TOWARDS ENVIRONMENTAL PROFILING FOR OFFICE BUILDINGS USING LIFE CYCLE ASSESSMENT (LCA)

by

Ashraf F. Ragheb

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Doctoral Committee:

Associate Professor Jong-Jin Kim, Chair
Professor Linda N. Groat
Professor Emeritus Khalil H. Mancy
Professor Jean D. Wineman

DEDICATION

To my wife, my life, Amal for her love and support to make this journey possible, without her patience and encouragement, this work could not be possible.

To my son, Andrew, for the joy he brings to my life and for his logistical help in the formatting of this work.

To my daughter, Maria, for her irresistible hug and smile which brings the happiness to my heart. Thank God Almighty for bringing her back to me after her injury.

To my Mom and my sisters for their continuous love, prayers, and support.

To the spirit of my son Mark whose tragic departure on his 10th. birthday broke my heart forever. Life has no taste after you departed. Enjoy the happiness in heaven and pray for us in front of the Throne of God.

To the spirit of my Dad whom I lost in the final round of this work and he could not make it to see his dream come true by attending my doctoral graduation, God repose his soul in the Paradise of Joy.

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ABBREVIATIONS

AISC	American Institute of Steel Construction
AP	Acidification Potential
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEES®	Building for Environmental and Economic Sustainability
BOD	Biological Oxygen Demand
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
Btu	British thermal unit
CO	Carbon monoxide
CO2	Carbon dioxide
COD	Chemical Oxygen Demand
DQIs	Data Quality Indicators
EIO-LCA	Economic Input Output – Life Cycle Assessment
EP	Eutrophication Potential
EPA	Environmental Protection Agency
EPDM	Ethylene Propylene Diene Monomer (M-class); a type of synthetic rubber used as roof membrane
GWP	Global Warming Potential
HSS	Hollow Structural Steel sections
ISO	International Standards Organization
kWh	Kilowatt-hour
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCEA	Life Cycle Energy Analysis
LCI	Life Cycle Inventory

LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LEED	Leadership in Energy and Environmental Design
MJ	Mega joule
NMVOC	Non-Methane Volatile Organic Compounds
NO2	Nitrogen dioxide
NOx	Nitrogen oxides
ODP	Ozone Depletion Potential
PAH	Polycyclic Aromatic Hydrocarbon
PM2.5	Particulate Matter with aerodynamic diameters of 2.5 microns or fine particles
PM10	Particulate Matter with aerodynamic diameters of 10 microns or inhalable particles
POCP	Photochemical Smog Creation Potential
SETAC	Society of Environmental Toxicology and Chemistry
SO2	Sulfur Dioxide
TRACI	Tool for the Reduction and Assessment of Chemical and other environmental Impacts
TRI	Toxics Release Inventory
UNEP	United Nations Environment Program
USGBC	United States Green Building Council
VOCs	Volatile Organic Compounds

GLOSSARY

Accidental Emission	An unintended environmental release
Allocation	Partitioning the input or output flows of a unit process to the product of interest.
Background Data	The background data include energy and materials that are delivered to the foreground system as aggregated data sets in which individual plants and operations are not identified.
By-Products	An incidental product deriving from a manufacturing process or chemical reaction, and not the primary product or service being produced. A by-product can be useful and marketable, or it can have negative ecological consequences.
Characterization	Characterization is the second step of an impact assessment and characterizes the magnitude of the potential impacts of each inventory flow to its corresponding environmental impact.
Characterization Factor	Factor derived from a characterization model which is applied to convert the assigned LCI results to the common unit of the category indicator.
Classification	Classification if the first step of an impact assessment and is the process of assigning inventory outputs into specific environmental impact categories.
Composite Data	Data from multiple facilities performing the same operation that have been combined or averaged in some manner
Consequential LCA	An LCA that attempts to account for flows/impacts that are caused beyond the immediate system in response to a change to the system.
Co-Product	A product produced together with another product.

Environmental Aspects	Elements of a business' products, actions, or activities that may interact with the environment
Environmental Loadings	Releases of pollutants to the environment, such as atmospheric and waterborne emissions and solid wastes.
Equivalency Factor	An indicator of the potential of each chemical to impact the given environmental impact category in comparison to the reference chemical used.
Fuel P&D	Activities involved in the *processing* and *delivery* of fuel used to run a process; also called *Pre-combustion Energy*.
Functional Unit	The unit of comparison that assures that the products being compared provide an equivalent level of function or service.
Green Technology	A technology that offers a more environmentally benign approach compared to an existing technology.
Impact Assessment	The assessment of the environmental consequences of energy and natural resource consumption and waste releases associated with an actual or proposed action.
Impact Categories	Classifications of human health and environmental impacts caused by a product throughout its life cycle.
Impact Indicators	Impact indicators measure the potential for an impact to occur rather than directly quantifying the actual impact.
Industrial System	A collection of operations that together perform some defined function.
Inventory Analysis	The identification and quantification of energy, resource usage, and environmental emissions for a particular product, process, or activity.
Interpretation	The evaluation of the results of the inventory analysis and impact assessment to reduce environmental releases and resource use with a clear understanding of the uncertainty and the assumptions used to generate the results.
Life Cycle Assessment	A cradle-to-grave approach for assessing industrial systems that evaluates all stages of a product's life. It provides a

	comprehensive view of the environmental aspects of the product or process.
Material P&D	Activities involved in the *processing* and *delivery* of materials to a process
Normalization	Is a technique for changing impact indicator values with differing units into a common, unit-less format by dividing the value(s) by a selected reference quantity. This process increases the comparability of data among various impact categories.
Pre-combustion Energy	The extraction, transportation, and processing of fuels used for power generation, including adjusting for inefficiencies in power generation and transmission losses.
Primary Energy	The Energy found in nature that has not been subjected to any conversion or transformation process. It is energy contained in raw fuels as well as other forms of energy received as input to a system.
Product Life Cycle	The life cycle of a product system begins with the acquisition of raw materials and includes bulk material processing, engineered materials production, manufacture and assembly, use, retirement, and disposal of residuals produced in each stage.
Routine emissions	Those releases that normally occur from a process, as opposed to accidental releases that proceed from abnormal process conditions.
Sensitivity Analysis	A systematic evaluation process for describing the effect of variations of inputs to a system on the output.
Stressors	A set of conditions that may lead to an environmental impact, For example, an increase in greenhouse gases may lead to global warming
System Flow Diagram	A depiction of the inputs and outputs of a system and how they are connected.
Weighting	The act of assigning subjective, value-based weighting factors to the different impact categories based on their perceived importance or relevance.

ABSTRACT

In the last two decades, architects and designers have tried to minimize the impacts their buildings have on the environment. Although many architects claim their buildings to be sustainable, unless an objective Life Cycle Analysis (LCA) is conducted, it is difficult to evaluate the total impact that a particular building has on its surrounding environment.

The theoretical foundation of the proposed framework consists of two major parts. These are the concepts of environmental sustainability and building environmental assessment. The purpose of this study is to quantify and compare the potential environmental impacts caused by office buildings throughout their entire life cycle, from extraction of raw materials to disposal of waste. The study also demonstrates how LCA could be applied from a single material to complex systems such as buildings.

To achieve the study objectives, a multiple case study method has been used with the LCA to determine which life cycle phase (manufacturing of materials, construction, use, maintenance, and demolition) contributes the most to the total impacts. The study also identifies how building key assembly systems (foundations, structure, walls, floors, roofs) influence its environmental impacts during its service life. Three recently-built typical office buildings are used as cases in southeast Michigan along with a streamlined LCA approach based on an inventory of energy use, material inputs and outputs, and environmental impact assessment. Furthermore, the study performed a sensitivity analysis to evaluate the effects of possible materials changes of some of building assembly components and examine the change on the total impacts during 60 years of life.

The study hypothesizes that a typical new office building, with different architectural features, would have significant environmental impacts of its life cycle phases and main assembly systems, and even a change with more environmental-friendly materials during service life would render an influence on the overall impacts. This can be significant in reducing the environmental impact and improving building environmental performance.

The study finds that the operation phase of the building has the highest impacts (90+% of total impacts) during its 60 years life cycle in the following impact categories: total energy (fossil fuel) consumption, global warming potential, acidification potential, and human health respiratory effects potential. Manufacturing phase has the highest impact in the following impact categories: ozone depletion potential with 87% of total impact, and in eutrophication with 65% of total impact respectively.

For building assembly systems, the study finds that the wall system, among others, has the highest contribution to the following impacts: global warming (26%), acidification (40%), smog potential (35%), and respiratory effect potential (57%). The structure system system has the highest contribution to total energy consumption (31%) and to eutrophication (56%) categories. The roof system has also significant impacts contribution (second to structure) to energy consumption (27%), global warming (17%), and comes second to walls in contributing to smog potential (29%). The foundations system contributes the most to ozone depletion at 58%. Through conducting a sensitivity analysis to the results, the study also find that replacing impact-sensitive building materials with more environmental-friendly alternatives (mainly to foundations, walls and roofs) yields a reduction in total buildings impacts by 6%-15% in different impact categories.

Future research could replicate the same profiling method to other building types and other construction methods e.g. wood or concrete for more application of LCA in building design and operation. This is specifically important during maintenance phase when some systems are replaced. Future studies will also serve the current needs for better LCA data availability, standardization, and quality for a wider application in building design and construction.

CHAPTER 1
INTRODUCTION

1.1 National Concerns

The building industry, both globally and in the United States, is one of the main contributors to the depletion of natural resources and a major cause of unwanted side effects such as air and water pollution, solid waste, deforestation, toxic wastes, health hazards, global warming, and other negative consequences. Although the traditional attitude of having unlimited resources is still dominant in the US, the awareness of environmental impacts is growing and many initiatives seeking to address sustainability concerns are gaining momentum.

There are also many reasons for the building sector to be targeted for ecological sustainable development. One reason is the large potential to save energy and resources. Another reason is the reduction of the generated waste going to landfill. The possibility to choose building materials and methods that address better indoor environments is also an important reason. There are pressing needs for guidelines driven by national and international legislations. These are important both as driving force for development and as basis for research. Therefore, it is important that the building industry adopts ‘environmental performance’ as one of its leading principles alongside economic efficiency and productivity principles to achieve sustainability.

In recent years, building and construction sector has been found to be responsible for a large part of the environmental impact of human activities (UNEP 2003). These impact which caused by *construction* and *operation* of buildings are many. One of the most significant effects is the climate change caused by consuming energy in these processes. As the use of fossil fuel has increased, climate change has emerged as an immediate problem since the relation between greenhouse gases and their influences on global temperature was discovered. Greenhouse gas emissions are hypothesized to contribute to a warmer climate, which can increase the melting of glaciers. In addition, emissions disturb hydrological cycles, resulted in variable climate change with extreme wind effects and flooding. One consequence might be the displacement of population along with enormous economical effects.

The environmental design of *office buildings* specifically grabs the interest of many organizations. This grows especially after the establishment of the environmental management system standards ISO 14001 (2001). In the US, as the economy transfers towards a service-based type, it is expected that the investment in commercial buildings especially offices will grow substantially. The environmental design of buildings is tied to the body or knowledge about building's life cycle (Gangemi, 2000). This knowledge of lifecycle also provides a venue for the optimization of requirements for both investors in end-users. This helps the design decisions especially in the early stages. The environmental knowledge also helps in minimize the degree of environmental impact (Roberts and Robinson, 1998).

1.2 Environmental/Economic Impact of Construction Industry

The construction industry represents one of the largest of the US economy. The value of new construction put in place in 2006 has $1,192 billion (US Dept of Commerce, 2008). The value of private construction put in place accounted for about $937 billion. The value of a state and local government construction put in place was $237.6 billion.

Buildings represent more than 50 % of the nation's wealth in the US. In 2010, new construction and renovation activity amounted to approximately $800 billion, representing 13 % of the Gross Domestic Product GDP, and employed 10 million people (NSTC, 1993). Buildings account for one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest and two-fifths of its material and energy flows (Roodman and Lenssen, 1995). Nearly one-quarter of all ozone-depleting chlorofluorocarbons (CFCs) are emitted by building air conditioners and the processes used to manufacture building materials (Energy Resource Center, 1995). Approximately 41% of U.S. energy consumption is directly or indirectly related to buildings and their construction (EIA, 2009).

Specific national concerns in the US are many. The nation has a wide diversity of climatic zones, and traditional building technologies vary from region to region. It has severe winters, hot summers, and variations in climate from northern sub-arctic to desert and subtropical. Because of this diversity and the legal domination by individual States in controlling construction practices, building codes vary from state to state. There are more than 76 million residential buildings and almost 5 million commercial buildings in the US, with an additional 15 million buildings projected by the year 2010 (US Census Bureau). Existing buildings use more than one-third of all primary energy consumed in the country, and account for two-thirds of the total electricity use. Lighting accounts for 14.1% of the electricity used in the U.S. annually (U.S. DOE 2009). Offices in the U.S. spend 30 to 40 cents of every dollar spent on energy for lighting power, making it one of the most expensive and wasteful building features (U.S. DOE 2009). Over 30% of the total energy and 60% of the electricity use in the United States is in buildings (Barnett and Browning 1995). This energy use produces nearly one-quarter of the country's total carbon emissions, a significant contribution to climate change. In addition to energy considerations, many regions suffer from air and water pollution. Despite the seriousness of present impacts, considerable progress has been made and both air and water are cleaner than they were a few decades earlier.

Commercial buildings contribute significantly to resource consumption, as well as to other environmental impacts, such as pollution emissions and solid waste generation. For example, 18% of the total year-2001 US primary energy consumption (U.S. DOE 2001) and 13% of the 1999 U.S. 100 year horizon global warming potential (GWP) was from the commercial sector (U.S. DOE 2000). Construction and demolition waste (C&D) in 1997 amounted to the equivalent of 65% of all Municipal Solid Waste (Franklin Associates 1999).

1.3 Design for the Environment

The awareness of sustainability has grown rapidly all over the world and in the US in the last decade. As this movement progresses, it is almost evident that we are consuming up non-renewable resources (energy, raw materials) in a rapid and inappropriate way. Sustainable development aims at helping the present generation to meet their needs without compromising the ability of the future generations to meet theirs (Brundtland 87). Towards achieving this goal, public interest has focused on many ways to reduce environmental impacts. These include a reduction of packaging use, reuse of old components in new products, recycling of municipal solid waste, etc. The public has viewed industry as a major environment polluter and the major consumer of energy and raw materials. Due to this pressure, industry began to use this materials and energy, to dispose waste in a safe way, to clean up production processes, and to recycle post consumer products and waste, and many more.

Environmental management principles and practices have become the norm and a mean for organizations to reduce the environmental impact. The international community effort in this respect has come up with an environmental management and standards through the International Organization for Standardization ISO. In September 1996, a set of standards called ISO 14000 have been published. These new standards became very important to companies that want to do business internationally. The U.S. government started more than decade ago to promote sustainable practices. For example, the 1995 U.S. federal procurement guidelines (EPA, 95) require contractors to use, sustainable practices if they wish to sell products and services to the government. Federal contractors must comply with Toxics Release Inventory (TRI) reporting requirements (EPA 95a), which require them to account for some of their toxic chemical emissions.

The U.S. EPA’s Energy Star program aimed at saving electricity used by computers and peripherals has also been endorsed by the federal government. It now requires that federally procured computers to be Energy Star rated. New efforts focus on “pollution prevention” and “design for environment” has come up to the pool of sustainability. Both offer a series of methods and tools expected to help society overcome environmental problems. These include reduction of waste generation and releases and the life cycle of a product is early as possible throughout its lifecycle. To help achieve this reduction, methods and tools are needed at the design stage. While there have been many efforts in the areas of pollution prevention, design for environment, and industrial ecology (Graedel, 2003), it lacks a critical literature, usable tools, and methodology. Metrics and tools are needed to help designers better understand the environmental implications of their decisions. Environmental performance measuring methods are needed to measure environmental friendliness of products and processes and to allow for industry wide benchmarking.

1.4 Problem Statement

Architects have not yet realized that their everyday decisions carry substantial implications for the environment. Recently, they began to pay more attention on minimizing the impact their buildings make on the environment. Although many claim their buildings to be sustainable, unless an objective Life Cycle Assessment (LCA) is carried out, it is difficult to determine the environmental impacts a particular building has on its surrounding environment.

Compared to other products, it is more difficult to environmentally evaluate buildings because they are large in scale and complex in materials modeling. Their components limited service life makes its modeling a dynamic process. Furthermore, building manufacturing processes are less standardized than most consumer products, for example, because of the uniqueness of each building design and complexity in the operation phase. The limitation of available data on the environmental impacts of the manufacturing of construction materials or the construction and demolition processes themselves makes the analysis even challenging. While there is substantial knowledge on energy-saving strategies for building operations, there is still less information on the upstream (extraction, manufacturing, transportation) and downstream (deconstruction, disposal) impacts of buildings.

LCA represents a comprehensive method for the analysis of the environmental impacts of products at all stages in their life cycle, from cradle to grave. The LCA concept shifts from single consumer or commercial products to building materials and components. However, LCA became the only way to go through these environmental analyses to model the entire building. LC analyses of existing whole buildings are essential to identify and evaluate how its key design systems (foundation, structure, walls, floors, roofs) will influence a building's environmental performance.

Several studies researched the environmental impact of buildings in the last two decades, yet few of them studied life cycle impact of office buildings in a detailed and comprehensive way. Several previous studies were based on a single case building, however they lacking complete life cycle phases and depend on only one or two environmental impacts categories. These studies have also been based on either generalized building information or subsets of the total building such as structural materials or embodied energy. Others were conducted on the material or product level rather than the building itself. Most concentrated on calculating the energy use and CO2 emissions neglecting the other environmental impacts (e.g. global warming, ozone depletion, smog formation, acidification, eutrophication, and respiratory effect potential) which greatly contribute to our current problems such as climate change, ozone depletion, acid rains, etc. Yet, very few studies have explored the *whole life cycle* of the building or considering *all the possible* impacts (EPA, Table 2.2) in each phase.

This study fills this gap by thoroughly tracks and quantifies all impacts in all phases of the building life cycle. It also considers eight impacts categories in each phase and computes the percentage contribution of building key assembly systems (foundation, structure, walls, floors, and roof) to the whole building's environmental impacts. This provides the necessary information to enable the inclusion of life cycle phases into the design process and give an extensive picture of how to profile a building with its environmental impacts.

1.5 Research Objectives

The primary objective of this study is to quantify and compare the environmental impacts caused by an office building during 60 years of service life. The study also determines the life cycle phases and building assembly systems that contribute most to these environmental impacts. The study also performs a sensitivity analysis to evaluate the effects of possible changes and retrofits in foundations, walls and roofs during the 60 years service life of the building. This study is expected to have important, theoretical, practical, and pedagogical outcome. The study is targeting to achieve the following objectives:

- Apply LCA model from a single material to a complex system such as a building over a long service life (60 years).
- Determine to what extent each building's life cycle phase contributes to the total impacts where some strategies could be applied to reduce these impacts at these specific phases.
- Calculate the contribution of each building key component (foundations, structure, walls, floors, and roofs) to the whole environmental impacts in terms of its energy and material consumption and emissions to the whole life cycle.
- Provide insights for selecting more environmentally sound materials and structures in early design and maintenance phases. These include materials with less energy use and less environmental impacts which is the focus of sensitivity analysis of this study.
- Determine how a LEED certified building will perform environmentally and verify if it actually perform better than other non-certified buildings. Although that's not the main focus of this study, it still represents an interesting point to look at building rating systems as other methods of environmental assessment and compare it with LCA results.

Finally, by achieving the aforementioned objectives, the study tests the magnitude of environmental impacts through the whole life cycle and tests its influence by materials and structural components selection.

1.6 Research Questions

Through achieving its objectives, the study addresses the following research questions:

1. How to quantify building sustainability based on actual performance and not a prescriptive set of criteria as the case with the current rating systems (BREEAM, LEED).
2. What phase of the building life cycle has the highest environmental impacts?
3. What building assembly system (foundation, structure, walls, floors, and roof) has the highest impact during the life cycle and the percentage of each system to the whole environmental impacts?
4. What are the interactions between environmental impacts and energy use during the life cycle?
5. Are there differences in environmental impacts due to the choice of building materials during its life cycle?
6. How to accomplish building design for low environmental impact?

1.7 Research Hypothesis

The study hypothesizes that a typical new office building, with different architectural features would have comparable significant environmental impacts of its life cycle phases and main assembly systems that affect its environmental performance, Furthermore, the study hypothesizes that even a smaller flow of impact-sensitive materials during life cycle phases would render an influence on the overall impacts throughout its 60 years of life. This can be significant in reducing the environmental impact and improving building environmental performance.

1.8 Scope and Limitations

The research focuses on the calculation of environmental impacts as well as energy consumption, both *embodied* and *operational*, in different buildings life cycle phases. In order to narrow the scope, the research will concentrate on the ecological part of sustainability which include economy of resources and ecosystem protection that can be quantitatively analyzed with respect to the energy and mass flows within a life cycle assessment method. Fig. 1.1 shows brief scope of the research.

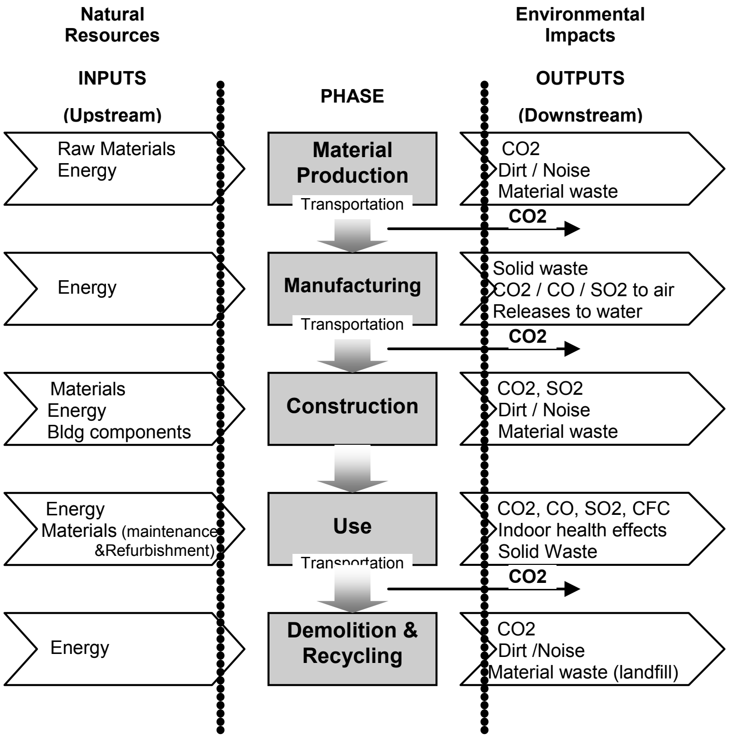


Fig 1.1: Inputs/Outputs of a Building Through its Life Cycle Phases
[Adapted from Kim, 1999]

This study primarily deals with the growing demand for including the environmental impacts of buildings in the design process from a life cycle perspective. Some limitations are made to narrow down the scope of research as follow:

1- The LCA focuses on physical characteristics of the industrial activities; it does not include market mechanisms or secondary effects on technological development (Guinee et al., 2002).

1- The environmental issues addressed in this study are limited to the environmental impacts resulted throughout the entire building life cycle. These include the use of resources, energy, negative emissions to air, water, and land from manufacturing, construction, operation, maintenance, and final demolition.

2- Indoor environmental quality, which is a concern for health and comfort while spending time in the building, and can be affected by emissions from materials, is beyond the scope of this study.

3- The environmental impacts in this study are strictly related to embodied energy of the material and operational energy consumption. These represent the major part of the total environmental impact. Another reason to limit the scope of impact is because too many complex variables will only find a limited use in practice among building practitioners.

4- The study employs the existing databases on the environmental impact. Therefore, the objective is not to produce new or better technical input data concerning LCA but rather to conduct an LCA analysis for the purpose of calculating the environmental impacts and choose better material alternatives during building life phases. This is tested through sensitivity analysis at the end of the study.

5- The literature in this study describes the situation in the U.S. and, to some extent, data and experiences from Canada.

7- Life Cycle Costing (LCC) which has similarities to LCA in that it analyze the building cost over its whole life, not just the capital cost, but the cost of operation, maintenance, disposal etc, is beyond the scope of this study as well. LCC makes use of some of the data used by LCA but does not consider environmental impacts. It considers only monetary value.

1.9 Dissertation Organization

This study includes an abstract followed by 7 chapters and references. The first chapter addresses the significance of the problem being studied and concludes by explaining the main research objectives, scope, and limitations. Chapter 2 presents the concept of Life Cycle Assessment LCA, a brief history and methodology and how it is applied to both products and buildings. Chapter 3 presents a comprehensive analysis and classification of the previous studies that have been conducted in LCA related to buildings and summarizes the need for this study. Chapter 4 presents the research method using multiple cases study and LCA method as a tool to calculate these cases' environmental impacts throughout 60 years of life. Chapter 5 describes the three building cases characteristics in details with some description of the followed procedures to obtain results. Chapter 6 presents the results of the study and discusses the environmental profile of each case with all emissions results. Chapter 7 summarizes the findings, discusses the validity and reliability of data and ends with the study significance and future research directions (Fig. 1-2).

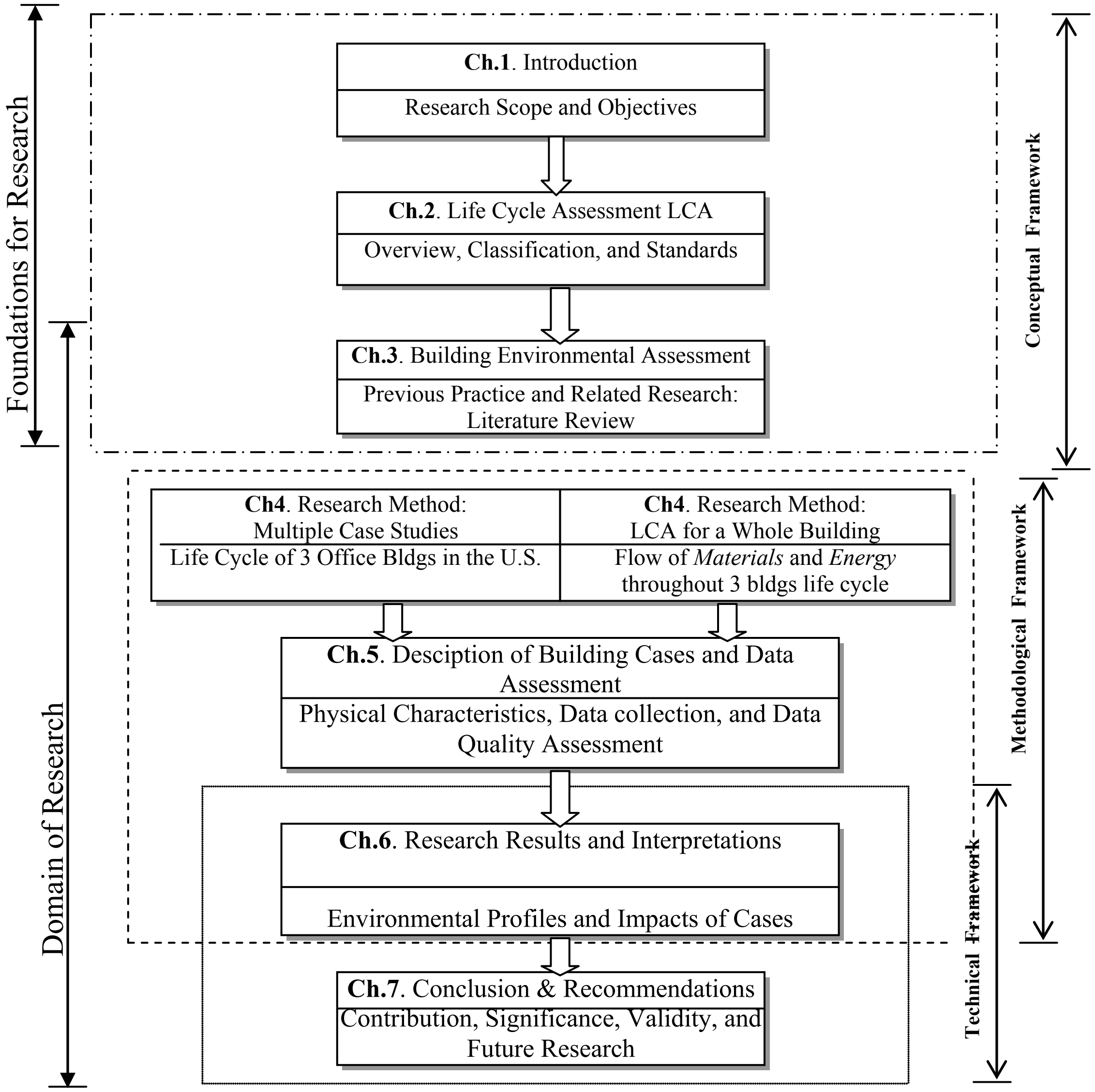


Fig 1.2: Research Design and Dissertation Organization

CHAPTER 2
LIFE CYCLE ASSESSMENT (LCA)

2.1 LCA: Historical Perspective

Life cycle assessment (LCA) involves evaluating the environmental impacts of a product, process, or activity holistically, by looking at the entire life cycle of the product or process from raw materials extraction through disposal. LCA is an important tool used in environmental management and green design efforts. Selection of product design, materials, processes, reuse or recycling strategies, and final disposal options requires careful examination of energy and resource consumption as well as environmental impacts associated with each design alternative.

It was not till 1970s, when the LCA studies began. But it was only in the 90s, when the society of environmental toxicology and chemistry SETAC started the work to develop broad consensus to conduct LCA and to promote it into research (Consoli et al., 1993). The definition of LCA by SETAC is:

> "A process to evaluate the environmental burdens associated with product, processes or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and released to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment include the entire lifecycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, reuse, maintenance; recycling and final disposal."

2.1.1 The Early Years

In 1969, Coca Cola Company funded a study to compare resource consumption and environmental releases associated with beverage containers. Meanwhile, in Europe, a similar inventory approach was being developed, later known as the '*Ecobalance*'. In 1972, in the UK, Ian Boustead (1996) calculated the total energy used in the production of various types of beverage containers, including glass, plastic, steel, and aluminum. Over the next few years, he consolidated his methodology to make it applicable to a variety of materials, and in 1979, he published the 'Handbook of Industrial Energy Analysis (Boustead and Hancock 1997).

Initially, energy use was considered a higher priority than waste and emissions outputs. There was little distinction, at that time, between inventory development (resources going into a product) and the interpretation of total associated impacts. But after the oil crisis subsided, energy issues declined in prominence. While interest in LCA continued, thinking progressed more slowly. It was not until the mid eighties and early nineties that a real wave of interest in LCA swept over a much broader range of industries, design establishments, and retailers.

2.1.2 Towards Maturity

Although the pace of development is slowing, the methodology began to consolidate moving the field towards maturity. In 1995, there was a growing confidence in the LCA community that the emerging tools would have a real future. Some scientists argue that LCA is a million miles away from the man in the street. Part of this difficulty in making the technique more accessible comes down to the competing needs of *simplicity*, or at least *clarity*, to aid practitioners and credibly, to enable decision-makers to have faith in the robustness of the results. Over the years, software designers have been responding to the challenge, and there has been a proliferation of LCA's software currently on the market.

The act of doing the assessment builds awareness about environmental impacts and focuses improvement efforts. This has led companies, such as AT&T, to develop internal LCA tools for their product lines (Graedel and Allenby, 2003) and government agencies, such as the EPA, to provide generic guidelines for conducting LCAs(US EPA 1993). However, LCA criteria began to find their way into environmental labeling schemes such as Germany's Blue Angel and the ISO 14000 environmental management standards. Most current LCA techniques are modifications of the approach developed by the Society for Environmental Toxicology and Chemistry (SETAC). Practical use of the SETAC approach involves streamlining LCA by drawing a boundary that limits consideration to a few producers of interest in the chain from raw materials to disposal. Simplified LCAs even pop up in popular magazines; for example, Consumer Reports occasionally comments on the environmental impacts of different products packaging types and chemicals.

2.1.3 Next Generation: LCA-Based Assessment

LCA-based Assessment is a new approach in environmental assessment developed specifically for building and intended as a comprehensive approach to integrate the strengths of LCA and bridge the inadequacies of eco-labeling systems. LCA-based assessment is conceptually well developed, but its applications are growing rapidly in the building sector. What makes LCA-based assessment a promising approach is its integrated structure and attention to details of the balancing of application and resolution (Crawley and Aho, 1999). In LCA-based software, the use of relative assessments based on industry norms, regional weighting but international standards, and assessment level consistency (like GBTool) all would strengthen LEED towards more development.

While LEED has accomplished more in terms of a national rating program than any other previous tool, in order to become an established standard in the building process that practitioners can rely on, it is critical that it move towards greater consistency, clarity and transparency. LEED has provided an important milestone to this effort, defining much of the green building arena and engaging a wide array of stakeholders. But LEED alone does not provide an environmental assessment tool that the building industry can rely on. For this reason, a much greater effort must be expended towards employing LCA in building process.

LCA- based assessment provides a compelling roadmap for the evolution of LEED and/or other environmental assessment methods. However, use of this roadmap requires an abundance of research such as the development of national databases of material and system environmental impacts which is currently underway by the U.S. DOE. Another requirement is the definition of more comprehensive metrics based on total life cycle principles. This data is going to emerge by some ongoing projects like US LCA database project. LCA- based software such as Building for Environmental and Economic Sustainability BEES (NIST, 2007) database are an important step towards the right direction, developing the infrastructure that allows comparative assessments to be made. Another tool such as ATHENA is also an asset towards this goal.

2.2 Life Cycle of a Single Material/Product

SETAC (1991) in its report identifies the life cycle of a generic industrial product as follow (Fig 1.2):

- Raw Material Acquisition: all activities necessary to extract raw material and energy inputs from the environment, including the transportation prior to processing.
- Processing and Manufacturing: activities needed to convert the raw material and energy inputs into the desired product. In practice this stage is often composed of a series of sub-

Fig 2.1 Life Cycle of a Product [Source: NIST 2010]

stages with intermediate products being formed along the processing chain.

- Distribution and Transportation: shipment of the final product to the end user.
- Use, Reuse, and Maintenance: utilization of the finished product over its service life.
- Recycle: begins after the product has served its initial intended function and is subsequently recycled within the same product system (closed-loop recycle) or enters a new product system (open-loop recycle).
- Waste Management: begins after the product has served its intended function and is returned to the environment as waste.

2.3 Life Cycle of the Whole Building

The expression 'life cycle of a building' refers to the following phases: manufacture of building materials, transport, construction of the building, occupancy/renovation, and finally demolition and removal, (see Fig 2.2).

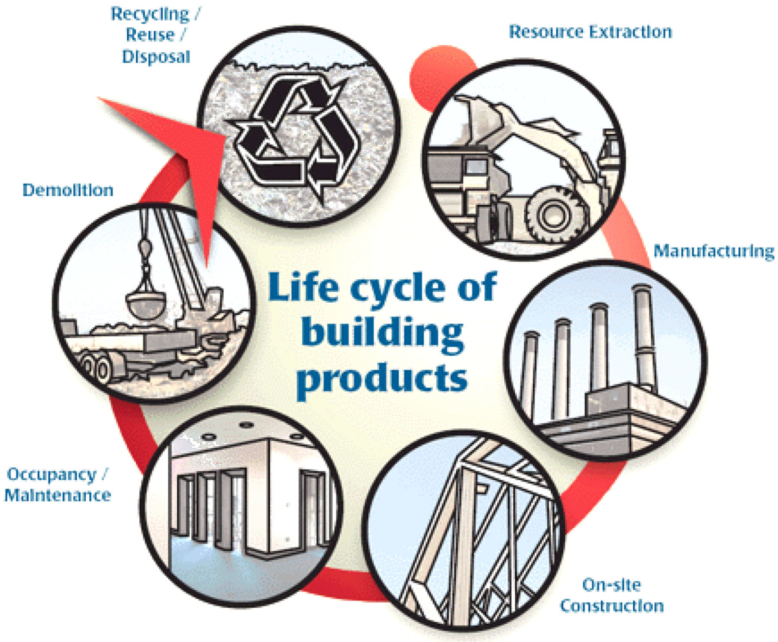


Fig 2.2: Life Cycle of the Building
[Adapted from Athena Institute (2009)]

2.3.1 Resource Extraction Phase

The life cycle of most building products starts with the extraction of raw resources such as iron ore, timber, etc. Here, the development of life cycle inventory data starts which tracks energy use and emissions to air, water and land per unit of resource. In addition to the actual harvesting, mining or quarrying of a resource, the extraction phase data includes the transportation of raw resources to the mill or plant gate, which defines the boundary between extraction and manufacturing. One of the great difficulties in assessing the environmental effects of resource extraction is that so many of the environmental effects that concern people — for example the effects on biodiversity, water quality, soil stability and so on — are very site specific and not easily measured. For that reason they are often left out of life cycle inventory studies or given only passing mention in this phase.

2.3.2 Manufacturing Phase

Manufacturing is the stage that typically accounts for the largest proportion of embodied energy and emissions associated with the life cycle of a building product. This stage starts with the delivery of raw resources and other materials at the mill or plant gate and ends with the delivery of building products to retailer.

2.3.3 On-Site Construction Phase

This stage is like an additional manufacturing step where individual products, components and sub-assemblies come together in the manufacturing of the entire building. This stage starts with the transportation of individual products and sub-assemblies from distribution centers to building sites within each city. The average or typical transportation distances to building sites are used in the LCA process. This stage in the life cycle can be important in terms of energy use and other environmental effects because it can result in the generation of significant amounts of waste. In addition to building product transportation and the energy use of on-site machines like cranes and mixers, the on-site construction activity stage includes such items as the transportation of equipment to and from the site, concrete form-work, and temporary heating and ventilation.

2.3.4 Operation/Maintenance Phase

During the occupancy stage we have to take account of functions like heating, cooling, lighting and water use, as well as the introduction of new products such as paints, stains, floor coverings and other interior finishes. We also have to take account of the fact a building may be remodeled or reconfigured several times over its life (a form of reuse), with changes to interior partitions and possibly the addition of new products or systems. In the course of maintenance, some parts of a building will be altered (e.g. by painting), but other parts may not be seen or touched until the building is demolished.

2.3.5 Demolition/Recycling/Disposal Phase

Demolition marks the end of a building's life cycle although it is not the end for individual component materials or products, which face a subsequent recycling/reuse/disposal stage. In this stage, demolition energy use for different structural systems is examined under different climatic conditions assuming 100 % recycling and 100 % reuse of the structural components. This is the final stage in the life cycle of the individual components or products comprising a building. It is an especially difficult area for building's LCA because, for a building being designed now, it deals with practices and pressures a long way in the future and is therefore quite unpredictable. Since most of the environmental burdens associated with recycling and reuse, like processing and transportation, are properly a charge to the next product use(closed-loop recycling), the concern will be primarily with the environmental implications of disposal, whether through landfill or incineration.

2.4 Life Cycle Assessment Approaches/Classification

There are two conceptually different approaches to LCA: process-based LCA and economic input-output analysis based LCA (EIO-LCA) (Hendrickson et al, 1998, 2006). The major difference between these two approaches is that while the former focuses on the individual phases that are used to make a product or generate a service, the latter uses a macro economic framework that includes all the monetary fluxes generated in a country's economy by the production of a product or by the offer of a service.

2.4.1 Process-based Life Cycle Assessment

The process based LCA was initially developed by the Society for Environmental Toxicology and Chemistry (SETAC). The procedures involved in this methodology were formalized by the International Organization for Standardization in their ISO 14040 series (Kluppel, 1998; Finkbeiner, 2006).

Process based LCA is conducted in 4 steps (Graedel and Allenby, 2003): goal, definition, scope, and boundaries of the process that need to be analyzed; data calculations of inputs and outputs through an inventory analysis; impacts assessment; and interpretation of the results (Fig.2). In process based analysis, data for the inventory phase is obtained from companies, governmental, and non-governmental databases. Data for impact assessment is collected from the literature and publicly available databases.

2.4.2 Economic Input-Output-Based Life Cycle Assessment

This type of LCA uses economic input-output tables coupled with data on resources consumption and environmental emissions and wastes to track out the various economic transactions, resource requirements, and environmental emissions required for a particular product or service (CMU, 2007). In this way, it allows for capturing all the resources used and emissions caused directly and indirectly (in the supply chain) by the manufacture of a product or offer of a service.

The 1997 economic input-output matrix for the United States includes 491 sectors and maps the relationships between sectors. The environmental data used in EIO-LCA are collected from publicly available databases on resource consumption, environmental emissions, and wastes. This environmental data for each economic sector are then combined with the economic input-output data to determine the environmental impact caused by the acquisition of a dollar value from a specific economic sector. Table 4 shows an example of the application of EIO-LCA in the production and distribution of energy (CMU, 2007).

Table 2-1: EIO-LCA Results for the Production and Distribution of Electricity (CMU, 2007)

Sector Code		**Total Economic ($million)**	**Value Added ($million)**	**Direct Economic (%)**	**CO (mt)**	**NOx (mt)**	**PM10 (mt)**	**GWP (MTCO2E)**	**CO2 (MTCO2E)**	**Total Energy (TJ)**
	Total for all sectors	1.73	1.00	79.80	5.54	25.70	1.34	10600.00	10100.00	100.00
221100	Power Generation and supply	1.01	0.63	99.30	2.66	24.31	1.14	9979.53	9793.60	96.01
211000	Oil and gas extraction	0.10	0.04	71.00	0.16	0.07	0.00	104.44	16.77	0.39
212100	Coal Mining	0.08	0.04	90.60	0.00	0.00	0.06	245.28	15.38	0.39
486000	Pipeline Transportation	0.03	0.01	93.10	0.21	0.01	0.00	35.08	28.82	0.40
482000	Rail Transportation	0.03	0.02	87.80	0.09	0.79	0.02	86.38	82.33	1.14
420000	Wholesale trade	0.03	0.02	32.60	0.17	0.02	0.00	7.89	0.75	0.01
533000	Lessors of nonfinancial intangible assets	0.02	0.02	3.03	0.00	0.00	0.00	0.27	0.09	0.00
324110	Petroleum refineries	0.02	0.00	43.50	0.01	0.01	0.00	30.07	14.87	0.29
336120	Heavy duty track manufacturing	1.E-06	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	1.E-04	1.E-04	3.E-06
…..										
339111	Lab apparatus and furniture manufacturing	1.E-06	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	4.E-05	3.E-05	1.E-06

2.4.3 Hybrid Life Cycle Assessment

The two previous LCA techniques have advantages and disadvantages. Process based LCA allows for a detailed analysis over specific process at a point in time and space. However, it is often characterized by subjectivity in the definition of the processes that should be considered, mainly with the boundary and the data sources that should be used. Furthermore, the local conditions and the specificity of time off an inventory may not be a representative of the conditions found in other assessments. Process based LCA is data intensive, and the lack of available data may limit the accuracy of the study (Suh et al., 2004). On the other hand, EIO-LCA allows for avoiding most of the subjectivity issues that affect the process based LCA. EIO-LCA suffers from lack of representativeness of the process being used due to over aggregation of data as it gives an average assessment for most products processes.

In order to take advantage of the positive sides of both approaches, the hybrid LCA uses the comprehensiveness of EIO-LCA with regards to supply chain emissions to overcome the need to perform a process based assessment of all the processes in supply chain, and use process based assessment to overcome the lack of accuracy of EIO-LCA when it is too aggregate for the purposes of a detailed LCA. A review of existing hybrid models and their uses to access construction processes are presented by Bilec et al. (2006).

2.5 Process-based Life Cycle Assessment Methodology

Process-based LCA is a process whereby the material and energy flows of a system are quantified and evaluated. Typically, upstream (extraction, production, transportation and construction), use, and downstream (deconstruction and disposal) flows of a material or service system are inventoried first. Subsequently, global and/or regional impacts are calculated based on energy consumption, waste generation and other impact categories, e.g. global warming, ozone depletion, eutrification and acidification, human toxicity, etc. (see table 4.1). An LCA allows for an evaluation of how impacts are distributed across processes and life cycle stages.

LCA is a method for analyzing the environmental interactions of a system with the environment (although in principle it could be widened to include health). It became a worldwide environmental management tool with the advent of the ISO14040 international standards. Often referred to as the cradle-to-grave approach, LCA analyses different pathways by which environmental damage is done. This approach gives a balanced view of:

a) Immediate or local impacts (e.g., human toxicity, smog formation)
b) Long-term or global concerns (e.g., global warming, depletion of nonrenewable resources).

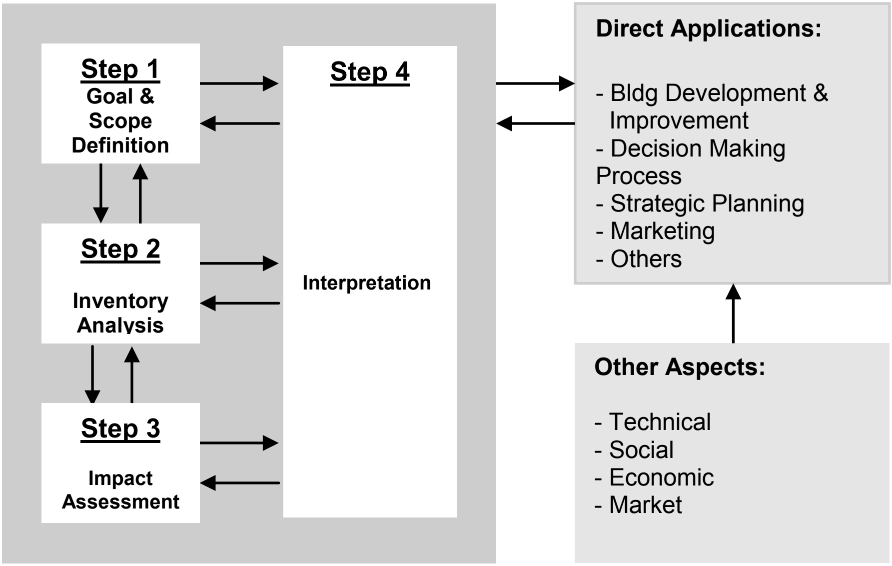


Fig 2.3: Life Cycle Assessment Framework (ISO 14040)

2.6 LCA Framework Standards

In the late 1990’s, International Standards Organization ISO 14040 (1997) series on LCA was released in Geneva as a development of the ISO 14000 Environmental Management Standards. The series provide principles, framework, and methodological standards for conducting LCA studies. These include the 4 steps of the LCA which are: goal and scope definition and inventory analysis (ISO 14041, 1998); impact assessment (ISO 14042, 1998a); and interpretation (ISO 14043, 1998b), as well as the general introductory framework (ISO 14040, 1997). LCA framework is shown in (Fig 2.3):

2.6.1 Goal and Scope Definition

The first part of an LCA study consists of defining the goal of the study and its scope. The goal of the study includes the reason for carrying out the study as well as the intended application of the results and the intended audience. In the scope of an LCA the following items are considered and described:

- The function of the system.
- The functional unit.
- The system boundaries.
- Type of impact assessment methodology and interpretation to be performed.
- Data requirements and quality.

- Assumptions and limitations.

The scope describes the depth of the study and show that the purpose can be fulfilled with the actual extent of the limitations.

a. Functional Unit

The functional unit is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related. This enables comparison of two essential different systems. For example, the functional unit for a paint system may be defined as the unit area (ft^2) for 10 years period. A comparison of the environmental impacts of two different paint systems with the same functional unit is therefore possible.

b. System Boundaries

The system boundaries determine which unit processes to be included in the LCA study. Defining system boundaries is partly based on a subjective choice, made during the scope phase when the boundaries are initially set. The following boundaries can be considered:

- Boundaries between the technological system and nature. A life cycle usually begins at the extraction point of raw materials and energy carriers from nature. Final stages normally include waste generation and/or heat production.
- Geographical area. Geography plays a crucial role in most LCA studies, e.g. infrastructures, such as electricity production, waste management and transport systems, vary from one region to another.
- Time horizon. Boundaries must be set not only in space, but also in time. Basically LCAs are carried out to evaluate present impacts and predict future scenarios. Limitations to time boundaries are given by technologies involved, pollutants lifespan, etc.

c. Data Quality Requirements

Reliability of the results from LCA studies strongly depends on the extent to which data quality requirements are met. Data assessment is discussed in details in Chapter 5.

2.6.2Life Cycle Inventory Analysis (LCI)

LCI comprises all stages dealing with data retrieval and management. Data are validated and related to the functional unit in order to allow the aggregation of results. LCI also involves the calculations to quantify material and energy inputs and outputs of a building system. A detailed description of raw materials and energy inputs are used at all points and the emissions, effluent and solid waste outputs. Examples of output are resource depletion (e.g. material and energy), pollutant emissions and discharges of chemical or physical load (e.g. substances, heat, or noise).

The data collection is the most resource consuming part of the LCA. Reuse of data from other studies can simplify the work but this must be made with great care so that the data is representative. The data quality aspect is therefore also crucial.

2.6.3 Life Cycle Impact Assessment (LCIA)

LCIA evaluates the significance of potential environmental impacts based on the LCI results, relating the identified inputs and outputs to environmental impacts. It involves selection of impact categories, category indicators and characterization models. Impact categories are selected and defined with respect to the goal and scope of the LCA. ISO 14040 suggests that LCIA includes the following steps (the first 3 are mandatory, the others are optional):

1- Classification (assignment of LCI results): The environmental loads are classified according to the impact categories. (Some environmental loads belong to more than one impact category.) (Fig. 4.2)
2- Characterization (calculation of category indicator results): The category indicator is modeled for the different environmental loads that caused by certain pollutants e.g. the Global Warming Potential is caused by CO_2 and CH_4.
3- Valuation: Expressing category indicators relative to a standard (e.g. ton of CO2 equivalent).
4- Grouping: Sorting and possibly ranking of the impact categories.
5- Weighting: Expressing the subjective importance of an impact category. Categories are often sorted by theme or damage category.

6- Data Quality Analysis: Understanding the reliability of the indicator results.

U.S EPA (2006), in its report, *LCA- Principles and Practice*, identified 10 impact categories that are considered especially important in literature and from an environmental and political point of view. Table 2.2 illustrates the commonly used impact categories of which some are carried out in this research.

Table 2-2. Commonly Used Life Cycle Env'l Impact Categories (U.S. EPA, 2006)

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

2.6.4 Interpretation of Results

The aim of the interpretation phase is to evaluate findings and to reach conclusions and recommendations in accordance with the defined goal and scope of the study. Results from the LCI and LCIA are combined together and reported in order to give a complete account of the study.

The life cycle interpretation of an LCA or an LCI comprises 3 main elements:

1. Identification of the significant issues based on the results of the LCI and LCIA phases of a LCA.
2. Evaluation of results, which considers completeness, sensitivity and consistency checks.
3. Conclusions and recommendations.

2.7 Embodied Energy, Operation Energy, and LCA

The output from an energy model, such as eQuest (used in this study) or BLAST, is the projected energy use within a building as it operates over a typical meteorological year. This energy is considered the *operational energy* and is one component of the input needed to complete a building LCA mainly its operation phase. The second major component of energy consumed by a building is the *embodied energy.* It is defined as the energy required to manufacturing products, including all associated processes including mining, transport and manufacturing. There are two components in the calculation of embodied energy: the *initial* embodied energy and the *recurring* energy component (due to maintenance and replacement). The need to understand embodied energy becomes more important as measures to reduce operational energy are taken.

CHAPTER 3

BUILDING ENVIRONMENTAL ASSESSMENT: REVIEW OF PRACTICES AND RELATED RESEARCH

3.1 Building Environmental Assessment

There are 3 main types of tools that can be used to assess the environmental impact of buildings: 1) Environmental Impact Assessment (EIA), 2) Rating or certification Systems (RS) and 3) Life Cycle Assessment (LCA).

3.1.1 Environmental Impact Assessment EIA

EIA studies the impact of a project on its surrounding environment. The International Association for Impact Assessment (IAIA) defines an environmental impact assessment as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made". EIA began to be used in the 1960s as part of a rational decision making process. It involved a technical evaluation that would lead to objective decision making. EIA was made legislation in the US in the National Environmental Policy Act (NEPA) in 1969. The International Organization for Standardization (ISO) Standard 14011 covers EIA and includes key steps for carrying out the assessment. These steps include the scope of EIA and include: identification of the reference situation, prediction of impacts, evaluation of impacts, and mitigation of impacts. The use of this tool is primarily based on the precautionary principles (Kriebel et al., 2001; Sandin, 2004; UNEP, 1992), of which the decision makers study all the consequences of a certain decision before it goes into implementation. EIA is used for different types of projects, mainly the huge ones, such as dams, interstate highways, manufacturing and power plants, and buildings. A significant disadvantage of EIA is that it is too generic and uses a broad scale of analysis. In this sense, it has difficulty contributing meaningfully and consistently to environmentally conscious building designs. EIA as it is practiced today is being used as a decision aiding tool rather than decision making tool. Almost all EIAs address the direct, *on-site effects* alone.

3.1.2 Rating / Certification Systems RS

Rating systems are list of requirements to be achieved by building design. The design then is awarded a number of credits for those requirements that are fulfilled. After collecting certain number of credits, the building design receives a label or certification. The list of these requirements and the minimum credits to receive a label, differ from one rating system to another and are usually described as “expert consensus”. The common problem, with few exceptions, is that the requirements are not adaptable to the situational context of the building. For example, using 50% of recycled or reused water in a building receives the same number of credits anywhere in the United States, but may have very different environmental relevance whether in California or Michigan. This non-inclusion of context of the building is one major criticism against rating systems. Nevertheless, it has to be acknowledged that RSs are powerful tools from education, public image, and even marketing point of view. They highly encourage people to consider the environmental impact of buildings. Despite their novelty, their ease of use and communication of results is leading to their fast growth in the number of users. An example of RS is LEED (USBBC, 2005) in the U.S. and BREEAM in the U.K.

3.1.3 Life Cycle Assessment LCA

LCA is the most scientifically defensible tool for environmental assessment. It is based on mass and energy balance method and assesses buildings using a consistent framework of analysis. It measures all inputs to a building and all outputs (emissions) released to the environment. LCA comprehensiveness is a major advantage while consistency is a weakness. LCA studies use different level of details or models e.g. the process-based model or EIO-LCA model. These may yield different results for the same project. Data collection and availability and the expertise needed to do it limit its widespread use among building designers.

3.2Development of Building Environmental Assessment

Since EIA is less used now in building environmental assessment, this section primarily discusses the development of rating systems and LCA-based tools. Until 1990's release of the Building Research Establishment Environmental Assessment Method (BREEAM), almost no attempt had been made to establish an objective and comprehensive way of assessing Building environmental impact or offering a summary of overall performance. Attaching a label of environmental performance increases the real market value of buildings with improved environmental qualities. This motivates change in the construction industry and market transformation. The field of building environmental assessment has matured remarkably and quickly since the introduction of BREEAM, and the past thirteen years have witnessed a rapid increase in the number of building environmental assessment methods in use world-wide (e.g. BREEAM - UK; LEED - US; NABERS- Australia; CASBEE - Japan, etc.)

Initially, the development of sustainable design and building environmental assessment methods was largely an attempt in structuring a broad range of existing knowledge and considerations into a *practical framework*. For example, Kim (1999) in a study entitled Introduction to Sustainable Design, examined the environmental impact of building design and construction and discussed the principles of sustainable architecture as means of reducing these impacts. Analyses of a building's phases of construction (pre-building, building, and post-building) were also used to explore the concepts of Economy of Resources, Life Cycle Design, and Humane Design. The study also discussed examples of environmentally friendly materials and products, problems of scarcity, costly extraction, and increased regulatory provisions associated with unsustainable natural resource consumption and waste disposal.

Building environmental assessment methods were conceived as being voluntary and motivational in their application. Their current success can be taken as a measure of how proactive the building industry is in creating positive change or its responsiveness to market demand. However, public authorities increasingly use market-based tools as a basis for specifying a minimum environmental performance level for new facilities.

The green building movement has sparked a demand for such evaluation tools. Released in 1996 by US Green Bldg Council, The Leadership in Energy and Environmental Design (LEED) rating system, for instance, alludes to the goal of lowering environmental product impact by awarding points for recycled content or local materials and by rewarding low Volatile Organic Compounds (VOC) materials. In reality, it's not always the case that the point system, like LEED, does give credit for real situations. For instance, recycled paint from a local source may actually have high-VOC content. The need for actual performance-based tools became the focus of attention. Such tools can identify areas where the simple LEED-approved response may not actually be the most sustainable choice for the material.

Although Life-Cycle Energy Analyses (LCEA) has provided a broader view of performance since the 1970s, it failed to enter mainstream environmental discourse at the time. Research by Kohler (1987) initiated the beginning of a much more rigorous and comprehensive understanding of life-cycle building impacts. The notion of Life-Cycle Assessment (LCA) has now been generally accepted within the environmental research community as the only legitimate basis on which to compare alternative materials, components, elements, services and whole buildings. Many assessment tools such as EcoEffect (Sweden), ENVEST (UK), BEES (US), and ATHENA (Canada) adhere to the rigors of LCA. Meaningful LCA assessment methods are usually data intensive and can involve enormous expense of collecting data and keeping it current, particularly in a period of considerable changes in materials manufacturing processes. Some of these tools aim to simplify this for practical use within the design process, but this can make these tools inflexible to novel design elements.

Fueled by the capability of information technologies, there is an increasing search for “indicators” to measure and benchmark performance at every scale – from buildings to national progress in sustainable development. Gann et al.(2003) indicate that a “new culture of performance measurement has began to take hold across the UK construction sector” particularly for production processes. The development of a Design Quality Index (DQI) to assess a broad range of issues was signaling interest in whole building performance assessment to embrace considerations that extend beyond the current interest in environmental assessment. This success derives from their ability to offer a recognizable structure for environmental issues and, more importantly, provide a focus for the debate of building environmental performance.

3.3 Energy and Materials Studies of Buildings

Buchanan and Honey(1994) investigated the amount of energy required to construct buildings, and the resulting carbon dioxide emissions to the atmosphere from the fossil fuel components of that energy. Energy requirements and carbon dioxide emissions were compared for typical commercial, industrial, and residential buildings using New Zealand as an example. A modest change from concrete and steel to more wood construction lead to a substantial reduction in energy requirements and carbon dioxide emissions, but the sustainability of such a change had significant forestry implications.

Cole (1999) assessed the impacts of different structural materials alternatives. The study examined the energy and greenhouse emissions associated with the *on-site construction* of a selection of alternative wood, steel and concrete structural assemblies. The objective was to determine the relative proportion that the construction process represents compared to the total initial embodied energy and greenhouse gas emissions and whether there are significant differences between the structural material alternatives.

Most recently, some studies have begun to take a full life cycle approach but still in a form of comparison for residential buildings while not considering all possible environmental impacts. Adalberth (2000) investigated the energy use and environmental impact of seven residential buildings built in the 1990s in Sweden during their life cycle. Results showed that for residential buildings, 70-90 % of the total environmental impact arises during the occupation phase, while the manufacture of construction and installation materials constitutes 10-20 % to the total impact.

Many environmental studies on the impact of buildings describe the issue in relatively broad term giving qualitative, yet sometimes extensive descriptions. For instance, one study stated that the use phase accounts for the major part of the environmental impact of buildings (Finnveden and Palm, 2002). Another study gives a description of the environmental issues of dwellings, noting that assessments should focus primarily on components that represent large quantities of building materials such as foundation, floors, and walls (Klunder, 2001) whereas some other materials should be neglected regardless of quantity such as lead. In this study, the environmental impact of water consumption is regarded as negligible portion compared to those of building materials used and energy consumption.

Several methods and tools have been presented in the literature to assess the environmental impact related to buildings and construction. These took a form of descriptive guidelines. In addition, several others generic environmental assessment methods have been applied to the building and construction sector. These included, for instance, Environmental Impact Assessment EIA, embodied energy analysis (Treloar et al., 1999), and Material Input per Service MIPS method (Horvath and Hendrickson, 1998).

Limitations of LCA in buildings have also been discussed in some studies. Reijnders (1999) points out that because of the scale and life-span of buildings and the required data resolution, only material and operational impact can currently be addressed, while topics such as indoor air quality, building site issues, and infrastructure are beyond the scope of a typical LCA.

3.4 LCA Studies with Few Impact Categories

Several studies of life cycle assessment presented data about the whole life cycle of a building but utilize only one or two indicators. These are often primary energy and sometimes CO2 emissions. The purpose was to access the environmental impacts of buildings. Thormark (2000) has collected data from several studies. She concluded that the use of energy accounts roughly for 85% of the primary energy consumption of new general buildings with assumed and lifecycle of 50 years. However, in another study, she also points out that examples can be found in case of ‘low energy’ buildings, where the impact of building materials is much more significant factor, equivalent to that of one half of a buildings primary energy use (Thormark 2002).

Some previous studies in LCA for buildings have focused on determining *primary energy* consumption for embodied energy of materials regardless of their applications.

Others have examined the relationship between *embodied energy* for construction materials (initial and replacements) and *operational energy* during the life cycle concentrating on CO_2 emissions as a major greenhouse gas but disregarding other impacts on the environment (Blanchard, & Reppe 1998; Suzuki and Oka, 1998; Adalberth, 1997).

Treloar et al. (2001a) have used a hybrid input - output model to estimate the primary energy consumption and the relative importance of life-cycle phases of commercial buildings. The study revealed that the embodied energy represents 20 to 50 times the "annual" operational energy of most Australian commercial buildings. However, comparing embodied energy to operational energy can be misguiding since the amount of operational energy is always less than the actual primary energy needed to produce this operational energy.

Cole and Kernan (1996) assessed the impacts of embodied and operational energy in an office building. The study examined the total *life-cycle energy use* in a 4620 m^2 (50,000 ft^2) three-storey, generic office building for alternative wood, steel and concrete structural systems. Detailed estimates were made of the initial embodied energy, the recurring embodied energy associated with maintenance and repair, and operating energy. Based on the results, it was found that operating energy represents the largest component of life-cycle energy use. Also the building structure has been indicated as another significant component of embodied energy.

