up almost half of the primary energy used.

Some studies analyze the connection between operational energy and embodied energy, focusing on CO2 emission, ignoring other environmental impacts [16] [17] [10]. On the other hand, many studies are centered on evaluating primary energy consumption irrespective of their use.

Treloar [12] used a hybrid Input-Output model to analyze primary energy consumption and the comparative significance of phases of a life cycle in the analysis. The said study concluded that out of the overall annual operational energy utilized by the majority of Australian commercial buildings, twenty to fifty percent was in the form of embodied energy. Nevertheless, the comparison of operational energy to embodied energy can be misleading, given that the primary energy is always more than the operational energy required for operational energy production.

A study assessing the environmental impacts of operational and embodied energy was conducted by Cole and Kernan in 1996 [18]. The study took a three-story, 50,000 sq ft typical office as a specimen for this study for alternative wood, steel, and concrete structures.

Estimations regarding repetitive embodied energy, which were related to the repair and maintenance of the building, were made. Estimations for operating energy were also made. The conclusion drawn from these results was that the largest part of lifecycle energy is the operating energy. Apart from that, another big component of embodied energy is the building structures.

3.5 L.C. Analysis on Components and Systems of Buildings

On the contrast of studies using fewer indicators, some studies use a broader range of environmental impact indicators. The studies focus on fewer phases in the lifecycle of building as well as building components in the calculation. In the study conducted conducted by Junilla and Saari [19] investing the inventory of a building's life cycle makes recommendations on estimating the consumption of main energy and the emissions of COx, NOx, SOx, VOCs and particulate matter, which come from certain building components they provide, including the ground floor slabs, load-bearing walls & the ceilings as well as the exterior walls, roofs, and window. Saari & Junilla concluded that in a three-story building during its life span of 40 years, the windows. However, the lightest of the element groups was the root of most harmful environmental releases. Said increases in the consumption of energy caused releases due to heat loss.

Another study conducted by Trusty and Meil [20] evaluates the effect on the environment of substituting designs for commercial buildings. These designs Comprise enveloping elements and structural elements, and then these are contrasted with annual H.V. A.C. operating energy. Conclusions drawn from the study were that designs that are less efficient in terms of energy, embodied energy of the structures in the initial stages and those of the envelope are approximately equal to the consumption of primary energy in the operation of the HVAC system in four years

3.6 In-depth Studies on LCA

Another type of study regarding LCA is the in-depth studies comprising all the stages of a building's life and a broader series of Impact Indicators. The majority of these studies are conducted at residential or domestic buildings. Scheuer et al. [21] studied the Life cycle analysis of a University of Michigan's building very comprehensively. The life span of this building was assumed to be seventy-five years. The conclusion drawn from this study was that the building's usage phase or operational stage contributed the most to the environmental releases amongst all the other analyzed stages. According to this study, the operational phase is the stage of the entire life cycle of the building when 83 percent of ozone depletion, 90 percent of eutrophication and acidification soil, and 93 percent of global warming is caused. Next to the usage of the building, the second most significant factor is material manufacturing, which comprises approx. 3-14 percent of the impact. Even though LCA is very comprehensive, it does not include two of the basic assumptions that focus on the weightage of Operational Energy. The first assumption being the calculation of heat and electricity to be combined, and the second being natural gas is used as the source of energy. In actuality, the impact of heat and power were separate, and the energy sources were coal, gas, and oil combined.

Two extensive LCA studies were conducted by Junnila et. Al., [22] focusing on evaluating the major aspects affecting the environment. The study was conducted on a brand new, advanced, and luxurious office building in U.S. and Europe for over 50 years. Junnila conducted a comprehensive, in-depth, and all-inclusive life cycle analysis, including assessing data quality. This study aimed to study the relationship between various elements of a building's life cycle and their effects on the environment. The study's outcomes suggest that a major part of the environmental impacts is related to the electricity consumption and manufacturing of materials used in buildings. Particularly the energy consumed by the HVAC system, lighting of the building, consumption of water, manufacturing of concrete and paint, and the management of the waste generated. On the contrary, it was found that the construction phase and demolition phase played a very trivial part.

Summary

This chapter gives the introduction to the environmental assessment tools: rating systems, environmental impact assessment and life cycle assessment. Further it gives the information about the different past studies that were conducted for life cycle assessment of buildings.

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CHAPTER 4

Design, Method, And Underlying Assumptions of Research

4.1 Foundation of the Study:

Every study needs to have a foundation on which the study would be based. Be it academic level, governmental level, or industrial level, choosing the framework is never easy. For this study, the framework of this study is centered on environmental sustainability. Although sustainability is an important concept, it is rather challenging to use it theoretically in environmental assessment. It is because the context of each building may differ. This flaw is covered by the fact that the sustainability approach accounts for the three major components of sustainability and caters to the need to explore regional circumstances. One of the key factors in designing the assessment tool is determining categories used to evaluate and quantify the environmental impacts.

4.1.1 Environmental-friendly Built Environment

Sustainability respects the current human need and caters to environmental needs. It also preserves the environment so the need of future generations can be fulfilled as well. Sustainability is a comprehensive Concept that involves environmental, economic, and social aspects as well.

After World War II, a concept of visionary economic growth, driven by technology created awareness that there is a close relationship between economic growth and the ecosystem. It gave rise to the contemporary Concept of sustainability. The environmental movements in the 1960s and books like "Silent Spring" [1] and "The Population Bomb" [2] increased the awareness among the public. Initially, the term adopted was "Sustainable development" in Agenda 21 program of the United Nations [3]. It was reported as "Meeting the needs of the present generation without compromising the ability of future generations to meet their needs." [4]

4.1.2 Concept of Sustainability in Buildings

There are different views on the different aspects of sustainable development. Kohler [5] gave a guideline in which defined the potential part that sustainability can play.

There are many types of sustainability: environmental sustainability, Economic sustainability, Social and cultural sustainability.

a. Social and cultural sustainability: It means the well-being of humans living in the building and value preservation.

b. Economic sustainability: instead of the traditional methods of cutting cost by using material at a lower cost, this gives us the Concept of choosing the building design that would last long and preserve the cost in the longer term

c. Environmental Sustainability: It refers to the preservation of natural resources and the environment as well. It doesn't only mean that the amount of material used should be monitored but also the kind of material which would help in increasing the durability.

Figure 4.1: Concept of sustainability (Adapted from [5])

4.2 Research Work Framework

The framework is based upon a single study method. This approach is realistic and assesses the buildings in a true-to-life context. The phenomenon under assessment in this study is the life cycle of the building. Theoretical replication approach is adopted in this study which, for foreseeable reasons, leads to contradicting outcomes. In this study, results are about the possible environmental impacts of certain phases of the life cycle of the building as well as the material used in the building. It is done so the impact of the building can be quantified and analyzed. Another reason this approach is adopted is because this approach analyzes true-to-life Open System.

The data collected (design of the building, features and specifications, observations, statistics, other legal documents, and so on) from the local authorities also supported choosing a single case study method.

4.2.1 Selection of the Building

The single building selected from this case is located in Islamabad. The building is chosen based on the availability of data, and it should be a green building. The criteria for choosing the building in this study are:

i. The building is rather new.

ii. It should be an educational building

iii. The building should be certified or registered for any rating system

4.2.2 Framework of LCA

The standard set by the international organizations for standards chosen as a framework for identifying, qualifying, and evaluating inputs, outputs, and the probable impacts in this study is ISO 14040 [6]. LCA is a very comprehensive approach to assessing environmental impacts.

The basis of LCA is set on system thinking, meaning that every product/service is considered a system [7]. A system is the collection of operations based on energy that has a fixed purpose. The system is surrounded by the environment and separated from the system by a System Boundary. The quantitative account of all the material and energy used is called system inventory.

The linear model is used in the LCA study, which is the mathematical formula of the system explaining the system by a linear function [8]. The most systematic and comprehensive approach for studying the different phases of the life cycle is LCA. The material and energy consumption and the consequent environmental releases are identified, quantified, and then evaluated.

The four main steps of LCA analysis [9] are:

i. Definition of the objectives and scope of the study
ii. Analysis of the system inventory
iii. Assessment of the impact
iv. Interpretation of the results

Step one is defining objectives and scope along with determining the system inventory and the unit of function. The second step is calculating the input/output of system inventory as determined in step one. Step three uses the results from step two to determine the effects and the subjects of that impact. Interpreting the results and concluding, and making recommendations is the fourth and final step of L.C. analysis.

4.2.3 Limitations

Most of the limitations of L.C. analysis lie in step one: definition of scope and objectives [7]. On the other hand, inventory analysis bears the most certainty. The limitations listed by ISO 14040 [10] are

- Data availability is a limitation to the scope of LCI
- Regional or global conditions may not represent local conditions adequately
- The choices made for the study are subjective (e.g., choosing the system inventory, boundary, and so on)
- Limited models are used for the Impact assessment

4.2.4 Summary of Evaluation of Environmental Impacts

To quantify the impact different life cycle phases, have on the environment, the study employs the L.C. analysis over 60 years. The four steps mentioned previously are followed. Following paragraph gives the summary of the study.

First of all, the scope and objectives of the study are defined along with the determination of system boundary, unit of function and requirement of data and its quality. Calculate the inputs and outputs of inventory in building and maintaining over 60 years. The inventory includes the material, energy and other characteristics required for operation. The third step is assessing the impact caused by the material and energy consumption and the operational energy consumed throughout a buildings service life. This stage of LCIA considers eight types of environmental impacts. The life cycle impact calculation tool used for steps two and three of the analysis is ATHENA 4.1. The results are interpreted, conclusions are drawn, and recommendations are made in step four.

4.3 Scope and Procedure Details

4.3.1 System Boundary

The system boundary of LCA includes all the related inflows and outflows of the material and energy. For example, the energy utilized in the transportation of each component plays a vital role in the environmental impact. Hence, it will be included in the calculation as the emissions and consumption of transportation energy.

This study has certain limitations in which the directly related to the LCA, are not included. It includes the supplies for the bathroom; partitions that are not permanent; furniture; production of material for office supplies, and the modifications done to the road and the sidewalk.

