Toward Sustainability: An Optimization Framework for Life Cycle Assessment and Life Cycle Costing of Office Buildings

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ABSTRACT

Toward Sustainability: An Optimization Framework for Life Cycle Assessment and Life Cycle Costing of Office Buildings

Amin Ganjidoost

This thesis presents an optimization model to minimize total life cycle cost of sustainable office building, subject to a set of environmental impact constraints with emphasis on relationship between reducing environmental impacts and minimizing total life cycle cost of office buildings due to sustainable building design strategies.

The concepts of green design, sustainability, life cycle assessment and life cycle costing have been reviewed and presented in this thesis. Three green assessment tools which are used for buildings are also described. The role of life cycle costing and life cycle assessment in previous studies on office buildings, and related previous studies on optimization of environmental performance of buildings are also reviewed in this study.

The methodology of this research was tested through a case study of an eight-story office building to demonstrate the capability of the proposed optimization model. Two of the structural components (walls and floors) and one of the envelope component (windows) were compared on the basis of six environmental indicators. The indicators used were primary energy, solid waste generated, water pollution index, air pollution index, global warming potential and weighted raw resource use. Also, the life cycle costing of each alternative was compared. The results of LCC and LCA have been used in the optimization model to find the optimum solution.

The result of the case study has shown that the optimum alternative of tilt-up building was the most cost effective and with lower environmental impacts. In a conclusion, the proposed optimization model can be used as a decision support tool in the preliminary stages of building design.

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NONECLASTURE

ASTM	American Society for Testing and Materials
ASCE	American Society of Civil Engineering
CaGBC	Canada Green Building Council
ELCC	Environmental Life Cycle Costing
EPA	Environmental Protection Agency
GWP	Global Warming Potential
GDP	Gross Domestic Products
LCA	Life Cycle Assessment or Analysis
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCM	Life Cycle Management
OBs	Office Buildings
O&P	Operation and Maintenance
PV	Present Value
SETAC	Society of Environmental Toxicology and Chemistry

CHAPTER 1

INTRODUCTION

This research presents an optimization framework for balancing between the environmental and economical life cycle of office buildings to improve environmental and economical performance of the construction. The research focuses specifically on the office building sector.

1.1 Problem Statement

Being able to assess the impact of buildings on environment is very important as buildings consume for 30-40% of the world's energy and 16% of the world's water demand (Heijungs, R 1996). It is also a major part of an economy (Horvath, 2003). Among the category of commercial buildings, office buildings are the number one in consuming more than 40% of the total capital expenditure in the market each year (Statistics of Canada 2009). Gross domestic product (GDP) of the construction industry from 2002 to 2007 is shown in Figure 1.1. As it is clear, the GDP in the construction industry sector has been increasing each year. It shows that the construction industry plays a significant role in the Canadian economy. GDP or gross domestic income (GDI) is one of the basic measures, or indices, of a country's overall economic performance. It is described as the market value of all final goods and services made within a year.

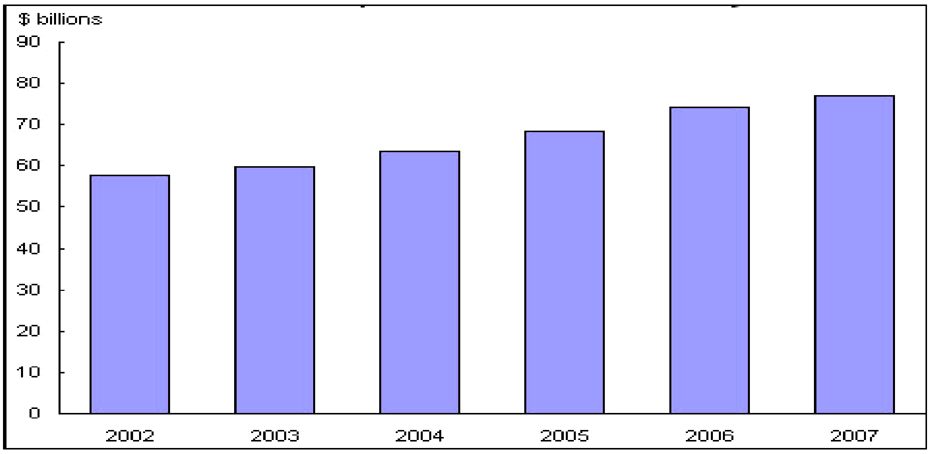


Figure 1.1 Gross Domestic Products, Construction Industry (Statistics Canada, 2009)

In a typical office building, 70% of all energy consumed is for lighting, cooling or heating of office space and 20% of energy consumption used to power office equipment. Water heating, cooling, and refrigeration systems and other miscellaneous uses consumed the remained energy (EIA, 1999). Guggemos (2005) was mentioned that "Energy use and environmental emissions from office buildings can be reduced through a careful selection of embedded and temporary materials and construction equipment"

The construction industry is recognized as an important source of waste and pollution (Ochoa et al., 2002; Junnila et al., 2005; Horvath, 2004; Hendrickson and Horvath, 2000). In office buildings, 30% of the energy consumed is wasted (Statistics Canada, 2009). This suggests a significant opportunity for energy use reduction, cost savings, and the mitigation of greenhouse gas emissions through cost-effective energy efficiency opportunities, such as combined heat and power.

The federal Government of Canada intends to reduce the environmental footprint of its operations related to real state property. To that effect, the Government of Canada is committed to ensure that new office buildings constructs and that existing office buildings renovation be at least 30 percent more energy efficient than the Model National Energy Code for Buildings. The mid-life refit of the Surrey Taxation Center in British Columbia is an example of this commitment (Statistics Canada, 2009).

1.2 Office Building Definition

U.S. department of energy (1999) described the office building as: "Buildings used for general office space, professional office, or administrative offices. Medical offices are included here if they do not use any type of diagnostic medical equipment (if they do, they are categorized as an outpatient health care building)". Dell'lsola (1981) has also defined the concept of office building as: "building designed or used as the offices of professional, commercial, industrial, religious, institutional, public, or semipublic persons or organizations". The office buildings are considered as a home for the people who work there full time or part time (Katz, 2002). These definitions are adapted in this research.

1.3 Office Building Development in Canada

From 2006, investment in non-residential building construction in Alberta and British Columbia hit $39.5 billion (Statistics Canada, 2009). Overall, seven provinces and three territories have recorded an increase in investment of commercial buildings. The largest contributors were given by British Columbia (+2.8% to $928 million), Quebec (+2.0%

to $1.1 billion), Manitoba (+16.5% to $137 million) and Newfoundland and Labrador (+54.1% to $49 million). In contrast, Ontario, Nova Scotia and Saskatchewan have recorded decline in such development resulting from lower spending in several commercial building categories. The growth of investment in nonresidential building construction from 2003 to 2008 is shown in figure 1.2. The investment in commercial building construction sectors is also shown in figure 1.3.

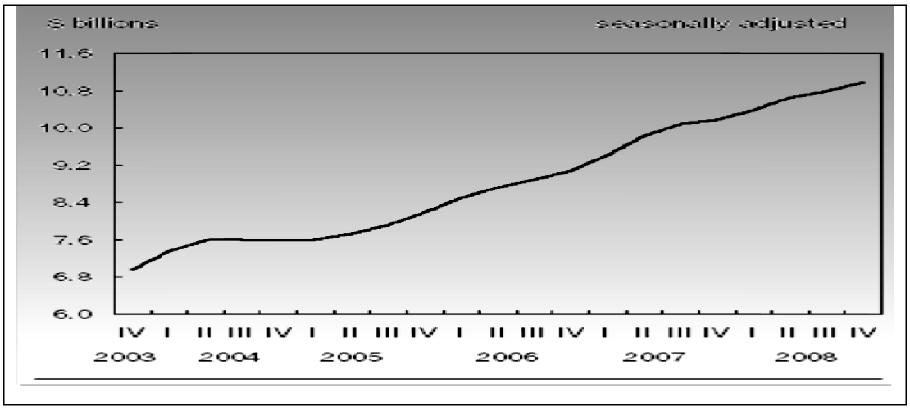


Figure 1.2 Investments in Nonresidential Building Construction, Canada (Statistics Canada, 2009)

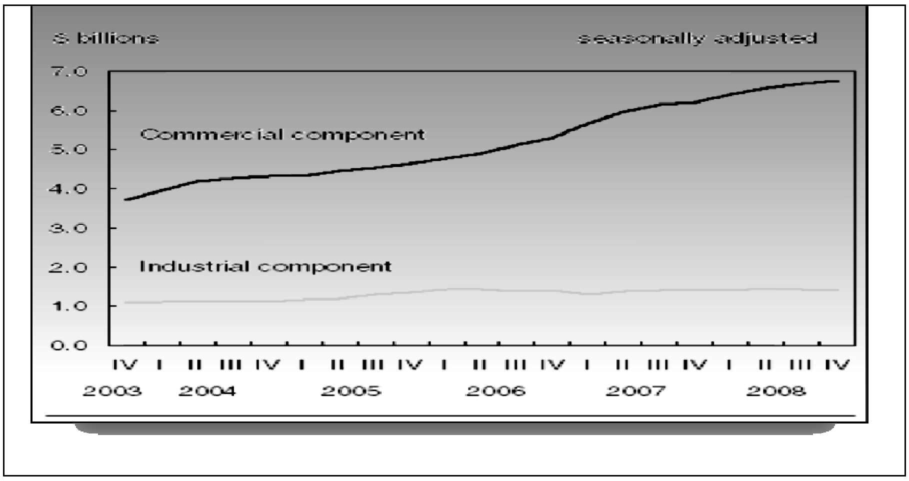


Figure 1.3 Investments in Commercial Building Construction (Statistics Canada, 2009)

1.4 Research Objectives

The main objective of this research is to optimize total life cycle costs of sustainable office building subject to a set of environmental impact constraints with the emphasis on relationship between reducing environmental impacts and minimizing total life cycle cost of office buildings due to sustainable building design strategies.

The following sub-objectives need to be achieved in order to realize the main objective.

- Identify the main indicators that make sustainable design in office buildings.
- Develop an optimization model to guide the designers to achieve the sustainability targets.
- Create a pattern for decision-making to one among many alternatives based on the least impacts on environment and also, lower cost to reach the concepts of the sustainable design.

1.5 Proposed Research Methodology

The following methodology has been applied to achieve the objectives of this research.

1. Conduct a literature review to identify the limitation of the previous related works.
2. Create a definition of sustainability for office building, and establish the sustainability indicators and targets.
3. Collect the necessary data from office building project.

4. Develop the optimization model to select the optimal combination of building components which meet or exceed the established sustainability targets.
5. Identify the objective functions, variables and constrains of the model.
6. Define LCA, LCC and LINDO tools to make the optimization model meaningful.
7. Test the methodology framework with a real case study to validate the optimization model.

1.6 Thesis Organization

This thesis includes an extended abstract followed by six chapters, references and along with five appendices.

- The introduction chapter provides a definition of the office building in order to narrow the goals of the study. The importance of office building in the construction industry is also elaborated. Finally this chapter presents the problem statement, objectives and methodology of the research. A brief summary of the thesis chapters is also outlined.

- Chapter Two presents a literature review about the concepts of green design and green assessment tools for office buildings in Canada and reviews the previous related works for life cycle assessment, life cycle costing and optimization of office buildings and identifies the limitation of the previous works to justify this research.

- Chapter Three describes the framework and methodology of the research. Sustainability for office building is defined, and the sustainability indicators and targets are established. The formula of the optimization model system is described, and the objective function of the model, constraint and variables are defined. Life cycle assessment and life cycle costing approaches are explained. The framework of translating CO_2e to a monetary value to calculate the global warming potential cost is elaborated as well. The model is tested with a hypothetical case.

- Chapter Four introduces the methodology of the research to a real case study. A description of base office building and alternatives to base office components which are tilt-up, pre-cast and triple glazed windows has been expressed. Also, In order to apply the research methodology to the case study some assumptions have been made.

- Chapter Five presents the life cycle assessment, life cycle costing and optimization model results of the case study, discussion on the results and also a sensitivity analysis to validate the model.

- Chapter Six concludes with research summary and contributions on the current research. It also describes challenges for future works to improve the present research.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Several studies have been done in the area of life cycle assessment, but few of them were in the field of buildings especially in office buildings. This chapter reviews the concepts of green design, life cycle assessment, and life cycle costing. The role of life cycle costing and life cycle assessment in previous studies on office buildings, and related previous studies on optimization of environmental performance of buildings are also reviewed in this chapter. Also, this chapter reviews the green assessments tools in the three main categories.

2.2 Green Design

Over the last few decades, the idea of sustainability has moved from concept to a way of life. The depletion of natural resources has led the construction industry to explore alternatives in material selection as well as construction procedures.

Sustainable building merges building materials and methods which promote economic vitality, environmental quality, and social benefits through the design, construction and operation of the built environment. Sustainable building combines sound, environmentally responsible practices into a discipline that looks at the economic, environmental, and social effects of a building or built project as a whole. The American Society of Civil Engineering (ASCE) defines sustainability as "systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological and engineering integrity" (ASCE, 1996).

The concept of green building design is mitigation of impacts on environment while considering cost and other criteria of performance. Green design consists of the practices which significantly reduce the negative impact of buildings on the environment and are categorized in five areas:

- Sustainable site planning
- Safeguarding water and water efficiency
- Energy efficiency and renewable energy
- Conservation of materials and resources
- Indoor environmental quality

Green building often is used in alternative words like: sustainable building, environment-friendly building and energy-efficient building. Although their concepts are similar, but their implications may be has a little different (Cole, 1999).

The U.S. Green Building Council and the LEED Green Building Rating System has defined the benefits of Green Buildings into seven areas (USGBC, 2005):

1. Environmental benefits (Reduce the impacts of natural resource consumption).

2. Economic benefits (Improve the bottom line).
3. Health and safety benefits (Enhance occupant comfort and health).
4. Community benefits (Minimize strain on local infrastructures and improve quality of life).
5. Competitive first costs (Integrated design allows high benefit at low cost by achieving synergies between disciplines and between technologies).
6. Reduce operating costs (Lower utility costs significantly).
7. Optimize life-cycle economic performance.

2.3 Green Assessment Tools

In order to assess the impacts of construction industry on environment, several tools have been developed to quantify the magnitude of impacts. These tools can be classified into three main categories of environmental impact assessment (EIA); certification or rating schemes (CS); and life cycle assessment (LCA).

2.3.1 Environmental Impact Assessment

Environmental impact assessment is a tool that can be used to assess different types of projects as they relate to impact on environment. It consists of different phases of identification of the reference satiation, prediction, evaluation, and mitigation of impacts. The EIA methodology mostly applies at a macro level and used for different types of projects including manufacturing plants, dams, roads and real estate developments (including buildings). Viera (2007) indicated that “a significant disadvantage is that the broad scale of analysis used can hardly induce more sustainable building designs". It considers a wide range of indicators including environmental, social and economic impacts. The recommendations of this tool are often related to location, dimension and geographical orientations and it rarely directed to proposing the detail of changing to a specific building design.

2.3.2 Certification or Rating Schemes

This section represents the three common certification schemes for office buildings which address the environmental and energy issues. These tools are not able to measure a specific impact of a project. For example: quantifying CO_2 emissions and subsequently global warming potential.

2.3.2.1 Leadership in Energy and Environmental Design (LEED)

Leadership in Energy and Environmental Design is a rating system for the environmental performance of a building which was initiated by U.S. Green Building Council in 2003. According to USGBC definition "LEED is an internationally recognized certification system that measures how well a building or community performs across all the metrics that matter most: energy savings, water efficiency, CO_2 emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts" (USGB, 2003). After evaluating the whole life cycle of the building, the building obtains one of the following certification categories: Certified, Silver, Gold or Platinum. The type of certification depends on the number of credits obtained from the five keys of

LEED certification: sustainable site, water efficiency, energy and atmosphere, materials and resources and indoor environmental quality. There are also bonus points in LEED certification which are innovation & design process, regional priority, locations & linkages and awareness & education. LEED rating system applied for new construction, core and shell, schools, healthcare, retail, commercial interiors, retail interiors, existing buildings and existing schools.

Table 2.1 shows the LEED green building rating system. It has tabulated energy savings, annual utility savings and typical payback for different levels of green building certification. The incremental construction cost for small and large buildings are also given in the table (Enermodal Engineering Company).

Table 2.1 LEED rating systems

LEED™ Rating	Certified	Silver	Gold	Platinum
LEED™ Points	26 to 32	33 to 38	39 to 51	52 to 69
Energy Savings	25 to 35%	35 to 50%	50 to 60%	>60%
Annual Utility Savings	$0.40/ft^2$	$0.60/ft^2$	$0.80/ft^2$	$1.00/ft^2$
Typical Payback	< 3 yrs	3-5 yrs	5-10 yrs	>10 years
Incremental Construction Cost				
Small Buildings	3%	7%	10%	15%
Large Buildings	1%	3%	5%	8%

In figure 2.1 and 2.2, the LEED certified projects in Canada excluding residential projects of less than 600 m^2 have broken down by rating level, province/territory and project category. Among of 146 LEED certified projects, 52 projects are office buildings which show that the office buildings carry a significant share toward sustainable buildings. Since April 2005, all new government office buildings have been required to meet Canada Green Building Council's Leadership in Energy and Environmental Design (LEED - Canada) Gold level (CaGBC 19 –Mar-2009 at 2:50 pm).

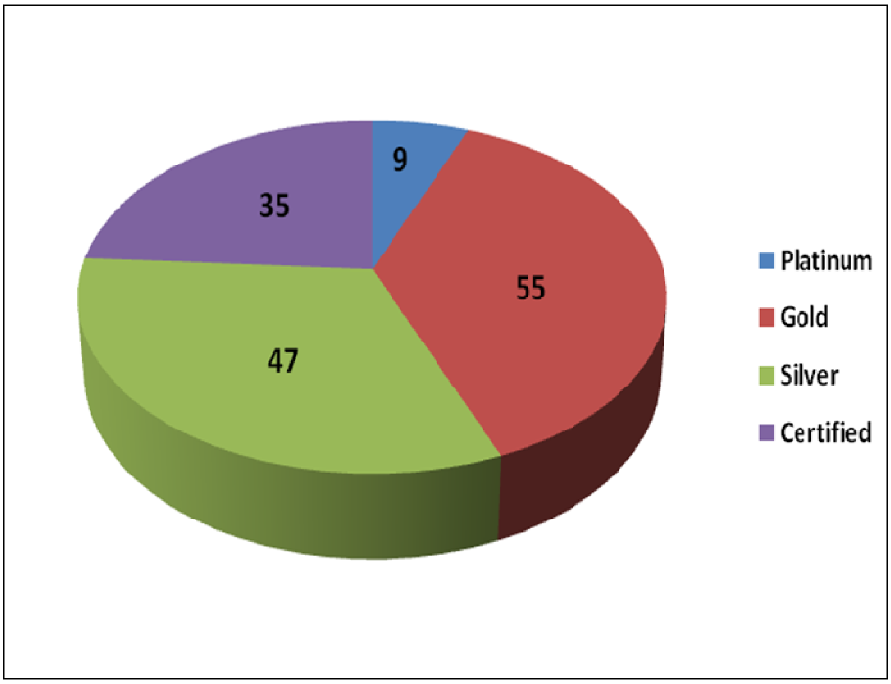


Figure 2.1 LEED certified projects in Canada; break down by rating level

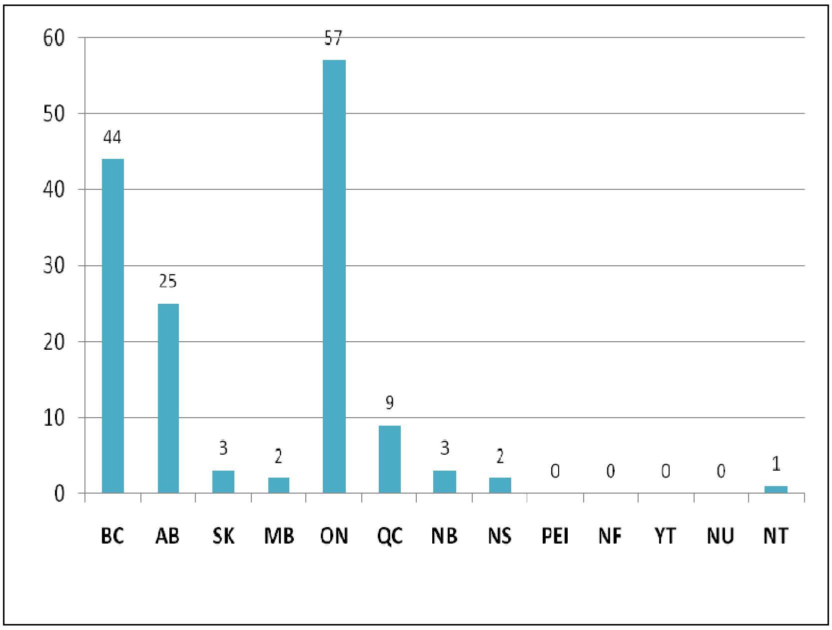


Figure 2.2 LEED certified projects in Canada; break down by province/Territory

Some examples of LEED certified projects in the Province of Quebec are given as follows (CaGBC 19 –Mar-2009):

- Pavilions Lassonde-Ecole Polytechnique du Montreal at Montreal, with Gold certification.
- TOHU (Previously Chapiteau des Arts) at Montreal, with Gold certification.
- Pavilion des Sciences Biologiques (at Universite du Quebec a Montreal) at Montreal, with Silver certification.
- Le supermarche IGA de Saint-Pscal-de-Kamouraska at St-Pascal-de-Kamouraska, with certification.
- La Maison de l'OACI / Place de la cité internationale at Montreal with Gold certification.
- Les Condos Wellington at Montreal, with certification.

- École primaire de la Grande-Hermine at Quebec, with certification.
- Head Office & Warehouse - Siège Social et Entrepôt (Outdoor Gear Canada - OGC) at St-laurent , with Silver certification.
- 801 Brennan, Centre administrative at Montreal with Silver certification.

2.3.2.2 Building Research Establishment Environmental Assessment (BREEAM) Method

The BREEAM was launched in 1990 by the Building Research Establishment (BRE) in UK with the first two versions covering offices and homes. BREEAM is the leading and most widely used environmental assessment method for buildings. It is LCA-based materials credits. BREEAM looks at broad range of environmental impacts: management health and well-being, energy, transport, water, material and waste, land-use and ecology and pollution.

BREEAM rating systems are: Bespoke (BREEAM Bespoke can assess buildings that fall outside the standard of BREEAM categories, including leisure complexes, Laboratories, higher & further education buildings and hotels at the design stage and post construction), Court, Eco-homes, Healthcare, Industrial, Multi-residential, Prisons, Offices, Retails, Education and Communities. BREEM rate of scale are: PASS, GOOD, VERY GOOD, EXCELLENT or OUTSTANDING

2.3.2.3 BREEAM VS. LEED

Liewelyn Davis Yeang (LDY) Eco Systems has done a comparison survey of LEED and BREEAM for a large office building in Malaysia. The results of this comparison have found that many of LEED points are not sufficient for locality. The occupant's health and comfort are more important in LEED and the environmental impacts are much more considered in BREEM. For instance, if a building gets higher score using LEED, it does not mean it will receive the same score with BREEM while it may get relatively poorly score in BREEM or vice-versa. Complying of BREEM criteria are easier than LEED. Both of LEED and BREEM have a little information for the construction cost of the projects. While it seems the BREEM is more relevant to local needs, but in a request by a client to prepare a quotation for an environmental assessment it has showed the BRE is unable to respond for two months whereas the US Green Building Council (LEED) responded immediately.

Eventually, this survey found each country should have their own system which is compatible with their local conditions like climate, local planning regulation to make the process of green assessment more effective. At the end, to achieve a greener with higher quality buildings, it suggested using BREEM where the local system is not available.

2.3.2.4 BOMA BESt (Building Environmental Standards)

The Building Owners and Managers Association (BOMA) was established in 1902 in Chicago, USA. BOMA is an organization for commercial real estate industry specializing in office buildings.

The BOMA BESt Certification program is an environmental certification program which addresses the environmental and energy performance issues of existing commercial buildings. It was launched in 2005 by BOMA Canada's Go Green program. This certification is applied to office buildings, shopping centers, open air retail and light industrial properties. Go Green Plus is the best tool to measure the environmental performance of commercial buildings. The performance is measured in the six categories of BOMA BESt Go Green plus assessment questionnaire which are as following:

1. Energy
2. Water
3. Waste reduction and site
4. Emissions and effluents
5. Indoor environment
6. Environmental management system

BOMA BESt has four level of certification:

- Level 1: meet Go Green Best Practices.
- Level 2: meet Go Green Best Practices (earn 70-79% on Go Green Plus assessment).
- Level 3: meet Go Green Best Practices (earn 80-89% on Go Green Plus assessment).
- Level 4: meet Go Green Best Practices (earn 90-100% on Go Green Plus assessment).

Table 2.2 shows some examples of the BOMA BESt certified projects in the province of Quebec.

Table 2.2 Examples of the BOMA BESt certified projects in the province of Quebec.

Level	Project	City	Date
2	Édifice Montval	Longueuil	Jan 2010
2	Palais de justice de Maniwaki	Maniwaki	Jan 2010
2	Poste Sûreté du Québec, Ste-Anne-des Monts	Ste-Anne-des Monts	Jan 2010
2	Poste Sûreté du Québec de Chandler	Chandler	Jan 2010
2	Centre administratif de Gatineau	Gatineau	Jan 2010
1	Centre administratif de Mont-Laurier	Mont-Laurier	Jan 2010
3	Édifice Gilles-Hocquart 535 Viger Est, Montréal	Montréal	Jan 2010
1	7210 - 7220 Frederick Banting	St. Laurent	Oct 2009
1	7150 Frederick Banting	saint Laurent	Oct 2009
3	Hôpital du Sacré-Coeur de Montréal	Montréal	Oct 2009
3	Hôpital Louis-H. Lafontaine	Montréal	Oct 2009
4	Le Centre CDP Capital	Montréal	Nov 2009
2	1801 McGill College	Montreal	Jan 2010

BOMA BESt Energy and Environmental Report (BBEER) has reported that between years 2005 to 2009 more than 450 office buildings and 132 million square feet achieved Levels 2, 3 and 4 of BOMA BESt . Figure 2.3 illustrates the average energy performance of BOMA BESt certified office buildings which is 31.52 ekwh/sf/yr lower than the national average energy performance for office building (35.48 ekwh/sf/yr).

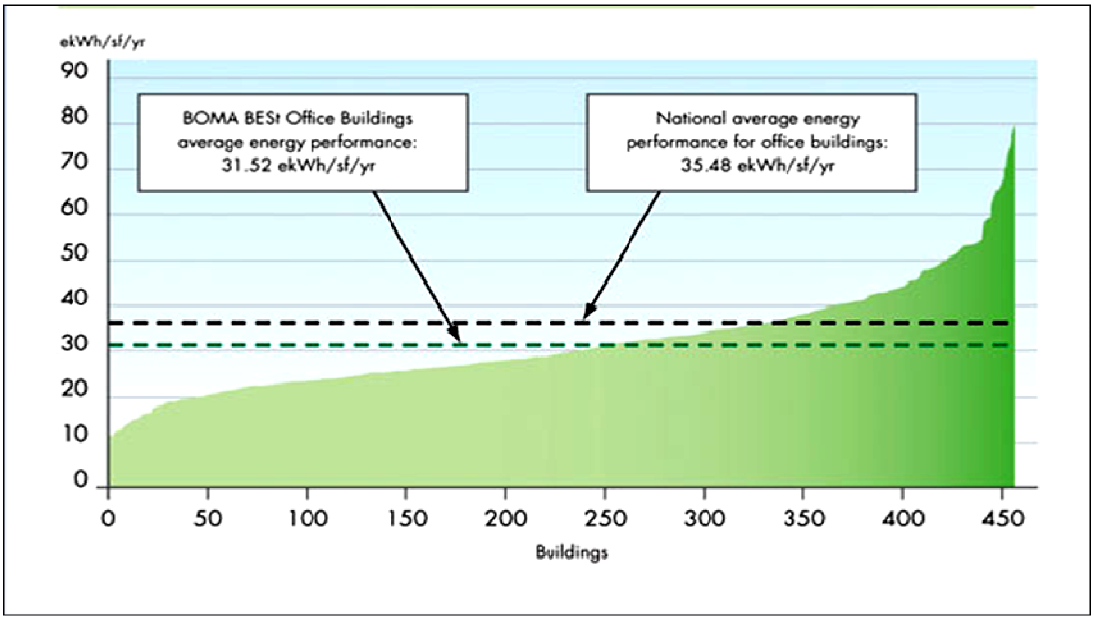


Figure 2.3 BOMA BESt Office Buildings Average Energy Performance (BOMA BESt Energy and Environmental Report, 2010)

2.3.3 Life Cycle Assessment (LCA)

"Life Cycle Assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements" (SETAC, 1990).

Cole and Larsson have indicated that "The notion of Life-Cycle Assessment (LCA) has been generally accepted within the environmental research community as the only legitimate basis on which to compare alternative materials, components and services" (Cole, 1996). Ross and Evans (2002) inferred that the LCA was the only quantitative and the most promising tool for environmental management. A LCA is a systematic, cradle-tograve process that evaluates the environmental impacts of products, processes, and services. Its quality depends on the life-cycle inventory (LCI) data it uses. This study is used LCA as a method to assess the environmental impact of buildings.

2.3.3.1 Life Cycle Stages

LCA considers the impacts of the building on environment over all phases throughout its life cycle stages which are: raw materials acquisition, manufacturing, use / reuse / maintenance and end-of-life (recycle / waste management). Figure 2.4 illustrates the possible life cycle stages that can be considered in a LCA process.

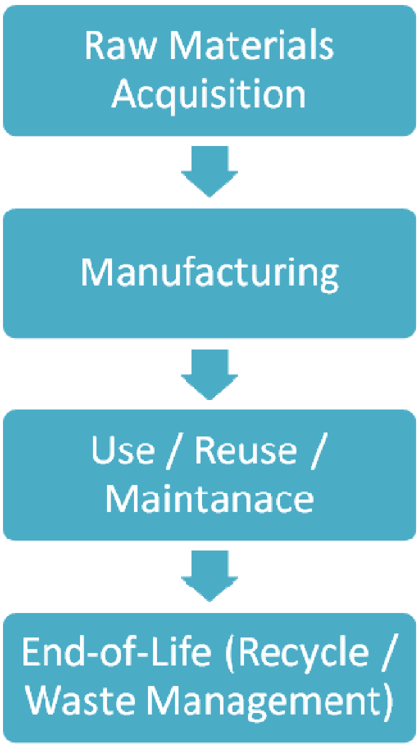


Figure 2.4 Life Cycle Stages (US EPA, 1993)

2.3.3.2 LCA Phases

The LCA process divided into four phases: goal and scope, life cycle inventory analysis, life cycle impact assessment and interpretation as shown in Figure 2.5.

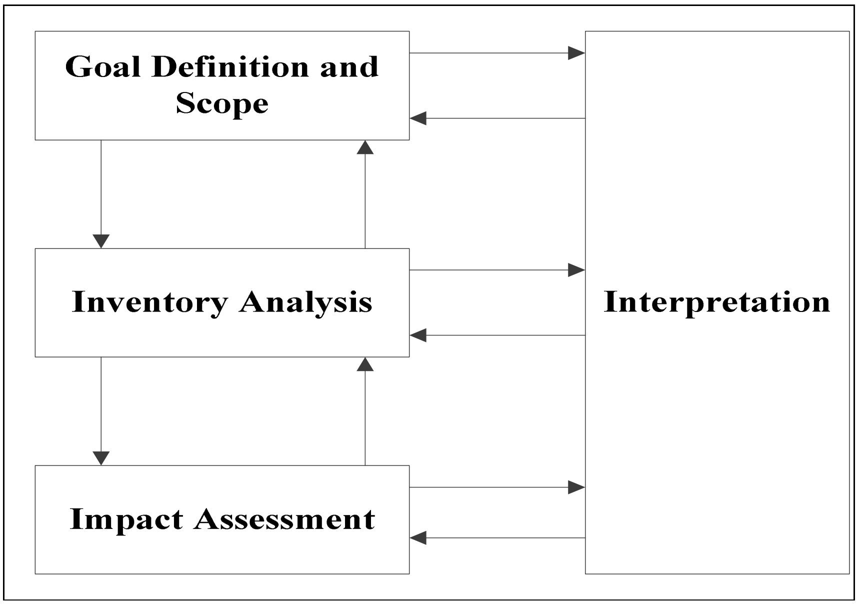


Figure 2.5 Phases of LCA (ISO 14040, 1997)

The goal definition and scope phase determines the purpose and boundary of the LCA. The inventory analysis consists of a collection of data and the calculation procedures to quantify the inputs and outputs of the system (Junnila, 2004). The impact assessment evaluates the possible impacts of a project on environment using the results of the inventory analysis. At the interpretation phase, the results of the impact assessment evaluated and checked according to the goal and scope definition phase. The possibilities to mitigate the environmental impacts of the studied project evaluated and finally conclusions and recommendations explored.

2.3.3.3 Benefits of using LCA

- Life cycle assessment is unique because it encompasses all processes and environmental releases.
- When deciding between two or more alternatives, LCA can help decision-makers compare all major environmental impacts caused by products, processes, or services**.**
- To help decision-makers to decide between two or more alternatives according to the least impact to the environment (as well as other factors, such as cost and performance data)
- It helps to decision-makers to study all environmental impacts of product system (air, water, land) instead of considering only one to avoid the sub-optimization (LCA principles and practice 2006).

2.3.3.4 Limitation of Conducting an LCA

In order to perform LCA few factors must be considered. Since LCA is time consuming and it needs recourses; therefore it is important to weight the avaibilty of data, the necessary time to conduct the study, and also, the financial resource required against the projected benefits of the LCA (LCA principles and practice, 2006).

LCA will determine one component of a more comprehensive decision process assessing the trade-offs with cost and performance, which product or process is the most cost effective or works the best. Therefore, the information developed in an LCA study should be used as one component of a more comprehensive decision process e.g., life cycle management (LCM). LCM is the application of life cycle thinking to modern business practice, with the aim to manage the total life cycle of an organization's product and services toward more sustainable consumption and production (Jensen and Remmen, 2004).

2.4 Life Cycle Costing (LCC)

American Society for Testing and Materials (ASTM, 1999) defines LCC as a technique that "justify a certain expenditure on a project/system by proving its saving along its life span". The life cycle cost (LCC) analysis is a forecasting the financial performance of a building or system over the period of study. LCC is a mathematical approach that to study the cash flow of LCC, it uses basic economic evaluation methods such as the Net Present Value (NPV) Method, Annual worth (AW) Method, Saving/Investment Ratio (SIR) Method and etc. Figure 2.6 shows an example of a cash flow profile:

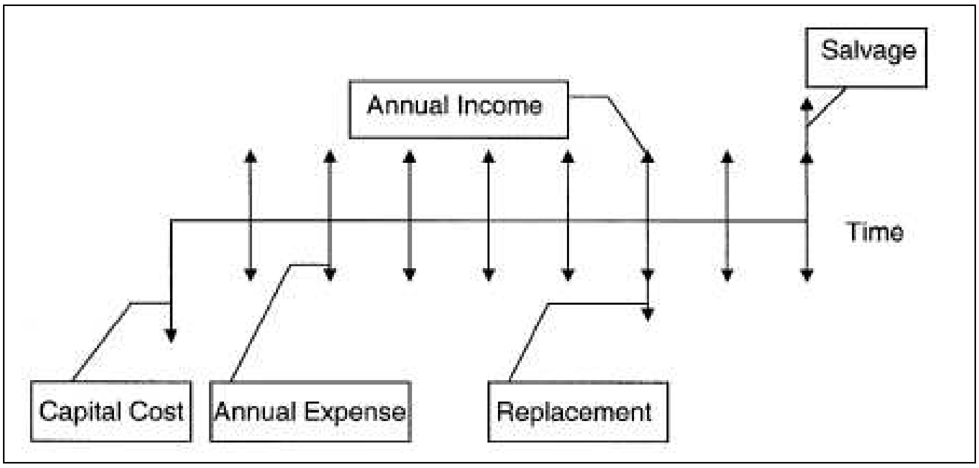


Figure 2.6 Cash flow of Life Span (Liu, 2006)

Figure 2.7 shows the net present value method that all income and expenditures are converted to a single sum equivalent at time zero (equation 2.5). In the annual worth method all income and expenditures are converted to equivalent yearly payments throughout the design life of the project (equation 2.6). The saving/investment ratio method is the ratio of the net positive present worth of saving to the net negative present worth of investment (equation 2.7). Therefore, for the ratio greater than one it means that the project is preferred.

$$NPV = PV_{(\text{Annual income})} + PV_{(\text{Salvage value})} - PV_{(\text{Capital cost})} - PV_{(\text{O\&M cost})} - PV_{(\text{Financial cost})} \quad \text{(Eq. 2.5)}$$

Where,

NPV = the net present value

PV = the present values of all incomes and cost incurred during the project life cycle

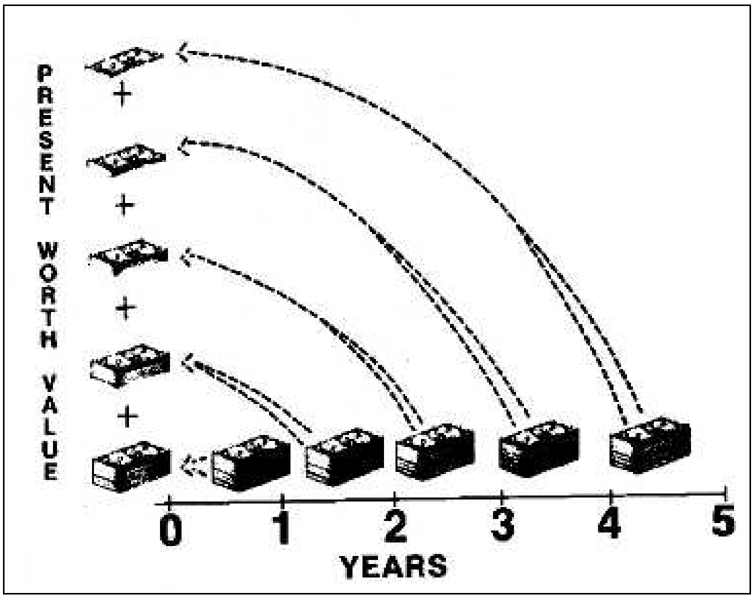


Figure 2.7 Net Present Values (Liu, 2006)

$$AW = AW_{(\text{Annual income})} + AW_{(\text{Salvage value})} - AW_{(\text{Capital cost})} - AW_{(\text{O\&M cost})} - AW_{(\text{Financial cost})}$$

(Eq. 2.6)

Where,

AW = the annual worth of all income and costs incurred during the project life cycle

$$SIR = PV_{(\text{Saving})} / PV_{(\text{Investment})} \quad \text{(Eq. 2.7)}$$

Equation 2.8 (Ruegg and Marshal, 1990) represents the components of LCC, which includes the present value of investment costs, energy costs, operating and maintenance costs, repair and maintenance cost and the cost of salvage value. LCC could be presented in both present value (PV) and annual value (AV).

$$LCC = Ip + Ep + Mp + Rp - Sp \quad \text{(Eq. 2.8)}$$

Where,

I: investment cost

E: energy cost

M: non fuel operating and maintenance cost

R: repair and maintenance cost

S: salvage value

P: represents the present value

The LCA is not the same as LCC. The two methodologies are complementary, but LCC focuses on the costs of building and maintaining a structure over its life cycle, while LCA focuses on environmental performance. Performance is measured in the units appropriate to each emission type or effect category.

2.5 LCA and LCC Studies in Office Buildings

Canadian wood council in 1996 has done a case study for an office building. For this study, they used Athena institute LCA tool to compare the environmental impacts of wood, steel and concrete. The office building with wood had lower environmental impact in all five environmental impacts indicators of total energy use, greenhouse gas index, air pollution index, ecological resource impact use and solid waste. Figure 2.8 shows the results of this study.

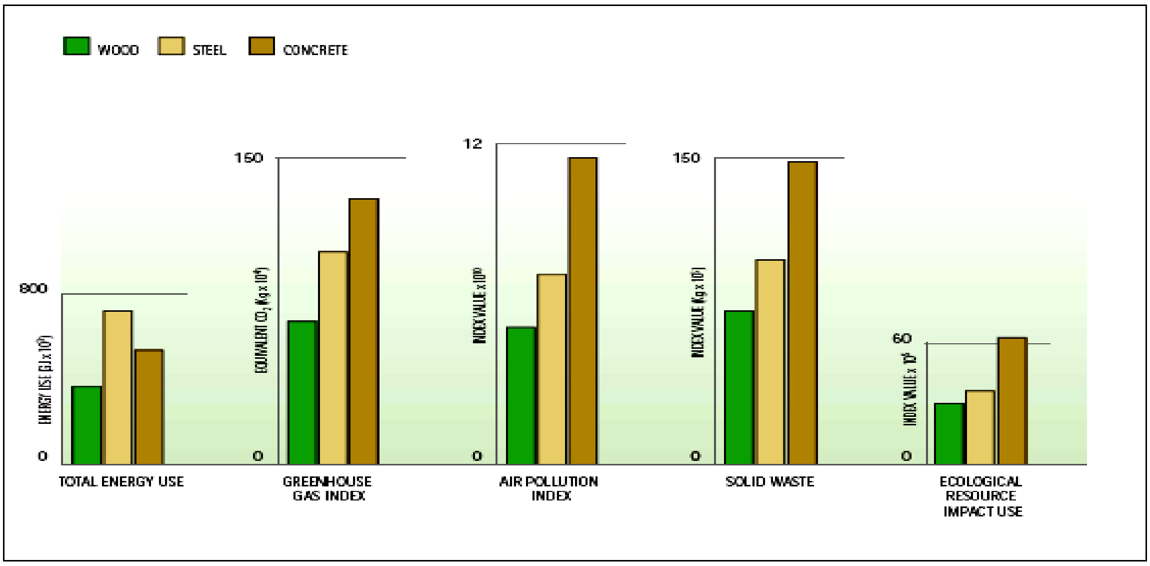
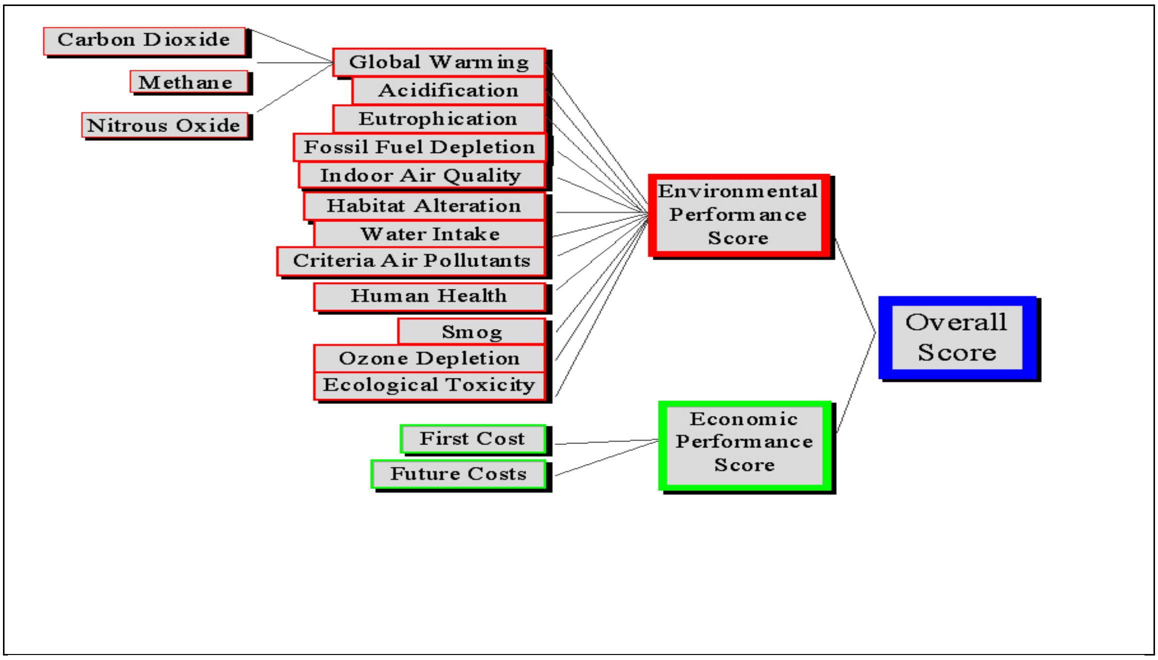


Figure 2.8 Office Building Life Cycle Comparison Chart (Canadian Wood Council, 1996)

Canadian wood council and Cole (1997) compared the energy consumption and greenhouse gas emissions of on-site construction for wood, steel, and concrete structural building frames but the end-of-life phase in their studies was not investigated. The life cycle assessment of this study carried out with help of Athena Version 1.0 and for the cost comparison RS Means catalogue data was used. The results of the study showed the amount of the energy consumption and greenhouse gas emissions for steel is lower than wood and concrete has the higher one.