3.5 LCA Studies of Building Components and Systems

Other LCA studies have used a wider set of environmental impact indicators in their analyses. They have concentrated on limited number of lifecycle phases or building components in their calculations. Junnila and Saari (1998) studied a life cycle inventory and notices to estimate the primary energy consumption and emissions of CO2, CO, NOx, SO2, VOC, and particulates of some specific building components that ease included ground-floor slab, load-bearing walls and slabs, external walls, roofs, and windows. They have concluded that in a three story residential building, one of the lightest element groups, the windows, cause the greatest environmental emissions during

40 years of use, most of which is caused by the increased energy consumption due to heat loss.

Trusty and Meil (2000) have evaluated the environmental impact of two alternative designs for an office building, including the structural and envelope elements, and compared them against the annual HVAC operating energy. They concluded that in less energy efficient design options, the initiate embodied energy of the structures, and that off the envelope are roughly equal in to the primary energy consumption during four years of operation of the HVAC system. They also reported, in more energy efficient buildings, the initiate invited energy of the structures and the and envelope, which was roughly the same in both cases (4% more in energy efficient design), is equivalent to the primary energy consumption for approximately 10 years of operation.

3.6 Detailed LCA Studies

A third type of LCA studies included all lifecycle phases of the building and used a wider set of environmental impact indicators. Most of these were studies of residential buildings. One piece studies indicated that material manufacturing was also mentioned as having a significant impact, especially with regard to some or smog potential and toxic releases (Ochoa et al. 2002, Junnila and Saari 1998).

Office buildings environmental studies have been less published than residential. Scheuer et al. (2003) have conducted a comprehensive LCA study for an educational building at the University of Michigan campus. The study assumed a building lifecycle of 75 years. The study concluded that operation phase, heat and electricity, accounts for a major part of the impact in all assessed categories. It reported that 93% of the global warming, 83% of the ozone depletion, and 90% of the acidification, and 90% of nutrification occurred in the operation phase. Materials production and placement, in this study, came the second greatest factor impacting the life cycle. It accounted for 3-14% of impact values. Although this LCA study is extensive, it was lacking two assumptions that might emphasize the significance of operating energy. In the actual study, the operating energy was calculated to be produced mostly by a combined heat and power plant. But in the actual LCA calculation, the energy production model was simplified by separating electricity and heat production. The second assumption concerns the fuel used in the energy production which was natural gas while the energy was actually produced with gas, oil, and coal combined. These 2 assumptions potentially increased the impact of operational energy, especially in the GWP and acidification categories.

Junnila et al. (2003 and 2005) conducted two detailed LCA studies by quantifying the significant environmental aspects of a new high-end office building in Europe and United States over 50 years of service life. A comprehensive environmental life-cycle assessment, including data quality assessment, was conducted to provide detailed information for establishing the causal connection between the different life-cycle elements and potential environmental impacts. The results show that most of the impacts are associated with electricity use and building materials manufacturing. In particular, electricity used in lighting, HVAC systems, heat conduction through the structures manufacturing and maintenance of steel, manufacturing of concrete and paint, water use and wastewater generation, and office waste management. Construction and demolition were found to have relatively insignificant impacts.

3.7 LCA of Multiple Case Studies

Some LCA studies employed a multiple building case studies to estimate the environmental impact. These studies analyzed the results at a coarse lifecycle phase level. Adalberth et al. (2001) compared the environmental impact of four multi-family houses in Sweden over 50 years of service life using LCA method. These environmental impacts included were open warming potential, acidification, eutrophication, photochemical ozone creation potentials, and human toxicity. The team has reported that occupation phase dealing with a life cycle contributing the most impact categories 70 to 90%. Building materials manufacturing contributed second at 10 to 20%. The study was short in considering some building materials that could have significant ozone depletion potential, such as paints which have been omitted from the inventory. In addition, the outcome showed that the widest range of variation between the case studies of the four buildings was found in the occupation phase equal to 40% of the total lifecycle impact.

Suzuki and Oka (1998) performed an economic input-output LCA and compare it to primary energy and CO2 emissions of 10 office buildings with 40 years of service life in Japan. The study reported that the energy use in operation phase contributed most of the impact in all 10 cases with an average percentage of 80%. The second most impact was caused by construction, including materials with 15 to 18%. The variation among the buildings seemed to be highest in the use of electricity around 45% of lifecycle impact. The second highest of variation among the cases was reported in finishing elements, 10% off the buildings lifecycle impact. The structural system had a variation of only 2% among the cases they studied. However, the study lacked considerations of other environmental impact.

3.8 Studies with Sensitivity Analysis

Sensitivity analysis typically is used to check either the significance of changing key parameters contributing to the overall LCA or key assumptions governing the methodology of the LCA itself. Although sensitivity analysis is a recommended part of an LCA study, it is still not a standard practice (Ross et al. 2002). The sensitivity has been assessed in some building LCA studies. For example, Adalberth et al. (2001) have assessed the effects of three alternative scenarios for a multi-family building in Sweden. The study found that the energy mix used could have a considerable influence on the result (25-45%), but only a minor influence by the material data and the amount of operational energy of around 15%.

In another study, Peuportier (2001) performed a sensitivity analysis for a single-family house in France. He tested 4 alternative scenarios and found that the type of heating energy used has a major influence on the result (around 40%); alternative building materials used having a minor influence on the results (18%).

CHAPTER 4

RESEARCH DESIGN, PROCEDURES, AND ASSUMPTIONS

4.1 Theoretical Framework

The theoretical foundation of the study framework is based on the concept of *environmental sustainability* in buildings. Each environmental assessment needs to have a reference framework to use in the evaluation. Selecting that framework is one major issue under discussion in the industry, government level, and academia. Chau et al. (2000) suggests that this reference framework could be the concept of building *environmental sustainability*. While this is a valuable approach, it is important to acknowledge that it is difficult to use sustainability concept in an abstract way in building environmental assessment. This is because each project has a sensitive context due to differences in regulations, monetary values, and natural resources. However, the ultimate value of this approach is that it calls for the need to account for the 3 components of sustainability (Fig. 4.1), and the needs to look at local conditions any time it is possible and meaningful. The determination of what categories to be used to measure the impacts of a building is a key factor in the development of assessment tools for buildings. This represents the theoretical framework of this study as well.

4.1.1 Sustainability in the Built Environment

Sustainability is a vision, philosophy, policy, or action that respects both human needs and global ecosystems of the present while sustaining the quality of the environment so that future generations may meet their own needs. As a theory, it is a combined economic, social, and ecological concept (Fig.4-1).

The modern concept of *Sustainability* goes back to the post-World War II period, when a utopian view of technology-driven economic growth gave way to a perception that the quality of the environment was linked closely to economic development. Interest grew sharply during the environmental movements of the 1960s, when popular books such as *Silent Spring* by Rachel Carson (1962) and *The Population Bomb* by Paul Ehrlich (1971) raised public awareness.

The original term in this process was *Sustainable Development*, a term adopted by the Agenda 21 program of the United Nations according to 1987 Brundtland Report: "Meeting the needs of the present generation without compromising the ability of future generations to meet their needs."(WCED, 1987). Some people now object to the term Sustainable Development as an umbrella term since it implies continued development, and insist that it should be reserved only for development activities. The term *Sustainability*, then, took over and is used now as an umbrella term for all of human activity.

4.1.2Sustainability in Buildings: Theory and Concept

Views on what actually constitute sustainable development, and more specifically the *sustainable built environment*, are varied. Kohler (1999) gave an interpretation that one can use as a guide in defining the possible roles of a sustainable building demonstration.

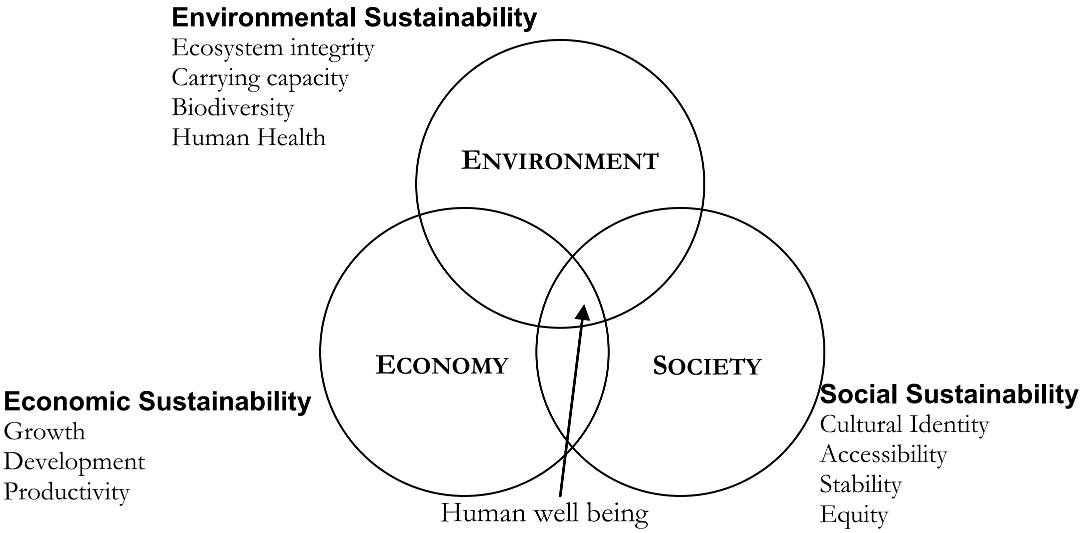


Fig. 4-1: Sustainability Concept

Sustainability is divided as follows:

- *Environmental Sustainability* is defined as economy of resources and ecosystem protection that can be quantitatively analyzed with respect to the energy and mass flows within a life cycle assessment. Theoretically, the objective of sustainability is not merely to improve qualitatively the building stock, but to improve it by reducing material throughput and improve functional quality and durability.
- *Economic Sustainability* is divided into building process investment and use costs. Instead of minimizing investment cost through crossing low-cost of building processes and products, it is preferable for a given investment to find solutions that have the highest durability and reusability. Those solutions that can be repaired and reused in several ways have the highest long-term resource productivity. Research proved that buildings with low-energy consumption are easy to operate, maintain and generally have low use costs.
- *Social and Cultural Sustainability* is comfort and health protection inside the building, and the preservation of values, which is one of the main motivations behind any conservation project (Cole 1999).

4.2 Research Method Framework

Research method employs a multiple case study approach that consists of three cases. The *case study* methodology is an empirical inquiry that investigates a phenomenon within its real life context (Yin, 2002). The studied phenomenon in this study is the building lifecycle, it is a real life context, and the boundaries between the phenomenon and the context are not clearly evident (Yin, 2002). The case study also follows a theoretical replication approach that produces contrasting results for predictable reasons (Groat and Wang, 2001). These results are, in this study, the potential environmental impacts of specific building life cycle phases and assembly components for the reason of quantifying these impacts. A third reason for using case study is that the study also investigates a real world open system (Robson, 2002).

Choosing case study method was also supported by data collection from multiple sources. Drawings and specifications of a building, architect documents, environmental statistics, interviews and observations, published energy data, all had to be used to collect the information needed for obtaining the environmental impacts. Furthermore, typical buildings were chosen so that results from the study could also be generalized to a larger context i.e. similar building type, neighborhood, or city.

4.2.1 Multiple Case Method

The multiple case approach is used to compare the environmental profiles of office buildings with different users and contexts. The results of comparative cases are often considered more compelling than those results of a single case (Yin 2002). All the chosen cases have embedded units of analysis. These are the materials and energy flows that are analyzed quantitatively by the LCA method (ISO 14040).

The multiple case studies also support the goal of this study to gain in-depth knowledge of each case. It helps to understand *why* and *how* a certain lifecycle phase and building elements contribute more than another to the total environmental impact. This kind of approach is called, a positivistic case study (Remenyi et al., 1998), because it includes a collection of numerical evidence and an application of a mathematical analysis.

4.2.2 Building Cases Selection

The selection consists of three office buildings in southeast Michigan. The number of cases supports the suggestion that a multiple case study should involve approximately three cases for literal replication (Yin, 2002). The cases are chosen based on replication logic that albeit buildings having considerable differences in their characteristics, they would produce comparable results. This type of sampling collected with a specific purpose in mind is called judgment or purposive sample (Remenyi, 1998).

Yin (2002) and Eisenhardt (1998) emphasize the significance of categories as factors that guide the selection of cases. In this study, the following main criteria are used: selected buildings are relatively new; they are constructed and used by different organizations in order to avoid the risk of having similar results. Also all cases a selected are located in Michigan where they all have the same climactic conditions. Furthermore, the interest of the designer and owners to participate in this study and the amount of data available were major factors in the selection of these cases. Research case studies are mostly of a quantitative/deductive character as it is used to generate data and analyzes the environmental impact of the chosen buildings. Detailed description of cases is presented later in chapter 5.

4.2.3 Life Cycle Assessment Framework

A lifecycle assessment framework (ISO 14040, 1997) is selected to assess the environmental impact of the office building. The ISO 14040(1997) defines the lifecycle assessment LCA as a framework for the identification, quantification, and evaluation of the inputs, outputs, and the potential environmental impact of a product, process or service throughout its life cycle, from cradle to grave, i.e. from raw material acquisition, through production, use, and to disposal. LCA is often mentioned as the most appropriate method for a holistic environment assessment (Curran, 1996).

The LCA models are based on system thinking, which states that any product or service can be described as a system (Consoli et al.,1993). The system is defined as a collection of material and energy-connected operations (processes), which perform a defined function. The system is defined from its surrounding by a system boundary. The whole region outside the system is known as a system environment. The inventory of the system is a quantitative description of all the material and energy flows across the system boundary.

Like most of the systems, LCA in this study is described using linear model. A linear model is a mathematical statement of the system in which the system is described through a set of linear functions. The LCA is widely used in industry to analyze environment issues and it is held to be a central tenant in industrial ecology (Graedel and Allenby, 2003). For studying the life cycle (material extraction, manufacturing, construction process, use, end-of-life), LCA he is considered the systematic and the most objective process. The LCA process identifies and quantifies energy and material use and environmental releases off a given system, and evaluates the corresponding environmental impact.

The LCA process consists of four main components/steps: goal and scope definition; inventory analysis; impact assessment; and interpretation (ISO 14040, 1997).

The goal and scope definition describes why LCA is being conducted and describes the system boundaries and functional unit. The inventory analysis includes the calculations of energy and materials as inputs and emissions as outputs. The impact assessment uses the results of inventory to characterize and evaluate the emissions into potential environmental impact categories. The interpretation renders the findings of the study combined with conclusions and recommendations.

4.2.4 LCA Limitations of the Analysis

Although LCA is widely used to assess environmental impacts of products and processes, it has its limitations, which are important to recognize while interpreting the results of an LCA study. Typically, the inventory analysis stage of the LCA is considered to have the least uncertainty. The most of the weaknesses are related to the scope definition, impact assessment, and interpretation stages of the LCA (Consoli et al., 1993).

ISO 14040 (ISO 1997) has listed the following limitations: There are subjective choices (e.g., system boundaries, selection of data sources, and impact categories), the models used in inventory and impact assessment are limited (e.g., linear instead of nonlinear), the local conditions may not be adequately represented by regional or global conditions, the accuracy of the study may be limited by the accessibility or availability of relevant data, and the lack of spatial and temporal dimensions introduces some uncertainty in impact assessment.

4.3 Quantifying and Assessing the Environmental Impacts: Scope and Procedures Summary

As mentioned earlie, the study employs an LCA method to the case study buildings to calculate the total environmental impacts and determine the contribution of different *life phases* and *building assembly systems* to the whole building life cycle impacts through the flow of energy and materials over 60 years. The study follows the same sequence of the LCA main 4 steps (ISO 14040, 1997). Before going into details, the study's scope and procedures are summarized as follow:

1. Identify the goal and scope, system boundary, functional unit, and data requirements and quality as first step in any LCA.
2. Compile inventory of installed and replacement buildings materials, energy use, and operational characteristics over 60 year's life span.
3. Assess the environmental impacts associated with material use and embodied and operational energy, throughout the entire life cycle. Eight environmental impact categories are considered for this LCIA step. ATHENA 4.1 (2010) impact estimator life-cycle calculation program is used to model the building cases for steps 2 and 3.
4. Interpret and assess the results of life cycle phases and building systems contributions to the whole impacts.

4.4 Scope and Procedures Details

Detailed description of the study scope and procedures of the LCA framework is as follow:

4.4.1 Goal and Scope: System boundary

System boundary means what is going to be included or excluded throughout the study. In LCA, the system boundary encompasses all energy and mass flows related to the analyzed product (the building). For instance, each material transport requires energy to move the vehicle, which is a significant component and will be calculated as transportation energy and emissions between phases.

The boundary of this analysis is limited by omitting the following factors not directly related to building LCA. These omissions are common practice for such study and are unable to be modeled. For instance: material production burdens for office equipment, bathroom supplies, moveable partitions, and furniture; street and sidewalk modifications; site location and local infrastructure impacts such as utility hookups and related streets modifications; weight of material packaging; burdens from planning and design of the building (e.g. architect's office heating, lighting, paper for drawings, etc.).

4.4.2 Goal and Scope: Functional unit

A functional unit of a ‘m^2 usable floor area’ is chosen. This alternative would make the calculations of the building easier. The unit is also widely used in other studies and is utilized to easily compare and draw conclusions between cases. Nevertheless, the functional unit ‘m^2 usable floor area’ is chosen, the usable floor area is defined as the floor areas in the building, staircases, cellar and attic if any. In order to replicate the findings of the study, the conclusion determines the environmental impacts per m^2 usable floor area of the case study buildings. This will give a rough estimate that can be used by practitioners in determining these impacts for similar building types.

4.4.3 Goal and Scope: Data Requirements and Quality

The data uncertainty in the study is assessed both quantitatively, through sensitivity analysis (ISO 14040), and qualitatively with data quality method developed by Weidema (1996) and Lindfors (1995). The sensitivity is simply a process of changing the input parameters in a given model to assess the level of change on its output. Using the most recent, accepted data sources serves as an asset to the reliability of the research which will yield same results if the study is conducted under the same conditions in another time or place. More details on data requirements and quality are presented in chapter 5.

4.4.4 Athena Life Cycle Program Concept and Limitations

Athena Impact Estimator is an LCA tool for building analysis developed by the Athena Institute of Merrickville in Ontario, Canada. This program allows full building modeling and includes many assumptions about ‘standard’ building practices. Data used are industry averages adjusted to regional conditions. This data is based mostly on information from the US Life Cycle Inventory Database (2011). The Athena program was developed in Canada and has the capability of placing the project in various Canadian cities and few cities in the United States, such as Los Angeles, Atlanta, Pittsburgh, Orlando, as well as a national U.S. average. When the location is specified, the program will adjust calculations to the appropriate power grid, resources, and average travel distances for the area.

The tool applies a set of algorithms to the input takeoff building data in order to complete the takeoff process and generate a bill of materials based on geometry and building specifications. This bill of materials then utilizes the Athena Life Cycle Inventory (LCI) Database in order to generate a cradle-to-grave LCI profile for the building. The LCI profile results include the life cycle stages of the building. These are manufacturing (including raw material extraction), transportation to construction site, on-site construction, operation, maintenance, structural system demolition, and transportation to landfill phases.

The program then filters the LCI results through a set of characterization measures based on the *mid-point impact assessment* methodology developed by the U.S. Environmental Protection Agency (U.S. EPA); the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) version 2.2. TRACI mid-point impact method includes emissions, fate, and exposure, and is less uncertain than the end-point method used by other LCA software. In order to generate a complete environmental impact profile, all of the available TRACI impact assessment categories available in the program are included in this study, and are described in details later. These are: primary energy (fossil fuel) consumption, weighted raw resource use, global warming potential, acidification potential, eutrophication potential, photochemical smog potential, human health respiratory effects potential, and ozone depletion potential.

Limitations to the analysis capabilities of the Athena Impact Estimator include: First, the data is aggregated such that it is difficult to understand some detailed underlying assumptions used in creating the dataset. Second, the program is not an energy simulation program so operational energy requirements must be calculated by a third party program, however, it does allow for the input of energy requirements based on fuel type, including electricity, natural gas, coal, as well as other fuel types for the building operation phase. Third, the program also does not recognize doors as part of the assembly, but the doors can be modeled as additional windows or neglected depending on the type of door used or added in the extra materials category after wood, or metal, quantity calculations.

4.4.5 Life Cycle Inventory (LCI)

As mentioned earlier, inventory analysis involves data collection and calculations to quantify material and energy inputs and outputs of the building cases. Fig 4-2 illustrates the model used in this study for the LCI stage. Identification and quantification of material and energy flows (inputs and outputs) of the case study office buildings are primarily derived from the floor plans, specifications sheets, and bill of materials provided by the architect. Some data are collected through on-site measurements and inquiries to sub-contractor. Inventory is completed using ATHENA 4.1 (2010) life-cycle calculation program. A complete list of materials is compiled based on the outcome from the modeling program (Appendix A-7, B-7, C-7). Material placement burdens are subdivided into material production, transportation in each life cycle phase (see appendices).

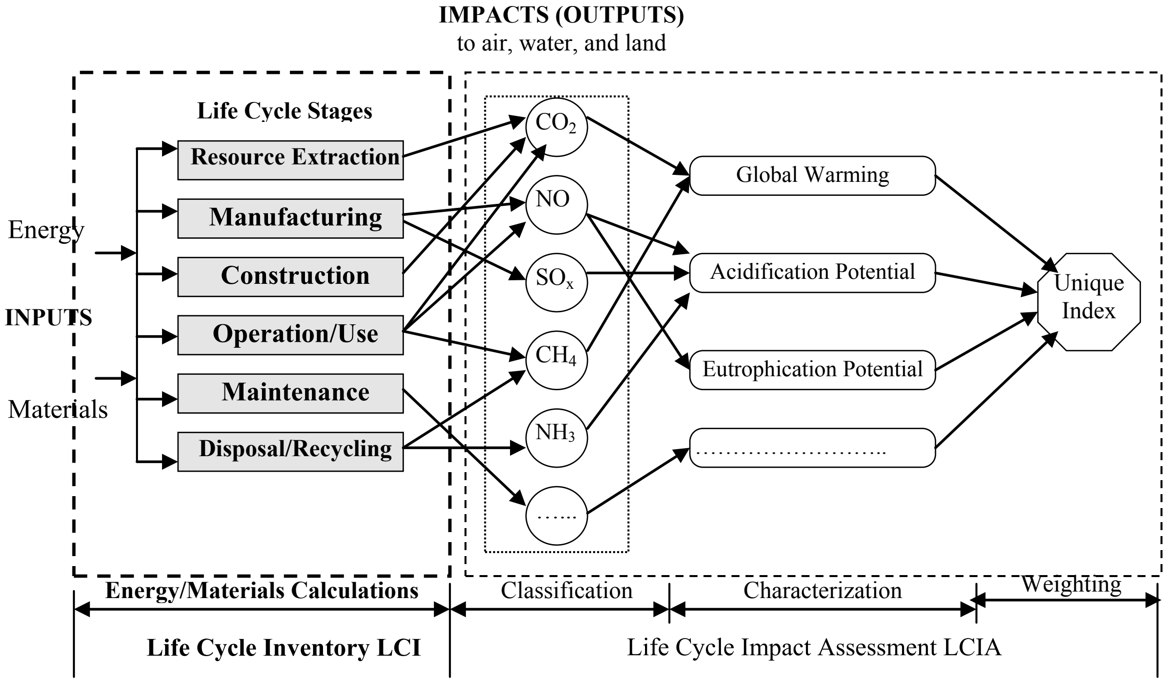


Fig. 4.2: LCA Model Used - Life Cycle Inventory LCI Stage

a. Materials Extraction and Manufacturing

This phase includes burdens from raw materials extraction (e.g. drilling for oil, mining for iron ore, harvesting wood, etc.), refinement of raw materials into engineered materials, manufacturing (e.g. extrusion of steel or aluminum, injection molding of plastics, etc.). Material embodied energy is the fuel energy content of the resource, plus the energy consumed during extraction, refining and production of engineered materials and for the transportation from the site of extraction to the refinery, steel mill, or similar operation. All materials are considered virgin unless otherwise stated.

b. Transportation

Usually there are 3 main transportation phases in a life cycle of building (Fig 1.1); First, is from resource extraction site to manufacturing facility. Second, is from manufacturers and building sites during construction and renovation. Third, is from building site to the final disposal/recycling facility. The majority of material data sets already accounted for the first phase of transportation energy from the point of extraction (e.g. iron ore), to the manufacturer of the engineered materials (e.g. steel rods). The study calculates all the 3 phases of transportation and associated emissions through the LCA modeling software.

c. Building Construction

The construction phase of the building includes all materials and energy used in on-site activities. Data are modeled for the use of electricity, construction equipment, and transportation of building materials to the site (average 100 mi radius). Some of the data are collected from the contractor, and were further confirmed by interview with his representative on-site.

d. Building Operation and Use

The impact of buildings operation phase is evaluated by means of its energy use. The use of the building is divided into mainly space heating/cooling, water heating/cooling, and electrical consumption. Annual energy is calculated taking into account the use and occupancy patterns of the building spaces, the architectural and mechanical features of the building, as well as local climate. For the purpose of energy simulation, all buildings are estimated to be used 55 hr/week for 60 years. Energy calculations are performed using eQUEST 3.64 (2010), a DOE 2 energy simulation program for electricity use and HVAC heating and cooling loads. All building parameters (dimensions, orientation, walls, windows, glass type, etc) are modeled in eQUEST.

e. Maintenance

The maintenance phase included all of the life-cycle elements needed during the 60 years of maintenance. These include the use of building materials, construction activities, and waste management of discarded building materials. An estimated 75% of building materials was assumed to go to landfill, and 25% was assumed recovered for other purposes such as recycling. Some assumptions regarding this phase include no extensions, re-constructions; no significant changes are made during the relevant 60-year phase. Only sequential maintenance, e.g. repainting, floors replacements, is considered.

f. Demolition

The conventional demolition process often results in landfill disposal of the majority of materials. Current demolition practices depend on variable factors such as customer demand, contractors chosen, and market prices. The demolition phase includes on-site demolition activities, transportation of discarded building materials (75% of the total) to a landfill (50 mi away), and shipping of recovered building materials to a recycling site (70 mi, on average). The buildings are assumed to be demolished. Energy needed for demolition is estimated by the LCA software based on bldg parameters and another report from Athena (1997) for steel buildings demolition energy. The LCI outcome from this phase will be given in terms of energy used for demolition and transportation to landfills. Accordingly, this energy will be converted into equivalent emissions (pollutants to air, water, and land) using Athena model. In LCIA phase, these gases will be categorized and assigned to its proper impact category (fig 4.3).

4.4.6 Life Cycle Impact Assessment (LCIA)

LCIA phase evaluates the significance of environmental impacts based on the LCI results. Fig 4-3 illustrates the model used in this study for the LCIA stage.

The *classification*, or assigning of inventory data to impact categories, and the *characterization*, or modeling of inventory data within the impact categories (ISO 1997), were performed using the ATHENA 4.1 life-cycle calculation program (2010) which is used to model the 3 building cases. The study also compares the environmental impacts of different building assembly systems (foundation, structure, walls, floors, roofs) so that the significant environmental impact could be identified within these systems.

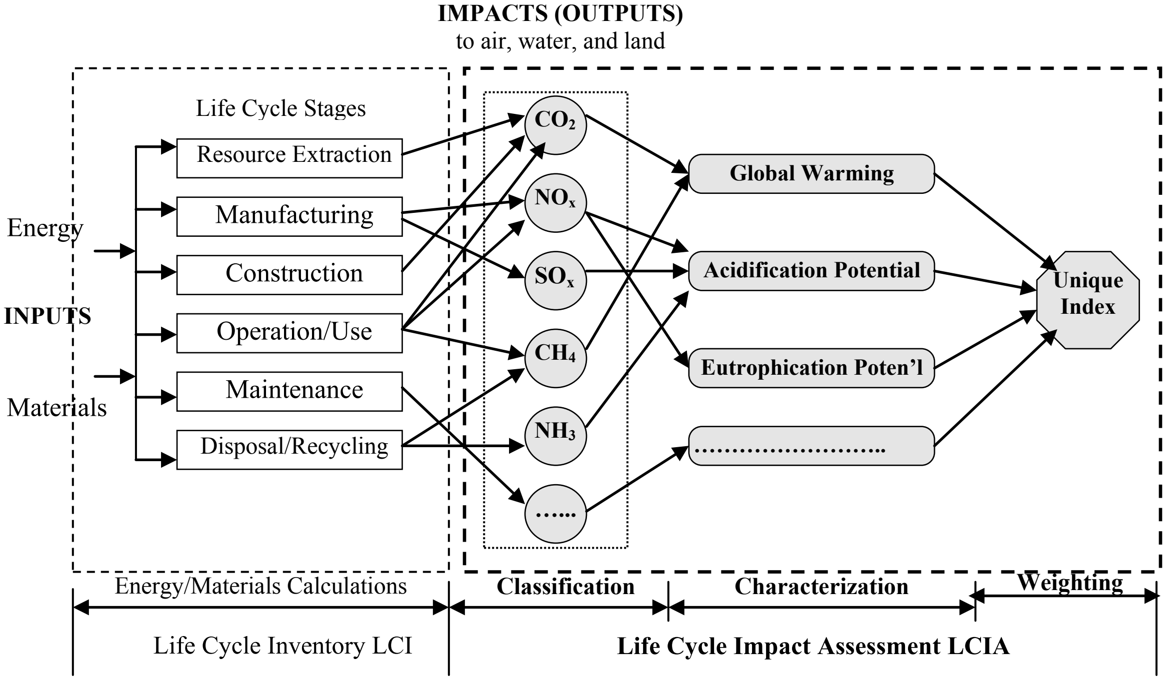


Fig. 4.3: LCA Model Used - Life Cycle Impact Assessment LCAI Stage

The following impact categories are considered for building environmental profiling in the 3 cases: Fossil Fuel Consumption FFC (or primary energy consumption) ; Weighted Resources Use WRU; Global Warming Potential GWP; Acidification Potential AP; Eutrophication Potential EP; Photochemical Ozone Creation Potential POCP (Smog); Human Health Respiratory Effect; and Ozone Depletion Potential ODP. The reason for choosing these effect categories is that they are considered especially important in literature and from an environmental and political point of view set by US EPA (2006) (Table 2.2). The chosen impact categories are also on the short list of environmental themes that most environmental experts agree to be of high importance in all regions of the world (Schmidt and Sullivan, 2002). Furthermore, the used impact categories are consistent with the air and water emissions that the World Bank (1998) has recommended to be targeted in environmental assessments of industrial enterprises. The study is among very few which carry out these many impact categories. It's important to mention that the impact assessment was conducted only until the end of the *mandatory step* of impact assessment (see 2.6.3), where the emissions from the inventory are classified and characterized *but not valuated* (UNEP 2003b).

Detailed description of each of the impact indicators considered in the results follows.

4.4.7 Environmental Impact Categories

a. Fossil Fuel Consumption FFC

FFC is also referred to as *primary energy consumption* or *fuel depletion*. It is usually given in mega-joule. This impact category is the total energy used to transform and transport raw materials into products during the manufacturing and construction phases. This includes inherent energy contained in raw materials in addition to indirect energy use associated with processing, converting, and delivering energy. This impact essentially characterizes the gain from the energy sources such as natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents e.g. in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations. It is important that the end energy use (e.g. 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end energy will not be accounted for.

b. Global Warming Potential GWP

GWP is also called Greenhouse Effect or Carbon Footprint. This effect represents an average increase in earth temperature due to the burning of fossil fuels and other forms of energy resulting in higher atmospheric concentrations of gases such as carbon dioxide, methane, and nitrous oxide. The occurring short-wave radiation from the sun comes into contact with the earth's surface and is partly absorbed and partly reflected as infrared radiation. The reflected part is absorbed by greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. Hence, the quantity of heat the earth can give away to the space is accordingly reduced and the (mean) temperature of the layers of the atmospheric envelope (that are close to the ground) tends to increase accordingly. Greenhouse gases that are considered to be caused or increased are carbon dioxide, methane and CFCs. Figure ….shows the main processes of the greenhouse effect. An analysis of the greenhouse effect should consider the possible long term global effects. For other gases than CO2, GWP is calculated in carbon dioxide equivalents (kg CO2-eq.). This means that the greenhouse potential of an emission is given in relation to CO2. Since the residence time of the gases in the atmosphere is incorporated into the calculation; a time range for the assessment must also be specified. A period of 100 years is customary for GWP.

c. Acidification Potential AP

Acidification, also named as "acid rain", comprises processes that increase the acidity (hydrogen ion concentration, H^+) of water, air, and soil systems. Acid rain generally reduces the alkalinity of lakes. Acid deposition also has deleterious (corrosive) effects on buildings, monuments, and historical artifacts.

The acidification of soils and waters occurs through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and even below forming "acid rain" that can pollute forests, lakes and rivers, as well as buildings. The most important substances contributing to AP is SO2 (sulfur dioxide) and NOx (nitrogen oxides) and their respective acids (H2SO4 und HNO3) produce relevant contributions. These are released into the atmosphere when fossil fuels such as oil and coal are combusted. This damages ecosystems, whereby forest dieback is the most well-known impact. Acid rain generally reduces the alkalinity of lakes. Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate. The resulting acidification characterization factors are expressed in hydrogen (H^+) mole equivalent deposition per kilogram of emission.

d. Eutrophication Potential EP

EP is also called “Over-fertilization”. The term “eutrophic” means well-nourished, thus, “eutrophication” refers to natural or artificial addition of nutrients to bodies of water and to the effects of the added nutrients. When the effects are undesirable, eutrophication is considered a form of pollution.” (National Academy of Sciences, 1969). The process happens when a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. These typically promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. Eutrophication is a natural, slow-aging process for a water body, but human activity greatly speeds up the process. The calculated result of EP is expressed on an equivalent mass in kg of nitrogen (N^+) ion basis.

e. Photochemical Ozone Creation Potential POCP (Smog)

POCP always referred to as “Summer Smog” which is the production of ground level ozone. It is the result of reactions that take place between nitrogen oxides (NO_x) and volatile organic compounds (VOC) exposed to UV radiation. Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog. While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x). The smog potential is expressed on a mass of equivalent NO_x basis that represents these air emissions from industry and transportation that are trapped at ground level

f. Human Health (HH) Respiratory Effect

Particulate Matter (PM) of various sizes PM_{10} and $PM_{2.5}$ (with aerodynamic diameters of 10 or 2.5 microns or less, respectively) have a considerable impact on human health. The US EPA (2002) has identified “particulates” (from diesel fuel combustion) as the number one cause of human health deterioration due to its impact on the human respiratory system – asthma, bronchitis, acute pulmonary disease, etc. These include PM_{10} (inhalable particles) and its fractions $PM_{2.5}$ (fine particles). It should be mentioned that particulates are an important environmental output of construction products production and need to be traced and addressed. The equivalent $PM_{2.5}$ basis is the measure of this impact indicator.

g. Ozone Depletion Potential ODP

ODP is also called “Ozone Hole”, which is the depletion of the stratospheric ozone layer. The ozone of the stratosphere absorbs a large portion of the hard UV sun rays. Depending on climatic conditions, the catalytic action of Chlorofluorocarbons CFC compounds degrades ozone down to oxygen. Some of these gases have a very long residence time in the stratosphere and may cause the ozone molecules to be destroyed even many years after their emission. Reduced concentration of the ozone (hole in the ozone layer) causes an increased transmission of UV sun rays with negative consequences for plants, animal and human beings (for instance increased skin cancer hazard, DNA damage, etc). The ozone depletion potential is expressed in terms of mass equivalence of Trichlorofluoromethane (CCl_3F = CFC-11), which is the measure used to assess the importance of the effect produced by the various gases.

h. Resources Use

Resources use, reported in kilograms (kg), addresses the resource extraction activities associated with the manufacturing of each building material. As stated in the Athena IE software, the values reported for this impact category are the sum of the weighted resource requirements for all products used in each of the building cases.

4.4.8 Energy Sources

In order to estimate the environmental impact, the emissions from energy production must be known. During a 60-year life cycle, the energy source or the energy supply system will supposedly change several times. In the calculations, however, it is assumed that the energy supply system will be constant during the entire life cycle.

The average US average electricity mix is used to determine the environmental impact due to energy use (fig 4.3). The purpose of using the US electricity mix, e.g. during the operation phase (and not the local electricity net i.e. Midwest Grid) is primarily to compare the impact of the building and not the impact of the energy supply systems. Since every region in the US has its own source of electricity e.g. Hydro, wind, coal, nuclear, etc., the emissions for every kilowatt of electricity is different *by source* of energy. Therefore, the average US electricity mix will be used for future replication to other buildings in order to get same *emission set* from the source. (Fig 4.3)

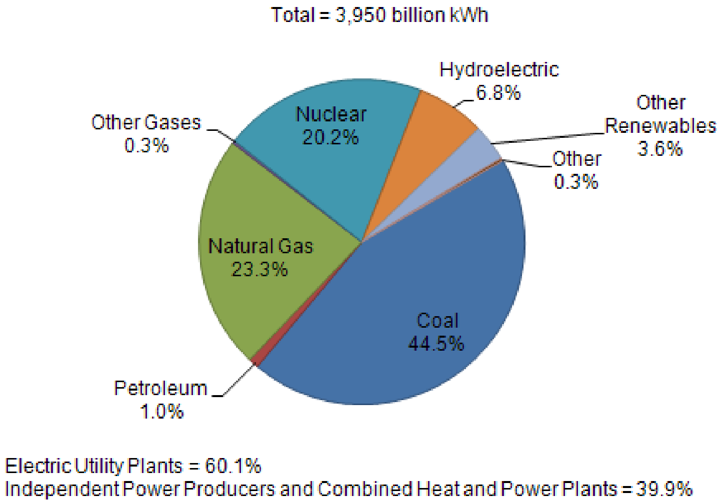


Fig. 4-4: The Electricity Mix of the US Grid (EIA, 2009)

4.4.9 Water Pollution Emissions Categories

Water pollution is the contamination of water bodies such as rivers, lakes, oceans, and groundwater. It occurs when pollutants are directly or indirectly released into water without proper treatment to remove the harmful compounds. Water pollution is a major global problem. It has been suggested that it is one of the leading worldwide cause of deaths and diseases. Water contaminants include *organic* such as: Insecticides, Herbicides, Petroleum hydrocarbons, Volatile Organic Compounds (VOCs) from industrial and chlorinated solvents; and *inorganic* contaminants such as: Sulfur Dioxide from power plants and acid rains, Fertilizers (nitrates and phosphates), and Heavy Metals from huge industries e.g. motor companies.

Despite the several water pollutants reported for the 3 buildings (Appendices A-10, B-10, C-10), this section will focus only on the main water pollutants, measured by potency of the impact on water and not only the release amount by weight or volume (Fig. 6-5).

a. Heavy Metals

Heavy metals are chemical elements with a specific gravity that is at least 5 times the specific gravity of water. The specific gravity of water is 1 at 4°C (39°F). Simply stated, specific gravity is a measure of density of a given amount of a solid substance when it is compared to an equal amount of water. Some well-known toxic metallic elements with a specific gravity that is 5 or more times that of water are arsenic, 5.7; cadmium, 8.65; iron, 7.9; lead, 11.34; and mercury, 13.54.

Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. Heavy metals may enter the human body through food, water, air, or absorption through the skin when they come in contact with humans in agriculture and in manufacturing, pharmaceutical, industrial, or residential settings. As a rule, acute poisoning is more likely to result from inhalation or skin contact of dust, fumes or vapors, or materials in the workplace. The Agency for Toxic Substances and Disease Registry (ATSDR) in Atlanta, Georgia, (a part of the U.S. Department of Health and Human Services) has compiled a Priority List for 2001 called the "Top 20 Hazardous Substances." The heavy metals arsenic (1), lead (2), mercury (3), and cadmium (7) appear on this list.

a.1 Arsenic

Arsenic is the most common cause of acute heavy metal poisoning in adults and is number 1 on the ATSDR's "Top 20 List." Arsenic is released into the environment by the smelting process of copper, zinc, and lead, as well as by the manufacturing of chemicals and glasses. Arsine gas is a common byproduct produced by the manufacturing of pesticides that contain arsenic. Arsenic may be also be found in water supplies worldwide, leading to exposure of shellfish, cod, and haddock. Other sources are paints, rat poisoning, fungicides, and wood preservatives. Target organs are the blood, kidneys, and central nervous, digestive, and skin systems.

a.2 Lead

Lead is number 2 on the ATSDR's "Top 20 List." Lead accounts for most of the cases of pediatric heavy metal poisoning (ATSDR 2001). It is a very soft metal and was used in pipes, drains, and soldering materials for many years. Millions of homes built before 1940 still contain lead (e.g., in painted surfaces), leading to chronic exposure from weathering, flaking, chalking, and dust. Every year, industry produces about 2.5 million tons of lead throughout the world. Most of this lead is used for batteries. The remainder is used for cable coverings, plumbing, ammunition, and fuel additives. Other uses are as paint pigments and in PVC plastics, x-ray shielding, crystal glass production, and pesticides. Target organs are the bones, brain, blood, kidneys, and thyroid gland (IATSDR ToxFAQs for Lead, 2001).

a.3 Mercury

Number 3 on ATSDR's "Top 20 List" is mercury. Mercury is generated naturally in the environment from the degassing of the earth's crust, from volcanic emissions. It exists in three forms: elemental mercury and organic and inorganic mercury. Mining operations and paper industries are significant producers of mercury. Atmospheric mercury is dispersed across the globe by winds and returns to the earth in rainfall, accumulating in aquatic food chains and fish in lakes. Mercury compounds were added to paint as a fungicide until 1990. These compounds are now banned; however, old paint supplies and surfaces painted with these old supplies still exist. Mercury continues to be used in thermometers, thermostats, and dental amalgam. Inhalation is the most frequent cause of exposure to mercury. The organic form is readily absorbed in the gastrointestinal tract (90-100%); lesser but still significant amounts of inorganic mercury are absorbed in the gastrointestinal tract (7-15%). Target organs are the brain and kidneys (ATSDR ToxFAQs for Mercury, 2001).

a.4 Cadmium

Cadmium is a byproduct of the mining and smelting of lead and zinc and is number 7 on ATSDR's "Top 20 list." It is used in nickel-cadmium batteries, PVC plastics, and paint pigments. It can be found in soils because insecticides, fungicides, sludge, and commercial fertilizers that use cadmium are used in agriculture. Cadmium may be found in reservoirs containing shellfish. Cigarettes also contain cadmium. Lesser-known sources of exposure are dental alloys, electroplating, motor oil, and exhaust.

Inhalation accounts for 15-50% of absorption through the respiratory system; 2-7% of ingested cadmium is absorbed in the gastrointestinal system. Target organs are the liver, placenta, kidneys, lungs, brain, and bones (ATSDR ToxFAQs for Cadmium, 2001).

a.5 Nickel

Small amounts of Nickel are needed by the human body to produce red blood cells, however, in excessive amounts, can become mildly toxic. Short-term overexposure to nickel is not known to cause any health problems, but long-term exposure can cause decreased body weight, heart and liver damage, and skin irritation. The EPA does not currently regulate nickel levels in drinking water. Nickel can accumulate in aquatic life, but its presence is not magnified along food chains.

b. Biological Oxygen Demand (BOD)

BOD is a chemical procedure for determining how fast biological organisms use up oxygen in a body of water. It is measured in milligram. It is usually performed over a 5-day period at 20° Celsius. It is used in water quality management and assessment, ecology and environmental science. BOD is not an accurate quantitative test, although it could be considered as an indication of the quality of a water source. Therefore, a low BOD is an indicator of good quality water, while a high BOD indicates polluted water. BOD can be used as a gauge of the effectiveness of wastewater treatment plants. It is listed as a conventional pollutant in the U.S. Clean Water Act.

c. Chemical Oxygen Demand (COD)

In environmental chemistry, the chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds (carbon and Hydrogen) in water. It is used as an indicator of dissolved organic carbon, often in conjunction with biological oxygen demand (BOD). Total organic carbon (TOC) = COD + BOD. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers), making COD a useful measure of water quality. It is expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution.

d. Suspended Solids

Suspended solids refer to small solid particles which remain in suspension in water or due to the motion of the water. It is used as one indicator of water quality. The smaller the particle size, the greater the surface area per unit mass of particle, and so the greater the pollutant load that is likely to be carried.

e. Phosphorus and Nitrogen

In the 1997 Clean Water Action Plan the U.S. Environmental Protection Agency identified nutrients as a significant national problem contributing to water pollution. States reported that more than half of all lakes were affected. Just as applying fertilizer to gardens and farm fields helps crops grow, nutrients entering lakes and rivers feed the growth of algae, bacteria, and other tiny organisms. Water bodies require some nutrients to be healthy, but too much can be harmful. When lakes receive an overabundance of nutrients, they can become polluted by excessive amounts of algae. Die-off and decomposition of algae blooms can reduce dissolved oxygen and suffocate fish and other aquatic life. Some forms of algae (blue-green) may produce toxins that can be harmful if ingested by humans and animals.

Phosphorus (P) and nitrogen (N) are the primary nutrients that in excessive amounts pollute our lakes, streams, and wetlands. Nitrogen is used primarily by plants and animals to synthesize protein. Nitrogen is a type of nutrient contributing to the poor water quality. While nitrogen is needed for plant growth, human activities contribute more nitrogen than water can handle. Elevated nitrogen levels cause more algae to grow, blocking out sunlight and reducing oxygen for fish and other species life.

Nitrate, a compound containing nitrogen, can exist in the atmosphere or as a dissolved gas in water, and at elevated levels can have harmful effects on humans and animals. Nitrates in water can cause severe illness in infants and domestic animals. Common sources of excess nitrate reaching lakes and streams include septic systems, animal feed lots, agricultural fertilizers, manure, industrial waste waters, sanitary landfills, and garbage dumps.

Phosphorus is a vital nutrient for converting sunlight into usable energy, and essential to cellular growth and reproduction. In the late 1960s scientists discovered phosphorus contributed by human activity to be a major cause, a fuel, of excessive algae growth and degraded lake water quality. Phosphates, the inorganic form, are preferred for plant growth, but other forms can be used when phosphates are unavailable. Phosphorus builds up in the sediments of a lake. When it remains in the sediments it is generally not available for use by algae; however, various chemical and biological processes can allow sediment phosphorus to be released back into the water.

CHAPTER 5

DESCRIPTION OF THE CASE STUDY BUILDINGS AND DATA ASSESSMENT

5.1 Data Collection and Requirements

One of the major barriers in lifecycle assessment is the availability of data. A hard to obtain data and/or empty data cells in the analysis can deter the researcher from pursuing such study. Sometimes, poor data quality can lead to high uncertainty in the assessment and thus in the reporting all findings. Several publications (Weidema and Wesnæs, 1996; Weidema, 1998; Huijbregts et al, 2001) have used the concept of pedigree matrix for data quality assessment (table 5-1). The goal of this matrix is to give an indication of reliability of the data, completeness of the data, and of the existence of different correlations (temporal, geographical, and technological) and between the data and the data quality goals or intended use. LCA is typically the most data intensive of all the environmental assessment tools, mainly because of their ambition for comprehensive assessments. For this reason, LCA tools are developed and used by teams of experts. Most of the burden of data collection is on the team that develops and use the tool.

The primary data in the inventory stage are directly obtained from the architect through the specification sheet of each project and bill of quantities. Other quantities of building data were obtained from floor plans and sections. Other data sources were interviews with the contractor on the site and direct observations during construction of the buildings. The buildings are owned, designed, constructed, and operated by different companies, and they were constructed during the years between 2006 and 2009. The following building systems were included in the study: foundations, structural frame, external walls, floors, roofs, and internal walls/partitions. Each floor plan of the presented cases represents a typical office building in the Midwestern area. Choosing a typical office plan helps in generalizing the research findings to bigger sample of the same type. Description of cases, similarities and differences are presented in Table 5.1.

5.2 Case 1: Brookside Office Building

Brookside is a newly built office building in Southeast Michigan in the U.S. Its construction ended in 2007. It is occupied by an insurance company with administrative employees. The building has 40,000 sq ft (3716 m^2) of gross floor area, and a volume of 600,000 cu ft (16990 m^3). The building consists of 2 floors (20,000 sq ft each, 14' 8" ft floor height each) with no basement. The structural frame is Hollow Structural Steel HSS columns and wide flange (W sections) beams. Floors are metal decking with 2" concrete topping. The exterior walls are brick veneer with steel studs backing. Interior walls are galvanized steel studs with gypsum board facing to receive paints or wall paper. Foundations are cast-in-place concrete. The annual energy consumption is calculated using eQUEST 3.64 (2010), a DOE interface for energy simulation. The estimated natural gas consumption (mainly for water heating) of the building is 69.81 Million Btu/year (1745 Btu/sq ft/year) and this is equivalent to 0.51 kWh/sq ft/year. The estimated electricity consumption is 425,000 kWh/year (10.6 kWh/sq ft/year) (appendix C-1). Figure 5-1 also shows the modeling set-up for Brookside office building using eQUEST.

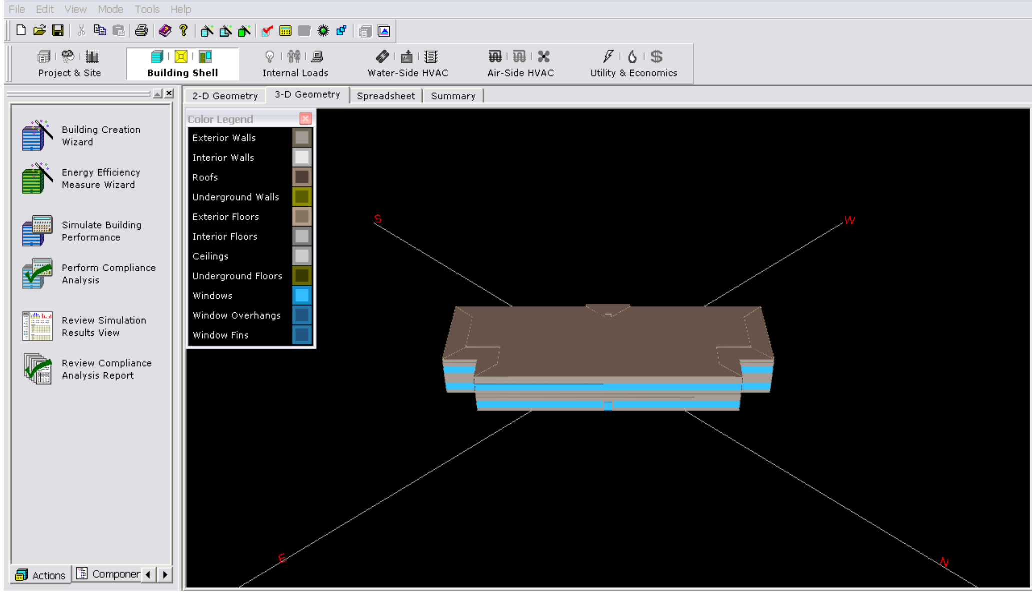


Figure 5-1: Brookside Building Set-up Using eQUEST

5.3 Case 2: Southfield Office Building

Southfield is a new office building in Southeast Michigan in the U.S. Its construction ended in 2009. The targeted use of the building is mainly medical offices. The building has 29,000 sq ft (2690 m^2) of gross floor area, and a volume of 423,000 cu ft (11978 m^3). The building consists of 3 floors (9700 sq ft each, 14.6 ft average height) plus a partial basement. The structural frame is broad flange (W sections) columns and W sections beams. Floors are metal decking with 2" concrete topping. The exterior walls are brick veneer with steel studs backing. Interior walls are galvanized steel studs with gypsum board facing to receive paints or wall paper. Foundations are cast-in-place concrete. The annual energy consumption is calculated using eQUEST 3.64 (2010). The estimated natural gas consumption (mainly for water heating) of the building is 45.97 MBtu (1585 Btu/sq ft/year) and this is equivalent to 0.46 kWh/sq ft/year. The estimated electricity consumption is 412,860 kWh/year (14.2 kWh/sq ft/year) (appendix C-2). Figure 5-2 shows the modeling set-up for Southfield office building using eQUEST.

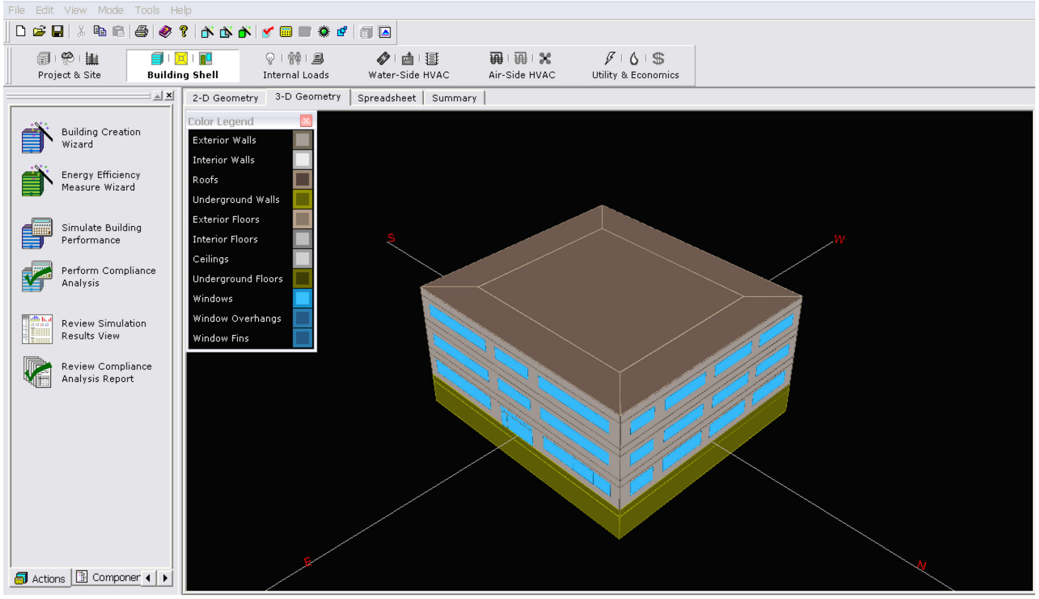


Figure 5-2: Southfield Building Set-up Using eQUEST

5.4 Case 3: Huron Office Building

Huron is a new office building in Southeast Michigan in the U.S. Its construction ended in 2008. The targeted use of the building is mainly medical offices. The building has 21,290 sq ft (1978 m^2) of gross floor area, and a volume of 351,285 cu ft (9947 m^3). The building consists of 1 main floor (16.5 ft high) with no basement. The structural frame is Hollow Structural Steel HSS columns and open web steel joist for roof support. Floors are light reinforced concrete of 1 floor. The exterior walls are brick veneer with steel studs backing. Interior walls are galvanized steel studs with gypsum board facing to receive paints or wall paper. Foundations are cast-in-place concrete. The annual energy consumption is calculated using equest 3.64 (2010). The estimated natural gas consumption (mainly for water heating) of the building is 34.42 Mbtu (1616 Btu/sq ft/year) and this is equivalent to 0.47 kWh/sq ft/year. The estimated electricity consumption is 183,870 kWh/year (8.6 kWh/sq ft/year) (appendix C-3). One important factor for Huron office building is that it is a LEED certified building and that might interprets its slightly lower use of electricity because it uses geothermal ground loops in heating and cooling. Figure 5-3 shows the modeling set-up for Huron office building using eQUEST.

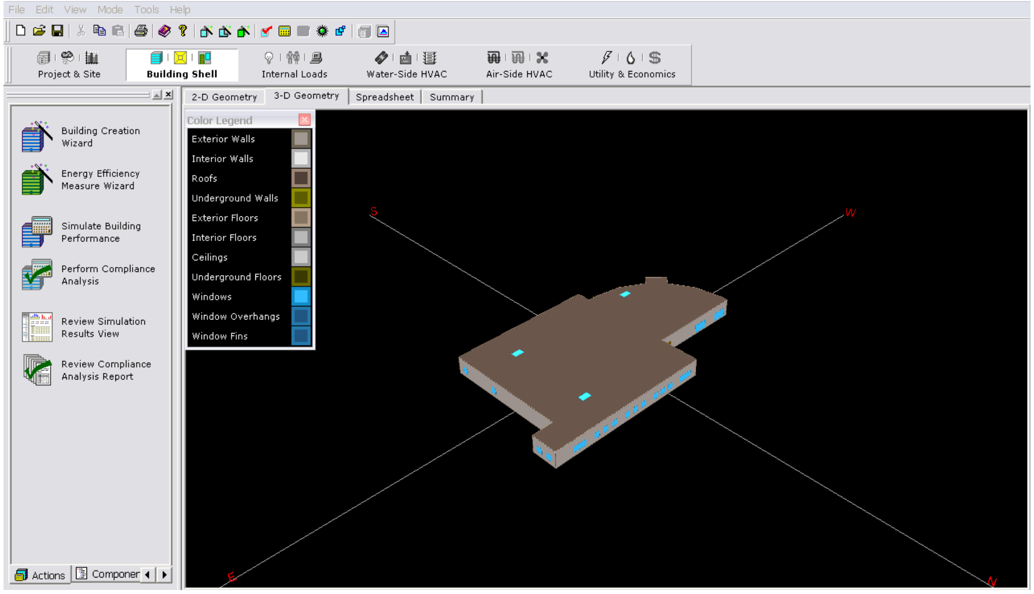


Figure 5-3: Huron Building Set-up Using eQUEST

Table 5.1: Comparison of Buildings Characteristics

	Brookside	**Southfield**	**Huron**
Floors area (sq ft)	40,000	29000	21,290
Number of floors	2	3 + partial basement	1
Electricity Consumption (kWh/year)	425,000	412,860	183,870
Consumption / sq ft/ year	10.6 kWh	14.2 kWh	8.6 kWh
1st floor height (ft)	14’ 8”	18’	Varies mostly 16’ -18’ entrance are (curtain wall)
Floor-to-floor height (ft)	14’ 8”	12’	16’
Foundations	Cast in place concrete	Cast in place concrete	Cast in place concrete
Structure: columns	Hollow Structure Steel HSS	Steel W-sections	Hollow Structure Steel HSS
Structure: Beams	Steel W-sections	Steel W-sections	Open-web joists-roof
Structure: Roof	Open-web steel joists	Open-web steel joists	Open-web steel joists
Structure: floor	2.5 “concrete plank over corrugated steel deck	2.5 “concrete plank over corrugated steel deck	Slab on grade for the first floor
Exterior skin	Brick veneer in front of 1.5” air barrier, densdeck sheathing, 6” cold-formed metal framing	Brick veneer in front of 1.5” air barrier, gyp board sheathing, 6” cold-formed metal framing	Brick veneer, stone accents in front of 2” air barrier, rigid insul. w/ CMU backing. Curtain wall in the entrance
Window-wall ratio	1 : 2.3	1 : 3.2	1 : 3.5
Glazing	1” dual pane glass w/ thermally broken aluminum frame	1” dual pane glass w/ thermally broken aluminum frame	high perf 1” tinted insulated glass with low-e coating and high reflectance in anodized aluminum framing
Insulation: exterior walls	6” fiberglass batt insulation w/ R-19	6” fiberglass batt insulation w/ R-19	6” fiberglass batt insulation w/ R-19
Insulation in cavity if any	-	-	2” air space, 2” rigid isocyanurate insulation w/ R-12
Insulation : roof	fully-adhered black EPDM over 3.25” rigid extruded polystyrene insulation w/ R-22	fully-adhered black EPDM over 3” rigid isocyanurate insulation w/ R-22	fully-adhered black EPDM over 4.75” rigid isocyanurate insulation w/ R-29
HVAC heating	Hot water	Hot water	Geo-thermal system w/ 20 wells. 16 heat pumps distribute conditioned air to the interior. System utilizes a central duplex pumping system.
HVAC cooling	Chilled water	Chilled water	Geo-thermal system w/ 20 wells. 16 heat pumps distribute conditioned air to the interior. System utilizes a central duplex pumping system.
HVAC equipment	2 AHUs with VAV boxes and reheat coil for zone heating/cooling	2 gas/electric package variable volume (VAV) rooftop units with electric supplemental heat for perimeter areas	Central duplex pumping sys w/ 16 heat pumps distribute conditioned air to the interior
Shading devices	-	Metal structure roof shed 8’ protrusion-roof only	-

5.5 Data Quality Assessment

Assessment of the quality of data used in the analysis is very important in LCA interpretation as higher quality lends more credibility to the results, increases the robustness of the findings, and gives more confidence to the LCA practitioner to draw correct conclusions and eventually make defensible decisions using the results.

Lindfors et al.(1995) and Weidema and Wesnæs (1996) developed a comprehensive matrix to assess data quality. They consider six aspects of data collection: 1) acquisition method; 2) independence of data supplier reliability; 3) completeness; 4) temporal correlation; 5) geographical correlation; and 6) technological correlation. These six aspects are ranked on a scale of 1 to 5, in which 1 represents the top quality data and 5 represents the lowest quality data (Table 5.1). In other literature these 6 aspects are also called Data Quality Indicators (DQIs).

Acquisition and *Independence of Data Supplier* represents the *Reliability* of the data and assesses the data sources, acquisition and verification methods. According to their assessment, the most reliable data have to be directly measured and verified. Verification can happen in different ways (e.g., on-site checking, by recalculation, through mass balances, or cross-checks with other sources).

The *Completeness* or Representativeness indicator assesses the statistical properties of the data and how representative they are of the processes being assessed. The most complete set of data should include sample data from a sufficient number of sites over an adequate period of time.

Temporal correlation or *Data Age* assesses the time correlation between the year of data collection and the year of assessment. This indicator allows considering for such aspects as technological change. Data collected within three years of the year of the study is considered top quality data.

Geographical correlation assesses the relationship between the geographical area of which data were collected and the area of the study. Understandably, the best data for this indicator have to come from the same geographic area under study.

Finally, the *technological* correlation indicator assesses all other aspects of technological correlation that are not covered by the temporal or geographical correlation indicators. This includes enterprise-, process-, or materials-specific aspects of the data. For example, one might choose more material-specific data over data with very good temporal correlation but weak representatives of the material being assessed.

