EVALUATING THE ENVIRONMENTAL PERFORMANCE OF SERVICE SECTOR INDUSTRIES

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The overall goal of this research is to evaluate and quantify the environmental impacts of service industries through the application of life cycle assessment (LCA). Service industries represent the majority of the United States economy, accounting for nearly 75% of the Gross Domestic Product (GDP), however, their environmental implications have often been overlooked as they are deemed cleaner by comparison to their manufacturing counterparts.

In order to identify which aspects of services are responsible for significant environmental loadings, and determine which areas have the most room for improvement the impacts need to be assessed using methods such as life cycle assessment. This research uses hybrid life cycle assessment to establish a framework for evaluating the impact of service industries. The evaluated service industries, professional services (consulting) and healthcare, combined account for more than 20% of the US GDP.

The results of the professional service assessment demonstrated the environmental significance of travel and transportation as well as building premise impacts on the overall impacts of the service. Of the total annual greenhouse gas (GHG) emissions from the professional services firm evaluated, 40% were a result of transportation while 24% were attributable to the impacts of the building premises, both primarily driven through the combustion of fossil fuels. Business travel and employee commuting were both about 20% of the annual GHG emissions for the firm, numbers that could be reduced greatly by purchasing more

fuel efficient vehicles and instituting telecommuting programs. Improving fleet fuel economy through purchasing more fuel efficient vehicles and allowing 50% of the work force to telecommute one time per week resulted in a 5% decrease in the firms overall annual GHG emissions.

This research also evaluated the impacts of healthcare services, focusing on determining the life cycle impacts of single-use disposable products in a hospital operating room setting. The research evaluated the impacts of the production and disposal of the single use disposable products used in multiple hysterectomy procedures. The research found that the major impacts of the products were a result of material production, which accounted for between 88-97% of the environmental impacts of products.

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PREFACE

I cannot express my gratitude for my advisor, Associate Professor Amy Landis as well as my pseudo Co-Advisor Assistant Professor Melissa Bilec. I would also like to thank my dissertation committee for their useful suggestions, guidance, and patience throughout my work.

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Finally, the support of my family and friends was invaluable. Their love, understanding, and inspiration meant the world to me. I can honestly say I don't know where I would be today without them bringing me to Earth when I was sky high and picking me up when I was down.

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1.0 INTRODUCTION

1.1 SERVICE INDUSTRIES – AN ECONOMIC AND ENVIRONMENTAL DRIVER.

Service industries have become strong economic drivers within the United States and other developed nations. Within the United States, services accounted for around 75% of the total GDP in 2010 (BEA 2011). Private service-producing industries also accounted for 60% of the GDP growth in 2010 (Gilmore 2011). The shift to service based economies is typically viewed to be an environmental positive, as manufacturing is often seen as the main contributor to environmental degradation. More recent research, however, shows that service industries may not be a better environmental alternative, and in fact still account for significant direct and indirect environmental impacts.

One of the major issues resulting in the underrepresented effects of the service industries is the lack of a clearly defined picture of the expansiveness of service companies. Manufacturing has distinctly visible point source emissions, for example CO_2 directly from smokestacks, thus environmental impacts from these sectors, in theory, are easily accounted for. Even the effects of the raw material acquisition and supply chain management required for the manufacturing production are becoming more easily attributable with tools such as life cycle assessment (LCA) and waste audits. Contrary to manufacturing, services do not always have direct point source emissions, and it becomes easy to overlook the hidden environmental effects and simply deem them cleaner by comparison. Typically service industries have been overlooked and under-regulated (Oliver-Solà, Núñez et al. 2007; Jeswani, Azapagic et al. 2010). To truly understand the impacts of services it is necessary to account for all of the actions of the service.

This research proposes to evaluate the environmental impacts of service sector industries, specifically two of the largest services, professional services (consulting) and healthcare. Two disparate sectors will be evaluated as case studies: professional and business services, and health care. These service areas accounted for 12% and 7.5% of US GDP in 2010 (Teresa Gilmore 2011). Each service industry presents many unique research challenges and opportunities with respect to quantification of environmental impacts.

The healthcare sector is a major component of national and often regional economic vitality, and also has unique waste management needs and associated environmental impacts. In 2010 health care expenditures amounted to 17.6% of the US gross domestic product (GDP) and have been continuing to increase by an average rate of 4.7% over the past decade (Organisation for Economic Co-operation and Health 2012). Hospital care accounts for 33% of every dollar spent on healthcare in the US (AHA 2011). In 2009, US hospitals spent nearly $342 billion on goods and services from other businesses and employed over 5.4 million people (AHA 2011). Hospitals are the second most energy intensive facility type in the US; the sector as a whole consumes 73 trillion kWh of electricity annually (USDOE 2009).

Healthcare produces large quantities of waste and has unique demands for infection control, with rapidly evolving medical technologies. It has been estimated that American health facilities are responsible for the landfilling and incineration of over 3.4 billion pounds of waste annually (EPA 2005; Diconsiglio 2008). Although the amount of waste generated in operating rooms (ORs) varies drastically between individual hospitals, ORs are found to account for between 20-

73% of hospital waste streams (Goldberg, Vekeman et al. 1996; U. S. Air Force Institute for Environment Safety and Occupational Health Risk Analysis 2001; Lee, Ellenbecker et al. 2002). Hospitals' consumption of material resources and energy affect both environmental and human health (Sattler 2002). Increases in operating costs have come along with the increases in material consumption, which can ill be afforded in an area which has seen insurance premiums and deductibles grow by more than 63% in the past seven years (C. Schoen 2011). These costs have been shown to have a negative impact on economic growth and are expected to continue to rise.