Building for Environmental and Economic Sustainability (BEES) (Lippiatt and Boyles, 2001) is a powerful technique for selecting cost-effective, environmentally-preferable building products. It is developed by the National Institute of Standards and Technology (NIST) in 1994. This software measures the environmental and economical performance of the building. It mmeasures the environmental performance of building products by using the LCA approach specified in the ISO 14040 series of standards. All stages in the life of a product are analyzed: raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management. Economic performance is measured using the ASTM standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. The major benefit of this software is that users don't need to know about LCA. This software does not assess all the building materials and uncertainty analysis does not incorporate. The framework of the BEES software in terms of environmental and economical scores and finally the measurement of overall score are shown in figure 2.9.



Characterization:

$$I_{kj} = \sum_{i=1}^{n} m_i \cdot EF_{ij}$$

where:

i = inventory flow

j = impact category

k = alternative

n = number of inventory flows in impact category j

m_i = mass of flow i

EF_{ij} = equivalecy or characterization factor for flow i in impact category j

I_{kj} = score for alternative k in impact category j

Figure 2.9 BEES Assessing Impact Framework (Lippiatt and Boyles, 2001)

Xing et al. (2007) developed a life cycle inventory model for office buildings in china. In energy consumption and environmental emissions of the steel-framed and concrete-framed building materials, it founded that steel-framed building is superior to concrete-framed building because it has life cycle energy consumption 75.1% as that of concrete, and the environmental emissions are less than 35.55% of concrete.

Econo-Enviro TLCC tool (Haddad, 2008). This tool evaluates total life cycle costing of several alternatives of building materials. It calculate the environmental impacts of the building materials an equivalent CO_2 as an environmental indicator based on GWP and then translates to a monetary value in order to use in TLCC. This tool represents the results of economic and environmental evaluation of building materials in a tabular and graphical format.

CEDST: Construction Environmental Decision Support Tool (Guggmos and Horvath, 2003; 2005; 2006) looks specifically at the effects of the construction phase of commercial building. It allows designers and contractors to estimate the energy use, environmental emissions, and waste generation associated with the construction of commercial buildings. In Figure 2.10 the Structure of the CEDST is explored. The Role of CEDST in Overall Building Life-cycle Assessment is shown in Figure 2.11 (Guggemos, 2003)

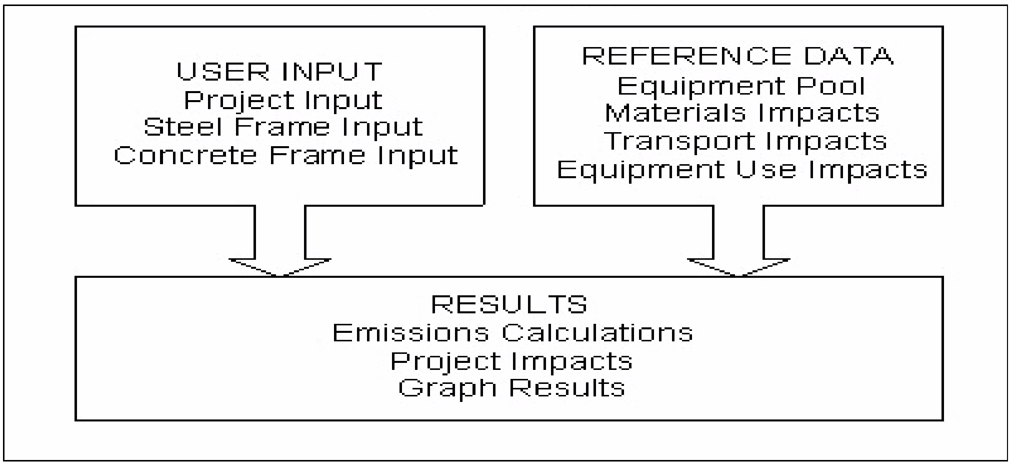


Figure 2.10 Structure of CEDST (Guggemos, 2003)

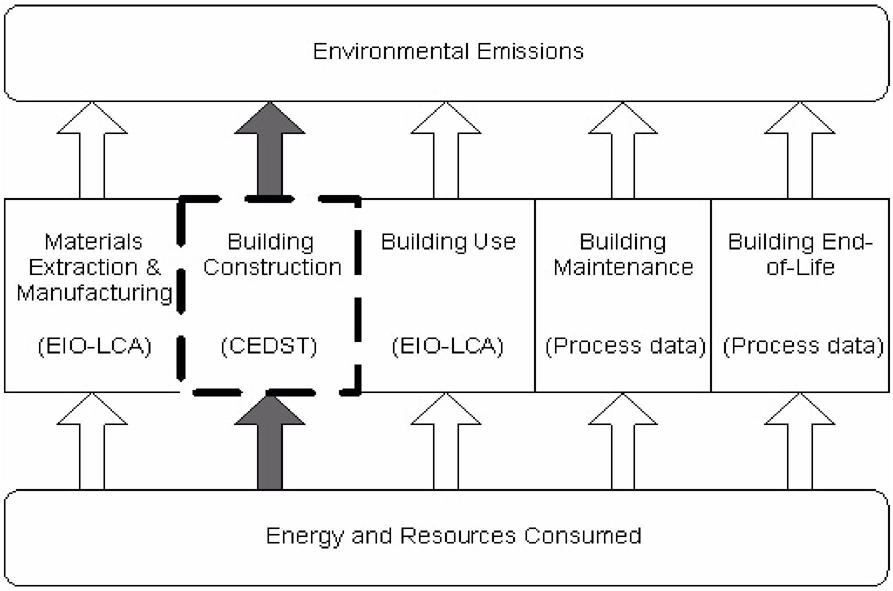


Figure 2.11 Roll of CEDST in Overall Building life Cycle Assessment (Guggemos, 2003)

Guggmos and Horvath (2005) with using LCA quantified the energy use and environmental emissions during the construction phase of two typical office buildings structural steel frame and cast-in-place concrete frame. The results showed that the concrete has more associated energy use, CO_2, CO, NO_2, particulate matter, So_2, and hydrocarbon emissions due to more formwork used. Larger transportation impacts due to a larger mass of materials, and longer equipment use due to the longer installation process. While steel frame construction has more volatile organic compound (VOC) and heavy metal (Cr, Ni, Mn) emissions duo to the painting, torch cutting, and welding of steel members (figures 2-12 to 2-14).

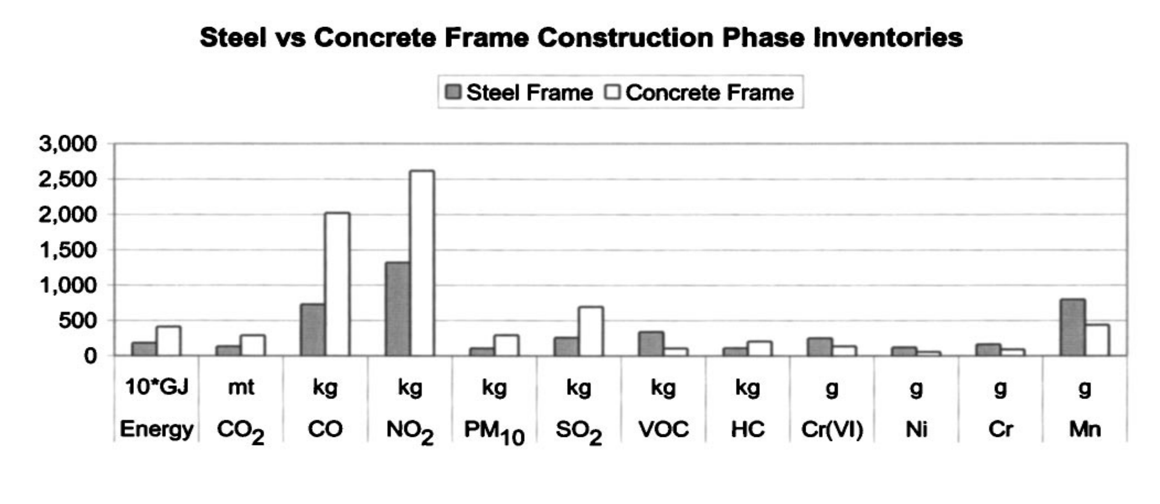


Figure 2.12 Summary of construction-phase impacts for steel and concrete frames (Guggmos and Horvath, 2005)

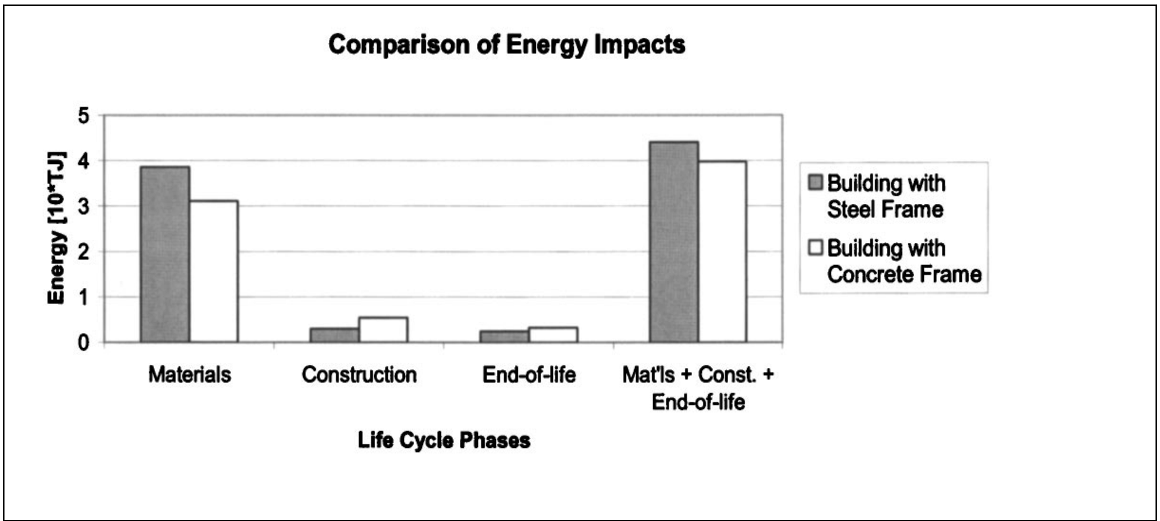


Figure 2.13 Comparison of energy use by life-cycle phase for steel- and concrete-framed buildings (Guggmos and Horvath, 2005)

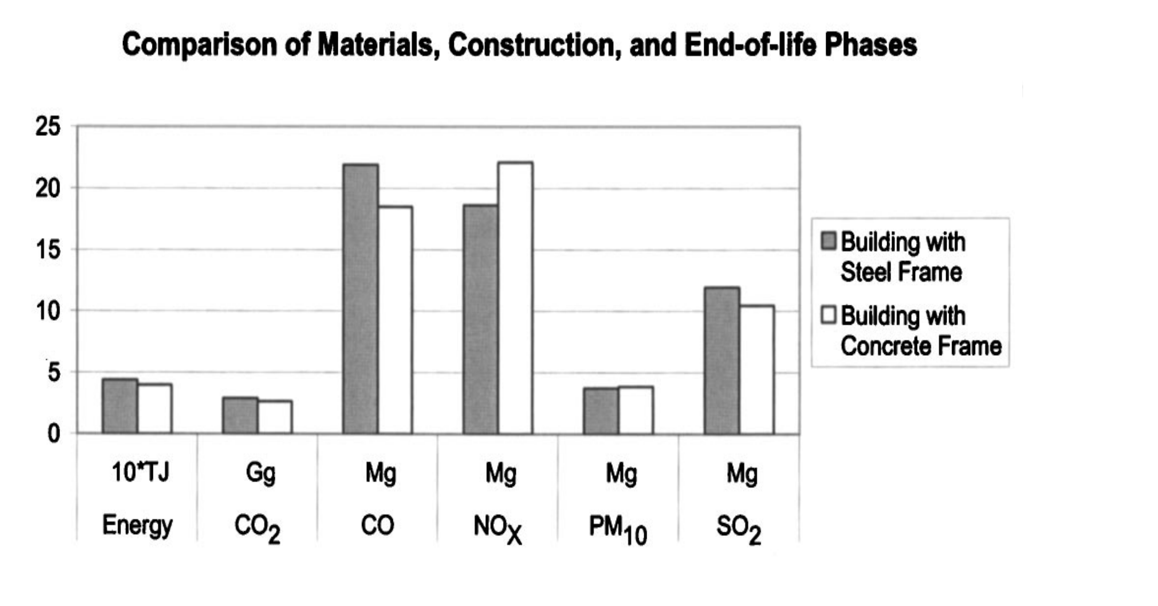


Figure 2.14 Comparison of the sum of materials extraction and manufacturing, construction, and end-of-life phases for steel- and concrete-framed buildings (Guggmos and Horvath, 2005)

Seppo Junnila (2004) studied LCA of office building in Europe and U.S. He compare the potential environmental impacts caused by an office building during its life cycle (50 years) using both a multiple case study and LCA methods. The key environmental issues found for electricity used in outlets, HVAC and lighting, heat in ventilation and conduction and material used in internal surfaces.

BuiLCA (Vieira 2007): This research developed a user-friendly hybrid LCA tool for office building that can be used to assess the environmental effects of all life cycle phases and the environmental consequences of decisions made over the life cycle of building. Also, this tool can assess the end-of life impacts of construction materials. They applied this methodology to concrete and it has been founded that with increasing 27% of current recycling rate to 50% could lead to 2-3% reduction in GWP or equivalent to removing 612,000 cars from U.S. roads annually.

2.6 Optimization

Optimization helps to find the answer that yields the most desirable result. Optimization problems are often classified as linear, integer or nonlinear. Optimization method is a way of finding the optimal solution which meet or exceed the targets of the optimization model. An optimization model is based on the objective function which is seeking to minimize or maximize the objective function. It has one objective or multiple objectives. In definition of Radford and Gero (1987), optimization is an automated process incorporating three steps: generation, simulation, and evaluation (Radford and Gero, 1987).

Radford and Gero (1987) applied a multi criteria design optimization with four performance criteria of: thermal load, daylight availability, construction cost, and usable area. Khajehpour (2001) considered three objective functions to the conceptual design of high-rise buildings. These objectives include capital cost minimization; annual operating cost minimization, and annual income revenue maximization.

Wright et al. (2002) applied a multi objective genetic algorithm with emphasis on mechanical system design of buildings thermal optimization. The operating energy cost and occupational thermal comfort considered as two performance criteria. Also, Nassif et al. (2003) used the same performance criteria of Wright (2002) to optimize HVAC system control. Mahdavi and Mahattanatawe (2003) applied a multi criteria optimization of passive solar building design with two criteria of thermal comfort and day-lighting quality.

The above studies explore ways of better building design, but there are some limitations on their applications in practice. The entire environmental performance criterion is not considered. Most of the previous studies dealt with environmental or economical performance and did not consider both in making decisions. The variables in optimization models are only some components of building and considering the whole building as a variable has not been undertaken in literatures. Also, minimizing the total life cycle costs of building over a defined design life as an objective function has not been applied. Finally applying an optimization approach for office building sector with emphasis on environmental and economical performance throughout its life cycle has not been undertaken in literatures.

CHAPTER 3

REASEARCH FRAMEWORK AND METHODOLOGY

3.1 Introduction

This chapter presents the framework and methodology of the research. Sustainability for office building is defined, and sustainability indicators and targets are established. Using the research methodology framework described in this chapter, an approach for developing the optimization model to move office building industry toward sustainability is presented. Also, the tools and techniques used to demonstrate the structure of the optimization model are described in this chapter. The optimization model developed in this research assists the designer and decision makers to achieve the sustainability targets that are the most cost effective and also, have the least impact on environment.

3.2 Definition of Sustainability for Office Building

From the literature review, a sustainable office building can be defined a building which meet the two factors of sustainability: 1- preserve the natural environment (which considers things such as water, air, land) and 2- within the context of human existence, the political, economic, social and cultural environments factors.

There are two different concepts of sustainability; inter-generational equity and intra-generational equity. Inter-generational equity is defined as “if the capital that future generations inherit is no less than the current capital stock, then development is equitable inter-generationally” (George, 1999); therefore, preserving the natural environment is considered as aspect of inter-generational equity. The intra-generational equity is also defined by Rio Declaration in 1992 as "equitably meeting the developmental and environment needs of present and future generations". The political, economic, social and cultural environments can be considered as aspects of the intra-generational-equity; therefore, to ensure these factors minimizing life cycle costing as an instrument within an optimization framework can be applied.

3.3 Establishing Sustainability Indicators

Sustainability indicators attempt to make a linkage between the economic, environmental and social dimensions of sustainability (Maclaren, 1996). Maclaren (1996) indicated that the most effective indicators are those that are measurable, scientifically valid, representative of the issues of concern, responsive to change towards realizing the goals set, cost effective to generate and monitor, clear and understandable by all potential users (Maclaren, 1996).

A good selection of indicator that balances economic, environmental and social dimensions of sustainability in the development of a community will make consensus and understandable common sense about sustainability (AtKisson, 1996). The emission of CO_2 in the atmosphere can be considered as an example because the effect of CO_2 on environment is well documented and is based on scientific approach which the stakeholders of building industry can understand its effect. If it can be shown that by choosing economical design alternatives the emissions reduced therefore more office building owners tend to follow these designs.

A list of seven sustainability criteria for evaluating project alternatives was developed by Baetz and Korol (1995) to address the sustainability issue. These criteria pointed out areas which more data is needed. The lists of criteria are as follows:

1- Integration synergy: it measure how well integrated development is with the natural environment.
2- Simplicity: man-made developments mirror natural ecosystems.
3- Input/output characteristics: indications of alternatives with reduced inputs such as energy resources, land resources and material resources.
4- Functionality: favors alternatives that serve many rather than a single function.
5- Adaptability: an indication of an alternatives ability to function effectively regardless of changes in economic, social and natural conditions.
6- Diversity: serving function for a wide range of stakeholders.
7- Carrying capacity: so that alternatives with lower impacts are selected on carrying capacity.

The indicators used in this thesis were selected because of the availability of a comprehensive set of data on the contemporary construction materials through the Athena sustainable material institute. These indicators are primary energy, solid waste, water emissions, air emissions, land resource use and global warming potential (Indicators are explained in chapter 4). The indicators used are reflection of the third and seventh criteria of Baetz and Korol (1995) since they are indications of alternatives with reduced inputs such as energy resources, land resources and material resources and alternatives with lower impacts are selected on carrying capacity. The other criteria are more related to architectural concepts which are outside of the capabilities of the proposed optimization model (optimization model is introduced in chapter 4).

3.4 Setting Sustainability Targets

The next step after establishing sustainability indicators is to establish the sustainability targets. There are many ways to establish targets.

Internationally agreed guidelines such as Kyoto Protocol can be considered as one approach for setting targets. In Kyoto, Japan in 1997 at the Third Conference of the Practices to the United Nations Framework Convention on Climate Change, Canada along with 160 other countries had the opportunity to sign the Kyoto Protocol. Targets were set to reduce the greenhouse gasses to 5.2% below 1990 levels during the period of 2008-2012. This reduction target can be calculated and imposed on new office building construction.

Ecological foot printing can be considered as another approach for setting targets. As described by Rees and Wackernagel (1996), it is a value-free method of converting human impacts into an equivalent land area. The ecological foot printing is based on this concept that each activity uses resources from natural environment and produces waste. This concept that earth has a carrying capacity will build an allowable limit for new developments and therefore, ecological foot printing provides a set of criteria which can be used as policy targets. In this research the targets are initially set at the impact level of the base office building described in the case study (chapter five). Then the possibility of improvements to these impacts level is explored.

The following proposed methodology has been applied to achieve the objectives of this research.

1- Conduct a literature review to identify the limitation of the previous related works.
2- Create a definition of sustainability for office building, and establish the sustainability indicators and targets.
3- Collect the necessary data from office building project.
4- Develop the optimization model to select the optimal combination of building components which meet or exceed the established sustainability targets.
5- Identify the objective functions, variables and constrains of the model.
6- Define LCA, LCC and LINDO tools to make the optimization model meaningful.
7- Test the methodology framework with a real case study to validate the optimization model.

Based on the proposed research methodology in chapter one, a literature review has been conducted in chapter two to identify the limitation of the previous related works. From the literature review, in this chapter (3.2 to 3.4) sustainable office building is defined and sustainability indicators and targets are established. No. 3 to 6 of the proposed research methodology is shown in figure 3.1, and No. 7 is presented in chapter four and five.

Figure 3.1 consists of 4 levels. In level 1 user enter the necessary information regarding building project including project name and description, location, building gross floor area and building design life. Then the required building envelope materials data will be collected to use in level 2. At level 2 environmental impact of building components will be quantified using a LCA tool and TLCC of building components will be calculated using RSMeans data cost, user and expert knowledge. In level 3 the results of LCA process and TLCC will be used in the proposed optimization model of this thesis. Eventually, level 4 will be presented the best building project alternative to satisfy the targets of sustainable office building.

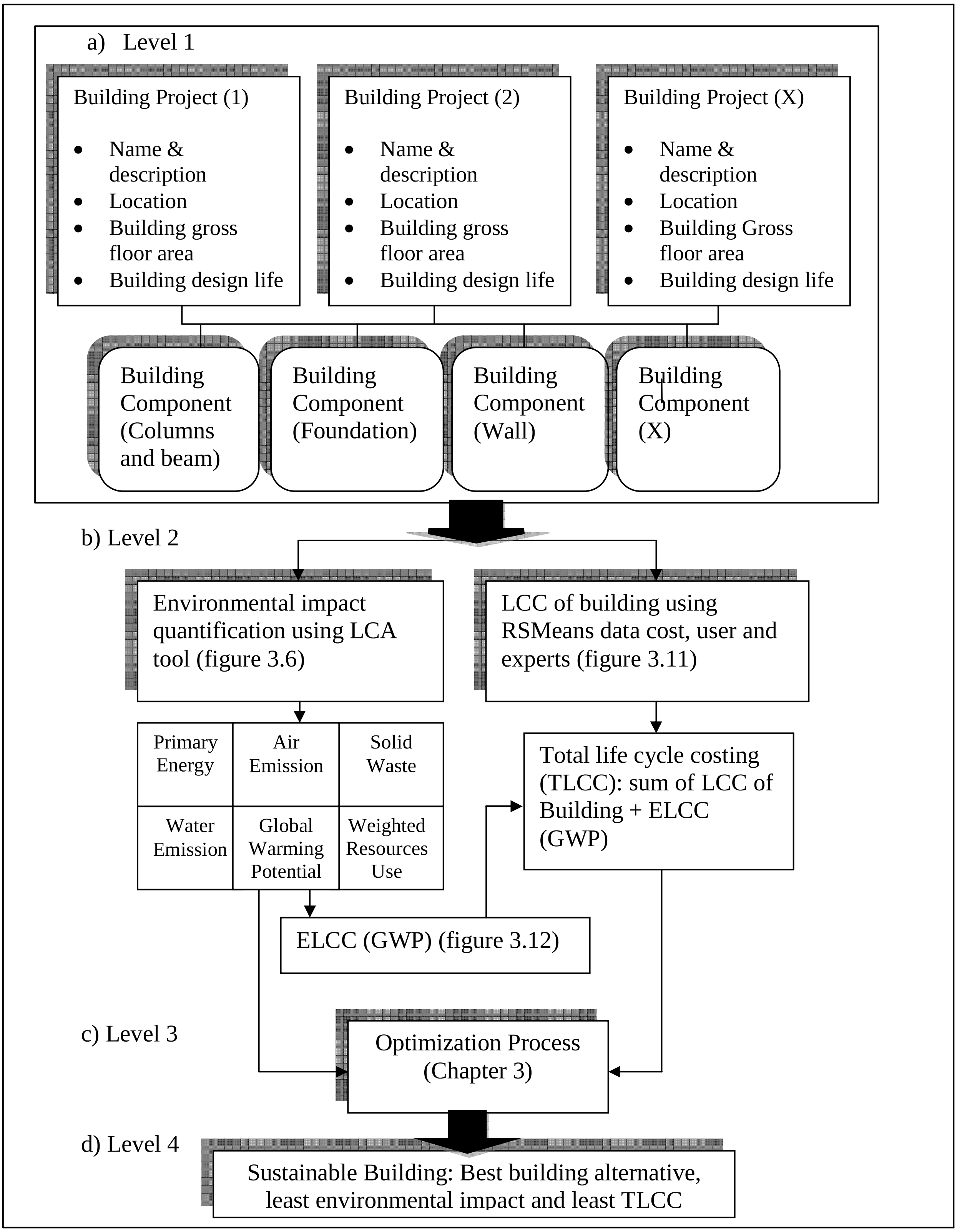


Figure 3.1 Framework of the Research Methodology (No. 3 to 6 of the Proposed Methodology)

3.5 The Optimization Model

The optimization model is described by equation 3.1 with the main objective of minimizing the total life cycle costing of office building. This model finds the optimum solution between alternatives components of the office buildings. Optimization model of the current thesis consists of three components of input, output and optimizer (figure 3.2). The inputs of the model are the environmental indicators resulted from the life cycle assessment process using a LCA tool and the total life cycle costing including the LCC and environmental LCC (global warming potential cost) of building components. The optimizer applies a linear optimization programming to minimize the total life cycle costs subject to a set of constrains. Eventually, the output of the model is the optimal combination of building components that meets or exceeds the established targets of the optimization model.

$$\textbf{Minimize} \sum_{\textbf{all A}} (\mathbf{L_A} + \mathbf{EL_A}) \qquad \text{(Eq. 3.1)}$$

Subject to

$$\sum_{\textbf{all A}} \mathbf{E_{I\,A}} \leq \mathbf{E_I}\,\mathbf{*}$$

where:

A: Component of Building (1 to N)

L_A*: Life cycle costing of component A*

EL_A*: Environmental life cycle costing of Global Warming Potential of component A*

$E_{I\,A}$*: environmental impacts I of component A*

E_I ***:** *targets of environmental impacts*

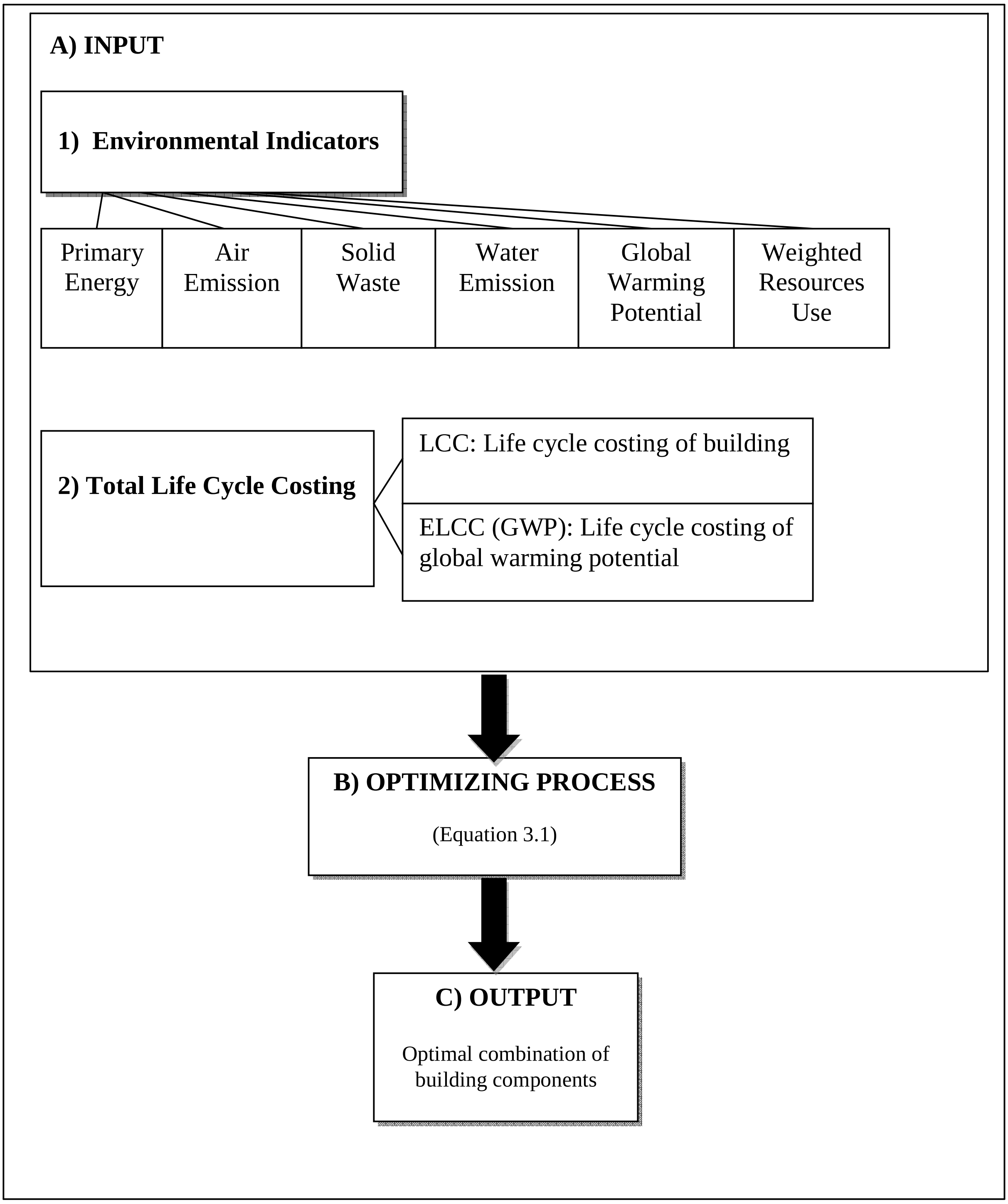


Figure 3.2 Framework of the Optimization Model

Objective Function:

The objective of the proposed optimization model was to minimize total life cycle costing which was sum of economical life cycle costing and environmental life cycle costing of building components (Equation 3.2).

$$\textbf{TLCC = LCC + ELCC (GWP cost)} \qquad \text{(Eq. 3.2)}$$

Environmental Indicators (E_I)

Environmental indicators of the optimization model are resulted from a LCA process using a LCA tool. These indicators are given as follows:

1. Primary Energy
2. Air Emission
3. Solid Waste
4. Water Emission
5. Global Warming Potential
6. Weighted Resources Use

Variables

The variables of the proposed optimization model are different alternatives of building components.

Equation 3.1 is expanded as following:

$$\text{Minimize } \{(L_1 + G_1) X_1 + (L_2 + G_2) X_2 + (L_3 + G_3) X_3 + \ldots + (L_N + G_N) X_N\}$$

Subject to:

E_I is Primary Energy $E_{I\,1} X_{1} + E_{I\,2} X_2 + E_{I\,3} X_3 + \ldots + E_{I\,N} X_N \leq E_I^*$

E_I is Air Emission $E_{I\,1} X_{1} + E_{I\,2} X_2 + E_{I\,3} X_3 + \ldots + E_{I\,N} X_N \leq E_I^*$

E_I is Solid Waste $E_{I\,1} X_{1} + E_{I\,2} X_2 + E_{I\,3} X_3 + \ldots + E_{I\,N} X_N \leq E_I^*$

E_I is Water Emission $E_{I\,1} X_{1} + E_{I\,2} X_2 + E_{I\,3} X_3 + \ldots + E_{I\,N} X_N \leq E_I^*$

E_I is Global Warming Potential $E_{I\,1} X_{1} + E_{I\,2} X_2 + E_{I\,3} X_3 + \ldots + E_{I\,N} X_N \leq E_I^*$

E_I is Weighted Resources Use $E_{I\,1} X_{1} + E_{I\,2} X_2 + E_{I\,3} X_3 + \ldots + E_{I\,N} X_N \leq E_I^*$

3.6 The Tools

For the purpose of the optimization approach, some tools must be applied to make the optimization meaningful. A comprehensive life cycle inventory database is needed to quantify the life cycle environmental impact of the building. Also, for life cycle costing, there must be a system for assigning life cycle costing of the components. Finally for analysis, the required data is imported from many sources and linear optimization software is used. Environmental impacts and costs of each building components are derived for each four life cycle stages of raw materials acquisition, manufacturing, use / reuse /maintenance and end-of-life (recycle / waste management). Figure 3.3 shows the tools that applied for the purpose of optimization approach. In the next sections (3.6.1 to 3.6.2) these tools are described in details.

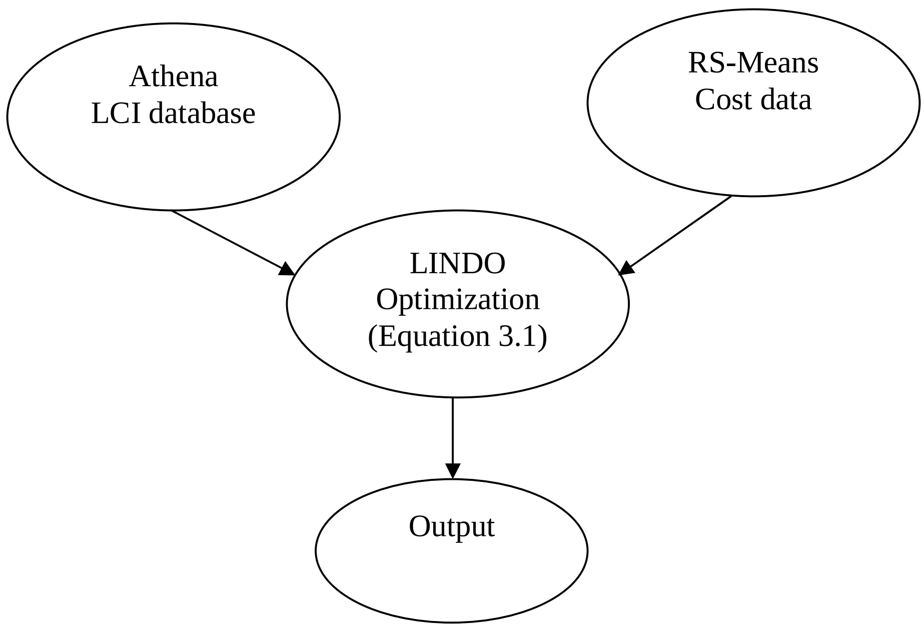


Figure 3.3 Methodology Tools for Optimization Approach

3.6.1 Athena

The Athena sustainable material institute (2002) has developed software called Athena impact estimator for analysis of the environmental implications of industrial, institutional, commercial and residential designs–both for new buildings and major renovations. Life cycle inventory of this software allows user to compare the environmental impacts of the building materials and assemblies through the life cycle of the building from the raw material acquisition to the end of life of the building. Athena software offers five categories of the assemblies including foundations, mixed beams and columns, floors, roofs and walls. For the other components, there is an option called extra basic materials. The user can add the other components into this section. This system does not include the capability of an operating energy simulation, but allows user to input the result of a simulation to calculate the fuel cycle burdens and relate them to the overall results. The user may compare the results of the analysis in different summary measurements of: primary energy, acidification potential, eutrophication potential, global warming potential, human health respiratory effects potential, ozone depletion potential, weighted raw resource use, and photochemical smog potential.

The environmental indicators used in the study methodology based on the Athena Sustainable Material Institute are described as following:

- **Primary Energy (MJ)**

Primary energy or embodied energy is the amount of energy associated with raw material acquisition, processing, manufacturing, transportation and assembly of product or buildings materials.

- **Solid Waste (Kg)**

The solid waste generates during the extraction of raw materials, manufacturing, construction and disposal of the product or buildings materials. The solid wastes measured by Athena are the wastes of wood, concrete, steel, blast furnace slag and blast furnace dust.

- **Air Emissions (index)**

The Athena measures the emissions of the buildings materials or products from the extraction of material to the end of life. the air emissions of the products or buildings materials measured by Athena include sulphur oxides, nitrous oxides, carbon monoxide, hydrogen chloride, hydrogen fluoride, metals, methane, particulate and volatile organic compounds.

- **Water Emissions (index)**

Water emission is the quantity of water use associated with the building material process, including the liquid waste material which deposited into water bodies. The considered factors into water emission index include aluminum, ammonia and ammonium, biochemical and chemical oxygen, chlorides cyanides dissolved organic compounds, dissolves solids, iron, nitrates, metals, phenols phosphates, sulphates, sulphides, suspended solids and polymer aromatic hydrocarbons.

- **Global Warming Potential (Kg)**

The Global warming is defined as climate changes that cause an increase in the average temperature of the earth's atmosphere (EPA, 2006). This climate changes is the results of the increasing greenhouse gases emission into the atmosphere. The existence of greenhouse gases is necessary for the earth because this gases like CO_2, CH_4, and water vapor trapped the heat to the atmosphere and without these gases no heat would be absorbed by the earth and the earth would be very cold (NASA, 2002). The major cause of global warming is CO_2. From the totally emitted greenhouse gases, 72% are carbon dioxide (CO_2), 18% Methane and 9% Nitrous oxide (NO_x). CO_2 is the results of burning fuels like e.g. oil, natural gas, diesel, organic-diesel, petrol, organic-petrol, and ethanol. Carbon dioxide is the common equivalent reference measure of the GWP. The All greenhouse gases translated to an equivalent CO_2. The figure 3.4 shows the increase of CO_2 emissions from the period of 1991 to 2005 in the world. Also, figure 3.5 shows the increase of world temperature from 1989 to 2005 (www.wri.org).

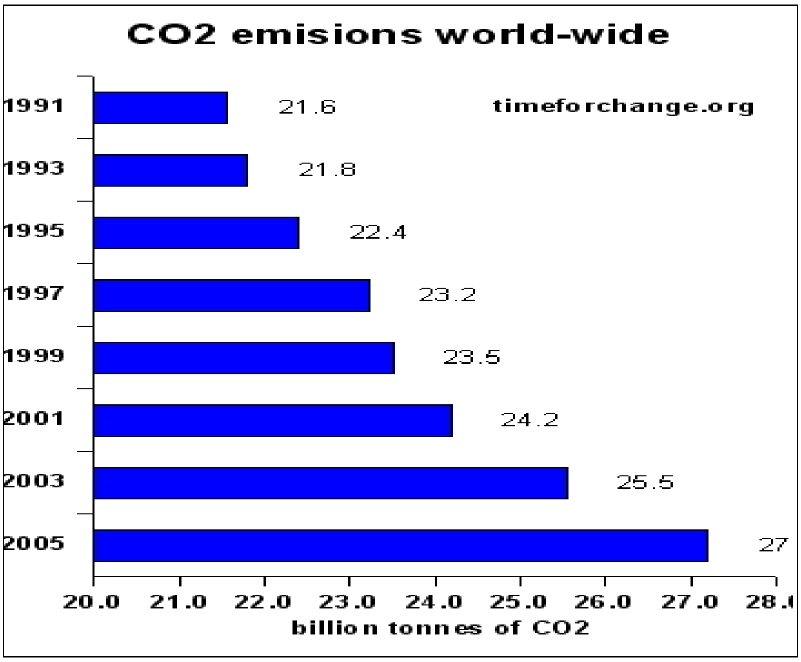


Figure 3.4 CO2-emissions world-wide by year (source: www.wri.org)

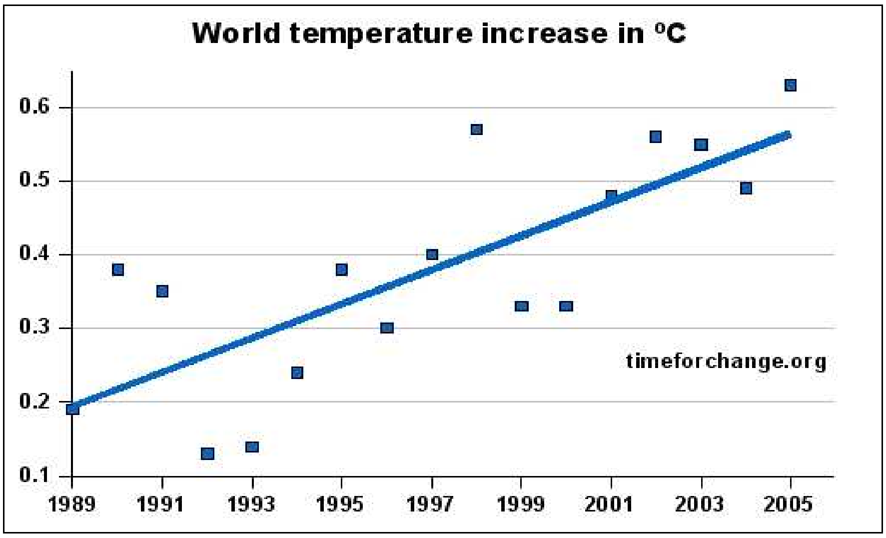


Figure 3.5 Increase of global average temperature for the last 20 years (source: www.wri.org)

- **Weighted Resource Use (Kg)**

Athena measures the amount of raw resource used in its mass and/or volume such as kilograms. Athena accounted resources are coal coarse aggregate, fine aggregate, gypsum, iron ore, limestone, sand, shale, clay, ash, scrape steel, semi cementitious materials, uranium and wood fiber.