Table 5-2: Pedigree Matrix Used for Data Quality Assessment [Based on Lindfors et al.(1995), and Weidema and Wesnæs (1996)]

	Indicator Score				
Item	**1**	**2**	**3**	**4**	**5**
Acquisition Method	Measured data	Calculated data based on measurements	Calculated data partly based on assumptions	Qualified estimate (by industrial expert)	Nonqualified estimate
Independence of data supplier (Reliability)	Verified data from public or other independent source	Verified information from enterprise with interest in the study	Independent source, but based on non-verified information from industry	Non-verified information from industry	Non-verified information from the enterprise interested in the study
Representativeness of sample (Completeness)	Representative data from sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from smaller number of sites but for adequate periods	Representative data from adequate number of sites, but from shorter periods	Data from adequate number of sites, but shorter periods	Representativeness unknown or incomplete data from smaller number of sites and/or from shorter periods
Temporal Correlation (Data age)	Less than 3 years of difference to year of study	Less than 5 years of difference	Less than 10 years of difference	Less than 20 years of difference	Age unknown or more than 20 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very Different production conditions
Technological Correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study, but from different enterprises	Data from processes and materials under study, but from different enterprises	Data on related processes or materials, but same technology	Data on related processes or materials, but different technology

The data used in this study were targeted at the level of *good* or better, which corresponds to number 2 in the used data quality assessment framework (Table 5-1). In practice this means that data have at least the following qualities: 1) are calculated data based on measurements; 2) verified information from an enterprise that might have an interest in the study; 3) representative data from smaller number of sites but for adequate periods; 4) less than 5 years old; 5) average data from a larger area in which the area under study is included; and from processes and materials under study but maybe from different enterprises.

5.6 Data Quality Results

The data quality results of the life-cycle inventory for the 3 buildings are presented in Table 5-3. The qualitative estimation framework (Weidema & Wesnæs 1996, Lindfors et al. 1995) started by giving data quality scores for every unit process included in the study. The scores were then aggregated to life-cycle elements and finally to the lifecycle phase level. The data quality scores in the table have been rounded to the nearest whole number.

As can be seen from the table, the data quality scores are "as targeted", two or better, with most of the used indicators. As life-cycle phases contributing the most (building materials, operation energy, and maintenance) attained a score of two or better, the overall quality of the data used can be considered very good. This supports the reliability of findings presented in the result section.

The quality of the data is borderline (score of 3 instead of 1 or 2) than targeted in the demolition phases because this phase has some uncertainties even within the ATHENA modeling program due to the lack of data during this phase. But since it only

Table 5-3: Data Quality Results for 3 Case Studies

Life Cycle Phases	Acquisition method			(Reliability) Independence of data supplier			Completeness			Data Age			Geographical correlation			Technological correlation		
	B	S	H	B	S	H	B	S	H	B	S	H	B	S	H	B	S	H
Manufacturing Materials	2	2	2	1	1	1	2	2	2	1	1	1	1	1	1	2	2	2
Construction	2	2	2	1	1	1	2	2	2	2	1	1	2	2	2	2	2	2
Operation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Maintenance	1	2	2	1	1	1	2	2	2	1	1	2	2	2	2	2	2	2
End of Life	3	3	3	2	2	2	2	2	2	1	1	1	2	2	2	3	3	3

* Maximum quality = 1
* Minimum quality = 5

B = Brookside
S = Southfield
H = Huron

have a negligible contribution to the total impacts; this should not cause significant uncertainty in the results. The data quality differs slightly throughout the cases, which should further support the findings presented in the results chapter.

5.7 Sensitivity Analysis

Sensitivity analysis is a quantitative method to assess the impact of data uncertainty in any LCA study. The key purpose of sensitivity analysis is to identify and focus on key data and assumptions that have most influence on a result. It can be used to simplify data collection and analysis without compromising the robustness of a result or to identify crucial data that must be thoroughly investigated. The type of the sensitivity in this study is the *scenario* analysis which refers to the different choices of input parameters and outside conditions of any system under study (Pesonin et al., 2000). Pesonin et al. (2000) identify two types of scenario development for LCA studies; *What-if* and *Cornerstone* scenarios. The *What-if* scenarios are used to compare different alternatives in a well-known situation where the researcher is familiar with the decision problem and can set defined hypothesis on the basis of existing data (the case here in this study). The *Cornerstone* scenario approach offers strategic information for long term planning, new ways of seeing the world, and also guidelines in the field of study. Results of a study using the Cornerstone scenario approach often serve as a basis for further, more specific research. According to the previous definitions, the What-if approach is used here to test specific changes in materials within the building assembly systems

CHAPTER 6

RESEARCH RESULTS AND INTERPRETATIONS

6.1 Normalization of Results

Since the 3 case studies are of different floor areas, the normalization of results is a must to ensure the validity of the comparison among cases. There are two possible normalization units here to normalize the results. These are: m^2 of the building floor area versus m^3 of the building volume. Before discussing in details why a specific normalization factor was selected, it should be mentioned that, although the selection of a normalization factor (m^2 vs. m^3) *does* affect the results in *absolute values* (total environmental impacts of each building), it *does not* affect the results in *relative values* (environmental impacts contribution to the building life cycle phases and assembly systems) which is the main focus of this study.

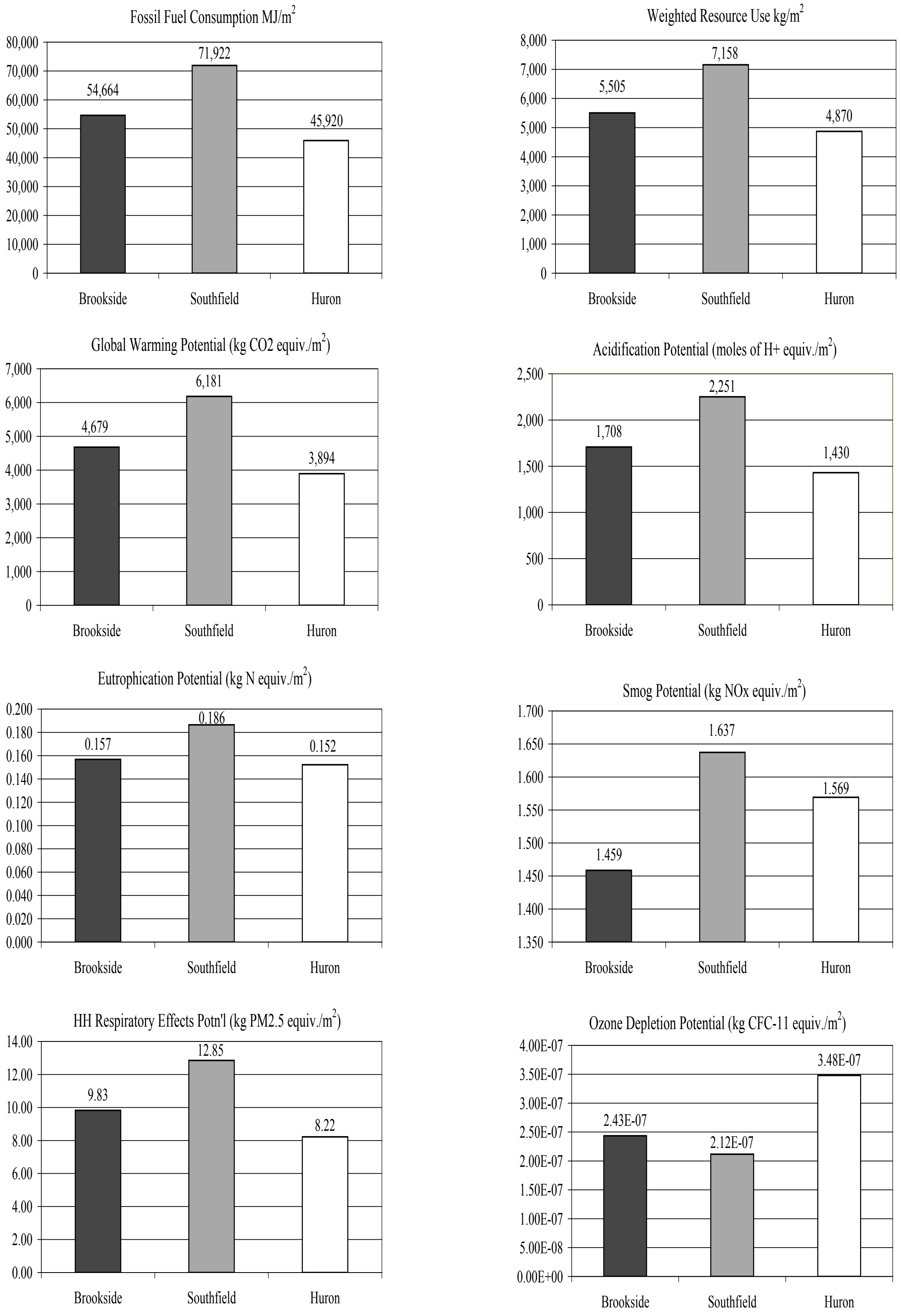
For comparison purposes, the results have been normalized per square meter (m^2) of floor area of the 3 buildings. Although the database used in the study (ATHENA) allows some inputs in imperial units, the results of impact assessment, which is more important to the study findings, are presented in metric units. For this reason and for consistency purposes the square meter (m^2) is used as normalization factor instead of the square foot (ft^2). Another normalization factor could have been used is the volume unit of the building in cubic meter (m^3). The specific factor between the two measures is the height of the office spaces which will influence the quantities of materials in columns and walls. Since the height in Huron case is 16.2 ft which is the highest among others (15 ft for Brookside and 14.5 ft average for Southfield), the results of this case per m^2 would render between 5-10% higher than they would have been if calculations are done in m^3.

6.2 Environmental Impact Absolute Values of the Cases

The results of impact assessment of the 3 office buildings are shown in Fig. 6-1. The results show that there are differences between the buildings impacts. Southfield (case 2) has the highest impacts in almost all categories per unit area (m^2) although its floor area (2690 m^2) falls between Brookside (3716 m^2) and Huron (1978 m^2). Huron (case 3) has the lowest impact values in all categories. The values of the impacts of Huron are around 15% less in values than Brookside (case 1) with some exception of Brookside being less than Huron only in the smog potential (or POCP) by 7% (fig. 6-1).

It's important to mention that Huron is a LEED certified building (achieved 26 – 32 points according to LEED NC 2.2 rating of 2005). By looking at the nature of the life cycle phases where operation phase has the most impacts on the whole life cycle, Huron case saves significant energy during that phase due to the use of geothermal (earth energy) loop system in its HVAC systems both for heating and cooling (eQuest results, Appendix C-3). Impact absolute values would have been close if not more than Brookside if Huron uses the traditional HVAC system which includes boilers and chiller as main components of its HVAC system. This is because Huron case has more roof insulation than the other two buildings (4.75" vs. 3"). This also interprets the smog potential results of Huron comes second to Southfield because of the extensive release of Nitrogen Oxides (NOx) and VOCs during manufacturing of insulation.

Since the 3 buildings are of typical steel construction, one conclusion on why Southfield case has the highest impacts absolute values could be the extra partial basement over the other two cases (no basement). Number of floors (3 vs. 2 and 1) is another factor to affect the results because structure has to be designed to support more floors which results in heavier columns and beams. This is supported by the Resources Use Impact results (Fig. 6-1) where the unit area uses more materials in Southfield. The use of steel W-sections (wide-flange beams and columns) as the structure system vs. HSS sections (Hollow Structural Steel) in columns for the other two cases is also a contributor to other impacts since W-sections have significant embodied energy than the HSS sections. A detailed environmental profile for each case in the 8 impact categories is shown in Table 6-1.



Fossil Fuel Consumption MJ/m^2

Weighted Resource Use kg/m^2

Global Warming Potential (kg CO2 equiv./m^2)

Acidification Potential (moles of H+ equiv./m^2)

Eutrophication Potential (kg N equiv./m^2)

Smog Potential (kg NOx equiv./m^2)

HH Respiratory Effects Potn'l (kg PM2.5 equiv./m^2)

Ozone Depletion Potential (kg CFC-11 equiv./m^2)

Figure 6-1: Environmental Impacts Absolute Values for 3 Buildings

Table 6-1: Environmental Profile – Brookside case

	Manufacturing				**Construction**				**Maintenance**				**End - Of - Life**				**Oper Energy**			**Total**	**/m2**
	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Annual	**Total**	**/m2**		
Fossil Fuel MJ	9E+06	2E+05	**9E+06**	**2493**	97938	2E+05	**3E+05**	**93.2**	2E+06	45598	**2E+06**	**585.3**	1E+05	69430	**2E+05**	**57.89**	3E+06	**2E+08**	**51434**	**2E+08**	**54664**
Resources kg	3E+06	4619	**3E+06**	**728.3**	2325	5853	**8177**	**2.201**	1E+05	1080	**1E+05**	**38.31**	3431	1636	**5067**	**1.364**	3E+05	**2E+07**	**4734**	**2E+07**	**5505**
GWP kg CO2 eq	7E+05	13084	**7E+05**	**185.2**	6500	18590	**25091**	**6.752**	1E+05	3382	**1E+05**	**34.9**	9499	5197	**14696**	**3.955**	3E+05	**2E+07**	**4448**	**2E+07**	**4679**
AP moles H+ eq	3E+05	4473	**3E+05**	**73.39**	3334	5864	**9198**	**2.475**	86676	1079	**87755**	**23.62**	526.6	1639	**2166**	**0.583**	99605	**6E+06**	**1608**	**6E+06**	**1708**
Resp kg PM2.5	1904	5.393	**1909**	**0.514**	3.706	7.048	**10.75**	**0.003**	1157	1.297	**1159**	**0.312**	0.501	1.97	**2.471**	**7E-04**	557.4	**33445**	**9**	**36526**	**9.829**
EP kg N eq	380.3	4.657	**384.9**	**0.104**	3.151	6.075	**9.226**	**0.002**	31.06	1.119	**32.18**	**0.009**	0.362	1.549	**1.91**	**5E-04**	2.574	**154.4**	**0.042**	**582.7**	**0.157**
ODP kg CFC-11	8E-04	5E-07	**8E-04**	**2E-07**	2E-11	8E-07	**8E-07**	**2E-10**	1E-04	1E-07	**1E-04**	**3E-08**	4E-07	2E-07	**6E-07**	**2E-10**	7E-08	**4E-06**	**1E-09**	**9E-04**	**2E-07**
Smog kg NOx eq	1729	100.9	**1830**	**0.492**	79	130.9	**209.9**	**0.056**	546.1	24.11	**570.2**	**0.153**	6.767	36.59	**43.35**	**0.012**	46.12	**2767**	**0.745**	**5420**	**1.459**

Table 6-2: Environmental Profile – Southfield case

	Manufacturing				**Construction**				**Maintenance**				**End - Of - Life**				**Oper Energy**			**Total**	**/m2**
	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Annual	**Total**	**/m2**		
Fossil Fuel MJ	7E+06	1E+05	**7E+06**	**2683.6**	59331	2E+05	**3E+05**	**99.2**	1E+06	27149	**1E+06**	**456.7**	1E+05	57096	**2E+05**	**65.85**	3E+06	**2E+08**	**68456**	**2E+08**	**71922**
Resources kg	2E+06	3514	**2E+06**	**763.48**	1458	4889	**6347**	**2.36**	86025	643.2	**86668**	**32.22**	2827	1345	**4172**	**1.551**	3E+05	**2E+07**	**6343**	**2E+07**	**7158**
GWP kg CO2 eq	5E+05	9922	**5E+05**	**189.26**	3991	15524	**19514**	**7.254**	76526	2012	**78538**	**29.2**	7826	4274	**12100**	**4.498**	3E+05	**2E+07**	**5937**	**2E+07**	**6181**
AP moles H+ eq	2E+05	3400	**2E+05**	**76.35**	2109	4899	**7008**	**2.605**	57280	642.4	**57922**	**21.53**	433.9	1348	**1782**	**0.662**	96163	**6E+06**	**2145**	**6E+06**	**2251**
Resp kg PM2.5eq	1407	4.1	**1411**	**0.5247**	2.431	5.887	**8.318**	**0.003**	746.5	0.772	**747.3**	**0.278**	0.413	1.62	**2.033**	**8E-04**	538.7	**32320**	**12.01**	**34489**	**12.85**
EP kg N eq	321.7	3.541	**325.2**	**0.1209**	1.964	5.075	**7.039**	**0.003**	19.1	0.666	**19.77**	**0.007**	0.298	1.274	**1.571**	**6E-04**	2.447	**146.8**	**0.055**	**500.4**	**0.186**
ODP kg CFC-11	5E-04	4E-07	**5E-04**	**2E-07**	3E-11	6E-07	**6E-07**	**2E-10**	7E-05	8E-08	**7E-05**	**3E-08**	4E-07	2E-07	**5E-07**	**2E-10**	7E-08	**4E-06**	**2E-09**	**6E-04**	**2E-07**
Smog kg NOx eq	1097	76.69	**1174**	**0.4362**	49.21	109.3	**158.6**	**0.059**	351.8	14.36	**366.15**	**0.136**	5.575	30.09	**35.66**	**0.013**	44.34	**2660**	**0.989**	**4394**	**1.637**

Table 6-3: Environmental Profile – Huron case

	Manufacturing				**Construction**				**Maintenance**				**End - Of - Life**				**Oper Energy**			**Total**	**/m2**
	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Matr'l	Transp	**Total**	**/m2**	Annual	**Total**	**/m2**		
Fossil Fuel MJ	5E+06	1E+05	**6E+06**	**2824**	86521	2E+05	**3E+05**	**130**	2E+06	23120	**2E+06**	**939**	92194	52735	**1E+05**	**73.27**	1E+06	**8E+07**	**41953**	**9E+07**	**45920**
Resources kg	2E+06	2962	**2E+06**	**968**	2029	4019	**6047**	**3.057**	90369	549.4	**90918**	**45.96**	2171	1243	**3414**	**1.726**	1E+05	**8E+06**	**3851**	**1E+07**	**4870**
GWP kg CO2 eq	4E+05	8482	**4E+05**	**214.8**	5818	12765	**18583**	**9.395**	80199	1709	**81907**	**41.41**	6011	3948	**9959**	**5.035**	1E+05	**7E+06**	**3624**	**8E+06**	**3894**
AP moles H+ eq	2E+05	2878	**2E+05**	**88.55**	2990	4027	**7016**	**3.547**	52054	547.9	**52601**	**26.59**	333.3	1245	**1578**	**0.798**	43208	**3E+06**	**1311**	**3E+06**	**1430**
Resp kg PM2.5	1193	3.469	**1197**	**0.605**	3.238	4.839	**8.077**	**0.004**	556.1	0.659	**556.8**	**0.281**	0.317	1.496	**1.814**	**9E-04**	241.7	**14502**	**7.332**	**16266**	**8.223**
EP kg N eq	201.8	2.995	**204.8**	**0.104**	2.806	4.171	**6.977**	**0.004**	19.86	0.568	**20.43**	**0.01**	0.229	1.176	**1.405**	**7E-04**	1.124	**67.43**	**0.034**	**301.1**	**0.152**
ODP kg CFC-11	6E-04	3E-07	**6E-04**	**3E-07**	8E-12	5E-07	**5E-07**	**3E-10**	9E-05	7E-08	**9E-05**	**4E-08**	3E-07	2E-07	**4E-07**	**2E-10**	3E-08	**2E-06**	**1E-09**	**7E-04**	**3E-07**
Smog kg NOx eq	1333	64.84	**1398**	**0.707**	71.31	89.87	**161.2**	**0.081**	297.5	12.25	**309.7**	**0.157**	4.282	27.79	**32.07**	**0.016**	20.04	**1203**	**0.608**	**3104**	**1.569**

6.3 Environmental Impacts Contribution to Life Cycle Phases

The overall environmental impact contribution to the life cycle phases of the 3 cases is shown in figure 6-2. However, very detailed results could be obtained for the appendices (A-1, B-1, C1).

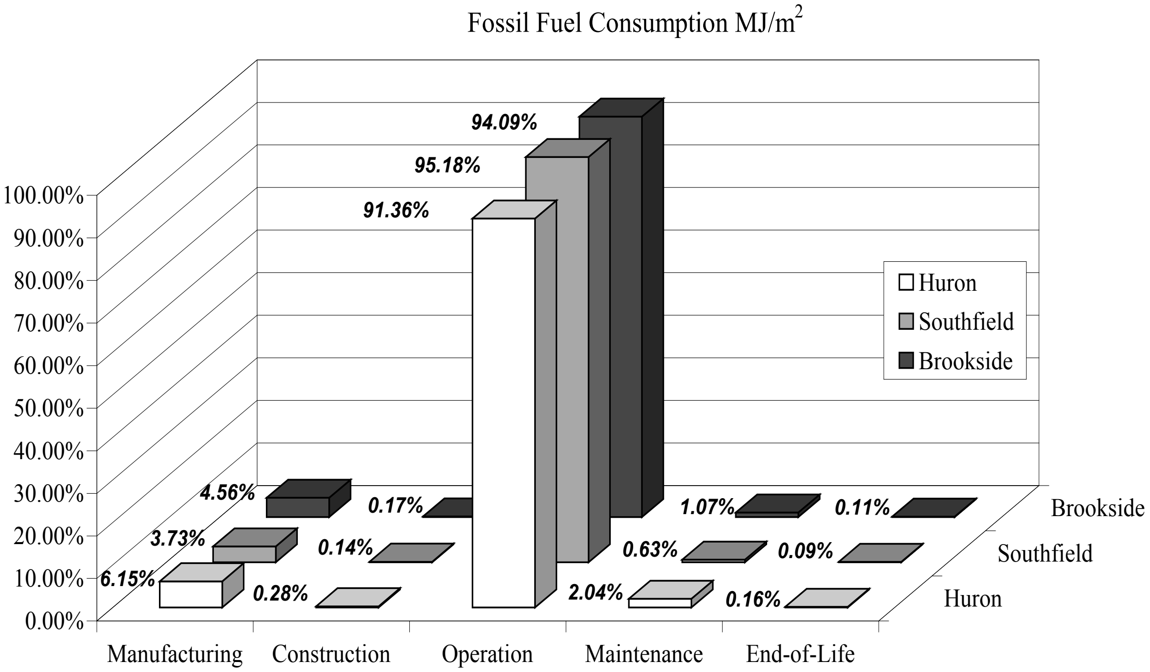
Transportation impact in every phase is considered for more accurate results to this study. Interestingly, results show that the transportation contributes 80% and 70% of the Global Warming Potential (GWP) and Acidification Potential (AP) respectively to the total life cycle impact during construction phase. At the end-of-life phase, this ratio represents 43% of GWP and 80% of the AP (Tables 6-1, 6-2, 6-3). In fact, the highest impact of transportation with higher ratios to the total phase impact is concentrated during these two phases; *construction* and *end-of-life*. This supports the argument of using local materials in building construction.

Although the 3 cases are different in floor areas and some architectural features, the contribution of each life cycle to the total impacts seems to follow a similar pattern. The following percentages represent an *average* of the 3 cases.

- The operation (use) phase in all buildings dominates the environmental impacts in all impact categories except in Eutrophication Potential (EP) and Ozone Depletion Potential (ODP) which are dominated by the manufacturing phase.
- Operation phase's share of impacts averages 93% in fuel consumption, 84% in resources use (WRU), 95% in GWP, 93% in AP, and 91% in respiratory effects potential (Fig. 6-2). These results are mostly associated with the energy consumed in this phase which results in massive air emissions such as CO_2 (main cause of GWP), SO_2 and NOx (main cause to AP), and effects of particulates ($PM_{2.5}$) on the human respiratory system.
- Manufacturing phase has the highest impact in the ozone depletion at 87%, and in eutrophication at 65%. These results are mainly due to the release of CFCs and Halon (main cause of ODP) to air specifically in this phase. Also, these results demonstrate that this phase has the highest releases of water pollutants such as

COD, BOD, heavy metals, nitrogen and phosphorous compounds (main cause of EP) during manufacturing processes of different building materials.

- The operation and manufacturing phases are somewhat balanced in the smog potential (POCP) impact category. Operation phase contributes to 49% of this impact and manufacturing contributes to 35%. The results reflect the influence on Nitrogen releases, whether to air or to water, in these two categories.
- It is also noteworthy to mention that besides these 2 impact-dominant phases (operation and manufacturing), the *maintenance* phase comes third to dominate the whole impacts especially in ODP (12%), smog (10%), and eutrophication (6%). This is due to the materials replacement, renovations, and retrofit during the building life cycle.



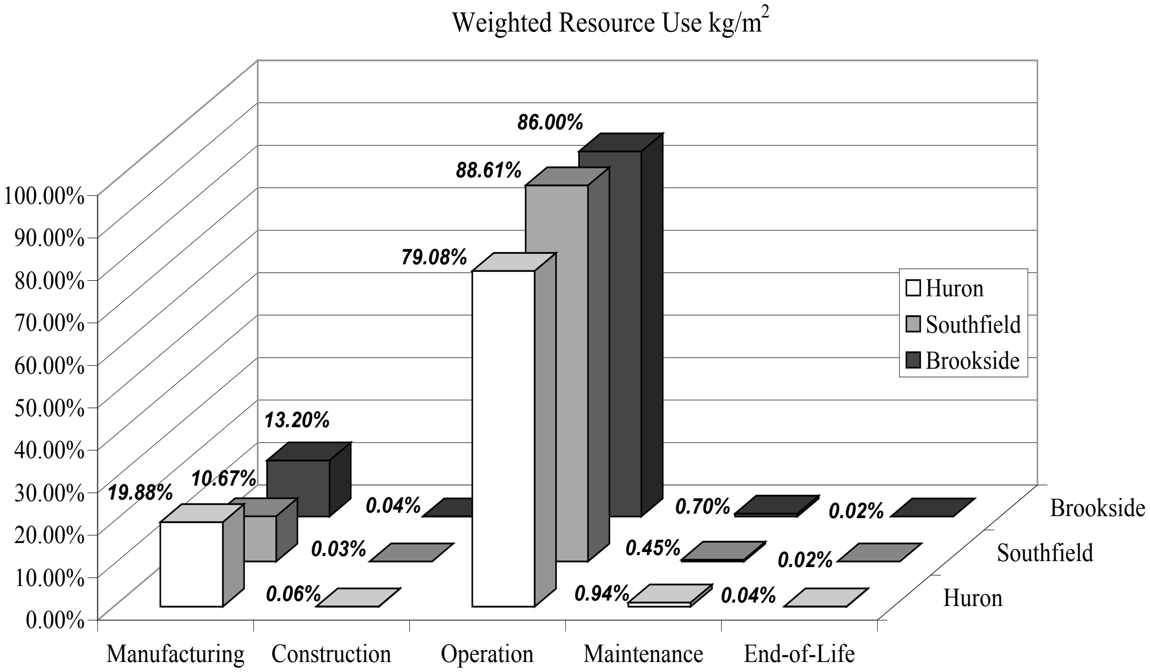
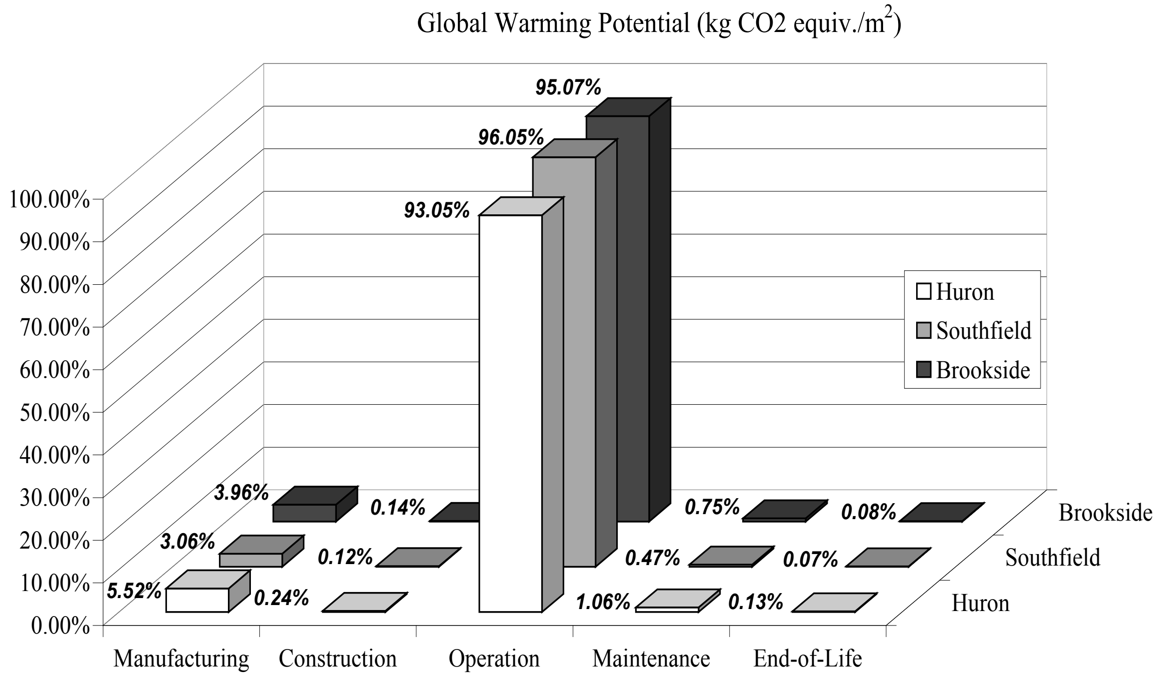


Figure 6-2: Contribution to Each Environmental Impact by Life Cycle Stage



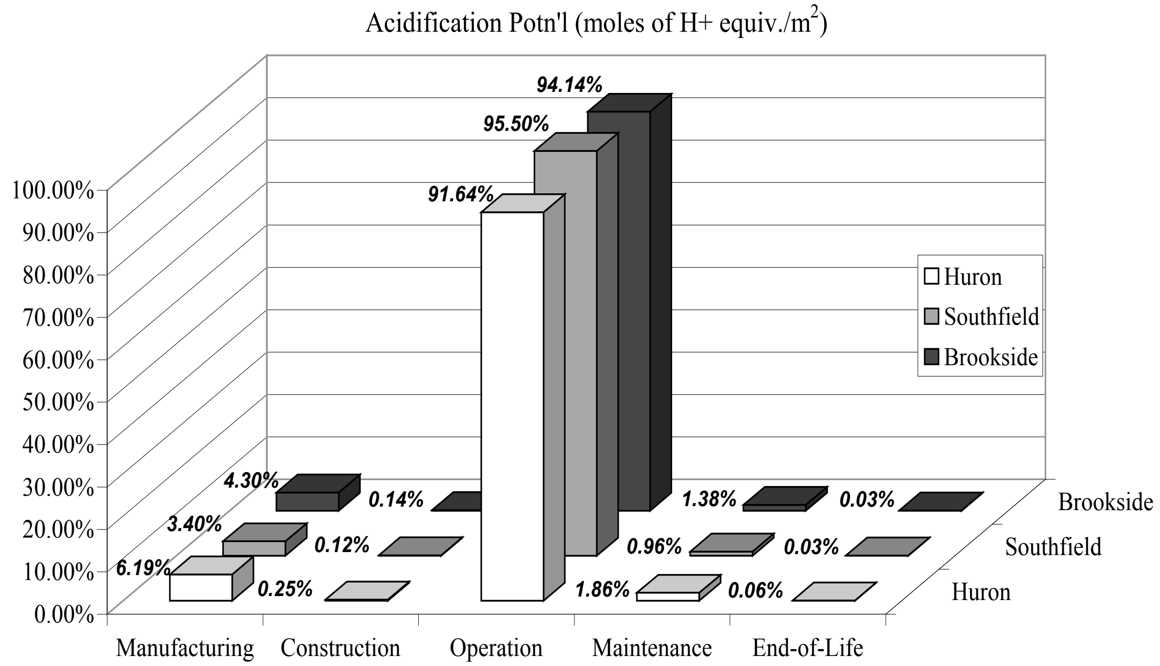
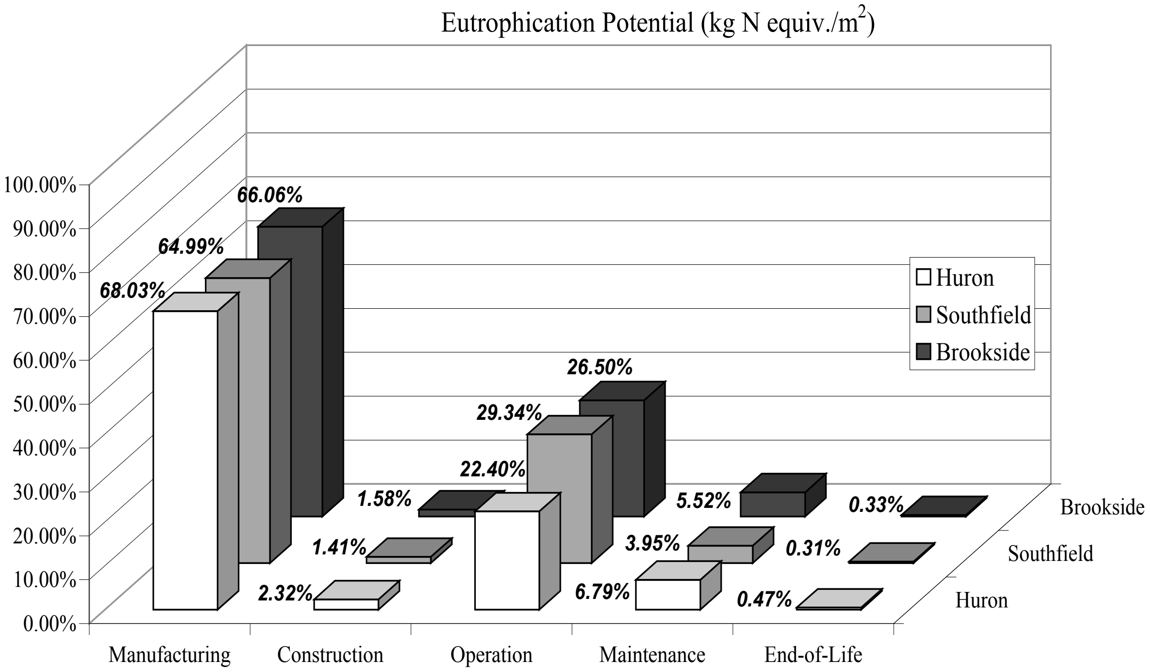


Figure 6-2: Contribution to Each Environmental Impact by Life Cycle Stage- Continued



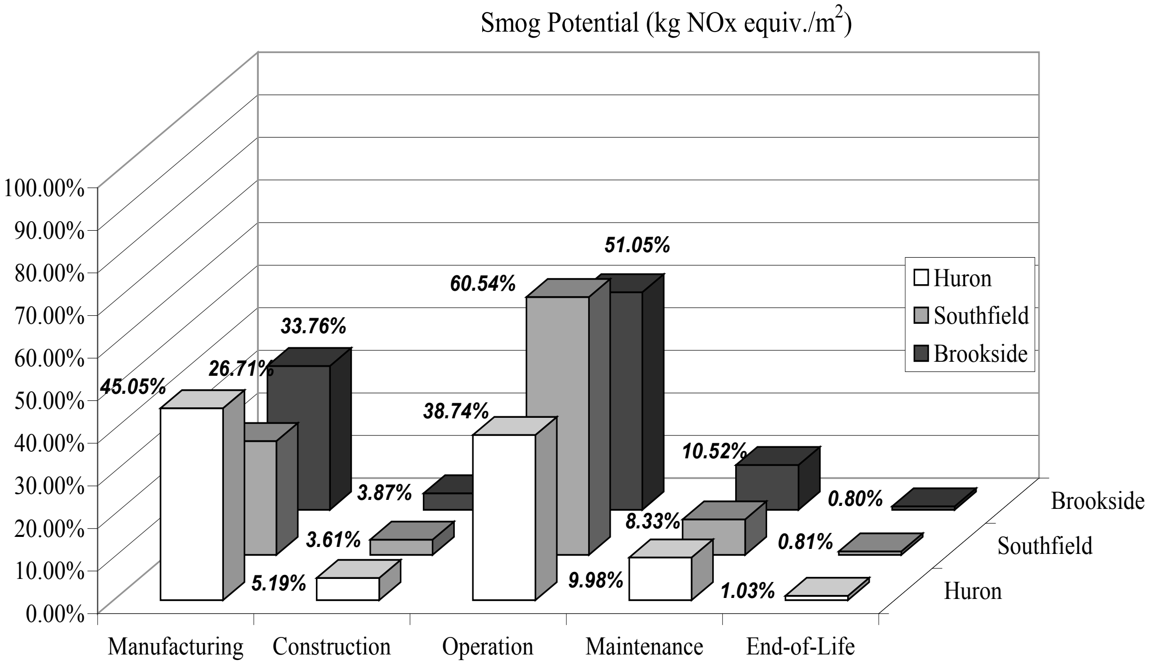
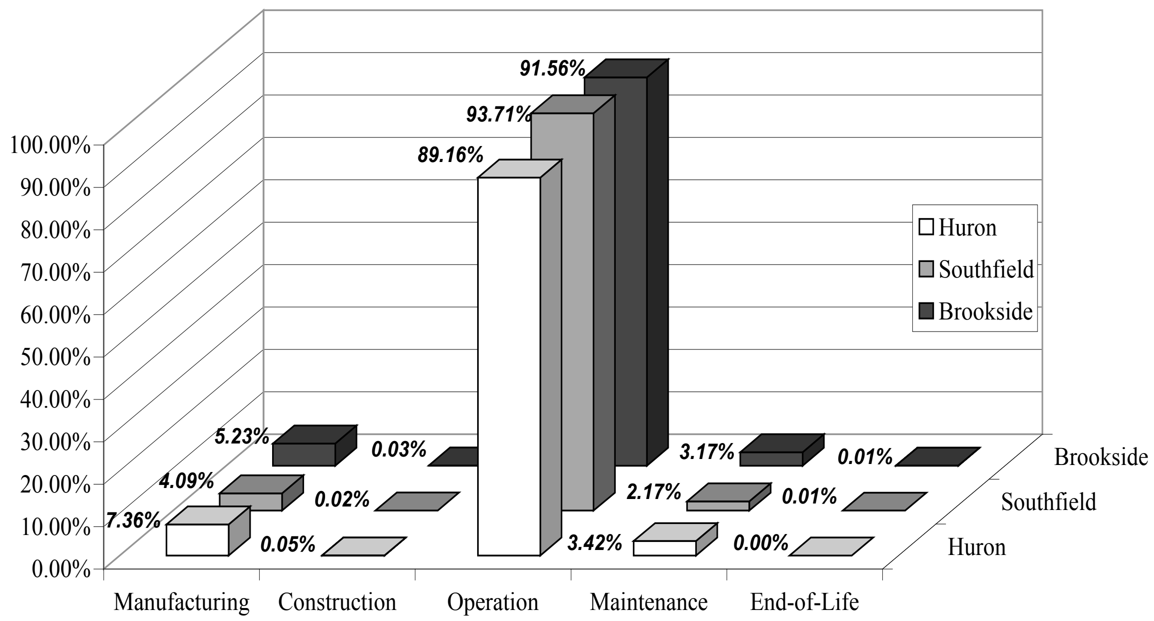
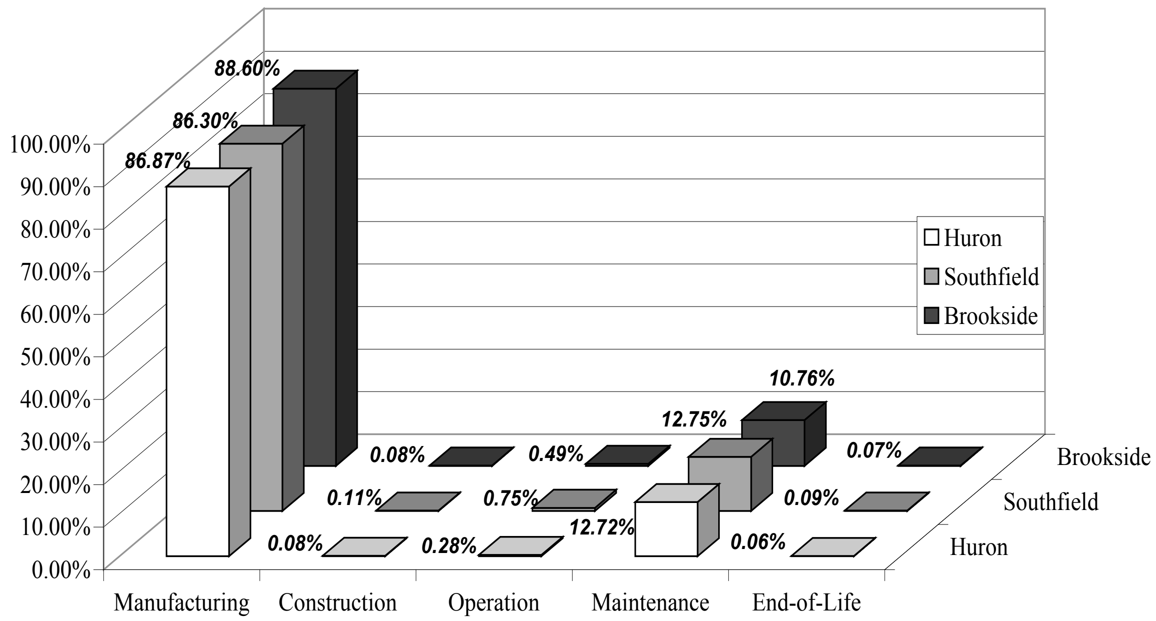


Figure 6-2: Contribution to Each Environmental Impact by Life Cycle Stage- Continued



HH Respiratory Effects Potn'l (kg PM2.5 equiv./m^2)



Ozone Depletion Potential (kg CFC-11 equiv./m^2)

Figure 6-2: Contribution to Each Environmental Impact by Life Cycle Stage- Continued

6.4 Environmental Impacts Contribution to Assembly Systems

It is important to mention here that in architectural practice, the design of the building systems has different order than the chronological order of its life cycle phases in this study. The design of the building assembly systems (foundations, structure, walls, floors, and roofs) usually takes place during the design process where determination of these systems is identified.

The overall environmental impact contribution to building assembly systems (foundations, structure, walls, floors, roof) of the 3 case studies are presented in (Figure 6-3). Although the 3 buildings have different architectural features (mainly number of floors, floor height, windows to wall ratios, and slight difference in insulation R-values, Table 5-1), the contribution of each assembly system to the total impacts seems to follow a similar pattern. The following percentages represent an *average* of the 3 cases:

- *Walls* system in all buildings dominates the environmental impacts in global warming (26%), acidification (40%), smog potential (35%), and respiratory effect potential (57%) categories. A major factor of these impacts attributed to the use of insulation materials which cover large areas of building facades. Other factor is the embodied energy of metals such as steel and anodized aluminum in windows and curtain walls.
- *Structure (beams and columns)* system of the buildings dominates the impacts in fossil fuel consumption (31%), eutrophication (56%) categories. These results attributed to the massive embodied energy of steel sections and the associated water emissions during manufacturing processes.
- *Roofs* system in all cases has also significant impacts (second to beams and columns) in fossil fuel consumption (27%), in global warming GWP (17%), and comes second to walls in smog potential (29%). A major factor of these impacts attributed to the manufacturing of roof insulation materials and to some extent the roof membrane (black EPDM rubber).
- *Foundations* system dominates the cause of ozone depletion at (58%). This high ratio associated with the release of CFCs during manufacturing of paint and

cement. Since foundation is the heaviest system among others, it also dominates the Resources Use (RU) at (40%) (Fig. 6-3).

It is also important to mention that the *roof* system of Huron building has highest potential impacts among other roof systems, while Southfield has the lowest roof impacts. Albeit a LEED certified, the impact of Huron roof is due to the use of thicker insulation layers which interprets the energy saving it has. It uses 1.5 times the insulation used in other buildings. Another note that slightly affect the results is that Huron has one-floor plan where the ratio of *roof area/floor area* in m^2 is equal to 1 (the roof cover the whole area of the building). On the other hand, Southfield building has 3 floors where the ratio of *roof area/floor area* in m^2 is $1/3^{rd}$. (the roof cover one third of the whole area of the building). In conclusion to this important point, roof has significant impacts as an assembly system and a minor change in its material flow with more environmental friendly alternatives (especially insulation as the case in sensitivity analysis) would render significant reduction of those impacts.

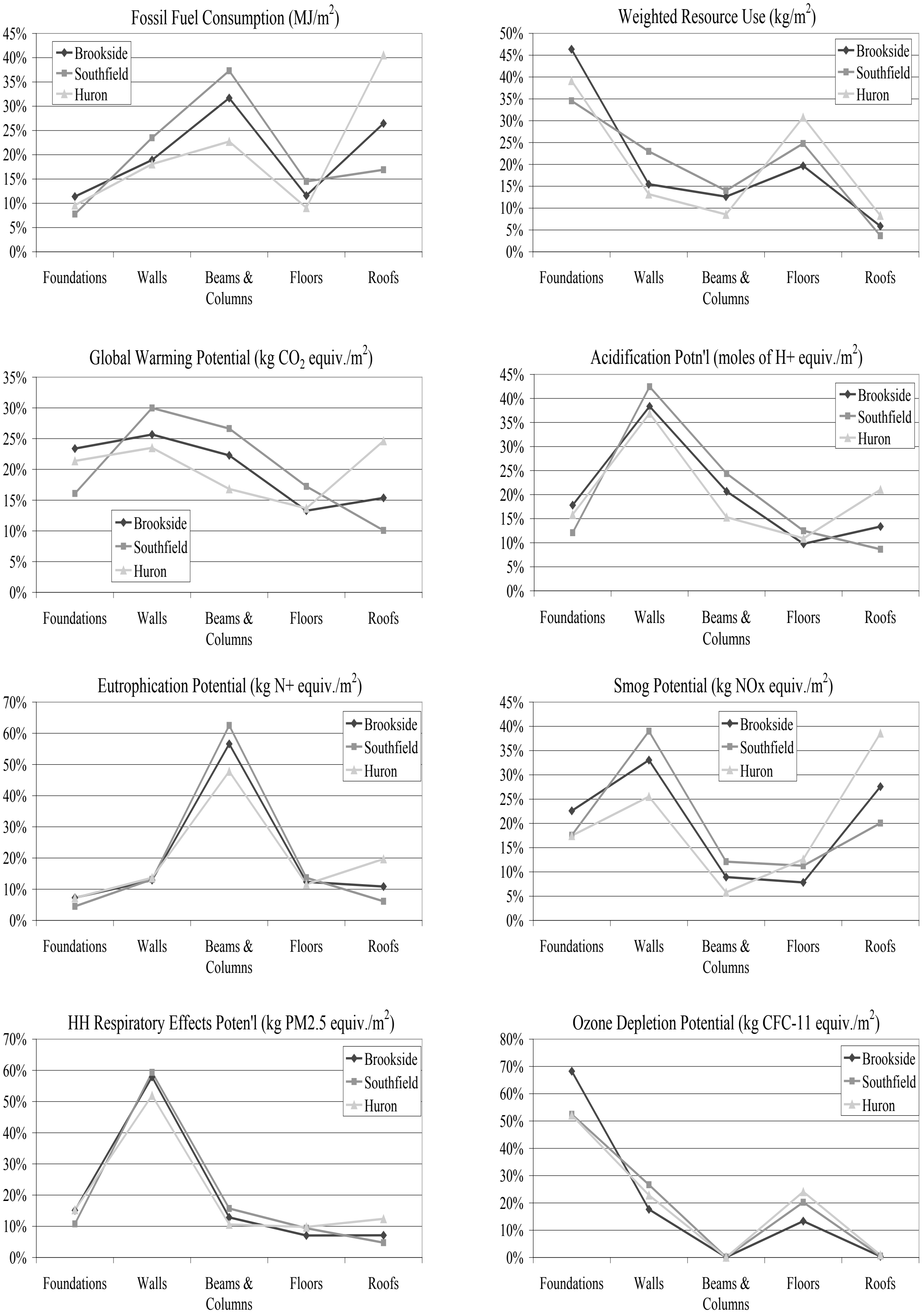


Fig. 6-3: Environmental Impact Contribution by Bldg Assembly Systems

6.5 Air Emissions

The life-cycle air pollutant emissions absolute values per m^2 for the 3 buildings are calculated. The detailed results and full set of releases to air are in the appendices section (A-8, B-8, C-8). However, major air emissions are chosen for the analysis shown in (Fig. 6-4a and 6-4b). These emissions are carbon dioxide (CO_2), Carbon Monoxide (CO), Methane, Nitrogen Oxides (NOx), Sulfur Dioxide (SO_2), Particulates greater than 2.5 micron and less than 10 micron of size, and Volatile Organic Compounds (VOCs). These emissions are responsible for global warming (CO_2, CO, Methane), acidification (NOx, SO_2), smog (NOx, VOCs), and respiratory effect potentials (Particulates). The analysis shows consistency with the impact values in those categories from previous sections.

In air emissions by life cycle stage, figure 6-4a shows that the operation phase dominates most of air emissions especially CO_2, Methane, and SO_2 (97%). This is due to the production of electricity as these emissions from the burning of coal at the power plants are released to produce this electricity. VOCs, particulates, and CO have around 10-15% release during the manufacturing phase. NOx has the highest release (30%) during manufacturing phase. Release of NOx contributes to the formation of acid rain and smog.

In air emission by building assembly systems, figure 6-4b shows that the walls system has the highest percentage of emissions in the 3 building. This is consistent with walls having the highest impacts in global warming, acidification, smog, and respiratory among other assembly systems due to these emissions (Fig. 6-3). The second highest contributor to air emissions is the roofing system due to air releases from insulation and membrane manufacturing (both tested in sensitivity analysis) while floors have the lowest percentage of the whole assembly systems.

The overall results here show that, throughout the building life cycle, air pollution mostly happen during operation phase. This interprets the high percentages of operation phase in most impact categories that are caused by releases to air i.e. energy, GWP, AP, smog, and respiratory effects are all caused by air pollutants.

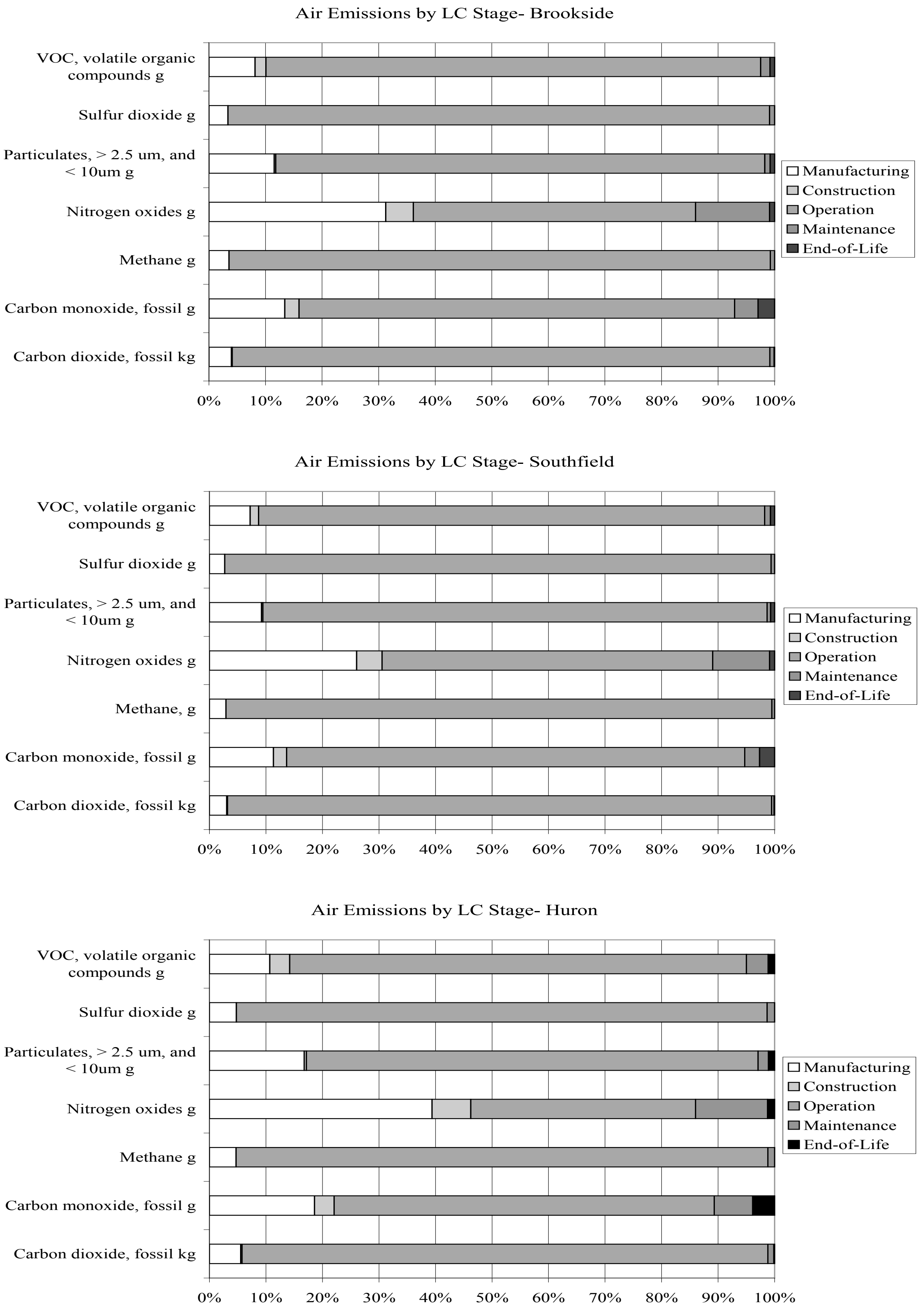
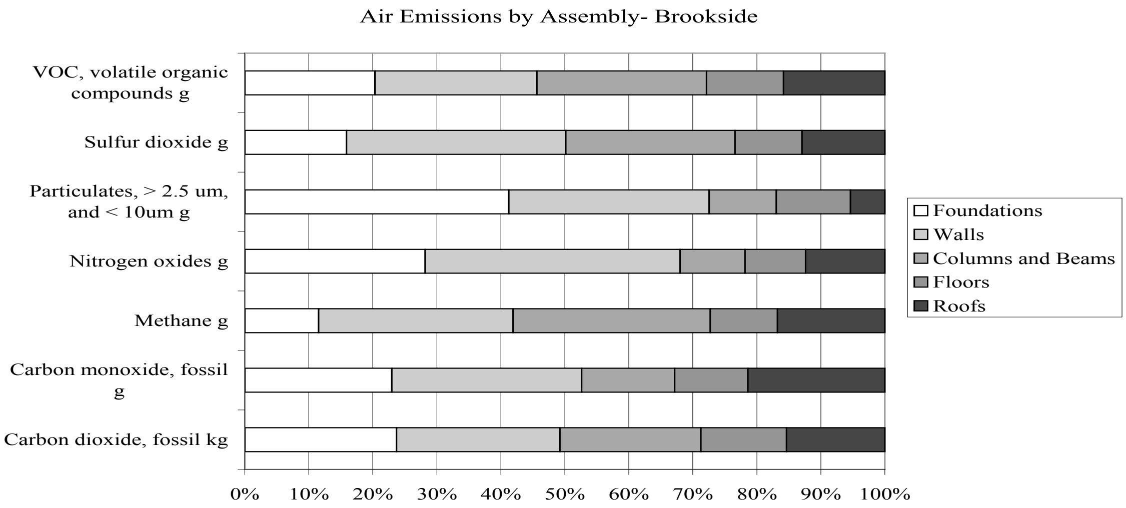
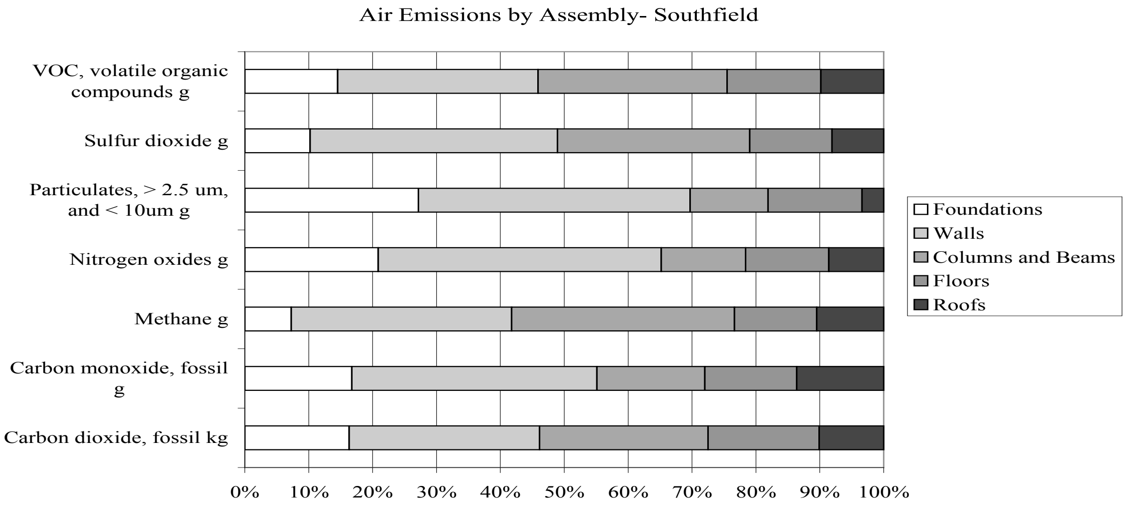


Figure 6-4a: Air Emissions/m^2 by Life Cycle Stage





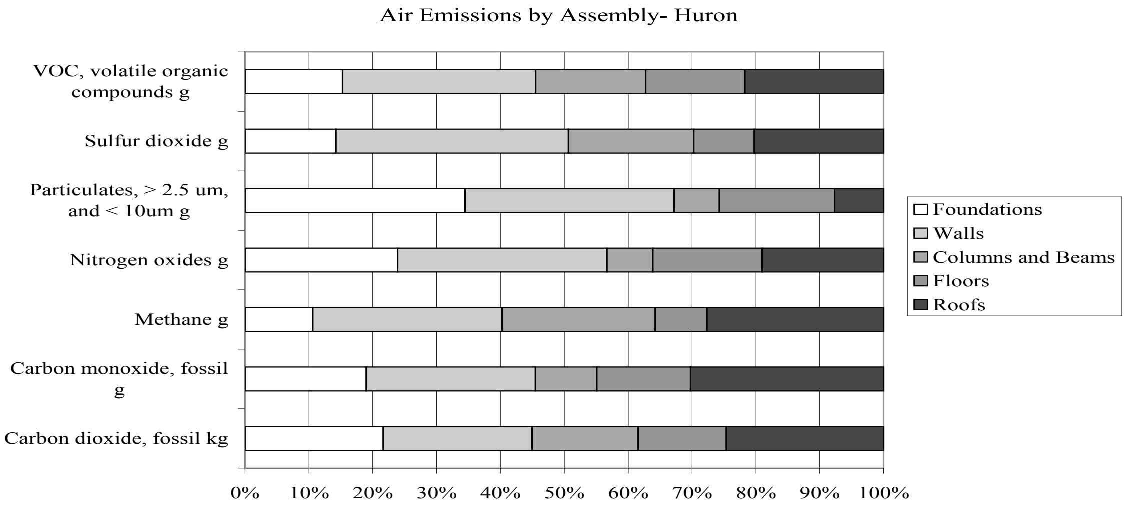


Figure 6-4b: Air Emissions/m^2 by Building Assembly

6.6 Water Emissions

The life-cycle water pollutant emissions absolute values per m^2 for the 3 buildings are calculated. The detailed results and full set of releases to air are in the appendices section (A-10, B-10, C-10). However, major water emissions are chosen for the analysis shown in (Fig. 6-5a and 6-5b). While most air emissions contribute to GWP, AP, POCP, and HH Respiratory effect potentials, the water emissions mostly contribute to the Eutrophication Potential (EP) and Human Toxicity (release of heavy metals) which is calculated in this section. The major water emissions considered here are: Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrogen, Phosphorous, and heavy metals group that include (Arsenic, Cadmium, Lead, Mercury, and Nickel). The analysis shows consistency with the impact values in the eutrophication category.

In water emissions by life cycle stage, figure 6-5a shows that the operation phase dominates most of water emissions especially Arsenic, BOD, Cadmium, COD, Mercury, and Nickel at 60%-80% in the 3 buildings. This is mostly due to the production of electricity as these emissions are released from the burning of coal and other energy sources at the power plants. Manufacturing phase dominates the release of Lead (90%), Nitrogen and Phosphorous (98%). Nitrogen and Phosphorous contribute most to the eutrophication (over-fertilization) impact category. This is consistent with eutrophication being the dominant impact in this phase (Fig. 6-2). The release of suspended solids is shared equally by the manufacturing and operation phases.

In water emission by building assembly systems, figure 6-5b shows that the roof system in the 3 buildings dominates the most water emissions releases. It is important to mention that the heavy metals (a human toxicity impact) have significant releases by building assembly systems. However, it is highly recommended to include and quantify these impacts in future LCA research and include them in the building environmental profile (Table 6-1, 6-2, 6-3). Structure system (columns and beams) has high releases of nitrogen, phosphorous and suspended solids (main constituents of eutrophication) which is consistent that structure has the highest percentage of eutrophication potential in all 3 cases (Fig. 6-3). The third highest contributor to water emissions is the walls system while foundations have the lowest percentages overall.