4.3.2 Unit of Function

The unit of function chosen for this study is 'm^2' of usable floor area. Choosing an alternative unit will make the calculation easier. This unit is also commonly used in many other studies, and the advantage of this unit is that we can use it to compare the results and draw conclusions very easily. Usable floor area includes all the area of building and staircases and attics if there are any.

4.3.3 Use and Limitations of ATHENA

The analysis for the study is done by using Athena Impact Estimator, which was developed by the Athena Institute of Marrickville in Ontario, Canada. We can model the entire building using this program; however, there are some assumptions about the standard of practices in the building. The data for this tool is taken via the "U.S. life cycle inventory database." The averages of industry used were adjusted according to the regional context. After specifying the building data, the software will adjust the calculation based on the appropriate resources, power grid, and average traveling distance. Algorithms use the data from the inputs of the building to produce a list of materials used depending upon the shape and geometry of the building. ATHENA uses this list of materials to give us a cradle-to-grave analysis of life cycle inventory for the various stages of a building's life cycle.

TRACI is a mid-point impact analysis which was developed by the US-EPA [11], the results from the life cycle inventory analysis is filtered by a set of characterization measures. It uses exposure, emission and fate. The pro of this Method is that it is more reliable than any other software used in L.C. analysis. All of the impact assessment categories included in TRACI which were available are a part of this study. The categories included are

- Consumption of primary energy
- Consumption of weighted raw resource
- The Potential of global warming
- The Potential of acidification
- The Potential of eutrophication
- The Potential of photochemical Smog
- The Potential human health respiratory effects
- The Potential of ozone depletion

Limitations to the scope of ATHENA are

i. Program does not calculate the operational energy requirements, but it does permit to enter the energy requirements

ii. Aggregated data is used; hence the assumption used in forming the grouped data is tough to understand

iii. Doors, furniture, and lab pieces of equipment are not recognized as components of the assembly.

4.3.4 Life Cycle Inventory (LCI)

For the quantification of impacts in LCI, collection & calculation of data is essential. Floor plans are used for identifying and quantifying the energy and material inflows and outflows. Other methods of data collection may be inquiring about the contractors or taking the measurements by self. A list of all the material is attached in the appendix.

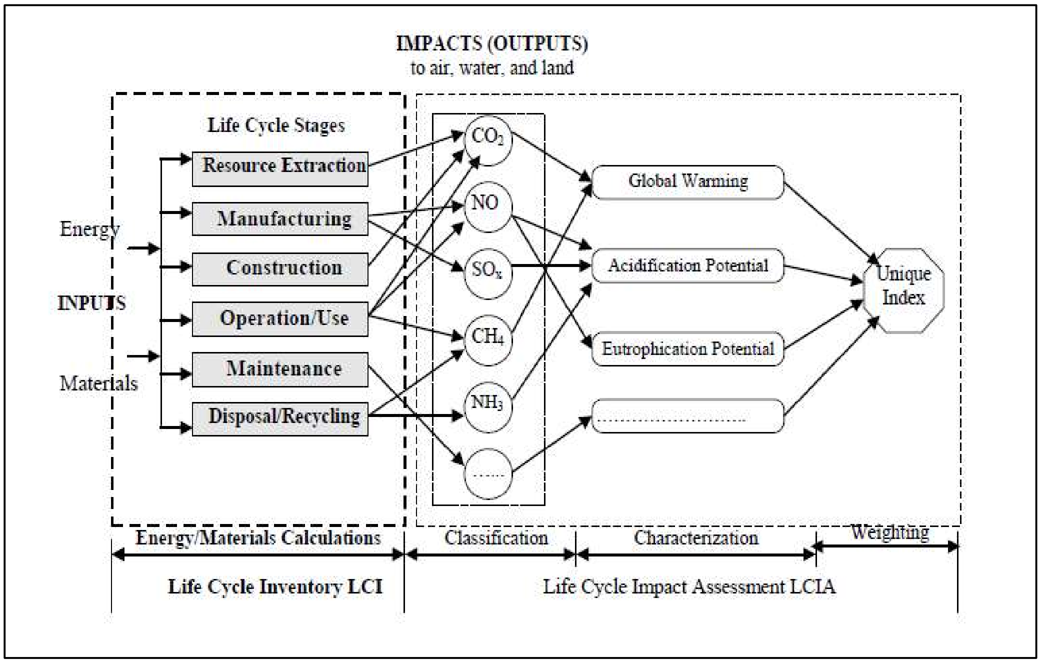

Figure 4.2: Life cycle inventory stages [10]

Further divisions of material burden are as following:

a. **Extraction and Manufacturing of Material:** The processes involved in extracting the raw material, e.g., drilling for oil extraction, harvesting for wood extraction, mining for iron extraction, and so on, fall under this phase. After extraction, the raw materials are refined. The energy contained in the resources includes the embodied energy and the energy utilized in extracting and refining the material and then transporting it to the construction site.

b. **Transportations:** There are three general phases in transportation during the life cycle of a building. The first phase is from the site of material extraction to the manufacturing site. The second phase of transportation is from the manufacturing facility to the construction site and finally from the building to waste disposal site. Energy consumption from all three phases is included in this study

c. **Construction of the Building:** This phase includes all the electricity, material, fuel for transportation, and all other related materials and energy consumption for the construction of the building. This data is collected from inquiring the contractors or the representatives present on the site of construction.

d. **Use and Operations of the Building:** The evaluation of the impact of the building in this phase is done by using energy consumption. Heating and cooling of space, heating, and cooling of water, and electricity consumption are the three major components of the said energy consumptions. Mechanical and Architectural features, occupancy patterns of the building, and the local climatic conditions are considered to calculate annual energy consumption. It is assumed that the buildings are used for 40 hours per week for 60 yrs. Actual annual data is used for the assessment.

e. **Maintenance of the Building:** This includes construction activities, management of waste, and all other maintenance elements in the service life building taken as 60 yrs. In this case, it is assumed that the building has not been extended or reconstructed or any other sizeable change has been done. It is estimated that approximately 75% of construction materials are landfilled, and 25% are recycled for other purposes.

f. **Demolition of the Building**: Many varying factors affect the demolition of the building. These factors include market prices, contractors, customer demand, and so on. The traditional process of demolition ends up in landfilling of the waste. The demolition is done on-site, and 42 approx. 75% of the waste is transported to landfills (55 miles away on average), and the rest is taken to a recycling facility (70 miles away on average). Based upon the parameters of the buildings, LCA software calculates the energy consumption. For the demolition of steel buildings, reports from ATHENA are used. The total energy consumption drawn from this process includes the energy needed for demolition and waste transportation.

4.4 Life Cycle Impact Assessment:

Based upon the LCI results, this phase evaluates the significance of the impacts. The modeling of inventory data within impact categories and allocation of inventory data to impact categories was carried out using the life cycle calculator ATHENA 4.1. In this study, ATHENA has been used to simulate the three Cases. This study also discusses the impact of various assembly systems (foundations, buildings, floors, walls, roofs) to determine the sizeable environmental impacts within these systems.

For these three cases, the categories taken for profiling are

- Potential of global warming
- Weighted resource used
- Potential for acidification
- Potential for Eutrophication
- Potential for creation of photochemical Ozone.

Considering the political and environmental views set by the US-EPA, the mentioned categories are selected. Not only that, but these impact categories are considered of importance throughout the globe. In addition to these facts, the chosen categories are recommended by World Bank as they are consistent with the emissions to water and air.

It should be noted that the impact assessment is only carried out till the mandatory impact assessment phase ends (see 2.3), when the inventory emissions have been classified but they are not estimated.

4.5 Environmental Impact Categories

A. Consumption of Fossil Fuels:

Fossil fuel are the primary energy sources. FFC is also referred to fuel depletion. This category includes all the primary energy consumption from the extraction of material to transportation, manufacturing, and construction phase. In addition to the inherent energy possessed by the raw material, it also includes energy related to the process, conversion, and delivery. Only sources of such as coal, crude oil, natural gas, uranium, and lignite are included in the category. Coal will be used for energy generation primarily. Natural gas and oil can not only be used to generate energy, but also as a component of materials such as plastics. Uranium is only used to generate electricity in nuclear power plants. The calculation of efficiency of supply or production may be compromised if end energy and primary energy are miscalculated with one another.

B. Potential for Global Warming:

Short-wave radioactive waves from the sun hit the Earth's surface, and part of it is absorbed by the surface of Earth and then reflected as infra-red radiations. These radiations are then absorbed by the greenhouse gases present in the Troposphere and then emitted frantically. As a result, the heat released by the Earth into the space is correspondingly decreased, and the temperature (middle) of the atmospheric envelope is correspondingly increased. It is called the Greenhouse Effect. This effect is caused by the increasing level of Carbon dioxide and CFCs in the environment. An increase in global warming has been seen, directly linked with the burning of fossil fuels. An analysis of GWP should not only be for the near future but also for the long term. For gases other than CO2 the calculations are made in equivalent units.

C. Potential for Acidification:

Acidification is basically the disturbance in the normal pH level of the environment by increase in the hydrogen ions concentration. This increase in H^+ ions cause acidity in air, water and soil. This phenomenon causes "acid rains" which disturbs the pH level of lakes as well, not only that it can have a harmful effect of buildings made of stone and metals etc. This happens when air pollutants turn acidic in nature. Acid rain happens when the pH level of water falls below 4 from the normal pH level of 5.4. The most significant contributions to Potential of acidification are made by SO_2 and Nitrogen Oxides, and the corresponding acids (for example, H2SO4 and HNO3) also play a role in A.P. accordingly. Such chemicals are released by the combustion of fossil fuels. The consequent characteristic of acidification factor is expressed in mole equivalents of hydrogen deposition (H +) per kilogram of emissions.