3.6.2 LCA Approach:

The environmental impact of the office building through its life cycle is carried out in three steps (figure 3.6):

a. Data collection of office building
b. Emission quantification, using the LCA tool: Athena impact estimator
c. Results of the LCA process: environmental indicators

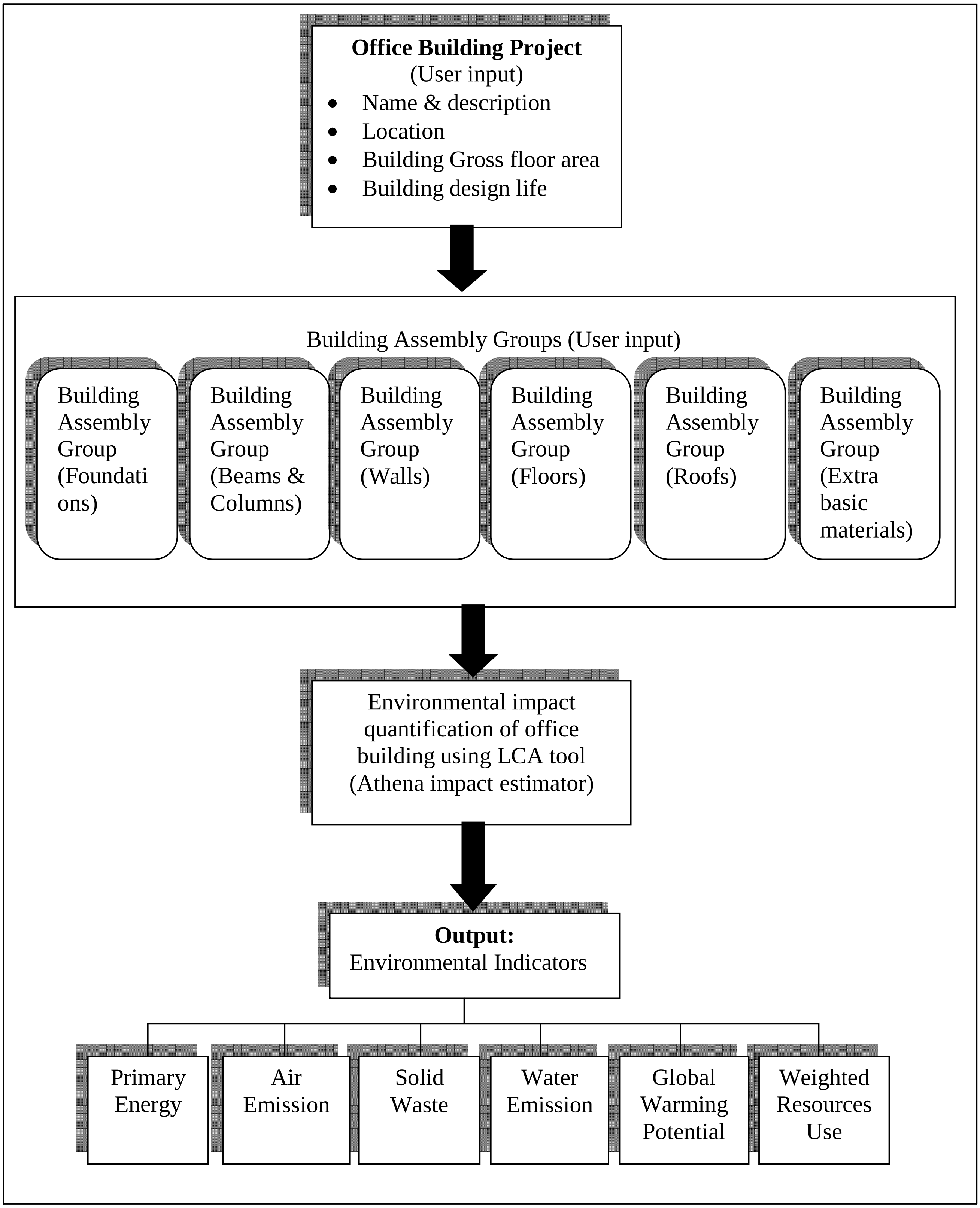


Figure 3.6 Framework of Life Cycle Assessment Process

Table 3.1 presents the building envelope elements including building surface area, foundations, columns and beams, floors, roofs, walls and extra basic materials used in the LCA process. The unit of the above building envelops is based on imperial.

Table 3.1 Building Elements Template

Building elements	**Total (m^2)**
Building surface area	(User input)
Foundations	(User input)
Columns and Beams	(User input)
Floors	(User input)
Roofs	(User input)
Walls	(User input)
Extra Basic Materials	(User input)

Figures 3.7 to 3.10 show the samples of Athena impact estimator windows. In figure 3.7 the user has to enter the project name, location, gross floor area, building life expediency, building type, units and three optional items including project number, description and operating energy consumption. Figure 3.8 and 3.9 show sample of adding building assembly's windows and figure 3.10 shows a sample of Athena report window.

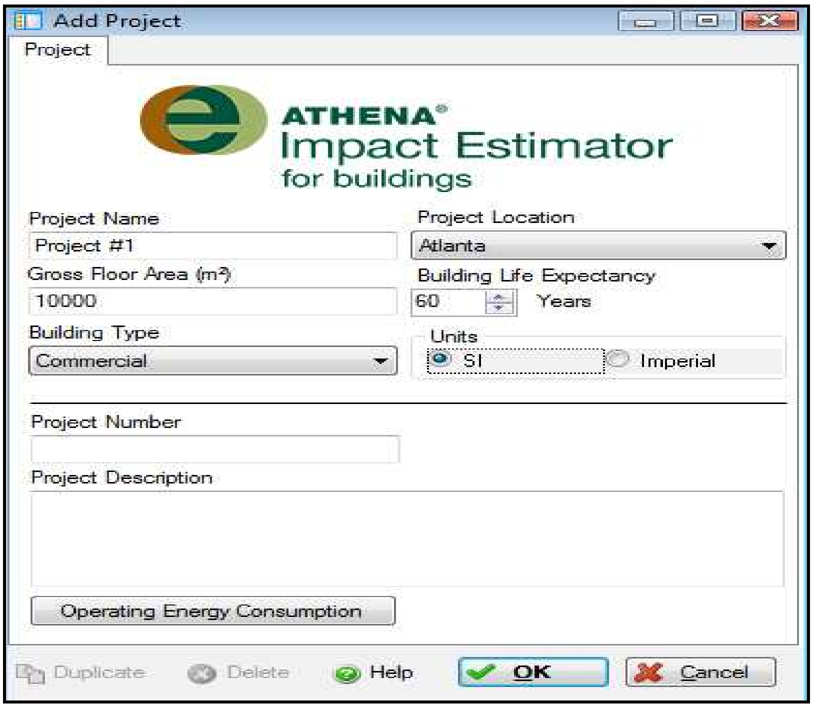


Figure 3.7 Athena Project Description Window

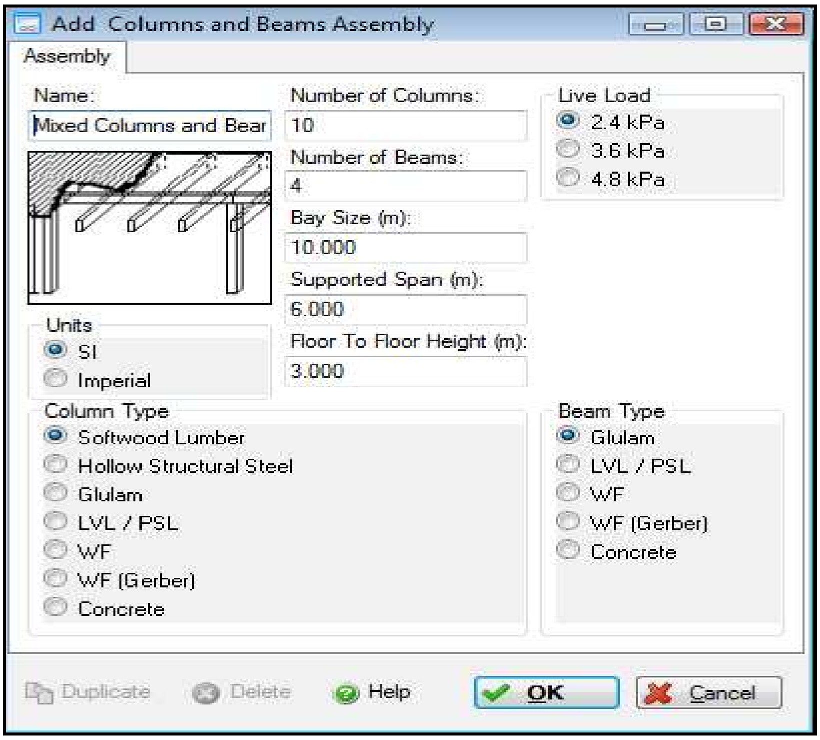


Figure 3.8 Athena Columns and Beams Assembly Window

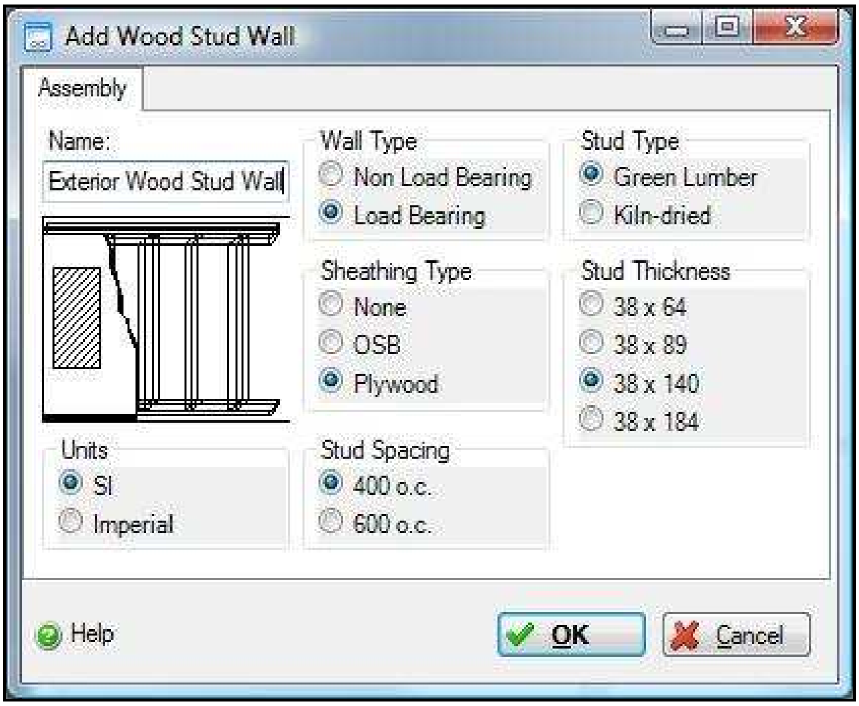


Figure 3.9 Athena Wood Stud Wall Building Assembly Window

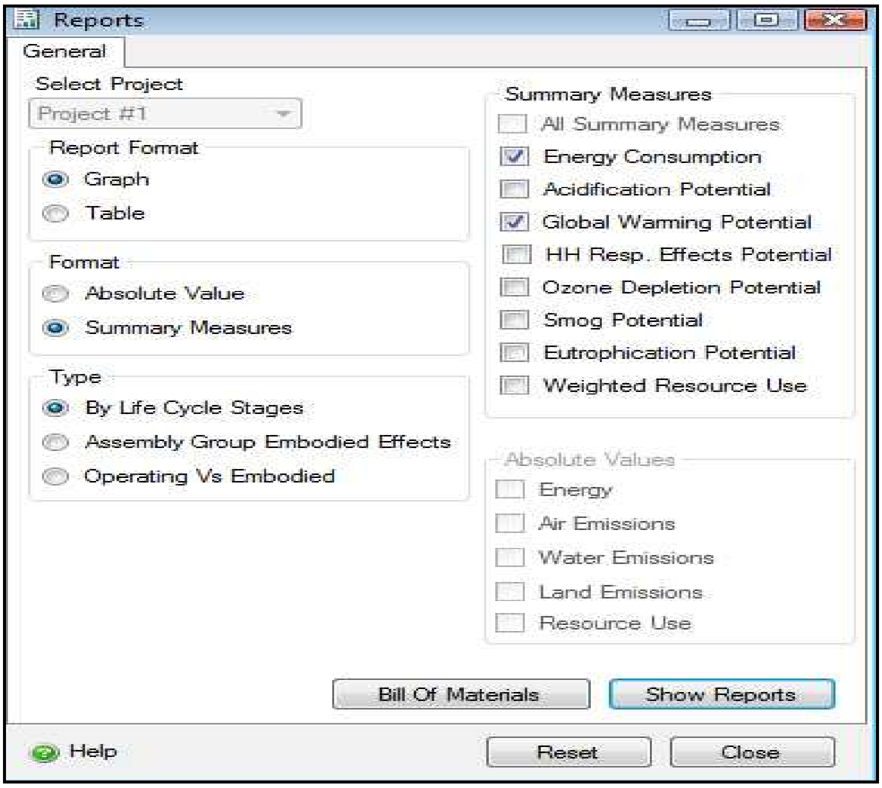


Figure 3.10 Athena Environmental Impact Report Window

3.6.3 LCC Approach

The life cycle costing for the current thesis defined as sum of raw material extraction, production and construction costs, annual maintenance and repair cost and end of life cost. The initial cost of the base office building and alternatives to the office building components is calculated based on Means Assemblies Cost Data (RS Means). Figure 3.11 shows life cycle costing evaluation and calculation process. Since 1942, RS Means Company Inc. is publishing the construction cost of the North America. For the purpose of construction new building or renovation of the existing buildings it provides accurate cost data for the stakeholder of the project. It divides the construction cost of the building into twelve systems which are as follow:

- Foundation
- Substructures
- Superstructures
- Exterior closures
- Roofing
- Interior construction
- conveying systems
- Mechanical
- Electrical
- General conditions & Profit
- Special construction
- Site work

Operating and Maintenance (O/M) cost of building is extracted from the Desjarlais Prevost & Associates (DPA) Inc. DPA is specialized firm in office buildings and shopping centers located in the province of Quebec, Canada.

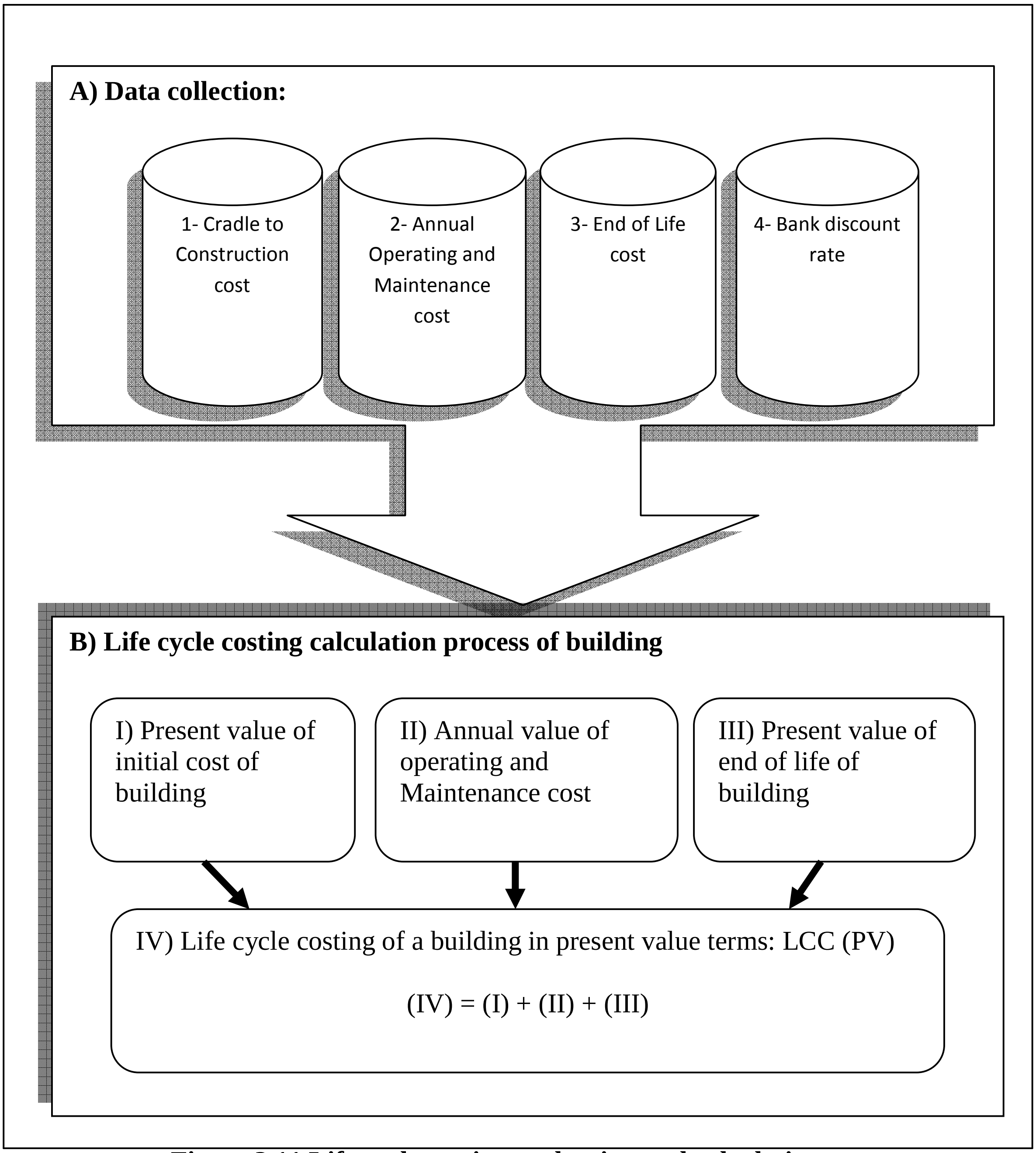


Figure 3.11 Life cycle costing evaluation and calculation process

Table 3.2 shows the steps of calculating life cycle costing (figure 3.11) for different alternatives of building components. The LCC for this thesis is calculated in terms of net present value (NPV). Liu Yiqun (2006) mentioned that "A fundamental criterion for evaluating an investment and comparing investment alternatives is the net present value (NPV) criterion". If the net present value is positive, it means that it should be accepted and for comparing between different alternatives, the alternative with the higher NPV should be selected. Therefore, by minimizing the total life cycle costing of the office building the NPV will be maximized.

Table 3.2 Template of life cycle costing for office building

	Cradle to Construction ($)	Annual Operating and Maintenance ($)	End of Life ($)	Life Cycle Costing (X yr) ($)
Base Office Building				
Alternative 1				
……				
Alternative X				

3.6.4 Environmental life cycle costing (Global Warming Potential Cost)

In order to minimize both economical life cycle costing and environmental life cycle costing the unit of GWP has to be equalized to the unit of LCC. For this purpose, the GWP (equivalent CO_2) measured in a LCA process is translated to a monetary value. The price of CO_2e is taken from the actual stock markets. Figure 3.12 shows the framework of this translation.

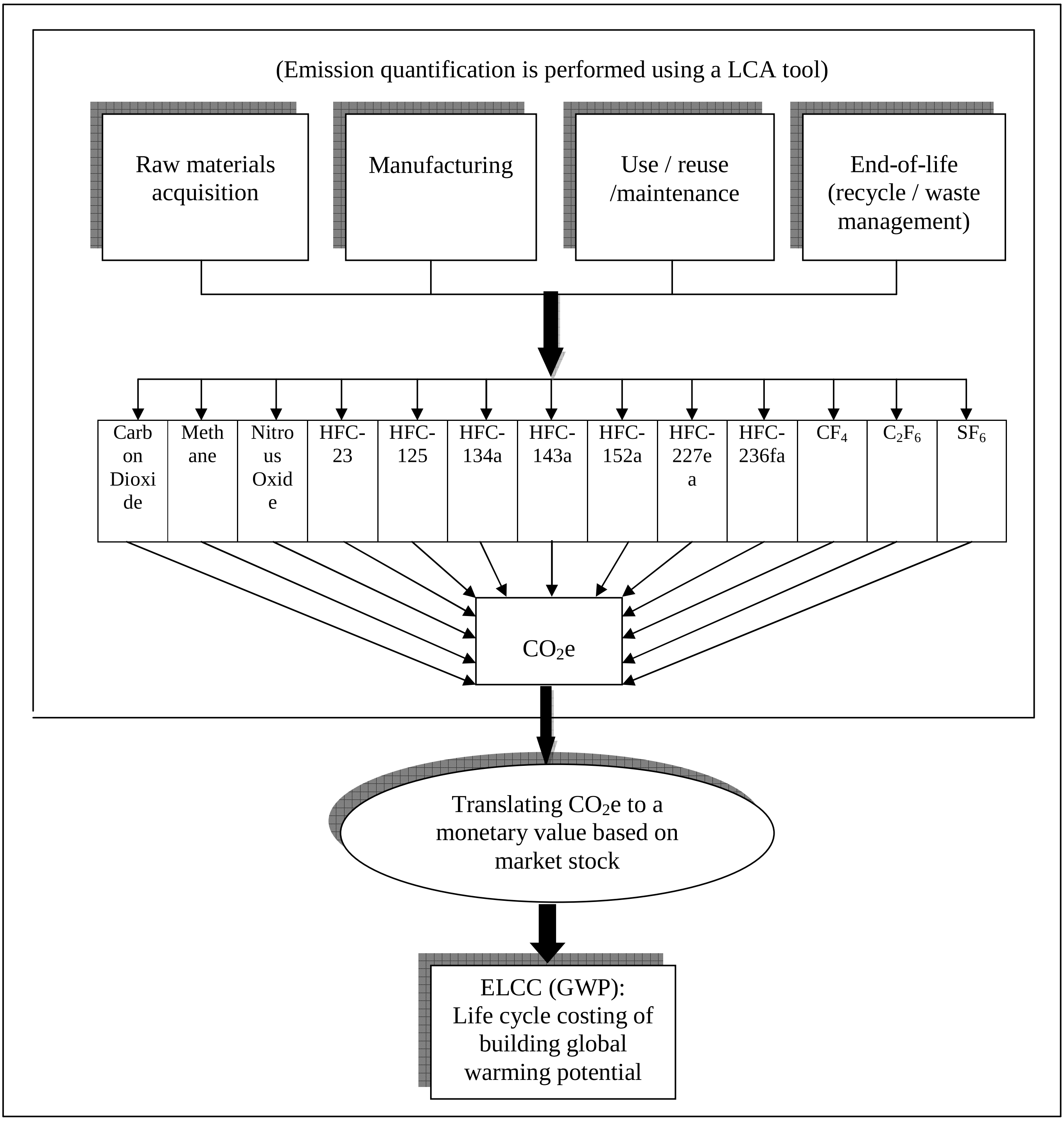


Figure 3.12 Environmental impact life cycle costing evaluation and calculation process

3.6.5 LINDO

LINDO (Linear Interactive and Discrete Optimizer) provides a very simple interface for solving general linear and integer optimization problems. LINDO minimize or maximize an objective function. If the programming problem intends to minimize or maximize multiple objectives function subject to a set of constrains, LINDO cannot be used. Also, it carries the maximum of 200 variables and 100 constrains.

3.7 Optimization Model hypothetical Case

This section represents a hypothetical case with some assumed date to see the process of the optimization model.

Some data assumed for environmental indicators and for calculating TLCC. In a real case the environmental indicators are resulted from entering real data of office building components to a LCA process, and TLCC is calculated through the collection of real data of building components. Then the environmental indicators and TLCC of different variables are entered as inputs to the proposed optimization model and through the optimization model process using LINDO programming software (equation 3.1), the optimal solution is obtained. Variables of X1, X2, X3, and X4 are assumed.

Environmental Indicators:

Six environmental indicators of primary energy, air emission, solid waste, water emission, global warming potential and weighted resource use are used in the hypothetical case:

X1:

- Primary Energy = 952000 MJ
- Air Emission = 198000 Index
- Solid Waste = 1205000 Kg
- Water Emission = 4566750 Index
- Global Warming Potential = 955060 Kg
- Weighted Resources Use = 400380 Kg

X2:

- Primary Energy = 10525000 MJ
- Air Emission = 203450 index
- Solid Waste = 71940000 kg
- Water Emission = 5568900 index
- Global Warming Potential = 1056070 kg
- Weighted Resources Use = 780300 kg

X3:

- Primary Energy = 10434000 MJ
- Air Emission = 214520 index
- Solid Waste = 74250000 kg
- Water Emission = 5566780 index
- Global Warming Potential = 1084030 kg
- Weighted Resources Use = 770400 kg

X4:

- Primary Energy = 933000 MJ

- Air Emission = 189000 index
- Solid Waste = 699000 kg
- Water Emission = 4566700 index
- Global Warming Potential = 902566 Kg
- Weighted Resources Use = 450600 Kg

Life Cycle Costing

The following assumed data are used to calculate the life cycle costing of variables X1, X2, X3 & X4 in terms of present value (PV). The bank discount rate is 4% and the design life span is assumed to be 40 years (table 3.3).

Table 3.3 Calculating Life Cycle Costing of variables X1, X2, X3 & X4

	Cradle to Construction	Annual Maintenance and Repair	End of Life	Life Cycle Cost (40- yr) $
X1	2,356,460.00	25,680.00	35,500.00	3,419,160.00
X2	2,768,690.00	24,350.00	37,000.00	3,779,690.00
X3	2,957,870.00	24,450.00	38,500.00	3,974,370.00
X4	2,445,652.00	22,580.00	35,500.00	3,384,352.00

Environmental life cycle costing (Global Warming Potential cost):

The cost of Global warming potential or cost of Co_2e in term of ton is obtained from www.pointcarbon.com.

G_1: 955060 × \$19 = \$18,146.140

G_2: 1056070 × \$19 = \$20,065.330

G_3: 1084030 × \$19 = \$20,596.57

G_4: 902566 × \$19 = \$ 17,148.754

Optimization model

The objective of the optimization model is to minimize total life cycle costing subject to a set of constrains. In order to run the optimization model the targets were equalized to the environmental indicators of variable X1. For instance primary energy could not exceed 952000 MJ. Figure 3.13 shows the LINDO programming of the hypothetical case (Appendix 4).

A 4.1 LINDO Programming of Hypothetical Case

```
!Let X1 be Alternative One
!Let X2 be Alternative Two
!Let X3 be Alternative Three
!Let X4 be Alternative Four
!
!objective: Minimize Total Life Cycle costs
!
min 3437306 X1 + 3799755 X2 + 3994966 X3 + 3401500 X4
!
subject to
!the following constrains
!
!Primary Energy
952000 X1 + 10525000 X2 + 10434000 X3 + 933000 X4 <= 952000
!
!Solid Waste
1205000 X1 + 71940000 X2 + 74250000 X3 + 699000 X4 <= 1205000
!
!Air Emission
198000 X1 + 203450 X2 + 214520 X3 + 189000 X4 <= 198000
!
!Water Emission
4566750 X1 + 5568900 X2 + 5566780 X3 + 4566700 X4 <= 4566750
!
!Global Warming Potential
955060 X1 + 1056070 X2 + 1084030 X3 + 902566 X4 <= 955060
!
!Weighted Resources Use
400380 X1 + 780300 X2 + 770400 X2 + 450600 X4 <= 400380
!
!choose at least one
X1 + X2 + X3 + X4 >= 1
!
END
!
!All Binary Integers
INT X1
INT X2
INT X3
INT X4
```

Figure 3.13 LINDO programming of the hypothetical case

3.7.1 Hypothetical Case Results

The result of the LINDO optimization programming using equation 3.1 found that variable X1 met all the targets with lower cost. Therefore the optimal solution is variable X1. Figure 3.14 shows the LINDO programming results of the hypothetical case (Appendix 4).

There are other methods to choose the most cost effective alternative in a project such as cost-benefit analysis. This thesis chose an optimization method because the goal of this research is not only choosing alternatives based on cost efficiency. Mitigation of environmental impacts is also an objective of this thesis which can obtain in an optimization approach with balancing between the total life cycle costing and life cycle assessment of the project. Thus the optimum solution is the most cost effective which has totally the least impacts on environment during the life design of the building.

A.4.1.1 LINDO Programming Results of Hypothetical Case

```
LP OPTIMUM FOUND AT STEP      8
 OBJECTIVE VALUE =   3437306.00


 NEW INTEGER SOLUTION OF    3437306.00     AT BRANCH      0 PIVOT       8
 RE-INSTALLING BEST SOLUTION...

       OBJECTIVE FUNCTION VALUE

       1)      3437306.

  VARIABLE        VALUE          REDUCED COST
       X1        1.000000    3437306.000000
       X2         0.000000    3799755.000000
       X3         0.000000    3994966.000000
       X4         0.000000    3401500.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
       2)         0.000000          0.000000
       3)         0.000000          0.000000
       4)         0.000000          0.000000
       5)         0.000000          0.000000
       6)         0.000000          0.000000
       7)         0.000000          0.000000
```

Figure 3.14 LINDO Programming Results of the Hypothetical Case

3.8 Methodology Summary

This chapter represented a concise description of the optimization model developed based on the framework of the research methodology. The tools for the purpose of the optimization approach are described in details. A hypothetical case was used to demonstrate the mechanism of the model. Methodology of the research was applied to a real case study to validate the proposed optimization model (chapters 4 and 5).

CHAPTER 4

CASE STUDY DESCRIPTION

4.1 Introduction

This chapter presents a description of the base office building's components and then a description for alternative components which substitute with the base office building's components to observe the mechanism of the optimization model. At the end the assumptions of the case study are explored.

4.2 Data Collection

An eight story office building in Kingston, Massachusetts in the United States is used as a case study to demonstrate the mechanism of the research optimization model. The required data to use in case study based on the research methodology was collected from U.S. Department of Commerce Technology Administration, National Institute of Standard and Technology (Robert P., et al.1999). This building has a total gross area of 54,000 SF.

4.3 Base Office Building

For the purpose of this study the targets are initially set at the impact level of the base office building. Then the possibility of improvements to these impact levels will explore. The size of the building is 60'*100' and the height of the floor to floor is 12'. The foundation is concrete spread and strip footings with 4'' concrete slab on grade and normal soil condition. The type of the building's columns is steel with wide flange. The floors consists of composite steel frame and deck with concrete slab. The roof is steel beams, opens web joist and deck. Appendix B provides the basement floor plan, ground floor plan, typical floor plan and the plane of front elevation. Table 4.1 shows the building elements of case study used in the optimization model approach.

Table 4.1Building Elements of Case Study

Building elements	Total (m^2)
Building surface area	4830
Foundation	557
Columns	4459
Slab-on-grade	557
Roof	557
Walls	2679
Windows	557
Doors	5 (LVS)

4.3.1 Athena Building Assemblies

The version four of the Athena impact estimator software offers five types of building assemblies. For the foundation, the Athena considers the only concrete footing with concrete slab on grade. For the wall assemblies, Athena has seven types of concrete block, cast in place, concrete tilt up, curtain, steel stud, wood stud and insulated concrete form. It offers 7 types of column and 5 types of Beam. Also, eleven types of floor and roofing systems are considered. Extra basic materials have defined for the types of the assemblies which do not exist in the five types of the building assemblies. For example for the triple glazed windows, since the Athena offers only double glazed windows; therefore, an extra layer of glazing can be added to the extra basic materials. The environmental impact of the mechanical and electrical systems of the building does not accounted in Athena software. So in the present case study, the impacts of the mechanical and electrical systems on environment have not been investigated.

4.3.2 Alternatives of the Base Office Building

To observe the performance of the optimization model of the present study, alternatives to the base office building components were explored. Two types of the alternatives were chosen from the structural components, the pre cast concrete substituted with base office building floor and tilt up concrete with wall components. For the envelope components, triple glazed windows have been chosen to substitute with the windows of the base office.

Pre-cast Concrete

Pre-cast concrete is a form of construction where concrete is cast prior to placement. Frequently used in high-rise and multi-unit residential developments, pre-cast concrete members, such as floor slabs and walls, can create entire buildings. Consequently this practice is considered as an alternative for the office building. The precast method is becoming increasingly popular with contractors because the conventional steps of concrete construction, such as forming, placing, finishing and curing, are eliminated and replaced with concrete member erection. As a result, the concrete construction schedule is shortened, which is a great advantage for developers operating in competitive markets. In addition, weather effects are eliminated because precast operations take place in the controlled environment of concrete fabrication plants, which proves especially useful in Canadian climates (Nunnally, S. W. 2010). Once the curing period for precast concrete has ended in the fabrication plant, the members are transported to the job site and erected into position by crane as shown as Figure 4.1 Pre cast components can even be erected in winter conditions, thereby providing year-round access for interior trades to perform their work.

Figure 4.1 Erection of Precast Concrete Members for Residential Developments (Canadian Precasting/Prestressing Concrete Institute, Accessed on April 1st, 2009 <http://www.cpci.ca/?sc=totalprecast>)

Tilt-up Concretes

Tilt-up concrete construction can be summarized as a combination of the cast-in-place and precast methods. Members are cast horizontally at the job site and then erected as shown in Figure 4.2 at its inception; this technique was primarily used for commercial and industrial construction. Nowadays, tilt-up concrete construction is used for rural, recreational and residential developments as well.

Figure 4.2 Typical Tilt-Up Panels in Building Construction (Triad Construction Company, Inc. 2009, Accessed on April 1st, 2009: <http://www.triadconstruction.com/kansas_city_construction/news.php>)

Triple Glazed (TG) Windows

For the envelope components, windows of base office building substituted with the triple glazed windows. TG windows consist of three layers of glass, or two layers with a low-emissivity (Low-E) film which is suspended between them. Figure 4.3 shows the framework of a TG window. Triple glazed windows enhanced energy saving and reduce sound transmission. This type of windows are a good option for areas which the weather and temperature are a major problem. Table 4.2 shows the improvement percentage of insulation from double glazed windows to the TG windows. Table 4.3 is also tabulated the rate of increase in cost from double glazed windows to TG windows.

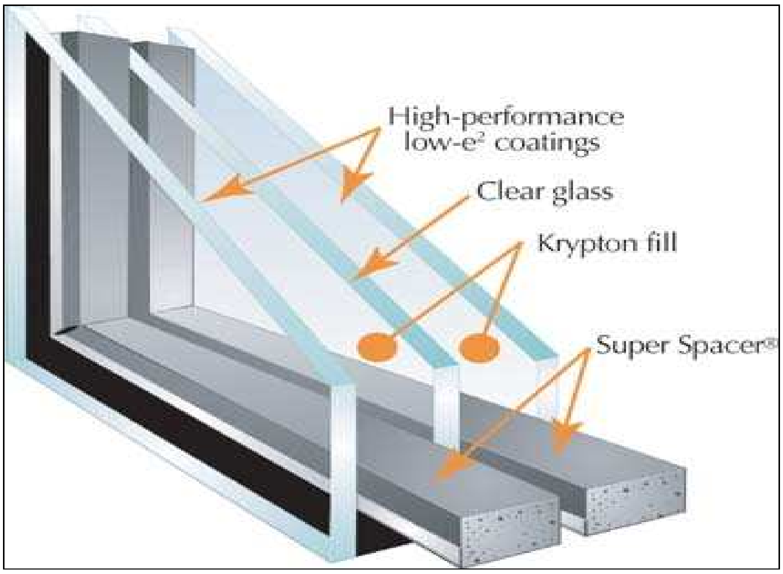


Figure 4.3 Framework of Triple Glazed Windows (ODW: www.omahadoor.com)

Table 4.2 Improvement Percentage of Insulation from Double Glazed Windows to Triple Glazed Windows

Window	Insulating Value	Percentage Improvement
Existing double glazed casement Metal spacer, clear glass	R-2.0 (U 0.50)	-39%
Thermotech double glazed casement (211) 1 SuperSpacer™, 1 (low-e & argon)	R-3.3 (U 0.30)	-
Thermotech triple glazed casement (321) 2 SuperSpacer™, 1 (low-e & argon)	R-4.3 (U 0.23)	+39%
Thermotech triple glazed casement (322) 2 SuperSpacer™, 2 (low-e & argon)	R-5.3 (U 0.19)	+61%

Table 4.3 Increasing Rate of TG windows

Window	Insulating Value	Typical Incremental Cost
Existing double glazed casement Metal spacer, clear glass	R-2.0 (U 0.5)	not available from Thermotech
Thermotech double glazed casement (211) 1 SuperSpacer™, 1 (low-e & argon)	R-3.3 (U 0.30)	-5%
Thermotech triple glazed casement (321) 2 SuperSpacer™, 1 (low-e & argon)	R-4.3 (U 0.23)	-
Thermotech triple glazed casement (322) 2 SuperSpacer™, 2 (low-e & argon)	R-5.3 (U 0.19)	+10%

4.4 Case Study Assumptions

Some assumptions have been made to decrease the complexity of the case study and to get a meaningful system in order to monitor the mechanism of the optimization model.

- Initial cost of the base office building and alternatives has obtained from Means Assemblies Cost Data (RS Means)
- Operating and maintenance cost obtained from DPA Inc.
- The bank discount rate is 4%
- The design life span of the office building is 50 years
- The cost of Co_2e in term of ton for the purpose of calculating GWP cost is obtained from www.pointcarbon.com

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

In this chapter the results of the case study has been explored. First the results of the environmental life cycle analysis and life cycle costing of base office building and alternatives are presented. Then the outputs of the results used in the optimization model of the present study. The optimum alternative based on the framework of optimization model has been selected. Eventually, to prove the performance of the model, a sensitivity analysis has been conducted, and the results of the assumption have been discussed.

5.2 LCA Results of Base Office Building

This section represents the environmental impacts of the base office building calculated by ATHENA software. The results of life cycle assessment by assembly groups are figured out in six categories: energy consumption, resource use, solid waste, air emissions and water emissions. Figures 5.1 to 5.3 show the absolute value chart by assembly groups for energy consumption, resource use and solid waste emissions. Also, Table 5.1 shows the bill of base office building's materials reported by ATHENA software. Appendix 2 represents the details of Athena life cycle environmental impact results.

Table 5.1 Bill of Materials Report Calculated by ATHENA Software (Base Office)

Material	Quantity	Unit
#15 Organic Felt	8896.6122	m^2
½" Fire-Rated Type X Gypsum Board	4913.3742	m^2
½" Gypsum Fibre Gypsum Board	5518.4406	m^2
½" Moisture Resistant Gypsum Board	1921.9161	m^2
5/8" Fire-Rated Type X Gypsum Board	1226.3201	m^2
5/8" Gypsum Fibre Gypsum Board	3678.9604	m^2
6 mil Polyethylene	8.8696	m^2
Aluminium	64.8433	tonnes
Ballast (aggregate stone)	38309.8354	kg
Batt. Rockwool	8786.0096	m^2 (25mm)
Clay Tile	208.7531	m^2
Cold Rolled Sheet	0.3096	tonnes
Concrete 20 MPa (flyash av)	234.8976	m^3
Concrete 30 MPa (flyash av)	1417.189	m^3
Concrete 60 MPa (flyash av)	4.2369	m^3
Concrete Blocks	52047.2979	blocks
EPDM membrane	2530.4058	kg
Expanded Polystyrene	1318.1452	m^2 (25mm)
Foam Polyisocyanurate	4228.4926	m^2 (25mm)
Galvanized Decking	5.5173	tonnes
Galvanized Sheet	3.9296	tonnes
Galvanized Studs	0.576	tonnes
Glazing Panel	0.2535	tonnes
Hollow Structural Steel	11.2155	tonnes
Joint Compound	17.2167	tonnes
Modified Bitumen membrane	2762.1391	kg
Mortar	210.3027	m^3
Nails	12.8257	Tonnes
Ontario (Standard) Brick	1609.5452	m2
Open Web Joists	2.5165	tonnes
Paper Tape	0.1976	tonnes
PVC membrane	174.156	kg
Rebar, Rod, Light Sections	268.2537	tonnes
Roofing Asphalt	15458.2201	kg
Screws Nuts & Bolts	0.0099	tonnes
Small Dimension Softwood Lumber, kiln-dried	0.8554	m^3
Softwood Plywood	328.188	m^2 (9mm)
Solvent Based Alkyd Paint	6625.6623	L
Standard Glazing	1965.578	m^2
Water Based Latex Paint	4399.1813	L
Welded Wire Mesh / Ladder Wire	0.5038	tonnes

The results of the energy consumption of the base office through its life cycle shows that the foundation accounts for 0.7%, walls for 70%, beams & columns for 1%, roofs for 9%, floors for 19% and extra basic materials for 0.3% of total energy consumption in base office.

The total consumption of the weighted resource use is 6624239.805 kg. The foundation accounts for 2.5%, walls for 39%, beams and columns for 7.85%, roofs for 8.43%, floor for 42.26% and extra basic materials for .02%. of the total weighted resource consumption of base office construction materials.

The total solid waste emissions are 726519.24 kg. The foundation accounts for 1.3%, walls for 64.6%, beams and columns for 0.4%, roofs for 1.85%, floor for 31.7% and extra basic materials for 0.15 %. of the total solid waste materials emissions.

From the total air emissions of the base office' construction materials, the foundation accounts for 0.6%, walls for 73.3%, beams and columns for 1.11%, roofs for 8%, floor for 16.7% and extra basic materials for 0.2 %.

The foundation accounts for 0.82%, walls for 69%, beams and columns for 1.44%, roofs for 9.18%, floor for 20.26% and extra basic materials for 0.3 % of the water emissions of base office's construction materials through its life cycle.