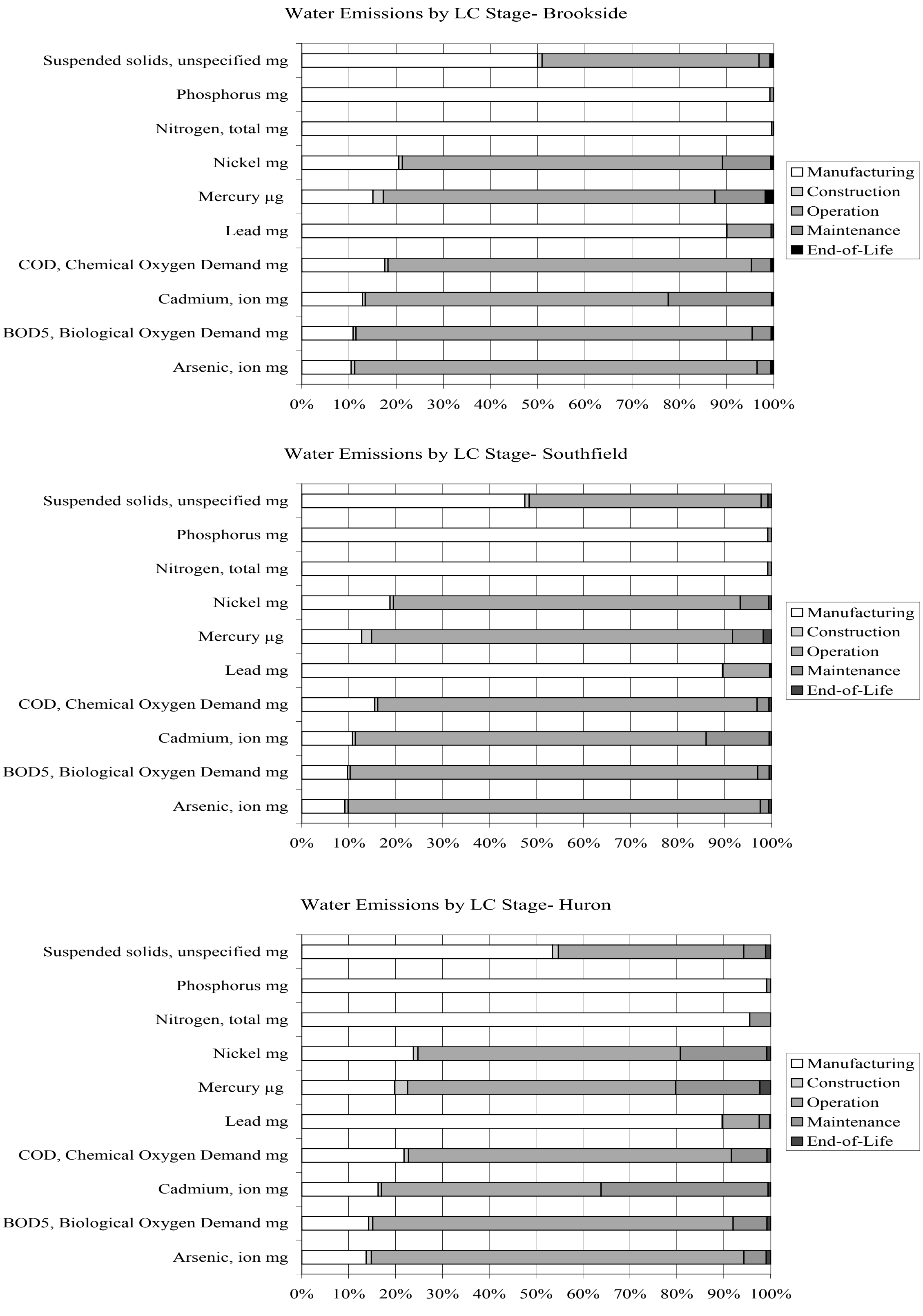
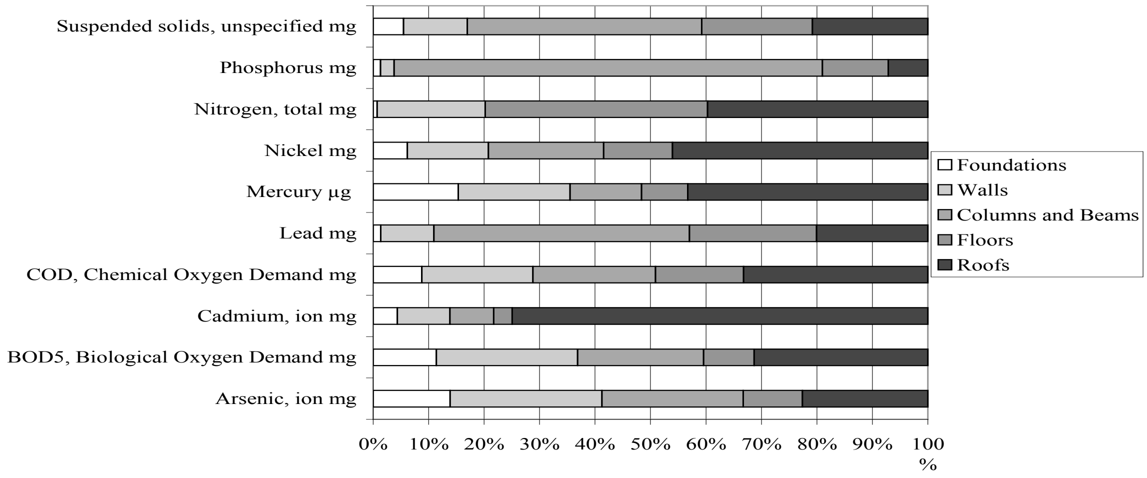
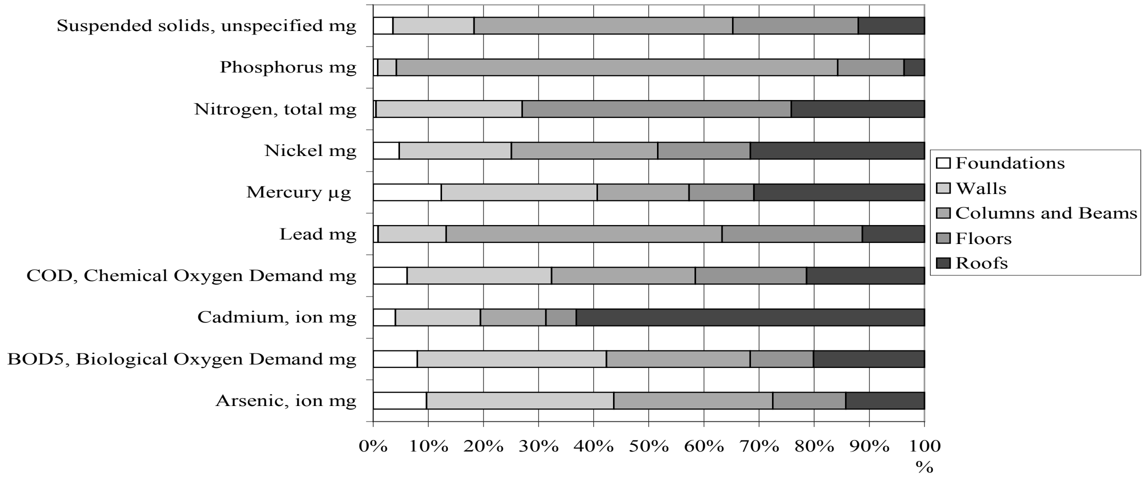


Figure 6-5a: Water Emissions/m^2 by Life Cycle Stage

Water Emissions by Building Assembly- Brookside



Water Emissions by Building Assembly- Southfield



Water Emissions by Building Assembly- Huron

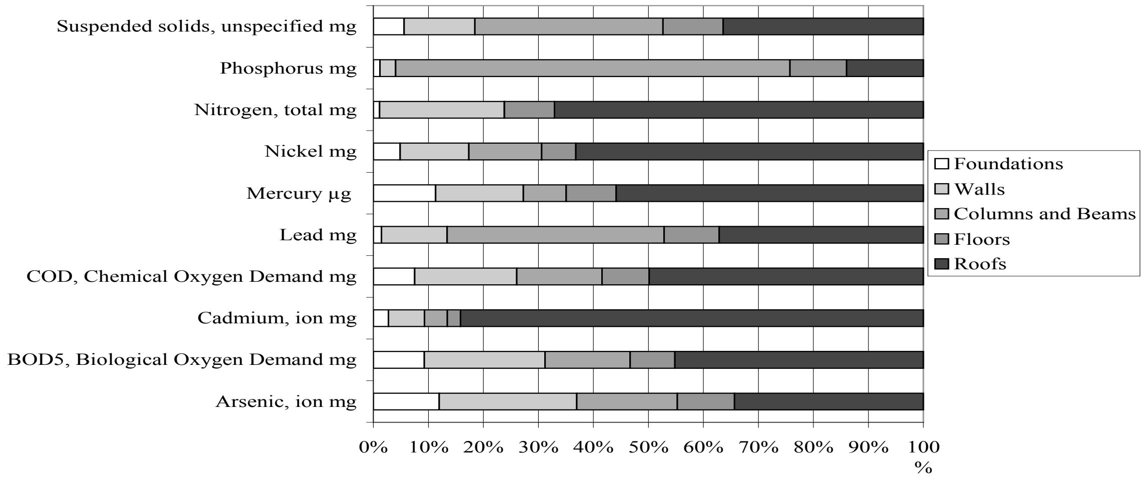


Figure 6-5b: Water Emissions/m^2 by Building Assembly

6.7 Land Emissions

The land pollutant emissions absolute values per m^2 for the 3 buildings are calculated. The detailed results and full set of releases to air are in the appendices section (A-12, B-12, C-12). However, since they are fewer than other impacts, all land emissions are chosen for the analysis shown in (Fig. 6-6a and 6-6b). These emissions are bark/wood waste, concrete solid waste, blast furnace slag, blast furnace dust, steel waste, and unspecified other waste. Although these emissions don't contribute directly to the environmental impact categories in this study, they are considered very important to determine the amount of materials that go to the landfill mainly during construction and end of life phases and to some extent operation phase

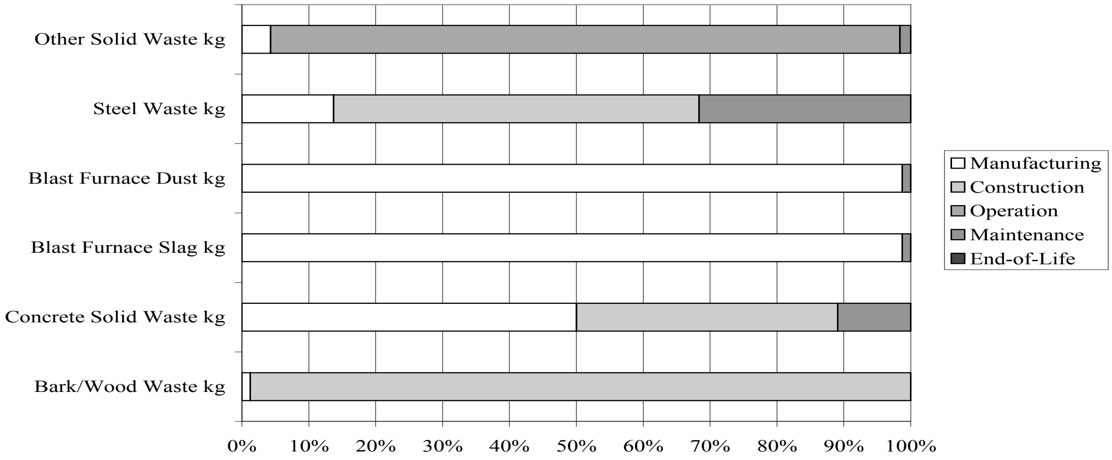
In land emissions by life cycle stage, figure 6-6a shows that manufacturing and construction phases dominate most of land emissions throughout the whole life cycle. However, some of the unspecified solid wastes are released during the operation phase at 96%. Concrete solid waste, blast furnace slag, and blast furnace dust have around 50%, 98%, and 98% release respectively during the construction phase. Bark/wood waste, concrete solid waste, and steel solid waste have 99%, 40%, and 55% release respectively during the construction phase.

In land emission by building assembly systems, figure 6-6b shows that foundations and floors dominate most of bark/wood waste and concrete waste emissions due to wood forms use and concrete pouring during construction. Structure system (columns and beams) dominate the blast furnace slag and blast furnace dust as main emissions due to steel manufacturing process for W-sections, HSS sections, and open-web steel joists. Both Electric Arc Furnace and Basic Oxygen/Blast Furnace which are used to manufacture steel W-sections and HSS/open-web joists respectively have these two substances as outputs from the process.

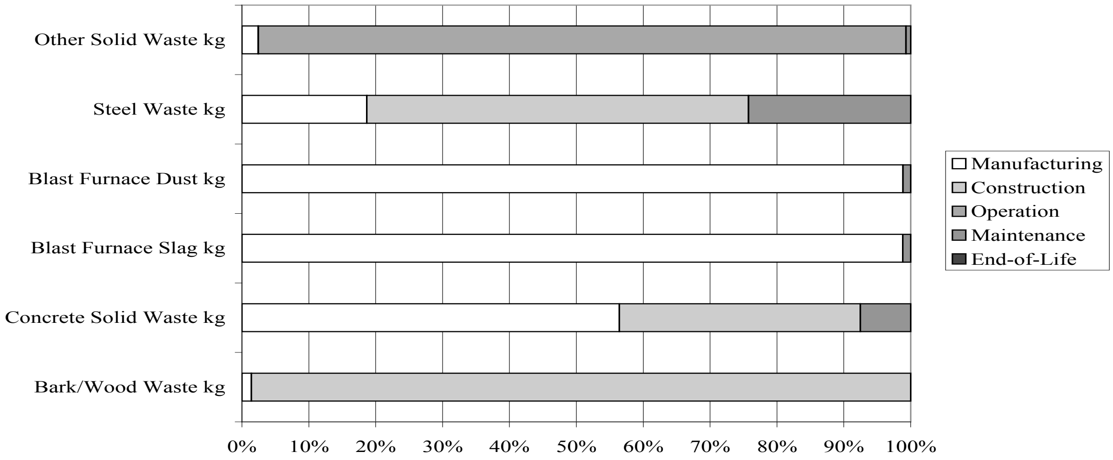
Roofs system dominates the steel waste due to manufacturing of open-web steel joists which are used instead of W-sections as main roof structure for the 3 building. Using open-web joists save considerable money from using the most expensive W-sections in roofs. It important to mention that this is a common practice (in the Midwest) with low-rise commercial/office steel construction since roofs don't have huge dead load like floors for example (have 3” concrete topping), this is why W-sections are used in all floors while open-web joists are used for roofs. However, open-web joists have a lot of waste scrap due to its manufacturing process. Structure systems contribute also to the steel waste (30%) due to steel beams sections preparation and welding on-site. Land emissions are evenly distributed among building assembly systems system has the highest percentage of emissions in the 3 building.

The overall results here show that land emissions mostly happen during manufacturing and construction phases throughout the building life cycle.

Land Emissions by LC Stage- Brookside



Land Emissions by LC Stage- Southfield



Land Emissions by LC Stage- Huron

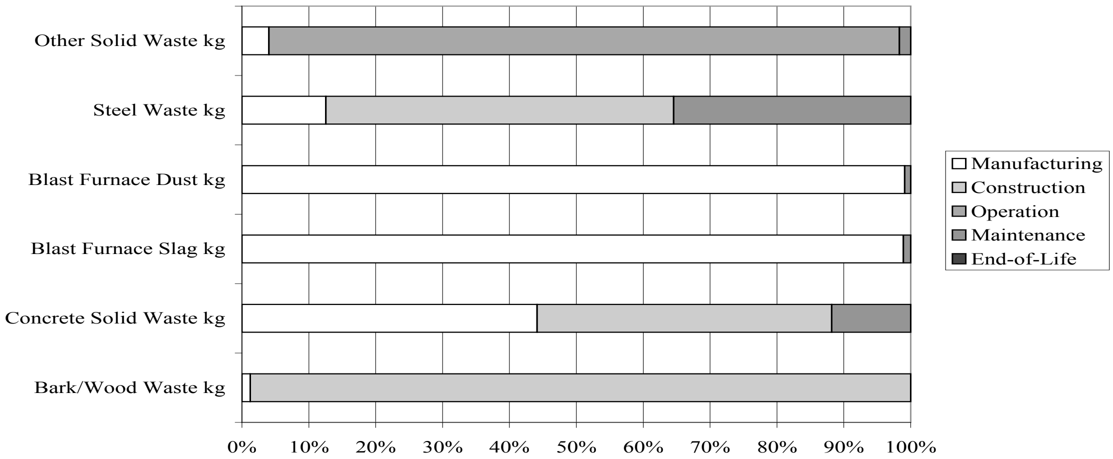


Figure 6-6a: Land Emissions/m^2 by Life Cycle Stage

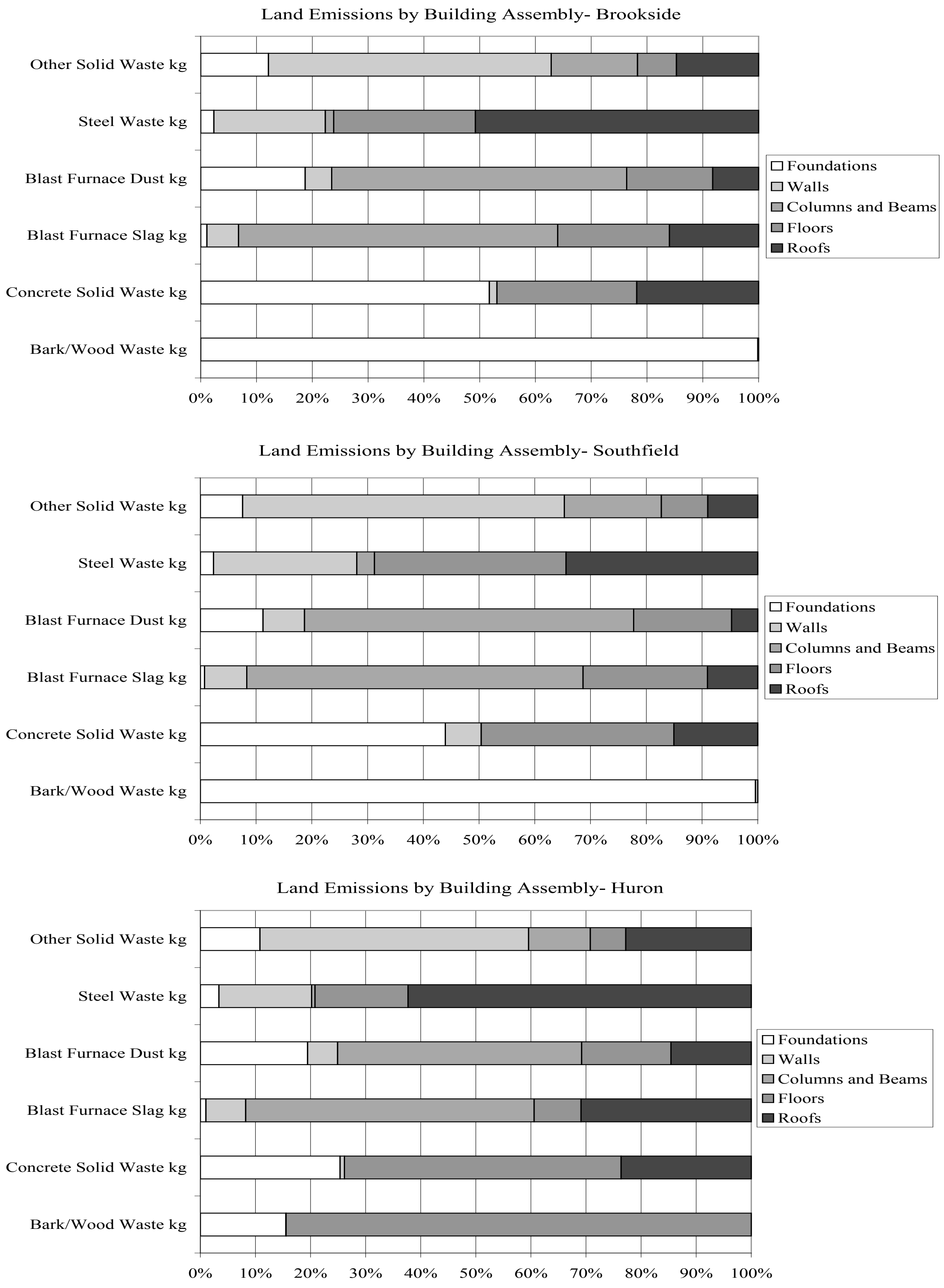


Figure 6-6b: Land Emissions/m^2 by Building Assembly

6.8 Sensitivity Analysis

Sensitivity analysis is typically used to check either the significance of changing key parameters contributing to the overall LCA or key assumptions governing the methodology of the LCA itself. As mentioned earlier (in 5-7), the *what if* scenario is used for sensitivity analysis according to Pesonen et al. (2000). Sensitivity scenarios are used to compare the replacement of materials that have potential high impacts within the building with more environmental friendly alternatives, and then quantify these changes in the environmental impacts at the end of the 60 years.

From the previous results, the study found that materials such as: cement in concrete mix, wall insulation, roof insulation and membrane have huge quantities and potential high impact in many categories. Therefore, the sensitivity analysis is completed to identify potential improvement that can be made during all phases in order to reduce the total life cycle environmental impacts. These changes takes place in *foundations*, *walls* and *roofs* materials (for the 3 case study) during life cycle phases and replaced with more environmentally friendly materials (with less emissions), then assess the total impacts again for the 3 cases with the new alternatives to test their sensitivity to the results.

The other systems (structure, floors) are not changed in this analysis because there are no other alternatives, for this type of construction, for the *structure* or *floors* to change either in the real-life or in the LCA modeling program. Except for fly-ash in the cement in concrete topping, this alternative has been chosen for improvement in much larger area in the foundations to test its sensitivity to results. The *structure* system includes steel w-sections for beams (Brookside and Southfield case) and hollow structural steel HSS column (Brookside and Huron case) or w-sections columns (Southfield case). The *floor* system is similar for all cases which include the regular 3 inches of concrete topping over corrugated steel decking. One other reason for no changes here is because the steel recycle content ratio is around 90% for all steel sections (according to AISC) in the United States so there is no change to make here in terms of materials. This also interprets the "no change" in *columns and beams* and *floors* categories in the sensitivity graphs (Fig. 6-7).

Two out of the three systems chosen for analysis (walls, and roofs) represent the highest impacts share by building systems, besides structure (Sec.6.4 & Fig. 6-3). This is consistent with ISO 14043 (1998b) to "asses the sensitivity of data elements that influence the results most greatly".

6.8.1 Sensitivity Assumptions and Scenarios

A list of changing variables included in the analysis is shown in table 6-2. The main assumptions for sensitivity analysis are as follow:

- No change for materials in *columns and beams* and *floors* systems for the previous reasons.
- *Foundations* change is to take place one time over 60 years since foundations are only built one time and remain without change the whole life cycle. However, it is suggested to replace the regular concrete and cement with 0% fly-ash with *35%* fly-ash cement for the whole foundations (columns footings, slab on grade, and walls perimeter)
- *Walls* change is suggested to take place 2 times during 60 years by replacing the fiberglass batt insulation with cellulose insulation at same thickness. Cellulose proved to be more environmental friendly and gives 10% improved R-value over similar fiberglass but with less environmental impact due to its recycling nature. Moreover, it is more durable and less vulnerable to moisture if enclosed with poly films. This seems quite reasonable assumption since the life expectancy of an ordinary wall insulation is around 30 years.
- *Roofs* change is suggested to take place 2 times during 60 years (every 30 years) by replacing the 3" thick *extruded* polystyrene insulation and 60 mil *black* EPDM membrane with 4" thick *expanded* polystyrene insulation and 60 mil *white* EPDM membrane. The materials that were chosen represent the most significant materials of these systems due to their high emissions during manufacturing.

Table 6-2: Sensitivity Analysis Variables

	Roof Insulation	Roof Membrane	Walls Insulation	Foundations
Brookside-base case	3.25” rigid extruded polystyrene insulation w/ R-22	fully-adhered 60 mil black EPDM	6” fiberglass batt insulation w/ R-19	Cement in concrete mix with 0% fly-ash content
Brookside-sensitivity	4” rigid expanded polystyrene insulation w/ R-22	fully-adhered 60 mil white EPDM	6” cellulose insulation w/ R-19	Cement in concrete mix with 35% fly-ash content
Southfield-base case	3” rigid isocyanurate insulation w/ R-22	fully-adhered 60 mil black EPDM	6” fiberglass batt insulation w/ R-19	Cement in concrete mix with 0% fly-ash content
Southfield-sensitivity	4” rigid expanded polystyrene insulation w/ R-22	fully-adhered 60 mil white EPDM	6” cellulose insulation w/ R-19	Cement in concrete mix with 35% fly-ash content
Huron-base case	4.75” rigid isocyanurate insulation w/ R-29	fully-adhered 60 mil black EPDM	6” fiberglass batt insulation w/ R-19	Cement in concrete mix with 0% fly-ash content
Huron -sensitivity	5.25” rigid expanded polystyrene insulation w/ R-29	fully-adhered 60 mil white EPDM	6” cellulose insulation w/ R-19	Cement in concrete mix with 35% fly-ash content

6.8.2 Sensitivity Results

Figure 6-7 shows results of all impact categories by building assembly systems for the 3 cases. A complete list of results is included in Appendix E-1. The two scenarios for each building system are plotted and placed beside each other for easy visual comparisons. These two scenarios are the *base-case* calculations scenario and the *sensitivity* scenario. Results show that sensitivity scenario has reduced values in all impact categories due to the change in the 4 systems shown in Table 6-2. These reductions range between 6% and 15% in the studied systems; foundations, walls, roofs, and have influence in most 8 impact categories this study has investigated. These results prove the hypothesis of the study that small materials flow within the life cycle would render changes in *all* life cycle impacts categories considered in this study. The sensitivity also highlights the importance of insulation and concrete mixes materials as sensitive materials that have huge quantities within buildings. They significantly reduce the whole impacts if chosen carefully by architects.

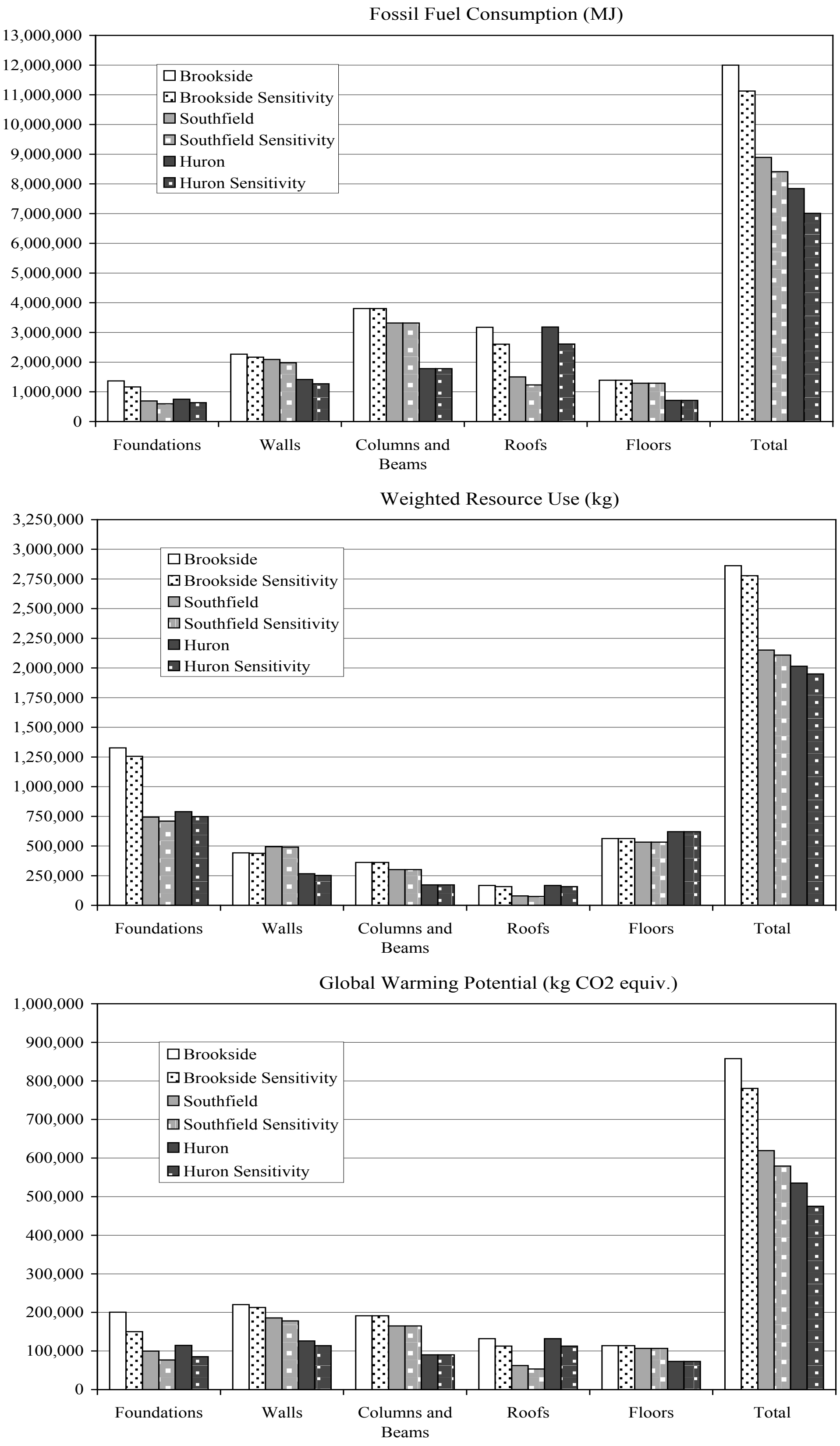
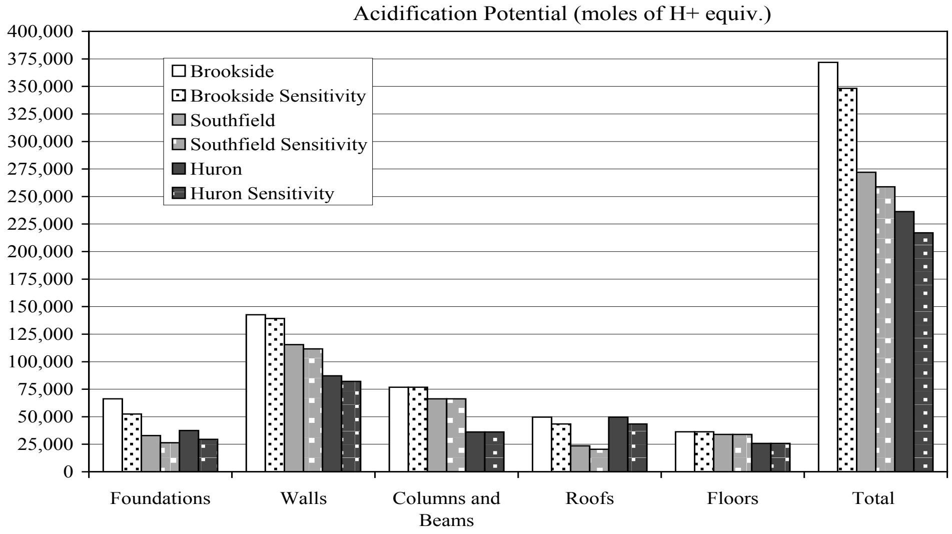
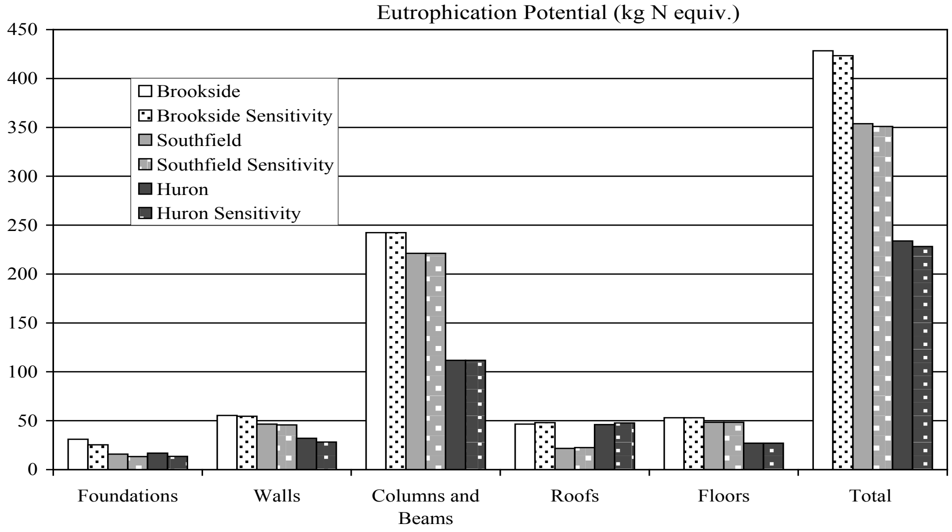


Figure 6-7: Environmental Impacts of 3 Buildings- Sensitivity Analysis





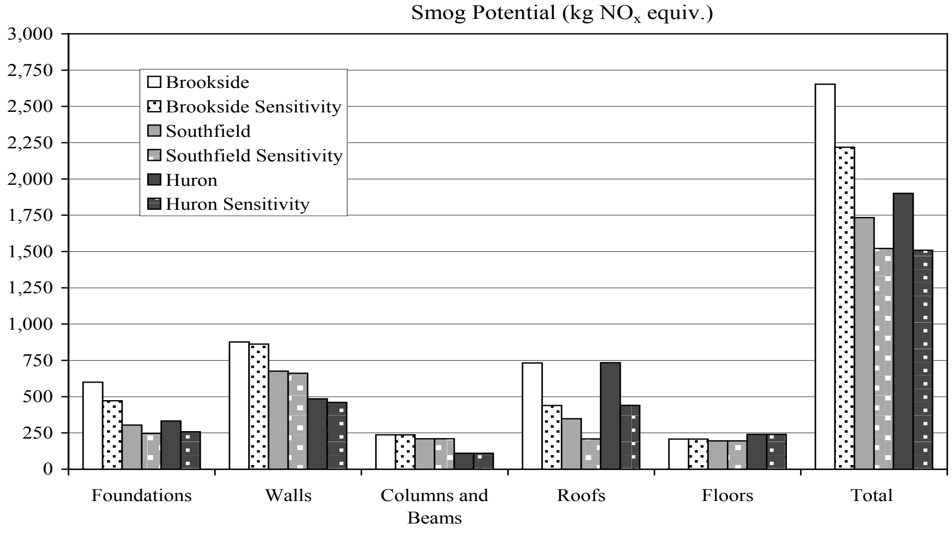
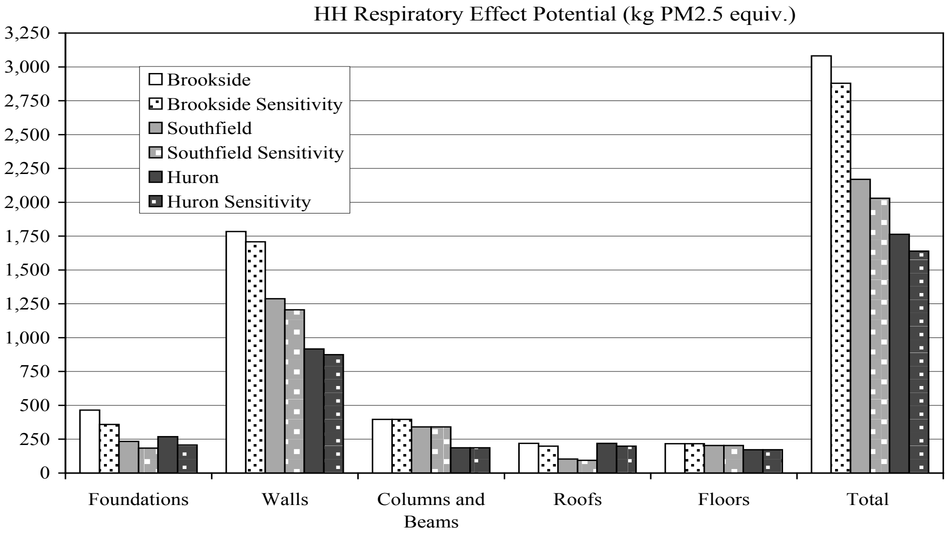


Figure 6-7: Environmental Impacts of 3 Buildings- Sensitivity Analysis- continued



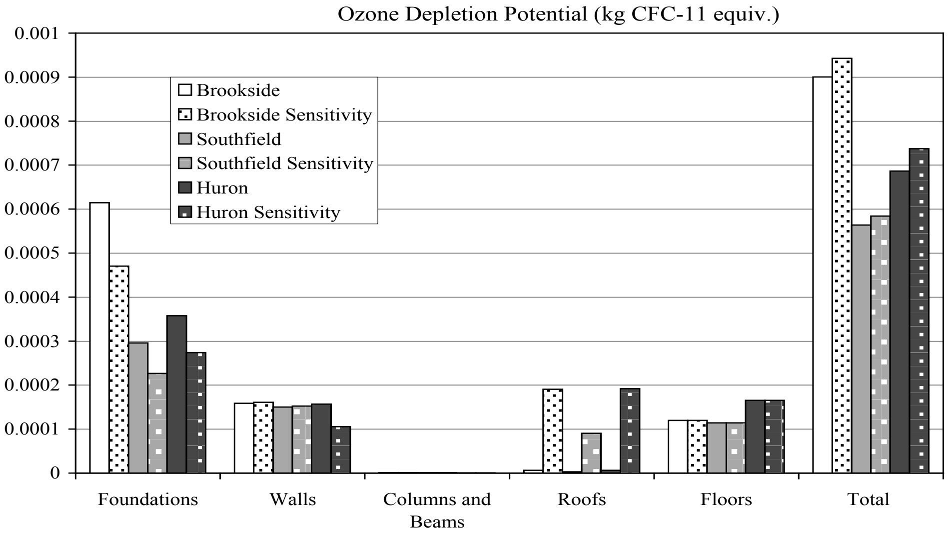


Figure 6-7: Environmental Impacts of 3 Buildings- Sensitivity Analysis- continued

CHAPTER 7

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

7.1 Contribution to knowledge

The objective of this study is to quantify and compare the potential environmental impacts caused by an office building throughout its life cycle. The study determined the life cycle phases and building systems that contribute most to the whole impact on the environment. The study also performed a sensitivity analysis to evaluate the effects of possible changes and retrofits in foundations, walls, and roofs during the 60 years service life of the building. The result of this study demonstrated the aforementioned hypothesis that a typical new office building, with different architectural features would have comparable significant environmental impacts of its life cycle phases and main assembly systems. Furthermore, even a smaller flow of impact-sensitive materials such as insulation throughout its life cycle would render an influence on the overall life impacts.

The study finds that the operation (use) phase of all buildings (Fig. 6-2) has the highest impacts (90+ % of total impacts) during its 60 years life cycle in the following impact categories: fossil fuel (energy) consumption, global warming potential, acidification potential, and human health respiratory effects potential. Manufacturing phase has the highest impact in the following impact categories: ozone depletion potential with 87% of total impact, and in eutrophication with 65% of total impact respectively.

Furthermore, the study finds that the wall system, among others, has the highest contribution to the following impacts: global warming (26%), acidification (40%), smog potential (35%), and respiratory effect potential (57%). The structure system (beams and columns) system has the highest contribution to fossil fuel consumption (31%) and to eutrophication (56%) categories. The roof system has also significant impacts contribution (second to structure) to fossil fuel consumption (27%), global warming (17%), and comes second to walls in contributing to smog potential (29%). The foundations system contributes the most to ozone depletion at 58%. Through conducting a sensitivity analysis to the results, the study also find that replacing impact-sensitive building materials with more environmental-friendly alternatives (mainly to foundations, walls and roofs) yields a reduction in total buildings impacts by 6%-15% in different impact categories (Fig. 6-7).

The findings of this study on the contribution of different life-cycle phases to the whole impacts are consistent with results from some previous studies. Most of these studies have emphasized the significance of operational energy impact (Sheuer *et al.* 2003; Seo and Hwang 2001; Treloar *et al.* 2001; Thormark 2000), and some have also reported the possible significance of some building materials (Ochoa *et al.* 2002; Junnila and Saari 1998). The findings also support the argument that operation energy is a *major environmental issue* in the life-cycle of an office building. That is obvious from the significant operation energy reduction presented in Huron case (LEED certified using geothermal HVAC) which rendered lower impact absolute values than other cases.

The study contributes to the *whole* building environmental analysis which has been under-utilized due to modeling difficulties and compensated by researching only building materials and components. The study results are targeting more environmentally conscious design practices and facilities management of office buildings. The study targets owners, project and facility managers, and designers who are not familiar with environmental impacts of office buildings. These audiences could use building environmental profiles, impacts per unit area, significant impacts phases of the building, and assembly systems that most contribute to the total impact, to help them focus their attention on environmentally sensitive areas of design, construction, use, maintenance of the building.

The study also acknowledges the relationship between LCA and LEED rating system. LCA results demonstrated that a LEED certified building (Huron case) has the lowest impact among other cases over 60 years of life. This is mainly due to using geo-thermal HVAC system which saved significant amount of energy during the operation phase in which most of the impacts would occur. One shortcoming though was the use of tighter envelope and thicker insulation without considering the negative impact of using such insulation alternative (polyisocyanurate). This resulted in that the roof system of the LEED building had the highest impact in most categories than the other two cases (not LEED certified). The LCA method in this study opens the way for more testing of LEED certified buildings with high ratings e.g. gold or platinum using LCA impact analysis to verify their environmental performance. This helps to narrow down the sensitive area of design and material choices (e.g. insulation) that LEED falls short by awarding points for overall energy savings without looking at the significant environmental impact of material alternatives that achieve this saving.

7.2 Validity of the study

Research validity is discussed under 2 sub categories: Internal validity (accuracy of data and results) and external validity (generalizability) (Yin, 2002). To meet *internal validity*, multiple sources of data were used and assessed to double check the accuracy of the input data used in calculations i.e. the data quality assessment that was discussed earlier. The quantification of materials and energy flows (inputs and outputs) were mostly based on data from the floor plans and specifications sheets provided by the architect or the contractor of the buildings, which represent actual and accurate data and measurements not just estimated values. This gives more accuracy to the outputs (environmental impacts) and, in turn, to more accuracy and reliability of the results.

External validity, in which the study findings can be generalized, depends on analytical generalization and replication logic in such research of multiple case studies (Yin, 2002). In this study, the 3 case studies environmental impact findings will not allow *statistical* generalization to all office buildings, but findings can be *analytically* generalized to new office cases based on *replication logic*, for example an office that has closer overall floors area, closer weather conditions, closer number of floors, and same type of construction to the 3 cases presented in the study.

7.3 Reliability of the Study

The reliability of the study is supported by the high quality data assessment which turns to have a rating of *good* or higher in all life cycle phases for all buildings cases under study. It is also supported by performing all the case studies under the same research protocol and reporting results at a detailed level in the appendices part at the end of this study. Data quality assessment has also been applied to the data in each phase according to Lindfors et al. (1995) and Weidema (1996). The selection of newly built cases and measured, not estimated, quantities of materials is also a factor to support the reliability of the study.

7.4 Study Limitations

Although this study aimed to be comprehensive, there are still some limitations that could marginally affect the reliability of the results. The LCA does not cover all impact areas that are listed in table 2.2 in addition to other important ones due to limitations of the modeling software and databases. These non-covered impacts include, for example, indoor air quality, site specific extraction effects, land use, and water use. The scope of the study was to examine the whole life cycle of an office building, but since this life cycle is not a definite system and cannot be separated from its context, some subjective choices had to be made i.e. some elements to be included or excluded from the study. For example, elements like office furniture, computers, construction of infrastructure, were excluded to focus the attention on modeling the building itself as simply as possible. Some other limitations on impacts including biodiversity, and indoor air quality are not assessed due to the lack of data and difficulty of modeling them.

The study has also some limitations that could limit the external validity (generalization). First, the selected building cases are located in the Midwest region in the United States Thus, a broad generalization cannot be justified concerning the characteristics of the buildings used as being representative of those found in the far south for example (hot dry or hot humid climate). Buildings in these regions, with the same construction systems, may yield closer environmental profile due to the use of the same electricity grid mix but the change in weather conditions may slightly affect, for instance, the annual energy consumption (multiplied by 60 years of life).

For other countries, it is difficult to generalize based on the results of this study. There are many *regional* conditions used in the calculations that could affect considerably the results outside the U.S. Building design, intensity of materials, construction methods, and intensity of energy use in the operation phase differ. Results may yield completely different results with countries that use more *hydro power* (almost no emissions) in their electricity grid mix such as Canada or some European countries, where the coal share (the major CO_2 contributor) is very low in the grid mix. The use of fossil fuel significantly affect the final emissions especially the release of CO_2, SO_2, and NOx to the air. Different type of construction (wood, concrete) will probably have different environmental profile due to their different embodied energy in the structural system which found to have the second highest environmental impact among the other assembly systems (foundations, walls, floors, roofs) in steel buildings.

Second, the sensitivity analysis investigated only some of the possible scenarios by replacing some materials during life cycle and calculates effects on the life-cycle phases and building systems with a high contribution to the total impacts. This approach may leave some undetected aspects with a low contribution but a high uncertainty, which could have an influence on the overall sensitivity (Heijungs 1996). Furthermore, the *what if* scenario approach used a static model for evaluating sensitivity in the software. This does not assess simultaneous effects of uncertainty as, for example, a Monte Carlo simulation would do in European LCA software such as SimaPro 7.2.

Although it is clear that LCA present the most consistent and scientifically sound approach to calculate the environmental impacts, they are also many challenges that need to be met in order to widen their use, namely in terms of data requirements, usability, and expertise. LCA tools should be developed in a way that reduce the level and complexity of data required to make it usable for non-expert users. This can be achieved with a design that is based on data easily available to the building owner or designer, such as the “bill of materials” and the characteristics of the occupants of the building.

It is also clear that existing LCA tools still do not account for the whole supply chain impacts. This is because they are process-oriented and lacking databases containing the entire supply chain like the case of Economic Input-Output LCA (EIO-LCA) (CMU, 2007). A new and improved tool using a *hybrid* approach to LCA can overcome these challenges by having the best advantage of the two approaches, which are the specificity of the process LCA and the broadness of analysis of EIO-LCA.

7.5 Significance of the Study

The study aimed at comprehensiveness; however, it researched some impacts that others have not covered in their previous studies or marginally touched on. These include categories such as: acidification, eutrophication, summer smog, human health respiratory effect, ozone depletion potential, and resource use. The study is among very few which carried out these many impact categories (8 impacts). The study also determined the building assembly systems that contribute most to the whole environmental impact categories throughout life cycle. Material transportation (to and from the building site) was another big factor influencing the life cycle impact that was rarely investigated; the study calculated in details its effect in each phase of the building life. The study is also unique in modeling the building with the U.S. electricity grid which depends on coal as resource at 45% (DOE, EIA 2009).

In the near future, it is expected that both construction drawings and building environmental profile (as in this study) might be tied together before the building is even constructed. Barcodes could also be developed for buildings so that architects, owners, and contractors will have handling data for the building or its main components' impacts on the environment even before its construction. Hence, this study will act as a guiding step towards the inclusion of environmental profiling for each building during the design process and construction documentation.

The study also utilized using the U.S. manufacturing data and inventory of construction materials that rarely was used in the past when most of the data relied on European manufacturing data for the lack of better alternative. For this reason, most significant studies, yet still few, have been done in Europe specifically in Sweden and

Netherlands because of the availability and reliability of LCA databases. Nowadays, there is a growing demand for LCA studies that are based on U.S. manufacturing data for more accurate research outcome. The U.S. Life Cycle Inventory (LCI) Database Project (2011) is a step to develop a publicly available LCI database. The National Renewable Energy Lab (NREL) was directed by the US DOE to lead the effort to develop this life-cycle inventory database. This research stands among the first attempts to study and analyze the whole building LCA based on North American manufacturing data (ATHENA model) derived from the US-LCI database. This will also open new opportunities for researchers to analyze cases in the U.S. where electricity grid mix and manufacturing data are different. This initiative is responding to the needs for better LCA data availability, standardization, and quality for a wider application in building design and construction in the United States.

7.6 Future Research Directions

The buildings included in the study presented conventional design solutions, thus, in the future, it would be interesting to compare the environmental impact of sustainable design solutions to the ones presented here. Further research could also have a more action-oriented approach, so that the implementing of new knowledge in design processes with its potential beneficial effect on the environmental performance of buildings could be tested. Since a majority of the environmental burdens of a given building stock are caused by old buildings, it would also be interesting to conduct a similar study from a facility management perspective. Finally, as the user of an office building plays a central role in deciding the value of environmental performance, it would be beneficial to compare the environmental impact of office buildings in a broader corporate and facilities management context. For example, how significant would the building-related impacts be compared to employees commuting, and the use of office supplies, for instance, in the office under study.

The practical applications of the study’s results may include conscious design and facilities management of office buildings based on environmental friendly alternatives. Owners, project and facility managers, and designers not yet familiar with environmental profiling could use the environmental impacts caused by the assembly systems (in this study) to help them focus their attention to the environmentally sensitive areas of design, impact-sensitive materials, construction, use, and maintenance. More experienced organizations could use the longer list of environmental impact as a check list with an eye on considering whether they have considered all the issues causing them, or to benchmark the environmental performance of their building against the impacts presented here in the case studies.

Furthermore, the methodology used in this study could be replicated in other types of buildings such as high-rise, apartment buildings, mixed use, etc. and other construction methods as well i.e. wood and concrete. It will be very important to see the ratios of the assembly systems (foundation, structure, walls, floors, roofs) contribution to the total environmental impacts for other building types and construction methods especially wood and concrete environmental profile. The results could be compared to the steel assembly profiles presented in this study and used for design decisions of selecting specific type of construction over another from an environmental point of view.

Findings of this study especially the impacts per unit area of buildings and the methodology could also be applied on a larger scale such as group of buildings. Environmental impacts of several buildings could also be calculated and compared to a similar allowed range of impacts as the case with the current EPA sets a range of allowed environmental impacts (global warming level, smog formation, acidification, ozone depletion, etc.) for each county in the U.S. Each county should comply with certain emissions ranges in order to keep its air clean. The estimated impact based on the unit area presented here could be a practical step towards this goal.

Finally, because the LCA of a building could be expected to be sensitive to some models and outside conditions, such as obsolescence and energy mix, these should be clearly stated when presenting the results of an LCA study. However, one can say that the conscious the designer will be to consider these environmental impacts, the better the result in effectiveness of reducing significantly the environmental impacts of office buildings.

APPENDICES

Appendix A-1: Brookside- All Impacts by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	
Fossil Fuel Consumption MJ	9087377	175465	**9E+06**	97938	2E+05	**3E+05**	2129484	45598	**2E+06**	145688	69430	**2E+05**	3E+06	**2E+08**	**2E+08**
Weighted Resource Use kg	2701614	4618.76	**3E+06**	2324.6	5853	**8177**	141294	1080.1	**1E+05**	3430.91	1635.9	**5067**	293215	**2E+07**	**2E+07**
Global Warming Potn'l (kg CO2 eq)	675012	13084.2	**7E+05**	6500.5	18590	**25091**	126290	3382.3	**1E+05**	9498.97	5197.3	**14696**	275476	**2E+07**	**2E+07**
Acidification Potn'l (moles of H+ eq)	268227	4472.71	**3E+05**	3333.5	5864	**9198**	86676.3	1078.9	**87755**	526.641	1639.2	**2166**	99605	**6E+06**	**6E+06**
HH Resp Effects Potn'l (kg PM2.5 eq)	1903.96	5.39294	**1909**	3.7061	7.048	**10.75**	1157.48	1.2973	**1159**	0.50135	1.97	**2.471**	557.41	**33445**	**36526**
Eutrophication Potential (kg N eq)	380.252	4.65722	**384.9**	3.1511	6.075	**9.226**	31.0591	1.1185	**32.18**	0.36161	1.5486	**1.91**	2.5738	**154.4**	**582.7**
Ozone Depl Potn'l (kg CFC-11 eq)	0.0008	5.4E-07	**8E-04**	2E-11	8E-07	**8E-07**	9.7E-05	1E-07	**1E-04**	4.3E-07	2E-07	**6E-07**	7E-08	**4E-06**	**9E-04**
Smog Potential (kg NOx eq)	1728.89	100.866	**1830**	79.002	130.9	**209.9**	546.052	24.112	**570.2**	6.76712	36.586	**43.35**	46.121	**2767**	**5420**

Appendix A-2: Brookside- All Impact by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Fossil Fuel Consumption MJ	1365968	2269300	3801521	3173458	1389130	**11999377**
Weighted Resource Use kg	1326770	442672	361310	167860	563240	**2861851**
Global Warming Potential (kg CO2 eq)	200598	220150	191120	131829	113859	**857556**
Acidification Potn'l (moles of H+ eq)	66268	142617	76869	49698	36367	**371818**
HH Respiratory Effects Poten'l (kg PM2.5 eq)	465	1783	396	219	217	**3081**
Eutrophication Potential (kg N eq)	31	55	242	47	53	**428**
Ozone Depletion Potn'l (kg CFC-11 eq)	0	0	0	0	0	**0**
Smog Potential (kg NOx eq)	599	877	237	732	208	**2653**

Appendix A-3: Brookside- Energy Consumption by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operating Energy**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Electricity kWh	317354	0	**3E+05**	105.445	0	**105.4**	56791.4	0	**56791**	0	0	**0**	425000	**3E+07**	374250	0	**3E+07**
Hydro MJ	66284.8	77.597	**66362**	5.27981	109.99	**115.3**	104069	20.014	**1E+05**	61.7396	30.75	**92.49**	21290	**1E+06**	170421	238.4	**1E+06**
Coal MJ	2541020	1132.3	**3E+06**	634.632	1605	**2240**	383777	292.06	**4E+05**	900.925	448.7	**1350**	3E+06	**2E+08**	2926332	3478	**2E+08**
Diesel MJ	154632	163507	**3E+05**	97184.7	231448	**3E+05**	51505.5	42514	**94019**	136205	64691	**2E+05**	69632	**4E+06**	439527	5E+05	**5E+06**
Feedstock MJ	3079737	0	**3E+06**	0	0	**0**	1252219	0	**1E+06**	0	0	**0**	0	**0**	4331956	0	**4E+06**
Gasoline MJ	210.776	0	**210.8**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	210.776	0	**210.78**
Heavy Fuel Oil MJ	355059	3740.4	**4E+05**	1.09758	5301.8	**5303**	79657.6	964.74	**80622**	2964.8	1482	**4447**	4486.3	**3E+05**	437682	11489	**718347**
Liquified Petrolium Gas LPG MJ	7117.45	169.39	**7287**	0.60653	240.1	**240.7**	546.816	43.69	**590.5**	134.267	67.13	**201.4**	2473.9	**1E+05**	7799.14	520.3	**156756**
Natural Gas MJ	2949601	6915.8	**3E+06**	116.724	9802.9	**9920**	361777	1783.8	**4E+05**	5483.26	2741	**8224**	550862	**3E+07**	3316978	21243	**4E+07**
Nuclear MJ	769936	300.87	**8E+05**	274.899	423.4	**698.3**	106461	77.081	**1E+05**	227.1	118.4	**345.5**	1E+06	**7E+07**	876899	919.7	**7E+07**
Wood MJ	1169.04	0	**1169**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1169.04	0	**1169**
Total Primary Ener Consum MJ	9924767	175844	**1E+07**	98218	248931	**3E+05**	2340013	45695	**2E+06**	145977	69579	**2E+05**	4E+06	**3E+08**	1.3E+07	5E+05	**3E+08**

Appendix A-4: Brookside- Energy Consumption by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Electricity kWh	29,896	89,555	148,451	55,322	51,026	**374,250**
Hydro MJ	2,410	150,008	8,326	6,059	3,855	**170,659**
Coal MJ	673,864	639,191	902,870	314,125	399,759	**2,929,810**
Diesel MJ	304,301	217,338	162,419	105,245	152,385	**941,688**
Feedstock MJ	44,518	238,082	1,447,144	2,191,566	410,646	**4,331,956**
Gasoline MJ	0	24	45	71	71	**211**
Heavy Fuel Oil MJ	101,608	106,512	6,110	188,103	46,838	**449,171**
LPG MJ	1,100	4,484	1,408	652	676	**8,319**
Natural Gas MJ	240,577	1,063,669	1,281,523	373,697	378,755	**3,338,221**
Nuclear MJ	81,114	167,389	383,718	123,516	122,083	**877,819**
Wood MJ	0	1,169	0	0	0	**1,169**

Appendix A-5: Brookside- Resource Use by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Limestone kg	282,293	0	**282,293**	0	0	**0**	13,171	0	**13,171**	0	0	**0**	0	**0**	295,464	0	**295,464**
Clay & Shale kg	200,859	0	**200,859**	0	0	**0**	147	0	**147**	0	0	**0**	0	**0**	201,005	0	**201,005**
Iron Ore kg	62,216	0	**62,216**	0	0	**0**	224	0	**224**	0	0	**0**	0	**0**	62,440	0	**62,440**
Sand kg	17,785	0	**17,785**	0	0	**0**	29,530	0	**29,530**	0	0	**0**	0	**0**	47,315	0	**47,315**
Ash kg	1,518	0	**1,518**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1,518	0	**1,518**
Other kg	9,325	0	**9,325**	0	0	**0**	13,226	0	**13,226**	0	0	**0**	0	**0**	22,551	0	**22,551**
Gypsum kg	55,136	0	**55,136**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	55,136	0	**55,136**
Semi-Cementitious Matr’l kg	34,685	0	**34,685**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	34,685	0	**34,685**
Coarse Aggregate kg	684,258	0	**684,258**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	684,258	0	**684,258**
Fine Aggregate kg	484,868	0	**484,868**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	484,868	0	**484,868**
Water L	3,245,190	0	**3,245,190**	0	0	**0**	8,831	0	**8,831**	0	0	**0**	0	**0**	3,254,021	0	**3,254,021**
Obsolete Scrap Steel kg	145,797	0	**145,797**	0	0	**0**	122	0	**122**	0	0	**0**	0	**0**	145,919	0	**145,919**
Coal kg	138,529	56	**138,585**	31	79	**110**	18,505	14	**18,519**	44	22	**66**	125,088	**7,505,270**	157,109	171	**7,662,550**
Wood Fiber kg	485	0	**485**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	485	0	**485**
Uranium kg	1	0	**1**	0	0	**0**	0	0	**0**	0	0	**0**	2	**105**	1	0	**107**
Natural Gas m3	78,111	183	**78,294**	3	259	**263**	9,651	47	**9,698**	145	73	**218**	14,611	**876,648**	87,910	562	**965,120**
Natural Gas as feedstock m3	6,846	0	**6,846**	0	0	**0**	10,329	0	**10,329**	0	0	**0**	0	**0**	17,175	0	**17,175**
Crude Oil L	18,141	4,927	**23,068**	2,542	6,200	**8,743**	4,680	1,145	**5,826**	3,645	1,733	**5,378**	1,736	**104,168**	29,009	14,006	**147,182**
Crude Oil as feedstock L	11,794	0	**11,794**	0	0	**0**	20,502	0	**20,502**	0	0	**0**	0	**0**	32,296	0	**32,296**
Metallurgical Coal, fdstk kg	13,149	0	**13,149**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	13,149	0	**13,149**
Prompt Scrap Steel, fdstk kg	91,912	0	**91,912**	0	0	**0**	77	0	**77**	0	0	**0**	0	**0**	91,989	0	**91,989**

Appendix A-6: Brookside- Resource Use by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Limestone kg	198072.5086	31954.612	17609.72156	4448.27246	43378.594	**295464**
Clay & Shale kg	54755.23799	135440.576	0	178.791885	10630.8404	**201005**
Iron Ore kg	1219.327466	6211.13801	11300.71611	21522.2664	22186.0688	**62439.5**
Sand kg	2406.64057	44441.1157	0	0.00425138	467.254276	**47315**
Ash kg	1211.619009	70.8115268	0	0.00634502	235.238359	**1517.68**
Other kg	0	22551.3093	0	0	0	**22551.3**
Gypsum kg	8509.54877	44974.0407	0	0.00039873	1652.14667	**55135.7**
Semi-Cementitious Material kg	29045.66091	0	0	0	5639.27574	**34684.9**
Coarse Aggregate kg	492946.3594	0	0	0	191311.369	**684258**
Fine Aggregate kg	320332.146	23596.5497	0	0	140939.493	**484868**
Water L	99014.73048	466208.116	865717.4589	898521.198	924559.469	**3254021**
Obsolete Scrap Steel kg	1933.503611	3506.82263	108773.2297	12481.6101	19223.8363	**145919**
Coal kg	43411.61969	30608.8772	46064.41283	15602.8049	21592.6486	**157280**
Wood Fiber kg	0.001052191	485.336172	0	0.08018695	0	**485.417**
Uranium kg	0.128344613	0.2648688	0.607148147	0.19543599	0.19316944	**1.38897**
Natural Gas m3	6368.906252	28258.3722	33923.46867	9894.52095	10027.0358	**88472.3**
Natural Gas as feedstock m3	386.0800055	1519.86212	0	15268.8656	0	**17174.8**
Crude Oil L	13611.99626	10508.0177	4957.341456	7976.11847	5961.0482	**43014.5**
Crude Oil as feedstock L	98.26707594	1367.02732	0	30830.42	0	**32295.7**
Metallurgical Coal as feedstock kg	0	2601.96828	0	5273.31658	5273.31658	**13148.6**
Prompt Scrap Steel as feedstock kg	1224.941757	2131.71122	68911.62256	7724.72912	11996.1638	**91989.2**

Appendix A-7: Brookside- Bill of Materials

Material	**Quantity**	**Unit**
1/2" Regular Gypsum Board	28746.666	sf
5/8" Regular Gypsum Board	25807.465	sf
6 mil Polyethylene	55170.154	sf
Air Barrier	12443.89	sf
Aluminum	5.3158	Tons
Batt. Fiberglass	83546.013	sf(1")
Cold Rolled Sheet	0.2427	Tons
Concrete 20 MPa (flyash av)	221.8314	yd³
Concrete 30 MPa (flyash av)	542.7184	yd³
EPDM membrane (black, 60 mil)	40292.386	lbs
Extruded Polystyrene	82252.213	sf(1")
Galvanized Decking	40.0604	Tons
Galvanized Studs	9.5751	Tons
Glazing Panel	0.4472	Tons
Hollow Structural Steel	9.6173	Tons
Joint Compound	5.5767	Tons
Metric Modular (Modular) Brick	12317.199	sf
Mortar	39.3161	yd³
Nails	0.7507	Tons
Open Web Joists	30.9194	Tons
Paper Tape	0.064	Tons

Rebar, Rod, Light Sections	3.3213	Tons
Screws Nuts & Bolts	9.3842	Tons
Small Dimension Softwood Lumber, kiln-dried	0.3966	Mbfm
Standard Glazing	28866.679	sf
Water Based Latex Paint	945.4589	US Gallon
Welded Wire Mesh / Ladder Wire	1.8994	Tons
Wide Flange Sections	169.7618	Tons