D. Potential for Eutrophication:

The term "eutrophication" means good nutrition, so "eutrophication" refers to the effect of natural or artificial addition of nutrients and added nutrients in the water body. It is also known as "Over-fertilization". Since its Unwelcome, eutrophication is considered a form of pollution. This process occurs when water bodies receive high concentrations of nutrients, particularly nitrates and phosphates, which usually boosts the algae. Rotting organisms consume the available oxygen in the water and causes the casualties in other organisms. Eutrophication is a natural process of gradual aging of water bodies, nonetheless human activities significantly speed up this process. The calculated E.P. result is expressed in kilograms as the base of nitrogen ion (N+).

E. PCOP Creation:

POCP has always been called “summer smog.” It means the formation of Ozone at ground level. PCOP is the consequence of the reaction of nitrogen oxides and VOCs when they are exposed to ultraviolet radiation. Air emissions from industries and traffics during certain weather conditions can get trapped on the surface of Earth. They produce photochemical Smog when exposed to sunlight. Although Ozone is not released directly into the environment, it is the product of the interaction of VOCs with NOx. Potential Smog is calculated in NOx equivalent mass, ground air releases from traffic and industries.

F. Effect of Particulate Matters on Human Health Respiratory:

The fine dust of different sizes, from PM10 with an aerodynamic diameter of 10 or less and PM2.5 with an aerodynamic diameter of 2.5 µm or less, have a significant impact on human health. The U.S. Environmental Protection Agency (2002) has identified “particulate matter” as the main source of deterioration of human health because of the impacts it causes on the human respiratory tract: acute lung disease, bronchitis, asthma. It includes PM10 (fine respirable dust) and its share of PM2.5 (fine dust). It is essential to note that particulate matter is a vital environmental protection product in products related to construction and must be tracked. The PM2.5 equivalent base is an indicator to measure this impact indicator.

G. Depletion of Ozone Layer:

There is a layer of O3 which is an isotope of oxygen in the stratosphere. The function of this layer is to protect the surface of Earth from the harmful ultra-violet radiations from the sun. CFCs and other harmful chemicals. According to climatic conditions, the catalysis caused by CFC decomposes the Ozone into oxygen. Some of these gases will stay in the stratosphere for a long time and destroy ozone molecules even after they are released for many years. Due to the depletion in the ozone layer, more and more U.V. radiation reaches Earth’s surface, causing many health problems such as skin diseases. The Potential of ozone layer depletion is expressed as the mass equivalent of trichlorofluoromethane.

H. Resource Use:

All the related consumption of resources falls under this category. The values from these Impact categories are the total weighted requirement of resources for all products used. It is expressed in kilograms.

4.6 Categories of Water Pollution Releases

The pollution of water bodies such as lakes, rivers, oceans, etc., is named Water Pollution. It happens when pollutants enter the water directly or indirectly without adequate remedy to remove toxic compounds. Pollution of water is a serious global crisis. It is considered to be one of the main causes of death and disease in the world. Water pollutants include organic substances, like herbicides, pesticides, petroleum hydrocarbons, chlorinated and volatile organic compounds (VOC) in industrial solvents; inorganic pollutants, like SO_2 in power generation plants and acid rain, chemical fertilizers (nitric acid salt & phosphate), and large industrial plants (such as automobile companies etc.).

Although different water pollutants were recorded for the case study building, this study will focus only on the key pollutants with the highest potential impact rather than the criteria being the amount released into the environment.

A. Heavy Metals:

Elements which have a specific gravity no less than five times than that of water. Specific gravity is the degree of density of a certain quantity of elements in solid form compared to the density of an equivalent quantity of water. Water's specific gravity is one at a temperature of 4^{o} Celsius. Some examples of heavy metals are arsenic with a Specific Gravity of 5. 7, iron having sg of about 7.9, lead with a specific gravity of 11.34, and cadmium having 8.65 specific gravity.

When heavy metals are not digested and broken down for energy by the body, they accumulate in the soft tissues. That is when they become toxic. Such heavy metals can enter the body through food, water or air, or be absorbed through the skin when in contact with people in agriculture, manufacturing, pharmaceuticals, industry, or living spaces. Contact with dust, smoke or materials in the workplace through inhalation or skin contact.

According to the list of "Top 20 Hazardous Substances" prepared by ATSDR in Atlanta following metals are of most priority

1. Arsenic
2. Lead
3. Mercury
4. Cadmium (appearing number 7 on the list)

1. Arsenic**:** It is the main source of acute heavy metal poisoning, and it ranks first in the ATSDR's top 20 list. When smelting copper, zinc, and lead and manufacturing chemicals and glass, arsenic is released into the environment. Arsenic hydrogen gas is a common by-product in the manufacturing process of pesticides containing arsenic. Arsenic is also present in water sources around the world and contaminating shellfish, haddock, and cod. Other sources include paint, rat poison, wood preservatives, and fungicides. The organs targeted are the kidney, blood, skin, digestive system, and central nervous system.

2. Lead: Lead ranks 2nd in ATSDR's top 20 list. Lead is the cause of heavy metal poisoning in most children (ATSDR 2001). It is a very soft metal that has been used for pipes, drains, and welding consumables for many years. Millions of houses built before 1940 still contain lead (for example, on painted surfaces), causing long-term weathering, chipping, plaster and dust. The industry produces approximately 2.5 million tons of lead globally each year. Most of the lead is used in batteries, and the rest is used in cables, paint, pipeline, ammunition, and fuel additives. Further applications include paint pigments and PVC plastics, X-ray protection, crystal glass production, and insecticides. The target organs are the brain, blood, bones, thyroid, and kidneys

3. Mercury: Mercury is ranked 3rd in ATSDR's top 20 list. Mercury is naturally produced in the environment through degassing of the Earth's crust and volcanic emissions. It exists in three forms: elemental mercury and organic and inorganic mercury. The mining and paper industries are the main producers of mercury. Mercury in the atmosphere drifts worldwide with the wind, returns to land with the rain, accumulates in aquatic food webs, and accumulates fish in lakes. By 1990, mercury compounds were added to paints as bactericides. These connections are prohibited; however, there are still old paints and surfaces painted with these old materials. Mercury is still used in thermostats, thermometers, and amalgam, etc. Mostly by Inhaling, organisms are exposed to this chemical. The organic mercury is easily absorbed from the digestive tract, about 90-100%; The gastrointestinal tract has absorbed a small but still large amount of inorganic mercury, about 7-15%. The target organs are the brain and kidneys.

4. ***Cadmium:*** Cadmium is a by-product of lead and zinc mining and smelting. It ranks 7^{th} in ATSDR's "Top 20". Cadmium is used in nickel-cadmium batteries, PVC plastics, and color pigments. It occurs in the soil because agriculture uses commercial pesticides, fungicides, muds, and cadmium fertilizers. Cadmium is found in deposits containing shellfish. They also contain cadmium. Lesser-known sources of exposure are dental alloys, electroplating, engine oil, and exhaust gas. Inhalation accounts for 15%-50% of airway absorption; 2-7% of cadmium is absorbed from the gastrointestinal tract. The target organs are the liver, placenta, kidneys, lungs, brain, and bones.

5. ***Nickel:*** The human body needs a small amount of nickel to produce red blood cells, but excessive nickel is easy to produce toxicity. Overexposure to nickel for a short period doesn't cause any health problems. However, exposure for a longer period can cause damage to the heart and liver, weight loss, and skin diseases. Presently, EPA doesn't regulate nickel content present in water used for drinking. Nickel can build up in organisms living in water, however, its content in the food web will not increase.

B. Biological Demand of Oxygen:

The biological oxygen demand, also known as BOD, is a biochemical process that determines the pace at which an organism present in a waterbody consumes oxygen. Its unit of measurement is milligram (mg). It usually occurs within five days at a temperature of 20°C. It is used in managing the quality of water & assessing water quality as well as environmental sciences. Biological oxygen demand is not a reliable quantitative assessment; however, it can be considered a quality indicator. A low BOD indicates good water quality, whereas a high amount of BOD indicates contaminated water. It can be used as an indicator of the efficiency of a treatment plant. Clean water method.

C. Chemical Oxygen Demand:

COD is a test that is often used to evaluate the content of organic in water indirectly. Chemical Oxygen Demand is an indicator of dissolved organic carbon and is usually combined with BOD. Total Organic carbon equals the sum of both.

$$\mathbf{TOC = COD + BOD}$$

COD measures the organic pollutants present in the surface waters, making COD a useful indicator of water quality. The value of COD is written in milligrams. Each liter (mg/L) represents the mass of oxygen consumed per liter of solution.

D. Suspended Solids:

It is another indicator to examine the quality of water. These are the small particles of solid substance which remain suspended in water. The toxicity depends upon the size of the particle. If the size of the particle is small, the surface area of mass per unit mass is greater and vice versa.

E. Phosphorus & Nitrogen:

Though nutritional in nature, phosphorus and Nitrogen are the chemical elements, play a significant role in water pollution. These elements are essential for living organisms to make protein. In the pollution of water bodies, Nitrogen has a sizeable part. Although Nitrogen and phosphorus are essential for plants and humans, their excessive release is very harmful to the environment. When excessive nutrients are released into the lakes, excessive algae will contaminate them. The death and decay of algal blooms will lessen dissolved oxygen, suffocating life prevailing in the water bodies. Certain kinds of blue-green algae release toxins. If animals or humans consume it, it may be harmful. The U.S. Environmental Protection Agency and Clean Water Action plan identified nutrients as the main national problem that causes water pollution in 1997. According to reports, more than half of the lakes have been affected by these pollutants.

Nitrate is a nitrogen-containing compound that can exist in the atmosphere or dissolve gas in water. At high concentrations, it will have harmful impacts on the health of humans and animals. Nitrate in the water can cause serious illnesses in babies and pets. Nitrate found in lakes and streams includes sewage treatment plants, agricultural fertilizers, manure, industrial sewage, animal feed areas, and landfills.

Phosphorus is an important nutrient that converts light from the sun into energy to grow and reproduce. Scientists in late 1960s discovered that the phosphorus contributed by humans was the main reason for the growth of algae and the deterioration of lake water quality. Phosphate is an inorganic form and is the first choice for plant growth, but other forms can also be used if phosphate is not available. Phosphorus accumulates in lake sediments. If it stays in the sediment, the algae usually cannot use it; however, phosphorus can flow back into the water from the sediment stream through various chemical and biological processes.