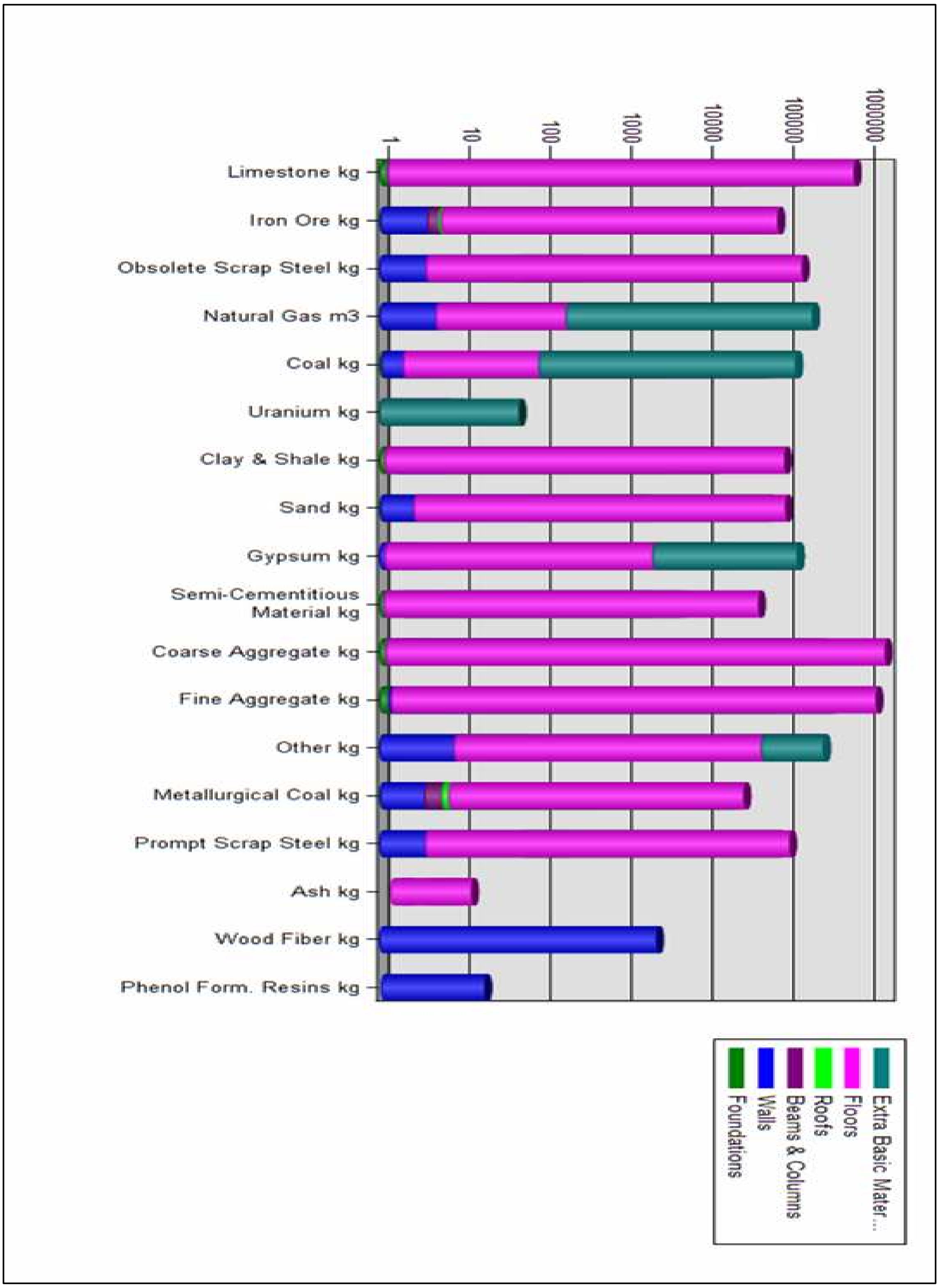


Figure 5.1 Resource Use Absolute Value Chart by Assembly Groups

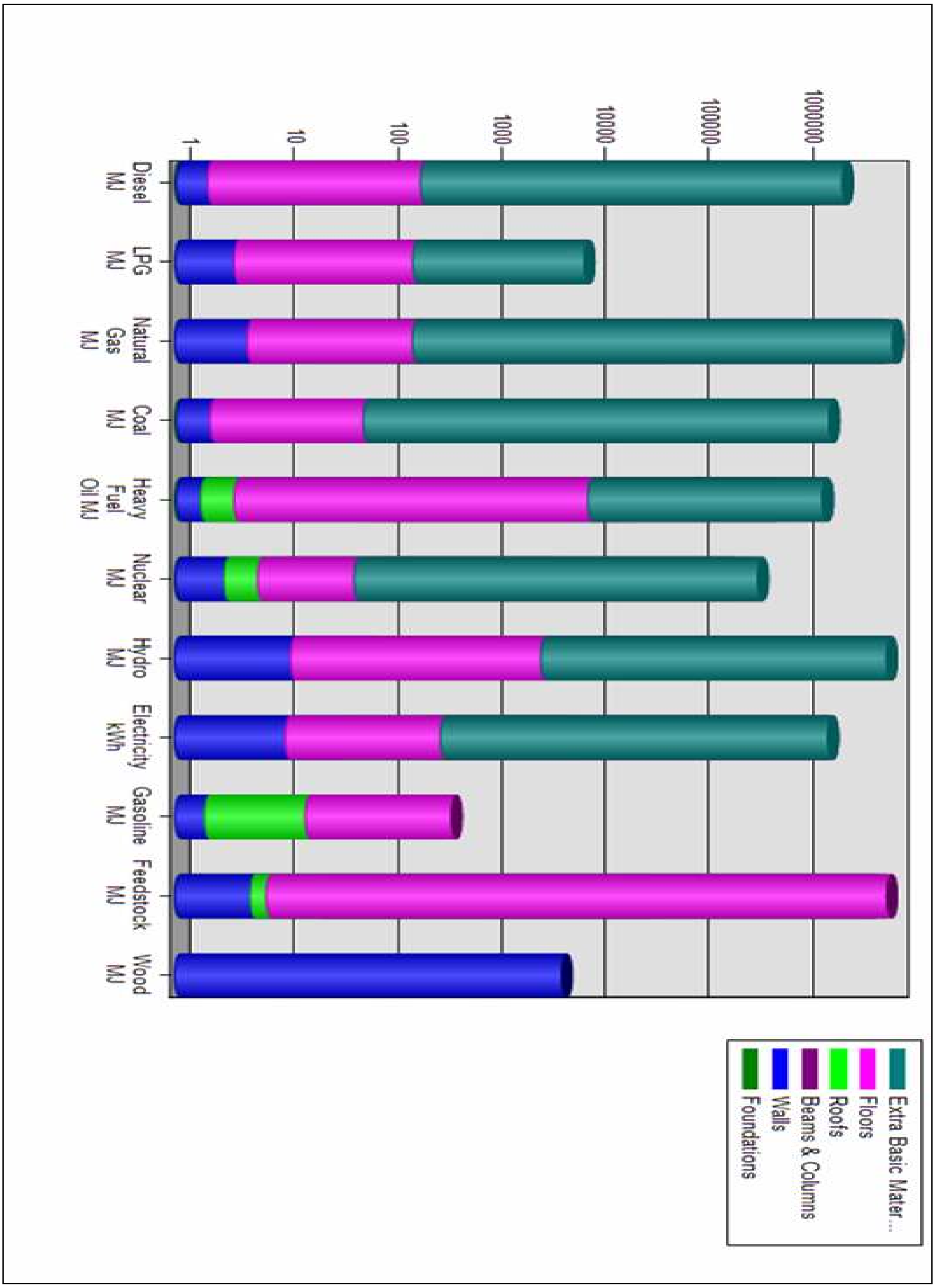


Figure 5.2 Energy Consumption Absolute Value Chart by Assembly Groups

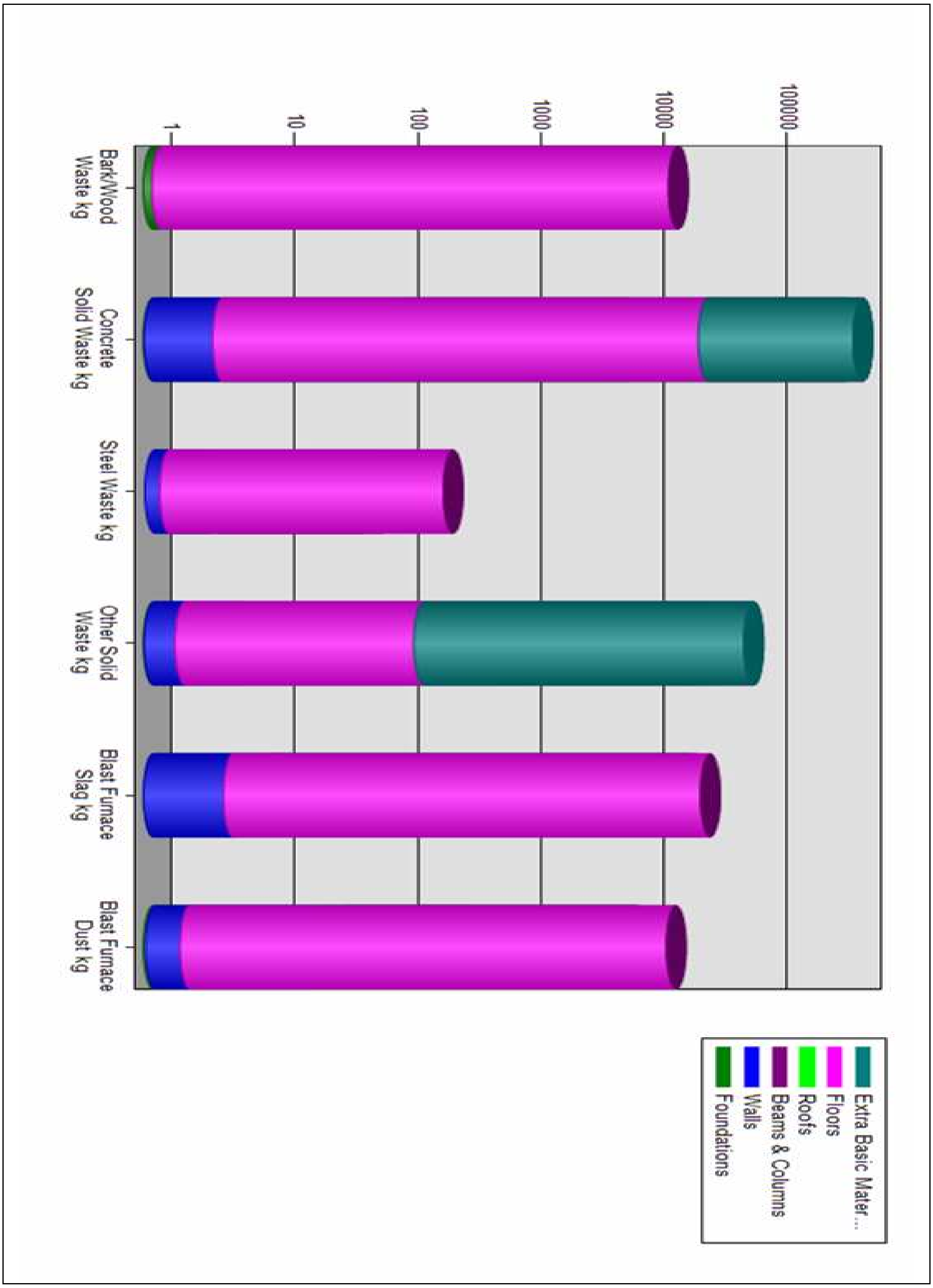


Figure 5.3 Solid Waste Emissions Absolute Value Chart by Assembly Groups

5.3 LCA Results of Alternatives Office Building

This section represents the comparison results of Athena Life Cycle Environmental Impact of three alternatives of Pre-cast office, Tilt up office and Triple glazed windows with base office building. These results have been compared in 6 categories of global warming potential, energy, solid waste, weighted recourse use, water emissions and air emissions provided by Athena impact estimator version 4. Although the results of Athena life cycle environmental impact of each alternatives can be represented separately, but it is most productive if the environmental impacts results of the changes to the base office building compared with the base office building. Table 5.2 to 5.4 shows the bill of alternatives to base office building's materials reported by ATHENA software. Also, results of life cycle assessment by assembly groups of alternatives are figured out in Figures 5.5 to 5.8.

Table 5.2 Bill of Materials Report Calculated by ATHENA Software (Pre-cast Office)

Material	Quantity	Unit
#15 Organic Felt	8896.6122	m^2
1/2" Fire-Rated Type X Gypsum Board	4913.3742	m^2
1/2" Gypsum Fibre Gypsum Board	5518.4406	m^2
1/2" Moisture Resistant Gypsum Board	1921.9161	m^2
5/8" Gypsum Fibre Gypsum Board	4905.2805	m^2
Aluminium	64.8433	m^2
Ballast (aggregate stone)	38309.8354	tonnes
Batt. Rockwool	8786.0096	Kg
Clay Tile	208.7531	m^2 (25mm)
Cold Rolled Sheet	0.3096	m^2
Concrete 20 MPa (flyash av)	183.3922	tonnes
Concrete 30 MPa (flyash av)	277.8897	m^3
Concrete 60 MPa (flyash av)	504.6954	m^3
Concrete Blocks	52047.2979	m^3
EPDM membrane	2530.4058	m^3
Expanded Polystyrene	1896.2791	Kg
Foam Polyisocyanurate	3646.7679	m^2 (25mm)
Galvanized Sheet	3.9296	m^2 (25mm)
Galvanized Studs	0.576	tonnes
Glazing Panel	0.2535	tonnes
Hollow Structural Steel	11.2155	tonnes
Joint Compound	17.2167	tonnes
Modified Bitumen membrane	2762.1391	tonnes
Mortar	210.3027	tonnes
Nails	12.8257	Kg
Ontario (Standard) Brick	1609.5452	m^3
Paper Tape	0.1976	tonnes
PVC membrane	174.156	m^2
Rebar, Rod, Light Sections	201.7326	tonnes
Roofing Asphalt	15458.2201	tonnes
Screws Nuts & Bolts	0.0099	Kg
Small Dimension Softwood Lumber, kiln-dried	0.8554	tonnes
Softwood Plywood	328.188	Kg
Solvent Based Alkyd Paint	5349.7989	tonnes
Standard Glazing	1965.578	m^3
Water Based Latex Paint	5850.1633	m^2 (9mm)
Welded Wire Mesh / Ladder Wire	6.9513	L

Table 5.3 Bill of Materials Report Calculated by ATHENA Software (Tilt-up Office)

Material	Quantity	Unit
#15 Organic Felt	8896.6122	m^2
1/2" Fire-Rated Type X Gypsum Board	4913.3742	m^2
1/2" Gypsum Fibre Gypsum Board	5518.4406	m^2
1/2" Moisture Resistant Gypsum Board	1921.9161	m^2
5/8" Fire-Rated Type X Gypsum Board	1226.3201	m^2
5/8" Gypsum Fibre Gypsum Board	3678.9604	m^2
Aluminium	64.8433	tonnes
Ballast (aggregate stone)	38309.8354	Kg
Batt. Rockwool	8786.0096	m^2 (25mm)
Clay Tile	208.7531	m^2
Cold Rolled Sheet	0.3096	tonnes
Concrete 20 MPa (flyash av)	491.4884	m^3
Concrete 30 MPa (flyash 25%)	275.1834	m^3
Concrete 30 MPa (flyash av)	1473.3768	m^3
Concrete 60 MPa (flyash av)	4.2369	m^3
EPDM membrane	2530.4058	Kg
Expanded Polystyrene	1318.1452	m^2 (25mm)
Foam Polyisocyanurate	4228.4926	m^2 (25mm)
Galvanized Decking	5.5173	tonnes
Galvanized Sheet	3.9296	tonnes
Galvanized Studs	0.576	tonnes
Glazing Panel	0.2535	tonnes
Hollow Structural Steel	11.2155	tonnes
Joint Compound	17.2167	tonnes
Modified Bitumen membrane	2762.1391	Kg
Mortar	44.6218	m^3
Nails	12.8257	tonnes
Ontario (Standard) Brick	1609.5452	m^2
Open Web Joists	2.5165	tonnes
Paper Tape	0.1976	tonnes
PVC membrane	174.156	Kg
Rebar, Rod, Light Sections	117.0152	tonnes
Roofing Asphalt	15458.2201	Kg
Screws Nuts & Bolts	0.0099	tonnes
Small Dimension Softwood Lumber, kiln-dried	0.8554	m^3
Softwood Plywood	328.188	m^2 (9mm)
Solvent Based Alkyd Paint	6625.6623	L
Standard Glazing	1965.578	m^2
Water Based Latex Paint	4399.1813	L
Welded Wire Mesh / Ladder Wire	0.5038	tonnes

Table 5.4 Bill of Materials Report Calculated by ATHENA Software (TG Office)

Material	Quantity	Unit
#15 Organic Felt	8896.6122	m^2
1/2" Fire-Rated Type X Gypsum Board	4913.3742	m^2
1/2" Gypsum Fibre Gypsum Board	5518.4406	m^2
1/2" Moisture Resistant Gypsum Board	1921.9161	m^2
5/8" Fire-Rated Type X Gypsum Board	1226.3201	m^2
5/8" Gypsum Fibre Gypsum Board	3678.9604	m^2
Aluminium	64.8433	tonnes
Ballast (aggregate stone)	38309.8354	Kg
Batt. Rockwool	8786.0096	m^2 (25mm)
Clay Tile	208.7531	m^2
Cold Rolled Sheet	0.3096	tonnes
Concrete 20 MPa (flyash av)	234.8976	m^3
Concrete 30 MPa (flyash av)	1417.189	m^3
Concrete 60 MPa (flyash av)	4.2369	m^3
Concrete Blocks	52047.2979	m^3
EPDM membrane	2530.4058	Kg
Expanded Polystyrene	1318.1452	m^2 (25mm)
Foam Polyisocyanurate	4228.4926	m^2 (25mm)
Galvanized Decking	5.5173	tonnes
Galvanized Sheet	3.9296	tonnes
Galvanized Studs	0.576	tonnes
Glazing Panel	0.2535	tonnes
Hollow Structural Steel	11.2155	tonnes
Joint Compound	17.2167	tonnes
Low E Tin Argon Filled Glazing	2167.5209	Kg
Modified Bitumen membrane	2762.1391	m^3
Mortar	210.3027	tonnes
Nails	12.8257	m^2
Ontario (Standard) Brick	1609.5452	tonnes
Open Web Joists	2.5165	tonnes
Paper Tape	0.1976	Kg
PVC membrane	174.156	tonnes
Rebar, Rod, Light Sections	268.2537	Kg
Roofing Asphalt	15458.2201	tonnes
Screws Nuts & Bolts	0.0099	m^3
Small Dimension Softwood Lumber, kiln-dried	0.8554	m^2 (9mm)
Softwood Plywood	328.188	L
Solvent Based Alkyd Paint	6625.6623	m^2
Standard Glazing	1965.578	L
Water Based Latex Paint	4399.1813	tonnes
Welded Wire Mesh / Ladder Wire	0.5038	m^2

The environmental impacts of the base office building and three alternatives of pre-cast, tilt-up and triple glazed windows measured by life cycle stages has been explored in table 5.5.

Table 5.5 Environmental Indicators Summary Measure by Life Cycle Stages

	Primary Energy (MJ)	Solid Waste (kg)	Weighted Resource Use (kg)	Global Warming Potential (Kg)	Air Pollution (Index)	Water Pollution (Index)
Base office	22,536,626	726,519	6,624,239	1,391,509	36,468,868	1.086e+11
Pre-cast office	20,120,840	617,209	4,673,594	1,180,705	34,129,195	9.97e+10
Tilt-up office	18,813,709	607,929	7,632,554	1,274,214	34,819,309	9.53 e+10
Triple glazed office	22,693,704	730,830	6,697,881	1,445,916	39,974,017	1.38e+11

Changing from base office to pre-cast floors resulted in a decrease of 11% in primary energy, and 17% in changing to tilt-up walls. While substitution of triple glazed windows led to increase of 0.7% in primary energy.

Substituting of the base office to pre-cast office led to a 15% decrease in solid waste and 16% in changing to tilt-up office while Substation with TGW resulted in 0.6% increase.

The result of substitution of base office with pre-cast office led to 29% decrease of weighted resource use of construction materials, 15% increase for tilt-up office and 1% in changing to triple glazed windows.

The base office produces 1391509.262 kg Co_2. Substitution with pre-cast office led to 15% decrease in global warming potential, and 8% decrease in changing to tilt-up office. Substitution of triple glazed windows resulted in 4% increase of global warming potential.

Changing to pre-cast office led to 6% decrease in air pollution. Also, the pollution of tilt-up office on air is 4.5% less than base office, but TGW has 10% more pollution on air in comparison with base office.

Comparing with base office both of the pre-cast office and tilt-up office have less water pollution. The water pollution of pre-cast office decrease by 8% and tilt-up office by 13%, while for triple glazed windows increase by 27%

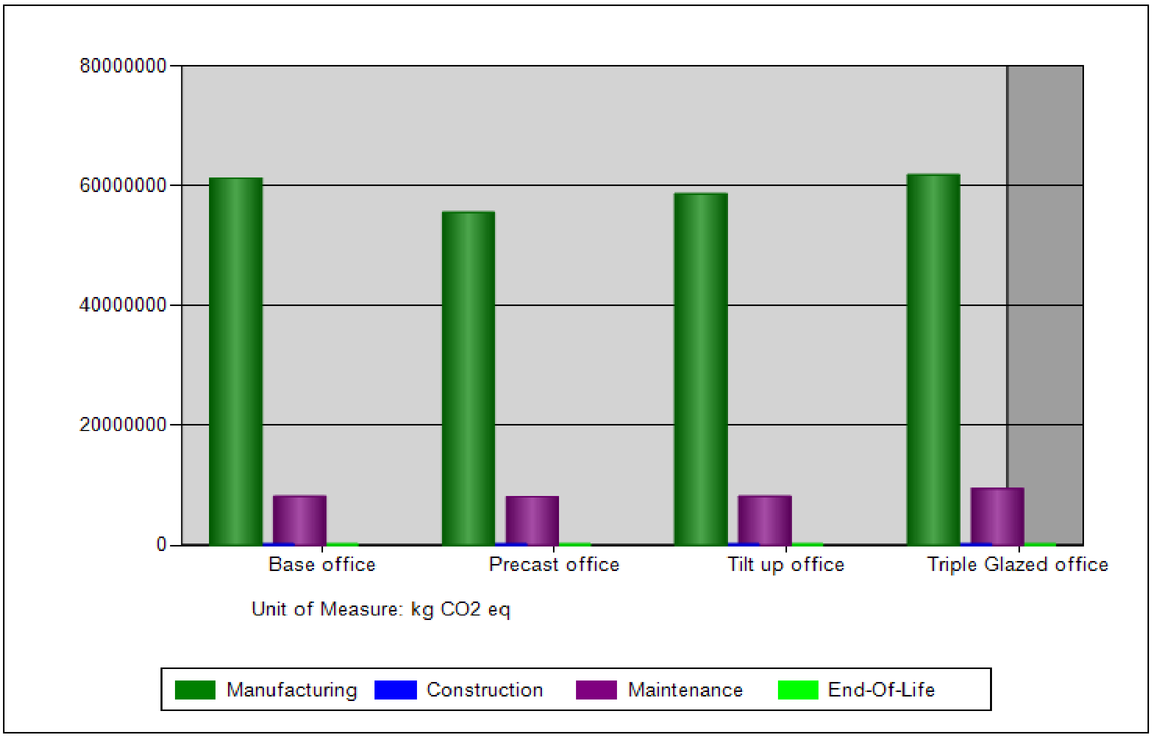


Figure 5.5 Comparison of Global Warming Potential by Life Cycle Stages

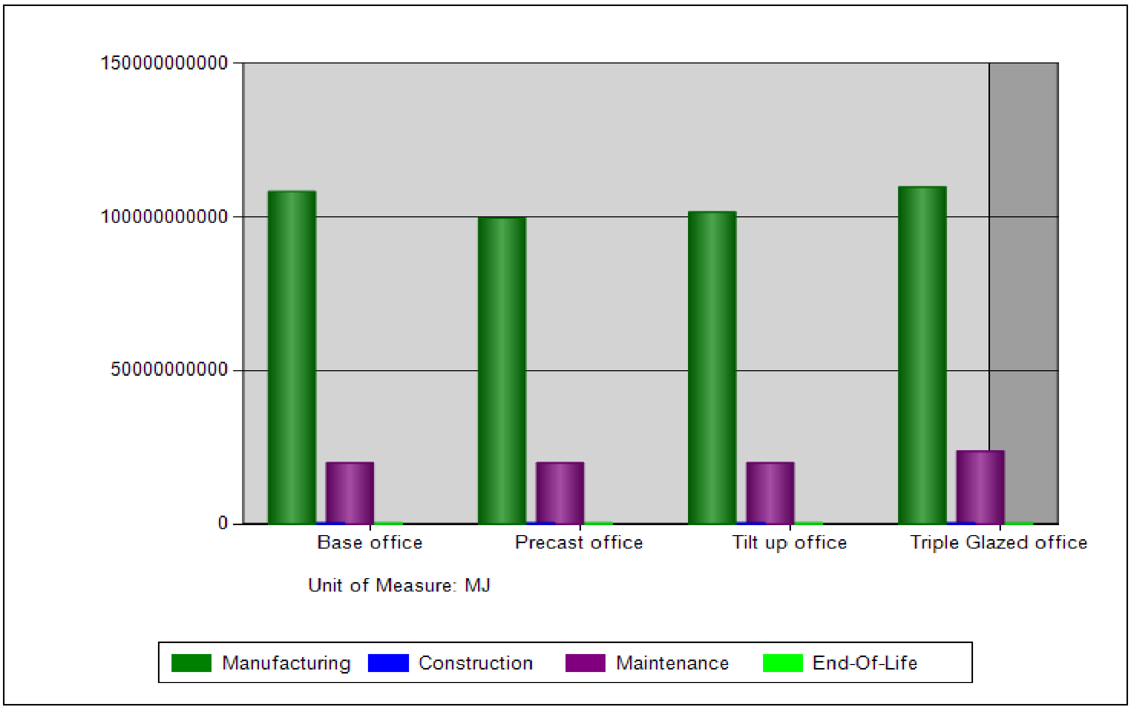


Figure 5.6 Comparison of Energy Consumption by Life Cycle Stages

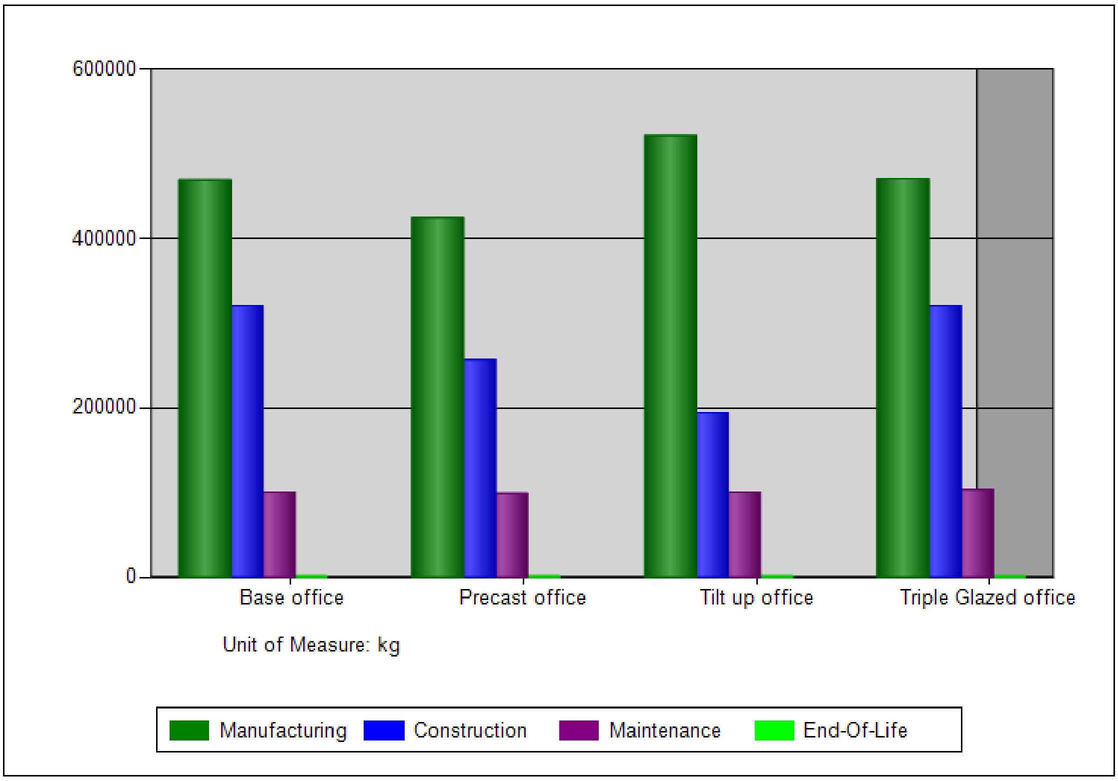


Figure 5.7 Comparison of Solid Waste by Life Cycle Stages

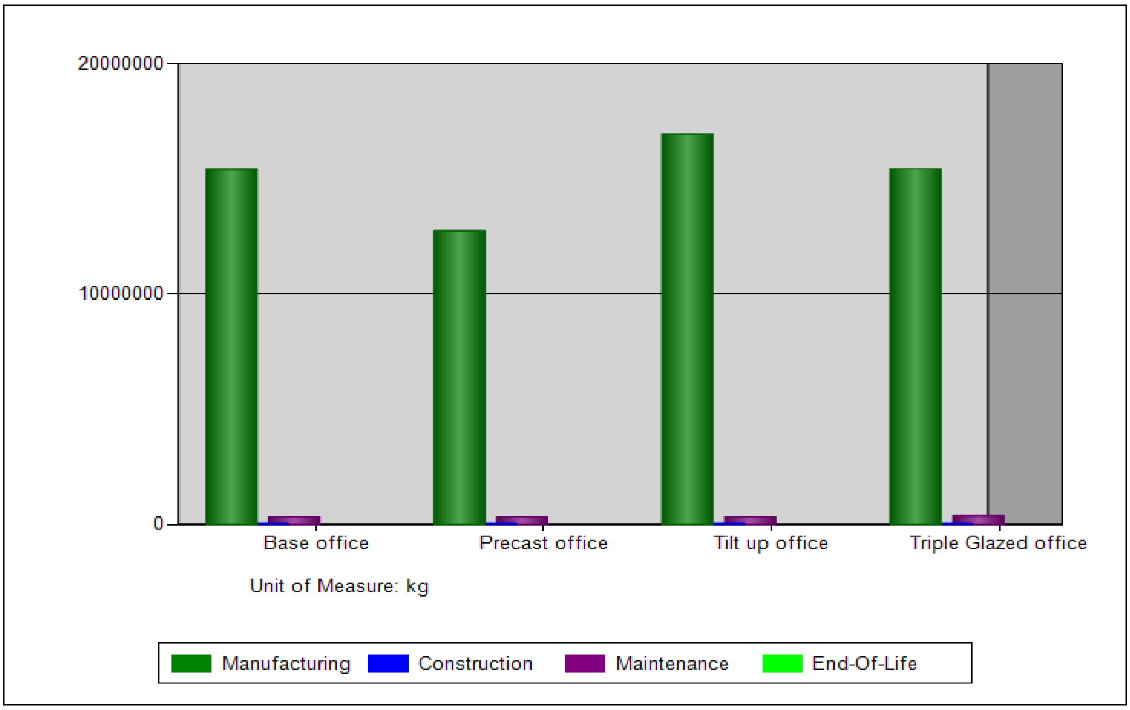


Figure 5.8 Comparison of Weighted Resource by Life Cycle Stages

5.4 LCC Results of Base Office Building and Alternatives

The total construction cost of base office building is estimated at $5,698,465.67 in 1999. Historical cost index from RS Means used to convert the initial cost of the building from year 1999 to year 2010. Also, in order to calculate the initial cost of office building in Montreal, Means Assemblies cost data provides city cost index which can be used to compare the cost of city to city. Following equations is used to achieve the total construction cost of base office building in year 2010 in Montreal. Figure 5.9 shows a sample of cost estimation for base office building conducted in RSMeans. Appendix 3 provided the detailed estimation of the office building costs.

Project	Example - 8 Story Office Building					
Input Code	Description	*Quantity*	*Unit*	*Rate*	*Cost*	Output Code
A	**SUBSTRUCTURE**			**-**	**145,193.70**	
A10	**FOUNDATIONS**			**-**	**69,726.50**	
A1010	**Standard Foundations**	**6,000.0**	**SF**	**7.67**	**46,026.50**	
A01.1-120-7900	Corner Spread ftgs, ld 400K, soil cap 6 KSF, 8'-6" sq x 27" d	4.0	EA	1,360.00	5,440.00	
A01.1-120-8010	Exterior Spread ftgs, ld 500K, soil cap 6 KSF, 9'-6" sq x 30" d	8.0	EA	1,820.00	14,560.00	
A01.1-120-8300	Interior Spread ftgs, ld 800K, soil cap 6 KSF, 12'-0" sq x 37" d	3.0	EA	3,400.00	10,200.00	
A01.1-140-2700	Strip footing, load 11.1KLF, 24"wide x 12"deep, reinf	210.0	LF	26.45	5,554.50	
A01.1-294-3000	Foundation underdrain, outside and inside, PVC, 4" diameter	640.0	LF	16.05	10,272.00	
A1020	**Special Foundations**			**-**		
A1030	**Slab on Grade**	**6,000.0**	**SF**	**3.95**	**23,700.00**	
A02.1-200-2240	Slab on grade, 4" thick, non industrial, reinforced	6,000.0	SF	3.60	21,600.00	
07.2-109-0600	Perimeter under slab insulation - polystyrene 1", R4	2,800.0	SF	0.75	2,100.00	
A20	**BASEMENT CONSTRUCTION**			**-**	**75,467.20**	
A2010	**Basement Excavation**	**2,700.0**	**CY**	**5.91**	**15,960.00**	
A01.9-100-3440	Basement Excav & backfill, 12' deep, sand, gravel, on site storage	6,000.0	SF	2.66	15,960.00	
A2020	**Basement Walls**	**3,840.0**	**SF**	**15.50**	**59,507.20**	
A01.1-210-7260	Basement Fdn walls, CIP,12' height,pumped,12" thick	320.0	LF	168.00	53,760.00	
A01.1-292-2800	Basement Foundation dampproofing, bituminous, 2 coats, 12' high	320.0	LF	12.44	3,980.80	
07.2-109-0700	Basement Wall insulation - polystyrene 2", R8	1,920.0	LF	0.92	1,766.40	
B	**SHELL**			**-**	**1,502,979.96**	
B10	**SUPERSTRUCTURE**			**-**	**688,569.96**	
B1010	**Floor Construction**	**48,000.0**	**SF**	**13.37**	**641,632.56**	
A03.5-540-3600	Floor, Composite bm,dk&slb,25x30',75 PSF superimposed load	48,000.0	SF	10.94	525,120.00	
A03.1-130-5800	Steel columns,400 KIPS,10' unsupported height	1,296.0	VLF	76.50	99,144.00	
A03.1-190-3650	Steel column fireproofing,gyp bd 1/2"fr	792.0	VLF	21.93	17,368.56	
B1020	**Roof Construction**	**6,000.0**	**SF**	**7.82**	**46,937.40**	
A03.7-420-3900	Roof - Open Web Joists, Beams & deck,25x30',40PSF superimposed load	6,000.0	SF	4.87	29,220.00	
A03.1-130-5800	Steel columns,400 KIPS,10' unsupported height	180.0	VLF	76.50	13,770.00	
A03.1-190-3650	Steel column fireproofing,gyp bd 1/2"fr	180.0	VLF	21.93	3,947.40	
B20	**EXTERIOR ENCLOSURE**			**-**	**794,141.00**	
B2010	**Exterior Walls**	**25,500.0**	**SF**	**18.43**	**469,900.00**	
A04.1-273-1200	4" Brick Wall & 6" Block c/w Insulation	16,500.0	SF.	19.80	326,700.00	
A04.1-211-3410	8" Conc block wall c/w styrofoam insulation	9,000.0	SF	9.46	85,140.00	
A04.1- 140-6776	Precast Concrete Coping - 14" wide	320.0	LF	25.25	8,080.00	
A06.1-680-0920	Gypsum plaster, 2 coats	24,500.0	SF	2.04	49,980.00	
B2020	**Exterior Windows**	**6,600.0**	**SF**	**47.58**	**314,041.00**	
A04.7-110-8800	Alu. Windows & Insulated glass,3'-0" x 5'-4"	406.0	EA	773.50	314,041.00	
B2030	**Exterior Doors**	**5.0**	**LVS**	**2,040.00**	**10,200.00**	
A04.6-100-6300	Single Alu. & Glass Door c/w hardware,3'-0"x 7'-0"opng	2.0	EA	1,870.00	3,740.00	

Figure 5.9 Cost Estimating Details of Base Office Building Case Study (Charette and Marshalle, 1999)

5.4.1 Base Office Building Initial Cost

Cost in Year A = (Index for year A / Index for Year B) × Cost in Year B (Eq. 5.1)

- *City index 1999 = 117.6*
- *City index 2010 = 182.8*

Cost in 2010 = (182.8 / 117.6) × 5,698,465.67 = $8,857,819.10

Unknown construction cost = Known construction cost × (unknown location factor) / 100 (Eq. 5.2)

- *IC= initial cost*
- *Location factor Montreal = 107.1*
- *Location factor Kingston = 117.2*

Montreal construction cost = Kingston construction cost × (Montreal location factor) / 100

Montreal construction cost = 8,857,819.10 × (107.1/100) = $9,486,724.256

5.4.2 Alternatives Office Building Initial Cost

The unit cost for precast concrete was provided by Groupe Tremca Préfabriqué, Inc ($30 Sq. /Ft.) and that for tilt-up was founded from www.tiltwall.ca ($21 Sq. /Ft.). The cost of Triple Glazed (two layers with a low-emissivity (Low-E)) extracted from RSMeans data cost 2010.

The initial cost of tilt-up office decreases to $9,230,514.716, the initial cost of pre-cast office increases to 9,960,402.823, and cradle to construction cost of triple glazed office increases to 9,727,193.286. The annual operating and maintenance cost is $17.56 per Sq. /Ft. obtained from DPA Inc., Montreal. Also, the cost of end of life extracted from building journal (Building Journal 2010). Table 5.6 presents the life cycle costs for each alternatives over a design life of 50-year.

Table 5.6 Life Cycle Costs (50 years)

	Cradle to Construction ($)	Annual Operating and Maintenance ($)	End of Life ($)	Life Cycle Cost (50- yr) ($)
Base office building (BO)	9,486,724	948,240	80,970	29,937,961
Tilt- up office building (TO)	9,230,514	948,240	80,970	29,681,751
Pre-cast office building (PO)	9,960,402	948,240	80,970	30,411,639
Triple glazed office building (TG)	9,727,193	948,240	80,970	30,178,430

The life cycle costs of base office are estimated $29,937,961.14. Substituting the base office walls to tilt-up results in 0.9% decrease in life cycle cost of base office while changing to pre-cast and triple glazed windows subsequently result in 1.6% and 0.8% increase in the life cycle costs (Figure 5.10).

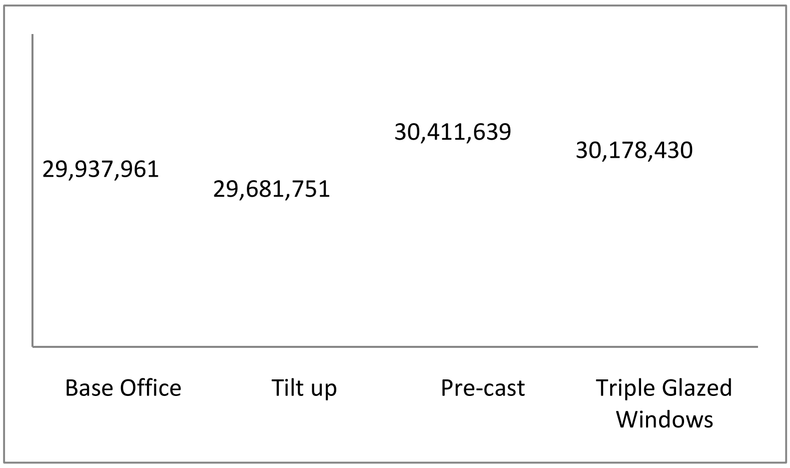


Figure 5.10 Life Cycle Costs Comparison of Each Alternative for 50-year Design Life

5.4.3 Global Warming Potential Cost

In order to calculate the cost of global warming for each alternative Co_2e extracted from the results of life cycle assessment process provided by Athena software is translated to a monetary value. The price of Co_2e is $19.5 per tone which has obtained from www.pointcarbon.com on June 11, 2010 at 3:30 am. Table 5.7 shows GWP cost of base office building and its three alternatives. Among the alternatives pre-cast office has the lowest cost and triple glazed windows have the highest cost.

Table 5.7 Global Warming Potential Cost for Base office and Three Alternatives

	Global Warming Pollution (Kg)	GWP Cost ($)
Base office	1,391,509	27,134
Pre-cast office	1,180,705	23,023
Tilt-up office	1,274,214	24,847
Triple glazed office	1,445,916	28,195

In figure 5.11 life cycle costing and the GWP cost of office building alternatives are compared. Life cycle costing of pre-cast office is higher than other alternatives while its GWP cost is the lower one.

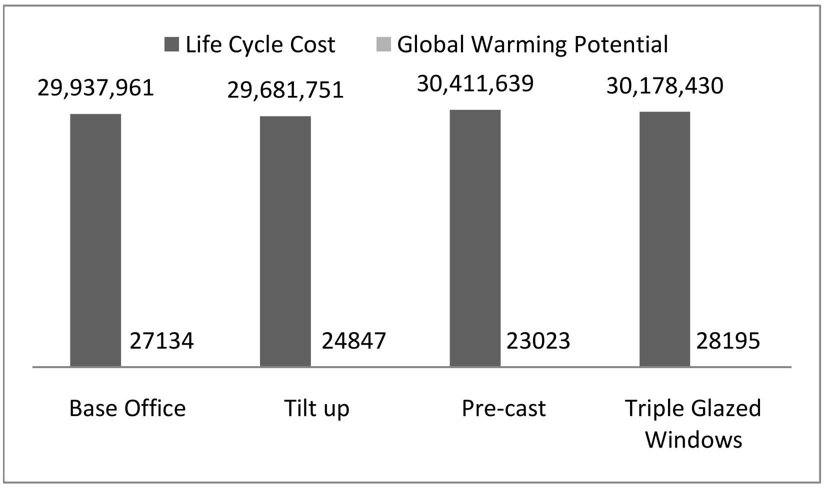


Figure 5.11 Comparison of Life Cycle Costing and Global Warming Potential Cost of Office Building Alternatives

5.5 Optimization Results

By applying the results of life cycle assessment and total life cycle costing into optimization model of the present study (equation 3.1), the optimum solutions are obtained. The objective of the optimization model is minimizing total life cycle costing of office building components subject to a set of constrains resulted. Figure 5.12 shows LINDO programming of case study using equation 3.1. The complete LINDO programming of case study is shown in Appendix 4.

A 4.2 LINDO Programming of Case Study

```
!Let BO be Alternative Base office
!Let TO be Alternative Tilt-up
!Let PO be Alternative Pre-cast
!Let TG be Alternative Triple glazed
!
!objective: Minimize Total Life Cycle costs
!
min 9831889 BO + 9573392 TO + 10301458 PO + 10073419 TG
!
subject to
!the following constrains
!
!Primary Energy
22536627 BO + 18813710 TO + 20120849 PO + 22693705 TG <= 22536627
!
!Solid Waste
726519 BO + 607929 TO + 617209 PO + 730831 TG <= 726519
!
!Air Emission
36468869 BO + 34819309 TO + 34129195 PO + 39974017 TG <= 36468868
!
!Water Emission
1086000 BO + 9530000 TO + 9970000 PO + 13800000 TG <= 10860000
!
```

Figure 5.12 LINDO Programming of Case Study

In the first run of the optimization model the targets were set to the environmental indicators of base office. For instance primary energy is equal or less than 22536627 MJ.

The result of the LINDO optimization programming (figure 5.13 and appendix 4) found that the base office met all the targets with lower cost in comparison with pre-cast and triple glazed windows, but has higher cost than tilt-up office. Therefore the optimal solution is base office.

In the second run of the optimization model the weighted resource use target relaxed to 7650000 Kg and the other targets remained as previous. After running model, the tilt-up office found as optimal solution that met all the environmental indicator constraint and had the lower cost than base office.

In the third run of the model the global warming potential constraint target was relaxed to 1,250,000 kg. Under these conditions, the alternative of pre-cast office found to be the optimal solution.

A.4.2.1 LINDO Optimization Programming Results OF Case Study

a. The target sets to base office building environmental indicator:

```
LP OPTIMUM FOUND AT STEP      2
OBJECTIVE VALUE =   29930474.0


NEW INTEGER SOLUTION OF    29937960.0     AT BRANCH      0 PIVOT
2
RE-INSTALLING BEST SOLUTION...

      OBJECTIVE FUNCTION VALUE

      1)     0.2993796E+08

 VARIABLE        VALUE          REDUCED COST
      BO        1.000000   29937960.000000
      TO        0.000000   29681752.000000
      PO        0.000000   30411640.000000
      TG        0.000000   30178430.000000
```

Figure 5.13 LINDO Optimization Programming Results of Case Study

Table 5.8 summarized the results of the three runs of the LINDO optimization programming.

Table 5.8 Summary of the Optimization Results

	Optimal Choice	Life Cycle Cost ($)
Run 1	Base office	29,937,961
Run 2	Tilt-up office	29,681,751
Run 3	Pre-cast office	30,411,639

5.6 Sensitivity Analysis

In order to calculate the life cycle cost of the case study some assumption were made. The effective discount rate was 4% and the design life was assumed 50-year. This section represents the effects of the discount rate and the design life on life cycle costing. The life cycle costing of office building is sum of initial costs, operation, maintenance and repair costs and the cost of the end of life. The initial cost and the end of life calculated in terms of present value, and the operation/maintenance and repair costs in terms of annul value, therefore changing to discount rate and design life has only effect on the cost of operation/maintenance and repair costs. Table 5.9 and 5.10 show the results of changing on discount rate and design life.

By increasing interest rate the life cycle costs of base office and alternatives are decreased, and the lower and higher LCC categorized the same as LCC with interest rate of 4%. Also, there were no change in the results of finding optimal solution and the results of running optimization programming remained as LCC with 4% discount rate. Therefore the choice of discounting rate does not affect the optimal solution.

According to most of the literatures, the design life of office building was assumed 50-year. Also, Athena considers 50-year for the design life of the commercial buildings. Changing to design life from 50-year to 200-year resulted in decreasing life cycle cost of base office and alternatives with the same lower and higher LCC priority of 50-year design life. The results of optimal solution remained as same as 50-year design life.