Appendix A-8: Brookside- Air Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
2-Chloroacetophenone g	0.08579	0	**0.086**	0	0	**0**	0.0043	0	**0.004**	0	0	**0**	9E-09	**6E-07**	0.0901	0	**0.0901**
Acenaphthene g	0.02629	0	**0.026**	7E-06	0	**7E-06**	0.004	0	**0.004**	0	0	**0**	0.0266	**1.594**	0.0303	0	**1.624**
Acenaphthylene g	0.01289	0	**0.013**	3E-06	0	**3E-06**	0.0019	0	**0.002**	0	0	**0**	0.013	**0.781**	0.0148	0	**0.7961**
Acetaldehyde g	29.6263	0	**29.63**	0	0	**0**	10.683	0	**10.68**	44.829	0	**44.8**	8E-07	**5E-05**	85.138	0	**85.138**
Acetophenone g	356.37	0	**356.4**	0	0	**0**	1413	0	**1413**	0	0	**0**	2E-08	**1E-06**	1769.3	0	**1769.3**
Acid Gases g	1.397	0	**1.397**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1.397	0	**1.397**
Acrolein g	17.7392	0	**17.74**	0.0037	0	**0.004**	2.5127	0	**2.513**	5.4064	0	**5.41**	15.103	**906.2**	25.662	0	**931.87**
Aldehydes g	109.327	0	**109.3**	0.0003	0	**3E-04**	238.37	0	**238.4**	0	0	**0**	1.0302	**61.81**	347.7	0	**409.51**
Ammonia g	3266.54	80.7476	**3347**	0.0228	114.46	**114.5**	1864.1	20.827	**1885**	64.005	32	**96**	91.995	**5520**	5194.7	248	**10962**
Ammonium chloride g	10223.7	0	**10224**	0.0696	0	**0.07**	5280.9	0	**5281**	0	0	**0**	280.36	**16821**	15505	0	**32326**
Anthracene g	0.01083	0	**0.011**	3E-06	0	**3E-06**	0.0016	0	**0.002**	0	0	**0**	0.0109	**0.656**	0.0125	0	**0.6687**
Antimony g	0.97158	0	**0.972**	0.0002	0	**2E-04**	0.2969	0	**0.297**	0	0	**0**	0.9375	**56.25**	1.2687	0	**57.516**
Arsenic g	21.9579	0	**21.96**	0.0053	0	**0.005**	4.6202	0	**4.62**	0	0	**0**	21.491	**1289**	26.583	0	**1316**
Benzene g	1368.57	0	**1369**	0.0169	0	**0.017**	543.45	0	**543.4**	54.532	0	**54.5**	68.183	**4091**	1966.6	0	**6057.6**
Benzene, chloro- g	0.26963	0	**0.27**	0	0	**0**	0.0136	0	**0.014**	0	0	**0**	3E-08	**2E-06**	0.2832	0	**0.2832**
Benzene, ethyl- g	5.76723	0	**5.767**	0	0	**0**	18.364	0	**18.36**	0	0	**0**	1E-07	**8E-06**	24.131	0	**24.131**
Benzo(a)anthracene g	0.00413	0	**0.004**	1E-06	0	**1E-06**	0.0006	0	**6E-04**	0	0	**0**	0.0042	**0.25**	0.0048	0	**0.2547**
Benzo(a)pyrene g	43.4799	0	**43.48**	5E-07	0	**5E-07**	97.723	0	**97.72**	0	0	**0**	0.002	**0.119**	141.2	0	**141.32**
Benzo(b,j,k)fluoranthene g	0.00567	0	**0.006**	1E-06	0	**1E-06**	0.0009	0	**9E-04**	0	0	**0**	0.0057	**0.344**	0.0065	0	**0.3503**
Benzo(ghi)perylene g	0.00139	0	**0.001**	3E-07	0	**3E-07**	0.0002	0	**2E-04**	0	0	**0**	0.0014	**0.084**	0.0016	0	**0.086**
Benzyl chloride g	8.57898	0	**8.579**	0	0	**0**	0.4322	0	**0.432**	0	0	**0**	9E-07	**6E-05**	9.0112	0	**9.0112**
Beryllium g	1.08172	0	**1.082**	0.0003	0	**3E-04**	0.1779	0	**0.178**	0	0	**0**	1.0984	**65.9**	1.2599	0	**67.164**
Biphenyl g	0.79422	0	**0.794**	2E-05	0	**2E-05**	2.8158	0	**2.816**	0	0	**0**	0.0885	**5.312**	3.6101	0	**8.9224**
Bromoform g	0.47797	0	**0.478**	0	0	**0**	0.0241	0	**0.024**	0	0	**0**	5E-08	**3E-06**	0.5021	0	**0.5021**
BTEX g	557.414	0	**557.4**	0	0	**0**	1256.5	0	**1257**	0	0	**0**	0	**0**	1814	0	**1814**
Butadiene g	3.31245	0	**3.312**	0	0	**0**	9.0897	0	**9.09**	2.2854	0	**2.29**	0	**0**	14.687	0	**14.687**
Cadmium g	4.96353	0	**4.964**	0.0007	0	**7E-04**	1.0544	0	**1.054**	0	0	**0**	2.9263	**175.6**	6.0186	0	**181.6**
Carbon dioxide, biogenic kg	121.126	0	**121.1**	0	0	**0**	91.568	0	**91.57**	0	0	**0**	0	**0**	212.69	0	**212.69**
Carbon dioxide, fossil kg	644880	12989.2	**7E+05**	6482.9	18452	**24935**	120171	3357.2	**1E+05**	9499	5159	**14658**	263055	**2E+07**	781033	39957	**2E+07**
Carbon disulfide g	11047.9	0	**11048**	0	0	**0**	43820	0	**43820**	0	0	**0**	2E-07	**1E-05**	54868	0	**54868**
Carbon monoxide g	265889	0	**3E+05**	50211	0	**50211**	152646	0	**2E+05**	0	0	**0**	0.4884	**29.3**	468746	0	**468775**
Carbon monoxide, fossil g	470568	72251.3	**5E+05**	12.146	101823	**1E+05**	149434	18543	**2E+05**	89876	28467	**1E+05**	51968	**3E+06**	709890	2E+05	**4E+06**
Chloride g	11.85	0	**11.85**	0	0	**0**	26.632	0	**26.63**	0	0	**0**	0	**0**	38.482	0	**38.482**
Chlorine g	2.03203	0	**2.032**	0	0	**0**	4.497	0	**4.497**	0	0	**0**	0	**0**	6.5291	0	**6.5291**
Chloroform g	0.72412	0	**0.724**	0	0	**0**	0.0405	0	**0.04**	0	0	**0**	8E-08	**5E-06**	0.7646	0	**0.7646**
Chromium g	17.6809	0	**17.68**	0.0034	0	**0.003**	11.887	0	**11.89**	0	0	**0**	13.909	**834.5**	29.571	0	**864.11**
Chromium VI g	4.13111	0	**4.131**	0.001	0	**0.001**	0.8461	0	**0.846**	0	0	**0**	4.1143	**246.9**	4.9782	0	**251.84**

Chrysene g	0.00516	0	**0.005**	1E-06	0	**1E-06**	0.0008	0	**8E-04**	0	0	**0**	0.0052	**0.312**	0.0059	0	**0.3184**
Chrysene, 5-methyl- g	0.00113	0	**0.001**	3E-07	0	**3E-07**	0.0002	0	**2E-04**	0	0	**0**	0.0011	**0.069**	0.0013	0	**0.0701**
Cobalt g	11.7689	0	**11.77**	0.0014	0	**0.001**	2.4326	0	**2.433**	0	0	**0**	5.6526	**339.2**	14.203	0	**353.36**
Copper g	1.16487	0	**1.165**	0	0	**0**	4.44	0	**4.44**	0	0	**0**	0.0002	**0.012**	5.6049	0	**5.6171**
Cumene g	2.90445	0	**2.904**	0	0	**0**	11.263	0	**11.26**	0	0	**0**	7E-09	**4E-07**	14.167	0	**14.167**
Cyanide g	31.4945	0	**31.49**	0	0	**0**	4.5304	0	**4.53**	0	0	**0**	3E-06	**2E-04**	36.025	0	**36.025**
Dinitrogen monoxide g	9605.98	316.581	**9923**	0.1063	460.45	**460.6**	728.45	83.684	**812.1**	0	128.7	**129**	429.59	**25775**	10335	989.4	**37099**
Dioxins g	6.1E-07	0	**6E-07**	0	0	**0**	2E-06	0	**2E-06**	0	0	**0**	0	**0**	2E-06	0	**2E-06**
Ethane, 1,1,1-trichloro- g	0.24633	0.00038	**0.247**	1E-08	0.0005	**5E-04**	0.0131	1E-04	**0.013**	0.0003	1E-04	**0**	5E-05	**0.003**	0.2597	0.001	**0.2639**
Ethane, 1,2-dibromo- g	0.01471	0	**0.015**	0	0	**0**	0.0007	0	**7E-04**	0	0	**0**	2E-09	**1E-07**	0.0154	0	**0.0154**
Ethane, 1,2-dichloro- g	0.52685	0	**0.527**	0	0	**0**	0.1418	0	**0.142**	0	0	**0**	5E-08	**3E-06**	0.6687	0	**0.6687**
Ethane, chloro- g	0.51474	0	**0.515**	0	0	**0**	0.0259	0	**0.026**	0	0	**0**	6E-08	**3E-06**	0.5407	0	**0.5407**
Ethene, tetrachloro- g	2.42592	0	**2.426**	0.0006	0	**6E-04**	0.8675	0	**0.867**	0	0	**0**	2.2449	**134.7**	3.294	0	**137.99**
Fluoranthene g	0.03661	0	**0.037**	9E-06	0	**9E-06**	0.0056	0	**0.006**	0	0	**0**	0.037	**2.219**	0.0422	0	**2.2608**
Fluorene g	0.09443	0	**0.094**	1E-05	0	**1E-05**	0.1944	0	**0.194**	0	0	**0**	0.0474	**2.844**	0.2889	0	**3.1325**
Fluoride g	776.214	0	**776.2**	0.0016	0	**0.002**	146.18	0	**146.2**	0	0	**0**	6.2983	**377.9**	922.4	0	**1300.3**
Formaldehyde g	256.152	0	**256.2**	0.0072	0	**0.007**	42.088	0	**42.09**	68.972	0	**69**	31.337	**1880**	367.22	0	**2247.5**
Furan g	0.67734	0	**0.677**	6E-08	0	**6E-08**	2.6862	0	**2.686**	0	0	**0**	0.0003	**0.016**	3.3635	0	**3.3791**
Hexane g	32.4882	0	**32.49**	0	0	**0**	125.6	0	**125.6**	0	0	**0**	9E-08	**5E-06**	158.09	0	**158.09**
Hydrazine, methyl g	2.08347	0	**2.083**	0	0	**0**	0.105	0	**0.105**	0	0	**0**	2E-07	**1E-05**	2.1884	0	**2.1884**
Hydrocarbons, unspecified g	650432	0	**7E+05**	0.4014	0	**0.401**	36758	0	**36758**	0	0	**0**	1618.1	**97086**	687190	0	**784276**
Hydrogen chloride g	73082.1	0	**73082**	15.517	0	**15.52**	9232.6	0	**9233**	0	0	**0**	62546	**4E+06**	82330	0	**4E+06**
Hydrogen fluoride g	16675.1	0	**16675**	1.9381	0	**1.938**	1151.2	0	**1151**	0	0	**0**	7812.1	**5E+05**	17828	0	**486553**
Hydrogen sulfide g	4.67122	0	**4.671**	0	0	**0**	17.139	0	**17.14**	0	0	**0**	0	**0**	21.81	0	**21.81**
Indeno(1,2,3-cd)pyrene g	0.00315	0	**0.003**	8E-07	0	**8E-07**	0.0005	0	**5E-04**	0	0	**0**	0.0032	**0.191**	0.0036	0	**0.1942**
Isophorone g	7.1083	0	**7.108**	0	0	**0**	0.3581	0	**0.358**	0	0	**0**	8E-07	**5E-05**	7.4664	0	**7.4665**
Isoprene g	0.00124	0	**0.001**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	0.0012	0	**0.0012**
Kerosene g	4896.4	0	**4896**	0.0333	0	**0.033**	2529.1	0	**2529**	0	0	**0**	134.27	**8056**	7425.6	0	**15482**
Lead g	63.7549	0	**63.75**	0.0055	0	**0.005**	10.006	0	**10.01**	0	0	**0**	22.091	**1325**	73.766	0	**1399.2**
Magnesium g	567.536	0	**567.5**	0.1421	0	**0.142**	87.322	0	**87.32**	0	0	**0**	572.89	**34373**	655	0	**35028**
Manganese g	28.3557	0	**28.36**	0.0064	0	**0.006**	5.2894	0	**5.289**	0	0	**0**	25.815	**1549**	33.652	0	**1582.5**
Mercaptans, unspecified g	2659.48	0	**2659**	0	0	**0**	133.98	0	**134**	0	0	**0**	0.0003	**0.018**	2793.5	0	**2793.5**
Mercury g	20.3477	0	**20.35**	0.0011	0	**0.001**	2.9222	0	**2.922**	0	0	**0**	4.388	**263.3**	23.271	0	**286.55**
Metals, unspecified g	568.207	0	**568.2**	0	0	**0**	0.0015	0	**0.002**	0	0	**0**	0	**0**	568.21	0	**568.21**
Methacrylic acid, ester g	0.24511	0	**0.245**	0	0	**0**	0.0123	0	**0.012**	0	0	**0**	3E-08	**2E-06**	0.2575	0	**0.2575**
Methane g	1184752	0	**1E+06**	761.43	0	**761.4**	256539	0	**3E+05**	0	0	**0**	534451	**3E+07**	1E+06	0	**3E+07**
Methane, bromo-,Halon g	1.96091	0	**1.961**	0	0	**0**	0.0988	0	**0.099**	0	0	**0**	2E-07	**1E-05**	2.0597	0	**2.0597**
Methane, dichlor-,HCC-30 g	30.6682	0	**30.67**	0.0038	0	**0.004**	43.941	0	**43.94**	0	0	**0**	15.421	**925.3**	74.613	0	**999.88**
Methane, di-CFC-12 g	0.00167	0.00046	**0.002**	2E-08	0.0006	**6E-04**	0.0016	0.0001	**0.002**	0.0004	2E-04	**0**	6E-05	**0.004**	0.0036	0.001	**0.0088**
Methane, fossil g	160131	14531.6	**2E+05**	5.0701	20579	**20584**	45204	3745.1	**48950**	11811	5753	**17565**	23425	**1E+06**	217152	44609	**2E+06**
Methane, monochlo-,R-40 g	6.55808	0	**6.558**	0	0	**0**	0.5754	0	**0.575**	0	0	**0**	7E-07	**4E-05**	7.1335	0	**7.1336**
Methane, tetrachl-,CFC10 g	0.03385	5E-05	**0.034**	2E-09	7E-05	**7E-05**	0.0774	1E-05	**0.077**	4E-05	2E-05	**0**	6E-06	**4E-04**	0.1113	2E-04	**0.1118**
Methyl ethyl ketone g	82.7083	0	**82.71**	0	0	**0**	309.32	0	**309.3**	0	0	**0**	5E-07	**3E-05**	392.03	0	**392.03**
Naphthalene g	4.78259	0	**4.783**	0.0002	0	**2E-04**	8.8451	0	**8.845**	0	0	**0**	0.8912	**53.47**	13.628	0	**67.102**
Nickel g	109.309	0	**109.3**	0.0052	0	**0.005**	26.001	0	**26**	0	0	**0**	21.024	**1261**	135.31	0	**1396.7**
Nitrogen oxides g	1158091	96422.4	**1E+06**	71142	124789	**2E+05**	502544	23002	**5E+05**	1244.4	34880	**36124**	33383	**2E+06**	2E+06	3E+05	**4E+06**
Nitrous oxides g	0.48911	0	**0.489**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	0.4891	0	**0.4891**
NMVOC, non-meth , uns g	39797.7	0	**39798**	0	0	**0**	18367	0	**18367**	0	0	**0**	0	**0**	58164	0	**58164**
Organic acids g	77.8291	0	**77.83**	0.0003	0	**3E-04**	23.546	0	**23.55**	0	0	**0**	1.0302	**61.81**	101.38	0	**163.19**
Organic subst, unspecified g	312.314	0	**312.3**	0.0783	0	**0.078**	47.217	0	**47.22**	0	0	**0**	315.46	**18928**	359.61	0	**19287**
Other g	7453.99	0	**7454**	0	0	**0**	3974.2	0	**3974**	0	0	**0**	0	**0**	11428	0	**11428**
PAH, g	384.285	0	**384.3**	0	0	**0**	856.9	0	**856.9**	9.8193	0	**9.82**	0	**0**	1251	0	**1251**
Particulates,>2.5&<10um g	90878.8	1728.45	**92607**	2.8068	2123.9	**2127**	7053.1	394.57	**7448**	5803.8	593.6	**6397**	11569	**7E+05**	103739	4841	**802701**

Particulates, unspecified g	1500554	922.859	**2E+06**	43.531	1308.1	**1352**	1E+06	238.03	**1E+06**	731.5	365.7	**1097**	175468	**1E+07**	3E+06	2835	**1E+07**
Phenanthrene g	0.13928	0	**0.139**	3E-05	0	**3E-05**	0.0212	0	**0.021**	0	0	**0**	0.1406	**8.437**	0.1605	0	**8.5977**
Phenol g	1545.54	0	**1546**	0	0	**0**	3.0489	0	**3.049**	0	0	**0**	2E-08	**1E-06**	1548.6	0	**1548.6**
Phenols, unspecified g	4.9156	0	**4.916**	0.0003	0	**3E-04**	1.1174	0	**1.117**	0	0	**0**	1.0727	**64.36**	6.0332	0	**70.393**
Phthalate, dioctyl- g	0.89467	0	**0.895**	0	0	**0**	0.0451	0	**0.045**	0	0	**0**	1E-07	**6E-06**	0.9397	0	**0.9397**
Propanal g	4.65778	0	**4.658**	0	0	**0**	0.2371	0	**0.237**	0	0	**0**	5E-07	**3E-05**	4.8949	0	**4.8949**
Propene g	72.8969	0	**72.9**	0	0	**0**	21.876	0	**21.88**	150.8	0	**151**	0	**0**	245.57	0	**245.57**
Propylene oxide g	0.01251	0	**0.013**	0	0	**0**	0.0493	0	**0.049**	0	0	**0**	0	**0**	0.0618	0	**0.0618**
Pyrene g	0.01701	0	**0.017**	4E-06	0	**4E-06**	0.0026	0	**0.003**	0	0	**0**	0.0172	**1.031**	0.0196	0	**1.0508**
Radioactive species, MBq	2319.83	0	**2320**	0.7311	0	**0.731**	782.88	0	**782.9**	0	0	**0**	2946.8	**2E+05**	3103.4	0	**179913**
Radionuclides, Inc Radon g	273811	0	**3E+05**	1.8628	0	**1.863**	141432	0	**1E+05**	0	0	**0**	7508.5	**5E+05**	415245	0	**865753**
Selenium g	67.9369	0	**67.94**	0.0168	0	**0.017**	10.504	0	**10.5**	0	0	**0**	67.76	**4066**	78.458	0	**4144.1**
Styrene g	1.39864	0	**1.399**	0	0	**0**	4.3482	0	**4.348**	0	0	**0**	3E-08	**2E-06**	5.7468	0	**5.7468**
Sulfur dioxide g	3915253	0	**4E+06**	453.57	0	**453.6**	1E+06	0	**1E+06**	0	0	**0**	2E+06	**1E+08**	5E+06	0	**1E+08**
Sulfur oxides g	355729	11896.9	**4E+05**	9078.7	16872	**25951**	263608	3070	**3E+05**	9267.7	4717	**13985**	1774.1	**1E+05**	637683	36556	**780687**
Sulfuric acid, dimeth ester g	0.59082	0	**0.591**	0	0	**0**	0.0396	0	**0.04**	0	0	**0**	6E-08	**4E-06**	0.6304	0	**0.6304**
Tar g	4.3E-11	0	**4E-11**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	4E-11	0	**4E-11**
t-Butyl methyl ether g	0.44179	0	**0.442**	0	0	**0**	0.0725	0	**0.073**	0	0	**0**	5E-08	**3E-06**	0.5143	0	**0.5143**
TOC, Total Organ Carbon g	2.05503	0	**2.055**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	2.055	0	**2.055**
Toluene g	51.8224	0	**51.82**	0	0	**0**	151.56	0	**151.6**	23.906	0	**23.9**	3E-07	**2E-05**	227.29	0	**227.29**
Toluene, 2,4-dinitro- g	0.00343	0	**0.003**	0	0	**0**	0.0002	0	**2E-04**	0	0	**0**	4E-10	**2E-08**	0.0036	0	**0.0036**
Vinyl acetate g	0.09314	0	**0.093**	0	0	**0**	0.0047	0	**0.005**	0	0	**0**	1E-08	**6E-07**	0.0978	0	**0.0978**
VOC, g	60805.5	4452.98	**65259**	9203.9	6073.2	**15277**	12199	1103.9	**13303**	4754.4	1698	**6452**	11655	**7E+05**	86963	13328	**799598**
Xylene g	99.8997	0	**99.9**	0	0	**0**	364.63	0	**364.6**	16.658	0	**16.7**	5E-08	**3E-06**	481.19	0	**481.19**
Zinc g	18.1493	0	**18.15**	0	0	**0**	71.832	0	**71.83**	0	0	**0**	0.0001	**0.008**	89.981	0	**89.989**

Appendix A-9: Brookside- Air Emissions by Bldg Assembly

Material ID	**Foundations**	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
2-Chloroacetophenone g	0	0	0	0	0	**0**
Acenaphthene g	0	0	0	0	0	**0**
Acenaphthylene g	0	0	0	0	0	**0**
Acetaldehyde g	20	13	26	14	13	**85**
Acetophenone g	0	31	0	1,739	0	**1,769**
Acid Gases g	0	1	0	0	0	**1**
Acrolein g	4	7	8	2	4	**26**
Aldehydes g	13	94	7	229	4	**348**
Ammonia g	943	2,644	611	843	402	**5,443**
Ammonium chloride g	2,691	8,394	1,868	1,452	1,100	**15,505**
Anthracene g	0	0	0	0	0	**0**
Antimony g	0	0	0	0	0	**1**
Arsenic g	5	6	8	5	3	**27**
Benzene g	948	164	57	595	203	**1,967**
Benzene, chloro- g	0	0	0	0	0	**0**
Benzene, ethyl- g	1	1	0	23	0	**24**
Benzo(a)anthracene g	0	0	0	0	0	**0**
Benzo(a)pyrene g	0	141	0	0	0	**141**
Benzo(b,j,k)fluoranthene g	0	0	0	0	0	**0**
Benzo(ghi)perylene g	0	0	0	0	0	**0**
Benzyl chloride g	7	1	0	0	1	**9**

Beryllium g	0	0	0	0	0	**1**
Biphenyl g	0	0	0	3	0	**4**
Bromoform g	0	0	0	0	0	**1**
BTEX, g	95	81	0	1,638	0	**1,814**
Butadiene g	1	1	1	11	1	**15**
Cadmium g	1	1	2	1	1	**6**
Carbon dioxide, biogenic kg	0	100	0	112	0	**213**
Carbon dioxide, fossil kg	194,503	209,627	180,818	126,149	109,893	**820,990**
Carbon disulfide g	1	948	0	53,918	0	**54,868**
Carbon monoxide g	41,254	253,704	46,991	64,586	62,211	**468,746**
Carbon monoxide, fossil g	213,731	276,122	135,332	199,380	106,409	**930,974**
Chloride g	0	38	0	0	0	**38**
Chlorine g	0	4	0	3	0	**7**
Chloroform g	1	0	0	0	0	**1**
Chromium g	3	4	6	14	2	**30**
Chromium VI g	1	1	1	1	1	**5**
Chrysene g	0	0	0	0	0	**0**
Chrysene, 5-methyl- g	0	0	0	0	0	**0**
Cobalt g	3	3	2	4	2	**14**
Copper g	0	0	0	5	0	**6**
Cumene g	0	0	0	14	0	**14**
Cyanide g	24	3	0	4	5	**36**
Dinitrogen monoxide g	7,582	1,451	275	378	1,637	**11,324**
Dioxins, g	0	0	0	0	0	**0**
Ethane, 1,1,1-trichloro-, HCFC-140 g	0	0	0	0	0	**0**
Ethane, 1,2-dibromo- g	0	0	0	0	0	**0**
Ethane, 1,2-dichloro- g	0	0	0	0	0	**1**
Ethane, chloro- g	0	0	0	0	0	**1**
Ethene, tetrachloro- g	1	1	1	1	0	**3**
Fluoranthene g	0	0	0	0	0	**0**
Fluorene g	0	0	0	0	0	**0**
Fluoride g	493	245	42	33	109	**922**
Formaldehyde g	105	77	84	52	49	**367**
Furan g	0	0	0	3	0	**3**
Hexane g	1	3	0	154	0	**158**
Hydrazine, methyl g	2	0	0	0	0	**2**
Hydrocarbons, unspecified g	15,530	58,017	10,783	596,514	6,347	**687,190**
Hydrogen chloride g	10,846	32,669	22,061	8,073	8,681	**82,330**
Hydrogen fluoride g	1,602	11,381	2,755	965	1,126	**17,828**
Hydrogen sulfide g	0	3	0	19	0	**22**
Indeno(1,2,3-cd)pyrene g	0	0	0	0	0	**0**
Isophorone g	6	1	0	0	1	**7**
Isoprene g	0	0	0	0	0	**0**
Kerosene g	1,289	4,020	895	696	527	**7,426**
Lead g	37	11	8	9	10	**74**
Magnesium g	150	143	202	72	89	**655**
Manganese g	6	8	9	6	4	**34**
Mercaptans, unspecified g	2,106	274	2	2	410	**2,793**
Mercury g	13	5	2	1	3	**23**
Metals, unspecified g	0	22	0	546	0	**568**
Methacrylic acid, methyl ester g	0	0	0	0	0	**0**
Methane g	166,091	438,582	444,301	242,021	151,058	**1,442,053**
Methane, bromo-, Halon 1001 g	2	0	0	0	0	**2**

Methane, dichloro-, HCC-30 g	5	6	6	54	3	**75**
Methane, dichlorodifluoro-, CFC-12 g	0	0	0	0	0	**0**
Methane, fossil g	40,878	67,646	60,095	63,589	29,552	**261,760**
Methane, monochloro-, R-40 g	5	1	0	0	1	**7**
Methane, tetrachloro-, CFC-10 g	0	0	0	0	0	**0**
Methyl ethyl ketone g	4	7	0	380	1	**392**
Naphthalene g	1	1	1	11	0	**14**
Nickel g	29	32	9	52	14	**135**
Nitrogen oxides g	566,882	801,647	203,824	249,057	190,704	**2,012,115**
Nitrous oxides g	0	0	0	0	0	**0**
NMVOC g	621	13,404	8,419	27,394	8,326	**58,164**
Organic acids g	25	40	7	25	4	**101**
Organic substances, unspecified g	82	79	111	39	49	**360**
Other g	0	11,428	0	0	0	**11,428**
PAH, g	3	1,229	6	10	3	**1,251**
Particulates, > 2.5 um, and < 10um g	44,780	33,992	11,386	5,817	12,604	**108,579**
Particulates, unspecified g	412,013	2,222,803	116,250	86,623	137,676	**2,975,366**
Phenanthrene g	0	0	0	0	0	**0**
Phenol g	0	1,545	0	4	0	**1,549**
Phenols, unspecified g	1	1	0	2	1	**6**
Phthalate, dioctyl- g	1	0	0	0	0	**1**
Propanal g	4	0	0	0	1	**5**
Propene g	48	40	86	31	40	**246**
Propylene oxide g	0	0	0	0	0	**0**
Pyrene g	0	0	0	0	0	**0**
Radioactive species, unspecified MBq	221	670	1,039	823	350	**3,103**
Radionuclides (Including Radon) g	72,062	224,799	50,036	38,897	29,451	**415,245**
Selenium g	18	17	24	9	11	**78**
Styrene g	0	0	0	5	0	**6**
Sulfur dioxide g	785,726	1,695,692	1,309,668	639,885	518,041	**4,949,012**
Sulfur oxides g	58,235	428,384	18,145	132,035	37,439	**674,239**
Sulfuric acid, dimethyl ester g	0	0	0	0	0	**1**
Tar g	0	0	0	0	0	**0**
t-Butyl methyl ether g	0	0	0	0	0	**1**
TOC, Total Organic Carbon g	0	2	0	0	0	**2**
Toluene g	10	10	14	187	7	**227**
Toluene, 2,4-dinitro- g	0	0	0	0	0	**0**
Vinyl acetate g	0	0	0	0	0	**0**
VOC, volatile organic compounds g	20,392	25,381	26,578	15,866	12,074	**100,291**
Xylene g	6	13	10	449	5	**481**
Zinc g	0	2	0	88	0	**90**

Appendix A-10: Brookside- Water Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
2-Hexanone mg	2039.9	92.29	**2132**	0.0646	130.81	**130.9**	486.599	23.803	**510.4**	73.1504	36.571	**109.7**	304.7	**18281**	2599.66	283.47	**21164**
Acetone mg	3124.1	141.3	**3265**	0.0989	200.33	**200.4**	745.236	36.454	**781.7**	112.028	56.008	**168**	466.6	**27997**	3981.42	434.13	**32412**
Acids, unspec mg	618570	0	**6E+05**	0	0	**0**	1936870	0	**2E+06**	0	0	**0**	0	**0**	2555440	0	**3E+06**
Aluminum mg	1E+07	1E+06	**1E+07**	215.37	2E+06	**2E+06**	4760882	326860	**5E+06**	1004490	502193	**2E+06**	1E+06	**6E+07**	1.6E+07	4E+06	**8E+07**
Ammonia mg	4E+06	3E+05	**5E+06**	125.09	381670	**4E+05**	1153472	69450	**1E+06**	213432	106705	**3E+05**	6E+05	**4E+07**	5662057	827088	**4E+07**
Ammonia, as N mg	4E-07	0	**4E-07**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	4E-07	0	**4E-07**
Ammonium, ion mg	3E+06	0	**3E+06**	0	0	**0**	4407610	0	**4E+06**	0	0	**0**	0	**0**	7302249	0	**7E+06**
Antimony mg	7667.9	791.9	**8460**	0.132	1122.5	**1123**	5030.65	204.25	**5235**	627.692	313.81	**941.5**	610.6	**36637**	13326.4	2432.4	**52396**
Arsenic, ion mg	72959	3910	**76869**	2.2128	5542.1	**5544**	19873	1008.5	**20881**	3099.19	1549.4	**4649**	10422	**6E+05**	95933.5	12010	**7E+05**
Barium mg	1E+08	2E+07	**2E+08**	3254.9	2E+07	**2E+07**	4.9E+07	4E+06	**5E+07**	1.4E+07	7E+06	**2E+07**	2E+07	**9E+08**	2.1E+08	5E+07	**1E+09**
Benzene mg	677093	23710	**7E+05**	16.596	33608	**33624**	159036	6115.4	**2E+05**	18793.6	9395.8	**28189**	78279	**5E+06**	854939	72829	**6E+06**
Benzene, 1-meth µg	31219	1412	**32631**	0.9886	2001.9	**2003**	7447.07	364.28	**7811**	1119.49	559.69	**1679**	4663	**3E+05**	39786.3	4338.2	**3E+05**
Benzene, ethyl- mg	32914	1334	**34247**	0.9336	1890.5	**1891**	20585	344.01	**20929**	1057.18	528.54	**1586**	4403	**3E+05**	54556.6	4096.8	**3E+05**
Benzene, pentamt µg	23414	1059	**24473**	0.7414	1501.5	**1502**	5585.31	273.22	**5859**	839.633	419.77	**1259**	3497	**2E+05**	29839.6	3253.7	**2E+05**
Benzenes, unsp mg	5401.2	694.7	**6096**	0.1156	984.73	**984.8**	1851.67	179.19	**2031**	550.668	275.31	**826**	534.4	**32063**	7803.68	2133.9	**42001**
Benzoic acid mg	316920	14337	**3E+05**	10.036	20323	**20333**	75599.3	3698	**79297**	11364.4	5681.6	**17046**	47336	**3E+06**	403894	44039	**3E+06**
Beryllium mg	3478.8	219.3	**3698**	0.1017	310.88	**311**	963.868	56.57	**1020**	173.848	86.915	**260.8**	478	**28681**	4616.61	673.7	**33972**
Biphenyl µg	349713	44980	**4E+05**	7.4817	63757	**63765**	119889	11602	**1E+05**	35653.4	17825	**53478**	34600	**2E+06**	505263	138164	**3E+06**
BOD5 mg	6E+07	3E+06	**6E+07**	1726.8	4E+06	**4E+06**	2.3E+07	668459	**2E+07**	2054274	1E+06	**3E+06**	8E+06	**5E+08**	8.5E+07	8E+06	**6E+08**
Boron mg	1E+06	44360	**1E+06**	31.049	62878	**62909**	1935778	11442	**2E+06**	35161.7	17579	**52741**	1E+05	**9E+06**	3380611	136258	**1E+07**
Bromide mg	7E+07	3E+06	**7E+07**	2120.1	4E+06	**4E+06**	1.6E+07	780996	**2E+07**	2400117	1E+06	**4E+06**	1E+07	**6E+08**	8.5E+07	9E+06	**7E+08**
Cadmium, ion mg	17693	577.1	**18270**	0.3225	818.03	**818.4**	30840.4	148.85	**30989**	457.446	228.7	**686.1**	1519	**91119**	48990.8	1772.7	**1E+05**
Calcium, ion mg	1E+09	5E+07	**1E+09**	31796	6E+07	**6E+07**	2.6E+08	1E+07	**3E+08**	3.6E+07	2E+07	**5E+07**	1E+08	**9E+09**	1.3E+09	1E+08	**1E+10**
Chloride mg	1E+10	5E+08	**1E+10**	357375	7E+08	**7E+08**	5E+09	1E+08	**5E+09**	4E+08	2E+08	**6E+08**	2E+09	**1E+11**	1.8E+10	2E+09	**1E+11**
Chromium mg	155194	33813	**2E+05**	1.1132	47928	**47929**	96088.2	8721.2	**1E+05**	26801.6	13399	**40201**	4603	**3E+05**	278085	103861	**7E+05**
Chromium VI µg	1E+07	1E+05	**1E+07**	4.6841	201664	**2E+05**	3.3E+07	36696	**3E+07**	112772	56380	**2E+05**	19368	**1E+06**	4.3E+07	437011	**5E+07**
Chromium, ion mg	138264	2192	**1E+05**	4.8464	3106.8	**3112**	31190.5	565.32	**31756**	1737.32	868.57	**2606**	22955	**1E+06**	171196	6732.4	**2E+06**
Cobalt mg	11722	313.1	**12036**	0.2192	443.84	**444.1**	18661.2	80.763	**18742**	248.196	124.09	**372.3**	1034	**62028**	30632.1	961.81	**93622**
COD mg	2E+08	5E+06	**2E+08**	2875	7E+06	**7E+06**	4.3E+07	1E+06	**4E+07**	3923792	2E+06	**6E+06**	1E+07	**8E+08**	2.3E+08	2E+07	**1E+09**
Copper, ion mg	60164	4067	**64231**	1.4647	5765.4	**5767**	24752.3	1049.1	**25801**	3224.02	1611.8	**4836**	6869	**4E+05**	88141.5	12494	**5E+05**
Cyanide mg	2E+07	1.02	**2E+07**	0.0007	1.4459	**1.447**	18333.8	0.2631	**18334**	0.80853	0.4042	**1.213**	3.368	**202.1**	1.7E+07	3.1332	**2E+07**
Decane mg	9106.5	412	**9519**	0.2884	583.98	**584.3**	2172.32	106.26	**2279**	326.562	163.26	**489.8**	1360	**81610**	11605.7	1265.5	**94481**
Detergents, oil mg	301665	11770	**3E+05**	9.7839	16683	**16693**	69612.2	3035.7	**72648**	9329.18	4664.1	**13993**	46193	**3E+06**	380616	36152	**3E+06**
Dibenzofuran µg	59403	2687	**62091**	1.8811	3809.3	**3811**	14170.3	693.15	**14863**	2130.16	1065	**3195**	8873	**5E+05**	75705.6	8254.8	**6E+05**
Dibenzothiophen µg	40564	138.8	**40703**	1.457	196.78	**198.2**	10359.6	35.808	**10395**	110.042	55.015	**165.1**	6911	**4E+05**	51035.4	426.43	**5E+05**
Dissolved organi mg	4E+06	0	**4E+06**	0	0	**0**	6432000	0	**6E+06**	0	0	**0**	0	**0**	1.1E+07	0	**1E+07**
Dissolved solids mg	1E+10	6E+08	**1E+10**	440867	9E+08	**9E+08**	1.7E+09	2E+08	**2E+09**	5E+08	2E+08	**7E+08**	2E+09	**1E+11**	1.6E+10	2E+09	**1E+11**
Docosane µg	334305	15124	**3E+05**	10.586	21437	**21448**	79746.3	3900.8	**83647**	11987.8	5993.3	**17981**	49933	**3E+06**	426049	46455	**3E+06**
Dodecane mg	17278	781.7	**18060**	0.5471	1108	**1109**	4121.66	201.61	**4323**	619.592	309.76	**929.4**	2581	**2E+05**	22020.1	2401	**2E+05**
Eicosane mg	4757.2	215.2	**4972**	0.1506	305.06	**305.2**	1134.8	55.51	**1190**	170.59	85.286	**255.9**	710.5	**42633**	6062.75	661.07	**49357**
Fluorene, 1-meth µg	35555	1609	**37163**	1.1259	2280	**2281**	8481.4	414.88	**8896**	1274.99	637.43	**1912**	5311	**3E+05**	45312.2	4940.8	**4E+05**
Fluorenes, unsp µg	313019	40261	**4E+05**	6.6967	57068	**57074**	107310	10384	**1E+05**	31912.5	15955	**47867**	30970	**2E+06**	452248	123667	**2E+06**
Fluoride mg	1E+07	0	**1E+07**	0	0	**0**	1972033	0	**2E+06**	0	0	**0**	0	**0**	1.5E+07	0	**1E+07**
Fluorine µg	171642	19819	**2E+05**	3.9454	28093	**28097**	56282.5	5111.9	**61394**	15709.8	7854.1	**23564**	18325	**1E+06**	243638	60878	**1E+06**
Halogenated orgn µg	7E-05	0	**7E-05**	0	0	**0**	0.00078	0	**8E-04**	0	0	**0**	0	**0**	0.00086	0	**9E-04**
Hexadecane mg	18859	853.2	**19712**	0.5972	1209.4	**1210**	4498.76	220.06	**4719**	676.289	338.11	**1014**	2817	**2E+05**	24034.8	2620.7	**2E+05**
Hexanoic acid mg	65630	2969	**68600**	2.0783	4208.6	**4211**	15655.8	765.82	**16422**	2353.47	1176.6	**3530**	9803	**6E+05**	83641.8	9120.2	**7E+05**
Hydrocarbons µg	7E+08	0	**7E+08**	0	0	**0**	2.6E+09	0	**3E+09**	0	0	**0**	0	**0**	3.3E+09	0	**3E+09**

Iron mg	4E+07	3E+06	**4E+07**	849.33	4E+06	**4E+06**	1.5E+07	647393	**2E+07**	1989535	994664	**3E+06**	4E+06	**2E+08**	5.4E+07	8E+06	**3E+08**
Lead mg	9E+06	8315	**9E+06**	3.2685	11787	**11790**	40247.5	2144.7	**42392**	6591.13	3295.2	**9886**	15344	**9E+05**	8902033	25542	**1E+07**
Lead-210/kg µg	7E+08	0.001	**7E+08**	1E-06	0.0021	**0.002**	1.4E+09	0.0004	**1E+09**	0.00116	0.0006	**0.002**	0.005	**0.291**	2E+09	0.0045	**2E+09**
Lithium, ion mg	3E+08	15172	**3E+08**	10121	21505	**31626**	4.9E+07	3913.2	**5E+07**	12026	6012.4	**18038**	5E+07	**3E+09**	3.2E+08	46603	**3E+09**
Magnesium mg	2E+08	9E+06	**2E+08**	6216.2	1E+07	**1E+07**	5E+07	2E+06	**5E+07**	7035179	4E+06	**1E+07**	3E+07	**2E+09**	2.5E+08	3E+07	**2E+09**
Manganese mg	1E+07	14144	**1E+07**	156.86	20049	**20206**	2.4E+07	3648.2	**2E+07**	11211.6	5605.2	**16817**	6E+05	**4E+07**	3.6E+07	43447	**7E+07**
Mercury µg	123708	13883	**1E+05**	2.3092	19678	**19681**	93300.3	3580.8	**96881**	11004.2	5501.5	**16506**	10679	**6E+05**	228015	42643	**9E+05**
Metallic ions, uns mg	602687	0	**6E+05**	0	0	**0**	1165414	0	**1E+06**	0	0	**0**	0	**0**	1768101	0	**2E+06**
Methane, mono µg	12575	568.9	**13144**	0.3982	806.36	**806.8**	2999.62	146.73	**3146**	450.922	225.44	**676.4**	1878	**1E+05**	16025.6	1747.4	**1E+05**
Methyl ethyl ket µg	25148	1138	**26286**	0.7964	1612.7	**1613**	5999.02	293.45	**6292**	901.813	450.86	**1353**	3756	**2E+05**	32050	3494.7	**3E+05**
Molybdenum mg	7289.2	324.9	**7614**	0.2274	460.53	**460.8**	2127.91	83.8	**2212**	257.531	128.75	**386.3**	1073	**64360**	9674.88	997.98	**75033**
m-Xylene mg	9465.6	428.2	**9894**	0.2997	606.97	**607.3**	2257.95	110.45	**2368**	339.421	169.69	**509.1**	1414	**84828**	12063.2	1315.3	**98207**
Naphthalene mg	-9951.9	257.6	**-9694**	0.1797	365.07	**365.3**	1293.11	66.43	**1360**	204.15	102.06	**306.2**	847.5	**50851**	-8454.4	791.12	**43188**
Naphthalene mg	4948.4	223.9	**5172**	0.1567	317.32	**317.5**	1180.42	57.741	**1238**	177.447	88.714	**266.2**	739.1	**44347**	6306.44	687.64	**51341**
Naphthalenes µg	88508	11384	**99892**	1.8935	16136	**16138**	30342.5	2936.2	**33279**	9023.49	4511.3	**13535**	8757	**5E+05**	127876	34968	**7E+05**
n-Hexacosane µg	208559	9435	**2E+05**	6.6043	13374	**13381**	49750.9	2433.6	**52185**	7478.92	3739.1	**11218**	31151	**2E+06**	265796	28982	**2E+06**
Nickel mg	148260	3885	**2E+05**	1.7779	5507.3	**5509**	74553.6	1002.1	**75556**	3079.68	1539.7	**4619**	8359	**5E+05**	225895	11934	**7E+05**
Nitrate mg	1E+06	0	**1E+06**	0	0	**0**	1508589	0	**2E+06**	0	0	**0**	0	**0**	2794567	0	**3E+06**
Nitrate compound mg	1E-08	0	**1E-08**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1.1E-08	0	**1E-08**
Nitric acid mg	2E-05	0	**2E-05**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	2.4E-05	0	**2E-05**
Nitrogen, total mg	2E+07	0	**2E+07**	0	0	**0**	68748.5	0	**68748**	0	0	**0**	0	**0**	1.8E+07	0	**2E+07**
Non-halogen Orgn µg	7E+08	0	**7E+08**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	6.6E+08	0	**7E+08**
o-Cresol mg	8987.3	406.6	**9394**	0.2846	576.31	**576.6**	2143.86	104.87	**2249**	322.276	161.12	**483.4**	1342	**80542**	11453.7	1248.9	**93244**
Octadecane mg	4659.2	210.8	**4870**	0.1475	298.77	**298.9**	1111.42	54.366	**1166**	167.076	83.529	**250.6**	695.9	**41755**	5937.84	647.45	**48340**
Oils, unspecified mg	5E+08	3E+05	**5E+08**	243.93	465530	**5E+05**	1.9E+07	84710	**2E+07**	260327	130150	**4E+05**	1E+06	**7E+07**	5.1E+08	1E+06	**6E+08**
Other mg	8E+08	0	**8E+08**	0	0	**0**	1.7E+09	0	**2E+09**	0	0	**0**	0	**0**	2.5E+09	0	**2E+09**
Other metals mg	1E+08	0	**1E+08**	0	0	**0**	2.1E+08	0	**2E+08**	0	0	**0**	0	**0**	3.1E+08	0	**3E+08**
p-Cresol mg	9696.8	438.7	**10135**	0.3071	621.79	**622.1**	2313.1	113.14	**2426**	347.709	173.84	**521.5**	1448	**86901**	12357.9	1347.4	**1E+05**
Pentanone, meth- mg	1256.4	59.4	**1316**	0.0416	84.192	**84.23**	164.798	15.32	**180.1**	47.0808	23.538	**70.62**	196.1	**11766**	1468.32	182.45	**13417**
Phenanthrene µg	49338	4032	**53370**	1.3406	5715.2	**5717**	14020.4	1040	**15060**	3195.98	1597.8	**4794**	6281	**4E+05**	66555.6	12385	**5E+05**
Phenanthrenes µg	36699	4720	**41419**	0.7851	6690.8	**6692**	12581.3	1217.5	**13799**	3741.51	1870.6	**5612**	3631	**2E+05**	53022.5	14499	**3E+05**
Phenol µg	2E+08	6E+06	**2E+08**	207.3	9E+06	**9E+06**	6.2E+07	2E+06	**6E+07**	4990776	2E+06	**7E+06**	9E+05	**5E+07**	3E+08	2E+07	**4E+08**
Phenol, 2,4-di- mg	8750.8	395.9	**9147**	0.2771	561.15	**561.4**	2087.45	102.11	**2190**	313.799	156.88	**470.7**	1307	**78423**	11152.3	1216	**90791**
Phenols, unspec mg	117216	884.4	**1E+05**	4.2469	1253.6	**1258**	22946.9	228.11	**23175**	701.028	350.48	**1052**	20136	**1E+06**	140868	2716.6	**1E+06**
Phosphate mg	6E+06	0	**6E+06**	0	0	**0**	516282	0	**5E+05**	0	0	**0**	0	**0**	6865161	0	**7E+06**
Phosphorus mg	4E+07	0	**4E+07**	0	0	**0**	31562.3	0	**31562**	0	0	**0**	0	**0**	3.9E+07	0	**4E+07**
Polynucl Hydroc µg	229.12	0	**229.1**	0	0	**0**	234.577	0	**234.6**	0	0	**0**	0	**0**	463.695	0	**463.7**
Radium-226/kg µg	10.807	0.511	**11.32**	0.0004	0.7242	**0.725**	1.41751	0.1318	**1.549**	0.40497	0.2025	**0.607**	1.687	**101.2**	12.6298	1.5693	**115.4**
Radium-228/kg µg	0.0553	0.003	**0.058**	2E-06	0.0037	**0.004**	0.00725	0.0007	**0.008**	0.00207	0.001	**0.003**	0.009	**0.518**	0.0646	0.008	**0.59**
Selenium µg	1E+06	2E+05	**1E+06**	25.99	217658	**2E+05**	646847	39606	**7E+05**	121716	60851	**2E+05**	1E+05	**7E+06**	2089590	471671	**1E+07**
Silver mg	655019	29690	**7E+05**	20.732	42084	**42105**	156653	7657.8	**2E+05**	23533.5	11766	**35299**	97786	**6E+06**	835227	91197	**7E+06**
Sodium, ion mg	3E+09	1E+08	**3E+09**	100791	2E+08	**2E+08**	9.3E+08	4E+07	**1E+09**	1.1E+08	6E+07	**2E+08**	5E+08	**3E+10**	4.3E+09	4E+08	**3E+10**
Solids, inorganic mg	149755	0	**1E+05**	0	0	**0**	591902	0	**6E+05**	0	0	**0**	0	**0**	741657	0	**7E+05**
Strontium mg	2E+07	8E+05	**2E+07**	539.3	1E+06	**1E+06**	5085270	198733	**5E+06**	610737	305336	**9E+05**	3E+06	**2E+08**	2.3E+07	2E+06	**2E+08**
Sulfate mg	2E+08	1E+06	**2E+08**	727.87	1E+06	**1E+06**	5.1E+07	264930	**5E+07**	814168	407042	**1E+06**	3E+06	**2E+08**	2.8E+08	3E+06	**5E+08**
Sulfide mg	5E+07	730.6	**5E+07**	0.0241	1035.6	**1036**	309454	188.44	**3E+05**	579.095	289.52	**868.6**	99.46	**5968**	5.2E+07	2244.1	**5E+07**
Sulfur mg	832496	37446	**9E+05**	26.21	53077	**53104**	216422	9658.2	**2E+05**	29681.2	14839	**44520**	1E+05	**7E+06**	1078625	115020	**9E+06**
Suspended solids mg	3E+09	4E+07	**3E+09**	9912.7	6E+07	**6E+07**	1.2E+08	1E+07	**1E+08**	3.1E+07	2E+07	**5E+07**	4E+07	**3E+09**	3E+09	1E+08	**6E+09**
Tar mg	6E-10	0	**6E-10**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	6.1E-10	0	**6E-10**
Tetradecane mg	7572.4	342.6	**7915**	0.2398	485.59	**485.8**	1806.36	88.36	**1895**	271.543	135.76	**407.3**	1131	**67862**	9650.56	1052.3	**78565**
Thallium µg	1E+06	2E+05	**1E+06**	27.895	236515	**2E+05**	458087	43037	**5E+05**	132261	66123	**2E+05**	1E+05	**8E+06**	1894656	512535	**1E+07**
Tin mg	41289	3178	**44466**	1.1426	4504.2	**4505**	11839.7	819.61	**12659**	2518.77	1259.3	**3778**	5358	**3E+05**	55648.3	9760.7	**4E+05**
Titanium, ion mg	217694	12161	**2E+05**	2.0299	17237	**17240**	342020	3136.6	**3E+05**	9639.3	4819.1	**14458**	9389	**6E+05**	569354	37354	**1E+06**

Toluene mg	510852	22401	**5E+05**	15.679	31752	**31767**	179952	5777.7	**2E+05**	17755.8	8877	**26633**	73957	**4E+06**	708575	68807	**5E+06**
Vanadium mg	14447	383.8	**14831**	0.2686	544	**544.3**	19478.1	98.989	**19577**	304.209	152.09	**456.3**	1267	**76026**	34229.7	1178.9	**1E+05**
Xylene mg	74114	11738	**85852**	0.5944	16638	**16638**	91222.2	3027.5	**94250**	9303.97	4651.5	**13955**	2585	**2E+05**	174641	36055	**4E+05**
Yttrium mg	2105.3	95.25	**2201**	0.0667	135.01	**135.1**	502.218	24.567	**526.8**	75.4983	37.745	**113.2**	314.5	**18867**	2683.11	292.57	**21843**
Zinc mg	2E+07	29195	**2E+07**	5.6131	41383	**41389**	170374	7530.3	**2E+05**	23141.7	11570	**34711**	26050	**2E+06**	1.6E+07	89679	**2E+07**

Appendix A-11: Brookside- Water Emissions by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
2-Hexanone mg	380	794	789	608	313	**2,883**
Acetone mg	582	1,215	1,208	931	479	**4,416**
Acids, unspecified mg	4	1,473,298	0	1,082,139	0	**2,555,440**
Aluminum mg	3,810,082	5,383,709	3,235,423	5,719,532	2,085,746	**20,234,492**
Ammonia mg	994,417	1,719,669	1,588,844	1,477,840	708,376	**6,489,145**
Ammonia, as N mg	0	0	0	0	0	**0**
Ammonium, ion mg	90,794	6,561,128	451,218	133,722	65,387	**7,302,249**
Antimony mg	2,644	3,098	1,993	6,735	1,289	**15,759**
Arsenic, ion mg	14,982	29,542	27,485	24,414	11,520	**107,943**
Barium mg	52,144,396	65,235,777	47,758,276	65,952,717	29,440,012	**260,531,177**
Benzene mg	98,604	231,254	202,592	256,631	138,686	**927,768**
Benzene, 1-methyl-4-(1-methylethyl)- µg	5,819	12,146	12,068	9,306	4,786	**44,125**
Benzene, ethyl- mg	5,498	11,823	11,396	25,416	4,520	**58,653**
Benzene, pentamethyl- µg	4,364	9,110	9,051	6,979	3,590	**33,093**
Benzenes, alkylated, unspecified mg	2,056	2,472	1,745	2,535	1,130	**9,938**
Benzoic acid mg	59,069	123,301	122,509	94,466	48,588	**447,933**
Beryllium mg	794	1,406	1,288	1,230	572	**5,290**
Biphenyl µg	133,096	160,047	112,998	164,123	73,162	**643,427**
BOD5, Biological Oxygen Demand mg	10,645,318	23,770,060	21,181,978	29,226,490	8,520,887	**93,344,733**
Boron mg	182,760	418,966	379,033	2,385,784	150,327	**3,516,869**
Bromide mg	12,476,417	26,046,556	25,880,357	19,954,303	10,263,517	**94,621,150**
Cadmium, ion mg	2,206	4,818	4,010	38,043	1,687	**50,763**
Calcium, ion mg	187,096,804	391,491,793	388,135,055	324,460,852	153,916,072	**1,445,100,576**
Chloride mg	2,171,262,715	7,345,134,900	4,399,179,589	3,887,589,483	1,818,264,333	**19,621,431,021**
Chromium mg	90,292	78,285	39,378	133,306	40,686	**381,947**
Chromium VI µg	426,924	6,582,284	142,844	36,525,287	168,729	**43,846,068**
Chromium, ion mg	16,237	50,222	56,172	36,932	18,366	**177,929**
Cobalt mg	1,479	3,414	2,676	22,964	1,061	**31,594**
COD, Chemical Oxygen Demand mg	21,277,567	48,577,230	53,547,515	80,571,134	38,475,908	**242,449,354**
Copper, ion mg	15,618	23,411	19,132	33,210	9,265	**100,635**
Cyanide mg	129,489	3,247,208	7,826	6,552,676	6,683,425	**16,620,625**
Decane mg	1,697	3,543	3,520	2,714	1,396	**12,871**
Detergents, oil mg	51,853	115,822	118,040	86,063	44,990	**416,768**
Dibenzofuran µg	11,072	23,112	22,963	17,707	9,107	**83,960**
Dibenzothiophene µg	3,580	14,898	16,558	11,465	4,961	**51,462**
Dissolved organic matter mg	1,333,306	925,858	5,981	8,234,650	250,836	**10,750,630**
Dissolved solids mg	2,526,741,452	5,122,831,036	5,381,776,353	2,338,802,819	2,134,294,764	**17,504,446,424**
Docosane µg	62,309	130,065	129,229	99,648	51,253	**472,504**
Dodecane mg	3,220	6,722	6,679	5,150	2,649	**24,421**
Eicosane mg	887	1,851	1,839	1,418	729	**6,724**
Fluorene, 1-methyl- µg	6,627	13,833	13,744	10,598	5,451	**50,253**

Fluorenes, alkylated, unspecified µg	119,131	143,254	101,142	146,902	65,486	**575,915**
Fluoride mg	225,993	2,455,432	5,518,065	3,718,109	2,814,564	**14,732,163**
Fluorine µg	60,057	77,064	57,125	75,891	34,380	**304,517**
Halogenated organics µg	0	0	0	0	0	**0**
Hexadecane mg	3,515	7,337	7,290	5,622	2,891	**26,656**
Hexanoic acid mg	12,233	25,534	25,370	19,563	10,062	**92,762**
Hydrocarbons, unspecified µg	170,729	57,806,495	30,674	3,193,553,290	34,846	**3,251,596,034**
Iron mg	8,184,654	20,403,200	10,320,196	14,952,936	7,475,345	**61,336,331**
Lead mg	121,432	856,501	4,113,998	1,790,682	2,044,961	**8,927,575**
Lead-210/kg µg	22,743,932	2,001,347,045	0	21,898,682	0	**2,045,989,659**
Lithium, ion mg	22,057,658	95,660,998	114,423,126	55,803,117	33,440,744	**321,385,643**
Magnesium mg	36,610,905	76,449,441	75,887,945	62,324,512	30,098,472	**281,371,275**
Manganese mg	215,226	34,397,943	331,149	966,710	140,464	**36,051,492**
Mercury µg	41,506	54,538	34,876	117,157	22,581	**270,658**
Metallic ions, unspecified mg	100,119	1,213,860	19,938	411,534	22,650	**1,768,101**
Methane, monochloro-, R-40 µg	2,344	4,892	4,861	3,748	1,928	**17,773**
Methyl ethyl ketone µg	4,687	9,784	9,721	7,496	3,856	**35,545**
Molybdenum mg	1,339	2,821	2,776	2,636	1,101	**10,673**
m-Xylene mg	1,764	3,683	3,659	2,821	1,451	**13,379**
Naphthalene mg	-5,949	2,120	2,194	1,694	-7,722	**-7,663**
Naphthalene, 2-methyl- mg	922	1,925	1,913	1,475	759	**6,994**
Naphthalenes, alkylated, unspecified µg	33,685	40,506	28,598	41,538	18,517	**162,843**
n-Hexacosane µg	38,873	81,143	80,621	62,167	31,975	**294,778**
Nickel mg	14,664	34,784	49,373	109,468	29,540	**237,829**
Nitrate mg	538,790	294,789	0	1,856,816	104,172	**2,794,567**
Nitrate compounds mg	0	0	0	0	0	**0**
Nitric acid mg	0	0	0	0	0	**0**
Nitrogen, total mg	129,253	3,520,604	2,454	7,176,725	7,247,854	**18,076,890**
Non-halogenated Organics µg	0	34,537,973	0	630,422,176	0	**664,960,149**
o-Cresol mg	1,675	3,497	3,474	2,679	1,378	**12,703**
Octadecane mg	868	1,813	1,801	1,389	714	**6,585**
Oils, unspecified mg	5,549,055	98,086,323	12,444,071	204,897,240	190,375,707	**511,352,396**
Other mg	0	2,477,227,756	0	5,127,434	0	**2,482,355,189**
Other metals mg	4,055	307,233,676	0	2,773,858	787	**310,012,375**
p-Cresol mg	1,807	3,773	3,748	2,890	1,487	**13,705**
Pentanone, methyl- mg	238	483	508	221	201	**1,651**
Phenanthrene µg	13,388	20,676	17,703	18,403	8,771	**78,941**
Phenanthrenes, alkylated, unspecified µg	13,967	16,795	11,858	17,223	7,678	**67,522**
Phenol µg	29,565,255	50,079,909	13,717,565	147,075,812	79,617,870	**320,056,410**
Phenol, 2,4-dimethyl- mg	1,631	3,405	3,383	2,608	1,342	**12,368**
Phenols, unspecified mg	11,567	42,130	48,569	26,341	14,978	**143,585**
Phosphate mg	85,179	147,014	5,021,742	954,216	657,010	**6,865,161**
Phosphorus mg	515,708	943,393	29,797,381	2,749,632	4,580,749	**38,586,862**
Polynuclear Aromatic Hydrocarbons µg	0	464	0	0	0	**464**
Radium-226/kg µg	2	4	4	2	2	**14**
Radium-228/kg µg	0	0	0	0	0	**0**
Selenium µg	469,841	704,315	390,834	745,023	251,248	**2,561,261**
Silver mg	122,211	254,868	253,125	195,771	100,450	**926,424**
Sodium, ion mg	593,069,746	1,244,572,379	1,230,353,860	1,158,741,530	487,906,670	**4,714,644,183**
Solids, inorganic mg	0	16,827	0	724,830	0	**741,657**
Strontium mg	3,174,366	6,652,740	6,583,477	6,330,956	2,611,062	**25,352,601**
Sulfate mg	60,615,045	145,380,718	8,912,631	52,972,477	14,459,126	**282,339,996**
Sulfide mg	360,534	9,631,375	2,480,936	19,798,321	20,007,956	**52,279,121**

Sulfur mg	154,273	322,470	319,959	270,045	126,898	**1,193,645**
Suspended solids, unspecified mg	171,603,715	359,777,741	1,322,043,631	651,157,561	624,967,789	**3,129,550,436**
Tar mg	0	0	0	0	0	**0**
Tetradecane mg	1,411	2,946	2,927	2,257	1,161	**10,703**
Thallium µg	494,042	595,429	420,769	625,082	271,868	**2,407,191**
Tin mg	10,739	17,119	14,925	15,430	7,197	**65,409**
Titanium, ion mg	36,000	381,497	30,631	138,777	19,804	**606,709**
Toluene mg	92,319	194,282	191,405	223,465	75,912	**777,382**
Vanadium mg	1,581	15,218	3,279	14,029	1,301	**35,409**
Xylene mg	32,762	31,278	14,135	117,914	14,607	**210,695**
Yttrium mg	392	819	814	628	323	**2,976**
Zinc mg	296,732	163,327	12,819,584	909,906	1,523,141	**15,712,690**

Appendix A-12: Brookside- Land Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operating Energy**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Bark/Wood Waste kg	6.255318	0	**6.255**	4917.4	0	**4917**	0	0	**0**	0	0	**0**	0	**0**	4923.66	0	**4924**
Concrete Solid Waste kg	29067.09	0	**29067**	22698.1	0	**22698**	6347.24	0	**6347**	0	0	**0**	0	**0**	58112.4	0	**58112**
Blast Furnace Slag kg	23177.02	0	**23177**	0	0	**0**	18.6702	0	**18.67**	0	0	**0**	0	**0**	23195.7	0	**23196**
Blast Furnace Dust kg	7017.81	0	**7018**	0	0	**0**	4.74701	0	**4.747**	0	0	**0**	0	**0**	7022.56	0	**7023**
Steel Waste kg	61.49111	0	**61.49**	245.016	0	**245**	141.832	0	**141.8**	0	0	**0**	0	**0**	448.339	0	**448.3**
Other Solid Waste kg	51095.96	125.31	**51221**	7.18021	177.6	**184.8**	19030.7	32.32	**19063**	99.3236	49.66	**149**	28983	**2E+06**	70233.2	384.9	**2E+06**