Summary

This chapter provides the information about the concept of sustainability and its association with the life cycle assessment, framework for this study, limitation of the data and harmful impacts to the air, water, and land.

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CHAPTER 5

Description of the case study building

5.1 Prerequisite of Data collection

The availability of comparable data is one of the most important hurdles in life span. Data cells containing nothing or difficult to obtain data can affect the ongoing research form pursuing such a study. At times, the availability of poor data quality can often lead to faulty findings and assessments. LCA is one of the most used tools for data interpolation and environmental assessment tool. It is mainly because of the use for the extensive and complete assessment. Due to the reasons mentioned above, LCA tools are being developed and used by professionals.

At the inventory stage the primary data is obtained from the specification sheets of each item. The other major quantity of data was obtained from the section and floor plans. On-site interview with the contractor and the direct observation of the process were the other source of the data collection. The study of the following building included: the foundation of the building, structure of the building, external/internal walls, roof, and partitions. The presented case provide floors plans of the usual office in the Midwestern area.

5.2 Case Study: U.S. Pakistan Center for Advanced Studies in Energy (USPCAS-E)

U.S. Pakistan Center for Advanced Studies in Energy was completed and occupied in 2015. The gross floor area of the building is about 6487 m^2. It does not contain basement, but it does have 3 floors each having area of seventeen thousand square feet and which about fourteen foots eight inches (14’ 8” ft) of height. Its structure is of concrete of columns and its beams are of concrete. The walls are made of bricks. The inside walls are of bricks. Actual energy consumption of this building was used for the assessment. And the estimated Electric consumption is about 227472 kWh/year. Figure 5-1 show the picture of USPCAS-E building.

Summary

This chapter provides the information of the study case used in this study. USPCAS-E is an educational building in Pakistan.

CHAPTER 6

Results

6.1 Normalization of Results

Since this case study is unique and different, the normalization of results is mandatory to ensure the rationality of the comparison with other buildings. There are two possible normalization units here to normalize the results. These are m^2 of the building floor area and m3 of the building volume. Before discussing in detail why a specific normalization factor was selected, it should be mentioned that, although the selection of a normalization factor (m^2 or m^3) does affect the results in absolute values (total environmental impacts of each building), it does not affect the results in relative values (environmental impacts contribution to the building life cycle phases and assembly systems) which is the main focus of this study. For comparison purposes, the results have been normalized per square meter (m^2) of floor area.

6.2 Energy Performance

Operational energy for the building is monitored from Jan 2019 to date. Electricity is supplied to the building through two electricity meters.

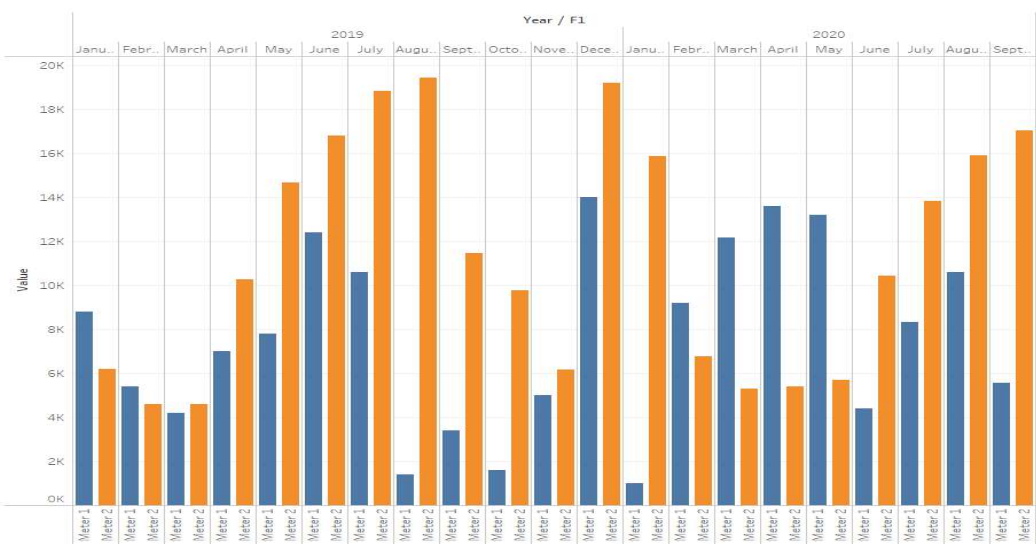

Figure 6.1: Energy Performance

Energy Benchmarking

Several works can be found in literature about the performance and energy consumption in buildings. Marie Rousse lot presented the energy efficiency trends in EU countries. It was reported that buildings account for almost 41% of final energy consumption in EU countries.

Energy star Portfolio Manager published the median energy use intensity of the buildings in the USA and Canada.

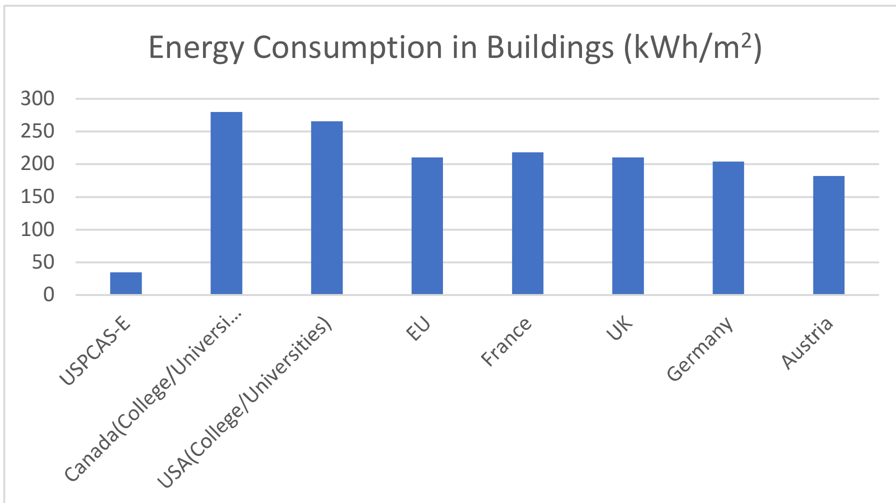

Figure 6.2: Energy Consumption in Buildings

EUI of the USPCAS-E building is calculated to be 35.06 kWh/m^2. Consumption of electricity in USPCAS-E is 87.5%, 86.8%, and 83.8% less than the buildings in the USA, Canada, and EU, respectively.

6.3 Life Cycle Performance

6.3.1 Absolute Environmental Impact Values

The environmental impact of the USPCAS-E building is shown in the Table-6.1. However, detailed results can be accessed from the data file.

Environmental Impacts over the Life Cycle Phases

The overall impacts over the life cycles phases are shown in figure 2. Detailed results can be accessed from the data file. Followings are some features of this study:

- The operational building phase stands over all the other phases in all the building life cycles.

– The operational phase contributes to the highest in 96% ozone depletion potential. The second highest contribution is in the HH particulate that is around 93%. Total primary energy has the 91% comes up from the operational phase. Similarly, the biggest addition to global warming potential is 85% from this phase.

Table 6.1: Environmental Impact - USPCAS-E

LCA Measures	Unit	Manufacturing	Construction	Maintenance	Operational	End of life
Global Warming Potential	kg CO_2 eq	1.49E+06	1.74E+05	9.39E+04	1.04E+07	1.02E+05
Acidification Potential	kg SO_2 eq	5.14E+03	1.28E+03	7.56E+02	2.80E+04	1.27E+03
HH Particulate	kg PM2.5 eq	2.30E+03	9.89E+01	5.46E+01	3.18E+04	6.51E+01
Eutrophication Potential	kg N eq	1.30E+03	1.30E+02	1.95E+01	9.72E+03	7.89E+01
Ozone Depletion Potential	kg CFC-11 eq	2.85E-02	1.42E-03	2.83E-03	8.99E-01	4.27E-06
Smog Potential	kg O_3 eq	8.32E+04	3.78E+04	6.05E+03	2.26E+05	4.15E+04
Total Primary Energy	MJ	1.37E+07	2.07E+06	1.03E+06	1.80E+08	1.50E+06
Non-Renewable Energy	MJ	1.34E+07	2.06E+06	1.03E+06	1.76E+08	1.50E+06
Fossil Fuel Consumption	MJ	1.03E+07	2.00E+06	1.02E+06	1.21E+08	1.50E+06

– Manufacturing (Product) phases have the second-largest share of the environmental impacts. The highest percentage contribution to the impacts from this phase is to the Smog Potential that is 21%. The lowest contribution from the manufacturing phase is in Ozone Depletion.