Table 5.9 The Effect of Discounting Rate on Life Cycle Costing

	2% ($)	4% ($)	6% ($)	8% ($)
Base office building (BO)	39,364,814	29,937,961	24,513,721	21,167,973
Tilt-up office building (TO)	39,108,604	29,681,751	24,257511	20,911,764
Pre-cast office building (PO)	39,838,493	30,411,639	24,987,399	21,641,652
Triple glazed office building (TG)	39,605,283	30,178,430	24,754,190	21,408,442

Table 5.10 The Effect of Design Life on Life Cycle Costing

	50-year ($)	100-year ($)	150-year ($)	200-year ($)
Base office building (BO)	29,937,961	32,804,314	33,207,646	$33,264,400
Tilt-up office building (TO)	29,681,751	32,548,105	32,951,437	33,008,191
Pre-cast office building (PO)	30,411,639	33,277,993	33,681,325	33,738,079
Triple glazed office building (TG)	30,178,430	33,044,783	33,448,115	33,504,869

The operating /maintenance and repair costs are based on dollar per Sq. Ft. Therefore for each alternative the cost of operating/ maintenance and repairs is equal. If the difference in operating/maintenance and repairs cost between the alternatives were not equal, then an increase in the design life would have made a difference to the selection of the optimal alternative.

5.7 Comparison to Results of other Research

To date the approach of using linear optimization to balance between life cycle assessment and life cycle costing over all the components, as a means of moving toward sustainability in office buildings, has not been undertaken. However the results of this research can be compared with the results of few studies which are narrower in focus. The values for manufacturing, construction, maintenance, and end of life phases for primary energy and CO_2e were obtained from Guggemos and Horvath (2005) for the steel framed building located in the United States, Canadian steel frame building (Cole and Kernan 1996) and Canadian concrete frame building (Cole and Kernan 1996). The results were normalized on a square meter basis.

5.7.1 Environmental Impacts of Manufacturing Phase

Cole (1999) provides a detailed examination of the energy and greenhouse gas emission associated with selection of alternatives wood, steel and concrete structural assemblies. Athena version 1.0 was used for LCA and cost estimates were deduced from the RS Means catalogue data. The study suggested that significant differences occur between the amount of energy and greenhouse gases associated with the manufacturing of wood, steel and concrete structural. Guggmos and Horvath 2005 have also suggested that manufacturing phase of steel and concrete frame buildings has the highest primary energy and global warming potential values. The trends are in keeping with the results generated in this thesis.

5.7.2 Primary Energy of a Complete Building

The results of primary energy obtained from a LCA for steel and concrete frames from a Canadian office building case study (Cole 1996), steel frame building and concrete frame building (Guggmos and Horvath 2005) were compared with the results of this research (Table 5.11). Also, included in the table is a range of primary energy values for office buildings in Japan, Australia, New Zealand, and Canada as noted in a literature conducted by (Cole and Kernan 1996). Primary energy of both steel and frame building for U.S. study (Guggmos and Horvath 2005) are at the higher end of range. Reasons for difference in the Canadian and U.S. results could be from difference in emissions data, building design, level of details in the study and boundary setting.

Table 5.11 Comparison of primary energy for buildings for this work, (Cole and Kernan 1996) and (Guggmos and Horvath 2005)

	Primary Energy (GJ/m^2)
Office buildings, range from literature survey (Cole and Kernan 1996)	4 – 12
Canadian steel frame building (Cole and Kernan 1996)	4.86
Canadian concrete frame building (Cole and Kernan 1996)	4.52
Steel frame building (Guggmos and Horvath 2005)	9.5
Concrete frame building (Guggmos and Horvath 2005)	8.3
Base office building	4.48
Pre-cast office building	4
Tilt-up office building	4.1
Triple glazed windows office building	4.52

5.7.3 GWP (CO_2e) of a Complete Building

The results of CO_2e obtained from a LCA for steel frame building and concrete frame building (Guggmos and Horvath 2005) were compared with the results of this research (Table 5.12).

Table 5.12 Comparison of primary energy for buildings for this work and (Guggmos and Horvath 2005)

	CO_2e (Kg/m[2)]
Steel frame Building (Guggmos and Horvath 2005)	200
Concrete frame Building (Guggmos and Horvath 2005)	220
Base office building	277
Pre-cast office building	235
Tilt-up office building	253
Triple glazed windows office building	287

CHAPTER 6

CONCLUSION AND RECOMMENDATION FOR FUTURE WORKS

6.1 Conclusion

The human population has an undisputed need for comfort and ease, which supersedes environmental conscious decisions. However, as the population increases, human must find a way to deal with depleting resources fundamental to their existence. This chapter concludes the literature review, research framework and methodology, and the results of chapter 5 which achieved from the office building case study.

This thesis reviewed life cycle assessment, life cycle costing, optimization, green design and sustainability concepts. Also, the previous studies on life cycle assessment, life cycle costing and optimization of office building were reviewed.

This thesis described the framework and methodology of the research. It is also proposed an optimization model for balancing between life cycle costing and life cycle assessment of office buildings. The equation of optimization model has been defined and the model's framework including objective function, constrains and variables were explored. The tools for the purpose of the optimization approach were discussed as well.

Furthermore, this thesis applied the proposed optimization model of the research to a case study to observe the mechanism of the model. Base office building was compared with three different alternatives. Two structural components of floor and wall substituted with tilt-up and pre-cast and one envelope components substituted with triple glazed windows.

The environmental impacts of the different alternatives of building components were compared trough a LCA process using Athena software. Also, the cost of global warming potential and life cycle costing were compared. Using the optimization model framework, the results of LCA process and LCC were used as inputs of the optimization model. Using LINDO programming, the result of the case study was found the optimum alternative of tilt-up building which is the most cost effective and has the lower environmental impacts. Therefore, stakeholders of a project must not only find the quickest way to complete their work but also the most-cost efficient way and least impacts on environment. As a conclusion, the proposed optimization model can be used as a decision support tool in the preliminary stages of building design.

Results of LCA process of office building components using Athena over the design life of 50-years were founded the base office consumed 22536626.75 MJ primary energy, 726519.24 kg solid waste, 6624239.805 kg weighted resource use, 1391509.262 kg global warming potential, 36468868.72 kg of air emission and 1.086e+11 of water pollution. Also, 50-years life cycle costing of base office estimated $9,804,754.386.

Changing from base office to pre-cast office resulted in decrease of all environmental indicators: 11% in primary energy, 15% in solid waste, 29% in weighted resource use of construction materials, 15% in global warming potential, 6% in air pollution and 8% in water pollution of pre-cast office. But the life cycle costing of pre-cast office led to 5% increase. Considering the environmental indicators of the optimization model as system targets, the pre-cast office has the lowest impact on environment. The Life Cycle

Management (LCM) can be used to manage total life cycle (trade of between life cycle assessment and life cycle costing) toward more sustainable office building design.

Substituting base office wall with tilt-up resulted in 17% and 16% decrease in primary energy and in solid waste respectively and 15% increase of weighted resource use of construction materials. It also resulted in 8% decrease in global warming potential, 4.5% in air pollution, 13% in water pollution of tilt-up office and 3% in life cycle costing of tilt-up office. Except in weighted resource use the tit-up office has the lower impact on environment in comparison with base office. One of the advantages of the model was to show the key area of improvement. For example designers of tilt up office should find a way to improve their products to mitigate the weighted resource use of tilt-up.

Changing to the envelope of base office with triple glazed windows resulted in increase of all environmental indicators: 0.7% in primary energy, 0.6% in solid waste, 1% in weighted resource use of construction materials, 4% in global warming potential, 10% in air pollution, and 27% in water pollution and 2.5% in life cycle costing of triple glazed windows office. In all of the environmental indicators the triple glazed windows office has the higher impacts on environment than the base office. Also its life cycle costing is more than base office.

Changing the interest rate has little effect on the life cycle costs of office building alternatives so discounting rate choice does not affect the optimal selection. Similarly the selection of optimal choice was not affected by increase in design life from 50-year to 200-year

6.2 Contributions

The current research contributed the following to the state of are of sustainable office building:

- A benchmark of sustainability has been created for office buildings, and sustainability indicators and targets have been established.
- An optimization model has been developed to select the optimal combination of building components which meet or exceed the established sustainability targets. The model is able to identify key area for improvement. For instance, the tilt up option of the case study was improvement to the base office in all area, with exception in weighted resource use. Therefore designer of tilt-up presented with an aspect of their products which need to be improved.

6.3 Recommendations for Further Work

The presented optimization model has great potential as a decision support tool that would encourage the stakeholders in the office buildings to move easily towards meeting sustainability targets, and cost effectively. However, to achieve the objectives of optimization model there are improvements to be made.

The variables of the case study analysis were limited to consideration of two structural and one envelope components. Increasing the number of variables can results more accurate selection of optimum solution since the project stakeholders are considering more alternative.

This study had only one objective, minimizing life cycle costing and global warming cost. To consider multi objective in the optimization model can open a new research title for future works.

Operating energy is a very important issue toward sustainability. Because of lack of necessary data, operating energy did not consider in LCA process of case study. Considering operating energy in LCA process will be explored better way of making decision to select optimal solution of building components alternatives.

Finally this research considers the economical and environmental impacts of office building throughout its life cycle. There are several other factors to consider when selecting the best method applicable to the project. There are other effects which built of an office building can caused on environment such as social effects. For example what are the impacts of an office building construction on the people life or what is the impact on the businesses around the new construction. These type of the impacts can also, include in future works which needs a collaboration of experts people from different related area like engineering, sociologist, architectural and etc.

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Appendix 1: Plan of the Office Building Case Study

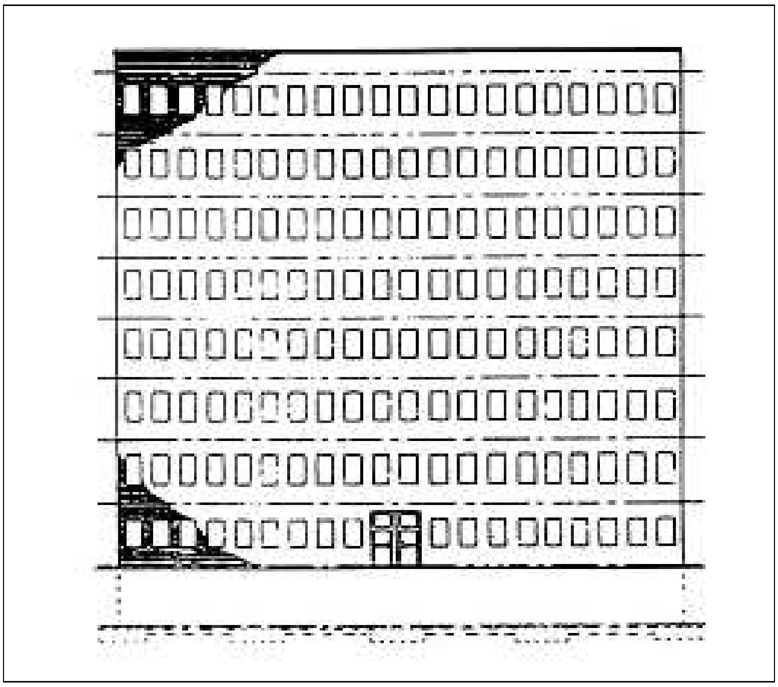

Figure A 1.1 Front Elevation

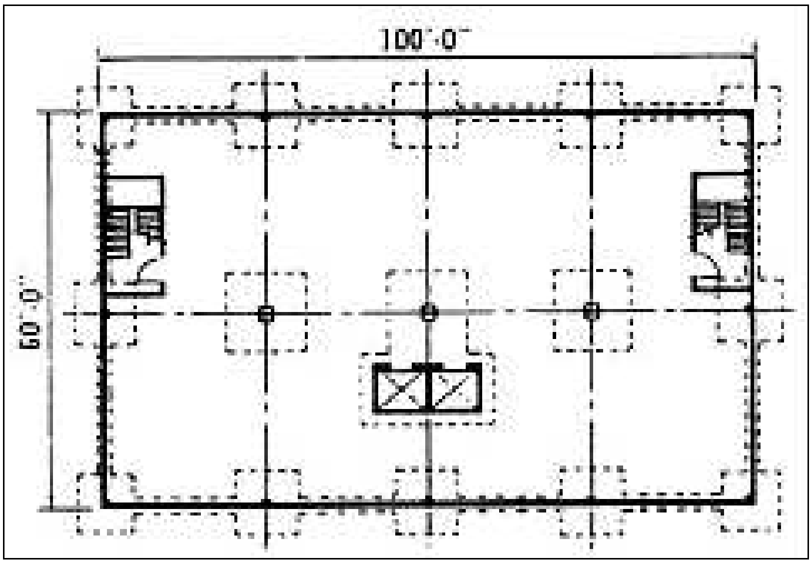

Figure A 1.2 Basement Plan

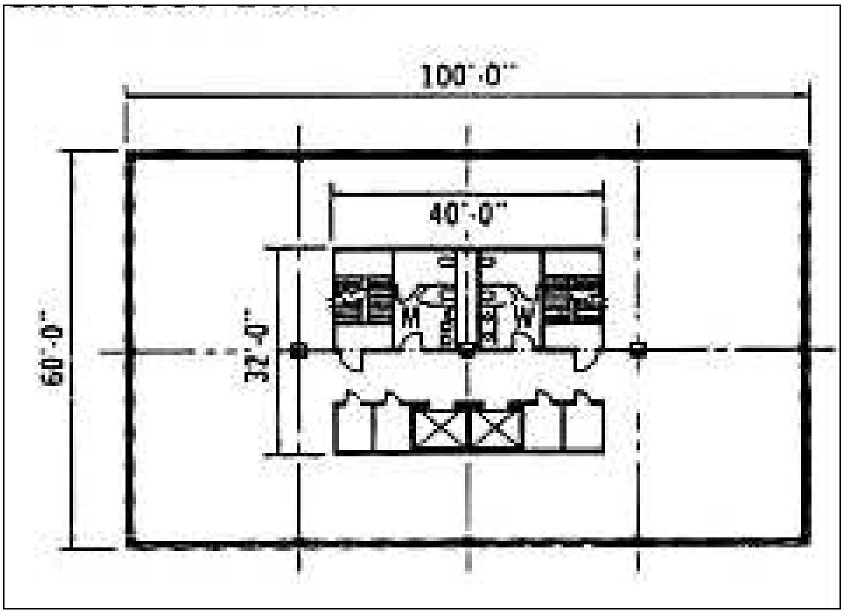

Figure A 1.3 Typical Floor plan

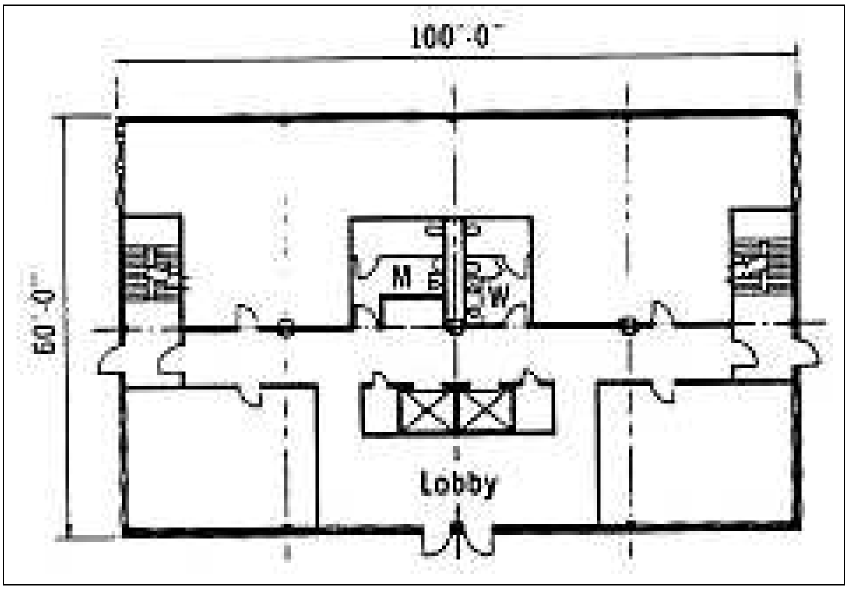

Figure A 1.4 Ground Floor Plan

Appendix 2: Athena Life Cycle Environmental Impact Results of Case study

3.1 Base Office Building

Table A.1.1 Energy consumption of Base Office by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Electricity kWh	6140.058848	1743627.36	7915.213911	44421.78423	170224.4992	5417.288748	**1977746.205**
Hydro MJ	20478.84566	6566331.38	12706.21862	82867.55416	551663.3668	2130.326519	**7236177.691**
Coal MJ	39567.5859	802474.6607	13098.66989	231669.9624	907905.8551	30816.65254	**2025533.387**
Diesel MJ	55424.3055	1246962.259	9559.879207	99189.38865	1295945.663	11577.99424	**2718659.489**
Feedstock MJ	35829.71264	4885228.016	227013.7274	1174038.802	951232.9324	0	**7273343.19**
Gasoline MJ	2.041766696	175.423209	37.01902162	226.2519904	25.74742594	0	**466.4834137**
Heavy Fuel Oil MJ	24395.59276	534552.1695	8880.20393	713918.0141	464900.3067	181.6879299	**1746827.975**
LPG MJ	94.89517317	5043.299491	40.05377173	1248.330295	2342.007111	44.65238828	**8813.23823**
Natural Gas MJ	44408.22661	6157099.211	48681.08968	386338.8671	1661712.146	42697.93746	**8340937.478**
Nuclear MJ	3932.874464	202898.3441	22907.28173	114380.8122	64804.0437	7758.077928	**416681.4341**
Wood MJ	0	5364.079072	0	0	0	0	**5364.079072**

Table A.2. 2 Solid Waste Emissions Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Bark/Wood Waste kg	1226.178422	1074.7717	0	561.8775859	15598.79203	0	**18461.61974**
Concrete Solid Waste kg	7071.868383	412019.7256	0	4233.54795	157449.0208	17.97451561	**580792.1372**
Blast Furnace Slag kg	157.0960783	21471.94215	2423.415617	2088.84957	7455.16366	0	**33596.46707**
Blast Furnace Dust kg	356.9412126	7889.9337	232.7239826	404.2882812	8854.86605	0	**17738.75323**
Steel Waste kg	1.546836062	49.16428877	21.73931136	0	200.6705664	0	**273.1210026**
Other Solid Waste kg	548.311665	27018.7608	168.1461956	6175.191674	41270.36458	476.370578	**75657.1455**

Table A.2.3 Resource Use Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Limestone kg	28505.30861	106834.8725	1575.546526	23503.94095	593899.5735	0	**754319.242**
Clay & Shale kg	3996.289957	8033.54533	0	2347.155743	89257.71644	0	**103634.7075**
Iron Ore kg	1037.340185	42141.23731	14698.97069	13203.66238	14708.18088	0	**85789.39144**
Sand kg	1944.14106	63684.00542	0	1010.536838	40270.92777	0	**106909.6111**
Ash kg	0	1.319282902	0	0.420898486	10.10156367	0	**11.84174506**
Other kg	59.38720923	249955.117	0	27524.95895	37551.01777	5.88170051	**315096.3627**
Gypsum kg	1.62011755	16170.67841	0	5061.259964	128107.4331	61.75405131	**149402.7456**
Semi-Cementitious Material kg	2151.980268	2472.261378	0	1133.119798	43483.06377	0	**49240.42521**
Coarse Aggregate kg	92109.98143	115839.1253	0	90853.47732	1531725.988	0	**1830528.572**
Fine Aggregate kg	79335.5002	274765.1956	0	47642.53697	1012734.582	0	**1414477.815**
Water L	81703.29955	3359282.652	931622.9869	738631.8001	1437209.027	0	**6548449.766**
Obsolete Scrap Steel kg	293.2340396	120269.4607	2460.224952	3412.334462	45347.20464	0	**171782.4588**
Coal kg	3246.187413	52706.47777	672.6328346	12202.70338	72315.16165	1515.532592	**142658.6956**
Wood Fiber kg	0	2707.988404	0	0	0	0	**2707.988404**
Phenol Form. Resins kg	0	19.07612532	0	0	0	0	**19.07612532**
Uranium kg	0.006220906	0.320969209	0.036245353	0.180979322	0.102491548	0.012274839	**0.659181177**
Natural Gas m3	1428.458584	168206.7592	1288.575543	12707.94676	45840.70075	1130.646331	**230603.0871**
Crude Oil L	1968.049531	84908.55093	335.2208985	41985.24962	36760.18591	73.44831192	**166030.7052**
Metallurgical Coal kg	356.4224568	16453.44649	6477.190197	4779.179448	4498.45912	0	**32564.69771**
Prompt Scrap Steel kg	193.5645751	84491.54851	1526.204878	1503.273236	32454.20325	0	**120168.7945**

Table A.2.4 Emissions to Water Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
2-Hexanone mg	43.99353316	3578.277082	30.90845794	575.3965783	1307.894931	23.08343353	**5559.554017**
Acetone mg	67.37575415	5480.17588	47.33657945	881.2117616	2003.040549	35.35265528	**8514.49318**
Acids, unspecified mg	26723.03708	47504317.46	0	885271.613	1741178.371	2174247.426	**52331737.91**
Aluminum mg	404194.7066	16138375.82	159090.3108	6070863.673	10017432.07	141426.1982	**32931382.78**
Ammonia mg	111837.8441	7294969.121	65210.2878	1505870.866	3088117.013	44895.77401	**12110900.91**
Ammonium, ion mg	15079.38196	16704923.81	3.289577205	104712.4469	354345.5277	6172.537702	**17185237**
Antimony mg	247.8765614	9549.226724	98.40364882	3774.062517	5957.042339	48.46183974	**19675.07363**
Arsenic, ion mg	1703.064896	125354.5974	1102.539741	22934.71268	48878.78888	792.3582862	**200766.0619**
Barium mg	5542243.628	227369794.5	2299122.578	83688954.39	135037117.1	1190123.017	**455127355.2**
Benzene mg	11302.88238	919352.2479	7941.160834	147830.9162	336028.407	5930.753094	**1428386.367**
Benzene, 1-methyl-4-(1-methylethyl)- µg	673.2862595	54763.63609	473.0361833	8805.943143	20016.42253	353.2808831	**85085.60509**
Benzene, ethyl- mg	635.8140954	51715.73364	446.7090732	8315.842837	18902.39635	333.6188294	**80350.11482**
Benzene, pentamethyl- µg	504.967817	41072.46079	354.7756179	6604.524277	15012.3405	264.9583005	**63814.0273**
Benzenes, alkylated, unspecified mg	217.3751403	8363.628838	86.21964046	3310.190233	5222.618367	42.41739097	**17242.44961**
Benzoic acid mg	6834.881796	555938.1736	4802.065366	89393.55524	203197.7037	3586.368624	**863752.7483**
Beryllium mg	88.63634687	5906.172068	52.97127611	1224.622537	2461.678945	36.48703233	**9770.568206**
Biphenyl µg	14074.17509	541522.849	5582.458276	214321.0815	338145.2377	2746.443133	**1116392.245**
Boron mg	21146.88312	1720027.765	14857.24002	276581.7757	628683.155	11095.90322	**2672392.722**
Bromide mg	1443685.953	117442747.4	1014419.77	18881211.27	42922165.94	757644.9987	**182461875.3**
Cadmium, ion mg	250.1014901	18294.66991	161.0975233	3373.770676	7162.847769	115.4832697	**29357.97064**

Calcium, ion mg	21648953.74	1761313245	15213182.61	283125912.7	643669067.5	11362791.26	**2736333153**
Chloride mg	257939655.4	24133093457	254738179.3	3254300530	7508760572	127720790.1	**35536553184**
Chromium mg	9195.116364	181066.2898	2414.318394	148682.9034	197936.6388	466.1980557	**539761.4647**
Chromium VI µg	38689.7039	761861.064	10158.57332	625603.5571	832845.3543	1961.591786	**2271119.844**
Chromium, ion mg	2061.690805	250937.9271	2042.67356	22791.37351	72370.11124	1721.87637	**351925.6526**
Cobalt mg	149.2712543	12141.4326	104.8749596	1952.324143	4437.755157	78.32457202	**18863.98269**
COD, Chemical Oxygen Demand mg	4354417.857	1512089268	26391527.26	51164872.41	90828736.99	1029219.311	**1685858041**
Copper, ion mg	1538.35231	89008.80435	824.9749974	22268.79973	40854.80372	527.6713268	**155023.4064**
Cyanide mg	437222.7858	20203106.1	7953441.163	6101664.922	5574100.482	16.05538188	**40269551.51**
Decane mg	196.3998401	15974.557	137.9849588	2568.731796	5838.833346	103.0518417	**24819.55878**
Detergents, oil mg	6085.282732	533809.4597	4552.656547	77642.11337	186081.1874	3491.709961	**811662.4097**
Dibenzofuran µg	1281.128594	104204.5709	900.0955024	16755.92377	38087.28246	672.2254076	**161901.2267**
Dibenzothiophene µg	483.6241031	73511.5665	583.7122249	4611.949579	18925.43299	516.5388055	**98632.8242**
Dissolved organic matter mg	198430.3366	9577397.293	85.52900733	1277243.477	5137758.145	43622.34032	**16234537.12**
Dissolved solids mg	305593267.6	26309587850	210940244.4	3957816459	8926717485	157548806.1	**39868204112**
Docosane µg	7209.802912	586434.2363	5065.48242	94297.12649	214344.004	3783.100081	**911133.7522**
Dodecane mg	372.6370371	30309.49543	261.8067046	4873.737031	11078.29145	195.5269382	**47091.49459**
Eicosane mg	102.5969115	8345.046586	72.08261147	1341.868022	3050.153578	53.83404363	**12965.58175**
Fluorene, 1-methyl- µg	766.8016835	62369.65521	538.7357776	10029.05196	22796.5408	402.347007	**96903.13244**
Fluorenes, alkylated, unspecified µg	12597.4526	484702.6867	4996.713839	191833.6634	302665.4273	2458.264799	**999254.2085**
Fluoride mg	12788.78508	129695.3368	285.0966911	620351.877	272068.2642	0	**1035189.36**
Fluorine µg	6400.623396	271115.7687	2716.101673	96222.93885	157086.808	1440.045716	**534982.2863**
Halogenated organics µg	0	2.21005E-05	0	0	0.001040354	0	**0.001062455**

Hexadecane mg	406.7321127	33082.44557	285.7592384	5319.681638	12091.88312	213.4149403	**51399.91662**
Hexanoic acid mg	1415.433428	115128.3334	994.4529975	18512.51814	42080.04987	742.6943606	**178873.4822**
Hydrocarbons, unspecified µg	19675.05397	199531.2873	438.610294	10934.42509	418566.5602	0	**649145.9369**
Iron mg	1020200.888	88559799.3	3229120.179	14803784.38	24298122.11	299257.5589	**132210284.4**
Lead mg	3186.261112	194629.9555	1777.010519	486465.3364	86144.09405	1175.782666	**773378.4402**
Lead-210/kg µg	0.000700016	0.056941037	0.000491842	0.009155434	0.020811578	0.000367332	**0.088467238**
Lithium, ion mg	3111006.722	507138400	3999387.097	27949552.59	126300585.8	3586175.749	**672085108**
Magnesium mg	4236891.761	344384695.1	2974275.396	55351876.35	125933873	2221444.192	**535103055.7**
Manganese mg	15561.06186	725102.0861	7592.530058	136862.2299	403236.8153	10587.72763	**1298942.451**
Mercury µg	4343.910474	167136.2871	1722.981704	66149.00401	104366.315	847.6616506	**344566.16**
Metallic ions, unspecified mg	12788.78508	129695.3368	285.0966911	7107.376309	272068.2642	0	**421944.859**
Methane, monochloro-, R-40 µg	271.1946368	22058.37135	190.5353493	3546.968059	8062.463112	142.298811	**34271.83131**
Methyl ethyl ketone µg	542.3693262	44115.03888	381.0561035	7093.679301	16124.32238	284.5865299	**68541.05252**
Molybdenum mg	154.8846404	12597.94709	108.81833	2025.745204	4604.62918	81.26947069	**19573.29391**
m-Xylene mg	204.1383034	16604.41286	143.4248753	2669.922163	6068.950221	107.1155771	**25797.964**
Naphthalene mg	122.5984573	9956.976826	86.02853747	1604.218829	3642.798686	64.21411189	**15476.83545**
Naphthalene, 2-methyl- mg	106.7209859	8680.462805	74.97990312	1395.808342	3172.756403	55.99778429	**13486.72622**
Naphthalenes, alkylated, unspecified µg	3562.014903	137052.1814	1412.849052	54242.30458	85580.5922	695.0849912	**282545.0271**
n-Hexacosane µg	4497.964667	365852.6519	3160.157316	58829.19422	133721.7003	2360.117454	**568421.7859**
Nickel mg	1563.098669	103471.9765	929.2703708	26350.55602	43320.71106	638.1945919	**176273.8072**
Nitrate mg	541199.516	22588995.06	8660557.564	7550593.476	7820931.866	306.6707477	**47162584.15**
Nitrogen, total mg	1574.004318	15962.50299	35.08882352	2142491.129	33485.32482	0	**2193548.05**
Non-halogenated Organics µg	27767866.84	2146449445	69430490.12	245440064.4	66684154.06	0	**2555772021**

o-Cresol mg	193.8249199	15765.35049	136.1775314	2535.042667	5762.313271	101.7025351	**24494.41142**
Octadecane mg	100.4832997	8173.110895	70.59749765	1314.224952	2987.314543	52.72486069	**12698.45605**
Oils, unspecified mg	12664567.84	1001746912	223259629.9	174952581.2	166898125.2	71430.69191	**1579593247**
Other mg	334136.7474	3454026082	2428801.114	2081320.808	3863212.468	0	**3462733553**
Other metals mg	232367.4745	508143428.5	1927700.002	4127974.105	14342041.01	683.4450465	**528774194.6**
p-Cresol mg	209.1241459	17010.02605	146.9283589	2735.128444	6217.186584	109.7322864	**26428.12587**
Pentanone, methyl- mg	28.3151188	2303.060768	19.89337373	370.3362587	841.7886946	14.85703684	**3578.251251**
Phenanthrene µg	1467.274471	82107.22825	765.0833092	21057.51588	38666.09288	483.5672983	**144546.7621**
Phenanthrenes, alkylated, unspecified µg	1476.957002	56827.40239	585.8247275	22491.07879	35485.2076	288.2103847	**117154.6809**
Phenol µg	7678550.145	845338634.1	82512124.26	191475737.8	127227503.1	98357.84761	**1254330907**
Phenol, 2,4-dimethyl- mg	188.7257869	15350.55804	132.594706	2468.352874	5610.713574	99.02665424	**23849.97163**
Phenols, unspecified mg	1535.332086	216057.0291	1729.481539	35814.24732	57777.25587	1506.680584	**314420.0265**
Phosphate mg	10821.53722	86426166.22	68486.43513	30490.89636	1939937.967	0	**88475903.06**
Phosphorus mg	73767.60559	31506083.28	596981.0868	694961.1044	12074162.32	0	**44945955.4**
Polynuclear Aromatic Hydrocarbons µg	0	477.9385937	0	0	0	0	**477.9385937**
Radium-226/kg µg	0.243554546	19.80977357	0.17111307	3.185482139	7.24068387	0.127792562	**30.77839975**
Radium-228/kg µg	0.001245742	0.101330134	0.000875275	0.01629427	0.037035676	0.000653681	**0.157434779**
Selenium µg	48185.03319	1871167.575	19235.02758	732898.6029	1159977.129	9534.984315	**3840998.352**
Silver mg	14138.2806	1148725.368	9924.313214	184977.9951	420156.6045	7408.891679	**1785331.453**
Sodium, ion mg	68627001.9	5583213891	48224702.54	897513505.1	2040407673	36018920.12	**8674005694**
Strontium mg	367305.8421	29875449.88	258058.1418	4804031.022	10919742.42	192726.3878	**46417313.7**
Sulfate mg	8041018.338	199512440.2	348048.5286	27479080.33	546732874.1	2032202.089	**784145663.6**
Sulfide mg	1288294.807	61978929.49	23371117.95	17969222.68	17236352.6	20.67577199	**121843938.2**
Sulfur mg	17850.94004	1451956.748	12541.68112	233473.2866	530698.4547	9366.590925	**2255887.702**

Suspended solids, unspecified mg	43182112.7	4901845583	464763931.8	575019898.9	1183609377	2789831.969	**7171210735**
Tetradecane mg	163.3120743	13283.4536	114.7395275	2135.966138	4855.177037	85.69172783	**20638.3401**
Thallium µg	52253.01608	2015879.6	20764.28483	795437.78	1256142.812	10238.01041	**4150715.503**
Tin mg	1182.795753	69022.09501	636.9754725	16832.74657	31546.53482	411.6034213	**119632.7511**
Titanium, ion mg	3807.316135	146766.0963	1512.113974	57963.92521	91510.86026	745.072519	**302305.3844**
Toluene mg	10678.71481	868582.9805	7502.628382	139667.4408	317472.144	5603.238893	**1349507.147**
Vanadium mg	182.958134	14881.43535	128.5425195	2392.917183	5439.245239	96.00034504	**23121.09877**
Xylene mg	3255.839026	73272.68085	920.2523818	52186.90934	71305.01669	235.5068866	**201176.2052**
Yttrium mg	45.40562763	3693.135148	31.90057445	593.8653604	1349.875891	23.82438601	**5738.006987**
Zinc mg	9367.587825	389414.2286	3922.488492	141196.1868	228921.8771	2050.858169	**774873.227**

Table A.2.5 Emissions to Air Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
2-Chloroacetophenone g	0.004970653	0.062222847	0	0.020182695	0.103446518	0	**0.190822713**
Acenaphthene g	0.000388723	0.007546829	0.000125643	0.002146286	0.008915574	0.000314167	**0.019437222**
Acenaphthylene g	0.00019055	0.003699426	6.15896E-05	0.001052101	0.004370379	0.000154004	**0.00952805**
Acetaldehyde g	3.14862619	61.24425414	0.81952312	12.52715648	61.08789561	0.000493766	**138.8279493**
Acetophenone g	0.0106514	0.133334673	0	0.043248631	0.22167111	0	**0.408905814**
Acid Gases g	0	3286.143752	0	267.282254	842.0698844	0	**4395.495891**
Acrolein g	0.452107188	19.03842919	0.170278355	2.12761148	9.343090488	0.17870176	**31.31021846**
Aldehydes g	0.003203203	0.171634856	0.02065462	0.099111105	0.050183405	0.007130017	**0.351917206**
Ammonia g	15.76943013	380.5748425	7.245983634	359.2805241	339.6065253	1.673920316	**1104.151226**
Ammonium chloride g	0.871681422	46.70666054	5.620701587	26.97091275	13.65631279	1.940277654	**95.76654674**
Anthracene g	0.000160062	0.003107518	5.17352E-05	0.000883765	0.003671119	0.000129363	**0.008003562**
Antimony g	0.013719623	0.284570769	0.004434399	0.075751016	0.314666768	0.011088136	**0.704230711**
Arsenic g	0.33743991	7.883002911	0.139975063	4.156674716	7.914345786	0.264608965	**20.69604735**
Benzene g	71.14736062	938.3573837	1.361363395	290.5413692	1478.004064	0.837344171	**2780.248885**
Benzene, chloro- g	0.015622053	0.19555752	0	0.063431326	0.325117628	0	**0.599728527**
Benzene, ethyl- g	0.066748772	0.835563951	0	0.271024756	1.389138956	0	**2.562476435**
Benzo(a)anthracene g	6.09761E-05	0.001183816	1.97087E-05	0.000336672	0.001398521	4.92812E-05	**0.003048976**
Benzo(a)pyrene g	2.89637E-05	0.000562313	9.36161E-06	0.000159919	0.000664298	2.34085E-05	**0.001448264**
Benzo(b,j,k)fluoranthene g	8.38422E-05	0.001627747	2.70994E-05	0.000462924	0.001922967	6.77616E-05	**0.004192342**
Benzo(ghi)perylene g	2.05794E-05	0.000399538	6.65167E-06	0.000113627	0.000472001	1.66324E-05	**0.001029029**
Benzyl chloride g	0.497065325	6.222284743	0	2.018269456	10.3446518	0	**19.08227132**
Beryllium g	0.014169477	0.380944887	0.006136825	0.131290286	0.336486886	0.013317765	**0.882346126**
Biphenyl g	0.001295743	0.025156097	0.000418809	0.007154288	0.029718579	0.001047225	**0.06479074**
Bromoform g	0.02769364	0.34667015	0	0.112446441	0.576344886	0	**1.063155117**
Butadiene g	0.139882202	2.863921735	0.041779156	0.5548497	2.684822266	2.51721E-05	**6.285280232**
Cadmium g	0.108173173	4.326499187	0.043359084	1.27173364	2.696108207	0.052128396	**8.498001687**
Carbon dioxide, biogenic kg	0	472.6587636	0	3.683353251	0	0	**476.3421169**
Carbon dioxide, fossil kg	21651.9381	681841.3486	22124.79877	126360.5897	478563.0255	4962.233519	**1335503.934**

Carbon disulfide g	0.092312132	1.155567167	0	0.37482147	1.92114962	0	**3.543850388**
Carbon monoxide g	21653.0811	7794970.54	253996.7592	302562.7294	250865.4381	0	**8624048.548**
Carbon monoxide, fossil g	18578.17298	554891.1878	6287.744808	273635.9342	415217.2214	2455.540309	**1271065.802**
Chlorine g	0	1.821327708	0	0	0	0	**1.821327708**
Chloroform g	0.041895506	0.524449714	0	0.170111283	0.871906366	0	**1.608362869**
Chromium g	0.231397988	7.976765469	0.1122985	2.809676995	5.741386011	0.188769396	**17.06029436**
Chromium VI g	0.060213831	1.169005625	0.019461761	0.33246104	1.381033906	0.048663784	**3.010839946**
Chrysene g	7.62202E-05	0.00147977	2.46358E-05	0.00042084	0.001748152	6.16014E-05	**0.00381122**
Chrysene, 5-methyl- g	1.67684E-05	0.000325549	5.41988E-06	9.25849E-05	0.000384593	1.35523E-05	**0.000838468**
Cobalt g	0.485430762	11.19670134	0.187187602	12.64596348	11.06667217	0.102923434	**35.68487879**
Copper g	0	0.089197159	0	0.001555496	0.001243539	0	**0.091996194**
Cumene g	0.003763495	0.047111584	0	0.015281183	0.078323792	0	**0.144480054**
Cyanide g	1.775233305	22.22244551	0	7.2081052	36.94518499	0	**68.15096901**
Dinitrogen monoxide g	533.2161249	6836.842115	9.377578424	2394.226561	11104.24443	13.38457417	**20891.29139**
Ethane, 1,1,1-trichloro-, HCFC-140 g	0.014273192	0.17947188	2.59654E-05	0.05928829	0.29710452	5.1468E-06	**0.550168995**
Ethane, 1,2-dibromo- g	0.000852112	0.010666774	0	0.00345989	0.017733689	0	**0.032712465**
Ethane, 1,2-dichloro- g	0.028403733	0.355559128	0	0.115329683	0.59112296	0	**1.090415504**
Ethane, chloro- g	0.02982392	0.373337085	0	0.121096167	0.620679108	0	**1.144936279**
Ethene, tetrachloro- g	0.037530728	0.755838444	0.012479943	0.323369332	0.861459007	0.026993466	**2.01767092**
Fluoranthene g	0.000541163	0.01050637	0.000174914	0.002987967	0.012411877	0.00043737	**0.027059662**
Fluorene g	0.000693604	0.013465911	0.000224186	0.003829648	0.015908181	0.000560573	**0.034682102**
Fluoride g	31.68548428	397.4443778	0.126271298	129.1812096	659.3202263	0.04358911	**1217.801158**
Formaldehyde g	12.34283992	384.4897281	3.576561275	113.1085289	275.8494275	1.599778357	**790.9668641**
Furan g	2.60543E-07	2.95436E-05	1.23179E-06	6.62581E-06	1.35172E-05	3.08007E-06	**5.42591E-05**
Hexane g	0.047576253	0.59556154	0	0.193177219	0.990130958	0	**1.826445969**
Hydrazine, methyl g	0.120715865	1.511126295	0	0.490151154	2.512272579	0	**4.634265892**
Hydrocarbons, unspecified g	24367.64844	2899289.393	29955.46076	234660.7143	356706.1024	11.19855753	**3544990.518**
Hydrogen chloride g	545.2800249	86755.43333	314.3295456	4780.877229	13382.22008	1807.31917	**107585.4594**
Hydrogen fluoride g	82.19549508	170128.0751	36.95368159	503.7011727	1953.462855	2016.789467	**174721.1778**
Indeno(1,2,3-cd)pyrene g	4.64943E-05	0.00090266	1.50279E-05	0.000256713	0.001066373	3.75769E-05	**0.002324844**

Isophorone g	0.411854127	5.155607358	0	1.672280406	8.571282918	0	**15.81102481**
Kerosene g	0.417472061	22.36909649	2.691907636	12.91710738	6.5403815	0.929252007	**45.86521707**
Lead g	2.668083135	38.02726789	0.153016265	13.98662284	56.54481189	0.276957666	**111.6567597**
Magnesium g	8.384213067	162.7739344	2.709907083	46.2922676	192.2963175	6.776074137	**419.2327139**
Manganese g	0.488141978	15.47143287	0.207908626	7.817084972	11.44856432	0.327977958	**35.76111072**
Mercaptans, unspecified g	154.0902509	1928.90827	0	625.6635314	3206.842057	0	**5915.50411**
Mercury g	0.944614327	12.95393439	0.028232643	4.145044931	19.88173154	0.0561501	**38.00970793**
Metals, unspecified g	20.68733974	168.5813639	7.2248E-07	0.075531747	0.000816135	0	**189.3450523**
Methacrylic acid, methyl ester g	0.014201866	0.177779564	0	0.057664842	0.29556148	0	**0.545207752**
Methane g	15911.26227	1545121.393	12297.0919	107486.9935	467521.249	14139.26686	**2162477.256**
Methane, bromo-, Halon 1001 g	0.113614932	1.422236513	0	0.461318733	2.364491839	0	**4.361662016**
Methane, dichloro-, HCC-30 g	0.547277094	13.01029991	0.199640631	11.00139543	12.40002444	0.208377231	**37.36701474**
Methane, dichlorodifluoro-, CFC-12 g	8.82002E-05	0.002092486	3.21149E-05	0.002008369	0.001907989	6.35559E-06	**0.006135514**
Methane, fossil g	4265.269554	275385.2135	2664.803372	76571.10134	115918.3019	1678.235563	**476482.9252**
Methane, monochloro-, R-40 g	0.376349461	4.711158448	0	1.528118302	7.832379218	0	**14.44800543**
Methane, tetrachloro-, CFC-10 g	8.82271E-06	0.103955923	3.21026E-06	0.000200524	0.000190918	6.39684E-07	**0.104360038**
Methyl ethyl ketone g	0.276936396	3.4667015	0	1.124464411	5.763448859	0	**10.63155117**
Naphthalene g	0.095176605	3.617568607	0.044599525	2.425290926	2.31998242	0.025527603	**8.528145685**
Nickel g	6.018630521	143.1862856	2.367427858	173.085124	137.2308198	0.767616407	**462.6559041**
Nitrogen oxides g	72452.46549	3262459.641	20199.31961	633827.9808	1424724.528	985.1509877	**5414649.086**
NMVOC, non-methane volatile organic compounds, uns g	0	0	0	2201.641926	0	0	**2201.641926**
Organic acids g	0.003203203	0.171634856	0.02065462	0.099111105	0.050183405	0.007130017	**0.351917206**
Organic substances, unspecified g	4.618225702	89.64693545	1.49225041	25.49233088	105.918994	3.731274145	**230.9000106**
Other g	5.90981102	13508.34402	0	18423.02504	0	0	**31937.27887**
PAH, polycyclic aromatic hydrocarbons g	0.614788719	12.44477526	0.179815161	2.391618514	11.82856918	0.000108154	**27.45967499**
Particulates, > 2.5 um, and < 10um g	3459.448472	66096.47521	344.4579352	18270.04626	73898.89421	249.7386352	**162319.0607**