Appendix A-13: Brookside- Land Emissions by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Bark/Wood Waste kg	4917.399951	6.25531832	0	0	0	**4923.655269**
Concrete Solid Waste kg	30065.84196	785.90686	0	12694.4735	14566.1632	**58112.38549**
Blast Furnace Slag kg	260.318625	1315.26796	13268.43173	3703.54106	4648.12757	**23195.68694**
Blast Furnace Dust kg	1314.661049	334.907455	3712.119509	576.620113	1084.24921	**7022.55734**
Steel Waste kg	10.63618514	89.5209171	6.774536128	227.604789	113.802394	**448.3388212**
Other Solid Waste kg	8581.18046	35784.4126	10934.44071	10400.0874	4917.98666	**70618.10787**

Appendix B-1: Southfield- All Impacts by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	
Fossil Fuel Consumption MJ	7085667	133147	**7E+06**	59331.38	207509	**3E+05**	1201288	27149	**1E+06**	120032	57096	**2E+05**	3E+06	**2E+08**	**2E+08**
Weighted Resource Use kg	2050248	3513.9	**2E+06**	1457.819	4889.4	**6347**	86025.07	643.21	**86668**	2826.72	1345.3	**4172**	284364	**2E+07**	**2E+07**
Global Warming Potential	499197	9921.8	**5E+05**	3990.919	15524	**19514**	76526.18	2012	**78538**	7826.18	4274.1	**12100**	266185	**2E+07**	**2E+07**
Acidification Potential	201980	3399.9	**2E+05**	2109.22	4898.7	**7008**	57279.93	642.37	**57922**	433.899	1348	**1782**	96163	**6E+06**	**6E+06**
HH Respiratory Effects Potential	1407.3	4.0998	**1411**	2.431179	5.8873	**8.318**	746.5228	0.7724	**747.3**	0.41306	1.62	**2.033**	538.67	**32320**	**34489**
Eutrophication Potential (kg N eq)	321.701	3.5407	**325.2**	1.964448	5.0747	**7.039**	19.10365	0.666	**19.77**	0.29793	1.2735	**1.571**	2.4468	**146.8**	**500.4**
Ozone Depletion Potential	0.00049	4E-07	**5E-04**	2.69E-11	6E-07	**6E-07**	7.23E-05	8E-08	**7E-05**	3.5E-07	2E-07	**5E-07**	7E-08	**4E-06**	**6E-04**
Smog Potential (kg NOx eq)	1096.81	76.694	**1174**	49.21333	109.34	**158.6**	351.7929	14.357	**366.2**	5.57542	30.087	**35.66**	44.34	**2660**	**4394**

Appendix B-2: Southfield- All Impacts by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Fossil Fuel Consumption MJ	691644.3358	2089828.42	3317453.474	1503412.61	1288881.83	**9E+06**
Weighted Resource Use kg	743235.2604	494534.755	301093.3893	79218.6286	532867.889	**2E+06**
Global Warming Potential (kg CO2 eq)	99550.82766	185656.599	164972.9916	62403.0027	106688.506	**6E+05**
Acidification Potential (moles of H+ eq)	32868.08409	115445.033	66334.77906	23512.1218	33932.4192	**3E+05**
HH Respiratory Effects Potential (kg PM2.5 eq)	233.6255335	1287.51152	341.019881	103.489736	203.397633	**2169**
Eutrophication Potential (kg N eq)	15.92682113	46.5588503	221.1593532	21.7189537	48.3809986	**353.7**
Ozone Depletion Potential (kg CFC-11 eq)	0.000295712	0.00015021	8.67195E-07	2.9266E-06	0.00011403	**6E-04**
Smog Potential (kg NOx eq)	304.2895045	676.36699	209.9737705	347.943139	195.299405	**1734**

Appendix B-3: Southfield- Energy Consumption by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Electricity kWh	254206	0	**3E+05**	159.77	0	**159.8**	34231	0	**34231**	0	0	**0**	4E+05	**2E+07**	288597	0	**3E+07**
Hydro MJ	49594.9	58.846	**49654**	7.99996	91.847	**99.85**	80762	11.906	**80774**	50.8672	25.288	**76.16**	20679	**1E+06**	130416	187.9	**1E+06**
Coal MJ	1916865	858.71	**2E+06**	961.594	1340.3	**2302**	249597	173.74	**2E+05**	742.271	369.01	**1111**	2E+06	**1E+08**	2E+06	2742	**2E+08**
Diesel MJ	124991	124079	**2E+05**	58190.3	193355	**3E+05**	29575.8	25314	**54890**	112219	53199	**2E+05**	67487	**4E+06**	324976	4E+05	**5E+06**
Feedstock MJ	2336549	0	**2E+06**	0	0	**0**	643069	0	**6E+05**	0	0	**0**	0	**0**	3E+06	0	**3E+06**
Gasoline MJ	138.557	0	**138.6**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	138.56	0	**138.6**
Heavy Fuel Oil MJ	242718	2836.5	**2E+05**	1.66305	4427.2	**4429**	49303.6	573.89	**49877**	2442.69	1218.9	**3662**	4339	**3E+05**	294466	9057	**6E+05**
LPG MJ	6264.28	128.46	**6393**	0.91901	200.5	**201.4**	346.313	25.99	**372.3**	110.622	55.202	**165.8**	2394	**1E+05**	6722.1	410.1	**2E+05**
Natural Gas MJ	2458141	5244.6	**2E+06**	176.86	8185.8	**8363**	229397	1061.1	**2E+05**	4517.65	2253.8	**6771**	5E+05	**3E+07**	3E+06	16745	**3E+07**
Nuclear MJ	621495	228.21	**6E+05**	416.526	353.56	**770.1**	64388.1	45.854	**64434**	187.107	97.343	**284.5**	1E+06	**6E+07**	686486	725	**7E+07**
Wood MJ	2735.55	0	**2736**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	2735.5	0	**2736**
Total Energy Consumption	7759492	133434	**8E+06**	59755.9	207954	**3E+05**	1346438	27207	**1E+06**	120270	57219	**2E+05**	4E+06	**2E+08**	9E+06	4E+05	**3E+08**

Appendix B-4: Southfield- Energy Consumption by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Electricity kWh	14587.06053	70139.9825	130490.9385	26057.1639	47321.4943	**288597**
Hydro MJ	1192.519979	115916.193	7024.755832	2868.36666	3601.84217	**130604**
Coal MJ	325762.4083	531508.804	792890.907	147849.365	372896.42	**2E+06**
Diesel MJ	172171.7833	212688.674	143210.0789	50190.0521	142663.471	**720924**
Feedstock MJ	14033.48185	253678.267	1293350.595	1040062.58	378493.175	**3E+06**
Gasoline MJ	0	37.4432099	0	33.7044712	67.4089424	**138.56**
Heavy Fuel Oil MJ	59669.83095	104493.447	5363.653738	89482.1604	44513.2652	**303522**
LPG MJ	563.3588061	4408.52202	1222.042253	307.491318	630.86929	**7132.3**
Natural Gas MJ	119443.4726	983013.263	1081416.197	175487.258	349617.218	**3E+06**
Nuclear MJ	39736.2702	134460.715	342003.4653	58074.1301	112936.747	**687211**
Wood MJ	0	2735.54907	0	0	0	**2735.5**

Appendix B-5: Southfield- Resources use by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Limestone kg	179948	0	**2E+05**	0	0	**0**	8183.86	0	**8184**	0	0	**0**	0	**0**	188132	0	**2E+05**
Clay & Shale kg	176000	0	**2E+05**	0	0	**0**	70.9537	0	**70.95**	0	0	**0**	0	**0**	176071	0	**2E+05**
Iron Ore kg	39789.8	0	**39790**	0	0	**0**	131.716	0	**131.7**	0	0	**0**	0	**0**	39921.5	0	**39922**
Sand kg	12008.7	0	**12009**	0	0	**0**	17520.1	0	**17520**	0	0	**0**	0	**0**	29528.9	0	**29529**
Ash kg	928.533	0	**928.5**	0	0	**0**	0.00294	0	**0.003**	0	0	**0**	0	**0**	928.536	0	**928.5**
Other kg	7816.13	0	**7816**	0	0	**0**	8671.66	0	**8672**	0	0	**0**	0	**0**	16487.8	0	**16488**
Gypsum kg	54099.9	0	**54100**	0	0	**0**	0.00016	0	**2E-04**	0	0	**0**	0	**0**	54099.9	0	**54100**
Semi-Cementitious Materials kg	20535.2	0	**20535**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	20535.2	0	**20535**
Coarse Aggregate kg	516787	0	**5E+05**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	516787	0	**5E+05**
Fine Aggregate kg	388967	0	**4E+05**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	388967	0	**4E+05**
Water L	2639063	0	**3E+06**	0	0	**0**	5328.04	0	**5328**	0	0	**0**	0	**0**	2644391	0	**3E+06**
Obsolete Scrap Stel kg	125589	0	**1E+05**	0	0	**0**	96.4179	0	**96.42**	0	0	**0**	0	**0**	125686	0	**1E+05**
Coal kg	102889	42.23	**1E+05**	47.0215	65.915	**113**	12025.1	8.5445	**12034**	36.5054	18.15	**54.7**	1E+05	**7E+06**	114998	134.84	**7E+06**
Wood Fiber kg	1135.68	0	**1136**	0	0	**0**	0.03338	0	**0.033**	0	0	**0**	0	**0**	1135.71	0	**1136**
Uranium kg	0.98338	4E-04	**0.984**	0.00066	0.0006	**0**	0.10189	7E-05	**0.102**	0.0003	2E-04	**0**	1.703	**102.2**	1.08622	0.0011	**103.3**
Natural Gas m3	65092.2	138.8	**65231**	4.69282	216.65	**221**	6129.76	28.084	**6158**	119.569	59.65	**179**	13528	**8E+05**	71346.3	443.2	**9E+05**
Natural Gas, as feedstock m3	3291.34	0	**3291**	0	0	**0**	5551.23	0	**5551**	0	0	**0**	0	**0**	8842.57	0	**8843**
Crude Oil L	12787.8	3749	**16537**	1522.27	5179.9	**6702**	3024.08	682.09	**3706**	3003.26	1425	**4428**	1682	**1E+05**	20337.5	11036	**1E+05**
Crude Oil, fdstock L	5727.18	0	**5727**	0	0	**0**	10293.3	0	**10293**	0	0	**0**	0	**0**	16020.5	0	**16021**
Metallurgical Coal, as feedstock kg	10243.7	0	**10244**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	10243.7	0	**10244**
Prompt Scrap Steel, as fdstock kg	79210.4	0	**79210**	0	0	**0**	61.0841	0	**61.08**	0	0	**0**	0	**0**	79271.5	0	**79271**

Appendix B-6: Southfield- Resources Use by Building Assembly

Material	Foundations	Walls	Columns & Beams	Roofs	Floors	Total
Limestone kg	95289.46352	33889.94875	15740.40016	2084.45927	41127.42779	**188131.6995**
Clay & Shale kg	26336.25866	139533.6225	0	85.06401407	10115.69351	**176070.6387**
Iron Ore kg	586.7395016	6541.742112	1565.312872	10218.00894	21009.70202	**39921.50544**
Sand kg	1157.550017	27926.69738	0	0.002022685	444.612173	**29528.86159**
Ash kg	582.7665603	121.9270492	0	0.003018777	223.8392319	**928.5358602**
Other kg	0	16487.78077	0	0	0	**16487.78077**
Gypsum kg	4092.937198	48434.88068	0	0.000189702	1572.087318	**54099.90538**
Semi-Cementitious Material kg	13970.43124	1198.789241	0	0	5366.008984	**20535.22946**
Coarse Aggregate kg	294077.5077	40668.69967	0	0	182040.8461	**516787.0535**
Fine Aggregate kg	201005.7841	53851.62133	0	0	134109.8787	**388967.2841**
Water L	50773.37243	503832.8019	791416.3422	425925.8799	872442.991	**2644391.387**
Obsolete Scrap Steel kg	1054.813527	4304.959868	97213.4868	5741.372814	17371.2248	**125685.8578**
Coal kg	20964.15817	26103.56648	40560.64863	7341.35593	20162.92393	**115132.6531**
Wood Fiber kg	0	1135.67671	0	0.038150634	0	**1135.71486**
Uranium kg	0.062873845	0.212764441	0.541144723	0.091889446	0.178697384	**1.087369839**
Natural Gas m3	3162.065497	26098.48875	28626.76583	4646.464968	9255.677507	**71789.46255**
Natural Gas as feedstock m3	0	1578.085979	0	7264.485163	0	**8842.571142**
Crude Oil L	7507.592112	10109.87873	4354.952687	3796.558564	5604.835073	**31373.81716**
Crude Oil as feedstock L	0	1352.280478	0	14668.2232	0	**16020.50368**
Metallurgical Coal as feedstock kg	0	2717.0575	0	2508.891697	5017.783394	**10243.73259**
Prompt Scrap Steel as feedstock kg	668.2610405	2633.371956	61588.12356	3550.386022	10831.32831	**79271.47089**

Appendix B-7: Southfield- Bill of Materials

Material	Quantity	Unit
1/2" Regular Gypsum Board	32680.9987	sf
5/8" Regular Gypsum Board	26129.3986	sf
6 mil Polyethylene	22570.6406	sf
Air Barrier	12599.1209	sf
Aluminum	4.1161	Tons
Batt. Fiberglass	90461.0939	sf(1")
Cold Rolled Sheet	0.2457	Tons
Concrete 20 MPa (flyash av)	390.4475	yd³
Concrete 30 MPa (flyash av)	198.2384	yd³
EPDM membrane (black, 60 mil)	19390.1303	lbs
Extruded Polystyrene	39133.2268	sf(1")
Galvanized Decking	28.5894	Tons
Galvanized Studs	10.0088	Tons
Glazing Panel	0.1677	Tons
Joint Compound	6.0118	Tons
Metric Modular (Modular) Brick	12470.8494	sf
Mortar	39.8065	yd³
Nails	0.7747	Tons
Open Web Joists	22.5177	Tons
Paper Tape	0.069	Tons
Rebar, Rod, Light Sections	3.6552	Tons

Screws Nuts & Bolts	8.4935	Tons
Small Dimension Softwood Lumber, kiln-dried	0.928	Mbfm
Standard Glazing	17126.8334	sf
Water Based Latex Paint	1030.9014	US Gallon
Welded Wire Mesh / Ladder Wire	0.979	Tons
Wide Flange Sections	161.0219	Tons

Appendix B-8: Southfield- Air Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
2-Chloroacetophenone g	0.0521	0	**0.052**	0	0	**0**	0.0031	0	**0.003**	0	0	**0**	6E-09	**4E-07**	0.05517	0	**0.055**
Acenaphthene g	0.0198	0	**0.02**	1E-05	0	**1E-05**	0.0026	0	**0.003**	0	0	**0**	0.026	**1.548**	0.02244	0	**1.571**
Acenaphthylene g	0.0097	0	**0.01**	5E-06	0	**5E-06**	0.0013	0	**0.001**	0	0	**0**	0.013	**0.759**	0.011	0	**0.77**
Acetaldehyde g	23.214	0	**23.21**	0	0	**0**	5.5399	0	**5.54**	36.9346	0	**36.93**	5E-07	**3E-05**	65.6886	0	**65.69**
Acetophenone g	172.25	0	**172.3**	0	0	**0**	679.24	0	**679.2**	0	0	**0**	1E-08	**8E-07**	851.495	0	**851.5**
Acid Gases g	1.4144	0	**1.414**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1.41443	0	**1.414**
Acrolein g	17.117	0	**17.12**	0.0057	0	**0.006**	1.609	0	**1.609**	4.45434	0	**4.454**	14.67	**880.3**	23.1856	0	**903.5**
Aldehydes g	66.184	0	**66.18**	0.0004	0	**4E-04**	132.53	0	**132.5**	0	0	**0**	1.001	**60.05**	198.718	0	**258.8**
Ammonia g	2387.5	61.24	**2449**	0.0345	95.576	**95.61**	1352.1	12.39	**1364**	52.7333	26.31	**79.05**	89.28	**5357**	3792.29	195.52	**9345**
Ammonium chloride g	7541.8	0	**7542**	0.1054	0	**0.105**	4046.8	0	**4047**	0	0	**0**	272.3	**16341**	11588.7	0	**27929**
Anthracene g	0.0082	0	**0.008**	4E-06	0	**4E-06**	0.0011	0	**0.001**	0	0	**0**	0.011	**0.637**	0.00925	0	**0.647**
Antimony g	0.7289	0	**0.729**	0.0004	0	**4E-04**	0.1666	0	**0.167**	0	0	**0**	0.911	**54.64**	0.89583	0	**55.54**
Arsenic g	16.608	0	**16.61**	0.0081	0	**0.008**	2.8038	0	**2.804**	0	0	**0**	20.87	**1252**	19.4201	0	**1272**
Benzene g	837.46	0	**837.5**	0.0256	0	**0.026**	276.63	0	**276.6**	44.9288	0	**44.93**	66.21	**3973**	1159.04	0	**5132**
Benzene, chloro- g	0.1638	0	**0.164**	0	0	**0**	0.0096	0	**0.01**	0	0	**0**	2E-08	**1E-06**	0.17339	0	**0.173**
Benzene, ethyl- g	2.9305	0	**2.931**	0	0	**0**	8.8415	0	**8.841**	0	0	**0**	8E-08	**5E-06**	11.772	0	**11.77**
Benzo(a)anthracene g	0.0031	0	**0.003**	2E-06	0	**2E-06**	0.0004	0	**4E-04**	0	0	**0**	0.004	**0.243**	0.00352	0	**0.246**
Benzo(a)pyrene g	31.927	0	**31.93**	7E-07	0	**7E-07**	77.399	0	**77.4**	0	0	**0**	0.002	**0.115**	109.327	0	**109.4**
Benzo(b,j,k)fluoranthene g	0.0043	0	**0.004**	2E-06	0	**2E-06**	0.0006	0	**6E-04**	0	0	**0**	0.006	**0.334**	0.00484	0	**0.339**
Benzo(ghi)perylene g	0.0011	0	**0.001**	5E-07	0	**5E-07**	0.0001	0	**1E-04**	0	0	**0**	0.001	**0.082**	0.00119	0	**0.083**
Benzyl chloride g	5.2119	0	**5.212**	0	0	**0**	0.3051	0	**0.305**	0	0	**0**	6E-07	**4E-05**	5.51699	0	**5.517**
Beryllium g	0.8249	0	**0.825**	0.0004	0	**4E-04**	0.1159	0	**0.116**	0	0	**0**	1.067	**64.01**	0.94118	0	**64.95**
Biphenyl g	0.4076	0	**0.408**	3E-05	0	**3E-05**	1.3559	0	**1.356**	0	0	**0**	0.086	**5.16**	1.76351	0	**6.924**
Bromoform g	0.2904	0	**0.29**	0	0	**0**	0.017	0	**0.017**	0	0	**0**	3E-08	**2E-06**	0.30738	0	**0.307**
BTEX g	251.54	0	**251.5**	0	0	**0**	604.04	0	**604**	0	0	**0**	0	**0**	855.581	0	**855.6**
Butadiene g	2.01	0	**2.01**	0	0	**0**	4.3856	0	**4.386**	1.88292	0	**1.883**	0	**0**	8.27849	0	**8.278**
Cadmium g	3.7319	0	**3.732**	0.0011	0	**0.001**	0.6203	0	**0.62**	0	0	**0**	2.831	**169.9**	4.35334	0	**174.2**
Carbon dioxide, biogenic kg	240.47	0	**240.5**	0	0	**0**	44.067	0	**44.07**	0	0	**0**	0	**0**	284.537	0	**284.5**
Carbon dioxide, fossil kg	475901	9850	**5E+05**	3977.4	15408	**19386**	72861	1997	**74858**	7826.18	4242	**12069**	3E+05	**2E+07**	560566	31498	**2E+07**
Carbon disulfide g	5339.6	0	**5340**	0	0	**0**	21065	0	**21065**	0	0	**0**	1E-07	**7E-06**	26404.5	0	**26405**
Carbon monoxide g	210129	0	**2E+05**	32328	0	**32328**	89995	0	**89995**	0	0	**0**	0.322	**19.3**	332452	0	**3E+05**
Carbon monoxide, fossil g	361189	54802	**4E+05**	18.403	85028	**85047**	85681	11031	**96713**	74048.6	23410	**97458**	49540	**3E+06**	520937	174272	**4E+06**
Chloride g	8.7018	0	**8.702**	0	0	**0**	21.095	0	**21.1**	0	0	**0**	0	**0**	29.7969	0	**29.8**
Chlorine g	1.9544	0	**1.954**	0	0	**0**	2.8354	0	**2.835**	0	0	**0**	0	**0**	4.78983	0	**4.79**
Chloroform g	0.4398	0	**0.44**	0	0	**0**	0.0277	0	**0.028**	0	0	**0**	5E-08	**3E-06**	0.46747	0	**0.467**
Chromium g	12.9	0	**12.9**	0.0052	0	**0.005**	6.1308	0	**6.131**	0	0	**0**	13.5	**809.8**	19.0358	0	**828.8**
Chromium VI g	3.102	0	**3.102**	0.0015	0	**0.002**	0.5111	0	**0.511**	0	0	**0**	3.997	**239.8**	3.61464	0	**243.4**
Chrysene g	0.0039	0	**0.004**	2E-06	0	**2E-06**	0.0005	0	**5E-04**	0	0	**0**	0.005	**0.304**	0.00441	0	**0.308**
Chrysene, 5-methyl- g	0.0009	0	**9E-04**	4E-07	0	**4E-07**	0.0001	0	**1E-04**	0	0	**0**	0.001	**0.067**	0.00097	0	**0.068**
Cobalt g	8.4584	0	**8.458**	0.0021	0	**0.002**	1.5119	0	**1.512**	0	0	**0**	5.49	**329.4**	9.9724	0	**339.4**

Copper g	0.5757	0	**0.576**	0	0	**0**	2.1504	0	**2.15**	0	0	**0**	1E-04	**0.008**	2.72604	0	**2.734**
Cumene g	1.4119	0	**1.412**	0	0	**0**	5.4155	0	**5.415**	0	0	**0**	5E-09	**3E-07**	6.82742	0	**6.827**
Cyanide g	19.02	0	**19.02**	0	0	**0**	2.5259	0	**2.526**	0	0	**0**	2E-06	**1E-04**	21.5459	0	**21.55**
Dinitrogen monoxide g	5921.4	239.9	**6161**	0.1611	384.49	**384.7**	471.33	49.78	**521.1**	0	105.9	**105.9**	417	**25020**	6392.9	780.05	**32193**
Dioxins, g	3E-07	0	**3E-07**	0	0	**0**	9E-07	0	**9E-07**	0	0	**0**	0	**0**	1.2E-06	0	**1E-06**
Ethane, HCFC-140 g	0.1498	3E-04	**0.15**	2E-08	0.0004	**4E-04**	0.0091	6E-05	**0.009**	0.00024	1E-04	**4E-04**	5E-05	**0.003**	0.15913	0.0009	**0.163**
Ethane, 1,2-dibromo- g	0.0089	0	**0.009**	0	0	**0**	0.0005	0	**5E-04**	0	0	**0**	1E-09	**6E-08**	0.00946	0	**0.009**
Ethane, 1,2-dichloro- g	0.3151	0	**0.315**	0	0	**0**	0.074	0	**0.074**	0	0	**0**	4E-08	**2E-06**	0.38912	0	**0.389**
Ethane, chloro- g	0.3127	0	**0.313**	0	0	**0**	0.0183	0	**0.018**	0	0	**0**	4E-08	**2E-06**	0.33102	0	**0.331**
Ethene, tetrachloro- g	1.7905	0	**1.791**	0.0008	0	**8E-04**	0.4766	0	**0.477**	0	0	**0**	2.181	**130.8**	2.26802	0	**133.1**
Fluoranthene g	0.0276	0	**0.028**	1E-05	0	**1E-05**	0.0036	0	**0.004**	0	0	**0**	0.036	**2.155**	0.03126	0	**2.187**
Fluorene g	0.0585	0	**0.059**	2E-05	0	**2E-05**	0.0951	0	**0.095**	0	0	**0**	0.046	**2.762**	0.15364	0	**2.916**
Fluoride g	501.46	0	**501.5**	0.0024	0	**0.002**	110.35	0	**110.4**	0	0	**0**	6.118	**367.1**	611.82	0	**978.9**
Formaldehyde g	192.78	0	**192.8**	0.0108	0	**0.011**	25.232	0	**25.23**	56.826	0	**56.83**	29.66	**1780**	274.849	0	**2055**
Furan g	0.3274	0	**0.327**	1E-07	0	**1E-07**	1.2913	0	**1.291**	0	0	**0**	3E-04	**0.015**	1.61872	0	**1.634**
Hexane g	15.809	0	**15.81**	0	0	**0**	60.405	0	**60.41**	0	0	**0**	6E-08	**4E-06**	76.2139	0	**76.21**
Hydrazine, methyl g	1.2658	0	**1.266**	0	0	**0**	0.0741	0	**0.074**	0	0	**0**	2E-07	**9E-06**	1.33984	0	**1.34**
Hydrocarbons, unspecified g	327013	0	**3E+05**	0.6083	0	**0.608**	30104	0	**30104**	0	0	**0**	1572	**94312**	357117	0	**5E+05**
Hydrogen chloride g	60710	0	**60710**	23.511	0	**23.51**	5970.5	0	**5970**	0	0	**0**	60758	**4E+06**	66703.7	0	**4E+06**
Hydrogen fluoride g	15113	0	**15113**	2.9366	0	**2.937**	745.3	0	**745.3**	0	0	**0**	7589	**5E+05**	15861.2	0	**5E+05**
Hydrogen sulfide g	2.4594	0	**2.459**	0	0	**0**	8.8019	0	**8.802**	0	0	**0**	0	**0**	11.2613	0	**11.26**
Indeno(1,2,3-cd)pyrene g	0.0024	0	**0.002**	1E-06	0	**1E-06**	0.0003	0	**3E-04**	0	0	**0**	0.003	**0.185**	0.00269	0	**0.188**
Isophorone g	4.3184	0	**4.318**	0	0	**0**	0.2528	0	**0.253**	0	0	**0**	5E-07	**3E-05**	4.57122	0	**4.571**
Isoprene g	0.0005	0	**5E-04**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	0.00051	0	**5E-04**
Kerosene g	3612	0	**3612**	0.0505	0	**0.05**	1938.1	0	**1938**	0	0	**0**	130.4	**7826**	5550.16	0	**13376**
Lead g	42.129	0	**42.13**	0.0083	0	**0.008**	5.9739	0	**5.974**	0	0	**0**	21.45	**1287**	48.1107	0	**1335**
Magnesium g	428.22	0	**428.2**	0.2154	0	**0.215**	56.504	0	**56.5**	0	0	**0**	556.5	**33391**	484.938	0	**33876**
Manganese g	22.684	0	**22.68**	0.0097	0	**0.01**	3.2896	0	**3.29**	0	0	**0**	25.07	**1504**	25.9837	0	**1530**
Mercaptans, unspecified g	1615.7	0	**1616**	0	0	**0**	94.572	0	**94.57**	0	0	**0**	2E-04	**0.012**	1710.27	0	**1710**
Mercury g	13.137	0	**13.14**	0.0016	0	**0.002**	2.0678	0	**2.068**	0	0	**0**	4.26	**255.6**	15.206	0	**270.8**
Metals, unspecified g	310.59	0	**310.6**	0	0	**0**	0.0012	0	**0.001**	0	0	**0**	0	**0**	310.588	0	**310.6**
Methacrylic acid, g	0.1489	0	**0.149**	0	0	**0**	0.0087	0	**0.009**	0	0	**0**	2E-08	**1E-06**	0.15763	0	**0.158**
Methane g	935604	0	**9E+05**	585.11	0	**585.1**	153177	0	**2E+05**	0	0	**0**	5E+05	**3E+07**	1089367	0	**3E+07**
Methane, bromo, g	1.1913	0	**1.191**	0	0	**0**	0.0697	0	**0.07**	0	0	**0**	1E-07	**9E-06**	1.26103	0	**1.261**
Methane, dichloro-, g	20.254	0	**20.25**	0.0058	0	**0.006**	21.695	0	**21.69**	0	0	**0**	14.98	**898.8**	41.9551	0	**940.7**
Methane, dichlorodifluoro-g	0.0011	3E-04	**0.001**	2E-08	0.0005	**5E-04**	0.0008	7E-05	**9E-04**	0.0003	1E-04	**5E-04**	6E-05	**0.004**	0.00226	0.0011	**0.007**
Methane, fossil g	125380	11020	**1E+05**	7.6822	17184	**17192**	25148	2228	**27376**	9731.3	4731	**14463**	21820	**1E+06**	160267	35164	**2E+06**
Methane, monochloro-, g	3.9764	0	**3.976**	0	0	**0**	0.3503	0	**0.35**	0	0	**0**	5E-07	**3E-05**	4.3267	0	**4.327**
Methane, tetrachloro-, g	0.0246	4E-05	**0.025**	2E-09	6E-05	**6E-05**	0.0601	8E-06	**0.06**	3E-05	2E-05	**5E-05**	6E-06	**4E-04**	0.08479	0.0001	**0.085**
Methyl ethyl ketone g	40.574	0	**40.57**	0	0	**0**	148.77	0	**148.8**	0	0	**0**	3E-07	**2E-05**	189.346	0	**189.3**
Naphthalene g	3.0919	0	**3.092**	0.0003	0	**3E-04**	4.3222	0	**4.322**	0	0	**0**	0.859	**51.56**	7.4145	0	**58.98**
Nickel g	76.437	0	**76.44**	0.0079	0	**0.008**	15.857	0	**15.86**	0	0	**0**	20.4	**1224**	92.3021	0	**1316**
Nitrogen oxides g	790592	73323	**9E+05**	44346	104246	**1E+05**	319796	13697	**3E+05**	1025.23	28684	**29709**	32331	**2E+06**	1155760	219949	**3E+06**
Nitrous oxides g	1.1445	0	**1.145**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1.14452	0	**1.145**
NMVOC g	31733	0	**31733**	0	0	**0**	9695.4	0	**9695**	0	0	**0**	0	**0**	41428.6	0	**41429**
Organic acids g	44.262	0	**44.26**	0.0004	0	**4E-04**	16.861	0	**16.86**	0	0	**0**	1.001	**60.05**	61.1239	0	**121.2**
Organic substances, g	235.71	0	**235.7**	0.1186	0	**0.119**	30.697	0	**30.7**	0	0	**0**	306.4	**18387**	266.521	0	**18653**
Other g	7286.5	0	**7287**	0	0	**0**	2357.9	0	**2358**	0	0	**0**	0	**0**	9644.47	0	**9644**
PAH, g	282.33	0	**282.3**	0	0	**0**	676.33	0	**676.3**	8.09014	0	**8.09**	0	**0**	966.746	0	**966.7**
Particulatesg	67803	1316	**69119**	4.2528	1774.7	**1779**	4505.2	235.1	**4740**	4781.76	488.1	**5270**	11158	**7E+05**	77093.9	3814.2	**8E+05**
Particulates, unspecified g	1E+06	699.9	**1E+06**	65.959	1092.3	**1158**	931515	141.6	**9E+05**	602.685	300.7	**903.4**	2E+05	**1E+07**	1992934	2234.5	**1E+07**
Phenanthrene g	0.1051	0	**0.105**	5E-05	0	**5E-05**	0.0138	0	**0.014**	0	0	**0**	0.137	**8.196**	0.11898	0	**8.315**
Phenol g	1672.9	0	**1673**	0	0	**0**	1.4685	0	**1.469**	0	0	**0**	1E-08	**9E-07**	1674.38	0	**1674**

Phenols, unspecified g	3.479	0	**3.479**	0.0004	0	**4E-04**	0.7004	0	**0.7**	0	0	**0**	1.042	**62.49**	4.17973	0	**66.67**
Phthalate, dioctyl- g	0.5435	0	**0.544**	0	0	**0**	0.0318	0	**0.032**	0	0	**0**	7E-08	**4E-06**	0.57534	0	**0.575**
Propanal g	2.8296	0	**2.83**	0	0	**0**	0.1668	0	**0.167**	0	0	**0**	3E-07	**2E-05**	2.99642	0	**2.996**
Propene g	62.225	0	**62.23**	0	0	**0**	11.582	0	**11.58**	124.242	0	**124.2**	0	**0**	198.05	0	**198**
Propylene oxide g	0.0061	0	**0.006**	0	0	**0**	0.0238	0	**0.024**	0	0	**0**	0	**0**	0.0299	0	**0.03**
Pyrene g	0.0128	0	**0.013**	6E-06	0	**6E-06**	0.0017	0	**0.002**	0	0	**0**	0.017	**1.002**	0.01452	0	**1.016**
Radioactive species, MBq	1827.1	0	**1827**	1.1077	0	**1.108**	443.24	0	**443.2**	0	0	**0**	2863	**2E+05**	2271.41	0	**2E+05**
Radionuclides g	201986	0	**2E+05**	2.8226	0	**2.823**	108381	0	**1E+05**	0	0	**0**	7294	**4E+05**	310369	0	**7E+05**
Selenium g	51.212	0	**51.21**	0.0255	0	**0.025**	6.804	0	**6.804**	0	0	**0**	65.82	**3949**	58.0412	0	**4007**
Styrene g	0.714	0	**0.714**	0	0	**0**	2.0938	0	**2.094**	0	0	**0**	2E-08	**1E-06**	2.80778	0	**2.808**
Sulfur dioxide g	3E+06	0	**3E+06**	687.24	0	**687.2**	710435	0	**7E+05**	0	0	**0**	2E+06	**1E+08**	3738841	0	**1E+08**
Sulfur oxides g	243703	9022	**3E+05**	5855.4	14089	**19944**	156248	1826	**2E+05**	7635.62	3879	**11515**	1702	**1E+05**	413442	28816	**5E+05**
Sulfuric acid, g	0.3586	0	**0.359**	0	0	**0**	0.0258	0	**0.026**	0	0	**0**	4E-08	**3E-06**	0.38441	0	**0.384**
Tar g	2E-11	0	**2E-11**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1.7E-11	0	**2E-11**
t-Butyl methyl ether g	0.2668	0	**0.267**	0	0	**0**	0.0397	0	**0.04**	0	0	**0**	3E-08	**2E-06**	0.30655	0	**0.307**
TOC, g	4.8088	0	**4.809**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	4.80877	0	**4.809**
Toluene g	29.696	0	**29.7**	0	0	**0**	73.081	0	**73.08**	19.6958	0	**19.7**	2E-07	**1E-05**	122.473	0	**122.5**
Toluene, 2,4-dinitro- g	0.0021	0	**0.002**	0	0	**0**	0.0001	0	**1E-04**	0	0	**0**	2E-10	**1E-08**	0.00221	0	**0.002**
Vinyl acetate g	0.0566	0	**0.057**	0	0	**0**	0.0033	0	**0.003**	0	0	**0**	7E-09	**4E-07**	0.0599	0	**0.06**
VOC g	49327	3380	**52706**	5677.1	5070.7	**10748**	6969.9	656.5	**7626**	3917.15	1396	**5314**	10895	**7E+05**	65890.7	10503	**7E+05**
Xylene g	51.371	0	**51.37**	0	0	**0**	175.55	0	**175.6**	13.7246	0	**13.72**	3E-08	**2E-06**	240.648	0	**240.6**
Zinc g	8.7859	0	**8.786**	0	0	**0**	34.558	0	**34.56**	0	0	**0**	9E-05	**0.005**	43.344	0	**43.35**

Appendix B-9: Southfield- Air Emissions by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Acenaphthene g	0.003	0.005	0.008	0.002	0.004	**0.022**
Acenaphthylene g	0.002	0.003	0.004	0.001	0.002	**0.011**
Acetaldehyde g	11.308	13.021	22.659	6.570	12.130	**65.689**
Acetophenone g	0.070	24.229	0.000	827.169	0.027	**851.495**
Acid Gases g	0.000	1.414	0.000	0.000	0.000	**1.414**
Acrolein g	2.293	9.082	7.409	1.131	3.271	**23.186**
Aldehydes g	4.966	75.142	5.822	109.000	3.787	**198.718**
Ammonia g	484.521	2,205.685	520.281	399.988	377.329	**3,987.804**
Ammonium chloride g	1,351.501	6,934.862	1,584.278	687.584	1,030.499	**11,588.724**
Anthracene g	0.001	0.002	0.003	0.001	0.002	**0.009**
Antimony g	0.118	0.206	0.290	0.145	0.136	**0.896**
Arsenic g	2.488	4.837	6.741	2.237	3.117	**19.420**
Benzene g	458.261	175.321	50.132	282.823	192.502	**1,159.039**
Benzene, chloro- g	0.103	0.031	0.000	0.000	0.040	**0.173**
Benzene, ethyl- g	0.439	0.448	0.001	10.716	0.169	**11.772**
Benzo(a)anthracene g	0.001	0.001	0.001	0.000	0.001	**0.004**
Benzo(a)pyrene g	0.000	109.314	0.001	0.011	0.000	**109.327**
Benzo(b,j,k)fluoranthene g	0.001	0.001	0.002	0.000	0.001	**0.005**
Benzo(ghi)perylene g	0.000	0.000	0.000	0.000	0.000	**0.001**
Benzyl chloride g	3.268	0.984	0.005	0.003	1.257	**5.517**
Beryllium g	0.122	0.243	0.347	0.073	0.156	**0.941**
Biphenyl g	0.011	0.066	0.027	1.646	0.013	**1.764**
Bromoform g	0.182	0.055	0.000	0.000	0.070	**0.307**

BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), g	0.000	76.487	0.000	779.094	0.000	**855.581**
Butadiene g	0.441	0.768	1.155	5.349	0.566	**8.278**
Cadmium g	0.633	1.188	1.322	0.550	0.660	**4.353**
Carbon dioxide, biogenic kg	0.000	231.017	0.000	53.520	0.000	**284.537**
Carbon dioxide, fossil kg	96,627.332	176,556.710	156,159.084	59,718.832	103,001.614	**592,063.573**
Carbon disulfide g	0.607	751.217	0.001	25,652.467	0.233	**26,404.526**
Carbon monoxide g	25,800.800	172,951.919	44,383.991	30,702.327	58,612.868	**332,451.904**
Carbon monoxide, fossil g	116,394.953	266,674.050	117,519.035	94,596.442	100,024.864	**695,209.344**
Chloride g	0.000	29.797	0.000	0.000	0.000	**29.797**
Chlorine g	0.000	3.408	0.000	1.381	0.000	**4.790**
Chloroform g	0.275	0.083	0.000	0.003	0.106	**0.467**
Chromium g	1.631	3.801	4.838	6.611	2.155	**19.036**
Chromium VI g	0.519	0.855	1.274	0.371	0.595	**3.615**
Chrysene g	0.001	0.001	0.002	0.000	0.001	**0.004**
Chrysene, 5-methyl- g	0.000	0.000	0.000	0.000	0.000	**0.001**
Cobalt g	1.662	2.992	1.823	1.964	1.532	**9.972**
Copper g	0.010	0.137	0.004	2.570	0.005	**2.726**
Cumene g	0.025	0.203	0.000	6.590	0.010	**6.827**
Cyanide g	11.673	3.590	0.018	1.775	4.490	**21.546**
Dinitrogen monoxide g	3,682.586	1,514.188	241.563	179.423	1,555.194	**7,172.954**
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p- g	0.000	0.000	0.000	0.000	0.000	**0.000**
Ethane, 1,1,1-trichloro-, HCFC-140 g	0.094	0.029	0.000	0.001	0.036	**0.160**
Ethane, 1,2-dibromo- g	0.006	0.002	0.000	0.000	0.002	**0.009**
Ethane, 1,2-dichloro- g	0.187	0.061	0.000	0.069	0.072	**0.389**
Ethane, chloro- g	0.196	0.059	0.000	0.000	0.075	**0.331**
Ethene, tetrachloro- g	0.295	0.496	0.696	0.448	0.333	**2.268**
Fluoranthene g	0.005	0.008	0.011	0.002	0.005	**0.031**
Fluorene g	0.006	0.015	0.015	0.112	0.007	**0.154**
Fluoride g	238.575	218.482	35.909	15.617	103.236	**611.820**
Formaldehyde g	54.346	77.571	72.884	24.631	45.416	**274.849**
Furan g	0.000	0.046	0.000	1.573	0.000	**1.619**
Hexane g	0.313	2.303	0.000	73.478	0.120	**76.214**
Hydrazine, methyl g	0.794	0.239	0.001	0.001	0.305	**1.340**
Hydrocarbons, unspecified g	7,800.356	50,440.869	9,143.863	283,784.463	5,947.656	**357,117.207**
Hydrogen chloride g	5,273.833	30,177.031	19,373.766	3,801.825	8,077.240	**66,703.694**
Hydrogen fluoride g	774.876	11,164.657	2,419.070	454.140	1,048.479	**15,861.221**
Hydrogen sulfide g	0.000	2.286	0.000	8.975	0.000	**11.261**
Indeno(1,2,3-cd)pyrene g	0.000	0.001	0.001	0.000	0.000	**0.003**
Isophorone g	2.708	0.815	0.004	0.002	1.042	**4.571**
Isoprene g	0.000	0.000	0.000	0.000	0.000	**0.001**
Kerosene g	647.271	3,321.295	758.754	329.303	493.534	**5,550.157**
Lead g	17.769	10.143	7.067	4.037	9.095	**48.111**
Magnesium g	72.324	118.512	177.420	33.831	82.850	**484.938**
Manganese g	3.129	8.095	8.160	2.707	3.893	**25.984**
Mercaptans, unspecified g	1,013.191	304.994	1.547	0.830	389.704	**1,710.266**
Mercury g	6.302	4.107	1.468	0.450	2.879	**15.206**
Metals, unspecified g	0.000	50.643	0.000	259.945	0.000	**310.588**
Methacrylic acid, methyl ester g	0.093	0.028	0.000	0.000	0.036	**0.158**
Methane g	79,070.476	375,873.346	380,060.253	114,350.829	140,011.977	**1,089,366.882**
Methane, bromo-, Halon 1001 g	0.747	0.225	0.001	0.001	0.287	**1.261**
Methane, dichloro-, HCC-30 g	2.759	5.754	4.828	25.793	2.822	**41.955**
Methane, dichlorodifluoro-, CFC-12 g	0.001	0.001	0.000	0.001	0.000	**0.003**
Methane, fossil g	22,321.005	64,173.340	51,193.841	30,142.577	27,599.907	**195,430.669**

Methane, monochloro-, R-40 g	2.475	0.749	0.004	0.147	0.952	**4.327**
Methane, tetrachloro-, CFC-10 g	0.000	0.083	0.000	0.002	0.000	**0.085**
Methyl ethyl ketone g	1.821	5.923	0.003	180.899	0.700	**189.346**
Naphthalene g	0.302	0.993	0.512	5.279	0.328	**7.414**
Nickel g	16.308	30.312	7.871	24.517	13.294	**92.302**
Nitrogen oxides g	287,114.395	609,723.725	181,502.048	118,249.011	179,119.740	**1,375,708.919**
Nitrous oxides g	0.000	1.145	0.000	0.000	0.000	**1.145**
NMVOC, non-methane volatile organic compounds, uns g	91.877	12,775.769	7,691.773	13,018.185	7,851.029	**41,428.633**
Organic acids g	4.966	34.510	5.822	12.038	3.787	**61.124**
Organic substances, unspecified g	39.831	65.246	97.699	18.121	45.624	**266.521**
Other g	0.000	9,644.471	0.000	0.000	0.000	**9,644.471**
PAH, polycyclic aromatic hydrocarbons g	1.946	952.577	4.982	4.785	2.456	**966.746**
Particulates, > 2.5 um, and < 10um g	21,982.419	34,416.176	9,868.926	2,746.491	11,894.114	**80,908.124**
Particulates, unspecified g	211,670.315	1,512,069.933	100,398.647	41,003.529	130,026.539	**1,995,168.963**
Phenanthrene g	0.018	0.029	0.044	0.008	0.020	**0.119**
Phenol g	0.075	1,672.495	0.000	1.778	0.029	**1,674.376**
Phenols, unspecified g	0.747	1.436	0.371	1.024	0.601	**4.180**
Phthalate, dioctyl- g	0.341	0.103	0.001	0.000	0.131	**0.575**
Propanal g	1.774	0.534	0.003	0.003	0.682	**2.996**
Propene g	29.085	40.786	76.209	14.611	37.359	**198.050**
Propylene oxide g	0.000	0.001	0.000	0.029	0.000	**0.030**
Pyrene g	0.002	0.004	0.005	0.001	0.002	**0.015**
Radioactive species, unspecified MBq	107.989	536.737	912.301	389.706	324.679	**2,271.412**
Radionuclides (Including Radon) g	36,195.896	185,729.524	42,430.157	18,414.883	27,598.835	**310,369.295**
Selenium g	8.686	14.291	21.008	4.162	9.894	**58.041**
Styrene g	0.117	0.109	0.000	2.536	0.045	**2.808**
Sulfur dioxide g	381,850.398	1,447,953.867	1,124,972.312	302,093.015	481,971.328	**3,738,840.920**
Sulfur oxides g	32,149.889	295,795.534	16,103.890	62,790.033	35,418.277	**442,257.623**
Sulfuric acid, dimethyl ester g	0.224	0.068	0.000	0.006	0.086	**0.384**
Tar g	0.000	0.000	0.000	0.000	0.000	**0.000**
t-Butyl methyl ether g	0.163	0.050	0.000	0.030	0.063	**0.307**
TOC, Total Organic Carbon g	0.000	4.809	0.000	0.000	0.000	**4.809**
Toluene g	5.731	9.411	12.083	88.893	6.353	**122.473**
Toluene, 2,4-dinitro- g	0.001	0.000	0.000	0.000	0.001	**0.002**
Vinyl acetate g	0.035	0.011	0.000	0.000	0.014	**0.060**
VOC, volatile organic compounds g	11,092.289	23,968.525	22,610.649	7,507.845	11,214.582	**76,393.891**
Xylene g	3.386	11.279	8.419	213.371	4.193	**240.648**
Zinc g	0.006	1.331	0.002	42.001	0.003	**43.344**

Appendix B-10: Southfield- Water Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Matr'l	Transp	**Total**	Matr'l	Transp	**Total**	Matr'l	Transp	**Total**	Matr'l	Transp	**Total**	Annual	**Total**	Matr'l	Transp	**Total**
2-Hexanone mg	1624	69.986	**1694**	0.098	109.2	**109.3**	279.2	14.16	**293.4**	60.27	30.075	**90.34**	282.1	**16926**	1963	223.45	**19113**
Acetone mg	2487	107.18	**2594**	0.15	167.3	**167.4**	427.6	21.69	**449.3**	92.3	46.059	**138.4**	432	**25923**	3007	342.21	**29272**
Acids, mg	4E+05	0	**4E+05**	0	0	**0**	2E+06	0	**2E+06**	0	0	**0**	0	**0**	2E+06	0	**2E+06**
Aluminum mg	8E+06	961031	**9E+06**	326.3	1E+06	**2E+06**	3E+06	2E+05	**3E+06**	8E+05	412985	**1E+06**	9E+05	**6E+07**	1E+07	3E+06	**7E+07**
Ammonia mg	3E+06	204198	**4E+06**	189.5	3E+05	**3E+05**	7E+05	41314	**7E+05**	2E+05	87750	**3E+05**	5E+05	**3E+07**	4E+06	651971	**4E+07**
Ammonia, as N mg	2E-07	0	**2E-07**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	2E-07	0	**2E-07**

Ammonium, ion mg	2E+06	0	**2E+06**	0	0	**0**	3E+06	0	**3E+06**	0	0	**0**	0	**0**	5E+06	0	**5E+06**
Antimony mg	5278	600.53	**5879**	0.2	937.3	**937.5**	2610	121.5	**2731**	517.2	258.07	**775.2**	568.6	**34117**	8406	1917.4	**44440**
Arsenic, ion mg	57579	2965.1	**60544**	3.353	4628	**4631**	11395	599.9	**11995**	2553	1274.2	**3828**	9654	**6E+05**	71531	9467.1	**7E+05**
Barium mg	1E+08	1E+07	**1E+08**	4932	2E+07	**2E+07**	3E+07	3E+06	**3E+07**	1E+07	6E+06	**2E+07**	1E+07	**8E+08**	1E+08	4E+07	**1E+09**
Benzene mg	5E+05	17980	**6E+05**	25.15	28064	**28089**	87746	3638	**91384**	15484	7726.8	**23211**	72479	**4E+06**	6E+05	57409	**5E+06**
Benzene, -methyl mg	24853	1071.1	**25924**	1.498	1672	**1673**	4273	216.7	**4490**	922.3	460.27	**1383**	4317	**3E+05**	30050	3419.7	**3E+05**
Benzene, ethyl- mg	25132	1011.4	**26144**	1.415	1579	**1580**	10563	204.6	**10767**	871	434.65	**1306**	4077	**2E+05**	36568	3229.4	**3E+05**
Benzene, penta- µg	18639	803.31	**19443**	1.123	1254	**1255**	3205	162.5	**3367**	691.8	345.21	**1037**	3238	**2E+05**	22537	2564.8	**2E+05**
Benze alkylated mg	4034	526.84	**4561**	0.175	822.3	**822.5**	1050	106.6	**1157**	453.7	226.4	**680.1**	497.6	**29858**	5538	1682.1	**37078**
Benzoic acid mg	3E+05	10873	**3E+05**	15.21	16970	**16985**	43377	2200	**45577**	9363	4672.4	**14036**	43829	**3E+06**	3E+05	34715	**3E+06**
Beryllium mg	2725	166.33	**2891**	0.154	259.6	**259.8**	547.2	33.65	**580.9**	143.2	71.476	**214.7**	443	**26580**	3416	531.06	**30527**
Biphenyl µg	3E+05	34111	**3E+05**	11.34	53240	**53251**	67979	6901	**74880**	29375	14658	**44033**	32221	**2E+06**	4E+05	108911	**2E+06**
BOD5, 5E+07	2E+06	**5E+07**	2617	3E+06	**3E+06**	1E+07	4E+05	**1E+07**	2E+06	844592	**3E+06**	8E+06	**5E+08**	6E+07	6E+06	**5E+08**	
Boron mg	1E+06	33640	**1E+06**	47.05	52506	**52553**	1E+06	6806	**1E+06**	28970	14456	**43426**	1E+05	**8E+06**	2E+06	107409	**1E+07**
Bromide mg	5E+07	2E+06	**6E+07**	3212	4E+06	**4E+06**	9E+06	5E+05	**1E+07**	2E+06	986782	**3E+06**	9E+06	**6E+08**	6E+07	7E+06	**6E+08**
Cadmium, ion mg	11798	437.65	**12235**	0.489	683.1	**683.6**	15071	88.55	**15160**	376.9	188.07	**565**	1407	**84405**	27247	1397.4	**1E+05**
Calcium, ion mg	8E+08	3E+07	**8E+08**	48178	5E+07	**5E+07**	1E+08	7E+06	**2E+08**	3E+07	1E+07	**4E+07**	1E+08	**8E+09**	1E+09	1E+08	**9E+09**
Chloride mg	1E+10	4E+08	**1E+10**	5E+05	6E+08	**6E+08**	3E+09	8E+07	**3E+09**	3E+08	2E+08	**5E+08**	2E+09	**9E+10**	1E+10	1E+09	**1E+11**
Chromium mg	1E+05	25642	**1E+05**	1.687	40022	**40024**	51759	5188	**56947**	22082	11019	**33101**	4435	**3E+05**	2E+05	81871	**5E+05**
Chromium VI µg	5E+06	107892	**5E+06**	7.097	2E+05	**2E+05**	2E+07	21829	**2E+07**	92912	46365	**1E+05**	18662	**1E+06**	2E+07	344484	**2E+07**
Chromium, ion mg	1E+05	1662.2	**1E+05**	7.343	2594	**2602**	17688	336.3	**18024**	1431	714.28	**2146**	21228	**1E+06**	1E+05	5307	**1E+06**
Cobalt mg	7814	237.46	**8051**	0.332	370.6	**371**	9178	48.04	**9226**	204.5	102.04	**306.5**	957.2	**57432**	17197	758.17	**75387**
COD, mg	1E+08	4E+06	**1E+08**	4356	6E+06	**6E+06**	2E+07	8E+05	**2E+07**	3E+06	2E+06	**5E+06**	1E+07	**8E+08**	2E+08	1E+07	**9E+08**
Copper, ion mg	44353	3084.5	**47437**	2.219	4814	**4817**	13266	624.1	**13890**	2656	1325.5	**3982**	6371	**4E+05**	60278	9848.5	**5E+05**
Cyanide mg	1E+07	0.7736	**1E+07**	0.001	1.207	**1.208**	13702	0.157	**13702**	0.666	0.3324	**0.999**	3.118	**187.1**	1E+07	2.4698	**1E+07**
Decane mg	7250	312.43	**7562**	0.437	487.6	**488.1**	1246	63.21	**1310**	269.1	134.26	**403.3**	1259	**75563**	8765	997.55	**85326**
Detergents, oil mg	2E+05	8925.6	**3E+05**	14.82	13931	**13946**	39994	1806	**41800**	7686	3835.6	**11522**	42758	**3E+06**	3E+05	28498	**3E+06**
Dibenzofuran µg	47290	2038	**49328**	2.85	3181	**3184**	8131	412.3	**8543**	1755	875.79	**2631**	8215	**5E+05**	57178	6507	**6E+05**
Dibenzothiophene g	33011	105.28	**33117**	2.208	164.3	**166.5**	5880	21.3	**5901**	90.66	45.243	**135.9**	6389	**4E+05**	38984	336.15	**4E+05**
Dissolved matter mg	3E+06	0	**3E+06**	0	0	**0**	3E+06	0	**3E+06**	0	0	**0**	0	**0**	6E+06	0	**6E+06**
Dissolved solids mg	1E+10	5E+08	**1E+10**	7E+05	7E+08	**7E+08**	1E+09	1E+08	**1E+09**	4E+08	2E+08	**6E+08**	2E+09	**1E+11**	1E+10	2E+09	**1E+11**
Docosane µg	3E+05	11469	**3E+05**	16.04	17901	**17917**	45757	2320	**48077**	9877	4928.7	**14805**	46233	**3E+06**	3E+05	36619	**3E+06**
Dodecane mg	13755	592.79	**14348**	0.829	925.2	**926**	2365	119.9	**2485**	510.5	254.74	**765.2**	2390	**1E+05**	16631	1892.7	**2E+05**
Eicosane mg	3787	163.21	**3950**	0.228	254.7	**255**	651.1	33.02	**684.1**	140.5	70.136	**210.7**	657.9	**39474**	4579	521.1	**44574**
Fluorene,methyl- µg	28304	1219.8	**29524**	1.706	1904	**1906**	4866	246.8	**5113**	1050	524.2	**1575**	4917	**3E+05**	34223	3894.7	**3E+05**
Fluorene, alkylat, µg	2E+05	30532	**3E+05**	10.15	47654	**47664**	60846	6177	**67023**	26293	13120	**39413**	28840	**2E+06**	3E+05	97483	**2E+06**
Fluoride mg	1E+07	0	**1E+07**	0	0	**0**	1E+06	0	**1E+06**	0	0	**0**	0	**0**	1E+07	0	**1E+07**
Fluorine µg	1E+05	15030	**1E+05**	5.978	23459	**23465**	32021	3041	**35061**	12943	6458.9	**19402**	17043	**1E+06**	2E+05	47989	**1E+06**
Halogenated orga µg	9E-05	0	**9E-05**	0	0	**0**	8E-04	0	**8E-04**	0	0	**0**	0	**0**	9E-04	0	**9E-04**
Hexadecane mg	15013	647.03	**15660**	0.905	1010	**1011**	2581	130.9	**2712**	557.2	278.05	**835.2**	2608	**2E+05**	18153	2065.9	**2E+05**
Hexanoic acid mg	52247	2251.7	**54499**	3.149	3514	**3518**	8983	455.6	**9438**	1939	967.61	**2907**	9076	**5E+05**	63172	7189.2	**6E+05**
Hydrocarbons, µg	3E+08	0	**3E+08**	0	0	**0**	1E+09	0	**1E+09**	0	0	**0**	0	**0**	2E+09	0	**2E+09**
Iron mg	3E+07	2E+06	**3E+07**	1287	3E+06	**3E+06**	9E+06	4E+05	**9E+06**	2E+06	817976	**2E+06**	4E+06	**2E+08**	4E+07	6E+06	**3E+08**
Lead mg	7E+06	6306	**7E+06**	4.952	9842	**9847**	24417	1276	**25693**	5430	2709.9	**8140**	14226	**9E+05**	7E+06	20134	**8E+06**
Lead-210/kg µg	5E+08	0.0011	**5E+08**	2E-06	0.002	**0.002**	1E+09	2E-04	**1E+09**	1E-03	0.0005	**0.001**	0.004	**0.269**	2E+09	0.0036	**2E+09**
Lithium, ion mg	2E+08	11506	**2E+08**	15335	17958	**33293**	3E+07	2328	**3E+07**	9908	4944.3	**14853**	4E+07	**3E+09**	3E+08	36736	**3E+09**
Magnesium mg	2E+08	7E+06	**2E+08**	9419	1E+07	**1E+07**	3E+07	1E+06	**3E+07**	6E+06	3E+06	**9E+06**	3E+07	**2E+09**	2E+08	2E+07	**2E+09**
Manganese mg	8E+06	10727	**8E+06**	237.7	16742	**16980**	2E+07	2170	**2E+07**	9237	4609.5	**13847**	6E+05	**4E+07**	3E+07	34248	**6E+07**
Mercury µg	88444	10528	**98973**	3.499	16432	**16436**	48849	2130	**50979**	9066	4524.3	**13591**	9945	**6E+05**	1E+05	33615	**8E+05**
Metallic ions, mg	4E+05	0	**4E+05**	0	0	**0**	8E+05	0	**8E+05**	0	0	**0**	0	**0**	1E+06	0	**1E+06**
MethaneR-40 µg	10010	431.41	**10442**	0.603	673.3	**673.9**	1721	87.28	**1808**	371.5	185.39	**556.9**	1739	**1E+05**	12104	1377.4	**1E+05**
Methyl µg	20020	862.8	**20883**	1.207	1347	**1348**	3442	174.6	**3617**	743	370.77	**1114**	3478	**2E+05**	24206	2754.8	**2E+05**
Molybdenum mg	5771	246.39	**6017**	0.345	384.6	**384.9**	1186	49.85	**1236**	212.2	105.88	**318.1**	993.2	**59591**	7169	786.68	**67547**

m-Xylene mg	7535	324.74	**7860**	0.454	506.8	**507.3**	1296	65.7	**1361**	279.6	139.55	**419.2**	1309	**78543**	9111	1036.8	**88691**
Naphthalene mg	-12671	195.32	**-12476**	0.272	304.9	**305.1**	728.4	39.52	**767.9**	168.2	83.934	**252.1**	784.7	**47083**	-11774	623.62	**35933**
Naphthalene,methal g	3939	169.77	**4109**	0.237	265	**265.2**	677.3	34.35	**711.6**	146.2	72.956	**219.2**	684.3	**41061**	4763	542.05	**46366**
Naphthalenes µg	66103	8633.1	**74736**	2.869	13474	**13477**	17205	1747	**18951**	7434	3709.9	**11144**	8155	**5E+05**	90745	27564	**6E+05**
n-Hexacosane µg	2E+05	7155.3	**2E+05**	10.01	11168	**11178**	28546	1448	**29994**	6162	3074.9	**9237**	28843	**2E+06**	2E+05	22846	**2E+06**
Nickel mg	1E+05	2946.4	**1E+05**	2.694	4599	**4601**	37455	596.1	**38051**	2537	1266.2	**3804**	7747	**5E+05**	2E+05	9407.5	**6E+05**
Nitrate mg	8E+05	0	**8E+05**	0	0	**0**	7E+05	0	**7E+05**	0	0	**0**	0	**0**	2E+06	0	**2E+06**
Nitrate comp mg	4E-09	0	**4E-09**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	4E-09	0	**4E-09**
Nitric acid mg	1E-05	0	**1E-05**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1E-05	0	**1E-05**
Nitrogen, total mg	1E+07	0	**1E+07**	0	0	**0**	38435	0	**38435**	0	0	**0**	0	**0**	1E+07	0	**1E+07**
Non-halogenated µg	3E+08	0	**3E+08**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	3E+08	0	**3E+08**
o-Cresol mg	7155	308.33	**7463**	0.431	481.2	**481.7**	1230	62.38	**1292**	265.5	132.5	**398**	1243	**74574**	8651	984.46	**84209**
Octadecane mg	3709	159.85	**3869**	0.224	249.5	**249.7**	637.7	32.34	**670**	137.7	68.691	**206.3**	644.3	**38661**	4485	510.37	**43656**
Oils, unspecified mg	4E+08	249064	**4E+08**	369.6	4E+05	**4E+05**	1E+07	50391	**1E+07**	2E+05	107030	**3E+05**	1E+06	**6E+07**	4E+08	795221	**5E+08**
Other mg	5E+08	0	**5E+08**	0	0	**0**	1E+09	0	**1E+09**	0	0	**0**	0	**0**	2E+09	0	**2E+09**
Other metals mg	7E+07	0	**7E+07**	0	0	**0**	1E+08	0	**1E+08**	0	0	**0**	0	**0**	2E+08	0	**2E+08**
p-Cresol mg	7719	332.67	**8052**	0.465	519.2	**519.7**	1327	67.31	**1395**	286.5	142.96	**429.4**	1341	**80462**	9334	1062.2	**90858**
Pentanone, methyl g	1017	45.044	**1062**	0.063	70.3	**70.37**	103.8	9.113	**112.9**	38.79	19.357	**58.15**	181.6	**10894**	1160	143.82	**12198**
Phenanthrene µg	38215	3057.7	**41272**	2.031	4772	**4774**	7994	618.6	**8613**	2633	1314	**3947**	5827	**3E+05**	48844	9762.8	**4E+05**
Phenanthr unspec.µg	27409	3579.6	**30989**	1.19	5587	**5588**	7134	724.2	**7858**	3083	1538.3	**4621**	3381	**2E+05**	37627	11429	**3E+05**
Phenol µg	2E+08	5E+06	**2E+08**	314.1	7E+06	**7E+06**	3E+07	1E+06	**3E+07**	4E+06	2E+06	**6E+06**	8E+05	**5E+07**	2E+08	2E+07	**3E+08**
Phenol, dimethyl- mg	6966	300.22	**7267**	0.42	468.6	**469**	1198	60.74	**1258**	258.5	129.01	**387.6**	1210	**72612**	8423	958.56	**81994**
Phenols, unspec mg	95849	670.7	**96520**	6.435	1047	**1053**	13285	135.7	**13421**	577.6	288.22	**865.8**	18616	**1E+06**	1E+05	2141.4	**1E+06**
Phosphate mg	6E+06	0	**6E+06**	0	0	**0**	3E+05	0	**3E+05**	0	0	**0**	0	**0**	6E+06	0	**6E+06**
Phosphorus mg	3E+07	0	**3E+07**	0	0	**0**	24357	0	**24357**	0	0	**0**	0	**0**	3E+07	0	**3E+07**
PolynuclCarbons µg	202.8	0	**202.8**	0	0	**0**	139.2	0	**139.2**	0	0	**0**	0	**0**	342	0	**342**
Radium-226/kg µg	8.752	0.3874	**9.139**	5E-04	0.605	**0.605**	0.893	0.078	**0.971**	0.334	0.1665	**0.5**	1.562	**93.7**	9.979	1.2371	**104.9**
Radium-228/kg µg	0.045	0.002	**0.047**	3E-06	0.003	**0.003**	0.005	4E-04	**0.005**	0.002	0.0008	**0.003**	0.008	**0.479**	0.051	0.0063	**0.537**
Selenium µg	1E+06	116450	**1E+06**	39.38	2E+05	**2E+05**	4E+05	23560	**4E+05**	1E+05	50042	**2E+05**	1E+05	**7E+06**	1E+06	371805	**9E+06**
Silver mg	5E+05	22515	**5E+05**	31.41	35142	**35173**	89850	4555	**94406**	19389	9675.5	**29065**	90541	**5E+06**	6E+05	71888	**6E+06**
Sodium, ion mg	3E+09	1E+08	**3E+09**	2E+05	2E+08	**2E+08**	5E+08	2E+07	**5E+08**	9E+07	5E+07	**1E+08**	4E+08	**3E+10**	3E+09	3E+08	**3E+10**
Solids, inorganic mg	72691	0	**72691**	0	0	**0**	3E+05	0	**3E+05**	0	0	**0**	0	**0**	4E+05	0	**4E+05**
Strontium mg	1E+07	584313	**1E+07**	817.1	9E+05	**9E+05**	3E+06	1E+05	**3E+06**	5E+05	251098	**8E+05**	2E+06	**1E+08**	2E+07	2E+06	**2E+08**
Sulfate mg	2E+08	778944	**2E+08**	1103	1E+06	**1E+06**	3E+07	2E+05	**3E+07**	7E+05	334736	**1E+06**	3E+06	**2E+08**	2E+08	2E+06	**4E+08**
Sulfide mg	4E+07	554.04	**4E+07**	0.036	864.7	**864.8**	2E+05	112.1	**2E+05**	477.1	238.09	**715.2**	95.83	**5750**	4E+07	1769	**4E+07**
Sulfur mg	7E+05	28397	**7E+05**	39.71	44322	**44362**	1E+05	5745	**1E+05**	24454	12203	**36657**	1E+05	**7E+06**	8E+05	90667	**8E+06**
Suspended solids, mg	2E+09	3E+07	**2E+09**	15020	5E+07	**5E+07**	7E+07	6E+06	**7E+07**	3E+07	1E+07	**4E+07**	4E+07	**3E+09**	2E+09	9E+07	**5E+09**
Tar mg	2E-10	0	**2E-10**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	2E-10	0	**2E-10**
Tetradecane mg	6028	259.79	**6288**	0.363	405.5	**405.8**	1036	52.56	**1089**	223.7	111.64	**335.4**	1047	**62834**	7289	829.48	**70952**
Thallium µg	1E+06	126538	**1E+06**	42.27	2E+05	**2E+05**	3E+05	25602	**3E+05**	1E+05	54378	**2E+05**	1E+05	**7E+06**	1E+06	404018	**9E+06**
Tin mg	32064	2409.8	**34474**	1.731	3761	**3763**	6723	487.6	**7211**	2075	1035.6	**3111**	4970	**3E+05**	40864	7694.1	**3E+05**
Titanium, ion mg	2E+05	9222.3	**2E+05**	3.076	14394	**14397**	2E+05	1866	**2E+05**	7942	3963.1	**11905**	8743	**5E+05**	4E+05	29445	**1E+06**
Toluene mg	4E+05	16988	**4E+05**	23.76	26514	**26538**	97559	3437	**1E+05**	14629	7300.1	**21929**	68477	**4E+06**	5E+05	54239	**5E+06**
Vanadium mg	10541	291.05	**10832**	0.407	454.3	**454.7**	12076	58.89	**12135**	250.6	125.07	**375.7**	1173	**70393**	22869	929.27	**94191**
Xylene mg	47334	8901.4	**56235**	0.901	13893	**13894**	45963	1801	**47764**	7666	3825.2	**11491**	2452	**1E+05**	1E+05	28421	**3E+05**
Yttrium mg	1676	72.232	**1748**	0.101	112.7	**112.8**	288.2	14.61	**302.8**	62.2	31.04	**93.24**	291.2	**17469**	2026	230.63	**19726**
Zinc mg	1E+07	22141	**1E+07**	8.505	34557	**34565**	92467	4480	**96947**	19066	9514.5	**28581**	24234	**1E+06**	1E+07	70691	**2E+07**