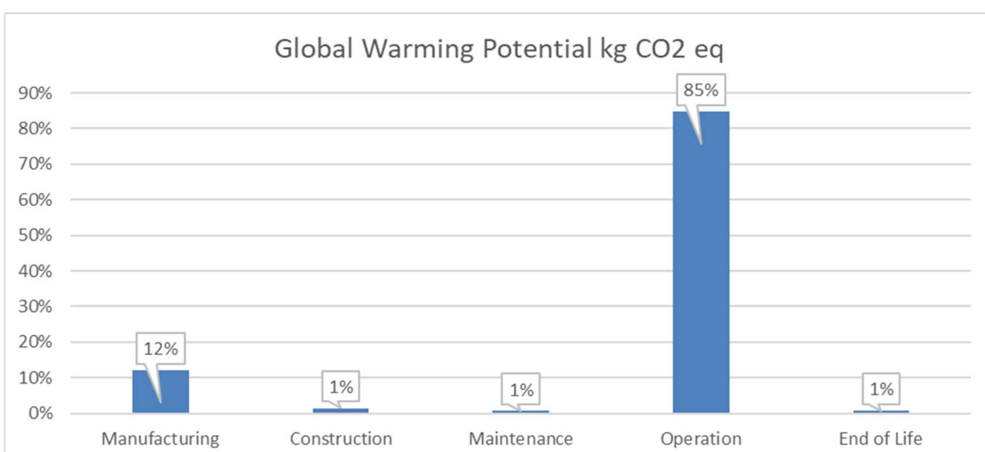

Figure 6.3: Global Warming Potential kg CO2 eq

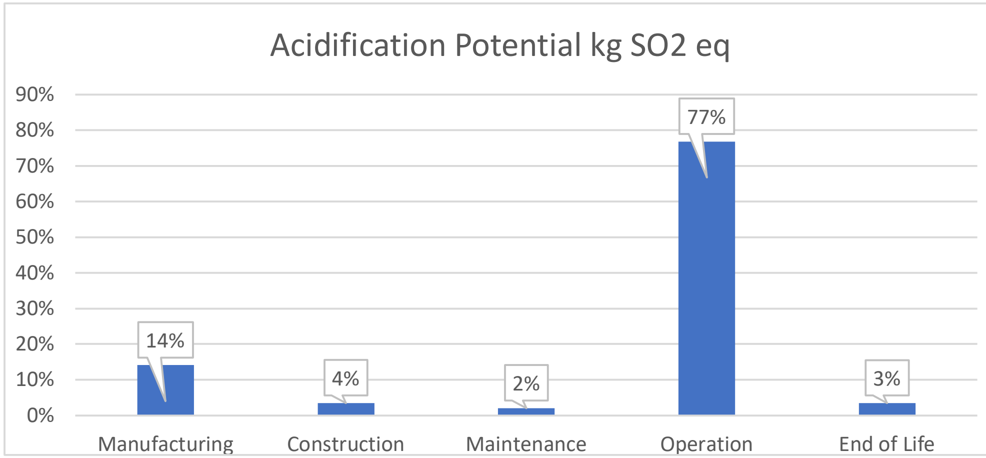

Figure 6.4: Acidification Potential kg SO2 eq

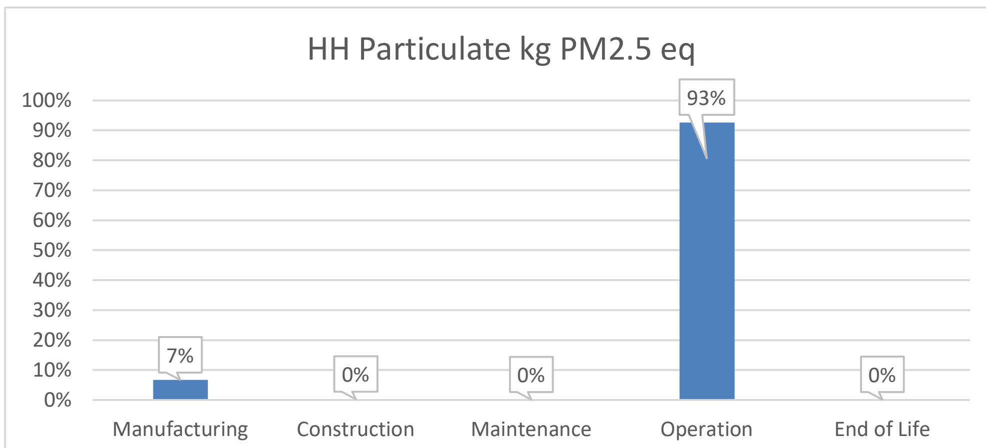

Figure 6.5: HH Particulate kg PM2.5 eq

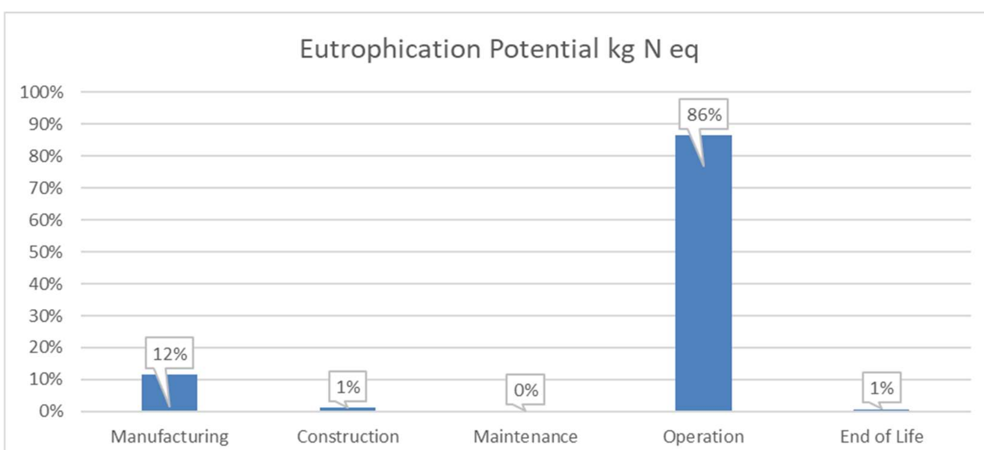

Figure 6.6: Eutrophication Potential kg N eq

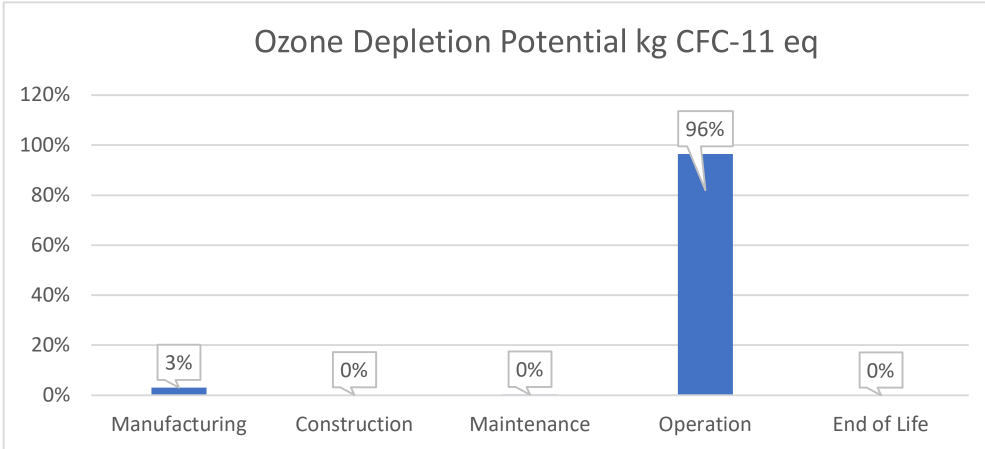

Figure 6.7: Ozone Depletion Potential kg CFC-11 eq

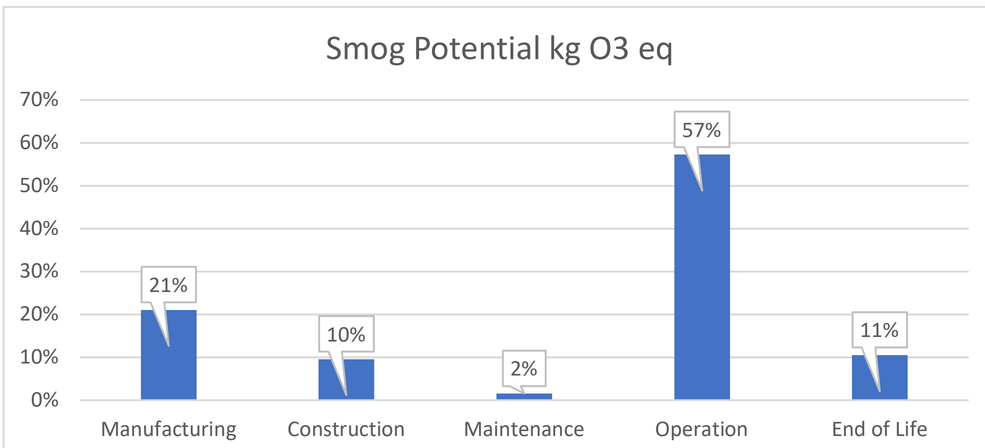

Figure 6.8: Smog Potential kg O3 eq

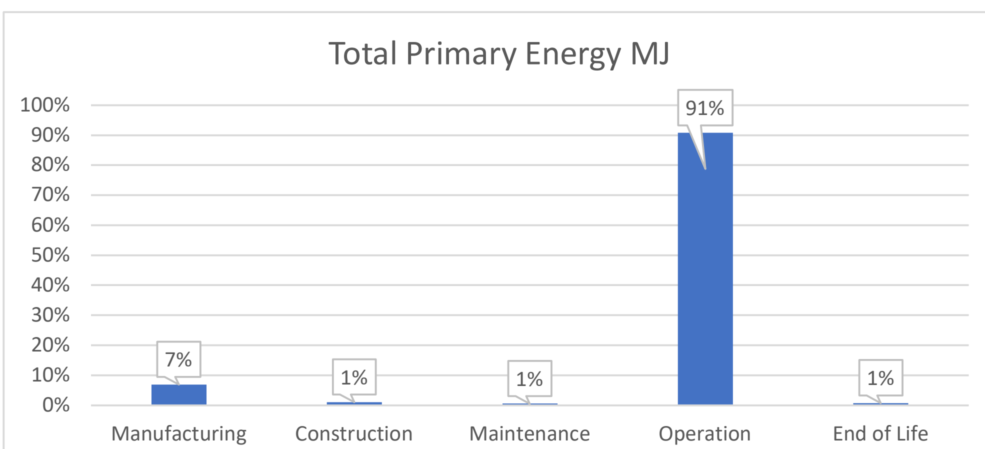

Figure 6.9: Total Primary Energy MJ

6.3.2 Environmental Impacts of The Building Assemblies

It is important to highlight that in design and construction practice, the building design systems follow a different sequence than the sequential sequence of its life cycle phases in this study. The design of the different assemblies of the building (foundation, structures, wall, floor, and roof) is normally done during the design process when these systems are determined.