Particulates, unspecified g	54814.37916	6319049.231	15941.61148	703670.6916	1224981.5	8079.002577	**8326536.416**
Phenanthrene g	0.002057945	0.039953801	0.000665167	0.011362692	0.047200096	0.001663239	**0.102902941**
Phenol g	0.011361493	36.88142797	0	0.046131873	0.236449184	0	**37.17537052**
Phenols, unspecified g	0.258010965	6.420203251	0.100536798	7.43713242	5.803081133	0.032262127	**20.0512267**
Phthalate, dioctyl- g	0.051836813	0.648895409	0	0.210476672	1.078799402	0	**1.990008295**
Propanal g	0.269835462	3.377811718	0	1.09563199	5.615668119	0	**10.35894729**
Propene g	9.229978052	188.9728242	2.756753107	36.61116628	177.1551366	0.001660955	**414.7275192**
Pyrene g	0.000251527	0.004883242	8.12982E-05	0.001388773	0.005768901	0.000203285	**0.012577026**
Radioactive species, unspecified MBq	3.007623575	336.2223553	13.96496658	76.69041165	154.3817166	34.86297515	**619.1300489**
Radionuclides (Including Radon) g	23.34537787	1250.898106	150.5336688	722.3351719	365.7434637	51.96452955	**2564.820318**
Selenium g	1.037495026	20.60082051	0.338973953	6.86365467	23.79467992	0.805747289	**53.44137137**
Styrene g	0.017752333	0.222224455	0	0.072081052	0.36945185	0	**0.68150969**
Sulfur dioxide g	41150.77529	3079043.982	28523.92942	281470.5167	1221130.253	37414.4084	**4688733.864**
Sulfur oxides g	14294.96638	810843.5979	38574.49897	186039.4626	162097.0157	180.6691544	**1212030.211**
Sulfuric acid, dimethyl ester g	0.034084479	0.426670954	0	0.13839562	0.709347552	0	**1.308498605**
t-Butyl methyl ether g	0.024853266	0.311114237	0	0.100913473	0.51723259	0	**0.954113566**
TOC, Total Organic Carbon g	0	9.429405475	0	0	0	0	**9.429405475**
Toluene g	1.633627598	32.0907412	0.437021135	6.495854188	31.63069589	0.000263307	**72.28820332**
Toluene, 2,4-dinitro- g	0.000198826	0.002488914	0	0.000807308	0.004137861	0	**0.007632909**
Vinyl acetate g	0.005396709	0.067556234	0	0.02191264	0.112313362	0	**0.207178946**
VOC, volatile organic compounds g	2644.418708	126756.954	882.0137862	32851.79863	62172.88605	709.2696208	**226017.3408**
Xylene g	1.045878319	21.20408929	0.304529314	4.150993288	20.11652533	0.00018348	**46.82219903**
Zinc g	0	0.059464773	0	0.001036998	0.000829026	0	**0.061330796**

3.2 Pre-Cast Office

Table A.2. 6 Energy consumption of Base Office by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Electricity kWh	6130.280337	1743627.36	7915.213911	40603.65752	89464.43728	5417.288748	**1893158.237**
Hydro MJ	20470.18928	6566331.38	12706.21862	78780.65329	235123.503	2130.326519	**6915542.27**
Coal MJ	39537.92332	802474.6607	13098.66989	250676.0091	562507.9807	30816.65254	**1699111.896**
Diesel MJ	55420.64053	1246962.259	9559.879207	121432.3447	720163.8732	11577.99424	**2165116.991**
Feedstock MJ	35769.13302	4885228.016	227013.7274	1084065.747	352457.0962	0	**6584533.719**
Gasoline MJ	2.041766696	175.423209	37.01902162	204.6777414	25.00563851	0	**444.1673772**
Heavy Fuel Oil MJ	24366.67571	534552.1695	8880.20393	725613.1926	281293.451	181.6879299	**1574887.381**
LPG MJ	94.78376403	5043.299491	40.05377173	1275.304114	1453.462425	44.65238828	**7951.555955**
Natural Gas MJ	44243.85941	6157099.211	48681.08968	356260.805	1043581.021	42697.93746	**7692563.923**
Nuclear MJ	3895.233508	202898.3441	22907.28173	101045.3755	52362.83492	7758.077928	**390867.1477**
Wood MJ	0	5364.079072	0	0	0	0	**5364.079072**

Table A.2. 7 Solid Waste Emissions Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Bark/Wood Waste kg	1226.178422	1074.7717	0	0	0	0	**2300.950122**
Concrete Solid Waste kg	7071.868383	412019.7256	0	5664.075455	75902.9675	17.97451561	**500676.6115**
Blast Furnace Slag kg	157.0960783	21471.94215	2423.415617	935.3043131	2359.099383	0	**27346.85754**
Blast Furnace Dust kg	356.9412126	7889.9337	232.7239826	538.5385209	4004.077739	0	**13022.21515**
Steel Waste kg	1.546836062	49.16428877	21.73931136	0	0	0	**72.45043619**
Other Solid Waste kg	547.8530485	27018.7608	168.1461956	6378.81244	39200.01587	476.370578	**73789.95893**

Table A.2.8 Resource Use Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Limestone kg	28505.30861	106834.8725	1575.546526	43992.27685	308864.1161	0	**489772.1206**
Clay & Shale kg	3996.289957	8033.54533	0	5334.093919	49547.66954	0	**66911.59874**
Iron Ore kg	1037.340185	42141.23731	14698.97069	5434.077759	12330.98923	0	**75642.61517**
Sand kg	1944.14106	63684.00542	0	2463.641897	20952.52657	0	**89044.31495**
Ash kg	0	1.319282902	0	0.420898486	10.10156367	0	**11.84174506**
Other kg	59.38720923	249955.117	0	27473.19871	41142.48581	5.88170051	**318636.0704**
Gypsum kg	1.62011755	16170.67841	0	5062.470885	128190.6663	61.75405131	**149487.1898**
Semi-Cementitious Material kg	2151.980268	2472.261378	0	2598.301643	22081.61252	0	**29304.1558**
Coarse Aggregate kg	92109.98143	115839.1253	0	126596.4392	744397.9807	0	**1078943.527**
Fine Aggregate kg	79335.5002	274765.1956	0	59460.61676	505042.7865	0	**918604.0991**
Water L	81672.87669	3359282.652	931622.9869	350340.431	898338.656	0	**5621257.603**
Obsolete Scrap Steel kg	293.2340396	120269.4607	2460.224952	1661.464803	6918.777242	0	**131603.1618**
Coal kg	3244.723619	52706.47777	672.6328346	14082.23511	41764.43388	1515.532592	**113986.0358**
Wood Fiber kg	0	2707.988404	0	0	0	0	**2707.988404**
Phenol Form. Resins kg	0	19.07612532	0	0	0	0	**19.07612532**
Uranium kg	0.006161347	0.320969209	0.036245353	0.159878514	0.082828604	0.012274839	**0.618357867**
Natural Gas m3	1423.301312	168206.7592	1288.575543	11885.29957	29348.78189	1130.646331	**213283.3638**
Crude Oil L	1966.521688	84908.55093	335.2208985	42964.91179	21316.83565	73.44831192	**151565.4893**
Metallurgical Coal kg	356.4224568	16453.44649	6477.190197	2181.718803	4365.329009	0	**29834.10695**
Prompt Scrap Steel kg	193.5645751	84491.54851	1526.204878	1024.38957	4783.254224	0	**92018.96176**

Table A.2.9 Emissions to Water Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
2-Hexanone mg	43.89515474	3578.277082	30.90845794	569.4314528	821.3774193	23.08343353	**5066.973001**
Acetone mg	67.22508648	5480.17588	47.33657945	872.0755122	1257.939482	35.35265528	**7760.105196**
Acids, unspecified mg	26646.93558	47504317.46	0	31600.75007	2321571.161	2174247.426	**52058383.73**
Aluminum mg	403745.0108	16138375.82	159090.3108	6186332.178	6323913.22	141426.1982	**29352882.73**
Ammonia mg	111635.8421	7294969.121	65210.2878	1508779.262	1925304.771	44895.77401	**10950795.06**
Ammonium, ion mg	15073.04017	16704923.81	3.289577205	110996.0123	244983.0184	6172.537702	**17082151.71**
Antimony mg	247.5989822	9549.226724	98.40364882	3844.024619	3696.763135	48.46183974	**17484.47895**
Arsenic, ion mg	1699.599831	125354.5974	1102.539741	22832.29523	30641.58172	792.3582862	**182422.9722**
Barium mg	5535675.858	227369794.5	2299122.578	85117961.76	83871664.08	1190123.017	**405384341.8**
Benzene mg	11277.60643	919352.2479	7941.160834	146298.1902	211030.8918	5930.753094	**1301830.85**
Benzene, 1-methyl-4-(1-methylethyl)- µg	671.7806313	54763.63609	473.0361833	8714.642505	12570.61419	353.2808831	**77546.99048**
Benzene, ethyl- mg	634.3922638	51715.73364	446.7090732	8229.623575	11870.98901	333.6188294	**73231.06639**
Benzene, pentamethyl- µg	503.8386024	41072.46079	354.7756179	6536.053452	9427.973288	264.9583005	**58160.06005**
Benzenes, alkylated, unspecified mg	217.1319927	8363.628838	86.21964046	3371.646477	3240.946904	42.41739097	**15321.99124**
Benzoic acid mg	6819.597275	555938.1736	4802.065366	88466.67757	127611.2277	3586.368624	**787224.1102**
Beryllium mg	88.47212013	5906.172068	52.97127611	1225.323057	1540.524908	36.48703233	**8849.950462**
Biphenyl µg	14058.43196	541522.849	5582.458276	218300.0196	209839.392	2746.443133	**992049.594**
BOD5, Biological Oxygen Demand	1358515.558	190849313.5	833902.3358	16276706.67	23299269.67	618546.2689	**233236254**

mg							
Boron mg	21099.59401	1720027.765	14857.24002	273714.2961	394822.4134	11095.90322	**2435617.211**
Bromide mg	1440457.098	117442747.4	1014419.77	18685280.14	26955834.18	757644.9987	**166296383.5**
Cadmium, ion mg	249.5956084	18294.66991	161.0975233	3359.844112	4489.817431	115.4832697	**26670.50785**
Calcium, ion mg	21600530.2	1761313245	15213182.61	280185976.2	404235664.5	11362791.26	**2493911390**
Chloride mg	257395216.7	24133093457	254738179.3	3192661876	4717469514	127720790.1	**32683079033**
Chromium mg	9189.334921	181066.2898	2414.318394	152968.254	121938.3788	466.1980557	**468042.7739**
Chromium VI µg	38665.37769	761861.064	10158.57332	643634.7534	513072.329	1961.591786	**1969353.689**
Chromium, ion mg	2054.909692	250937.9271	2042.67356	21699.35504	45797.39078	1721.87637	**324254.1326**
Cobalt mg	148.9374473	12141.4326	104.8749596	1932.081957	2786.97708	78.32457202	**17192.62862**
COD, Chemical Oxygen Demand mg	4348025.263	1512089268	26391527.26	39558551.7	58782944.69	1029219.311	**1642199536**
Copper, ion mg	1535.84222	89008.80435	824.9749974	22413.83601	25502.42814	527.6713268	**139813.557**
Cyanide mg	437222.7847	20203106.1	7953441.163	2699356.46	5352817.704	16.05538188	**36645960.27**
Decane mg	195.9606479	15974.557	137.9849588	2542.100831	3666.874354	103.0518417	**22620.52963**
Detergents, oil mg	6070.661649	533809.4597	4552.656547	76437.7968	117024.1166	3491.709961	**741386.4012**
Dibenzofuran µg	1278.263676	104204.5709	900.0955024	16582.19342	23919.38735	672.2254076	**147556.7363**
Dibenzothiophene µg	481.6514674	73511.5665	583.7122249	4212.832683	12028.2699	516.5388055	**91334.57158**
Dissolved organic matter mg	198404.9695	9577397.293	85.52900733	320092.4406	3502408.777	43622.34032	**13642011.35**
Dissolved solids mg	304921473.2	26309587850	210940244.4	3908169163	5605922269	157548806.1	**36497089805**
Docosane µg	7193.679958	586434.2363	5065.48242	93319.40005	134611.2752	3783.100081	**830407.174**
Dodecane mg	371.8037317	30309.49543	261.8067046	4823.205665	6957.33358	195.5269382	**42919.17205**
Eicosane mg	102.3674794	8345.046586	72.08261147	1327.955054	1915.542447	53.83404363	**11816.82822**
Fluorene, 1-methyl- µg	765.0869409	62369.65521	538.7357776	9925.073349	14316.5689	402.347007	**88317.46719**
Fluorenes,	12583.36134	484702.6867	4996.713839	195395.1268	187822.036	2458.264799	**887958.1894**

alkylated, unspecified µg							
Fluoride mg	12788.78508	129695.3368	285.0966911	629641.9888	138492.3243	0	**910903.5316**
Fluorine µg	6392.815958	271115.7687	2716.101673	97790.00927	97610.24501	1440.045716	**477064.9863**
Halogenated organics µg	0	2.21005E-05	0	0	0.001387139	0	**0.001409239**
Hexadecane mg	405.8225697	33082.44557	285.7592384	5264.529452	7593.883258	213.4149403	**46845.85503**
Hexanoic acid mg	1412.26818	115128.3334	994.4529975	18320.57838	26426.90404	742.6943606	**163025.2313**
Hydrocarbons, unspecified µg	19675.05397	199531.2873	438.610294	25226.9048	213065.1142	0	**457936.9706**
Iron mg	1019028.997	88559799.3	3229120.179	13759705.72	15540920.81	299257.5589	**122407832.6**
Lead mg	3180.82078	194629.9555	1777.010519	486664.0329	53817.5793	1175.782666	**741245.1817**
Lead-210/kg µg	0.00069845	0.056941037	0.000491842	0.009060471	0.013070082	0.000367332	**0.080629215**
Lithium, ion mg	3097423.971	507138400	3999387.097	25047778.24	80380516.09	3586175.749	**623249681.1**
Magnesium mg	4227424.942	344384695.1	2974275.396	54780399.74	79077055.99	2221444.192	**487665295.3**
Manganese mg	15539.51287	725102.0861	7592.530058	140234.3877	251646.4651	10587.72763	**1150702.71**
Mercury µg	4339.05149	167136.2871	1722.981704	67377.09444	64765.54745	847.6616506	**306188.6239**
Metallic ions, unspecified mg	12788.78508	129695.3368	285.0966911	16397.48812	138492.3243	0	**297659.0309**
Methane, monochloro-, R-40 µg	270.5881813	22058.37135	190.5353493	3510.192937	5063.347973	142.298811	**31235.3346**
Methyl ethyl ketone µg	541.1564619	44115.03888	381.0561035	7020.132556	10126.31638	284.5865299	**62468.28691**
Molybdenum mg	154.5382824	12597.94709	108.81833	2004.742462	2891.776198	81.26947069	**17839.09183**
m-Xylene mg	203.6817951	16604.41286	143.4248753	2642.237668	3811.392991	107.1155771	**23512.26577**
Naphthalene mg	122.3246868	9956.976826	86.02853747	1587.739488	2287.669999	64.21411189	**14104.95365**
Naphthalene, 2-methyl- mg	106.4823321	8680.462805	74.97990312	1381.336394	1992.53875	55.99778429	**12291.79797**
Naphthalenes, alkylated, unspecified µg	3558.030524	137052.1814	1412.849052	55249.34006	53107.88217	695.0849912	**251075.3682**

n-Hexacosane µg	4487.906199	365852.6519	3160.157316	58219.2694	83979.22931	2360.117454	**518059.3316**
Nickel mg	1560.22035	103471.9765	929.2703708	26369.57699	27107.15456	638.1945919	**160076.3934**
Nitrate mg	541193.1742	22588995.06	8660557.564	3759557.072	7245171.88	306.6707477	**42795781.42**
Nitrogen, total mg	1574.004318	15962.50299	35.08882352	2143634.527	17045.20914	0	**2178251.332**
Non-halogenated Organics µg	27641031	2146449445	69430490.12	65055689.69	46474924.99	0	**2355051581**
o-Cresol mg	193.3914798	15765.35049	136.1775314	2508.758609	3618.819566	101.7025351	**22324.20022**
Octadecane mg	100.2585947	8173.110895	70.59749765	1300.598786	1876.078508	52.72486069	**11573.36914**
Oils, unspecified mg	12664012.66	1001746912	223259629.9	79546903.26	154866929.1	71430.69191	**1472155818**
Other mg	334124.0638	3454026082	2428801.114	1232422.87	1883239.775	0	**3459904669**
Other metals mg	232049.9414	508143428.5	1927700.002	3498499.601	2022067.716	683.4450465	**515824429.2**
p-Cresol mg	208.6564861	17010.02605	146.9283589	2706.767109	3904.487971	109.7322864	**24086.59826**
Pentanone, methyl- mg	28.25180022	2303.060768	19.89337373	366.4968869	528.6558299	14.85703684	**3261.215696**
Phenanthrene µg	1464.964305	82107.22825	765.0833092	21221.97663	24127.27368	483.5672983	**130170.0935**
Phenanthrenes, alkylated, unspecified µg	1475.304917	56827.40239	585.8247275	22908.63721	22020.69605	288.2103847	**104106.0757**
Phenol µg	7677473.573	845338634.1	82512124.26	66445478.22	93900124.41	98357.84761	**1095972192**
Phenol, 2,4-dimethyl- mg	188.3037508	15350.55804	132.594706	2442.760673	3523.61251	99.02665424	**21736.85633**
Phenols, unspecified mg	1529.521203	216057.0291	1729.481539	34716.19152	36666.00547	1506.680584	**292204.9094**
Phosphate mg	10815.19542	86426166.22	68486.43513	33027.67876	269971.018	0	**86808466.55**
Phosphorus mg	73767.60559	31506083.28	596981.0868	422232.9385	1798684.737	0	**34397749.65**
Polynuclear Aromatic Hydrocarbons µg	0	477.9385937	0	0	0	0	**477.9385937**
Radium-226/kg µg	0.243009911	19.80977357	0.17111307	3.152459179	4.5472565	0.127792562	**28.05140479**

Radium-228/kg µg	0.001242956	0.101330134	0.000875275	0.016125296	0.023259149	0.000653681	**0.143486492**
Selenium µg	48130.68615	1871167.575	19235.02758	746353.3833	719924.2053	9534.984315	**3414345.862**
Silver mg	14106.69667	1148725.368	9924.313214	183072.9955	263859.4323	7408.891679	**1627097.697**
Sodium, ion mg	68473503.18	5583213891	48224702.54	888195242.2	1281411881	36018920.12	**7905538140**
Strontium mg	366484.4694	29875449.88	258058.1418	4754226.667	6857760.663	192726.3878	**42304706.21**
Sulfate mg	8039911.387	199512440.2	348048.5286	32697519.93	475116786.5	2032202.089	**717746908.6**
Sulfide mg	1288294.683	61978929.49	23371117.95	7969124.251	15805476.74	20.67577199	**110412963.8**
Sulfur mg	17811.02108	1451956.748	12541.68112	231052.6169	333286.6067	9366.590925	**2056015.265**
Suspended solids, unspecified mg	43166687.02	4901845583	464763931.8	383321117.5	608905315.4	2789831.969	**6404792467**
Tetradecane mg	162.9468695	13283.4536	114.7395275	2113.820233	3049.124175	85.69172783	**18809.77613**
Thallium µg	52194.4266	2015879.6	20764.28483	810157.8816	779539.7121	10238.01041	**3688773.915**
Tin mg	1180.859588	69022.09501	636.9754725	16937.66205	19698.09815	411.6034213	**107887.2937**
Titanium, ion mg	3803.050179	146766.0963	1512.113974	59037.62031	56789.39425	745.072519	**268653.3476**
Toluene mg	10654.83467	868582.9805	7502.628382	138219.363	199377.2763	5603.238893	**1229940.322**
Vanadium mg	182.5489956	14881.43535	128.5425195	2368.107046	3415.927843	96.00034504	**21072.5621**
Xylene mg	3253.553054	73272.68085	920.2523818	53614.88125	43980.14671	235.5068866	**175277.0211**
Yttrium mg	45.3040914	3693.135148	31.90057445	587.708735	847.7420988	23.82438601	**5229.615034**
Zinc mg	9356.353623	389414.2286	3922.488492	143561.6434	142209.6224	2050.858169	**690515.1947**

Table A.2.10 Emissions to Air Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
2-Chloroacetophenone g	0.00496966	0.062222847	0	0.02383195	0.053906166	0	**0.144930623**
Acenaphthene g	0.000388442	0.007546829	0.000125643	0.002336741	0.005538375	0.000314167	**0.016250197**
Acenaphthylene g	0.000190413	0.003699426	6.15896E-05	0.001145461	0.00271489	0.000154004	**0.007965783**
Acetaldehyde g	3.148545299	61.24425414	0.81952312	13.06806766	34.81876931	0.000493766	**113.0996533**
Acetophenone g	0.010649271	0.133334673	0	0.051068464	0.115513212	0	**0.310565621**
Acid Gases g	0	3286.143752	0	264.1787873	0	0	**3550.32254**
Acrolein g	0.45196743	19.03842919	0.170278355	2.192004813	5.736254374	0.17870176	**27.76763592**
Aldehydes g	0.003169469	0.171634856	0.02065462	0.086863292	0.042414133	0.007130017	**0.331866387**
Ammonia g	15.75297121	380.5748425	7.245983634	363.8723002	224.7816368	1.673920316	**993.9016546**
Ammonium chloride g	0.862501482	46.70666054	5.620701587	23.6379392	11.54207575	1.940277654	**90.31015621**
Anthracene g	0.000159947	0.003107518	5.17352E-05	0.000962187	0.002280507	0.000129363	**0.006691258**
Antimony g	0.013709709	0.284570769	0.004434399	0.082472962	0.195471432	0.011088136	**0.591747408**
Arsenic g	0.33710465	7.883002911	0.139975063	4.298070271	5.209693008	0.264608965	**18.13245487**
Benzene g	71.13315104	938.3573837	1.361363395	340.3250255	776.2949216	0.837344171	**2128.309189**
Benzene, chloro- g	0.015618931	0.19555752	0	0.074900414	0.169419378	0	**0.455496244**
Benzene, ethyl- g	0.066735432	0.835563951	0	0.320029043	0.723882796	0	**1.946211222**
Benzo(a)anthracene g	6.09321E-05	0.001183816	1.97087E-05	0.000366548	0.000868765	4.92812E-05	**0.002549051**
Benzo(a)pyrene g	2.89427E-05	0.000562313	9.36161E-06	0.00017411	0.000412663	2.34085E-05	**0.001210799**
Benzo(b,j,k)fluoranthene g	8.37816E-05	0.001627747	2.70994E-05	0.000504003	0.001194551	6.77616E-05	**0.003504944**
Benzo(ghi)perylene g	2.05646E-05	0.000399538	6.65167E-06	0.00012371	0.000293208	1.66324E-05	**0.000860305**
Benzyl chloride g	0.496965986	6.222284743	0	2.383194999	5.390616567	0	**14.49306229**
Beryllium g	0.014155616	0.380944887	0.006136825	0.136966812	0.220807086	0.013317765	**0.772328991**
Biphenyl g	0.001294807	0.025156097	0.000418809	0.007789135	0.01846125	0.001047225	**0.054167323**
Bromoform g	0.027688105	0.34667015	0	0.132778007	0.300334352	0	**0.807470614**
Butadiene g	0.139882202	2.863921735	0.041779156	0.567276419	1.551279127	2.51721E-05	**5.164163812**
Cadmium g	0.108038005	4.326499187	0.043359084	1.307908294	1.674773821	0.052128396	**7.512706786**
Carbon dioxide,	0	472.6587636	0	0	0	0	**472.6587636**

biogenic kg							
Carbon dioxide, fossil kg	21636.42287	681841.3486	22124.79877	125774.4521	273896.5985	4962.233519	**1130235.854**
Carbon disulfide g	0.092293683	1.155567167	0	0.442593357	1.001114505	0	**2.691568712**
Carbon monoxide g	21653.0811	7794970.54	253996.7592	201296.495	218195.7536	0	**8490112.629**
Carbon monoxide, fossil g	18562.72112	554891.1878	6287.744808	279389.8542	257058.7426	2455.540309	**1118645.791**
Chlorine g	0	1.821327708	0	0	0	0	**1.821327708**
Chloroform g	0.041887133	0.524449714	0	0.200869293	0.454351968	0	**1.221558108**
Chromium g	0.231105757	7.976765469	0.1122985	2.881731293	3.767320129	0.188769396	**15.15799054**
Chromium VI g	0.060170323	1.169005625	0.019461761	0.361963111	0.857898218	0.048663784	**2.517162822**
Chrysene g	7.61651E-05	0.00147977	2.46358E-05	0.000458184	0.001085956	6.16014E-05	**0.003186313**
Chrysene, 5-methyl- g	1.67563E-05	0.000325549	5.41988E-06	0.000100801	0.00023891	1.35523E-05	**0.000700989**
Cobalt g	0.484866608	11.19670134	0.187187602	12.86648095	7.562398475	0.102923434	**32.40055841**
Copper g	0	0.089197159	0	0.001555496	0.001562841	0	**0.092315496**
Cumene g	0.003762742	0.047111584	0	0.018044191	0.040814668	0	**0.109733186**
Cyanide g	1.77487852	22.22244551	0	8.51141071	19.25220203	0	**51.76093677**
Dinitrogen monoxide g	533.0918335	6836.842115	9.377578424	2778.266761	5825.937511	13.38457417	**15996.90037**
Ethane, 1,1,1-trichloro-, HCFC-140 g	0.01427029	0.17947188	2.59654E-05	0.069740127	0.155036788	5.1468E-06	**0.418550197**
Ethane, 1,2-dibromo- g	0.000851942	0.010666774	0	0.004085477	0.009241057	0	**0.02484525**
Ethane, 1,2-dichloro- g	0.028398056	0.355559128	0	0.136182571	0.308035232	0	**0.828174988**
Ethane, chloro- g	0.029817959	0.373337085	0	0.1429917	0.323436994	0	**0.869583738**
Ethene, tetrachloro- g	0.037501167	0.755838444	0.012479943	0.341564201	0.544040879	0.026993466	**1.718418101**
Fluoranthene g	0.000540772	0.01050637	0.000174914	0.003253109	0.007710287	0.00043737	**0.022622823**
Fluorene g	0.000693103	0.013465911	0.000224186	0.004169478	0.009882199	0.000560573	**0.028995449**
Fluoride g	31.67894952	397.4443778	0.126271298	152.3541754	343.6723762	0.04358911	**925.3197392**
Formaldehyde g	12.33435311	384.4897281	3.576561275	116.9877845	162.6139694	1.599778357	**681.6021747**
Furan g	2.58498E-07	2.95436E-05	1.23179E-06	5.8864E-06	1.57934E-05	3.08007E-06	**5.57938E-05**
Hexane g	0.047566744	0.59556154	0	0.228105807	0.515959014	0	**1.387193105**
Hydrazine, methyl g	0.120691739	1.511126295	0	0.578775928	1.309149738	0	**3.5197437**

Hydrocarbons, unspecified g	24340.98654	2899289.393	29955.46076	246122.8359	18589.91976	11.19855753	**3218309.795**
Hydrogen chloride g	544.6439062	86755.43333	314.3295456	4944.404336	9261.734166	1807.31917	**103627.8645**
Hydrogen fluoride g	82.11931215	170128.0751	36.95368159	533.1238723	1280.429571	2016.789467	**174077.491**
Indeno(1,2,3-cd)pyrene g	4.64607E-05	0.00090266	1.50279E-05	0.000279493	0.000662433	3.75769E-05	**0.001943651**
Isophorone g	0.411771817	5.155607358	0	1.974647285	4.46651087	0	**12.00853733**
Kerosene g	0.413075537	22.36909649	2.691907636	11.32085524	5.527815588	0.929252007	**43.25200249**
Lead g	2.667246964	38.02726789	0.153016265	15.82645834	30.64035297	0.276957666	**87.5913001**
Magnesium g	8.378155013	162.7739344	2.709907083	50.400126	119.4547165	6.776074137	**350.4929131**
Manganese g	0.487616196	15.47143287	0.207908626	8.01779325	7.654296661	0.327977958	**32.16702556**
Mercaptans, unspecified g	154.0594555	1928.90827	0	738.7904496	1671.091136	0	**4492.849311**
Mercury g	0.944369111	12.95393439	0.028232643	4.8147543	10.55375762	0.0561501	**29.35119817**
Metals, unspecified g	20.68733974	168.5813639	7.2248E-07	20.69154424	0.000519856	0	**209.9607685**
Methacrylic acid, methyl ester g	0.014199028	0.177779564	0	0.068091286	0.154017616	0	**0.414087494**
Methane g	15871.73145	1545121.393	12297.0919	103193.7854	295032.1993	14139.26686	**1985655.468**
Methane, bromo-, Halon 1001 g	0.113592225	1.422236513	0	0.544730285	1.23214093	0	**3.312699953**
Methane, dichloro-, HCC-30 g	0.546714868	13.01029991	0.199640631	11.25767841	8.210768905	0.208377231	**33.43347995**
Methane, dichlorodifluoro-, CFC-12 g	8.81213E-05	0.002092486	3.21149E-05	0.002039776	0.001260301	6.35559E-06	**0.005519155**
Methane, fossil g	4257.170966	275385.2135	2664.803372	76517.47427	74787.22838	1678.235563	**435290.126**
Methane, monochloro-, R-40 g	0.376274246	4.711158448	0	1.80441907	4.081466829	0	**10.97331859**
Methane, tetrachloro-, CFC-10 g	8.81483E-06	0.103955923	3.21026E-06	0.000203662	0.000126078	6.39684E-07	**0.104298328**
Methyl ethyl ketone g	0.276881049	3.4667015	0	1.327780071	3.003343516	0	**8.074706135**
Naphthalene g	0.095036918	3.617568607	0.044599525	2.456621932	1.575508813	0.025527603	**7.814863398**

Nickel g	6.011263877	143.1862856	2.367427858	175.784009	94.80921026	0.767616407	**422.9258129**
Nitrogen oxides g	72429.7008	3262459.641	20199.31961	670204.8978	753632.0896	985.1509877	**4779910.8**
NMVOC, non-methane volatile organic compounds, uns g	0	0	0	2201.641926	0	0	**2201.641926**
Organic acids g	0.003169469	0.171634856	0.02065462	0.086863292	0.042414133	0.007130017	**0.331866387**
Organic substances, unspecified g	4.61488978	89.64693545	1.49225041	27.75537545	65.79366159	3.731274145	**193.0343868**
Other g	5.90981102	13508.34402	0	18107.21248	0	0	**31621.46631**
PAH, polycyclic aromatic hydrocarbons g	0.614788719	12.44477526	0.179815161	2.455015015	6.814353058	0.000108154	**22.50885537**
Particulates, > 2.5 um, and < 10um g	3458.165354	66096.47521	344.4579352	20325.86632	40121.2279	249.7386352	**130595.9314**
Particulates, unspecified g	54808.37385	6319049.231	15941.61148	728339.2601	756585.7031	8079.002577	**7882803.182**
Phenanthrene g	0.002056458	0.039953801	0.000665167	0.01237098	0.02932081	0.001663239	**0.086030454**
Phenol g	0.011359223	36.88142797	0	0.054473029	0.123214093	0	**37.07047432**
Phenols, unspecified g	0.257698866	6.420203251	0.100536798	7.554611491	3.987565537	0.032262127	**18.35287807**
Phthalate, dioctyl- g	0.051826453	0.648895409	0	0.248533193	0.562164299	0	**1.511419354**
Propanal g	0.269781535	3.377811718	0	1.293734428	2.926334708	0	**7.867662388**
Propene g	9.229978052	188.9728242	2.756753107	37.43113011	102.3595003	0.001660955	**340.7518467**
Pyrene g	0.000251345	0.004883242	8.12982E-05	0.001512009	0.003583654	0.000203285	**0.010514833**
Radioactive species, unspecified MBq	2.984409833	336.2223553	13.96496658	68.34584056	179.706519	34.86297515	**636.0870663**
Radionuclides (Including Radon) g	23.09952067	1250.898106	150.5336688	633.0714511	309.1199527	51.96452955	**2418.687229**
Selenium g	1.036720409	20.60082051	0.338973953	7.369715051	14.86144891	0.805747289	**45.01342612**
Styrene g	0.017748785	0.222224455	0	0.085114107	0.19252202	0	**0.517609368**
Sulfur dioxide g	41063.1449	3079043.982	28523.92942	279062.528	764923.6218	37414.4084	**4230031.614**
Sulfur oxides g	14278.47546	810843.5979	38574.49897	186021.3264	93864.70857	180.6691544	**1143763.276**
Sulfuric acid, dimethyl ester g	0.034077668	0.426670954	0	0.163419086	0.369642279	0	**0.993809986**

t-Butyl methyl ether g	0.024848299	0.311114237	0	0.11915975	0.269530828	0	**0.724653115**
TOC, Total Organic Carbon g	0	9.429405475	0	0	0	0	**9.429405475**
Toluene g	1.633593539	32.0907412	0.437021135	6.750958319	18.07500547	0.000263307	**58.98758297**
Toluene, 2,4-dinitro- g	0.000198786	0.002488914	0	0.000953278	0.002156247	0	**0.005797225**
Vinyl acetate g	0.005395631	0.067556234	0	0.025874689	0.058526694	0	**0.157353248**
VOC, volatile organic compounds g	2641.784191	126756.954	882.0137862	32490.23647	204392.9601	709.2696208	**367873.2181**
Xylene g	1.045873068	21.20408929	0.304529314	4.260860876	11.59224491	0.00018348	**38.40778094**
Zinc g	0	0.059464773	0	0.001036998	0.001041894	0	**0.061543664**

3.2 Tilt-up Office

Table A.2.112 Energy consumption of Base Office by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Electricity kWh	6130.280337	1629354.086	7915.213911	44421.78423	170224.4992	5417.288748	**1863463.152**
Hydro MJ	20470.18928	6168679.561	12706.21862	82867.55416	551663.3668	2130.326519	**6838517.216**
Coal MJ	39537.92332	778901.7307	13098.66989	231669.9624	907905.8551	30816.65254	**2001930.794**
Diesel MJ	55420.64053	572518.0418	9559.879207	99189.38865	1295945.663	11577.99424	**2044211.608**
Feedstock MJ	35769.13302	3300787.178	227013.7274	1174038.802	951232.9324	0	**5688841.773**
Gasoline MJ	2.041766696	125.7148669	37.01902162	226.2519904	25.74742594	0	**416.7750716**
Heavy Fuel Oil MJ	24366.67571	547674.2343	8880.20393	713918.0141	464900.3067	181.6879299	**1759921.123**
LPG MJ	94.78376403	4480.179072	40.05377173	1248.330295	2342.007111	44.65238828	**8250.006402**
Natural Gas MJ	44243.85941	4762398.476	48681.08968	386338.8671	1661712.146	42697.93746	**6946072.375**
Nuclear MJ	3895.233508	144955.7143	22907.28173	114380.8122	64804.0437	7758.077928	**358701.1634**
Wood MJ	0	5364.079072	0	0	0	0	**5364.079072**

Table A.2.12 Solid Waste Emissions Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Bark/Wood Waste kg	1226.178422	135.4550759	0	561.8775859	15598.79203	0	**17522.30311**
Concrete Solid Waste kg	7071.868383	313277.413	0	4233.54795	157449.0208	17.97451561	**482049.8246**
Blast Furnace Slag kg	157.0960783	7020.943878	2423.415617	2088.84957	7455.16366	0	**19145.4688**
Blast Furnace Dust kg	356.9412126	4349.297131	232.7239826	404.2882812	8854.86605	0	**14198.11666**
Steel Waste kg	1.546836062	2.3500753	21.73931136	0	200.6705664	0	**226.3067891**
Other Solid Waste kg	547.8530485	26149.34047	168.1461956	6175.191674	41270.36458	476.370578	**74787.26655**

Table A.2.13 Resource Use Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Limestone kg	28505.30861	282032.9836	1575.546526	23503.94095	593899.5735	0	**929517.3532**
Clay & Shale kg	3996.289957	33925.72979	0	2347.155743	89257.71644	0	**129526.8919**
Iron Ore kg	1037.340185	23831.40235	14698.97069	13203.66238	14708.18088	0	**67479.55649**
Sand kg	1944.14106	76280.20528	0	1010.536838	40270.92777	0	**119505.8109**
Ash kg	0	1.319282902	0	0.420898486	10.10156367	0	**11.84174506**
Other kg	59.38720923	249955.117	0	27524.95895	37551.01777	5.88170051	**315096.3627**
Gypsum kg	1.62011755	16181.17521	0	5061.259964	128107.4331	61.75405131	**149413.2424**
Semi-Cementitious Material kg	2151.980268	34625.58881	0	1133.119798	43483.06377	0	**81393.75264**
Coarse Aggregate kg	92109.98143	729466.2143	0	90853.47732	1531725.988	0	**2444155.661**
Fine Aggregate kg	79335.5002	613645.6216	0	47642.53697	1012734.582	0	**1753358.241**
Water L	81672.87669	1582742.241	931622.9869	738631.8001	1437209.027	0	**4771878.931**
Obsolete Scrap Steel kg	293.2340396	32263.57544	2460.224952	3412.334462	45347.20464	0	**83776.57354**
Coal kg	3244.723619	50236.06134	672.6328346	12202.70338	72315.16165	1515.532592	**140186.8154**
Wood Fiber kg	0	2707.988404	0	0	0	0	**2707.988404**
Phenol Form. Resins kg	0	19.07612532	0	0	0	0	**19.07612532**
Uranium kg	0.006161347	0.22933916	0.036245353	0.180979322	0.102491548	0.012274839	**0.567491569**
Natural Gas m3	1423.301312	131319.5527	1288.575543	12707.94676	45840.70075	1130.646331	**193710.7234**
Crude Oil L	1966.521688	81463.1887	335.2208985	41985.24962	36760.18591	73.44831192	**162583.8151**
Metallurgical Coal kg	356.4224568	7768.72184	6477.190197	4779.179448	4498.45912	0	**23879.97306**
Prompt Scrap Steel kg	193.5645751	21490.09013	1526.204878	1503.273236	32454.20325	0	**57167.33608**