Appendix B11: Southfield- Water Emissions by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
2-Hexanone mg	197.3244408	742.1010011	668.7779868	287.848959	290.853448	**2186.91**
Acetone mg	302.1997882	1136.532524	1024.242304	440.845373	445.4427239	**3349.26**
Acids, unspecified mg	0	1594940.2	0	514850.313	0	**2109791**
Aluminum mg	2055010.666	4996114.759	2778953.777	2715089.39	1956163.869	**1.5E+07**
Ammonia mg	522829.7126	1614756.946	1351078.454	700195.659	660407.3926	**4849268**
Ammonia, as N mg	0	9.12296E-08	0	7.2203E-08	0	**1.6E-07**
Ammonium, ion mg	43820.31319	4084283.069	412487.8638	62805.7016	58405.92213	**4661803**
Antimony mg	1267.10207	2934.239311	1712.158526	3200.42114	1209.03502	**10323**
Arsenic, ion mg	7831.448783	27536.55576	23338.64524	11565.1574	10726.24445	**80998.1**
Barium mg	28128164.88	61841551.13	40967131.57	31288670.4	27593932.93	**1.9E+08**
Benzene mg	51233.47186	220100.2014	171826.5316	121727.778	130237.3491	**695125**
Benzene, 1-methyl-4-(1-methylethyl)- µg	3019.880988	11357.40161	10235.29936	4405.32283	4451.319969	**33469.2**
Benzene, ethyl- mg	2851.807618	11004.53537	9665.647756	12071.3202	4203.579066	**39796.9**
Benzene, pentamethyl- µg	2264.932358	8518.030157	7676.421198	3304.0003	3338.489552	**25101.9**
Benzenes, alkylated, unspecified mg	1111.338593	2346.567425	1499.43058	1202.72031	1059.834713	**7219.89**
Benzoic acid mg	30656.33958	115295.4754	103904.6247	44720.831	45187.83625	**339765**
Beryllium mg	416.632199	1318.811326	1094.9465	583.060879	533.2259755	**3946.68**
Biphenyl µg	71954.58649	151932.4831	97084.32608	77871.6158	68620.53125	**467464**
BOD5, Biological Oxygen Demand mg	5509096.81	23651944.9	17970937.46	13866436.8	7927137.808	**6.9E+07**
Boron mg	94850.00367	386391.9826	321472.3355	1134395.34	139808.5452	**2076918**
Bromide mg	6475102.263	24355306.86	21950110.26	9446448.8	9545356.607	**7.2E+07**
Cadmium, ion mg	1151.74784	4424.058616	3405.257479	18092.2455	1570.56783	**28643.9**
Calcium, ion mg	97095375.38	365938673.3	329191638.8	153660749	143146049.7	**1.1E+09**
Chloride mg	1124359474	5958705801	3733531975	1841574841	1692624134	**1.4E+10**
Chromium mg	49565.8076	75265.26531	34927.29427	63345.0714	38348.07369	**261452**
Chromium VI µg	208437.8793	5175935.758	126078.0005	17377388.3	159205.5932	**2.3E+07**
Chromium, ion mg	8029.060142	46635.79288	47469.56534	17469.4847	17001.55737	**136605**
Cobalt mg	669.5236673	3108.689717	2269.228619	10920.6173	986.8834264	**17954.9**
COD, Chemical Oxygen Demand mg	11012520.25	46887135.35	46625124.51	38235834.3	36155239.82	**1.8E+08**
Copper, ion mg	7363.621438	22048.19659	16298.05073	15764.8353	8651.368707	**70126.1**
Cyanide mg	73216.83465	3459309.725	7074.637366	3117559.8	6359494.242	**1.3E+07**
Decane mg	880.911925	3312.966626	2985.636423	1285.04313	1298.457637	**9763.02**
Detergents, oil mg	26725.75414	108154.7106	100034.4506	40731.543	41804.91684	**317451**
Dibenzofuran µg	5746.221952	21610.90703	19475.79071	8382.45361	8469.983098	**63685.4**
Dibenzothiophene µg	1669.075753	13671.68012	13973.02779	5424.72493	4581.321105	**39319.8**
Dissolved organic matter mg	619027.6104	949679.9043	5371.100939	3917797.62	238629.4976	**5730506**
Dissolved solids mg	1346641944	4827556912	4564491018	1102913003	1984953900	**1.4E+10**
Docosane µg	32337.95611	121619.9855	109604.3308	47173.9647	47666.59703	**358403**
Dodecane mg	1671.383272	6285.86952	5664.831369	2438.1704	2463.628172	**18523.9**
Eicosane mg	460.1758744	1730.672346	1559.685774	671.294128	678.3039138	**5100.13**
Fluorene, 1-methyl- µg	3439.329047	12934.83101	11656.85877	5017.18818	5069.568594	**38117.8**
Fluorenes, alkylated, unspecified µg	64404.82301	135990.8982	86897.57743	69700.9637	61420.52077	**418415**
Fluoride mg	117932.126	2259752.857	5044147.696	1758995.97	2631552.096	**1.2E+07**
Fluorine µg	32359.7955	72935.66041	48964.90165	35999.7411	32213.13673	**222473**
Halogenated organics µg	0	0.000932568	0	0	0	**0.00093**
Hexadecane mg	1824.313351	6860.967857	6183.092684	2661.24869	2689.031195	**20218.7**
Hexanoic acid mg	6348.621852	23876.40007	21517.43503	9261.20524	9357.905002	**70361.6**
Hydrocarbons, unspecified µg	74120.69478	45768232.54	27544.10738	1519400345	32894.61614	**1.6E+09**
Iron mg	4377569.138	16794024.67	8907377.661	7095053.65	7023713.553	**4.4E+07**

Lead mg	66493.35241	926490.653	3758255.421	844518.448	1911100.84	**7506859**
Lead-210/kg µg	0.003138403	1552742270	0.01064184	10418760.2	0.004627354	**1.6E+09**
Lithium, ion mg	10235278.41	88489498.26	96521914.05	26343605.8	30857657.33	**2.5E+08**
Magnesium mg	18998967.85	71474669.39	64363701.67	29513705.9	27992486.61	**2.1E+08**
Manganese mg	105845.725	26662868.07	287126.7071	459338.854	130881.2187	**2.8E+07**
Mercury µg	22208.37763	50951.79892	29964.20542	55674.2897	21179.25745	**179978**
Metallic ions, unspecified mg	48178.45161	945137.2752	17903.6698	195759.389	21381.50049	**1228360**
Methane, monochloro-, R-40 µg	1216.385458	4574.67459	4122.699786	1774.43066	1792.957808	**13481.1**
Methyl ethyl ketone µg	2432.682644	9149.001178	8245.080577	3548.72889	3585.780448	**26961.3**
Molybdenum mg	694.7022749	2633.969655	2354.550523	1248.85646	1023.992719	**7956.07**
m-Xylene mg	915.6149064	3443.564394	3103.35912	1335.69226	1349.636456	**10147.9**
Naphthalene mg	-3549.889143	-2896.78293	1860.852552	801.815388	-7366.5334	**-11150.5**
Naphthalene, 2-methyl- mg	478.6739157	1800.235906	1622.37473	698.277376	705.5684482	**5305.13**
Naphthalenes, alkylated, unspecified µg	18210.91062	38452.23538	24570.72634	19708.4004	17367.03594	**118309**
n-Hexacosane µg	20174.68402	75874.11894	68377.68526	29430.2084	29737.46386	**223594**
Nickel mg	7751.513087	33537.13781	43695.28894	51991.6585	27688.04023	**164664**
Nitrate mg	258069.5868	326108.3659	0	883419.413	99123.66148	**1566721**
Nitrate compounds mg	0	2.46187E-09	0	1.9484E-09	0	**4.4E-09**
Nitric acid mg	0	5.52209E-06	0	4.3704E-06	0	**9.9E-06**
Nitrogen, total mg	73711.1813	3746075.131	2203.52859	3414474.04	6896618.244	**1.4E+07**
Non-halogenated Organics µg	0	35923631.78	0	299936660	0	**3.4E+08**
o-Cresol mg	869.3592798	3269.564167	2946.537406	1268.20085	1281.443372	**9635.11**
Octadecane mg	450.6960043	1695.015952	1527.550938	657.464283	664.3293488	**4995.06**
Oils, unspecified mg	3083357.964	103127231.4	11218105.68	97461647.2	181045145.3	**4E+08**
Other mg	0	1533099362	0	2439484.83	0	**1.5E+09**
Other metals mg	1950.154475	190182810.3	0	1319721.3	749.0496667	**1.9E+08**
p-Cresol mg	937.9767223	3527.679042	3179.168561	1368.31029	1382.602583	**10395.7**
Pentanone, methyl- mg	127.0018111	455.283666	430.440837	104.006756	187.1995044	**1303.93**
Phenanthrene µg	7126.085976	19474.28808	15091.10546	8722.85813	8192.680349	**58607**
Phenanthrenes, alkylated, unspecified µg	7550.988557	15943.86384	10188.02086	8171.9077	7201.081686	**49055.9**
Phenol µg	15482685.48	51910188.69	12306058.41	69948254.1	75637424.67	**2.3E+08**
Phenol, 2,4-dimethyl- mg	846.4888004	3183.543213	2869.012605	1234.83619	1247.72968	**9381.61**
Phenols, unspecified mg	5552.113518	39015.05423	41004.59421	12444.5639	13842.83399	**111859**
Phosphate mg	46290.24634	172064.2341	4590745.582	444912.961	582744.5167	**5836758**
Phosphorus mg	281051.549	1152390.293	27239988.93	1254344.71	4107020.667	**3.4E+07**
Polynuclear Aromatic Hydrocarbons µg	0	341.96071	0	0	0	**341.961**
Radium-226/kg µg	1.092415857	3.9161274	3.702434197	0.89461804	1.610201641	**11.2158**
Radium-228/kg µg	0.005583951	0.020026694	0.018936885	0.00457596	0.008233551	**0.05736**
Selenium µg	246095.7707	643631.2095	335711.7613	353723.698	235628.4576	**1814791**
Silver mg	63432.53791	238322.8895	214687.7028	92680.0369	93422.20543	**702545**
Sodium, ion mg	307793492	1162802761	1043508710	549050335	453766337.7	**3.5E+09**
Solids, inorganic mg	0	13256.14733	0	344852.959	0	**358109**
Strontium mg	1647477.454	6216893.888	5583705.59	3000070.94	2428364.946	**1.9E+07**
Sulfate mg	29315288.61	150142597.5	7560446.519	25186510.6	13682435.77	**2.3E+08**
Sulfide mg	208400.1753	10269236.03	2267983.96	9414985.35	19017452.88	**4.1E+07**
Sulfur mg	80066.55646	301468.7094	271370.0755	127895.813	118018.5256	**898820**
Suspended solids, unspecified mg	91770225.96	376749204.3	1202435941	307405169	583478084.9	**2.6E+09**
Tar mg	0	1.39137E-10	0	1.1012E-10	0	**2.5E-10**
Tetradecane mg	732.5011717	2754.848069	2482.671641	1068.55366	1079.710808	**8118.29**
Thallium µg	267066.2551	565144.4199	361485.0125	296602.56	254984.2386	**1745282**
Tin mg	5702.989857	16108.75744	12714.2657	7313.56039	6719.028687	**48558.6**
Titanium, ion mg	19460.98609	303005.2018	26316.22422	65968.2649	18574.19641	**433325**
Toluene mg	47897.08871	181431.4201	162337.7722	105968.691	70600.52842	**568236**

Vanadium mg	820.6191473	12317.79823	2781.333821	6668.65281	1209.59803	**23798**
Xylene mg	17406.53859	29752.52731	12384.46209	56071.8406	13768.5071	**129384**
Yttrium mg	203.6580669	765.9212633	690.2449176	297.088348	300.189331	**2257.1**
Zinc mg	160743.0371	223164.4081	11714690.35	409733.201	1340994.374	**1.4E+07**

Appendix B-12: Southfield- Land Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Bark/Wood Waste kg	14.6374	0	**14.64**	2794.5	0	**2795**	0	0	**0**	0	0	**0**	0	**0**	2809.15	0	**2809**
Concrete Solid Waste kg	22636.4	0	**22636**	14466	0	**14466**	3019.83	0	**3020**	0	0	**0**	0	**0**	40122.1	0	**40122**
Blast Furnace Slag kg	19206.8	0	**19207**	0	0	**0**	14.7884	0	**14.8**	0	0	**0**	0	**0**	19221.6	0	**19222**
Blast Furnace Dust kg	5663.21	0	**5663**	0	0	**0**	3.76004	0	**3.76**	0	0	**0**	0	**0**	5666.97	0	**5667**
Steel Waste kg	58.7892	0	**58.79**	179.77	0	**180**	76.3459	0	**76.3**	0	0	**0**	0	**0**	314.903	0	**314.9**
Other Solid Waste kg	42420.7	95.026	**42516**	10.879	148.32	**159**	12209.5	19.226	**12229**	81.8325	40.836	**123**	28142	**2E+06**	54723	303.4	**2E+06**

Appendix B-13: Southfield- Land Emissions by Bldg Assembly

Material ID	**Foundations**	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Bark/Wood Waste kg	2794.51518	14.6374449	0	0	0	**2809.153**
Concrete Solid Waste kg	17632.80282	2589.26777	0	6039.66379	13860.3193	**40122.05**
Blast Furnace Slag kg	141.9997985	1460.79799	11591.79944	1734.20266	4292.75818	**19221.56**
Blast Furnace Dust kg	637.2647844	421.458023	3346.525314	266.528303	995.192449	**5666.969**
Steel Waste kg	7.402725957	80.9912448	9.933657552	108.287783	108.287783	**314.9032**
Other Solid Waste kg	4170.015353	31757.4202	9581.59319	4928.60693	4588.72209	**55026.36**

Appendix C-1: Huron- All impacts by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	
Fossil Fuel Consumption MJ	5E+06	113813	**6E+06**	86520.6	2E+05	**3E+05**	1834303	23120	**2E+06**	92193.6	52735	**1E+05**	1E+06	**8E+07**	**90829556.63**
Weighted Resource Use kg	2E+06	2962.4	**2E+06**	2028.83	4019	**6047**	90368.6	549.4	**90918**	2171.13	1242.6	**3414**	126947	**8E+06**	**9631887.14**
Global Warming Potential (kg CO2 eq)	416368	8482.4	**4E+05**	5817.86	12765	**18583**	80198.8	1709	**81907**	6011.09	3947.6	**9959**	119455	**7E+06**	**7702618.941**
Acidification Potential (moles of H+ eq)	172277	2877.9	**2E+05**	2989.76	4027	**7016**	52053.6	547.9	**52601**	333.267	1245.1	**1578**	43208	**3E+06**	**2828800.961**
HH Resp. Effects Potn’l (kg PM2.5 eq)	1193.5	3.469	**1197**	3.23752	4.839	**8.077**	556.103	0.659	**556.8**	0.31726	1.4963	**1.814**	241.7	**14502**	**16265.54388**
Eutrophication Potential (kg N eq)	201.84	2.9953	**204.8**	2.80577	4.171	**6.977**	19.8634	0.568	**20.43**	0.22883	1.1763	**1.405**	1.1238	**67.43**	**301.0838348**
Ozone Depletion Potential (kg CFC-11 eq)	0.0006	3E-07	**6E-04**	7.6E-12	5E-07	**5E-07**	8.8E-05	7E-08	**9E-05**	2.7E-07	2E-07	**4E-07**	3E-08	**2E-06**	**0.000688426**
Smog Potential (kg NOx eq)	1333.5	64.84	**1398**	71.3102	89.87	**161.2**	297.496	12.25	**309.7**	4.28234	27.789	**32.07**	20.043	**1203**	**3103.871696**

Appendix C-2: Huron- All impacts by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Fossil Fuel Consumption MJ	753049.2368	1417895.56	1783170.886	3180202.34	711331.734	**7845650**
Weighted Resource Use kg	788919.8848	265856.129	172308.9596	167481.191	620503.241	**2015069**
Global Warming Potential (kg CO2 eq)	114390.0256	125834.761	90013.12836	131871.155	73189.8586	**535299**
Acidification Potential (moles of H+ eq)	37498.12712	87191.7618	36181.15606	49709.9795	25769.7659	**236351**
HH Respiratory Effects Potential (kg PM2.5 eq)	269.1075071	916.35968	186.7937531	218.883494	172.428802	**1763.57**
Eutrophication Potential (kg N eq)	16.87766099	32.0184945	111.7296756	46.0384938	27.1029357	**233.767**
Ozone Depletion Potential (kg CFC-11 eq)	0.000357765	0.00015671	4.76971E-07	6.1943E-06	0.00016537	**0.00069**
Smog Potential (kg NOx eq)	332.0556413	485.227981	110.0178502	733.829004	240.166574	**1901.3**

Appendix C-3: Huron- Energy Consumption by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Electricity kWh	172361	0	**2E+05**	45.275	0	**45.27**	35817.7	0	**35818**	0	0	**0**	183870	**1E+07**	208224	0	**1E+07**
Hydro MJ	61140.1	50.29	**61190**	2.267	75.524	**77.79**	58941.3	10.111	**58951**	39.0698	23.36	**62.4**	9211.5	**6E+05**	120123	159.29	**7E+05**
Coal MJ	1521506	733.9	**2E+06**	272.49	1102.1	**1375**	269903	147.55	**3E+05**	570.119	340.8	**911**	1E+06	**7E+07**	1792252	2324.3	**7E+07**
Diesel MJ	91027.8	1E+05	**2E+05**	86197	158916	**2E+05**	41723.3	21562	**63285**	86192.5	49136	**1E+05**	30155	**2E+06**	305141	335677	**2E+06**
Feedstock MJ	1897949	0	**2E+06**	0	0	**0**	1241600	0	**1E+06**	0	0	**0**	0	**0**	3139548	0	**3E+06**
Gasoline MJ	114.044	0	**114**	0	0	**0**	1.87523	0	**1.875**	0	0	**0**	0	**0**	115.919	0	**115.9**
Heavy Fuel Oil MJ	299198	2424	**3E+05**	0.4713	3640.4	**3641**	62818.3	487.39	**63306**	1876.17	1126	**3002**	1944.7	**1E+05**	363893	7677.9	**5E+05**
LPG MJ	4501.18	109.8	**4611**	0.2604	164.86	**165.1**	382.458	22.072	**404.5**	84.9662	50.99	**136**	1072.1	**64325**	4968.87	347.71	**69642**
Natural Gas MJ	1658114	4482	**2E+06**	50.118	6731	**6781**	217874	901.16	**2E+05**	3469.89	2082	**5552**	243180	**1E+07**	1879508	14196	**2E+07**
Nuclear MJ	419442	194.9	**4E+05**	118.03	290.72	**408.8**	71822.1	38.952	**71861**	143.712	89.91	**234**	479374	**3E+07**	491526	614.44	**3E+07**
Wood MJ	701.423	0	**701.4**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	701.423	0	**701.4**
Total Energy Consumption MJ	5953693	1E+05	**6E+06**	86641	170920	**3E+05**	1965066	23169	**2E+06**	92376.4	52849	**1E+05**	2E+06	**1E+08**	8097777	360996	**1E+08**

Appendix C-4: Huron- Energy Consumption by Bldg aAssembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Electricity kWh	16641.102	51238.014	69452.47297	55121.0312	15770.9656	**208224**
Hydro MJ	1362.024833	107769.951	3953.706732	6065.42816	1130.88262	**120282**
Coal MJ	387704.2145	442526.036	422553.9592	312750.833	229041.368	**2E+06**
Diesel MJ	156353.909	123447.81	75890.82592	106097.57	179027.309	**640817**
Feedstock MJ	11782.20498	154595.272	672712.3803	2200321.77	100136.575	**3E+06**
Gasoline MJ	0	16.0849792	28.82488953	71.0088668	0	**115.92**
Heavy Fuel Oil MJ	60938.00788	66162.0906	2859.99867	188804.38	52806.7953	**371571**
LPG MJ	639.5909172	2915.63522	661.9695914	650.131194	449.250103	**5316.6**
Natural Gas MJ	135631.3096	628232.63	608462.9278	371506.646	149870.437	**2E+06**
Nuclear MJ	45336.66851	102953.22	178583.6184	122889.449	42377.0866	**492140**
Wood MJ	0	701.422838	0	0	0	**701.42**

Appendix C-5: Huron- Resources use by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Limestone kg	193179	0	**2E+05**	0	0	**0**	5618.8	0	**5619**	0	0	**0**	0	**0**	198797	0	**2E+05**
Clay & Shale kg	135350	0	**1E+05**	0	0	**0**	146.81	0	**146.8**	0	0	**0**	0	**0**	135496	0	**1E+05**
Iron Ore kg	32922.3	0	**32922**	0	0	**0**	910.95	0	**910.9**	0	0	**0**	0	**0**	33833.2	0	**33833**
Sand kg	9075.93	0	**9076**	0	0	**0**	11314	0	**11314**	0	0	**0**	0	**0**	20390.3	0	**20390**
Ash kg	1076.8	0	**1077**	0	0	**0**	0.0055	0	**0.006**	0	0	**0**	0	**0**	1076.8	0	**1077**
Other kg	4789.97	0	**4790**	0	0	**0**	5637.6	0	**5638**	0	0	**0**	0	**0**	10427.5	0	**10428**
Gypsum kg	32327.1	0	**32327**	0	0	**0**	0.0003	0	**3E-04**	0	0	**0**	0	**0**	32327.1	0	**32327**
Semi-Cementitious Material kg	24707.8	0	**24708**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	24707.8	0	**24708**
Coarse Aggregate kg	561573	0	**6E+05**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	561573	0	**6E+05**
Fine Aggregate kg	405159	0	**4E+05**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	405159	0	**4E+05**
Water L	1811290	0	**2E+06**	0	0	**0**	51124	0	**51124**	0	0	**0**	0	**0**	1862414	0	**2E+06**
Obsolete Scrap Steel kg	72988.3	0	**72988**	0	0	**0**	228.9	0	**228.9**	0	0	**0**	0	**0**	73217.2	0	**73217**
Coal kg	84300.7	36.094	**84337**	13.3247	54.201	**67.53**	13323	7.2565	**13331**	28.0389	16.762	**44.8**	54118	**3E+06**	97665.5	114.3	**3E+06**
Wood Fiber kg	291.217	0	**291.2**	0	0	**0**	0.0664	0	**0.066**	0	0	**0**	0	**0**	291.283	0	**291.3**
Uranium kg	0.66368	0.0003	**0.664**	0.00019	0.0005	**6E-04**	0.1136	6E-05	**0.114**	0.00023	0.0001	**0**	0.7585	**45.51**	0.77774	1E-03	**46.29**
Natural Gas m3	43926.8	118.64	**44045**	1.32983	178.15	**179.5**	5808.8	23.851	**5833**	91.8379	55.095	**147**	6449.7	**4E+05**	49828.8	375.7	**4E+05**
Natural Gas as feedstock m3	6364.62	0	**6365**	0	0	**0**	10012	0	**10012**	0	0	**0**	0	**0**	16376.9	0	**16377**
Crude Oil L	13723.2	3158.2	**16881**	2254.98	4257.3	**6512**	3494.4	582.79	**4077**	2306.73	1316.4	**3623**	752.04	**45123**	21779.4	9315	**76217**
Crude Oil as feedstock L	11611.7	0	**11612**	0	0	**0**	20287	0	**20287**	0	0	**0**	0	**0**	31898.9	0	**31899**
Metallurgical Coal as feedstock kg	6775.51	0	**6776**	0	0	**0**	305.56	0	**305.6**	0	0	**0**	0	**0**	7081.06	0	**7081**
Prompt Scrap Steel as feedstock kg	46005.9	0	**46006**	0	0	**0**	134.42	0	**134.4**	0	0	**0**	0	**0**	46140.3	0	**46140**

Appendix C-6: Huron- Resources use by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Limestone kg	115264.7107	16613.8636	8185.545514	4411.41478	54321.9513	**2E+05**
Clay & Shale kg	31874.54566	88738.5383	0	180.162042	14703.107	**1E+05**
Iron Ore kg	705.3173183	4309.76577	6952.983684	21539.8203	325.349139	**33833**
Sand kg	1400.972756	18343.0583	0	0.00428348	646.241441	**20390**
Ash kg	705.3173183	46.1317122	0	0.00639359	325.349139	**1077**
Other kg	0	10427.5285	0	0	0	**10428**
Gypsum kg	4953.646426	25088.4516	0	0.00040178	2285.0206	**32327**
Semi-Cementitious Material kg	16908.29188	0	0	0	7799.46567	**24708**
Coarse Aggregate kg	296977.1852	0	0	0	264595.407	**6E+05**
Fine Aggregate kg	194726.8664	15504.178	0	0	194927.999	**4E+05**
Water L	54807.41564	311686.63	398907.5559	898203.869	198808.819	**2E+06**
Obsolete Scrap Steel kg	885.5984082	2040.78236	50563.79636	12200.3749	7526.67189	**73217**
Coal kg	25044.47586	21527.4541	21537.17857	15532.2989	14138.4184	**97780**
Wood Fiber kg	0	291.202539	0	0.08079612	0	**291.3**
Uranium kg	0.071735235	0.16291032	0.282569016	0.19444533	0.06705235	**0.779**
Natural Gas m3	3590.619445	16703.4543	16106.67112	9836.56478	3967.24982	**50205**
Natural Gas as feedstock m3	0	1010.99087	0	15365.8973	0	**16377**
Crude Oil L	7425.279188	6422.85359	2319.531234	8016.62708	6909.73511	**1094**
Crude Oil as feedstock L	0	866.668881	0	31032.1904	0	**31899**
Metallurgical Coal as feedstock kg	0	1795.30822	0	5285.75438	0	**7081**
Prompt Scrap Steel as feedstock kg	561.0573798	1230.81362	32033.92287	7546.12563	4768.40831	**46140**

Appendix C-7: Huron- Bill of Materials

Material	**Quantity**	**Unit**
1/2" Regular Gypsum Board	12627.9995	sf
5/8" Regular Gypsum Board	16956.8657	sf
6 mil Polyethylene	29184.3747	sf
Air Barrier	8176.2923	sf
Aluminum	3.9173	Tons
Batt. Fiberglass	54365.5977	sf(1")
Cold Rolled Sheet	0.1595	Tons
Commercial(26 ga.) Steel Cladding	2351.7996	sf
Concrete 20 MPa (flyash av)	330.0543	yd^3
Concrete 30 MPa (flyash av)	304.8889	yd^3
EPDM membrane (black, 60 mil)	40412.8152	lbs
Expanded Polystyrene	70.0731	sf(1")
Extruded Polystyrene	82446.2153	sf(1")
Galvanized Decking	20.0775	Tons
Galvanized Sheet	0.2856	Tons
Galvanized Studs	4.5142	Tons
Glazing Panel	5.3822	Tons
Hollow Structural Steel	6.1826	Tons
Joint Compound	3.0242	Tons
Low E Tin Glazing	8029.4567	sf
Metric Modular (Modular) Brick	8093.0495	sf

Mortar	25.8327	yd^3
Nails	0.4765	Tons
Open Web Joists	9.8879	Tons
Paper Tape	0.0347	Tons
Rebar, Rod, Light Sections	14.9875	Tons
Screws Nuts & Bolts	4.4198	Tons
Small Dimension Softwood Lumber, kiln-dried	0.2379	Mbfm
Solvent Based Alkyd Paint	0.1558	US Gallon
Water Based Latex Paint	540.1653	US Gallon
Wide Flange Sections	77.0621	Tons

Appendix C-8: Huron- Air Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
2-Chloroacetophenone g	0.06296	0	**0.063**	0	0	**0**	0.00586	0	**0.0059**	0	0	**0**	5E-09	**3E-07**	0.06882	0	**0.069**
Acenaphthene g	0.01574	0	**0.016**	3E-06	0	**3E-06**	0.0028	0	**0.0028**	0	0	**0**	0.0115	**0.689**	0.01854	0	**0.708**
Acenaphthylene g	0.00772	0	**0.008**	1E-06	0	**1E-06**	0.00137	0	**0.0014**	0	0	**0**	0.0056	**0.338**	0.00909	0	**0.347**
Acetaldehyde g	18.4905	0	**18.49**	0	0	**0**	9.53604	0	**9.536**	28.369	0	**28.37**	4E-07	**2E-05**	56.395	0	**56.4**
Acetophenone g	354.507	0	**354.5**	0	0	**0**	1420.08	0	**1420.1**	0	0	**0**	1E-08	**6E-07**	1774.58	0	**1775**
Acid Gases g	1.30701	0	**1.307**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1.30701	0	**1.307**
Acrolein g	10.2738	0	**10.27**	0.0016	0	**0.002**	1.65476	0	**1.6548**	3.4213	0	**3.421**	6.5343	**392.1**	15.3514	0	**407.4**
Aldehydes g	98.0184	0	**98.02**	0.0001	0	**1E-04**	214.098	0	**214.1**	0	0	**0**	0.4457	**26.74**	312.116	0	**338.9**
Ammonia g	2500.28	52.335	**2553**	0.0098	78.59	**78.6**	1220.38	10.52	**1230.9**	40.503	24.305	**64.81**	39.817	**2389**	3761.17	165.8	**6316**
Ammonium chloride g	7744.18	0	**7744**	0.0299	0	**0.03**	3153.2	0	**3153.2**	0	0	**0**	121.29	**7278**	10897.4	0	**18175**
Anthracene g	0.00648	0	**0.006**	1E-06	0	**1E-06**	0.00115	0	**0.0012**	0	0	**0**	0.0047	**0.284**	0.00764	0	**0.292**
Antimony g	0.59725	0	**0.597**	1E-04	0	**1E-04**	0.2559	0	**0.2559**	0	0	**0**	0.4056	**24.33**	0.85326	0	**25.19**
Arsenic g	13.4214	0	**13.42**	0.0023	0	**0.002**	3.5663	0	**3.5663**	0	0	**0**	9.2982	**557.9**	16.99	0	**574.9**
Benzene g	1021.14	0	**1021**	0.0073	0	**0.007**	561.52	0	**561.52**	34.509	0	**34.51**	29.503	**1770**	1617.17	0	**3387**
Benzene, chloro- g	0.19788	0	**0.198**	0	0	**0**	0.01841	0	**0.0184**	0	0	**0**	1E-08	**9E-07**	0.21629	0	**0.216**
Benzene, ethyl- g	5.43716	0	**5.437**	0	0	**0**	18.476	0	**18.476**	0	0	**0**	6E-08	**4E-06**	23.9132	0	**23.91**
Benzo(a)anthracene g	0.00247	0	**0.002**	4E-07	0	**4E-07**	0.00044	0	**0.0004**	0	0	**0**	0.0018	**0.108**	0.00291	0	**0.111**
Benzo(a)pyrene g	48.912	0	**48.91**	2E-07	0	**2E-07**	55.1488	0	**55.149**	0	0	**0**	0.0009	**0.051**	104.061	0	**104.1**
Benzo(b,j,k)fluoranthene g	0.00339	0	**0.003**	6E-07	0	**6E-07**	0.0006	0	**0.0006**	0	0	**0**	0.0025	**0.149**	0.004	0	**0.153**
Benzo(ghi)perylene g	0.00083	0	**8E-04**	1E-07	0	**1E-07**	0.00015	0	**0.0001**	0	0	**0**	0.0006	**0.037**	0.00098	0	**0.037**
Benzyl chloride g	6.2961	0	**6.296**	0	0	**0**	0.5859	0	**0.5859**	0	0	**0**	5E-07	**3E-05**	6.882	0	**6.882**
Beryllium g	0.64802	0	**0.648**	0.0001	0	**1E-04**	0.1235	0	**0.1235**	0	0	**0**	0.4752	**28.51**	0.77163	0	**29.29**
Biphenyl g	0.7554	0	**0.755**	9E-06	0	**9E-06**	2.82597	0	**2.826**	0	0	**0**	0.0383	**2.298**	3.58138	0	**5.88**
Bromoform g	0.35078	0	**0.351**	0	0	**0**	0.03264	0	**0.0326**	0	0	**0**	3E-08	**2E-06**	0.38343	0	**0.383**
BTEX g	442.447	0	**442.4**	0	0	**0**	1262.85	0	**1262.9**	0	0	**0**	0	**0**	1705.3	0	**1705**
Butadiene g	2.82844	0	**2.828**	0	0	**0**	9.06861	0	**9.0686**	1.4462	0	**1.446**	0	**0**	13.3433	0	**13.34**
Cadmium g	3.12359	0	**3.124**	0.0003	0	**3E-04**	0.85777	0	**0.8578**	0	0	**0**	1.2683	**76.1**	3.98167	0	**80.08**
Carbon dioxide, biogenic kg	81.8095	0	**81.81**	0	0	**0**	91.9591	0	**91.959**	0	0	**0**	0	**0**	173.769	0	**173.8**
Carbon dioxide, fossil kg	398191	8420.7	**4E+05**	5801.1	12670	**18471**	75927.2	1696	**77623**	6011.1	3918.3	**9929**	114055	**7E+06**	485931	26705	**7E+06**
Carbon disulfide g	10991.2	0	**10991**	0	0	**0**	44039.8	0	**44040**	0	0	**0**	9E-08	**5E-06**	55031	0	**55031**
Carbon monoxide g	132724	0	**1E+05**	52661	0	**52661**	65147.6	0	**65148**	0	0	**0**	0.2408	**14.45**	250533	0	**3E+05**
Carbon monoxide, fossil g	329232	46803	**4E+05**	5.215	69915	**69920**	127928	9372	**137299**	56875	21622	**78497**	22665	**1E+06**	514039	1E+05	**2E+06**
Chloride g	13.3309	0	**13.33**	0	0	**0**	15.0274	0	**15.027**	0	0	**0**	0	**0**	28.3583	0	**28.36**
Chlorine g	1.95087	0	**1.951**	0	0	**0**	3.56613	0	**3.5661**	0	0	**0**	0	**0**	5.517	0	**5.517**
Chloroform g	0.5317	0	**0.532**	0	0	**0**	0.05345	0	**0.0535**	0	0	**0**	4E-08	**2E-06**	0.58515	0	**0.585**
Chromium g	11.5869	0	**11.59**	0.0015	0	**0.001**	11.1613	0	**11.161**	0	0	**0**	6.0204	**361.2**	22.7497	0	**384**

Chromium VI g	2.49576	0	**2.496**	0.0004	0	**4E-04**	0.66438	0	**0.6644**	0	0	**0**	1.78	**106.8**	3.16057	0	**110**
Chrysene g	0.00309	0	**0.003**	6E-07	0	**6E-07**	0.00055	0	**0.0006**	0	0	**0**	0.0023	**0.135**	0.00364	0	**0.139**
Chrysene, 5-methyl- g	0.00068	0	**7E-04**	1E-07	0	**1E-07**	0.00012	0	**0.0001**	0	0	**0**	0.0005	**0.03**	0.0008	0	**0.031**
Cobalt g	8.55161	0	**8.552**	0.0006	0	**6E-04**	1.86497	0	**1.865**	0	0	**0**	2.4458	**146.7**	10.4172	0	**157.2**
Copper g	1.15054	0	**1.151**	0	0	**0**	4.44101	0	**4.441**	0	0	**0**	0.0001	**0.006**	5.59155	0	**5.598**
Cumene g	2.87245	0	**2.872**	0	0	**0**	11.3195	0	**11.32**	0	0	**0**	4E-09	**2E-07**	14.192	0	**14.19**
Cyanide g	23.2896	0	**23.29**	0	0	**0**	5.09344	0	**5.0934**	0	0	**0**	2E-06	**1E-04**	28.383	0	**28.38**
Dinitrogen monoxide g	6996.78	205.75	**7203**	0.0457	316.2	**316.2**	834.305	42.25	**876.55**	0	97.776	**97.78**	185.91	**11155**	7831.13	661.9	**19648**
Dioxins, g	5.4E-07	0	**5E-07**	0	0	**0**	1.9E-06	0	**2E-06**	0	0	**0**	0	**0**	2.4E-06	0	**2E-06**
Ethane, 1,1,1- g	0.18087	0.0002	**0.181**	5E-09	4E-04	**4E-04**	0.0174	5E-05	**0.0174**	0.0002	0.0001	**3E-04**	2E-05	**0.001**	0.19846	8E-04	**0.201**
Ethane, 1,2-dibromo- g	0.01079	0	**0.011**	0	0	**0**	0.001	0	**0.001**	0	0	**0**	8E-10	**5E-08**	0.0118	0	**0.012**
Ethane, 1,2-dichloro- g	0.39304	0	**0.393**	0	0	**0**	0.15078	0	**0.1508**	0	0	**0**	3E-08	**2E-06**	0.54382	0	**0.544**
Ethane, chloro- g	0.37777	0	**0.378**	0	0	**0**	0.03515	0	**0.0352**	0	0	**0**	3E-08	**2E-06**	0.41292	0	**0.413**
Ethene, tetrachloro- g	1.52134	0	**1.521**	0.0002	0	**2E-04**	0.7662	0	**0.7662**	0	0	**0**	0.9712	**58.27**	2.28777	0	**60.56**
Fluoranthene g	0.02192	0	**0.022**	4E-06	0	**4E-06**	0.0039	0	**0.0039**	0	0	**0**	0.016	**0.96**	0.02582	0	**0.986**
Fluorene g	0.07542	0	**0.075**	5E-06	0	**5E-06**	0.19265	0	**0.1926**	0	0	**0**	0.0205	**1.23**	0.26807	0	**1.498**
Fluoride g	575.079	0	**575.1**	0.0007	0	**7E-04**	108.168	0	**108.17**	0	0	**0**	2.7249	**163.5**	683.248	0	**846.7**
Formaldehyde g	169.067	0	**169.1**	0.0031	0	**0.003**	34.202	0	**34.202**	43.647	0	**43.65**	13.708	**822.5**	246.918	0	**1069**
Furan g	0.6738	0	**0.674**	3E-08	0	**3E-08**	2.69967	0	**2.6997**	0	0	**0**	0.0001	**0.007**	3.37347	0	**3.38**
Hexane g	32.1091	0	**32.11**	0	0	**0**	126.228	0	**126.23**	0	0	**0**	4E-08	**3E-06**	158.337	0	**158.3**
Hydrazine, methyl g	1.52905	0	**1.529**	0	0	**0**	0.14229	0	**0.1423**	0	0	**0**	1E-07	**7E-06**	1.67134	0	**1.671**
Hydrocarbons, unspecified g	636712	0	**6E+05**	0.1724	0	**0.172**	21799.7	0	**21800**	0	0	**0**	700.05	**42003**	658512	0	**7E+05**
Hydrogen chloride g	43985.2	0	**43985**	6.6625	0	**6.663**	6282.02	0	**6282**	0	0	**0**	27060	**2E+06**	50273.9	0	**2E+06**
Hydrogen fluoride g	10462.3	0	**10462**	0.8322	0	**0.832**	793.888	0	**793.89**	0	0	**0**	3379.8	**2E+05**	11257.1	0	**2E+05**
Hydrogen sulfide g	4.7511	0	**4.751**	0	0	**0**	16.4281	0	**16.428**	0	0	**0**	0	**0**	21.1792	0	**21.18**
Indeno(1,2,3-cd)pyrene g	0.00188	0	**0.002**	3E-07	0	**3E-07**	0.00034	0	**0.0003**	0	0	**0**	0.0014	**0.082**	0.00222	0	**0.085**
Isophorone g	5.21677	0	**5.217**	0	0	**0**	0.48546	0	**0.4855**	0	0	**0**	4E-07	**2E-05**	5.70223	0	**5.702**
Isoprene g	0.00066	0	**7E-04**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	0.00066	0	**7E-04**
Kerosene g	3708.9	0	**3709**	0.0143	0	**0.014**	1510.15	0	**1510.2**	0	0	**0**	58.09	**3485**	5219.07	0	**8704**
Lead g	44.2274	0	**44.23**	0.0024	0	**0.002**	9.48459	0	**9.4846**	0	0	**0**	9.5585	**573.5**	53.7143	0	**627.2**
Magnesium g	339.866	0	**339.9**	0.061	0	**0.061**	61.8671	0	**61.867**	0	0	**0**	247.85	**14871**	401.794	0	**15273**
Manganese g	17.5635	0	**17.56**	0.0027	0	**0.003**	3.93553	0	**3.9355**	0	0	**0**	11.169	**670.2**	21.5018	0	**691.7**
Mercaptans, unspecified g	1951.79	0	**1952**	0	0	**0**	181.628	0	**181.63**	0	0	**0**	0.0001	**0.009**	2133.42	0	**2133**
Mercury g	14.5358	0	**14.54**	0.0005	0	**5E-04**	2.45715	0	**2.4571**	0	0	**0**	1.899	**113.9**	16.9934	0	**130.9**
Metals, unspecified g	561.012	0	**561**	0	0	**0**	0.00085	0	**0.0008**	0	0	**0**	0	**0**	561.013	0	**561**
Methacrylic acid, g	0.17989	0	**0.18**	0	0	**0**	0.01674	0	**0.0167**	0	0	**0**	1E-08	**8E-07**	0.19663	0	**0.197**
Methane g	698998	0	**7E+05**	728.55	0	**728.6**	174820	0	**174820**	0	0	**0**	232356	**1E+07**	874546	0	**1E+07**
Methane, bromog	1.43911	0	**1.439**	0	0	**0**	0.13392	0	**0.1339**	0	0	**0**	1E-07	**6E-06**	1.57303	0	**1.573**
Methane, dichloro-, g	23.6263	0	**23.63**	0.0016	0	**0.002**	43.185	0	**43.185**	0	0	**0**	6.6719	**400.3**	66.813	0	**467.1**
Methane, dichlorodifluoro-g	0.00138	0.0003	**0.002**	7E-09	4E-04	**4E-04**	0.00147	6E-05	**0.0015**	0.0002	0.0001	**4E-04**	3E-05	**0.002**	0.00308	9E-04	**0.006**
Methane, fossil g	102061	9417.6	**1E+05**	2.1769	14130	**14132**	37864.1	1892	**39756**	7474.4	4369.9	**11844**	10315	**6E+05**	147402	29810	**8E+05**
Methane, monochlor R-40 g	4.8293	0	**4.829**	0	0	**0**	0.69305	0	**0.6931**	0	0	**0**	4E-07	**2E-05**	5.52235	0	**5.522**
Methane, tetrachl CFC-10 g	0.03791	3E-05	**0.038**	7E-10	5E-05	**5E-05**	0.0453	6E-06	**0.0453**	2E-05	1E-05	**4E-05**	3E-06	**2E-04**	0.08323	1E-04	**0.083**
Methyl ethyl ketone g	81.0433	0	**81.04**	0	0	**0**	310.927	0	**310.93**	0	0	**0**	3E-07	**2E-05**	391.971	0	**392**
Naphthalene g	3.9535	0	**3.954**	9E-05	0	**9E-05**	8.75899	0	**8.759**	0	0	**0**	0.3868	**23.21**	12.7126	0	**35.92**
Nickel g	86.7024	0	**86.7**	0.0022	0	**0.002**	20.5922	0	**20.592**	0	0	**0**	9.101	**546.1**	107.297	0	**653.4**
Nitrogen oxides g	797229	61970	**9E+05**	63348	85682	**1E+05**	265848	11691	**277539**	787.45	26493	**27280**	14462	**9E+05**	1127212	2E+05	**2E+06**
Nitrous oxides g	0.29347	0	**0.293**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	0.29347	0	**0.293**
NMVOC, non g	23572.7	0	**23573**	0	0	**0**	17657.3	0	**17657**	0	0	**0**	0	**0**	41230	0	**41230**
Organic acids g	50.2411	0	**50.24**	0.0001	0	**1E-04**	15.7483	0	**15.748**	0	0	**0**	0.4457	**26.74**	65.9895	0	**92.73**
Organic substances, g	186.943	0	**186.9**	0.0336	0	**0.034**	33.1953	0	**33.195**	0	0	**0**	136.48	**8189**	220.171	0	**8409**
Other g	4490.43	0	**4490**	0	0	**0**	1522.74	0	**1522.7**	0	0	**0**	0	**0**	6013.17	0	**6013**
PAH, g	429.399	0	**429.4**	0	0	**0**	486.735	0	**486.73**	6.2138	0	**6.214**	0	**0**	922.347	0	**922.3**

Particulates, 10um g	62091.7	1105.9	**63198**	1.2051	1458	**1460**	6679.91	201.3	**6881.2**	3672.7	450.85	**4124**	5020.5	**3E+05**	72445.5	3216	**4E+05**
Particulates, unspecified g	931347	598.14	**9E+05**	18.691	898.2	**916.9**	626775	120.3	**626895**	462.91	277.78	**740.7**	75914	**5E+06**	1558603	1894	**6E+06**
Phenanthrene g	0.08341	0	**0.083**	1E-05	0	**1E-05**	0.01489	0	**0.0149**	0	0	**0**	0.0608	**3.65**	0.09831	0	**3.749**
Phenol g	1006	0	**1006**	0	0	**0**	3.06682	0	**3.0668**	0	0	**0**	1E-08	**6E-07**	1009.07	0	**1009**
Phenols, unspecified g	3.87398	0	**3.874**	0.0001	0	**1E-04**	0.86333	0	**0.8633**	0	0	**0**	0.4642	**27.85**	4.73743	0	**32.59**
Phthalate, dioctyl- g	0.65659	0	**0.657**	0	0	**0**	0.0611	0	**0.0611**	0	0	**0**	5E-08	**3E-06**	0.71769	0	**0.718**
Propanal g	3.4185	0	**3.419**	0	0	**0**	0.32053	0	**0.3205**	0	0	**0**	3E-07	**2E-05**	3.73903	0	**3.739**
Propene g	41.7016	0	**41.7**	0	0	**0**	17.5732	0	**17.573**	95.427	0	**95.43**	0	**0**	154.702	0	**154.7**
Propylene oxide g	0.01246	0	**0.012**	0	0	**0**	0.04943	0	**0.0494**	0	0	**0**	0	**0**	0.06189	0	**0.062**
Pyrene g	0.01018	0	**0.01**	2E-06	0	**2E-06**	0.00181	0	**0.0018**	0	0	**0**	0.0074	**0.446**	0.01199	0	**0.458**
Radioactive species, MBq	1332.55	0	**1333**	0.3139	0	**0.314**	641.317	0	**641.32**	0	0	**0**	1274.9	**76495**	1974.18	0	**78469**
Radionuclides g	207405	0	**2E+05**	0.7998	0	**0.8**	84449	0	**84449**	0	0	**0**	3248.4	**2E+05**	291855	0	**5E+05**
Selenium g	40.8661	0	**40.87**	0.0072	0	**0.007**	7.44087	0	**7.4409**	0	0	**0**	29.316	**1759**	48.3142	0	**1807**
Styrene g	1.31155	0	**1.312**	0	0	**0**	4.37541	0	**4.3754**	0	0	**0**	2E-08	**1E-06**	5.68695	0	**5.687**
Sulfur dioxide g	2462333	0	**2E+06**	194.75	0	**194.7**	690275	0	**690275**	0	0	**0**	809241	**5E+07**	3152802	0	**5E+07**
Sulfur oxides g	240970	7711.2	**2E+05**	8723.3	11585	**20308**	115931	1551	**117482**	5864.7	3582.7	**9447**	771.66	**46299**	371490	24430	**4E+05**
Sulfuric acid, g	0.43428	0	**0.434**	0	0	**0**	0.05008	0	**0.0501**	0	0	**0**	3E-08	**2E-06**	0.48435	0	**0.484**
Tar g	2.3E-11	0	**2E-11**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	2.3E-11	0	**2E-11**
t-Butyl methyl ether g	0.32759	0	**0.328**	0	0	**0**	0.08048	0	**0.0805**	0	0	**0**	2E-08	**1E-06**	0.40807	0	**0.408**
TOC g	1.23302	0	**1.233**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1.23302	0	**1.233**
Toluene g	45.8998	0	**45.9**	0	0	**0**	151.649	0	**151.65**	15.128	0	**15.13**	2E-07	**1E-05**	212.677	0	**212.7**
Toluene, 2,4-dinitro- g	0.00252	0	**0.003**	0	0	**0**	0.00023	0	**0.0002**	0	0	**0**	2E-10	**1E-08**	0.00275	0	**0.003**
Vinyl acetate g	0.06836	0	**0.068**	0	0	**0**	0.00636	0	**0.0064**	0	0	**0**	5E-09	**3E-07**	0.07472	0	**0.075**
VOC,	37731.5	2873.7	**40605**	9293.8	4170	**13464**	14176.4	557.6	**14734**	3008.7	1289.8	**4298**	5124.9	**3E+05**	64210.4	8891	**4E+05**
Xylene g	95.8942	0	**95.89**	0	0	**0**	365.775	0	**365.77**	10.542	0	**10.54**	2E-08	**1E-06**	472.211	0	**472.2**
Zinc g	18.054	0	**18.05**	0	0	**0**	72.1545	0	**72.155**	0	0	**0**	7E-05	**0.004**	90.2086	0	**90.21**

Appendix C-9: Huron- Air Emissions by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
2-Chloroacetophenone g	0.039554134	0.01092666	2.83157E-05	5.652E-05	0.01825433	**0.0688**
Acenaphthene g	0.003991873	0.00457502	0.004383772	0.00322791	0.00235876	**0.0185**
Acenaphthylene g	0.001956801	0.00224266	0.002148908	0.00158215	0.00115626	**0.0091**
Acetaldehyde g	11.78740761	8.17153859	11.98064235	13.9192764	10.5361595	**56.395**
Acetophenone g	0.084758859	22.5495921	6.06764E-05	1751.90938	0.03911641	**1774.6**
Acid Gases g	0	1.30701383	0	0	0	**1.307**
Acrolein g	2.508499948	4.44627303	3.936735311	2.39389508	2.0659849	**15.351**
Aldehydes g	5.765856717	68.7022237	3.25397375	230.826957	3.56729208	**312.12**
Ammonia g	550.7394337	1877.45341	289.0514021	845.696988	363.983177	**3926.9**
Ammonium chloride g	1569.051404	6019.55697	885.4975647	1452.54431	970.760274	**10897**
Anthracene g	0.001643713	0.00188907	0.001805083	0.00132901	0.00097125	**0.0076**
Antimony g	0.140889212	0.1667143	0.154719646	0.30768414	0.08325002	**0.8533**
Arsenic g	2.91588644	3.88715787	3.595716095	4.73225865	1.85899491	**16.99**
Benzene g	552.103512	177.016111	26.65177563	598.999366	262.40103	**1617.2**
Benzene, chloro- g	0.124312993	0.03434095	8.89921E-05	0.00017763	0.05737074	**0.2163**
Benzene, ethyl- g	0.531155514	0.44024616	0.000380239	22.6962773	0.24512953	**23.913**
Benzo(a)anthracene g	0.000626176	0.00072029	0.000687651	0.00050629	0.00037	**0.0029**
Benzo(a)pyrene g	0.000297434	104.03655	0.000326634	0.02346172	0.00017575	**104.06**
Benzo(b,j,k)fluoranthene g	0.000860992	0.00098677	0.000945519	0.00069615	0.00050875	**0.004**

Benzo(ghi)perylene g	0.000211334	0.00024456	0.000232082	0.00017087	0.00012488	**0.001**
Benzyl chloride g	3.9554134	1.09266644	0.002831567	0.00565201	1.82543264	**6.882**
Beryllium g	0.144538194	0.19793811	0.184967164	0.15364125	0.09054941	**0.7716**
Biphenyl g	0.013306244	0.05994305	0.014612573	3.48565067	0.00786254	**3.5814**
Bromoform g	0.220373032	0.06087713	0.000157759	0.0003149	0.10170268	**0.3834**
BTEX g	0	55.6985256	0	1649.60347	0	**1705.3**
Butadiene g	0.436722404	0.50594792	0.610653667	11.328594	0.46135407	**13.343**
Cadmium g	0.743552706	0.8941578	0.719610506	1.16350427	0.46084318	**3.9817**
Carbon dioxide, biogenic kg	0	60.4154164	0	113.353142	0	**173.77**
Carbon dioxide, fossil kg	110931.0068	119444.447	85145.89675	126192.346	70921.6915	**512635**
Carbon disulfide g	0.734576774	699.054939	0.000525862	54330.8861	0.33900892	**55031**
Carbon monoxide g	29750.88637	111723.058	21370.91171	64774.4294	22913.2932	**250533**
Carbon monoxide, fossil g	125637.7968	175348.208	63593.96636	200079.273	97091.3926	**661751**
Chloride g	0	28.3582704	0	1.4423E-11	0	**28.358**
Chlorine g	0	2.59132586	0	2.92567416	0	**5.517**
Chloroform g	0.333384844	0.09219409	0.000238661	0.00547593	0.15385789	**0.5852**
Chromium g	1.909344043	2.99414385	2.597372692	13.997085	1.25173834	**22.75**
Chromium VI g	0.618344219	0.71233805	0.679035974	0.78548334	0.36537244	**3.1606**
Chrysene g	0.00078272	0.00090354	0.000859563	0.00063286	0.0004625	**0.0036**
Chrysene, 5-methyl- g	0.000172198	0.00019735	0.000189104	0.00013923	0.00010175	**0.0008**
Cobalt g	1.811080263	2.13107245	0.974912524	4.14613787	1.35397119	**10.417**
Copper g	0.011535032	0.12798827	0.002120198	5.44408898	0.00581615	**5.5915**
Cumene g	0.02994813	0.18997296	2.1439E-05	13.958195	0.01382113	**14.192**
Cyanide g	14.12647643	3.96709315	0.01011274	3.75992635	6.51940228	**28.383**
Dinitrogen monoxide g	4417.531784	1432.0379	128.788382	379.508794	2135.19666	**8493.1**
Dioxins, - g	0	5.1081E-08	0	2.3705E-06	0	**2E-06**
Ethane, 1,1,1-trichloro-, HCFC-140 g	0.113460927	0.03173757	0.000234378	0.00125298	0.05254102	**0.1992**
Ethane, 1,2-dibromo- g	0.006780709	0.00187314	4.85412E-06	9.6892E-06	0.00312931	**0.0118**
Ethane, 1,2-dichloro- g	0.226023623	0.06628172	0.000161804	0.1470448	0.10431044	**0.5438**
Ethane, chloro- g	0.237324804	0.06555999	0.000169894	0.00033912	0.10952596	**0.4129**
Ethene, tetrachloro- g	0.34956331	0.4097197	0.370980596	0.94776607	0.20974257	**2.2878**
Fluoranthene g	0.005557314	0.00638622	0.006102898	0.00449331	0.00328377	**0.0258**
Fluorene g	0.007122754	0.01260788	0.007822025	0.23631296	0.00420877	**0.2681**
Fluoride g	287.2318001	204.851202	20.07344216	32.9920516	138.099006	**683.25**
Formaldehyde g	61.54926902	52.1873093	39.70474224	52.0985653	41.3785066	**246.92**
Furan g	1.08831E-05	0.04287371	4.29579E-05	3.33053299	1.0086E-05	**3.3735**
Hexane g	0.378589568	2.1604372	0.000271021	155.622851	0.17471998	**158.34**
Hydrazine, methyl g	0.960600397	0.26536185	0.000687666	0.00137263	0.44331935	**1.6713**
Hydrocarbons, unspecified g	9055.978346	40840.2576	5110.761031	597902.469	5602.86553	**658512**
Hydrogen chloride g	6204.78665	21575.4887	10324.90279	8041.40992	4127.30323	**50274**
Hydrogen fluoride g	918.2858114	7513.22182	1289.158279	960.69236	575.703741	**11257**
Hydrogen sulfide g	0	2.16989739	0	19.0092743	0	**21.179**
Indeno(1,2,3-cd)pyrene g	0.000477459	0.00054896	0.000524334	0.00038605	0.00028213	**0.0022**
Isophorone g	3.277342532	0.90535219	0.002346156	0.0046831	1.51250133	**5.7022**
Isoprene g	0	0.00018395	0	0.00047265	0	**0.0007**
Kerosene g	751.4616084	2882.93038	424.0889894	695.663178	464.923632	**5219.1**
Lead g	21.4011452	9.57048655	3.774215532	8.54440074	10.4240696	**53.714**
Magnesium g	86.09893027	98.7009989	94.55076599	71.5682458	50.8749845	**401.79**
Manganese g	3.628730376	5.40485881	4.354868317	5.72236753	2.39094134	**21.502**
Mercaptans, unspecified g	1226.178154	338.726596	0.877785816	1.75212408	565.884118	**2133.4**
Mercury g	7.611506562	4.0297097	0.785935331	0.95234011	3.6138856	**16.993**
Metals, unspecified g	0.000147584	13.3580252	2.34448E-05	547.654565	7.1396E-05	**561.01**
Methacrylic acid, methyl ester g	0.113011811	0.03121904	8.09019E-05	0.00016149	0.05215522	**0.1966**