- The floor system has the highest impact in all life cycle impact measures except the HH particulate (28%). The highest impact from the floor system is in the LCA measure eutrophication potential (35%).
- Column and beams contribute the highest to the impact category HH Particulate (31%). Besides this category, this system has the third-highest share of all the other measures.
- Foundations are the second major contributor to all the LCA measures; by average, they have shares of 26% to the LCA measure.
- Wall systems have the lowest addition to the HH particulate (7%) eutrophication potential (6%).
- Roof systems contribute the least to LCA measures except for HH particulate and eutrophication potential. The share of roof systems is 11% by average to the LCS measures.

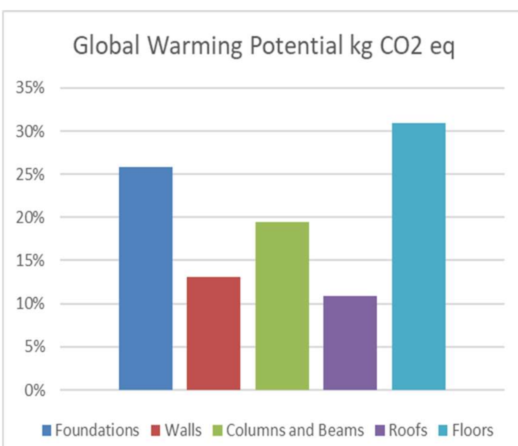

Figure 6.10: Global Warming Potential kg CO2 eq

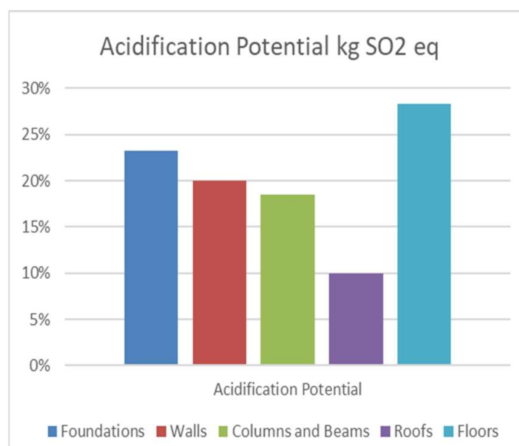

Figure 6.11: Acidification Potential kg SO2 eq

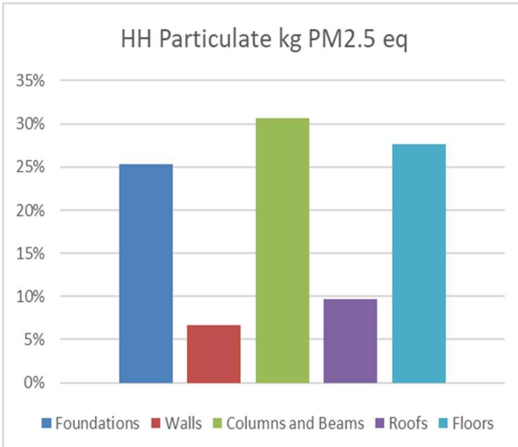

Figure 6.12: HH Particulate kg PM2.5 eq

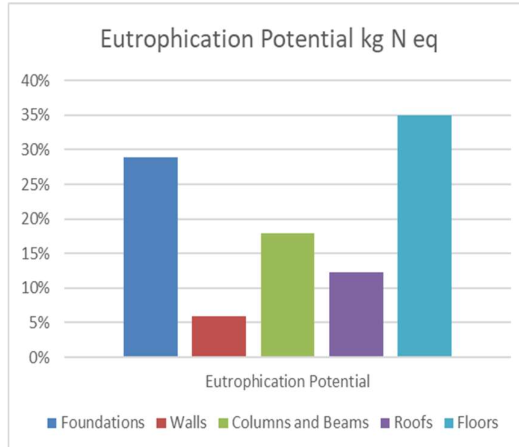

Figure 6.13: Eutrophication Potential kg N eq

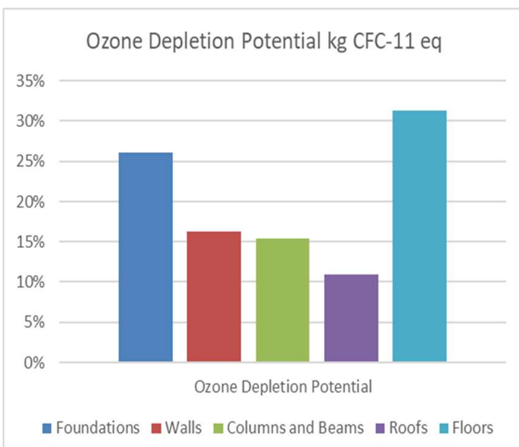

Figure 6.14: Ozone Depletion Potential CFC-11

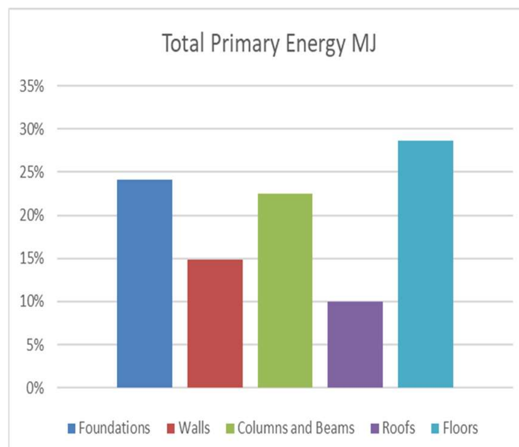

Figure 6.15: Total Primary Energy MJ

6.3.3 Air Emissions

The LCA air pollution elements' absolute values for USPCAS-E building are calculated. The comprehensive findings and complete set of air pollutants may be found in the appendices. However, for the study provided in, main air emissions are chosen presented in the figure. Carbon dioxide, methane, carbon monoxide (CO), sulfur dioxide (SO2), nitrogen oxides (NOx), particulates larger than 2.5 microns and smaller than 10 microns, and volatile organic compounds are all examples of these pollutants. Carbon dioxide, methane, and carbon monoxide cause global warming. NOx and sulfur dioxide are the source of acidification. NOx and VOCs are the reason for smog in urban areas. Respiratory effect potentials are mainly because of the particulates. The analysis shows consistency with the impact values in those categories from previous sections.

In the LCA stage emissions calculation of air emissions, the figure clearly shows that the operation phase dominates most air emissions, especially CO2, particulate, and SO2 (97%). It is due to the production of electricity. These emissions emit from burning coal, and other fossil fuels at the power plants are released to produce this electricity. In the LCA manufacturing phase, CO and VOCs are having the highest emittance of 29%. NOx has a release percentage of 18% in the manufacturing stage. The release of NOx is the major source of acid rain and smog.

In air emissions in LCA by building assembly groups, the figure clearly shows that the roof system has the greatest emissions in the USPCAS-E building. It is in line with roofs having the highest impacts in GWP, acidification, smog, and respiratory Among other assembly systems due to these emissions. The second-highest Contributor to air emissions is the foundation and structure systems. The aggregate findings reveal that air pollution occurs more frequently throughout the operating phase of a building's life cycle.