Table A.2.14 Emissions to Water Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
2-Hexanone mg	43.89515474	2841.94849	30.90845794	575.3965783	1307.894931	23.08343353	**4823.127046**
Acetone mg	67.22508648	4352.476094	47.33657945	881.2117616	2003.040549	35.35265528	**7386.642726**
Acids, unspecified mg	26646.93558	47504317.46	0	885271.613	1741178.371	2174247.426	**52331661.8**
Aluminum mg	403745.0108	13742494.6	159090.3108	6070863.673	10017432.07	141426.1982	**30535051.86**
Ammonia mg	111635.8421	5871429.763	65210.2878	1505870.866	3088117.013	44895.77401	**10687159.55**
Ammonium, ion mg	15073.04017	16706791.52	3.289577205	104712.4469	354345.5277	6172.537702	**17187098.37**
Antimony mg	247.5989822	8080.713039	98.40364882	3774.062517	5957.042339	48.46183974	**18206.28237**
Arsenic, ion mg	1699.599831	100175.4674	1102.539741	22934.71268	48878.78888	792.3582862	**175583.4668**
Barium mg	5535675.858	191035004.3	2299122.578	83688954.39	135037117.1	1190123.017	**418785997.2**
Benzene mg	11277.60643	730169.5693	7941.160834	147830.9162	336028.407	5930.753094	**1239178.413**
Benzene, 1-methyl-4-(1-methylethyl)- µg	671.7806313	43494.4732	473.0361833	8805.943143	20016.42253	353.2808831	**73814.93658**
Benzene, ethyl- mg	634.3922638	41073.76258	446.7090732	8315.842837	18902.39635	333.6188294	**69706.72193**
Benzene, pentamethyl- µg	503.8386024	32620.66776	354.7756179	6604.524277	15012.3405	264.9583005	**55361.10506**
Benzenes, alkylated, unspecified mg	217.1319927	7078.483429	86.21964046	3310.190233	5222.618367	42.41739097	**15957.06105**
Benzoic acid mg	6819.597275	441538.0352	4802.065366	89393.55524	203197.7037	3586.368624	**749337.3254**
Beryllium mg	88.47212013	4751.786493	52.97127611	1224.622537	2461.678945	36.48703233	**8616.018403**
Biphenyl µg	14058.43196	458311.9775	5582.458276	214321.0815	338145.2377	2746.443133	**1033165.63**
BOD5, Biological Oxygen Demand	1358515.558	171156632.1	833902.3358	16927766.63	37159458.59	618546.2689	**228054821.5**

mg							
Boron mg	21099.59401	1366084.17	14857.24002	276581.7757	628683.155	11095.90322	**2318401.838**
Bromide mg	1440457.098	93274818.26	1014419.77	18881211.27	42922165.94	757644.9987	**158290717.3**
Cadmium, ion mg	249.5956084	14625.84359	161.0975233	3373.770676	7162.847769	115.4832697	**25688.63844**
Calcium, ion mg	21600530.2	1398853031	15213182.61	283125912.7	643669067.5	11362791.26	**2373824516**
Chloride mg	257395216.7	19921050611	254738179.3	3254300530	7508760572	127720790.1	**31323965899**
Chromium mg	9189.334921	170326.7532	2414.318394	148682.9034	197936.6388	466.1980557	**529016.1467**
Chromium VI µg	38665.37769	716673.0018	10158.57332	625603.5571	832845.3543	1961.591786	**2225907.456**
Chromium, ion mg	2054.909692	195405.7555	2042.67356	22791.37351	72370.11124	1721.87637	**296386.6999**
Cobalt mg	148.9374473	9642.988758	104.8749596	1952.324143	4437.755157	78.32457202	**16365.20504**
COD, Chemical Oxygen Demand mg	4348025.263	1432472926	26391527.26	51164872.41	90828736.99	1029219.311	**1606235307**
Copper, ion mg	1535.84222	72447.87503	824.9749974	22268.79973	40854.80372	527.6713268	**138459.967**
Cyanide mg	437222.7847	9566224.474	7953441.163	6101664.922	5574100.482	16.05538188	**29632669.88**
Decane mg	195.9606479	12687.3496	137.9849588	2568.731796	5838.833346	103.0518417	**21531.91219**
Detergents, oil mg	6070.661649	422145.6937	4552.656547	77642.11337	186081.1874	3491.709961	**699984.0226**
Dibenzofuran µg	1278.263676	82761.52402	900.0955024	16755.92377	38087.28246	672.2254076	**140455.3148**
Dibenzothiophene µg	481.6514674	56785.61906	583.7122249	4611.949579	18925.43299	516.5388055	**81904.90413**
Dissolved organic matter mg	198404.9695	9603285.521	85.52900733	1277243.477	5137758.145	43622.34032	**16260399.98**
Dissolved solids mg	304921473.2	21283878055	210940244.4	3957816459	8926717485	157548806.1	**34841822523**
Docosane µg	7193.679958	465758.6355	5065.48242	94297.12649	214344.004	3783.100081	**790442.0284**
Dodecane mg	371.8037317	24072.46124	261.8067046	4873.737031	11078.29145	195.5269382	**40853.6271**
Eicosane mg	102.3674794	6627.8161	72.08261147	1341.868022	3050.153578	53.83404363	**11248.12183**
Fluorene, 1-methyl- µg	765.0869409	49535.35439	538.7357776	10029.05196	22796.5408	402.347007	**84067.11688**
Fluorenes,	12583.36134	410222.9767	4996.713839	191833.6634	302665.4273	2458.264799	**924760.4074**

alkylated, unspecified µg							
Fluoride mg	12788.78508	116448.6968	285.0966911	620351.877	272068.2642	0	**1021942.72**
Fluorine µg	6392.815958	226998.8312	2716.101673	96222.93885	157086.808	1440.045716	**490857.5413**
Halogenated organics µg	0	2.21005E-05	0	0	0.001040354	0	**0.001062455**
Hexadecane mg	405.8225697	26274.81126	285.7592384	5319.681638	12091.88312	213.4149403	**44591.37276**
Hexanoic acid mg	1412.26818	91437.42822	994.4529975	18512.51814	42080.04987	742.6943606	**155179.4118**
Hydrocarbons, unspecified µg	19675.05397	179151.8412	438.610294	10934.42509	418566.5602	0	**628766.4908**
Iron mg	1019028.997	76703935.44	3229120.179	14803784.38	24298122.11	299257.5589	**120353248.7**
Lead mg	3180.82078	157585.7875	1777.010519	486465.3364	86144.09405	1175.782666	**736328.832**
Lead-210/kg µg	0.00069845	0.045223751	0.000491842	0.009155434	0.020811578	0.000367332	**0.076748386**
Lithium, ion mg	3097423.971	390892428	3999387.097	27949552.59	126300585.8	3586175.749	**555825553.3**
Magnesium mg	4227424.942	273518275.5	2974275.396	55351876.35	125933873	2221444.192	**464227169.4**
Manganese mg	15539.51287	607531.0444	7592.530058	136862.2299	403236.8153	10587.72763	**1181349.86**
Mercury µg	4339.05149	141454.1304	1722.981704	66149.00401	104366.315	847.6616506	**318879.1443**
Metallic ions, unspecified mg	12788.78508	116448.6968	285.0966911	7107.376309	272068.2642	0	**408698.219**
Methane, monochloro-, R-40 µg	270.5881813	17519.23965	190.5353493	3546.968059	8062.463112	142.298811	**29732.09316**
Methyl ethyl ketone µg	541.1564619	35037.12989	381.0561035	7093.679301	16124.32238	284.5865299	**59461.93066**
Molybdenum mg	154.5382824	10005.5656	108.81833	2025.745204	4604.62918	81.26947069	**16980.56607**
m-Xylene mg	203.6817951	13187.57492	143.4248753	2669.922163	6068.950221	107.1155771	**22380.66955**
Naphthalene mg	122.3246868	7908.745752	86.02853747	1604.218829	3642.798686	64.21411189	**13428.3306**
Naphthalene, 2-methyl- mg	106.4823321	6894.212234	74.97990312	1395.808342	3172.756403	55.99778429	**11700.237**
Naphthalenes, alkylated, unspecified µg	3558.030524	115992.737	1412.849052	54242.30458	85580.5922	695.0849912	**261481.5983**

n-Hexacosane µg	4487.906199	290568.2418	3160.157316	58829.19422	133721.7003	2360.117454	**493127.3173**
Nickel mg	1560.22035	83286.96804	929.2703708	26350.55602	43320.71106	638.1945919	**156085.9204**
Nitrate mg	541193.1742	11707019.88	8660557.564	7550593.476	7820931.866	306.6707477	**36280602.63**
Nitrogen, total mg	1574.004318	14332.1473	35.08882352	2142491.129	33485.32482	0	**2191917.694**
Non-halogenated Organics µg	27641031	2053569594	69430490.12	245440064.4	66684154.06	0	**2462765334**
o-Cresol mg	193.3914798	12521.18239	136.1775314	2535.042667	5762.313271	101.7025351	**21249.80987**
Octadecane mg	100.2585947	6491.261921	70.59749765	1314.224952	2987.314543	52.72486069	**11016.38237**
Oils, unspecified mg	12664012.66	692713579.5	223259629.9	174952581.2	166898125.2	71430.69191	**1270559359**
Other mg	334124.0638	3446602188	2428801.114	2081320.808	3863212.468	0	**3455309646**
Other metals mg	232049.9414	493829503.3	1927700.002	4127974.105	14342041.01	683.4450465	**514459951.8**
p-Cresol mg	208.6564861	13509.71821	146.9283589	2735.128444	6217.186584	109.7322864	**22927.35037**
Pentanone, methyl- mg	28.25180022	1829.14242	19.89337373	370.3362587	841.7886946	14.85703684	**3104.269584**
Phenanthrene µg	1464.964305	66953.52416	765.0833092	21057.51588	38666.09288	483.5672983	**129390.7478**
Phenanthrenes, alkylated, unspecified µg	1475.304917	48095.30462	585.8247275	22491.07879	35485.2076	288.2103847	**108420.931**
Phenol µg	7677473.573	728347518.5	82512124.26	191475737.8	127227503.1	98357.84761	**1137338715**
Phenol, 2,4-dimethyl- mg	188.3037508	12191.74706	132.594706	2468.352874	5610.713574	99.02665424	**20690.73861**
Phenols, unspecified mg	1529.521203	167331.4868	1729.481539	35814.24732	57777.25587	1506.680584	**265688.6734**
Phosphate mg	10815.19542	82659402.84	68486.43513	30490.89636	1939937.967	0	**84709133.33**
Phosphorus mg	73767.60559	8069098.149	596981.0868	694961.1044	12074162.32	0	**21508970.26**
Polynuclear Aromatic Hydrocarbons µg	0	477.9385937	0	0	0	0	**477.9385937**
Radium-226/kg µg	0.243009911	15.73337368	0.17111307	3.185482139	7.24068387	0.127792562	**26.70145523**

Radium-228/kg µg	0.001242956	0.080478914	0.000875275	0.01629427	0.037035676	0.000653681	**0.136580772**
Selenium µg	48130.68615	1581942.847	19235.02758	732898.6029	1159977.129	9534.984315	**3551719.277**
Silver mg	14106.69667	912401.2742	9924.313214	184977.9951	420156.6045	7408.891679	**1548975.775**
Sodium, ion mg	68473503.18	4434251979	48224702.54	897513505.1	2040407673	36018920.12	**7524890283**
Strontium mg	366484.4694	23727752.36	258058.1418	4804031.022	10919742.42	192726.3878	**40268794.8**
Sulfate mg	8039911.387	192525361.5	348048.5286	27479080.33	546732874.1	2032202.089	**777157478**
Sulfide mg	1288294.683	28783505.61	23371117.95	17969222.68	17236352.6	20.67577199	**88648514.21**
Sulfur mg	17811.02108	1153175.681	12541.68112	233473.2866	530698.4547	9366.590925	**1957066.715**
Suspended solids, unspecified mg	43166687.02	3295591885	464763931.8	575019898.9	1183609377	2789831.969	**5564941611**
Tetradecane mg	162.9468695	10550.00806	114.7395275	2135.966138	4855.177037	85.69172783	**17904.52936**
Thallium µg	52194.4266	1705586.246	20764.28483	795437.78	1256142.812	10238.01041	**3840363.56**
Tin mg	1180.859588	56090.65917	636.9754725	16832.74657	31546.53482	411.6034213	**106699.379**
Titanium, ion mg	3803.050179	124186.7438	1512.113974	57963.92521	91510.86026	745.072519	**279721.766**
Toluene mg	10654.83467	689847.5499	7502.628382	139667.4408	317472.144	5603.238893	**1170747.837**
Vanadium mg	182.5489956	11819.15933	128.5425195	2392.917183	5439.245239	96.00034504	**20058.41362**
Xylene mg	3253.553054	67156.48295	920.2523818	52186.90934	71305.01669	235.5068866	**195057.7213**
Yttrium mg	45.3040914	2933.171204	31.90057445	593.8653604	1349.875891	23.82438601	**4977.941507**
Zinc mg	9356.353623	326709.9402	3922.488492	141196.1868	228921.8771	2050.858169	**712157.7044**

Table A.2.15Emissions to Air Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
2-Chloroacetophenone g	0.00496966	0.063192095	0	0.020182695	0.103446518	0	**0.191790967**
Acenaphthene g	0.000388442	0.007407203	0.000125643	0.002146286	0.008915574	0.000314167	**0.019297315**
Acenaphthylene g	0.000190413	0.003630982	6.15896E-05	0.001052101	0.004370379	0.000154004	**0.009459468**
Acetaldehyde g	3.148545299	49.88411803	0.81952312	12.52715648	61.08789561	0.000493766	**127.4677323**
Acetophenone g	0.010649271	0.135411632	0	0.043248631	0.22167111	0	**0.410980644**
Acid Gases g	0	3286.143752	0	267.282254	842.0698844	0	**4395.495891**
Acrolein g	0.45196743	17.56000464	0.170278355	2.12761148	9.343090488	0.17870176	**29.83165415**
Aldehydes g	0.003169469	0.120766861	0.02065462	0.099111105	0.050183405	0.007130017	**0.301015478**
Ammonia g	15.75297121	357.60015	7.245983634	359.2805241	339.6065253	1.673920316	**1081.160075**
Ammonium chloride g	0.862501482	32.86405175	5.620701587	26.97091275	13.65631279	1.940277654	**81.91475801**
Anthracene g	0.000159947	0.003050025	5.17352E-05	0.000883765	0.003671119	0.000129363	**0.007945953**
Antimony g	0.013709709	0.279642858	0.004434399	0.075751016	0.314666768	0.011088136	**0.699292887**
Arsenic g	0.33710465	7.678051926	0.139975063	4.156674716	7.914345786	0.264608965	**20.49076111**
Benzene g	71.13315104	935.9930514	1.361363395	290.5413692	1478.004064	0.837344171	**2777.870343**
Benzene, chloro- g	0.015618931	0.198603727	0	0.063431326	0.325117628	0	**0.602771611**
Benzene, ethyl- g	0.066735432	0.848579559	0	0.271024756	1.389138956	0	**2.575478702**
Benzo(a)anthracene g	6.09321E-05	0.001161914	1.97087E-05	0.000336672	0.001398521	4.92812E-05	**0.00302703**
Benzo(a)pyrene g	2.89427E-05	0.000551909	9.36161E-06	0.000159919	0.000664298	2.34085E-05	**0.001437839**
Benzo(b,j,k)fluoranthene g	8.37816E-05	0.001597632	2.70994E-05	0.000462924	0.001922967	6.77616E-05	**0.004162166**
Benzo(ghi)perylene g	2.05646E-05	0.000392146	6.65167E-06	0.000113627	0.000472001	1.66324E-05	**0.001021623**
Benzyl chloride g	0.496965986	6.319209481	0	2.018269456	10.3446518	0	**19.17909672**
Beryllium g	0.014155616	0.368614177	0.006136825	0.131290286	0.336486886	0.013317765	**0.870001555**
Biphenyl g	0.001294807	0.024690675	0.000418809	0.007154288	0.029718579	0.001047225	**0.064324383**
Bromoform g	0.027688105	0.352070243	0	0.112446441	0.576344886	0	**1.068549674**
Butadiene g	0.139882202	2.280760278	0.041779156	0.5548497	2.684822266	2.51721E-05	**5.702118774**
Cadmium g	0.108038005	3.740041148	0.043359084	1.27173364	2.696108207	0.052128396	**7.91140848**
Carbon dioxide,	0	472.6587636	0	3.683353251	0	0	**476.3421169**

biogenic kg							
Carbon dioxide, fossil kg	21636.42287	571564.2922	22124.79877	126360.5897	478563.0255	4962.233519	**1225211.363**
Carbon disulfide g	0.092293683	1.173567475	0	0.37482147	1.92114962	0	**3.561832248**
Carbon monoxide g	21653.0811	7322448.784	253996.7592	302562.7294	250865.4381	0	**8151526.792**
Carbon monoxide, fossil g	18562.72112	484674.8529	6287.744808	273635.9342	415217.2214	2455.540309	**1200834.015**
Chlorine g	0	1.821327708	0	0	0	0	**1.821327708**
Chloroform g	0.041887133	0.532619085	0	0.170111283	0.871906366	0	**1.616523866**
Chromium g	0.231105757	7.168651665	0.1122985	2.809676995	5.741386011	0.188769396	**16.25188832**
Chromium VI g	0.060170323	1.147378115	0.019461761	0.33246104	1.381033906	0.048663784	**2.989168929**
Chrysene g	7.61651E-05	0.001452393	2.46358E-05	0.00042084	0.001748152	6.16014E-05	**0.003783787**
Chrysene, 5-methyl- g	1.67563E-05	0.000319526	5.41988E-06	9.25849E-05	0.000384593	1.35523E-05	**0.000832433**
Cobalt g	0.484866608	11.24749644	0.187187602	12.64596348	11.06667217	0.102923434	**35.73510973**
Copper g	0	0.089197159	0	0.001555496	0.001243539	0	**0.091996194**
Cumene g	0.003762742	0.047845443	0	0.015281183	0.078323792	0	**0.145213161**
Cyanide g	1.77487852	22.56860529	0	7.2081052	36.94518499	0	**68.496774**
Dinitrogen monoxide g	533.0918335	6904.83751	9.377578424	2394.226561	11104.24443	13.38457417	**20959.16249**
Ethane, 1,1,1-trichloro-, HCFC-140 g	0.01427029	0.182153712	2.59654E-05	0.05928829	0.29710452	5.1468E-06	**0.552847925**
Ethane, 1,2-dibromo- g	0.000851942	0.010832931	0	0.00345989	0.017733689	0	**0.032878452**
Ethane, 1,2-dichloro- g	0.028398056	0.361097685	0	0.115329683	0.59112296	0	**1.095948384**
Ethane, chloro- g	0.029817959	0.379152569	0	0.121096167	0.620679108	0	**1.150745803**
Ethene, tetrachloro- g	0.037501167	0.745345513	0.012479943	0.323369332	0.861459007	0.026993466	**2.007148428**
Fluoranthene g	0.000540772	0.010311988	0.000174914	0.002987967	0.012411877	0.00043737	**0.026864889**
Fluorene g	0.000693103	0.013216773	0.000224186	0.003829648	0.015908181	0.000560573	**0.034432464**
Fluoride g	31.67894952	403.3080577	0.126271298	129.1812096	659.3202263	0.04358911	**1223.658304**
Formaldehyde g	12.33435311	328.4581125	3.576561275	113.1085289	275.8494275	1.599778357	**734.9267616**
Furan g	2.58498E-07	2.74824E-05	1.23179E-06	6.62581E-06	1.35172E-05	3.08007E-06	**5.21958E-05**
Hexane g	0.047566744	0.604838622	0	0.193177219	0.990130958	0	**1.835713543**
Hydrazine, methyl g	0.120691739	1.53466516	0	0.490151154	2.512272579	0	**4.657780632**

Hydrocarbons, unspecified g	24340.98654	2899209.499	29955.46076	234660.7143	356706.1024	11.19855753	**3544883.961**
Hydrogen chloride g	544.6439062	86359.92403	314.3295456	4780.877229	13382.22008	1807.31917	**107189.314**
Hydrogen fluoride g	82.11931215	170080.7155	36.95368159	503.7011727	1953.462855	2016.789467	**174673.742**
Indeno(1,2,3-cd)pyrene g	4.64607E-05	0.00088596	1.50279E-05	0.000256713	0.001066373	3.75769E-05	**0.00230811**
Isophorone g	0.411771817	5.235916427	0	1.672280406	8.571282918	0	**15.89125157**
Kerosene g	0.413075537	15.73949274	2.691907636	12.91710738	6.5403815	0.929252007	**39.2312168**
Lead g	2.667246964	38.1133201	0.153016265	13.98662284	56.54481189	0.276957666	**111.7419757**
Magnesium g	8.378155013	159.7624394	2.709907083	46.2922676	192.2963175	6.776074137	**416.2151607**
Manganese g	0.487616196	15.17782526	0.207908626	7.817084972	11.44856432	0.327977958	**35.46697733**
Mercaptans, unspecified g	154.0594555	1958.954939	0	625.6635314	3206.842057	0	**5945.519983**
Mercury g	0.944369111	12.96469187	0.028232643	4.145044931	19.88173154	0.0561501	**38.02022019**
Metals, unspecified g	20.68733974	168.5813303	7.2248E-07	0.075531747	0.000816135	0	**189.3450187**
Methacrylic acid, methyl ester g	0.014199028	0.180548842	0	0.057664842	0.29556148	0	**0.547974192**
Methane g	15871.73145	1239852.077	12297.0919	107486.9935	467521.249	14139.26686	**1857168.41**
Methane, bromo-, Halon 1001 g	0.113592225	1.444390739	0	0.461318733	2.364491839	0	**4.383793536**
Methane, dichloro-, HCC-30 g	0.546714868	13.03773037	0.199640631	11.00139543	12.40002444	0.208377231	**37.39388297**
Methane, dichlorodifluoro-, CFC-12 g	8.81213E-05	0.001984923	3.21149E-05	0.002008369	0.001907989	6.35559E-06	**0.006027872**
Methane, fossil g	4257.170966	224733.9292	2664.803372	76571.10134	115918.3019	1678.235563	**425823.5423**
Methane, monochloro-, R-40 g	0.376274246	4.784544321	0	1.528118302	7.832379218	0	**14.52131609**
Methane, tetrachloro-, CFC-10 g	8.81483E-06	0.103944906	3.21026E-06	0.000200524	0.000190918	6.39684E-07	**0.104349013**
Methyl ethyl ketone g	0.276881049	3.520702425	0	1.124464411	5.763448859	0	**10.68549674**
Naphthalene g	0.095036918	3.312207236	0.044599525	2.425290926	2.31998242	0.025527603	**8.222644627**

Nickel g	6.011263877	143.7258028	2.367427858	173.085124	137.2308198	0.767616407	**463.1880547**
Nitrogen oxides g	72429.7008	3188369.97	20199.31961	633827.9808	1424724.528	985.1509877	**5340536.651**
NMVOC, non-methane volatile organic compounds, uns g	0	0	0	2201.641926	0	0	**2201.641926**
Organic acids g	0.003169469	0.120766861	0.02065462	0.099111105	0.050183405	0.007130017	**0.301015478**
Organic substances, unspecified g	4.61488978	87.98734637	1.49225041	25.49233088	105.918994	3.731274145	**229.2370856**
Other g	5.90981102	13508.34402	0	18423.02504	0	0	**31937.27887**
PAH, polycyclic aromatic hydrocarbons g	0.614788719	9.92490159	0.179815161	2.391618514	11.82856918	0.000108154	**24.93980132**
Particulates, > 2.5 um, and < 10um g	3458.165354	61012.24396	344.4579352	18270.04626	73898.89421	249.7386352	**157233.5463**
Particulates, unspecified g	54808.37385	6303712.676	15941.61148	703670.6916	1224981.5	8079.002577	**8311193.855**
Phenanthrene g	0.002056458	0.039214602	0.000665167	0.011362692	0.047200096	0.001663239	**0.102162255**
Phenol g	0.011359223	36.8836434	0	0.046131873	0.236449184	0	**37.17758368**
Phenols, unspecified g	0.257698866	6.496309468	0.100536798	7.43713242	5.803081133	0.032262127	**20.12702081**
Phthalate, dioctyl- g	0.051826453	0.659003274	0	0.210476672	1.078799402	0	**2.000105801**
Propanal g	0.269781535	3.430428004	0	1.09563199	5.615668119	0	**10.41150965**
Propene g	9.229978052	150.4935368	2.756753107	36.61116628	177.1551366	0.001660955	**376.2482318**
Pyrene g	0.000251345	0.004792896	8.12982E-05	0.001388773	0.005768901	0.000203285	**0.012486498**
Radioactive species, unspecified MBq	2.984409833	312.7994426	13.96496658	76.69041165	154.3817166	34.86297515	**595.6839224**
Radionuclides (Including Radon) g	23.09952067	880.1652613	150.5336688	722.3351719	365.7434637	51.96452955	**2193.841616**
Selenium g	1.036720409	20.24607234	0.338973953	6.86365467	23.79467992	0.805747289	**53.08584859**
Styrene g	0.017748785	0.225686053	0	0.072081052	0.36945185	0	**0.68496774**
Sulfur dioxide g	41063.1449	2473957.852	28523.92942	281470.5167	1221130.253	37414.4084	**4083560.104**
Sulfur oxides g	14278.47546	805380.1173	38574.49897	186039.4626	162097.0157	180.6691544	**1206550.239**
Sulfuric acid, dimethyl ester g	0.034077668	0.433317222	0	0.13839562	0.709347552	0	**1.315138061**

t-Butyl methyl ether g	0.024848299	0.315960474	0	0.100913473	0.51723259	0	**0.958954836**
TOC, Total Organic Carbon g	0	9.429405475	0	0	0	0	**9.429405475**
Toluene g	1.633593539	26.0239479	0.437021135	6.495854188	31.63069589	0.000263307	**66.22137596**
Toluene, 2,4-dinitro- g	0.000198786	0.002527684	0	0.000807308	0.004137861	0	**0.007671639**
Vinyl acetate g	0.005395631	0.06860856	0	0.02191264	0.112313362	0	**0.208230193**
VOC, volatile organic compounds g	2641.784191	82129.85113	882.0137862	32851.79863	62172.88605	709.2696208	**181387.6034**
Xylene g	1.045873068	16.95853402	0.304529314	4.150993288	20.11652533	0.00018348	**42.5766385**
Zinc g	0	0.059464773	0	0.001036998	0.000829026	0	**0.061330796**

3.2 Triple Glazed Office

Table A.2.16 Energy consumption of Base Office by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Electricity kWh	6130.280337	1743627.36	7915.213911	44421.78423	170224.4992	44974.5455	**2017293.683**
Hydro MJ	20470.18928	6566331.38	12706.21862	82867.55416	551663.3668	149356.0018	**7383394.71**
Coal MJ	39537.92332	802474.6607	13098.66989	231669.9624	907905.8551	48790.51412	**2043477.586**
Diesel MJ	55420.64053	1246962.259	9559.879207	99189.38865	1295945.663	38758.92901	**2745836.759**
Feedstock MJ	35769.13302	4885228.016	227013.7274	1174038.802	951232.9324	0	**7273282.611**
Gasoline MJ	2.041766696	175.423209	37.01902162	226.2519904	25.74742594	0	**466.4834137**
Heavy Fuel Oil MJ	24366.67571	534552.1695	8880.20393	713918.0141	464900.3067	7648.218459	**1754265.588**
LPG MJ	94.78376403	5043.299491	40.05377173	1248.330295	2342.007111	113.2729196	**8881.747352**
Natural Gas MJ	44243.85941	6157099.211	48681.08968	386338.8671	1661712.146	140277.8026	**8438352.976**
Nuclear MJ	3895.233508	202898.3441	22907.28173	114380.8122	64804.0437	14891.19901	**423776.9143**
Wood MJ	0	5364.079072	0	0	0	0	**5364.079072**

Table A.2.17 Solid Waste Emissions Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Bark/Wood Waste kg	1226.178422	1074.7717	0	561.8775859	15598.79203	0	**18461.61974**
Concrete Solid Waste kg	7071.868383	412019.7256	0	4233.54795	157449.0208	17.97451561	**580792.1372**
Blast Furnace Slag kg	157.0960783	21471.94215	2423.415617	2088.84957	7455.16366	0	**33596.46707**
Blast Furnace Dust kg	356.9412126	7889.9337	232.7239826	404.2882812	8854.86605	0	**17738.75323**
Steel Waste kg	1.546836062	49.16428877	21.73931136	0	200.6705664	0	**273.1210026**
Other Solid Waste kg	547.8530485	27018.7608	168.1461956	6175.191674	41270.36458	4788.347382	**79968.66369**

Table A.2.18 Resource Use Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
Limestone kg	28505.30861	106834.8725	1575.546526	23503.94095	593899.5735	12983.4503	**767302.6923**
Clay & Shale kg	3996.289957	8033.54533	0	2347.155743	89257.71644	0	**103634.7075**
Iron Ore kg	1037.340185	42141.23731	14698.97069	13203.66238	14708.18088	0	**85789.39144**
Sand kg	1944.14106	63684.00542	0	1010.536838	40270.92777	33015.67863	**139925.2897**
Ash kg	0	1.319282902	0	0.420898486	10.10156367	0	**11.84174506**
Other kg	59.38720923	249955.117	0	27524.95895	37551.01777	13622.24811	**328712.7291**
Gypsum kg	1.62011755	16170.67841	0	5061.259964	128107.4331	61.75405131	**149402.7456**
Semi-Cementitious Material kg	2151.980268	2472.261378	0	1133.119798	43483.06377	0	**49240.42521**
Coarse Aggregate kg	92109.98143	115839.1253	0	90853.47732	1531725.988	0	**1830528.572**
Fine Aggregate kg	79335.5002	274765.1956	0	47642.53697	1012734.582	0	**1414477.815**
Water L	81672.87669	3359282.652	931622.9869	738631.8001	1437209.027	1673.326149	**6550092.669**
Obsolete Scrap Steel kg	293.2340396	120269.4607	2460.224952	3412.334462	45347.20464	0	**171782.4588**
Coal kg	3244.723619	52706.47777	672.6328346	12202.70338	72315.16165	2411.194253	**143552.8935**
Wood Fiber kg	0	2707.988404	0	0	0	0	**2707.988404**
Phenol Form. Resins kg	0	19.07612532	0	0	0	0	**19.07612532**
Uranium kg	0.006161347	0.320969209	0.036245353	0.180979322	0.102491548	0.023560429	**0.670407209**
Natural Gas m3	1423.301312	168206.7592	1288.575543	12707.94676	45840.70075	3712.456155	**233179.7397**
Crude Oil L	1966.521688	84908.55093	335.2208985	41985.24962	36760.18591	590.849848	**166546.5789**
Metallurgical Coal kg	356.4224568	16453.44649	6477.190197	4779.179448	4498.45912	0	**32564.69771**
Prompt Scrap Steel kg	193.5645751	84491.54851	1526.204878	1503.273236	32454.20325	0	**120168.7945**

Table A.2.19 Emissions to Water Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
2-Hexanone mg	43.89515474	3578.277082	30.90845794	575.3965783	1307.894931	82.44601385	**5618.818219**
Acetone mg	67.22508648	5480.17588	47.33657945	881.2117616	2003.040549	126.2670896	**8605.256947**
Acids, unspecified mg	26646.93558	47504317.46	0	885271.613	1741178.371	2174247.426	**52331661.8**
Aluminum mg	403745.0108	16138375.82	159090.3108	6070863.673	10017432.07	420783.9119	**33210290.79**
Ammonia mg	111635.8421	7294969.121	65210.2878	1505870.866	3088117.013	167541.4162	**12233344.55**
Ammonium, ion mg	15073.04017	16704923.81	3.289577205	104712.4469	354345.5277	4926445.022	**22105503.14**
Antimony mg	247.5989822	9549.226724	98.40364882	3774.062517	5957.042339	220.989751	**19847.32396**
Arsenic, ion mg	1699.599831	125354.5974	1102.539741	22934.71268	48878.78888	2889.459935	**202859.6984**
Barium mg	5535675.858	227369794.5	2299122.578	83688954.39	135037117.1	5259157.018	**459189821.4**
Benzene mg	11277.60643	919352.2479	7941.160834	147830.9162	336028.407	21182.51917	**1443612.858**
Benzene, 1-methyl-4-(1-methylethyl)- µg	671.7806313	54763.63609	473.0361833	8805.943143	20016.42253	1261.792502	**85992.61108**
Benzene, ethyl- mg	634.3922638	51715.73364	446.7090732	8315.842837	18902.39635	1191.566697	**81206.64086**
Benzene, pentamethyl- µg	503.8386024	41072.46079	354.7756179	6604.524277	15012.3405	946.3382893	**64494.27808**
Benzenes, alkylated, unspecified mg	217.1319927	8363.628838	86.21964046	3310.190233	5222.618367	193.5544877	**17393.34356**
Benzoic acid mg	6819.597275	555938.1736	4802.065366	89393.55524	203197.7037	12809.20426	**872960.2995**
Beryllium mg	88.47212013	5906.172068	52.97127611	1224.622537	2461.678945	136.2013259	**9870.118273**
Biphenyl µg	14058.43196	541522.849	5582.458276	214321.0815	338145.2377	12532.13906	**1126162.198**
BOD5, Biological Oxygen Demand	1358515.558	190849313.5	833902.3358	16927766.63	37159458.59	2216103.868	**249345060.5**

mg							
Boron mg	21099.59401	1720027.765	14857.24002	276581.7757	628683.155	39630.64472	**2700880.174**
Bromide mg	1440457.098	117442747.4	1014419.77	18881211.27	42922165.94	2705961.588	**184406963**
Cadmium, ion mg	249.5956084	18294.66991	161.0975233	3373.770676	7162.847769	421.7089771	**29663.69046**
Calcium, ion mg	21600530.2	1761313245	15213182.61	283125912.7	643669067.5	40581850.17	**2765503788**
Chloride mg	257395216.7	24133093457	254738179.3	3254300530	7508760572	2645336163	**38053624118**
Chromium mg	9189.334921	181066.2898	2414.318394	148682.9034	197936.6388	4223.644889	**543513.1301**
Chromium VI µg	38665.37769	761861.064	10158.57332	625603.5571	832845.3543	17771.56086	**2286905.487**
Chromium, ion mg	2054.909692	250937.9271	2042.67356	22791.37351	72370.11124	5774.185542	**355971.1807**
Cobalt mg	148.9374473	12141.4326	104.8749596	1952.324143	4437.755157	279.7471014	**19065.07141**
COD, Chemical Oxygen Demand mg	4348025.263	1512089268	26391527.26	51164872.41	90828736.99	3742921.455	**1688565351**
Copper, ion mg	1535.84222	89008.80435	824.9749974	22268.79973	40854.80372	2048.468598	**156541.6936**
Cyanide mg	437222.7847	20203106.1	7953441.163	6101664.922	5574100.482	16.71153412	**40269552.16**
Decane mg	195.9606479	15974.557	137.9849588	2568.731796	5838.833346	368.0649894	**25084.13273**
Detergents, oil mg	6070.661649	533809.4597	4552.656547	77642.11337	186081.1874	12295.79706	**820451.8757**
Dibenzofuran µg	1278.263676	104204.5709	900.0955024	16755.92377	38087.28246	2400.94621	**163627.0825**
Dibenzothiophene µg	481.6514674	73511.5665	583.7122249	4611.949579	18925.43299	1690.637919	**99804.95068**
Dissolved organic matter mg	198404.9695	9577397.293	85.52900733	1277243.477	5137758.145	43622.34032	**16234511.75**
Dissolved solids mg	304921473.2	26309587850	210940244.4	3957816459	8926717485	562684356.6	**40272667868**
Docosane µg	7193.679958	586434.2363	5065.48242	94297.12649	214344.004	13511.85481	**920846.384**
Dodecane mg	371.8037317	30309.49543	261.8067046	4873.737031	11078.29145	698.3519861	**47593.48633**
Eicosane mg	102.3674794	8345.046586	72.08261147	1341.868022	3050.153578	192.2757103	**13103.79399**
Fluorene, 1-methyl- µg	765.0869409	62369.65521	538.7357776	10029.05196	22796.5408	1437.040536	**97936.11123**
Fluorenes,	12583.36134	484702.6867	4996.713839	191833.6634	302665.4273	11217.18431	**1007999.037**

alkylated, unspecified µg							
Fluoride mg	12788.78508	129695.3368	285.0966911	620351.877	272068.2642	0	**1035189.36**
Fluorine µg	6392.815958	271115.7687	2716.101673	96222.93885	157086.808	6269.475228	**539803.9084**
Halogenated organics µg	0	2.21005E-05	0	0	0.001040354	0	**0.001062455**
Hexadecane mg	405.8225697	33082.44557	285.7592384	5319.681638	12091.88312	762.2427226	**51947.83486**
Hexanoic acid mg	1412.26818	115128.3334	994.4529975	18512.51814	42080.04987	2652.637369	**180780.2599**
Hydrocarbons, unspecified µg	19675.05397	199531.2873	438.610294	10934.42509	418566.5602	0	**649145.9369**
Iron mg	1019028.997	88559799.3	3229120.179	14803784.38	24298122.11	7024076.555	**138933931.5**
Lead mg	3180.82078	194629.9555	1777.010519	486465.3364	86144.09405	4488.955381	**776686.1726**
Lead-210/kg µg	0.00069845	0.056941037	0.000491842	0.009155434	0.020811578	0.001311974	**0.089410315**
Lithium, ion mg	3097423.971	507138400	3999387.097	27949552.59	126300585.8	11661625.62	**680146975.1**
Magnesium mg	4227424.942	344384695.1	2974275.396	55351876.35	125933873	7933775.408	**540805920.1**
Manganese mg	15539.51287	725102.0861	7592.530058	136862.2299	403236.8153	23735.28868	**1312068.463**
Mercury µg	4339.05149	167136.2871	1722.981704	66149.00401	104366.315	3867.935313	**347581.5747**
Metallic ions, unspecified mg	12788.78508	129695.3368	285.0966911	7107.376309	272068.2642	0	**421944.859**
Methane, monochloro-, R-40 µg	270.5881813	22058.37135	190.5353493	3546.968059	8062.463112	508.2403145	**34637.16636**
Methyl ethyl ketone µg	541.1564619	44115.03888	381.0561035	7093.679301	16124.32238	1016.441379	**69271.6945**
Molybdenum mg	154.5382824	12597.94709	108.81833	2025.745204	4604.62918	290.2655207	**19781.94361**
m-Xylene mg	203.6817951	16604.41286	143.4248753	2669.922163	6068.950221	382.5772704	**26072.96919**
Naphthalene mg	122.3246868	9956.976826	86.02853747	1604.218829	3642.798686	229.4170762	**15641.76464**
Naphthalene, 2-methyl- mg	106.4823321	8680.462805	74.97990312	1395.808342	3172.756403	200.0039372	**13630.49372**
Naphthalenes, alkylated, unspecified µg	3558.030524	137052.1814	1412.849052	54242.30458	85580.5922	3171.716793	**285017.6745**

n-Hexacosane µg	4487.906199	365852.6519	3160.157316	58829.19422	133721.7003	8429.501329	**574481.1113**
Nickel mg	1560.22035	103471.9765	929.2703708	26350.55602	43320.71106	2386.227472	**178018.9618**
Nitrate mg	541193.1742	22588995.06	8660557.564	7550593.476	7820931.866	306.6707477	**47162577.81**
Nitrogen, total mg	1574.004318	15962.50299	35.08882352	2142491.129	33485.32482	0	**2193548.05**
Non-halogenated Organics µg	27641031	2146449445	69430490.12	245440064.4	66684154.06	0	**2555645185**
o-Cresol mg	193.3914798	15765.35049	136.1775314	2535.042667	5762.313271	363.244704	**24755.52015**
Octadecane mg	100.2585947	8173.110895	70.59749765	1314.224952	2987.314543	188.3141934	**12833.82068**
Oils, unspecified mg	12664012.66	1001746912	223259629.9	174952581.2	166898125.2	253213.4456	**1579774474**
Other mg	334124.0638	3454026082	2428801.114	2081320.808	3863212.468	1870570552	**5333304092**
Other metals mg	232049.9414	508143428.5	1927700.002	4127974.105	14342041.01	231925421.7	**760698615.3**
p-Cresol mg	208.6564861	17010.02605	146.9283589	2735.128444	6217.186584	391.9228752	**26709.8488**
Pentanone, methyl- mg	28.25180022	2303.060768	19.89337373	370.3362587	841.7886946	53.06413461	**3616.39503**
Phenanthrene µg	1464.964305	82107.22825	765.0833092	21057.51588	38666.09288	1895.207668	**145956.0923**
Phenanthrenes, alkylated, unspecified µg	1475.304917	56827.40239	585.8247275	22491.07879	35485.2076	1315.122646	**118179.9411**
Phenol µg	7677473.573	845338634.1	82512124.26	191475737.8	127227503.1	798038.3392	**1255029511**
Phenol, 2,4-dimethyl- mg	188.3037508	15350.55804	132.594706	2468.352874	5610.713574	353.6875992	**24104.21054**
Phenols, unspecified mg	1529.521203	216057.0291	1729.481539	35814.24732	57777.25587	4969.781078	**317877.3161**
Phosphate mg	10815.19542	86426166.22	68486.43513	30490.89636	1939937.967	0	**88475896.71**
Phosphorus mg	73767.60559	31506083.28	596981.0868	694961.1044	12074162.32	0	**44945955.4**
Polynuclear Aromatic Hydrocarbons µg	0	477.9385937	0	0	0	146.9579183	**624.8965119**
Radium-226/kg µg	0.243009911	19.80977357	0.17111307	3.185482139	7.24068387	0.456431073	**31.10649363**

Radium-228/kg µg	0.001242956	0.101330134	0.000875275	0.01629427	0.037035676	0.002334723	**0.159113035**
Selenium µg	48130.68615	1871167.575	19235.02758	732898.6029	1159977.129	43299.99445	**3874709.015**
Silver mg	14106.69667	1148725.368	9924.313214	184977.9951	420156.6045	26467.55068	**1804358.528**
Sodium, ion mg	68473503.18	5583213891	48224702.54	897513505.1	2040407673	128641042	**8766474317**
Strontium mg	366484.4694	29875449.88	258058.1418	4804031.022	10919742.42	688351.3111	**46912117.25**
Sulfate mg	8039911.387	199512440.2	348048.5286	27479080.33	546732874.1	12844039.46	**794956394**
Sulfide mg	1288294.683	61978929.49	23371117.95	17969222.68	17236352.6	101.8618609	**121844019.3**
Sulfur mg	17811.02108	1451956.748	12541.68112	233473.2866	530698.4547	33454.09963	**2279935.291**
Suspended solids, unspecified mg	43166687.02	4901845583	464763931.8	575019898.9	1183609377	11954900.48	**7180360378**
Tetradecane mg	162.9468695	13283.4536	114.7395275	2135.966138	4855.177037	306.060067	**20858.34324**
Thallium µg	52194.4266	2015879.6	20764.28483	795437.78	1256142.812	46651.25731	**4187070.16**
Tin mg	1180.859588	69022.09501	636.9754725	16832.74657	31546.53482	1592.79917	**120812.0106**
Titanium, ion mg	3803.050179	146766.0963	1512.113974	57963.92521	91510.86026	3396.466917	**304952.5129**
Toluene mg	10654.83467	868582.9805	7502.628382	139667.4408	317472.144	20012.75979	**1363892.788**
Vanadium mg	182.5489956	14881.43535	128.5425195	2392.917183	5439.245239	342.8786837	**23367.56797**
Xylene mg	3253.553054	73272.68085	920.2523818	52186.90934	71305.01669	1705.741687	**202644.154**
Yttrium mg	45.3040914	3693.135148	31.90057445	593.8653604	1349.875891	85.09242394	**5799.173489**
Zinc mg	9356.353623	389414.2286	3922.488492	141196.1868	228921.8771	9006.386546	**781817.5212**

Table A.2.20 Emissions to Air Absolute Value Table by Assembly Groups

Material ID	Foundations	Walls	Beams and Columns	Roofs	Floors	Extra Basic Mater	**Total**
2-Chloroacetophenone g	0.00496966	0.062222847	0	0.020182695	0.103446518	0.002391073	**0.193212792**
Acenaphthene g	0.000388442	0.007546829	0.000125643	0.002146286	0.008915574	0.000488374	**0.019611148**
Acenaphthylene g	0.000190413	0.003699426	6.15896E-05	0.001052101	0.004370379	0.000239399	**0.009613308**
Acetaldehyde g	3.148545299	61.24425414	0.81952312	12.52715648	61.08789561	3.195443123	**142.0228178**
Acetophenone g	0.010649271	0.133334673	0	0.043248631	0.22167111	0.005123727	**0.414027412**
Acid Gases g	0	3286.143752	0	267.282254	842.0698844	0	**4395.495891**
Acrolein g	0.45196743	19.03842919	0.170278355	2.12761148	9.343090488	0.591564001	**31.72294095**
Aldehydes g	0.003169469	0.171634856	0.02065462	0.099111105	0.050183405	0.013514476	**0.358267931**
Ammonia g	15.75297121	380.5748425	7.245983634	359.2805241	339.6065253	11.14900617	**1113.609853**
Ammonium chloride g	0.862501482	46.70666054	5.620701587	26.97091275	13.65631279	3.677668057	**97.49475721**
Anthracene g	0.000159947	0.003107518	5.17352E-05	0.000883765	0.003671119	0.000201095	**0.008075179**
Antimony g	0.013709709	0.284570769	0.004434399	0.075751016	0.314666768	0.017236609	**0.71036927**
Arsenic g	0.33710465	7.883002911	0.139975063	4.156674716	7.914345786	0.416593888	**20.84769701**
Benzene g	71.13315104	938.3573837	1.361363395	290.5413692	1478.004064	37.13568803	**2816.53302**
Benzene, chloro- g	0.015618931	0.19555752	0	0.063431326	0.325117628	0.007514799	**0.607240205**
Benzene, ethyl- g	0.066735432	0.835563951	0	0.271024756	1.389138956	0.032108688	**2.594571783**
Benzo(a)anthracene g	6.09321E-05	0.001183816	1.97087E-05	0.000336672	0.001398521	7.66077E-05	**0.003076259**
Benzo(a)pyrene g	2.89427E-05	0.000562313	9.36161E-06	0.000159919	0.000664298	3.63887E-05	**0.001461223**
Benzo(b,j,k)fluoranthene g	8.37816E-05	0.001627747	2.70994E-05	0.000462924	0.001922967	0.000105336	**0.004229855**
Benzo(ghi)perylene g	2.05646E-05	0.000399538	6.65167E-06	0.000113627	0.000472001	2.58551E-05	**0.001038237**
Benzyl chloride g	0.496965986	6.222284743	0	2.018269456	10.3446518	0.239107252	**19.32127923**
Beryllium g	0.014155616	0.380944887	0.006136825	0.131290286	0.336486886	0.0198409	**0.8888554**
Biphenyl g	0.001294807	0.025156097	0.000418809	0.007154288	0.029718579	0.001627914	**0.065370493**
Bromoform g	0.027688105	0.34667015	0	0.112446441	0.576344886	0.01332169	**1.076471272**
Butadiene g	0.139882202	2.863921735	0.041779156	0.5548497	2.684822266	0.152977317	**6.438232377**
Cadmium g	0.108038005	4.326499187	0.043359084	1.27173364	2.696108207	0.134207186	**8.579945309**
Carbon dioxide,	0	472.6587636	0	3.683353251	0	0	**476.3421169**

biogenic kg							
Carbon dioxide, fossil kg	21636.42287	681841.3486	22124.79877	126360.5897	478563.0255	57559.45169	**1388085.637**
Carbon disulfide g	0.092293683	1.155567167	0	0.37482147	1.92114962	0.044405633	**3.588237572**
Carbon monoxide g	21653.0811	7794970.54	253996.7592	302562.7294	250865.4381	164731.5898	**8788780.137**
Carbon monoxide, fossil g	18562.72112	554891.1878	6287.744808	273635.9342	415217.2214	16718.30563	**1285313.115**
Chlorine g	0	1.821327708	0	0	0	0	**1.821327708**
Chloroform g	0.041887133	0.524449714	0	0.170111283	0.871906366	0.020153326	**1.628507821**
Chromium g	0.231105757	7.976765469	0.1122985	2.809676995	5.741386011	0.331867772	**17.2031005**
Chromium VI g	0.060170323	1.169005625	0.019461761	0.33246104	1.381033906	0.075648746	**3.0377814**
Chrysene g	7.61651E-05	0.00147977	2.46358E-05	0.00042084	0.001748152	9.57596E-05	**0.003845323**
Chrysene, 5-methyl- g	1.67563E-05	0.000325549	5.41988E-06	9.25849E-05	0.000384593	2.10671E-05	**0.000845971**
Cobalt g	0.484866608	11.19670134	0.187187602	12.64596348	11.06667217	0.308693358	**35.89008456**
Copper g	0	0.089197159	0	0.001555496	0.001243539	0	**0.091996194**
Cumene g	0.003762742	0.047111584	0	0.015281183	0.078323792	0.001810383	**0.146289686**
Cyanide g	1.77487852	22.22244551	0	7.2081052	36.94518499	0.853954473	**69.00456869**
Dinitrogen monoxide g	533.0918335	6836.842115	9.377578424	2394.226561	11104.24443	269.2404758	**21147.023**
Ethane, 1,1,1-trichloro-, HCFC-140 g	0.01427029	0.17947188	2.59654E-05	0.05928829	0.29710452	0.006878245	**0.557039191**
Ethane, 1,2-dibromo- g	0.000851942	0.010666774	0	0.00345989	0.017733689	0.000409898	**0.033122193**
Ethane, 1,2-dichloro- g	0.028398056	0.355559128	0	0.115329683	0.59112296	0.013663272	**1.104073099**
Ethane, chloro- g	0.029817959	0.373337085	0	0.121096167	0.620679108	0.014346435	**1.159276754**
Ethene, tetrachloro- g	0.037501167	0.755838444	0.012479943	0.323369332	0.861459007	0.043691733	**2.034339626**
Fluoranthene g	0.000540772	0.01050637	0.000174914	0.002987967	0.012411877	0.000679893	**0.027301794**
Fluorene g	0.000693103	0.013465911	0.000224186	0.003829648	0.015908181	0.000871413	**0.03499244**
Fluoride g	31.67894952	397.4443778	0.126271298	129.1812096	659.3202263	15.31511858	**1233.066153**
Formaldehyde g	12.33435311	384.4897281	3.576561275	113.1085289	275.8494275	12.22503214	**801.583631**
Furan g	2.58498E-07	2.95436E-05	1.23179E-06	6.62581E-06	1.35172E-05	3.08007E-06	**5.4257E-05**
Hexane g	0.047566744	0.59556154	0	0.193177219	0.990130958	0.02288598	**1.849322441**
Hydrazine, methyl g	0.120691739	1.511126295	0	0.490151154	2.512272579	0.058068904	**4.692310671**