Methane g	92767.08336	259149.278	209937.7049	241929.348	70762.861	**874546**
Methane, bromo-, Halon 1001 g	0.904094491	0.24975233	0.000647215	0.00129189	0.41724175	**1.573**
Methane, dichloro-, HCC-30 g	3.150429797	4.39045863	2.57534077	54.6155186	2.08125094	**66.813**
Methane, dichlorodifluoro-, CFC-12 g	0.000551822	0.00065476	0.000188712	0.00214936	0.00047375	**0.004**
Methane, fossil g	23736.63273	40176.7052	28436.99206	63763.363	21098.0981	**177212**
Methane, monochloro-, R-40 g	2.994813003	0.83126153	0.002143901	0.31201915	1.38211328	**5.5224**
Methane, tetrachloro-, CFC-10 g	5.77428E-05	0.07854304	1.94416E-05	0.0046626	4.9323E-05	**0.0833**
Methyl ethyl ketone g	2.203730323	5.61156525	0.001577587	383.136661	1.01702676	**391.97**
Naphthalene g	0.326487685	0.66283644	0.281305115	11.1791063	0.26285008	**12.713**
Nickel g	17.06594788	20.1808523	4.256387915	51.7503352	14.0432654	**107.3**
Nitrogen oxides g	313590.7369	430529.128	94237.60014	249811.046	224879.886	**1E+06**
Nitrous oxides g	0	0.29346605	0	0	0	**0.2935**
NMVOC, g	87.33067052	8983.54106	3880.30476	27536.6436	742.220511	**41230**
Organic acids g	5.765856717	27.9981871	3.25397375	25.4041681	3.56729208	**65.989**
Organic substances, unspecified g	47.41771426	54.3368172	52.06570877	38.3333699	28.017874	**220.17**
Other g	0	6013.16921	0	0	0	**6013.2**
PAH, g	1.9391324	905.625411	2.633694479	10.1361983	2.01259003	**922.35**
Particulates, > 2.5 um, and < 10um g	26087.13297	24748.7751	5353.939034	5810.24381	13661.7493	**75662**
Particulates, unspecified g	241660.7075	1028979.65	54739.71347	86658.9642	148458.583	**2E+06**
Phenanthrene g	0.021133447	0.0243936	0.023208205	0.01708725	0.01248756	**0.0983**
Phenol g	0.090409449	1005.17069	6.47215E-05	3.7657111	0.04172417	**1009.1**
Phenols, unspecified g	0.788714327	0.95607727	0.199796398	2.16125964	0.63157912	**4.7374**
Phthalate, dioctyl- g	0.412493112	0.1139495	0.000295292	0.00058942	0.19036655	**0.7177**
Propanal g	2.147224417	0.59320105	0.001537136	0.00612208	0.99094915	**3.739**
Propene g	28.81666252	24.193658	40.29333154	30.956655	30.4419565	**154.7**
Propylene oxide g	0	0.00113811	0	0.06074858	0	**0.0619**
Pyrene g	0.002582977	0.00296031	0.002836558	0.00208844	0.00152626	**0.012**
Radioactive species, unspecified MBq	123.3158532	425.476332	486.172823	824.943023	114.276166	**1974.2**
Radionuclides (Including Radon) g	42022.34556	161215.816	23715.40191	38902.0519	25998.9084	**291855**
Selenium g	10.32165387	11.8627978	11.19634682	8.80428311	6.12908233	**48.314**
Styrene g	0.141264764	0.10820413	0.000101127	5.37219014	0.06519402	**5.687**
Sulfur dioxide g	448763.4536	1148546.96	617910.808	639155.037	298426.087	**3E+06**
Sulfur oxides g	34351.7028	194221.918	8473.257097	132439.992	26432.4604	**395919**
Sulfuric acid, dimethyl ester g	0.271228347	0.07530289	0.000194165	0.01245578	0.12517252	**0.4844**
Tar g	0	6.3123E-12	0	1.6219E-11	0	**2E-11**
t-Butyl methyl ether g	0.19777067	0.0554653	0.000141578	0.0634169	0.09127163	**0.4081**
TOC, Total Organic Carbon g	0	1.23301694	0	0	0	**1.233**
Toluene g	5.924374753	6.63760181	6.388571307	188.274678	5.45174941	**212.68**
Toluene, 2,4-dinitro- g	0.001582165	0.00043707	1.13263E-06	2.2608E-06	0.00073017	**0.0028**
Vinyl acetate g	0.042944488	0.01186324	3.07427E-05	6.1365E-05	0.01981898	**0.0747**
VOC, volatile organic compounds g	11169.1531	22092.6687	12583.32836	15895.4269	11361.0524	**73102**
Xylene g	3.39235237	8.99610332	4.451219505	451.911714	3.45930848	**472.21**
Zinc g	0.007690021	1.24016679	0.001413465	88.955415	0.00387743	**90.209**

Appendix C-10: Huron- Water Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
2-Hexanone mg	1241.29	59.814	**1301**	0.02773	89.82	**89.85**	386.601	12.025	**398.6**	46.2907	27.778	**74.07**	134.5	**8069**	1674.2	189.44	**9933**

Acetone mg	1901.05	91.603	**1993**	0.04248	137.56	**137.6**	592.088	18.416	**610.5**	70.8929	42.541	**113.4**	206	**12359**	2564.1	290.12	**15213**
Acids, mg	565020	0	**6E+05**	0	0	**0**	1371979	0	**1E+06**	0	0	**0**	0	**0**	2E+06	0	**2E+06**
Aluminum mg	7349625	821353	**8E+06**	92.4745	1E+06	**1E+06**	4017160	165130	**4E+06**	635657	381442	**1E+06**	4E+05	**3E+07**	1E+07	3E+06	**4E+07**
Ammonia mg	2687661	174519	**3E+06**	53.7111	262068	**3E+05**	940830	35086	**1E+06**	135063	81048	**2E+05**	3E+05	**2E+07**	4E+06	552722	**2E+07**
Ammonia, as N mg	2.1E-07	0	**2E-07**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	2E-07	0	**2E-07**
Ammonium, ion mg	2182940	0	**2E+06**	0	0	**0**	3236861	0	**3E+06**	0	0	**0**	0	**0**	5E+06	0	**5E+06**
Antimony mg	5343.5	513.25	**5857**	0.05669	770.73	**770.8**	4702.03	103.19	**4805**	397.213	238.36	**635.6**	268.9	**16135**	10443	1625.5	**28203**
Arsenic, ion mg	45205.8	2534.2	**47740**	0.9501	3805.4	**3806**	16046.3	509.48	**16556**	1961.22	1176.9	**3138**	4600	**3E+05**	63214	8025.9	**3E+05**
Barium mg	9.8E+07	1E+07	**1E+08**	1397.55	2E+07	**2E+07**	4.1E+07	2E+06	**4E+07**	8703107	5E+06	**1E+07**	7E+06	**4E+08**	1E+08	4E+07	**6E+08**
Benzene mg	408210	15367	**4E+05**	7.12576	23076	**23083**	133994	3089.5	**1E+05**	11892.9	7136.6	**19029**	34555	**2E+06**	554104	48670	**3E+06**
Benzene, µg	18997.3	915.39	**19913**	0.42446	1374.6	**1375**	5916.66	184.03	**6101**	708.43	425.11	**1134**	2058	**1E+05**	25623	2899.1	**2E+05**
Benzene, ethyl- mg	21353.4	864.44	**22218**	0.40084	1298.1	**1298**	19189.8	173.79	**19364**	669.002	401.45	**1070**	1944	**1E+05**	41213	2737.8	**2E+05**
Benzene, - µg	14247.9	686.55	**14934**	0.31835	1031	**1031**	4437.5	138.03	**4576**	531.332	318.84	**850.2**	1544	**92624**	19217	2174.4	**1E+05**
Benzene alkylated g	3681.61	450.27	**4132**	0.04961	676.15	**676.2**	1562.38	90.525	**1653**	348.471	209.11	**557.6**	235.3	**14120**	5592.5	1426.1	**21139**
Benzoic acid mg	192852	9292.5	**2E+05**	4.309	13954	**13958**	60063.3	1868.2	**61931**	7191.6	4315.5	**11507**	20895	**1E+06**	260111	29430	**2E+06**
Beryllium mg	2178.2	142.15	**2320**	0.04365	213.46	**213.5**	789.074	28.579	**817.7**	110.014	66.017	**176**	210.9	**12656**	3077.3	450.21	**16184**
Biphenyl µg	238372	29153	**3E+05**	3.21242	43778	**43781**	101159	5861.1	**1E+05**	22562	13539	**36101**	15238	**9E+05**	362096	92331	**1E+06**
BOD5,mg	3.8E+07	2E+06	**4E+07**	741.453	3E+06	**3E+06**	2E+07	337705	**2E+07**	1299976	780083	**2E+06**	4E+06	**2E+08**	6E+07	5E+06	**3E+08**
Boron mg	1023624	28751	**1E+06**	13.3317	43174	**43188**	1896058	5780.3	**2E+06**	22250.9	13352	**35603**	64648	**4E+06**	3E+06	91058	**7E+06**
Bromide mg	4.1E+07	2E+06	**4E+07**	910.308	3E+06	**3E+06**	1.3E+07	394559	**1E+07**	1518831	911413	**2E+06**	4E+06	**3E+08**	5E+07	6E+06	**3E+08**
Cadmium, ion mg	13599.3	374.05	**13973**	0.13846	561.69	**561.8**	30455.1	75.2	**30530**	289.479	173.71	**463.2**	670.3	**40215**	44344	1184.6	**85744**
Calcium, ion mg	6.2E+08	3E+07	**6E+08**	13652.4	4E+07	**4E+07**	2.1E+08	6E+06	**2E+08**	2.3E+07	1E+07	**4E+07**	7E+07	**4E+09**	9E+08	9E+07	**5E+09**
Chloride mg	7.6E+09	3E+08	**8E+09**	153446	5E+08	**5E+08**	3.2E+09	7E+07	**3E+09**	2.6E+08	2E+08	**4E+08**	7E+08	**4E+10**	1E+10	1E+09	**6E+10**
Chromium mg	120098	21915	**1E+05**	0.47799	32909	**32910**	87797.1	4406	**92203**	16960.5	10178	**27138**	1999	**1E+05**	224856	69408	**4E+05**
Chromium VI µg	9816455	92211	**1E+07**	2.01122	138470	**1E+05**	3.2E+07	18539	**3E+07**	71363.5	42823	**1E+05**	8409	**5E+05**	4E+07	292043	**4E+07**
Chromium, ion mg	80944.4	1420.6	**82365**	2.08089	2133.2	**2135**	24690.6	285.6	**24976**	1099.4	659.72	**1759**	10138	**6E+05**	106737	4499.1	**7E+05**
Cobalt mg	8774.81	202.95	**8978**	0.09411	304.75	**304.8**	18331.5	40.801	**18372**	157.062	94.249	**251.3**	456.3	**27381**	27263	642.75	**55287**
COD, mg	1.1E+08	3E+06	**1E+08**	1234.45	5E+06	**5E+06**	3.9E+07	645038	**4E+07**	2483035	1E+06	**4E+06**	6E+06	**4E+08**	2E+08	1E+07	**5E+08**
Copper, ion mg	38801.8	2636.2	**41438**	0.62889	3958.7	**3959**	22056.2	530	**22586**	2040.21	1224.3	**3264**	3030	**2E+05**	62899	8349.2	**3E+05**
Cyanide mg	9498945	0.6611	**9E+06**	0.00031	0.9928	**0.993**	390954	0.1329	**4E+05**	0.51165	0.307	**0.819**	1.487	**89.19**	1E+07	2.0938	**1E+07**
Decane mg	5541.52	267.02	**5809**	0.12382	400.98	**401.1**	1725.9	53.684	**1780**	206.654	124.01	**330.7**	600.4	**36025**	7474.2	845.7	**44345**
Detergents, oil mg	181923	7628.3	**2E+05**	4.2009	11455	**11459**	54926.1	1533.6	**56460**	5903.65	3542.6	**9446**	20393	**1E+06**	242757	24160	**1E+06**
Dibenzofuran µg	36148.1	1741.8	**37890**	0.80767	2615.6	**2616**	11258.2	350.18	**11608**	1348	808.9	**2157**	3917	**2E+05**	48755	5516.4	**3E+05**
Dibenzothiophene g	23587.5	89.98	**23678**	0.62557	135.12	**135.7**	8287.55	18.09	**8306**	69.6364	41.787	**111.4**	3053	**2E+05**	31945	284.98	**2E+05**
Dissolved organic mg	3561712	0	**4E+06**	0	0	**0**	6412352	0	**6E+06**	0	0	**0**	0	**0**	1E+07	0	**1E+07**
Dissolved solids mg	7.9E+09	4E+08	**8E+09**	189295	6E+08	**6E+08**	1.1E+09	8E+07	**1E+09**	3.2E+08	2E+08	**5E+08**	9E+08	**6E+10**	9E+09	1E+09	**7E+10**
Docosane µg	203431	9802.2	**2E+05**	4.54537	14720	**14724**	63358	1970.7	**65329**	7586.08	4552.2	**12138**	22042	**1E+06**	274380	31045	**2E+06**
Dodecane mg	10514.2	506.63	**11021**	0.23492	760.78	**761**	3274.64	101.86	**3376**	392.088	235.28	**627.4**	1139	**68352**	14181	1604.6	**84138**
Eicosane mg	2894.86	139.49	**3034**	0.06468	209.46	**209.5**	901.596	28.043	**929.6**	107.952	64.779	**172.7**	313.7	**18819**	3904.5	441.77	**23166**
Fluorene, µg	21635.8	1042.5	**22678**	0.48342	1565.5	**1566**	6738.44	209.6	**6948**	806.831	484.16	**1291**	2344	**1E+05**	29182	3301.8	**2E+05**
Fluorene alkylated g	213361	26094	**2E+05**	2.87535	39185	**39188**	90544.5	5246.1	**95791**	20194.7	12118	**32313**	13639	**8E+05**	324103	82643	**1E+06**
Fluoride mg	7101907	0	**7E+06**	0	0	**0**	1696605	0	**2E+06**	0	0	**0**	0	**0**	9E+06	0	**9E+06**
Fluorine µg	115087	12846	**1E+05**	1.69405	19290	**19291**	47093.5	2582.6	**49676**	9941.39	5965.6	**15907**	8074	**5E+05**	172124	40683	**7E+05**
Halogenated µg	3E+08	0	**3E+08**	0	0	**0**	6E+08	0	**6E+08**	0	0	**0**	0	**0**	9E+08	0	**9E+08**
Hexadecane mg	11476.2	552.99	**12029**	0.25642	830.4	**830.7**	3574.24	111.18	**3685**	427.966	256.81	**684.8**	1243	**74605**	15479	1751.4	**91836**
Hexanoic acid mg	39937.5	1924.4	**41862**	0.89234	2889.8	**2891**	12438.5	386.89	**12825**	1489.31	893.7	**2383**	4327	**3E+05**	53866	6094.8	**3E+05**
Hydrocarbons, µg	6.5E+08	0	**7E+08**	0	0	**0**	2.6E+09	0	**3E+09**	0	0	**0**	0	**0**	3E+09	0	**3E+09**
Iron mg	2.3E+07	2E+06	**2E+07**	364.674	2E+06	**2E+06**	1E+07	327063	**1E+07**	1259008	755499	**2E+06**	2E+06	**1E+08**	3E+07	5E+06	**1E+08**
Lead mg	4666849	5389.4	**5E+06**	1.4034	8093.1	**8095**	116436	1083.5	**1E+05**	4170.97	2502.9	**6674**	6769	**4E+05**	5E+06	17069	**5E+06**
Lead-210/kg µg	7.2E+08	0.001	**7E+08**	4.4E-07	0.0014	**0.001**	7.8E+08	0.0002	**8E+08**	0.00074	0.0004	**0.001**	0.002	**0.128**	1E+09	0.003	**1E+09**
Lithium, ion mg	1.5E+08	9833.4	**2E+08**	4345.59	14766	**19112**	3.7E+07	1977	**4E+07**	7610.21	4566.7	**12177**	2E+07	**1E+09**	2E+08	31143	**1E+09**
Magnesium mg	1.2E+08	6E+06	**1E+08**	2669.06	9E+06	**9E+06**	4E+07	1E+06	**4E+07**	4451969	3E+06	**7E+06**	1E+07	**8E+08**	2E+08	2E+07	**1E+09**
Manganese mg	1.3E+07	9167.5	**1E+07**	67.3504	13766	**13834**	1.4E+07	1843.1	**1E+07**	7094.87	4257.5	**11352**	3E+05	**2E+07**	3E+07	29035	**4E+07**

Mercury µg	88908.9	8998	**97907**	0.99148	13512	**13513**	86663	1809	**88472**	6963.64	4178.7	**11142**	4703	**3E+05**	182537	28498	**5E+05**
Metallic ions, mg	600157	0	**6E+05**	0	0	**0**	804302	0	**8E+05**	0	0	**0**	0	**0**	1E+06	0	**1E+06**
Methane µg	7651.95	368.71	**8021**	0.17097	553.68	**553.8**	2383.19	74.128	**2457**	285.35	171.23	**456.6**	829.1	**49745**	10321	1167.7	**61233**
Methyl µg	15303.3	737.4	**16041**	0.34193	1107.3	**1108**	4766.19	148.25	**4914**	570.681	342.45	**913.1**	1658	**99486**	20641	2335.4	**1E+05**
Molybdenum mg	4477.68	210.58	**4688**	0.09764	316.22	**316.3**	1772.31	42.336	**1815**	162.97	97.794	**260.8**	473.5	**28410**	6413.1	666.93	**35490**
m-Xylene mg	5759.98	277.54	**6038**	0.1287	416.77	**416.9**	1793.93	55.798	**1850**	214.791	128.89	**343.7**	624.1	**37445**	7768.8	878.99	**46093**
Naphthalene mg	-66978	166.93	**-66811**	0.07715	250.67	**250.7**	1041.8	33.561	**1075**	129.189	77.523	**206.7**	374.1	**22447**	-65807	528.69	**-48231**
Naphthalene, mg	3011.21	145.1	**3156**	0.06728	217.88	**218**	937.836	29.171	**967**	112.291	67.383	**179.7**	326.3	**19576**	4061.4	459.53	**24097**
Naphthalenes, µg	60329	7378.3	**67707**	0.81302	11080	**11081**	25602	1483.4	**27085**	5710.2	3426.5	**9137**	3856	**2E+05**	91642	23368	**3E+05**
n-Hexacosane µg	126913	6115.4	**1E+05**	2.83566	9183.2	**9186**	39526.8	1229.5	**40756**	4732.77	2840	**7573**	13751	**8E+05**	171175	19368	**1E+06**
Nickel mg	91664	2518.2	**94182**	0.76336	3781.5	**3782**	72486.1	506.27	**72992**	1948.87	1169.5	**3118**	3688	**2E+05**	166100	7975.4	**4E+05**
Nitrate mg	985359	0	**1E+06**	0	0	**0**	1515601	0	**2E+06**	0	0	**0**	0	**0**	3E+06	0	**3E+06**
Nitrate compounds g	5.7E-09	0	**6E-09**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	6E-09	0	**6E-09**
Nitric acid mg	1.3E-05	0	**1E-05**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	1E-05	0	**1E-05**
Nitrogen, total mg	1E+07	0	**1E+07**	0	0	**0**	474273	0	**5E+05**	0	0	**0**	0	**0**	1E+07	0	**1E+07**
Non-ferrous metl mg	36414.9	0	**36415**	0	0	**0**	72829.8	0	**72830**	0	0	**0**	0	**0**	109245	0	**1E+05**
Non-halogenated µg	6.5E+08	0	**7E+08**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	7E+08	0	**7E+08**
o-Cresol mg	5468.93	263.52	**5732**	0.12219	395.72	**395.8**	1703.28	52.98	**1756**	203.941	122.38	**326.3**	592.6	**35553**	7376.3	834.6	**43764**
Octadecane mg	2835.21	136.61	**2972**	0.06335	205.15	**205.2**	883.021	27.466	**910.5**	105.728	63.445	**169.2**	307.2	**18432**	3824	432.67	**22688**
Oils, unspecified mg	2.8E+08	212864	**3E+08**	104.735	319649	**3E+05**	2.8E+07	42795	**3E+07**	164739	98856	**3E+05**	5E+05	**3E+07**	3E+08	674165	**3E+08**
Other mg	3.8E+08	0	**4E+08**	0	0	**0**	6.4E+08	0	**6E+08**	0	0	**0**	0	**0**	1E+09	0	**1E+09**
Other metals mg	4.9E+07	0	**5E+07**	0	0	**0**	7.9E+07	0	**8E+07**	0	0	**0**	0	**0**	1E+08	0	**1E+08**
p-Cresol mg	5900.68	284.32	**6185**	0.13184	426.94	**427.1**	1837.74	57.16	**1895**	220.036	132.04	**352.1**	639.3	**38360**	7958.6	900.46	**47219**
Pentanone,methyl mg	749.454	38.497	**788**	0.01785	57.81	**57.83**	106.129	7.7397	**113.9**	29.7935	17.878	**47.67**	86.56	**5194**	885.39	121.92	**6201**
Phenanthrene µg	31601.2	2613.3	**34215**	0.57561	3924.3	**3925**	11503.8	525.39	**12029**	2022.46	1213.6	**3236**	2770	**2E+05**	45128	8276.6	**2E+05**
Phenan alkylated, µg	25014.9	3059.4	**28074**	0.33711	4594.1	**4594**	10615.7	615.07	**11231**	2367.68	1420.8	**3788**	1599	**95943**	37999	9689.3	**1E+05**
Phenol µg	1.1E+10	4E+06	**1E+10**	89.0079	6E+06	**6E+06**	2.1E+10	820442	**2E+10**	3158239	2E+06	**5E+06**	4E+05	**2E+07**	3E+10	1E+07	**3E+10**
Phenol, - mg	5325.04	256.59	**5582**	0.11898	385.31	**385.4**	1658.47	51.586	**1710**	198.577	119.16	**317.7**	577	**34618**	7182.2	812.64	**42613**
Phenol, unspecified g	69489.6	573.22	**70063**	1.82348	860.78	**862.6**	21301.7	115.24	**21417**	443.621	266.21	**709.8**	8894	**5E+05**	91237	1815.4	**6E+05**
Phosphate mg	3189540	0	**3E+06**	0	0	**0**	508037	0	**5E+05**	0	0	**0**	0	**0**	4E+06	0	**4E+06**
Phosphorus mg	1.9E+07	0	**2E+07**	0	0	**0**	59826.7	0	**59827**	0	0	**0**	0	**0**	2E+07	0	**2E+07**
Polynucl Carbons µg	111.457	0	**111.5**	0	0	**0**	50.3619	0	**50.36**	0	0	**0**	0	**0**	161.82	0	**161.8**
Radium-226/kg µg	6.44643	0.3311	**6.778**	0.00015	0.4973	**0.497**	0.91287	0.0666	**0.979**	0.25627	0.1538	**0.41**	0.745	**44.67**	7.6157	1.0487	**53.34**
Radium-228/kg µg	0.03297	0.0017	**0.035**	7.9E-07	0.0025	**0.003**	0.00467	0.0003	**0.005**	0.00131	0.0008	**0.002**	0.004	**0.229**	0.039	0.0054	**0.273**
Selenium µg	923709	99525	**1E+06**	11.1594	149452	**1E+05**	540071	20009	**6E+05**	77023.5	46220	**1E+05**	52961	**3E+06**	2E+06	315206	**5E+06**
Silver mg	398680	19243	**4E+05**	8.90155	28896	**28905**	124545	3868.7	**1E+05**	14892.3	8936.5	**23829**	43165	**3E+06**	538126	60944	**3E+06**
Sodium, ion mg	2E+09	9E+07	**2E+09**	43276.7	1E+08	**1E+08**	7.8E+08	2E+07	**8E+08**	7.2E+07	4E+07	**1E+08**	2E+08	**1E+10**	3E+09	3E+08	**2E+10**
Solids, inorganic mg	149156	0	**1E+05**	0	0	**0**	593631	0	**6E+05**	0	0	**0**	0	**0**	742787	0	**7E+05**
Strontium mg	1.1E+07	499388	**1E+07**	231.559	749911	**8E+05**	4254119	100400	**4E+06**	386483	231919	**6E+05**	1E+06	**7E+07**	2E+07	2E+06	**8E+07**
Sulfate mg	1.4E+08	665731	**1E+08**	312.525	999700	**1E+06**	4.5E+07	133842	**4E+07**	515218	309170	**8E+05**	2E+06	**9E+07**	2E+08	2E+06	**3E+08**
Sulfide mg	3E+07	473.52	**3E+07**	0.01033	711.06	**711.1**	1408821	95.198	**1E+06**	366.46	219.9	**586.4**	43.18	**2591**	3E+07	1499.7	**3E+07**
Sulfur mg	508442	24270	**5E+05**	11.2539	36445	**36456**	175932	4879.3	**2E+05**	18782.7	11271	**30054**	54573	**3E+06**	703168	76865	**4E+06**
Suspended solids mg	1.6E+09	3E+07	**2E+09**	4256.22	4E+07	**4E+07**	1.3E+08	5E+06	**1E+08**	2E+07	1E+07	**3E+07**	2E+07	**1E+09**	2E+09	8E+07	**3E+09**
Tar mg	3.2E-10	0	**3E-10**	0	0	**0**	0	0	**0**	0	0	**0**	0	**0**	3E-10	0	**3E-10**
Tetradecane mg	4607.97	222.04	**4830**	0.10296	333.42	**333.5**	1435.14	44.639	**1480**	171.836	103.11	**275**	499.3	**29956**	6215.1	703.21	**36874**
Thallium µg	889611	108147	**1E+06**	11.9771	162400	**2E+05**	388456	21743	**4E+05**	83696.5	50224	**1E+05**	56821	**3E+06**	1E+06	342514	**5E+06**
Tin mg	26313.3	2059.6	**28373**	0.4906	3092.7	**3093**	9749.69	414.06	**10164**	1593.92	956.47	**2550**	2364	**1E+05**	37657	6522.8	**2E+05**
Titanium, ion mg	200359	7881.9	**2E+05**	0.87159	11836	**11837**	235855	1584.6	**2E+05**	6099.89	3660.4	**9760**	4135	**2E+05**	442315	24963	**7E+05**
Toluene mg	316907	14519	**3E+05**	6.73225	21802	**21809**	155902	2918.9	**2E+05**	11236.1	6742.5	**17979**	32646	**2E+06**	484052	45982	**2E+06**
Vanadium mg	11564.9	248.75	**11814**	0.11534	373.53	**373.6**	15576.2	50.009	**15626**	192.508	115.52	**308**	559.3	**33560**	27334	787.81	**61681**
Xylene mg	59535.3	7607.7	**67143**	0.2552	11424	**11424**	88261.3	1529.5	**89791**	5887.7	3533.1	**9421**	1130	**67776**	153685	24094	**2E+05**
Yttrium mg	1281.14	61.734	**1343**	0.02862	92.703	**92.73**	399.01	12.411	**411.4**	47.7764	28.669	**76.45**	138.8	**8329**	1728	195.52	**10252**
Zinc mg	7573349	18923	**8E+06**	2.41011	28415	**28418**	152789	3804.3	**2E+05**	14644.5	8787.8	**23432**	11477	**7E+05**	8E+06	59930	**8E+06**

Appendix C-11: Huron- Water Emissions by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
2-Hexanone mg	215.6788305	474.437679	373.7144005	609.091888	190.7271851	**1863.6**
Acetone mg	330.3094324	726.604497	572.3486445	932.834172	292.0970679	**2854.2**
Acids, unspecified mg	0	848306.469	0	1088692.89	0	**2E+06**
Aluminum mg	2216760.032	3347294.64	1526453.835	5744140.73	1769202.003	**1E+07**
Ammonia mg	569710.1202	1031276.61	752318.5383	1481484.66	481538.3408	**4E+06**
Ammonia, as N mg	0	5.9204E-08	0	1.5212E-07	0	**2E-07**
Ammonium, ion mg	50238.87314	5005664.71	207914.0805	132793.673	23189.2862	**5E+06**
Antimony mg	1364.772688	1896.32613	940.1406066	6772.89788	1094.190412	**12068**
Arsenic, ion mg	8534.850582	17804.8409	13021.06234	24471.8083	7407.643501	**71240**
Barium mg	30319474.26	39411213.8	22542679.02	66181269	24439332.61	**2E+08**
Benzene mg	56382.70704	135757.566	96017.01516	257366.939	57249.40776	**602774**
Benzene, 1-methyl-4-g	3300.780923	7260.97882	5719.506052	9321.71664	2918.927136	**28522**
Benzene, ethyl- mg	3117.073893	7117.15778	5401.18358	25558.4496	2756.472436	**43950**
Benzene, pentamethyl- µg	2475.60833	5445.72036	4289.598927	6991.30471	2189.209847	**21391**
Benzenes, alkylated, mg	1196.985044	1494.8558	823.2960099	2543.86576	959.5688203	**7018.6**
Benzoic acid mg	33507.90413	73710.3484	58062.12105	94629.8223	29631.55263	**289542**
Beryllium mg	452.906354	844.487511	609.8175977	1233.66114	386.6711991	**3527.5**
Biphenyl µg	77499.85928	96786.9813	53306.36655	164705.74	62128.24076	**454427**
BOD5, mg	6023802.279	14245364.3	10037895.62	29346543.2	5276743.112	**6E+07**
Boron mg	103672.6301	255679.029	179639.3721	2402333.9	91679.02501	**3E+06**
Bromide mg	7077427.486	15570768.8	12265791.95	19988802.4	6258843.981	**6E+07**
Cadmium, ion mg	1254.983258	2970.68888	1899.657971	38315.2768	1088.050674	**45529**
Calcium, ion mg	106127711.9	234157397	183953636.1	325171389	93854847.57	**9E+08**
Chloride mg	1233051043	3847642933	2084474076	3896778906	1085113426	**1E+10**
Chromium mg	53067.39739	47921.5822	18358.09692	134007.638	40908.76367	**294263**
Chromium VI µg	223288.299	4807434.94	66718.09638	36803696.1	172129.1924	**4E+07**
Chromium, ion mg	8934.278597	29880.811	26656.4335	36979.4399	8784.705899	**111236**
Cobalt mg	731.8007411	2132.67175	1268.04961	23126.5556	647.1420836	**27906**
COD, mg	12177060.01	30110542.2	25137406.22	80822570.3	13946012.07	**2E+08**
Copper, ion mg	7978.59706	14174.7086	9052.966326	33357.7238	6684.040653	**71248**
Cyanide mg	125293.5339	2241758.93	3621.707384	6568126.27	951101.5525	**1E+07**
Decane mg	962.8512735	2118.03546	1668.379413	2719.16685	851.4610777	**8319.9**
Detergents, oil mg	29285.60839	69167.4168	55960.2787	86193.047	26310.19176	**266917**
Dibenzofuran µg	6280.718335	13816.2184	10883.11194	17737.3737	5554.131706	**54272**
Dibenzothiophene µg	1889.348358	8960.19472	7861.666862	11485.4169	2033.687735	**32230**
Dissolved organic matter mg	749182.4964	580858.484	2775.448911	8295272.94	345975.3282	**1E+07**
Dissolved solids mg	1471948823	3024759927	2550650032	2332446343	1301567330	**1E+10**
Docosane µg	35345.94091	77753.715	61247.12962	99820.683	31256.96295	**305424**
Dodecane mg	1826.850166	4018.66264	3165.519281	5159.1982	1615.509496	**15786**
Eicosane mg	502.980074	1106.4481	871.5556336	1420.46654	444.7927739	**4346.2**
Fluorene, 1-methyl- µg	3759.244124	8269.45592	6513.87583	10616.4311	3324.349199	**32483**
Fluorenes alkylated unspecified, g	69368.26143	86631.5621	47713.09514	147424.048	55609.48308	**406746**
Fluoride mg	133425.214	1737158.07	2542692.636	3718048.86	667187.1778	**9E+06**
Fluorine µg	34895.11218	46585.8077	26971.02448	76146.2991	28208.75957	**212807**
Halogenated organics µg	0	895806280	0	0	0	**9E+08**
Hexadecane mg	1994.004814	4386.33257	3455.124334	5631.23454	1763.323853	**17230**
Hexanoic acid mg	6939.151029	15264.5862	12023.98646	19596.8228	6136.389841	**59961**
Hydrocarbons, unspecified µg	89596.8829	42604544.8	14233.07134	3218028259	43343.51433	**3E+09**
Iron mg	4754239.342	10887184.3	4860418.742	15002401.4	4238515.36	**4E+07**

Lead mg	71498.66287	572359.565	1896187.876	1783319.17	481160.4221	**5E+06**
Lead-210/kg µg	0.00343033	1473788311	0.00594672	21950332.7	0.003033782	**1E+09**
Lithium, ion mg	11670772.85	56720360.7	54334504.3	55773526.5	13018946.73	**2E+08**
Magnesium mg	20768388.94	45713495.4	35966442.54	62454917.9	18358347.47	**2E+08**
Manganese mg	123065.8571	25324796.3	155709.0437	972684.64	82386.13675	**3E+07**
Mercury µg	23919.89229	33641.2742	16452.52609	117844.824	19175.51498	**211034**
Metallic ions, unspecified mg	58237.97388	894175.948	9251.496372	414619.426	28173.28432	**1E+06**
Methane, monochloro-, R-40 µg	1329.529832	2924.66678	2303.772992	3754.71684	1175.721892	**11488**
Methyl ethyl ketone µg	2658.963026	5849.11104	4607.3676	7509.15344	2351.35746	**22976**
Molybdenum mg	759.3212585	1690.4065	1315.72756	2643.05281	671.4781634	**7080**
m-Xylene mg	1000.783029	2201.52915	1734.163762	2826.34109	885.0091893	**8647.8**
Naphthalene mg	-6810.283851	1254.72653	1039.824829	1696.64934	-62458.8346	**-65278**
Naphthalene, 2-methyl- mg	523.1986943	1150.92125	906.5863074	1477.56341	462.6720989	**4520.9**
Naphthalenes, alkylated, µg	19614.35597	24495.5888	13491.11453	41685.1073	15723.95879	**115010**
n-Hexacosane µg	22051.26658	48507.6056	38209.58615	62274.6784	19500.22505	**190543**
Nickel mg	8460.925077	21782.7107	23037.35029	110027.778	10766.35511	**174075**
Nitrate mg	312339.5939	173509.6	0	1871035.05	144075.7175	**3E+06**
Nitrate compounds mg	0	1.5976E-09	0	4.105E-09	0	**6E-09**
Nitric acid mg	0	3.5836E-06	0	9.2077E-06	0	**1E-05**
Nitrogen, total mg	121384.9386	2433152.31	1138.645707	7193981.21	974195.6236	**1E+07**
Non-ferrous metals mg	0	109244.668	0	0	0	**109245**
Non-halogenated Organics µg	0	22884461.6	0	631909107	0	**7E+08**
o-Cresol mg	950.2244784	2090.28767	1646.531166	2683.52841	840.2974871	**8210.9**
Octadecane mg	492.6183794	1083.65236	853.5985927	1391.20241	435.6295779	**4256.7**
Oils, unspecified mg	4600996.883	67607433.8	5765489.453	205444294	28219656.48	**3E+08**
Other mg	0	1012944114	0	5139527.41	0	**1E+09**
Other metals mg	2360.255038	125620697	0	2780400.07	1088.739728	**1E+08**
p-Cresol mg	1025.225015	2255.30502	1776.52635	2895.36124	906.6243862	**8859**
Pentanone, methyl- mg	138.815069	285.26231	240.5311674	219.954113	122.7558135	**1007.3**
Phenanthrene µg	7718.084237	12428.8817	8374.633663	18453.2574	6429.773134	**53405**
Phenanthrenes, alkylated, µg	8132.914357	10156.8694	5593.963786	17284.3479	6519.796211	**47688**
Phenol µg	17807079.97	3.1272E+10	6367475.416	147763903	20934810.28	**3E+10**
Phenol, 2,4-dimethyl- mg	925.2265818	2035.29299	1603.210087	2612.92839	818.1910688	**7994.8**
Phenols, unspecified mg	6242.025406	30921.7805	23056.21439	26343.9915	6488.140323	**93052**
Phosphate mg	37183.32226	85083.1408	2313931.369	945359.477	316019.839	**4E+06**
Phosphorus mg	232106.186	543944.393	13730115.02	2671213.79	1971666.873	**2E+07**
Polynuclear Hydrocarbons µg	0	161.819154	0	0	0	**161.82**
Radium-226/kg µg	1.194028249	2.45368625	2.068927088	1.89194359	1.055891724	**8.6645**
Radium-228/kg µg	0.006103509	0.01254834	0.010582062	0.00967726	0.005397714	**0.0443**
Selenium µg	265090.14	445530.95	184389.5054	748335.561	212673.6076	**2E+06**
Silver mg	69330.45406	152365.235	119965.9643	196112.33	61296.60812	**599071**
Sodium, ion mg	336425850.3	744895324	583116731.1	1161992045	297519327.7	**3E+09**
Solids, inorganic mg	0	12402.093	0	730384.585	0	**742787**
Strontium mg	1800719.908	3980759.34	3120185.377	6349348.66	1592397.704	**2E+07**
Sulfate mg	35221723.83	79881901.4	4223811.07	53332415.5	17271629.83	**2E+08**
Sulfide mg	350965.4344	6639331.11	1143176.822	19839660.3	2941316.458	**3E+07**
Sulfur mg	87514.09886	192835.926	151642.1492	270650.703	77389.95452	**780033**
Suspended solids, unspecified mg	99843972.68	229822160	610398869.2	649536243	195372149.1	**2E+09**
Tar mg	0	9.0294E-11	0	2.32E-10	0	**3E-10**
Tetradecane mg	800.6361625	1761.22094	1387.321959	2261.07254	708.013913	**6918.3**
Thallium µg	287657.0304	360115.503	198500.1477	627363.972	230652.8466	**2E+06**
Tin mg	6181.744315	10285.5645	7062.192919	15472.7775	5177.929689	**44180**
Titanium, ion mg	20961.23017	275402.41	14450.47109	139657.755	16806.29464	**467278**

Toluene mg	52352.32614	116369.426	90714.67586	224301.175	46295.89639	**530034**
Vanadium mg	896.9506249	10755.5329	1554.215013	14121.6052	793.1863009	**28121**
Xylene mg	18661.19895	19331.5136	6620.533654	118697.448	14468.23502	**177779**
Yttrium mg	222.6015934	489.666376	385.7101672	628.642547	196.8490968	**1923.5**
Zinc mg	138005.6708	99095.9739	5907965.696	876374.171	779274.1339	**8E+06**

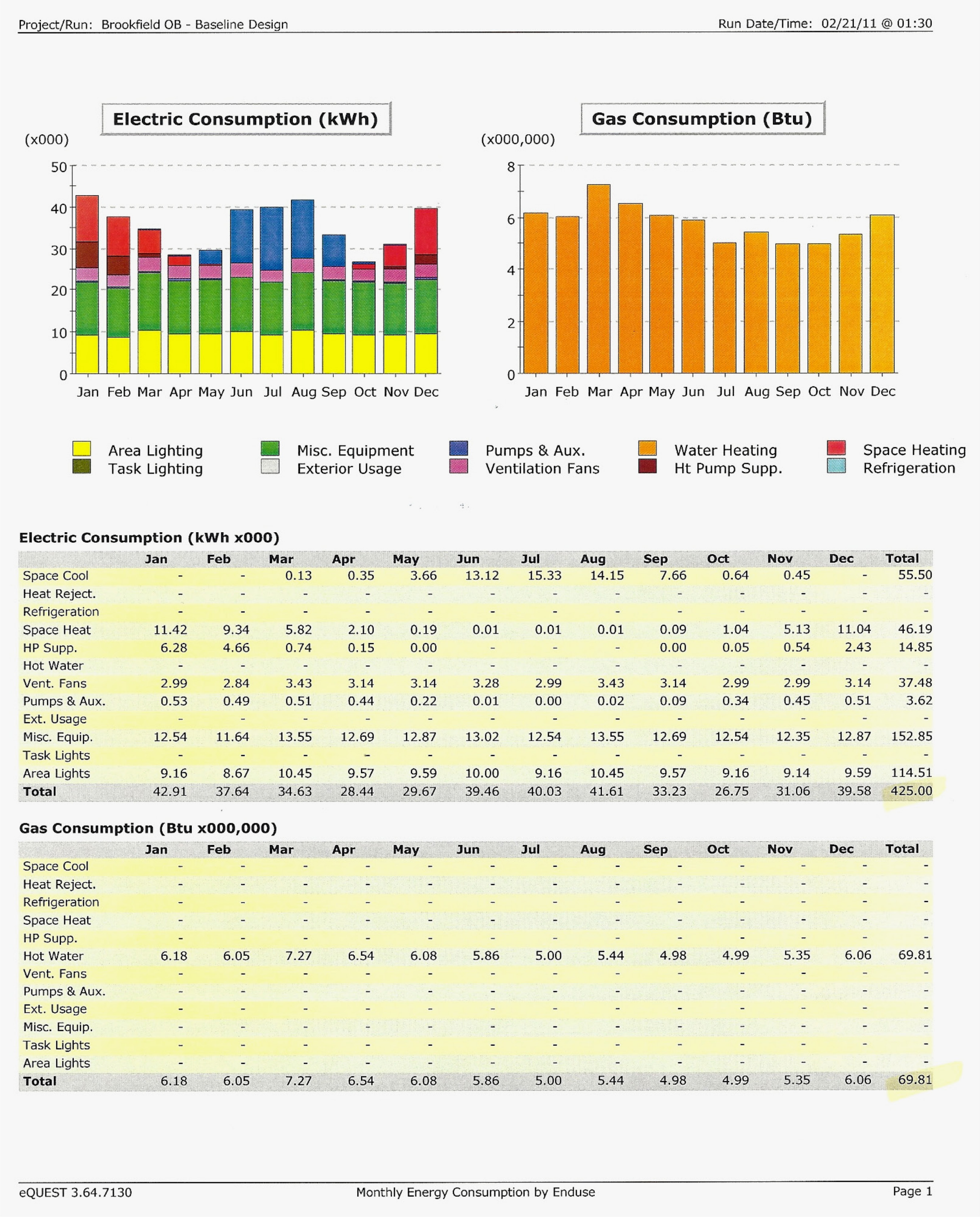
Appendix C-12: Huron- Land Emissions by LC Stage

	Manufacturing			**Construction**			**Maintenance**			**End - Of - Life**			**Operation**		**Total**		
	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Material	Transp	**Total**	Annual	**Total**	Material	Transp	**Total**
Bark/Wood Waste kg	3.7532	0	**3.753**	10830.3	0	**10830**	0	0	**0**	0	0	**0**	0	**0**	10834.1	0	**10834**
Concrete Solid Waste kg	23934	0	**23934**	23898.8	0	**23899**	6404.3	0	**6404**	0	0	**0**	0	**0**	54237.5	0	**54237**
Blast Furnace Slag kg	11746	0	**11746**	0	0	**0**	131.09	0	**131.1**	0	0	**0**	0	**0**	11876.9	0	**11877**
Blast Furnace Dust kg	3867.4	0	**3867**	0	0	**0**	15.28	0	**15.28**	0	0	**0**	0	**0**	3882.65	0	**3882.7**
Steel Waste kg	46.239	0	**46.24**	191.722	0	**191.7**	130.64	0	**130.6**	0	0	**0**	0	**0**	368.602	0	**368.6**
Other Solid Waste kg	32097	81.215	**32178**	3.08296	121.96	**125**	13361	16.33	**13378**	62.8535	37.72	**100.6**	12542	**8E+05**	45524.4	257.22	**798282**

Appendix C-13: Huron- Land Emissions by Bldg Assembly

	Foundations	**Walls**	**Col & Beams**	**Roofs**	**Floors**	**Total**
Bark/Wood Waste kg	1682.319425	3.75319099	0	0	9148.0137	**10834.1**
Concrete Solid Waste kg	13751.888	435.167778	0	12808.6	27241.8096	**54237.5**
Blast Furnace Slag kg	118.9936203	857.239334	6220.986309	3668.38316	1011.32288	**11876.9**
Blast Furnace Dust kg	755.7890241	211.306816	1719.840569	565.663191	630.051837	**3882.65**
Steel Waste kg	12.42445819	62.0545963	2.2645116	229.651013	62.2078756	**368.602**
Other Solid Waste kg	4945.043746	22334.4511	5121.566969	10432.972	2947.5494	**45781.6**

Appendix D-1: eQuest simulation- Brookside Office Building



Project/Run: Brookfield OB - Baseline Design

Run Date/Time: 02/21/11 @ 01:30

🟨 Area Lighting
🟫 Task Lighting
🟩 Misc. Equipment
⬜ Exterior Usage
🟦 Pumps & Aux.
🟪 Ventilation Fans
🟧 Water Heating
🟥 Ht Pump Supp.
🟥 Space Heating
🟦 Refrigeration

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	0.13	0.35	3.66	13.12	15.33	14.15	7.66	0.64	0.45	-	55.50
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	11.42	9.34	5.82	2.10	0.19	0.01	0.01	0.01	0.09	1.04	5.13	11.04	46.19
HP Supp.	6.28	4.66	0.74	0.15	0.00	-	-	-	0.00	0.05	0.54	2.43	14.85
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	2.99	2.84	3.43	3.14	3.14	3.28	2.99	3.43	3.14	2.99	2.99	3.14	37.48
Pumps & Aux.	0.53	0.49	0.51	0.44	0.22	0.01	0.00	0.02	0.09	0.34	0.45	0.51	3.62
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	12.54	11.64	13.55	12.69	12.87	13.02	12.54	13.55	12.69	12.54	12.35	12.87	152.85
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	9.16	8.67	10.45	9.57	9.59	10.00	9.16	10.45	9.57	9.16	9.14	9.59	114.51
Total	42.91	37.64	34.63	28.44	29.67	39.46	40.03	41.61	33.23	26.75	31.06	39.58	425.00

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	6.18	6.05	7.27	6.54	6.08	5.86	5.00	5.44	4.98	4.99	5.35	6.06	69.81
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	6.18	6.05	7.27	6.54	6.08	5.86	5.00	5.44	4.98	4.99	5.35	6.06	69.81

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Monthly Energy Consumption by Enduse

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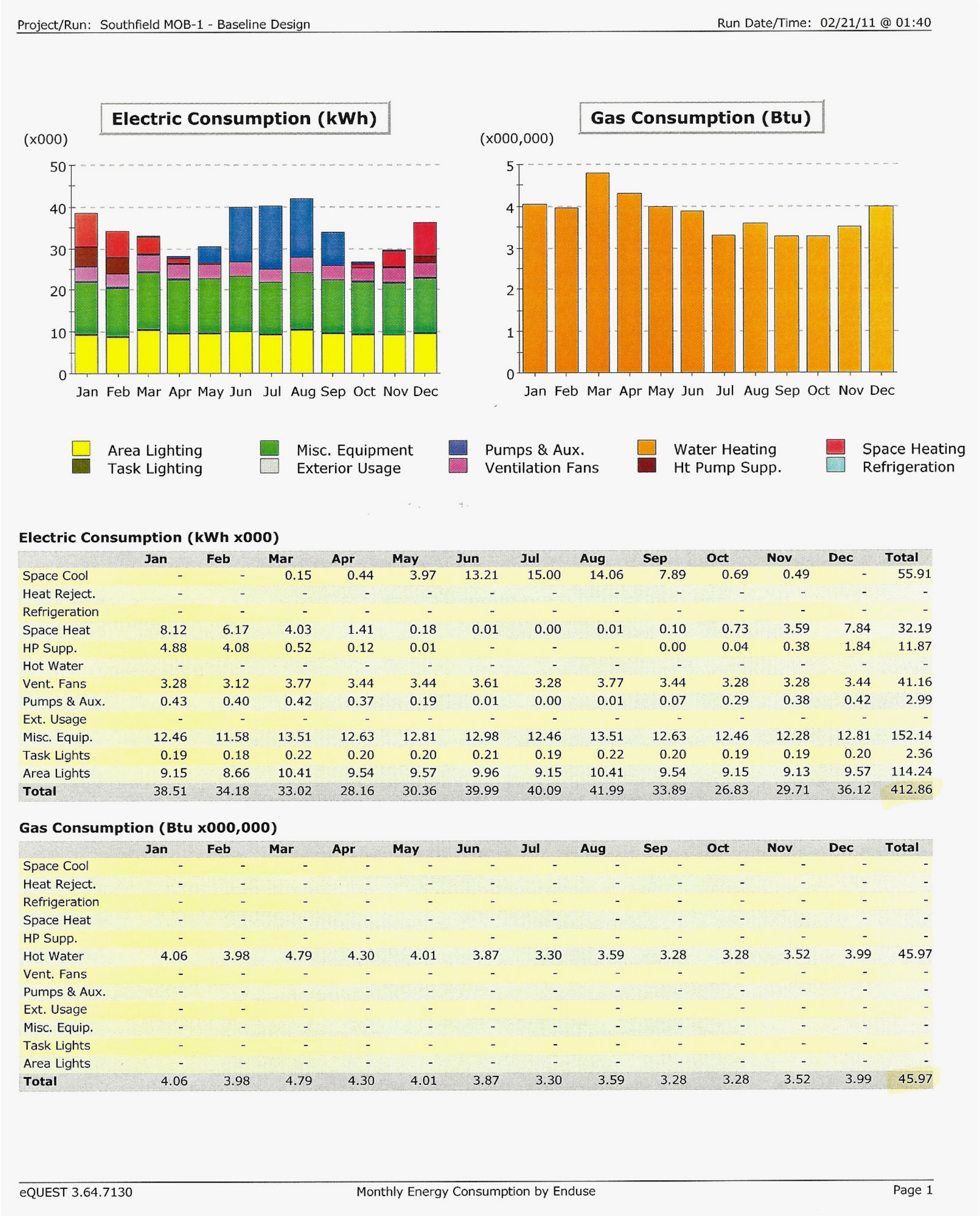
Appendix D-2: eQuest simulation- Southfield Office Building



Project/Run: Southfield MOB-1 - Baseline Design Run Date/Time: 02/21/11 @ 01:40

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	0.15	0.44	3.97	13.21	15.00	14.06	7.89	0.69	0.49	-	55.91
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	8.12	6.17	4.03	1.41	0.18	0.01	0.00	0.01	0.10	0.73	3.59	7.84	32.19
HP Supp.	4.88	4.08	0.52	0.12	0.01	-	-	-	0.00	0.04	0.38	1.84	11.87
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	3.28	3.12	3.77	3.44	3.44	3.61	3.28	3.77	3.44	3.28	3.28	3.44	41.16
Pumps & Aux.	0.43	0.40	0.42	0.37	0.19	0.01	0.00	0.01	0.07	0.29	0.38	0.42	2.99
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	12.46	11.58	13.51	12.63	12.81	12.98	12.46	13.51	12.63	12.46	12.28	12.81	152.14
Task Lights	0.19	0.18	0.22	0.20	0.20	0.21	0.19	0.22	0.20	0.19	0.19	0.20	2.36
Area Lights	9.15	8.66	10.41	9.54	9.57	9.96	9.15	10.41	9.54	9.15	9.13	9.57	114.24
Total	38.51	34.18	33.02	28.16	30.36	39.99	40.09	41.99	33.89	26.83	29.71	36.12	412.86

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	4.06	3.98	4.79	4.30	4.01	3.87	3.30	3.59	3.28	3.28	3.52	3.99	45.97
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	4.06	3.98	4.79	4.30	4.01	3.87	3.30	3.59	3.28	3.28	3.52	3.99	45.97

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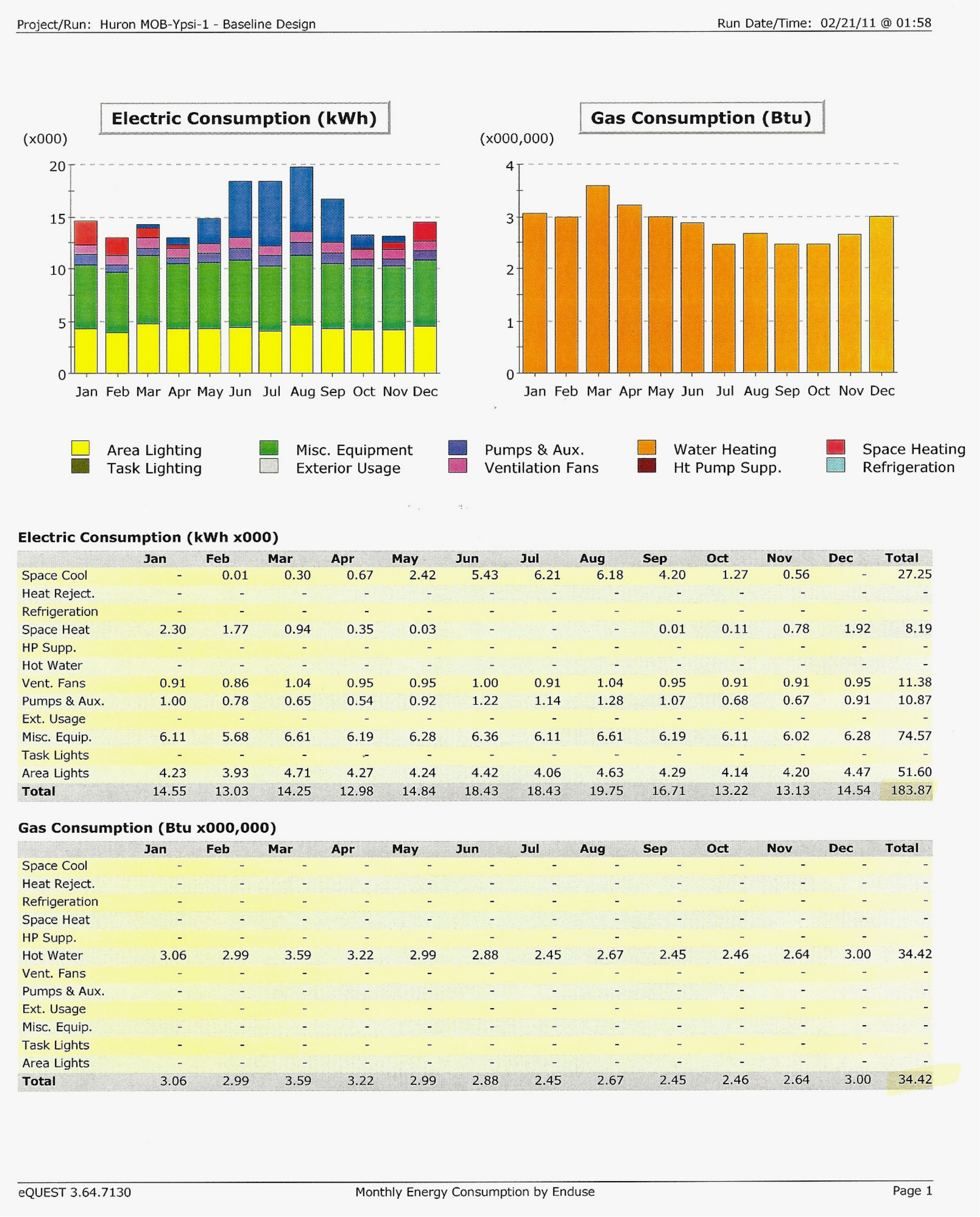
Appendix D-3: eQuest simulation- Huron Office Building



Project/Run: Huron MOB-Ypsi-1 - Baseline Design Run Date/Time: 02/21/11 @ 01:58

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	0.01	0.30	0.67	2.42	5.43	6.21	6.18	4.20	1.27	0.56	-	27.25
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	2.30	1.77	0.94	0.35	0.03	-	-	-	0.01	0.11	0.78	1.92	8.19
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.91	0.86	1.04	0.95	0.95	1.00	0.91	1.04	0.95	0.91	0.91	0.95	11.38
Pumps & Aux.	1.00	0.78	0.65	0.54	0.92	1.22	1.14	1.28	1.07	0.68	0.67	0.91	10.87
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	6.11	5.68	6.61	6.19	6.28	6.36	6.11	6.61	6.19	6.11	6.02	6.28	74.57
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	4.23	3.93	4.71	4.27	4.24	4.42	4.06	4.63	4.29	4.14	4.20	4.47	51.60
Total	14.55	13.03	14.25	12.98	14.84	18.43	18.43	19.75	16.71	13.22	13.13	14.54	183.87

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	3.06	2.99	3.59	3.22	2.99	2.88	2.45	2.67	2.45	2.46	2.64	3.00	34.42
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	3.06	2.99	3.59	3.22	2.99	2.88	2.45	2.67	2.45	2.46	2.64	3.00	34.42

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Appendix E-1: Sensitivity Analysis Results by Building Systems

Fossil Fuel (Energy) Consumption (MJ)

	Foundations	Walls	Columns and Beams	Roofs	Floors	Total
Brookside	1365968.237	2269299.933	3801520.621	3173458	1389130.5	11999377
Brookside Sensitivity	1166569.771	2166420.736	3801520.621	2604692.9	1389130.5	11128334
Southfield	691644.3358	2089828.42	3317453.474	1503412.6	1288881.8	8891220.7
Southfield Sensitivity	595613.1581	1978433.941	3317453.474	1232810.6	1288881.8	8413193
Huron	753049.2368	1417895.559	1783170.886	3180202.3	711331.73	7845649.8
Huron Sensitivity	636951.9777	1269083.034	1783170.886	2608569.8	711331.73	7009107.4

Resources Use (kg)

	Foundations	Walls	Columns and Beams	Roofs	Floors	Total
Brookside	1326769.967	442671.516	361310.2144	167859.64	563239.55	2861850.9
Brookside Sensitivity	1256047.202	438945.5078	361310.2144	158384.55	563239.55	2777927
Southfield	743235.2604	494534.7553	301093.3893	79218.629	532867.89	2150949.9
Southfield Sensitivity	709174.981	490500.3463	301093.3893	74710.656	532867.89	2108347.3
Huron	788919.8848	265856.1287	172308.9596	167481.19	620503.24	2015069.4
Huron Sensitivity	747742.4611	251813.3315	172308.9596	157969.07	620503.24	1950337.1

Global Warming Potential (kg CO_2 equiv.)

	Foundations	Walls	Columns and Beams	Roofs	Floors	Total
Brookside	200598.1117	220149.7837	191119.9157	131829.31	113858.54	857555.66
Brookside Sensitivity	150221.5978	212891.2905	191119.9157	112669.75	113858.54	780761.09
Southfield	99550.82766	185656.5987	164972.9916	62403.003	106688.51	619271.93
Southfield Sensitivity	76637.02787	177797.322	164972.9916	53287.436	106688.51	579383.28
Huron	114390.0256	125834.7607	90013.12836	131871.15	73189.859	535298.93
Huron Sensitivity	85295.92149	113929.4449	90013.12836	112643.81	73189.859	475072.17

Acidification Potential (moles of H+ equiv.)

	Foundations	Walls	Columns and Beams	Roofs	Floors	Total
Brookside	66267.64582	142617.2891	76868.99366	49697.783	36366.548	371818.26
Brookside Sensitivity	52533.93698	139163.5437	76868.99366	43397.181	36366.548	348330.2
Southfield	32868.08409	115445.0334	66334.77906	23512.122	33932.419	272092.44
Southfield Sensitivity	26409.50388	111705.4224	66334.77906	20514.477	33932.419	258896.6
Huron	37498.12712	87191.76181	36181.15606	49709.98	25769.766	236350.79
Huron Sensitivity	29529.2141	82137.1086	36181.15606	43395.097	25769.766	217012.34

Eutrophication Potential (kg N+ equiv.)

	Foundations	Walls	Columns and Beams	Roofs	Floors	Total
Brookside	31.10316946	55.31870841	242.3650102	46.559293	53.026071	428.37225
Brookside Sensitivity	25.37762356	54.47077269	242.3650102	48.113745	53.026071	423.35322
Southfield	15.92682113	46.55885026	221.1593532	21.718954	48.380999	353.74498
Southfield Sensitivity	13.3293773	45.64073114	221.1593532	22.458517	48.380999	350.96898
Huron	16.87766099	32.01849454	111.7296756	46.038494	27.102936	233.76726
Huron Sensitivity	13.57216895	28.15070434	111.7296756	47.620311	27.102936	228.1758

Smog Potential (kg NOx equiv.)

	Foundations	Walls	Columns and Beams	Roofs	Floors	Total
Brookside	599.3753777	876.5986855	237.1913262	731.95363	208.04998	2653.169
Brookside Sensitivity	472.1010185	862.6717073	237.1913262	438.97862	208.04998	2218.9927
Southfield	304.2895045	676.3669896	209.9737705	347.94314	195.2994	1733.8728
Southfield Sensitivity	246.534585	661.2872792	209.9737705	208.55409	195.2994	1521.6491
Huron	332.0556413	485.2279812	110.0178502	733.829	240.16657	1901.2971
Huron Sensitivity	258.5743886	460.200611	110.0178502	440.14361	240.16657	1509.103

HH Respiratory Effects (kg PM2.5 equiv.)

	Foundations	Walls	Columns and Beams	Roofs	Floors	Total
Brookside	465.4045283	1783.410557	396.253542	219.00042	217.27946	3081.3485
Brookside Sensitivity	358.454561	1708.403237	396.253542	199.06436	217.27946	2879.4552
Southfield	233.6255335	1287.511518	341.019881	103.48974	203.39763	2169.0443
Southfield Sensitivity	184.4574633	1206.295863	341.019881	94.004734	203.39763	2029.1756
Huron	269.1075071	916.3596803	186.7937531	218.88349	172.4288	1763.5732
Huron Sensitivity	207.2486095	874.5159335	186.7937531	198.90124	172.4288	1639.8883

Ozone Depletion Potential (kg CFC-11 equiv.)

	Foundations	Walls	Columns and Beams	Roofs	Floors	Total
Brookside	0.000614596	0.000158743	1.01062E-06	6.155E-06	0.0001198	0.0009004
Brookside Sensitivity	0.000470454	0.000160787	1.01062E-06	0.0001905	0.0001198	0.0009426
Southfield	0.000295712	0.000150206	8.67195E-07	2.927E-06	0.000114	0.0005637
Southfield Sensitivity	0.000226292	0.000152419	8.67195E-07	9.061E-05	0.000114	0.0005842
Huron	0.000357765	0.000156706	4.76971E-07	6.194E-06	0.0001654	0.0006865
Huron Sensitivity	0.00027384	0.000105696	4.76971E-07	0.0001919	0.0001654	0.0007373

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