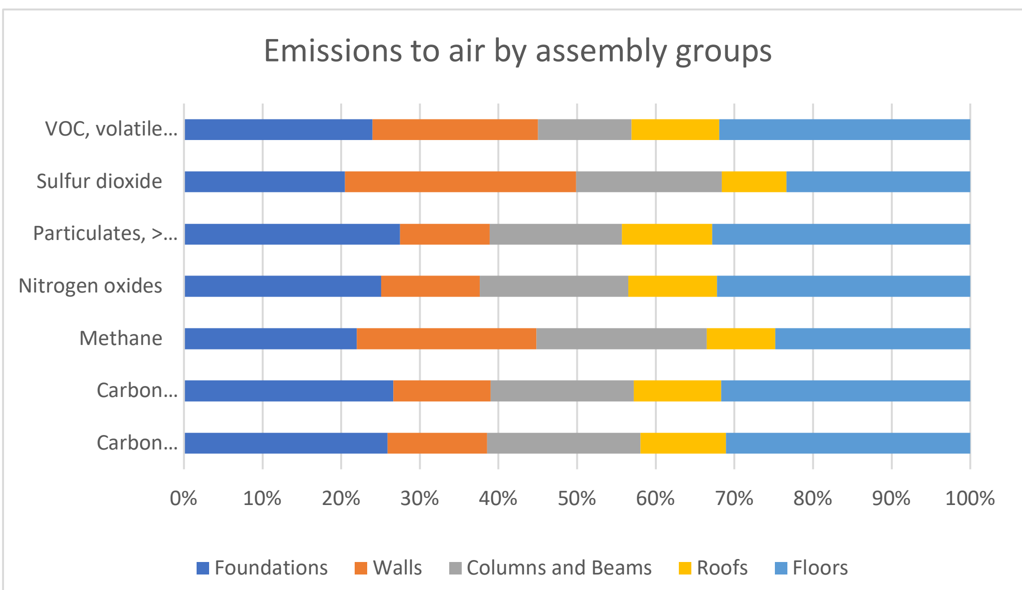

Figure 6.16: Emissions to air by assembly groups

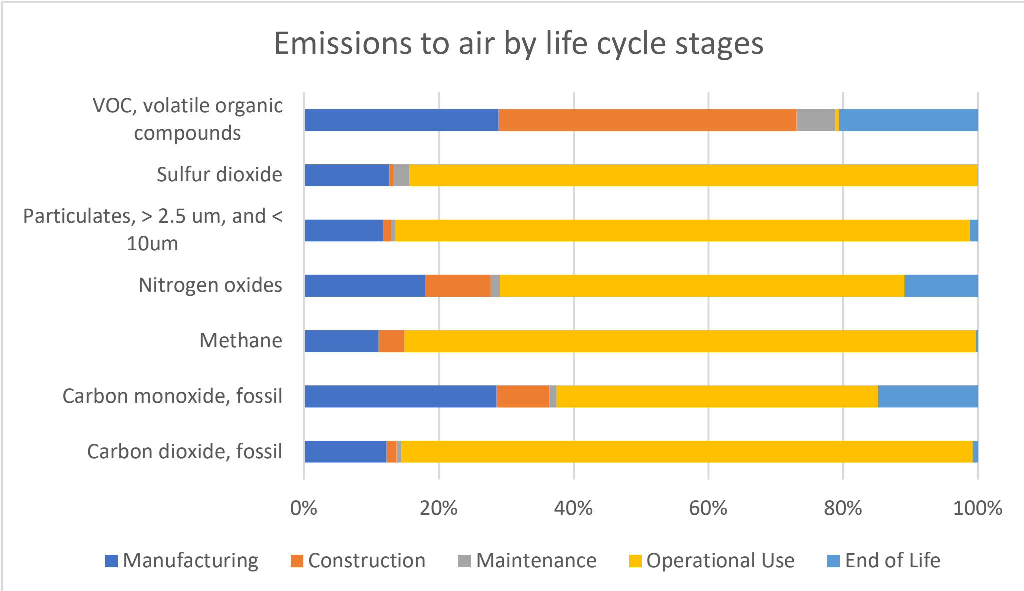

Figure 6.17: Emissions to air by life cycle stages

6.3.4 Water Emissions

The LCA water pollution elements' absolute values for USPCAS-E building are calculated. The comprehensive set of results are presented in the appendix. However, only major water emissions are selected for the results, and analyses are presented in the following figures. As most of the air emissions contribute to global warming potential, acidification potential, and HH particulate effect potentials, on the other side, water emissions are the major source of the Eutrophication Potential and release of metals which is calculated in this section. The important water emissions analyzed here are Biological Oxygen Demand (BOD), nitrogen, heavy metal group, Chemical Oxygen Demand (COD), and Phosphorous. The Analysis shows results are aligned with the impact values in the eutrophication impact category.

In life cycle assessment emissions estimation of water, the figure demonstrates that the operation phase has the highest domination of water emissions, specifically in Arsenic, Biological oxygen demand, Cadmium, Chemical Oxygen Demand, Lead, Phosphorus, and Suspended Particles from 56% to 97% in the USPCAS-E building. It is mostly related to electricity generation, as these pollutants are emitted during the combustion of coal, gas, and other fossil fuels in power plants. The manufacturing stage accounts for 95% of the emission of nitrogen and 53% of mercury. Nitrogen and phosphorus have the greatest influence on eutrophication. It is similar to eutrophication being the most significant influence at this timeframe.

In emissions by building assemblies, the figure shows that the floor system in the USPCAS-E building has a major share of the most water emissions. It is important to mention that heavy metals have significant releases by building assembly systems. The floor system has the highest release of arsenic ions, chromium, mercury, and nitrogen. Wall systems have the highest emission of phosphorus and BOD. Overall, foundation systems have the third-highest percentage of contribution to water emissions.

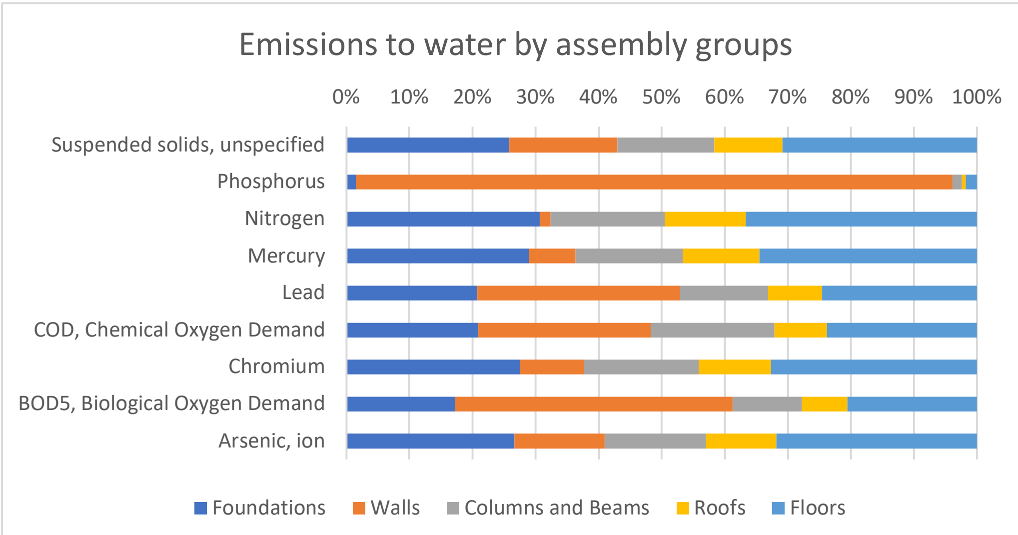

Figure 6.18: Emissions to water by assembly groups

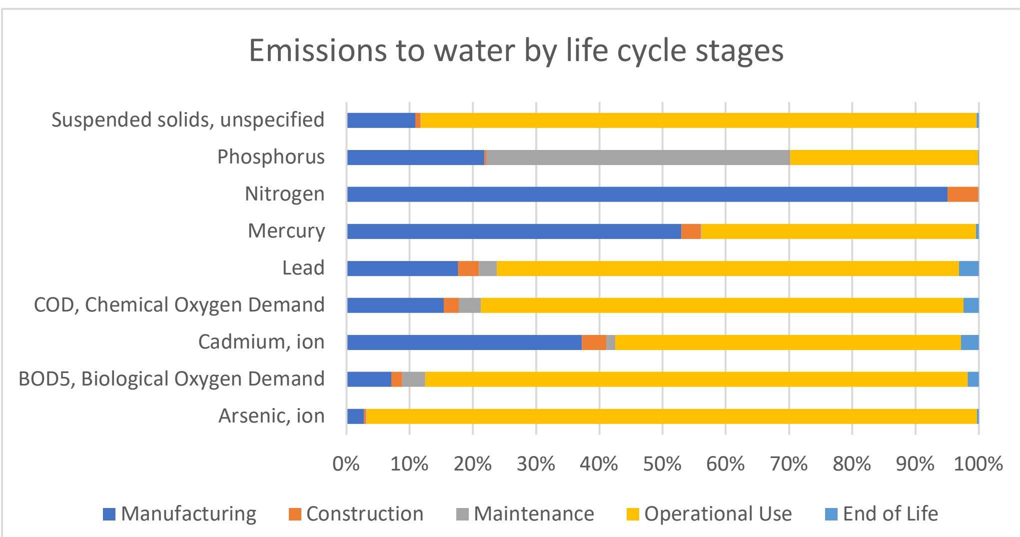

Figure 6.19: Emissions to water by life cycles stages

6.3.5 Land Emissions

The pollutant of eland emissions absolute values of the USPCAS-E building are calculated. The complete results and full data of land emissions are in the appendix (A-12, B-12, C-12). However, there are fewer numbers emissions than other impacts. All land emissions are selected for the analysis shown in (Fig. 6-6a and 6-6b). These emissions are wood waste, concrete waste, blast furnace slag, blast furnace dust, steel waste, and unspecified other waste. Although these emissions do not contribute significantly to the environment, they are thought to be highly important in determining the quantity of waste that goes in landfills, mostly during the building end-of-life phases and to a lesser extent during the operation phase.

Land emissions by building assembly systems, figure 6-6b shows that foundations and floors lead most of bark/wood waste and concrete waste emissions due to wood use and concrete pouring during the construction phase. Wall systems have a major contribution to waste.

The aggregate results show that most of the waste generated is during the manufacturing and construction phase of building life.