Hydrocarbons, unspecified g	24340.98654	2899289.393	29955.46076	234660.7143	356706.1024	21.22612567	**3544973.883**
Hydrogen chloride g	544.6439062	86755.43333	314.3295456	4780.877229	13382.22008	2036.312858	**107813.817**
Hydrogen fluoride g	82.11931215	170128.0751	36.95368159	503.7011727	1953.462855	2052.557862	**174756.87**
Indeno(1,2,3-cd)pyrene g	4.64607E-05	0.00090266	1.50279E-05	0.000256713	0.001066373	5.84134E-05	**0.002345647**
Isophorone g	0.411771817	5.155607358	0	1.672280406	8.571282918	0.198117438	**16.00905994**
Kerosene g	0.413075537	22.36909649	2.691907636	12.91710738	6.5403815	1.761335764	**46.69290431**
Lead g	2.667246964	38.02726789	0.153016265	13.98662284	56.54481189	1.557985962	**112.9369518**
Magnesium g	8.378155013	162.7739344	2.709907083	46.2922676	192.2963175	10.53347382	**422.9840555**
Manganese g	0.487616196	15.47143287	0.207908626	7.817084972	11.44856432	0.548127556	**35.98073454**
Mercaptans, unspecified g	154.0594555	1928.90827	0	625.6635314	3206.842057	74.12324822	**5989.596563**
Mercury g	0.944369111	12.95393439	0.028232643	4.145044931	19.88173154	0.51578111	**38.46909373**
Metals, unspecified g	20.68733974	168.5813639	7.2248E-07	0.075531747	0.000816135	0	**189.3450523**
Methacrylic acid, methyl ester g	0.014199028	0.177779564	0	0.057664842	0.29556148	0.006831636	**0.55203655**
Methane g	15871.73145	1545121.393	12297.0919	107486.9935	467521.249	90235.46926	**2238533.928**
Methane, bromo-, Halon 1001 g	0.113592225	1.422236513	0	0.461318733	2.364491839	0.054653086	**4.416292396**
Methane, dichloro-, HCC-30 g	0.546714868	13.01029991	0.199640631	11.00139543	12.40002444	0.439601102	**37.59767638**
Methane, dichlorodifluoro-, CFC-12 g	8.81213E-05	0.002092486	3.21149E-05	0.002008369	0.001907989	5.76222E-05	**0.006186702**
Methane, fossil g	4257.170966	275385.2135	2664.803372	76571.10134	115918.3019	6681.11696	**481477.708**
Methane, monochloro-, R-40 g	0.376274246	4.711158448	0	1.528118302	7.832379218	0.181038348	**14.62896856**
Methane, tetrachloro-, CFC-10 g	8.81483E-06	0.103955923	3.21026E-06	0.000200524	0.000190918	5.7699E-06	**0.10436516**
Methyl ethyl ketone g	0.276881049	3.4667015	0	1.124464411	5.763448859	0.133216898	**10.76471272**
Naphthalene g	0.095036918	3.617568607	0.044599525	2.425290926	2.31998242	0.08416144	**8.586639836**

Nickel g	6.011263877	143.1862856	2.367427858	173.085124	137.2308198	3.329371586	**465.2102926**
Nitrogen oxides g	72429.7008	3262459.641	20199.31961	633827.9808	1424724.528	329739.3507	**5743380.521**
NMVOC, non-methane volatile organic compounds, uns g	0	0	0	2201.641926	0	0	**2201.641926**
Organic acids g	0.003169469	0.171634856	0.02065462	0.099111105	0.050183405	0.013514476	**0.358267931**
Organic substances, unspecified g	4.61488978	89.64693545	1.49225041	25.49233088	105.918994	5.800371674	**232.9657722**
Other g	5.90981102	13508.34402	0	18423.02504	0	4443.417882	**36380.69675**
PAH, polycyclic aromatic hydrocarbons g	0.614788719	12.44477526	0.179815161	2.391618514	11.82856918	0.657281741	**28.11684857**
Particulates, > 2.5 um, and < 10um g	3458.165354	66096.47521	344.4579352	18270.04626	73898.89421	2338.583696	**164406.6227**
Particulates, unspecified g	54808.37385	6319049.231	15941.61148	703670.6916	1224981.5	1351039.545	**9669490.953**
Phenanthrene g	0.002056458	0.039953801	0.000665167	0.011362692	0.047200096	0.00258551	**0.103823725**
Phenol g	0.011359223	36.88142797	0	0.046131873	0.236449184	0.005465309	**37.18083356**
Phenols, unspecified g	0.257698866	6.420203251	0.100536798	7.43713242	5.803081133	0.137312993	**20.15596546**
Phthalate, dioctyl- g	0.051826453	0.648895409	0	0.210476672	1.078799402	0.024935471	**2.014933406**
Propanal g	0.269781535	3.377811718	0	1.09563199	5.615668119	0.12980108	**10.48869444**
Propene g	9.229978052	188.9728242	2.756753107	36.61116628	177.1551366	10.09404526	**424.8199035**
Pyrene g	0.000251345	0.004883242	8.12982E-05	0.001388773	0.005768901	0.000316007	**0.012689566**
Radioactive species, unspecified MBq	2.984409833	336.2223553	13.96496658	76.69041165	154.3817166	34.89469393	**619.1385539**
Radionuclides (Including Radon) g	23.09952067	1250.898106	150.5336688	722.3351719	365.7434637	98.49533136	**2611.105262**
Selenium g	1.036720409	20.60082051	0.338973953	6.86365467	23.79467992	1.269808762	**53.90465822**
Styrene g	0.017748785	0.222224455	0	0.072081052	0.36945185	0.008539545	**0.690045687**
Sulfur dioxide g	41063.1449	3079043.982	28523.92942	281470.5167	1221130.253	90281.01613	**4741512.842**
Sulfur oxides g	14278.47546	810843.5979	38574.49897	186039.4626	162097.0157	262354.1564	**1474187.207**
Sulfuric acid, dimethyl ester g	0.034077668	0.426670954	0	0.13839562	0.709347552	0.016395926	**1.324887719**

t-Butyl methyl ether g	0.024848299	0.311114237	0	0.100913473	0.51723259	0.011955363	**0.966063962**
TOC, Total Organic Carbon g	0	9.429405475	0	0	0	0	**9.429405475**
Toluene g	1.633593539	32.0907412	0.437021135	6.495854188	31.63069589	1.682163231	**73.97006918**
Toluene, 2,4-dinitro- g	0.000198786	0.002488914	0	0.000807308	0.004137861	9.56429E-05	**0.007728512**
Vinyl acetate g	0.005395631	0.067556234	0	0.02191264	0.112313362	0.002596022	**0.209773889**
VOC, volatile organic compounds g	2641.784191	126756.954	882.0137862	32851.79863	62172.88605	2668.368837	**227973.8055**
Xylene g	1.045873068	21.20408929	0.304529314	4.150993288	20.11652533	1.127694012	**47.94970431**
Zinc g	0	0.059464773	0	0.001036998	0.000829026	0	**0.061330796**

Appendix 3: Cost Estimating Details of Base Office Building Case Study

Table A. 3.1 Cost Summary for Office Building

Project	Example - 8 Story Office Building					*GFA*	54,000.00 SF	
	LEVEL 2 GROUP ELEMENTS	*Ratio*	*Element*				*Cost per*	*%*
	Level 3 Elements	*Qty/GFA*	*Quantity*	*Unit*	*Rate*	*Cost*	*Unit GFA*	
A10	**FOUNDATIONS**	-	-		-	**69,726.50**	**1.29**	**1.6%**
A1010	Standard Foundations	0.11	6,000.00	SF	7.67	46,026.50	0.85	
A1020	Special Foundations	-	-		-	-		
A1030	Slab on Grade	0.11	6,000.00	SF	3.95	23,700.00	0.44	
A20	**BASEMENT CONSTRUCTION**	-	-		-	**75,467.20**	**1.40**	**1.7%**
A2010	Basement Excavation	0.05	2,700.00	CY	5.91	15,960.00	0.30	
A2020	Basement Walls	0.07	3,840.00	SF	15.50	59,507.20	1.10	
B10	**SUPERSTRUCTURE**	-	-		-	**688,569.96**	**12.75**	**15.8%**
B1010	Floor Construction	0.89	48,000.00	SF	13.37	641,632.56	11.88	
B1020	Roof Construction	0.11	6,000.00	SF	7.82	46,937.40	0.87	
B20	**EXTERIOR ENCLOSURE**	-	-		-	**794,141.00**	**14.71**	**18.2%**
B2010	Exterior Walls	0.47	25,500.00	SF	18.43	469,900.00	8.70	
B2020	Exterior Windows	0.12	6,600.00	SF	47.58	314,041.00	5.82	
B2030	Exterior Doors	0.00	5.00	LVS	2,040.00	10,200.00	0.19	
B30	**ROOFING**	-	-		-	**20,269.00**	**0.38**	**0.5%**
B3010	Roof Coverings	0.11	6,000.00	SF	3.25	19,472.00	0.36	
B3020	Roof Openings	0.00	11.30	SF	70.53	797.00	0.01	
C10	**INTERIOR CONSTRUCTION**	-	-		-	**235,604.00**	**4.36**	**5.4%**
C1010	Partitions	0.54	28,979.00	SF	5.37	155,653.80	2.88	
C1020	Interior Doors	0.00	66.00	EA	693.50	45,771.00	0.85	
C1030	Fittings	0.00	1.00	Lot	34,179.20	34,179.20	0.63	
C20	**STAIRS**	-	-		-	**120,600.00**	**2.23**	**2.8%**
C2010	Stair Construction	0.00	18.00	FLT	6,700.00	120,600.00	2.23	
C2020	Stair Finishes	-	-		-	-		
C30	**INTERIOR FINISHES**	-	-		-	**325,583.43**	**6.03**	**7.5%**
C3010	Wall Finishes	0.81	43,484.00	SF	0.90	39,125.68	0.72	
C3020	Floor Finishes	0.69	37,350.00	SF	4.16	155,469.75	2.88	
C3030	Ceilling Finishes	0.96	52,100.00	SF	2.51	130,988.00	2.43	
D10	**CONVEYING**	-	-		-	**270,000.00**	**5.00**	**6.2%**
D1010	Elevators & Lifts	0.00	18.00	STOP	15,000.00	270,000.00	5.00	
D1020	Escalators & Moving Walks	-	-		-	-		
D1090	Other Conveying Systems	-	-		-	-		
D20	**PLUMBING**	-	-		-	**134,925.20**	**2.50**	**3.1%**
D2010	Plumbing Fixtures	0.00	78.00	FIX	1,007.51	78,586.00	1.46	
D2020	Domestic Water Distribution	0.00	78.00	FIX	334.10	26,060.00	0.48	
D2030	Sanitary Waste	0.00	78.00	FIX	312.24	24,355.00	0.45	
D2040	Rain Water Drainage	0.11	6,000.00	SF	0.99	5,924.20	0.11	
D2090	Other Plumbing Systems	-	-		-	-		
D30	**HVAC**	-	-		-	**752,460.00**	**13.93**	**17.2%**
D3010	Energy Supply	-	-		-	-		
D3020	Heat Generating Systems	0.02	1,088.00	MBH	21.69	23,600.00	0.44	
D3030	Cooling Generating Systems	0.00	150.00	TR	985.00	147,750.00	2.74	
D3040	Distribution Systems	0.89	48,000.00	SF	10.01	480,600.00	8.90	
D3050	Terminal & Package Units	0.11	6,000.00	SF	1.48	8,880.00	0.16	
D3060	Controls and Instrumentation	1.00	54,000.00	SF	1.60	86,400.00	1.60	
D3070	Systems Testing & Balancing	1.00	54,000.00	SF	0.10	5,230.00	0.10	
D3090	Other HVAC Systems & Equipment	-	-		-	-		
D40	**FIRE PROTECTION**	-	-		-	**103,655.00**	**1.92**	**2.4%**
D4010	Sprinklers	0.01	270.00	HDS	308.22	83,220.00	1.54	
D4020	Standpipes	0.00	9.00		2,270.56	20,435.00	0.38	
D4030	Fire Protection Specialties	-	-		-	-		
D4090	Other Fire Protection Systems	-	-		-	-		
D50	**ELECTRICAL**	-	-		-	**702,805.00**	**13.01**	**16.1%**
D5010	Electrical Service & Distribution	0.01	360.00	kW	242.15	87,175.00	1.61	
D5020	Lighting & Branch Wiring	1.00	54,000.00	SF	8.64	466,380.00	8.64	
D5030	Communication & Security	1.00	54,000.00	SF	2.48	133,665.00	2.48	
D5090	Other Electrical Systems	0.00	30.00	kW	519.50	15,585.00	0.29	
E10	**EQUIPMENT**	-	-		-	**17,310.00**	**0.32**	**0.4%**
E1010	Commercial Equipment	-	-		-	-		
E1020	Institutional Equipment	-	-		-	-		
E1030	Vehicular Equipment	0.00	1.00	Lot	10,655.00	10,655.00	0.20	
E1090	Other Equipment	0.00	1.00	Lot	6,655.00	6,655.00	0.12	
E20	**FURNISHINGS**	-	-		-	**55,716.00**	**1.03**	**1.3%**
E2010	Fixed Furnishings	0.00	1.00	Lot	55,716.00	55,716.00	1.03	
E2020	Movable Furnishings	-	-		-	-		
F10	**SPECIAL CONSTRUCTION**	-	-		-	**-**		**0.0%**
F1010	Special Structures	-	-		-	-		
F1020	Integrated Construction	-	-		-	-		
F1030	Special Construction Systems	-	-		-	-		
F1040	Special Facilities	-	-		-	-		
F1050	Special Controls and Instrumentation	-	-		-	-		
F20	**SELECTIVE BUILDING CONSTRUCTION**	-	-		-	**-**		**0.0%**
F2010	Building Elements Demolition	-	-		-	-		
F2020	Hazardous Components Abatement	-	-		-	-		
	Building Elemental Cost without Design Allowance					**4,366,832.29**	**80.87**	**100.00%**
Z10	**Design Allowance**				6.00%	262,009.94	4.85	
	Building Elemental Cost with Design Allowance					**4,628,842.23**	**85.72**	**106.00%**
Z20	**Overhead & Profit**				14.00%	648,037.91	12.00	
Z2010	Overhead				9.00%	416,595.80	7.71	
Z2020	Profit				5.00%	231,442.11	4.29	
	Building Construction Cost without Inflation					**5,276,880.14**	**97.72**	**120.84%**
Z30	**Inflation Allowance**				3.50%	184,690.80	3.42	
	Building Construction Cost (BCC)					**5,461,570.94**	**101.14**	**125.07%**

Table 3.2 Detailed Cost Estimates for Building

Project: Example - 8 Story Office Building

Input Code	Description	Quantity	Unit	Rate	Cost	Output Code
A	**SUBSTRUCTURE**			-	**145,193.70**	
A10	**FOUNDATIONS**			-	**69,726.50**	
A1010	**Standard Foundations**	**6,000.0**	**SF**	**7.67**	**46,026.50**	
A01.1-120-7900	Corner Spread ftgs, ld 400K, soil cap 6 KSF, 8'-6" sq x 27" d	4.0	EA	1,360.00	5,440.00	
A01.1-120-8010	Exterior Spread ftgs, ld 500K, soil cap 6 KSF, 9'-6" sq x 30" d	8.0	EA	1,820.00	14,560.00	
A01.1-120-8300	Interior Spread ftgs, ld 800K, soil cap 6 KSF, 12'-0" sq x 37" d	3.0	EA	3,400.00	10,200.00	
A01.1-140-2700	Strip footing, load 11.1KLF, 24"wide x 12"deep, reinf	210.0	LF	26.45	5,554.50	
A01.1-294-3000	Foundation underdrain, outside and inside, PVC, 4" diameter	640.0	LF	16.05	10,272.00	
A1020	**Special Foundations**			-		
A1030	**Slab on Grade**	**6,000.0**	**SF**	**3.95**	**23,700.00**	
A02.1-200-2240	Slab on grade, 4" thick, non industrial, reinforced	6,000.0	SF	3.60	21,600.00	
07.2-109-0600	Perimeter under slab insulation - polystyrene 1", R4	2,800.0	SF	0.75	2,100.00	
A20	**BASEMENT CONSTRUCTION**			-	**75,467.20**	
A2010	**Basement Excavation**	**2,700.0**	**CY**	**5.91**	**15,960.00**	
A01.9-100-3440	Basement Excav & backfill, 12' deep, sand, gravel, on site storage	6,000.0	SF	2.66	15,960.00	
A2020	**Basement Walls**	**3,840.0**	**SF**	**15.50**	**59,507.20**	
A01.1-210-7260	Basement Fdn walls, CIP,12' height,pumped,12" thick	320.0	LF	168.00	53,760.00	
A01.1-292-2800	Basement Foundation dampproofing, bituminous, 2 coats, 12' high	320.0	LF	12.44	3,980.80	
07.2-109-0700	Basement Wall insulation - polystyrene 2", R8	1,920.0	LF	0.92	1,766.40	
B	**SHELL**			-	**1,502,979.96**	
B10	**SUPERSTRUCTURE**			-	**688,569.96**	
B1010	**Floor Construction**	**48,000.0**	**SF**	**13.37**	**641,632.56**	
A03.5-540-3600	Floor, Composite bm,dk&slb,25x30',75 PSF superimposed load	48,000.0	SF	10.94	525,120.00	
A03.1-130-5800	Steel columns,400 KIPS,10' unsupported height	1,296.0	VLF	76.50	99,144.00	
A03.1-190-3650	Steel column fireproofing,gyp bd 1/2"fr	792.0	VLF	21.93	17,368.56	
B1020	**Roof Construction**	**6,000.0**	**SF**	**7.82**	**46,937.40**	
A03.7-420-3900	Roof - Open Web Joists, Beams & deck,25x30',40PSF superimposed load	6,000.0	SF	4.87	29,220.00	
A03.1-130-5800	Steel columns,400 KIPS,10' unsupported height	180.0	VLF	76.50	13,770.00	
A03.1-190-3650	Steel column fireproofing,gyp bd 1/2"fr	180.0	VLF	21.93	3,947.40	
B20	**EXTERIOR ENCLOSURE**			-	**794,141.00**	
B2010	**Exterior Walls**	**25,500.0**	**SF**	**18.43**	**469,900.00**	
A04.1-273-1200	4" Brick Wall & 6" Block c/w Insulation	16,500.0	SF.	19.80	326,700.00	
A04.1-211-3410	8" Conc block wall c/w styrofoam insulation	9,000.0	SF	9.46	85,140.00	
A04.1- 140-6776	Precast Concrete Coping - 14" wide	320.0	LF	25.25	8,080.00	
A06.1-680-0920	Gypsum plaster, 2 coats	24,500.0	SF	2.04	49,980.00	
B2020	**Exterior Windows**	**6,600.0**	**SF**	**47.58**	**314,041.00**	
A04.7-110-8800	Alu. Windows & Insulated glass,3'-0" x 5'-4"	406.0	EA	773.50	314,041.00	
B2030	**Exterior Doors**	**5.0**	**LVS**	**2,040.00**	**10,200.00**	
A04.6-100-6300	Single Alu. & Glass Door c/w hardware,3'-0"x 7'-0"opng	2.0	EA	1,870.00	3,740.00	

Table 4.2 Detailed Cost Estimates for Building (cont.)

Project Example - 8 Story Office Building

Input Code	Description	*Quantity*	*Unit*	*Rate*	*Cost*	Output Code
C3030	**Ceilling Finishes**	**52,100.0**	**SF**	**2.51**	**130,988.00**	
A06.7-810-3260	T-bar suspension system, 2' x 4' grid	41,600.0	SF	0.80	33,280.00	
A06.7-810-2780	Suspended Ceiling - Mineral fiber boards, 5/8" thick, 2 hour rating	41,600.0	SF	1.43	59,488.00	
A06.7-100-5400	Drywall,1/2"fr	10,500.0	SF	2.87	30,135.00	
A06.5-100-0080	Painting, interior on drywall, primer & 2 coats	10,500.0	SF	0.77	8,085.00	
D	**SERVICES**			**-**	**1,963,845.20**	
D10	**CONVEYING**			**-**	**270,000.00**	
D1010	**Elevators & Lifts**	**18.0**	**STOP**	**15,000.00**	**270,000.00**	
A07.1-200-1600	Elevator - Traction gearless, 2500 lb, 9 floors, 200 FPM (interpolation)	2.0	EA	135,000.00	270,000.00	
D1020	**Escalators & Moving Walks**			**-**		
D1090	**Other Conveying Systems**			**-**		
D20	**PLUMBING**			**-**	**134,925.20**	
D2010	**Plumbing Fixtures**	**78.0**	**FIX**	**1,007.51**	**78,586.00**	
A08.1-433-1560	Lavatory w/trim, vanity top, 20" x 18"	31.0	EA	656.00	20,336.00	
A08.1-434-4340	Service sink w/trim, 24" x 20"	8.0	EA	1,480.00	11,840.00	
A08.1-450-2000	Urinal, wall hung	8.0	EA	880.00	7,040.00	
A08.1-470-2080	Water Closet, wall hung	31.0	EA	1,270.00	39,370.00	
D2020	**Domestic Water Distribution**	**78.0**	**FIX**	**334.10**	**26,060.00**	
A08.1-160-1940	Electric water heater, 120 gal, 36 KW 147 GPH	1.0	EA	5,125.00	5,125.00	
R8.1-030	Allowance for piping (22.5% of fixture cost D2010)	1.0	Lot	20,935.00	20,935.00	
D2030	**Sanitary Waste**	**78.0**	**FIX**	**312.24**	**24,355.00**	
15.1-100-0840	Floor Drain - 3" dia.	20.0	EA	171.00	3,420.00	
R8.1-030	Allowance for piping (22.5% of fixture cost D2010)	1.0	Lot	20,935.00	20,935.00	
D2040	**Rain Water Drainage**	**6,000.0**	**SF**	**0.99**	**5,924.20**	
A08.1-310-4200	Roof Drain System, CI, soil,single hub,4" diam, 10' high	2.0	EA	860.00	1,720.00	
A08.1-310-4240	Roof drain, additional foot	196.0	LF	21.45	4,204.20	
D2090	**Other Plumbing Systems**			**-**		
D30	**HVAC**			**-**	**752,460.00**	
D3010	**Energy Supply**			**-**		
D3020	**Heat Generating Systems**	**1,088.0**	**MBH**	**21.69**	**23,600.00**	
A08.7-220-1070	Boiler, cast iron, gas, hot water, 1088 MBH c/w circulating pump	1.0	EA	23,600.00	23,600.00	
D3030	**Cooling Generating Systems**	**150.0**	**TR**	**985.00**	**147,750.00**	
A08.8-110-1030	Chiller, reciprocating, water cooled, std. controls, 150 ton	1.0	EA	103,000.00	103,000.00	
A08.5-414-1040	Chilled Water Pump, base mtd w/ motor, 5" size, 10 HP, (interpolation)	1.0	EA	10,600.00	10,600.00	
A08.8-160-1020	Cooling tower, galvanized steel, packaged unit, draw thru, 150 ton (interpolation)	1.0	EA	25,250.00	25,250.00	
A08.5-414-1030	Cooling Tower Pump, base mtd with motor, 4" size, 7-1/2 HP, to 350 GPM	1.0	EA	8,900.00	8,900.00	
D3040	**Distribution Systems**	**48,000.0**	**SF**	**10.01**	**480,600.00**	
A08.3-142-3400	Hot Water heating distribution,fin tube radiation (interpolation)	48,000.0	SF	4.35	208,800.00	
A08.4-120-4000	Cooling air distribution supply and return air ducts c/w devices (interpolation)	48,000.0	SF	4.20	201,600.00	

Table 5.2 Detailed Cost Estimates for Building (cont.)

Project Example - 8 Story Office Building

Input Code	Description	*Quantity*	*Unit*	*Rate*	*Cost*	Output Code
A08.8-310-1010	Air Handling Unit, field fab, VAV cool/heat, c/w return air, 52,800 CFM (interpolation)	1.0	EA	70,200.00	70,200.00	
D3050	**Terminal & Package Units**	**6,000.0**	**SF**	**1.48**	**8,880.00**	
15.5-461-0160	Direct Gas Fired 6000 CFM, 500 MBH, Parking Garage Make up air Unit	1.0	EA	7,400.00	7,400.00	
R155-020	Allowance for gas & vent piping (20.0% of unit cost)	1.0	Lot	1,480.00	1,480.00	
D3060	**Controls and Instrumentation**	**54,000.0**	**SF**	**1.60**	**86,400.00**	
R155-021	Allowance for controls & instrumentation	54,000.0	SF	1.60	86,400.00	
D3070	**Systems Testing & Balancing**	**54,000.0**	**SF**	**0.10**	**5,230.00**	
R155-022	Allowance for balancing of HVAC Systems - 0.5% system costs	1.0	Lot	5,230.00	5,230.00	
D3090	**Other HVAC Systems & Equipment**			-		
D40	**FIRE PROTECTION**			-	**103,655.00**	
D4010	**Sprinklers**	**270.0**	**HDS**	**308.22**	**83,220.00**	
A08.2-110-0600	First Office Floor - Wet pipe sprinkler system	6,000.0	SF	2.01	12,060.00	
A08.2-110-0720	Seven add. Office Floors - Wet pipe sprinkler system	42,000.0	SF	1.33	55,860.00	
A08.2-120-1060	Basement Parking - Dry pipe sprinkler system	6,000.0	SF	2.55	15,300.00	
D4020	**Standpipes**	**9.0**		**2,270.56**	**20,435.00**	
A08.2-310-0560	Wet standpipe risers, class I, 4" diam pipe, 1 fl	1.0	FLR	3,700.00	3,700.00	
A08.2-310-0580	Wet standpipe risers, class I, 4" diam pipe, addl fls	8.0	FLR	1,130.00	9,040.00	
A08.2-390-8400	Fire Cabinet assy	9.0	EA	855.00	7,695.00	
D4030	**Fire Protection Specialties**			-		
D4090	**Other Fire Protection Systems**			-		
D50	**ELECTRICAL**			-	**702,805.00**	
D5010	**Electrical Service & Distribution**	**360.0**	**kW**	**242.15**	**87,175.00**	
A09.1-210-0560	3 ph, 4 W, 120/208 V, 2000 A Service	1.0	EA	29,175.00	29,175.00	
A09.1-310-0560	2000 amperes Feeder	50.0	LF	356.00	17,800.00	
A09.1-410-0400	2000 amperes Switchgear	1.0	EA	40,200.00	40,200.00	
D5020	**Lighting & Branch Wiring**	**54,000.0**	**SF**	**8.64**	**466,380.00**	
A09.2-213-0240	Basement - Fluor fixture, 40 FC, 10 fxtr per 1000 SF	6,000.0	SF	3.44	20,640.00	
A09.2-522-0560	Basement - Receptacles ,10 per 1000 SF, 1.2 W per SF	6,000.0	SF	2.17	13,020.00	
A09.2-213-0280	Office Floors - Fluor fixture 60 FC, 15 fxtr per 1000 SF	48,000.0	SF	5.17	248,160.00	
A09.2-522-0640	Office - Receptacles,16.5 per 1000 SF, 2.0 W per SF	48,000.0	SF	2.87	137,760.00	
A09.2-542-0280	Wall switches, 2.0 per 1000 SF	54,000.0	SF	0.27	14,580.00	
A09.2-582-0320	Miscellaneous connections, 1.2 watts/SF	54,000.0	SF	0.19	10,260.00	
A09.2-710-0680	Elevator Motor - 10 HP	2.0	EA	2,100.00	4,200.00	
A09.2-610-0280	Central air conditioning power, 4 watts/SF	48,000.0	SF	0.37	17,760.00	
D5030	**Communication & Security**	**54,000.0**	**SF**	**2.48**	**133,665.00**	
A09.4-100-0400	Fire Detection System - 50 detectors	1.0	EA	21,825.00	21,825.00	
A09.4-150-0560	Telephone systems, telepoles, high density	48,000.0	S.F.	2.33	111,840.00	
D5090	**Other Electrical Systems**	**30.0**	**kW**	**519.50**	**15,585.00**	
A09.4-310-0320	Emergency Generator Set, 30KW	30.0	kW	519.50	15,585.00	

Table 6.2 Detailed Cost Estimates for Building (cont.)

Project Example - 8 Story Office Building

Input Code	Description	*Quantity*	*Unit*	*Rate*	*Cost*	Output Code
E	**EQUIPMENT & FURNISHINGS**			**-**	**73,026.00**	
E10	**EQUIPMENT**			**-**	**17,310.00**	
E1010	**Commercial Equipment**			**-**		
E1020	**Institutional Equipment**			**-**		
E1030	**Vehicular Equipment**	**1.0**	**Lot**	**10,655.00**	**10,655.00**	
A11.1-200-3500	Dock leveler, hydraulic, 7' x 8', 10 ton capacity	1.0	EA	7,190.00	7,190.00	
A11.1-200-6300	Parking equipment, Automatic Gates, 8 FT arm, 1 way	1.0	EA	3,465.00	3,465.00	
E1090	**Other Equipment**	**1.0**	**Lot**	**6,655.00**	**6,655.00**	
A11.1-200-8500	Waste Handling Compactor	1.0	EA	6,655.00	6,655.00	
E20	**FURNISHINGS**			**-**	**55,716.00**	
E2010	**Fixed Furnishings**	**1.0**	**Lot**	**55,716.00**	**55,716.00**	
A11.1-500-4100	Vertical PVC blinds-interior	6,000.0	SF	7.95	47,700.00	
A11.1-500-5600	Laminated plastic Counter Top for Washroom	160.0	LF	50.10	8,016.00	
E2020	**Movable Furnishings**			**-**		
F	**SPECIAL CONSTRUCTION & DEMOLITION**			**-**	**0.00**	
F10	**SPECIAL CONSTRUCTION**			**-**	**0.00**	
F1010	**Special Structures**			**-**		
F1020	**Integrated Construction**			**-**		
F1030	**Special Construction Systems**			**-**		
F1040	**Special Facilities**			**-**		
F1050	**Special Controls and Instrumentation**			**-**		
F20	**SELECTIVE BUILDING CONSTRUCTION**			**-**	**0.00**	
F2010	**Building Elements Demolition**			**-**		
F2020	**Hazardous Components Abatement**			**-**		
	Building Elemental Cost without Design Allowance	54,000.00	SF	$80.87	**$4,366,832.29**	

Table A.3.3 Cost Summary for Site work

Project	Example - 8 Story Office Building				NSA		37,560.00 SF	
	LEVEL 2 GROUP ELEMENTS / Level 3 Elements	Ratio Qty/NSA	Element Quantity	Unit	Rate	Cost	Cost per Unit NSA	%
G10	**SITE PREPARATION**	-	-		-	**26,357.50**	**0.70**	**13.9%**
G1010	Site Clearing	0.23	8,500.0	SF	0.35	2,950.00	0.08	
G1020	Site Demolition and Relocations	-	-		-	-		
G1030	Site Earthwork	1.16	43,650.0	SF	0.54	23,407.50	0.62	
G1040	Hazardous Waste Remediation	-	-		-	-		
G20	**SITE IMPROVEMENTS**	-	-		-	**58,601.18**	**1.56**	**30.9%**
G2010	Roadways	0.06	2,400.0	SF	3.50	8,400.00	0.22	
G2020	Parkings Lots	0.49	18,500.0	SF	1.99	36,900.00	0.98	
G2030	Pedestrian Paving	0.03	1,000.0	SF	4.26	4,262.50	0.11	
G2040	Site Development	-	-		-	-		
G2050	Landscaping	0.43	16,250.0	SF	0.56	9,038.68	0.24	
G30	**SITE MECHANICAL UTILITIES**	-	-		-	**59,765.05**	**1.59**	**31.6%**
G3010	Water Supply	0	80.0	LF	19.59	1,567.20	0.04	
G3020	Sanitary Sewer	0	120.0	LF	10.87	1,304.40	0.03	
G3030	Storm Sewer	1.00	37,560.0	SF	0.97	36,526.60	0.97	
G3040	Heating Distribution	-	-		-	-		
G3050	Cooling Distribution	-	-		-	-		
G3060	Fuel Distribution	0	135.0	LF	21.99	2,968.65	0.08	
G3090	Other Site Mechanical Utilities	0.43	16,260.0	SF	1.07	17,398.20	0.46	
G40	**SITE ELECTRICAL UTILITIES**	-	-		-	**44,686.90**	**1.19**	**23.6%**
G4010	Electrical Distribution	0	160.0	SF	195.69	31,310.90	0.83	
G4020	Site Lighting	0.50	18,600.0	SF	0.61	11,256.00	0.30	
G4030	Site Communications & Security	0.50	18,600.0	SF	0.11	2,120.00	0.06	
G4090	Other Site Electrical Utilities	-	-		-	-		
G90	**OTHER SITE CONSTRUCTION**	-	-		-	**-**		**0.0%**
G9010	Service and Pedestrian Tunnels	-	-		-	-		
G9090	Other Site Systems	-	-		-	-		
	Sitework Elemental Cost without Design Allowance					**189,410.63**	**5.04**	**100.00%**
Z50	**Design Allowance**				6.00%	11,364.64	0.30	
	Sitework Elemental Cost with Design Allowance					**200,775.27**	**5.35**	**106.00%**
Z60	**Overhead & Profit**				14.00%	28,108.53	0.75	
Z6010	Overhead				9.00%	18,069.77	0.48	
Z6020	Profit				5.00%	10,038.76	0.27	
	Sitework Construction Cost without Inflation					**228,883.80**	**6.09**	**120.84%**
Z70	**Inflation Allowance**				3.50%	8,010.93	0.21	
	Sitework Construction Cost (SCC)					**236,894.73**	**6.31**	**125.07%**

Appendix 4: LINDO Optimization Programming Results

A 4.1 LINDO Programming of Testifying Case

```
!Let X1 be Alternative One
!Let X2 be Alternative Two
!Let X3 be Alternative Three
!Let X4 be Alternative Four
!
!objective: Minimize Total Life Cycle costs
!
min 3437306 X1 + 3799755 X2 + 3994966 X3 + 3401500 X4
!
subject to
!the following constrains
!
!Primary Energy
952000 X1 + 10525000 X2 + 10434000 X3 + 933000 X4 <= 952000
!
!Solid Waste
1205000 X1 + 71940000 X2 + 74250000 X3 + 699000 X4 <= 1205000
!
!Air Emission
198000 X1 + 203450 X2 + 214520 X3 + 189000 X4 <= 198000
!
!Water Emission
4566750 X1 + 5568900 X2 + 5566780 X3 + 4566700 X4 <= 4566750
!
!Global Warming Potential
955060 X1 + 1056070 X2 + 1084030 X3 + 902566 X4 <= 955060
!
!Weighted Resources Use
400380 X1 + 780300 X2 + 770400 X2 + 450600 X4 <= 400380
!
!choose at least one
X1 + X2 + X3 + X4 >= 1
!
END
!
!All Binary Integers
INT X1
INT X2
INT X3
INT X4
```

A.4.1.1 LINDO Programming Results of testifying example

LP OPTIMUM FOUND AT STEP 8
OBJECTIVE VALUE = 3437306.00

NEW INTEGER SOLUTION OF 3437306.00 AT BRANCH 0 PIVOT 8
RE-INSTALLING BEST SOLUTION...

OBJECTIVE FUNCTION VALUE

1) 3437306.

VARIABLE	VALUE	REDUCED COST
X1	1.000000	3437306.000000
X2	0.000000	3799755.000000
X3	0.000000	3994966.000000
X4	0.000000	3401500.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	0.000000
3)	0.000000	0.000000
4)	0.000000	0.000000
5)	0.000000	0.000000
6)	0.000000	0.000000
7)	0.000000	0.000000
8)	0.000000	0.000000

NO. ITERATIONS= 8
BRANCHES= 0 DETERM.= 1.000E 0

OBJECTIVE FUNCTION VALUE

1) 3437306.

VARIABLE	VALUE	REDUCED COST
X1	1.000000	3437306.000000
X2	0.000000	3799755.000000
X3	0.000000	3994966.000000
X4	0.000000	3401500.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	0.000000
3)	0.000000	0.000000

4)	0.000000	0.000000
5)	0.000000	0.000000
6)	0.000000	0.000000
7)	0.000000	0.000000
8)	0.000000	0.000000

A 4.2 LINDO Programming of Case Study

```
!Let BO be Alternative Base office
!Let TO be Alternative Tilt-up
!Let PO be Alternative Pre-cast
!Let TG be Alternative Triple glazed
!
!objective: Minimize Total Life Cycle costs
!
min 9831889 BO + 9573392 TO + 10301458 PO + 10073419 TG
!
subject to
!the following constrains
!
!Primary Energy
22536627 BO + 18813710 TO + 20120849 PO + 22693705 TG <= 22536627
!
!Solid Waste
726519 BO + 607929 TO + 617209 PO + 730831 TG <= 726519
!
!Air Emission
36468869 BO + 34819309 TO + 34129195 PO + 39974017 TG <= 36468868
!
!Water Emission
1086000 BO + 9530000 TO + 9970000 PO + 13800000 TG <= 10860000
!
!Global Warming Potential
1391509 BO + 1274215 TO + 1180706 PO + 1445917 TG <= 1391509
!
!Weighted Resources Use
6624240 BO + 7632554 TO + 4673595 PO + 6697881 TG <= 6624240
!choose at least one
BO + TO + PO + TG >= 1
!
END
!
!All Binary Integers
INT BO
INT TO
INT PO
```

INT TG

A.4.2.1 LINDO Optimization Programming Results OF Case Study

a. The target sets to base office building environmental indicator:

LP OPTIMUM FOUND AT STEP 2
OBJECTIVE VALUE = 29930474.0

NEW INTEGER SOLUTION OF 29937960.0 AT BRANCH 0 PIVOT 2
RE-INSTALLING BEST SOLUTION...

OBJECTIVE FUNCTION VALUE

1) 0.2993796E+08

VARIABLE	VALUE	REDUCED COST
BO	1.000000	29937960.000000
TO	0.000000	29681752.000000
PO	0.000000	30411640.000000
TG	0.000000	30178430.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	0.000000
3)	0.000000	0.000000
4)	0.000000	0.000000
5)	9774000.000000	0.000000
6)	0.000000	0.000000
7)	0.000000	0.000000
8)	0.000000	0.000000

NO. ITERATIONS= 2
BRANCHES= 0 DETERM.= 1.000E 0

b. The weighted resource use relaxed to 7560000 kg

Weighted resource <= 7560000
LP OPTIMUM FOUND AT STEP 2
OBJECTIVE VALUE = 29681752.0

NEW INTEGER SOLUTION OF 29681752.0 AT BRANCH 0 PIVOT 2

RE-INSTALLING BEST SOLUTION...

OBJECTIVE FUNCTION VALUE

1) 0.2968175E+08

VARIABLE	VALUE	REDUCED COST
BO	0.000000	29937960.000000
TO	1.000000	29681752.000000
PO	0.000000	30411640.000000
TG	0.000000	30178430.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	3722918.000000	0.000000
3)	118590.000000	0.000000
4)	1649560.000000	0.000000
5)	1330000.000000	0.000000
6)	25785.000000	0.000000
7)	17446.000000	0.000000
8)	0.000000	0.000000

NO. ITERATIONS= 2
BRANCHES= 0 DETERM.= 1.000E 0

c. Global warming potential <= 1250000 kg

LP OPTIMUM FOUND AT STEP 2
OBJECTIVE VALUE = 9761931.00

NEW INTEGER SOLUTION OF 10301458.0 AT BRANCH 0 PIVOT 2
RE-INSTALLING BEST SOLUTION...

OBJECTIVE FUNCTION VALUE

1) 0.1030146E+08

VARIABLE	VALUE	REDUCED COST
BO	0.000000	9831889.000000
TO	0.000000	9573392.000000
PO	1.000000	10301458.000000
TG	0.000000	10073419.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	2415780.000000	0.000000

3)	109310.000000	0.000000
4)	2339672.000000	0.000000
5)	890000.000000	0.000000
6)	69294.000000	0.000000
7)	2976405.000000	0.000000
8)	0.000000	0.000000

NO. ITERATIONS= 2
BRANCHES= 0 DETERM. = 1.000E 0

Appendix 5: Publications

A 5.1 Conference Papers

- **A. Ganjidoost**, S. Alkass and Z. Chen "An Optimization Model of Life Cycle Costing and Environmental Life Cycle Analysis of Office Buildings - A Hypothetical Case" 2011 CSCE Annual General, 3rd International / 9th Construction Specialty Conference, June 14 – 17, 2011 Ottawa, Ontario.

- **A. Ganjidoost**, S. Alkass and Z.Chen, "Environmental Life Cycle Analysis of Office Buildings in Canada" 2010 International Conference on Construction and Project Management (ICCPM 2010), November 16 to18, 2010, Chengdu,China.

- **A. Ganjidoost**, S. Alkass and Z.Chen, "An Optimization Framework for Life Cycle Assessment and Life Cycle Costing of Office Buildings" The American Center for Life Cycle Assessment, November 2 to 4 2010- Portland, Oregon, USA.

- **A. Ganjidoost** and S. Alkass, "Framework for Life Cycle Assessment and Life Cycle Cost of Office Buildings in Canada" 4th Canadian Forum on the Life Cycle Management of Products and Services,May 4-5, 2010, Holiday Inn Montréal-Midtown