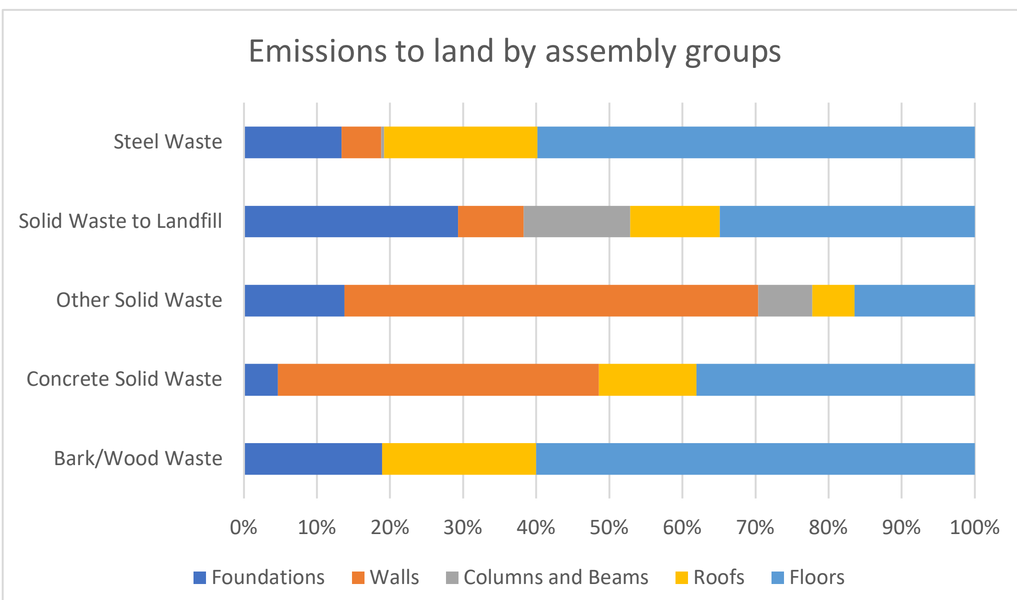

Figure 6.20: Emissions to land by assembly groups

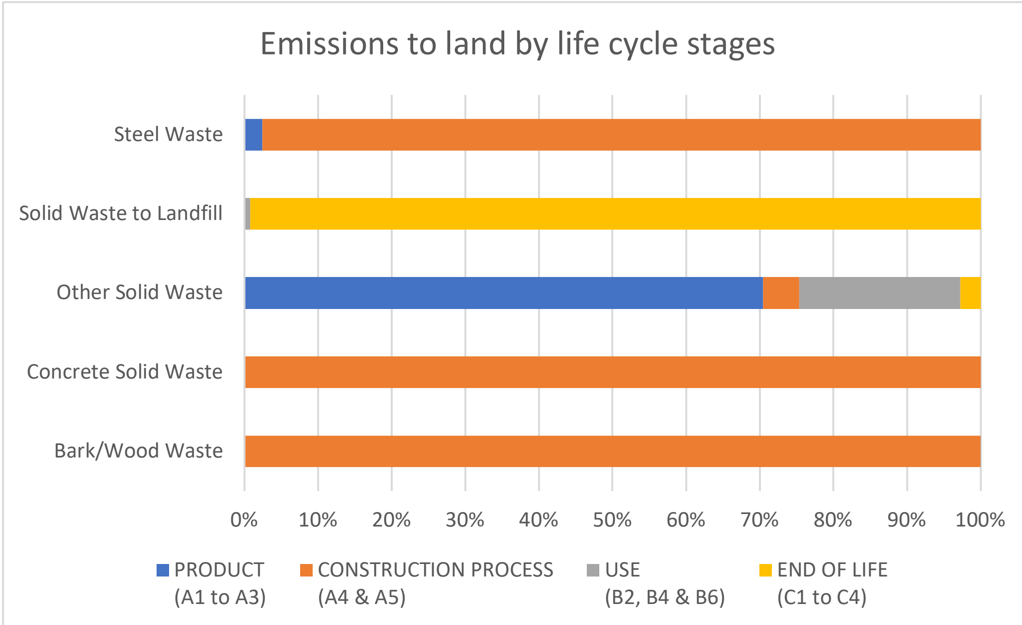

Figure 6.21: Emissions to land by life cycles stages

Summary

ATHENA Impact Estimator is used for the life cycle assessment of the USPCAS-E building. Emissions by life cycle stages and by assembly groups are presented. Further air emissions, water emissions, and land emissions are presented.

CHAPTER 7

Conclusion and Future Directions

7.1 The Influence of Study on Knowledge

The purpose of the study was to assess the impact of buildings on the environment by quantifying the impacts and analyzing the environmental impacts over the life span. The phase of the life cycle of a building that plays the most significant role in environmental impacts was identified in this study.

The study concludes that the operational phase of the life cycle has the highest impact on the environment. This phase accounts for more than 90% of the total impacts in the impact categories during the building's entire service life, the highest being the consumption of fossil fuels. The second to the operational phase is the manufacturing stage, with the highest impact on the depletion of the ozone layer. This stage is responsible for 91% of the impact in depletion of ozone and 86% of impact in soil eutrophication.

Results of this study also show that amongst the building systems, the floor system has the greatest impact. It contributes to 31% of global warming, 28% of acidification, and 33% of smog potential. Another system that has a significant impact is the beams and column systems. Its contribution to fossil fuel consumption is 23% and to HH particulate is 23%.

The outcomes from this study are coherent with the results from the studies conducted previously. We can see a common theme in these studies. The majority concludes that operational energy is the significant cause of harmful environmental impacts[1]–[3]. Other studies [4],[5] highlights the significance of impact caused by the materials used in building. The research contributed to the overall environmental analysis of the building, which was not fully utilized due to difficulties in modeling and was compensated by an exclusive investigation of building materials and components. The research results show that planning and building management practices are more environmentally friendly than office buildings. Contractors, Managers, and planners and visitors who have not yet been acquainted with the environmental impact of buildings can bring to use the building's environmental profile, the impact on the floor space, the stage of significant building impact, and the installation system that contributes the most to the overall impact. Help them focus on planning, construction, building operation and maintenance in environmentally sensitive areas.

LEED building systems have the greatest impact in most categories. The method of LCA in this study paves a pathway for more assessments of high-level LEED-certified buildings. Analyze the impact of life cycle assessment to review your environmental performance. It helps reduce sensitive areas for designs and material options (insulating materials) that do not comply with LEED standards. Without considering the significant impacts of alternative materials, reward points for total energy savings.

7.2 Validity

The validity of research is divided into two sub-categories for analysis: internal validity and external validity. To ensure the internal validity, data was collected from several sources, and sources were evaluated to determine the precision of the input data. The calculations were based upon the data collected from the floor plans and specification sheets, representing correct and accurate measurements and other data, not just estimates. It ensures higher precision of results, thereby ensuring higher reliability of the results.

The external validity of research results that can be summarized relies on the analysis and replication logic for many case studie. Due to the results of the one case studies don't allow statistical generalization on environmental impact. However, the results can be analyzed and extended to recently constructed educational cases based upon replication logic and other assumptions.

7.3 Limitations

Even though this study should be comprehensive, few scope limitations can easily influence the reliability of the results. Due to the limitation of modeling software, all the impact areas are not covered by LCA. Indoor air quality, extraction impacts at specific locations, and land and water resources usage are examples of impacts that have not been covered.

The purpose of this research is to investigate the complete life cycle of a educational building. Since the LCA does not have definite system boundary, so some items have to be excluded to make the study simple. Office furniture, computers, equipment, and other items are excluded. So, the focus can be centered on modeling the buildings as easy as possible.

Because of the inadequacy of data availability and modeling difficulties and some other limitations, few factors, such as biodiversity and indoor air quality, were not evaluated. The selected life cycle impact library was of U.S.

The existing life cycle assessment tools have not considered the impact of the entire supply chain because they are process-oriented and do not have a database that contains the complete supply chain, such as in the economic life cycle. Periodic Evaluation of Input-Output (EIO-LCA) [6] these challenges can be overcome by using a latest tool based on hybrid LCA models.

7.4 Significance of the Study

The research is intended for completeness; however, he studied some effects that others had overlooked or had little influence in previous studies. Categories such as acidification, summer smog, effects on the respiratory tract, eutrophication, resource depletion and ozone depletion potential. Few people complete these different types of interventions (8 interventions). The building assembly system that has the most contribution towards environmental impact categories over the course of its life is also included in this study. Material transportation (in & out of the construction site) is also important factor that affects the building's life-cycle, but the research is insufficient; the study describes the impact on each stage of the building's life cycle.

It is expected in the future that the architectural drawings and the environmental profile of the building (as in this study) can be linked even before the construction of building. You can also design barcodes of the buildings for the use by owners, architects, and contractors. The environmental impact data of the building or its key components are managed prior to construction, so this research will be a milestone step in incorporating the development of the environmental profile of each building into the construction planning and documentation process. The study also used US production construction material lists that were hardly ever used before. At that time, most of the data was based on European production data and there was no better alternative. Due to the availability and reliability of the LCA database, it is carried out in Europe, especially in Sweden and the Netherlands. There is an increasing demand for LCA research that relies on US production data to provide more accurate research, nowadays. The

Inventory Database (LCI) project (2011) is a significant step towards creating LCI database that is accessible to the public. The National Renewable Energy Laboratory (NREL) led by the US Department of Energy is making efforts towards the advancement of the development of this inventory database. The first attempt to study and analyze the life cycle assessment of the entire building was based on ATHENA model which uses north American production data. This database provided by LCI will also open up further prospects for researchers for analyzing the US based case. The combination of power grid and production data is different. The plan addresses the need to improve the availability, standardization, and quality of life cycle assessment data for wider use in designing and construction of buildings in the US.

7.5 Directions for Future Research

The architecture understudy has traditional design concepts, so comparing the solutions given by sustainable design and the solutions presented in the future will be interesting. Researchers in the future can be more action-oriented to test the introduction of new knowledge into the process and also test the potential positive impacts on the sustainability of the building. Since most of the environmental pollution in the complex is caused by old buildings, a similar assessment would be interesting. After all, the users of office buildings play a key role in the making decision regarding the performance value, so it makes sense to conduct a comparison of the impact of office buildings in the wider context of Corporate Governance and facility management. Such as, how big is the impact of the building as compared to the employee commuting? What impact does use of office supplies cause?

The careful design of buildings and its management based upon sustainable alternatives can be a possible practical application of this study. This research helps them focus on the design, impact-sensitive construction, materials, maintenance and use of environmentally sensitive areas. Look at any problems they cause or compare the performance of any building with the impact mentioned in this study. In addition to this, the methods applied in this study can be used for other building types as well using the replication principle. Other buildings may include multi-family complexes, high-rise, other construction methods such as wood and concrete. The proportion of the installation system (foundation, structure, wall, floor, ceiling) contributes to the overall environmental impact of other types of buildings and construction methods, especially the ecological characteristics of wood and concrete. The result is comparable to the profile of the steel components provided. In this study, it is used in design decisions to favor a building in terms of the environment. The results of this study, especially the impact on building unit area and method, can also be replicated to a wider range, such as in a cluster of buildings. It is also possible to calculate multiple impacts on buildings and compare them with similar acceptable impact ranges currently set by the EPA. Allowable environmental impacts (smog production, global warming, acidification, ozone depletion and so on) per US county. Each and every region must comply with a certain emission range to keep the air clean. The unified areas presented here may be practical steps to achieve this goal. Finally, since it can be assumed that the life cycle assessment of a building will respond to certain external patterns and conditions. This should be stated explicitly when the results of the life cycle assessment study are presented. Planners must consider these environmental impacts in order to effectively reduce the impact of office buildings on the environment.

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Appendix

Environmental Profiling of Green Educational Building Using Life Cycle Assessment

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Abstract: Over the last twenty years, architects and designers have been working towards minimizing the impact that buildings have on the environment. In spite of the fact that many architects claim their buildings are environment-friendly, the claims cannot be justified unless a Life Cycle Analysis (LCA) is conducted. The two major parts of the theoretical basis of the proposed scheme are the concept of sustainability of the environment and methods of assessing the building's environmental impacts. The objective of this report is to evaluate the possible ecological impact of an educational building through its life cycle, from extracting raw materials to the end of life. In order to accomplish the goal of the study, a single-case method of a life cycle assessment was used to determine which stage of the life cycle (manufacturing, construction, consumption, maintenance, and dismantling) made the most contribution to the overall impact. The main installation system (foundation, frame, wall, floor, roof) of a building will have an impact on the environment during its life cycle. A typical new educational building was used as a case study in Islamabad, along with an optimized LCA method based on energy consumption inventories, the material input and output, and the assessment of the environmental impact.

Keywords: life cycle assessment; impact assessment, ATHENA Impact Estimator

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