At a time when the human population is concerned with limiting the detrimental effects of increased resource consumption on the ability of future generations to meet their needs, it is evident that improving waste management strategies is of utmost importance. By effectively using tools such as Life Cycle Assessment (LCA) and waste audits to become more aware of the hidden impacts of waste management from service industries, it becomes easier to develop effective and innovative approaches to limit these impacts and ensure the sustainability of future generations.

1.2 RESEARCH GOALS AND OBJECTIVES

The aim of the research is to develop a framework to be used by various service industries to systematically quantify the environmental impacts from daily operations and then determine overarching feasible strategies for reducing those impacts. The framework will be used to identify and account for all material, energy, and waste flows through services, thus simplifying the currently complex environment that facilities management and employees parse through in their daily decision-making. The results of the assessment will provide a comprehensive representation of the effects directly related to the service provided, and facilitate in determining the areas of greatest environmental impacts.

Figure 1. Research objectives (represented by oval shapes) and methods (represented by rectangular shapes) for the completed research

The framework will be used on two large (by GDP contribution and total people employed), and disparate service sector industries: consulting and health care. Figure 1 demonstrates the approach and methods utilized to achieve the specific objectives (ovals). The findings from the completion of the three objectives displayed on the perimeter of the figure will be the basis for the results of the final objective displayed in the center.

The specific objectives for the research are:

1) To develop and refine a framework for the assessment and quantification of the environmental impacts of service industries.
2) To evaluate organizational behaviors associated with environmental sustainability.
3) To evaluate and quantify contents and impacts of service industry waste streams.
4) To develop best practices for sustainable strategies across the services.

1.3 INTELLECUTAL MERIT

This study will further contribute to the currently limited scientific understanding of all service industries, and specifically the waste management strategies employed by these industries. In addition to producing the assessment framework, the research will result in recommendations for best practices in waste management strategies derived from the commonalities found across the service industries. By making the framework as versatile as possible it increases the potential for having a lasting impact on multiple industries.

Due to the variety of service industries evaluated in this research, the developed framework will be applicable to nearly all service industries, and thus, make it possible to quantify the associated environmental impacts of providing their services. The implementation of the framework will result in identifying the areas of the most significant environmental concern, and make apparent the areas that can most easily be improved, e.g. the low hanging fruit. Businesses will then be able to take the results of the framework and use them to develop informed, practical, and effective solutions to reduce their environmental impacts and promote sustainable business strategies.

2.0 BACKGROUND AND LITERATURE REVIEW

2.1 SERVICE INDUSTRIES

Service industries are defined herein as those industries that typically generate revenue through providing intangible products rather than producing material goods. While service industries may at first appear to be more environmentally friendly than a primary industry (e.g. mining operations) or a secondary industry (e.g. product manufacturing) there are significant material and energy flows required to support the service sector, which in turn results in significant waste generation. These material and energy flows result in environmental impacts which are directly attributable to the upstream and downstream effects of the activities of service industries (Suh 2006). Service industries are expected to continue to grow, and until recently, the majority of research focusing upon their impacts has been done only at a highly aggregated level (Rosenblum, Horvath et al. 2000).

2.2 ASSESSMENT METHODS FOR SERVICE INDUSTRIES

There are a disparate number of tools and methods that could be applied to assess the environmental performance of service industries. These methods include: the Greenhouse Gas

Protocol (GHG Protocol) from the World Resource Institute, Publicly Available Specification (PAS) 2050 from the British Standards Institute, ISO 14064 from the International Organization for Standardization (ISO), and the method of composed of financial statements (MC3) from Spain (World Resource Institute 2004; ISO 2006; BSI 2008; Carballo-Penela and Doménech 2010). The GHG Protocol is one of the most widely recognized tools for evaluating the environmental performance of governments and businesses, but it is limited strictly to the quantification of GHGs and overlooks other environmental impacts, such as eutrophication or smog. Similarly, ISO 14064 is a specification regarding the guidance of quantifying and reporting GHG emissions only. PAS 2050 and MC3 are both life cycle assessment (LCA) based approaches for evaluating the impacts of goods or organizations.

2.2.1 Life Cycle Assessment

Life cycle assessment is a tool used to quantify the environmental impacts of a given product or process. Process LCA traditionally provides a method to track a product from its raw materials extraction (i.e. cradle) through its disposal or end of life (i.e. grave), but it does not always necessarily include every production stage. LCAs can help to standardize what people determine as “green,” but they can also reveal the effects of a given product, process, or service and assist in making improvements at various stages of development.

Established guidelines for performing detailed LCAs are well documented by the Environmental Protection Agency (EPA), Society for Environmental Toxicologists and Chemists (SETAC), the International Organization of Standardization (ISO), and the American National Standards Institute (ANSI) (Fava, Denison et al. 1991; Vigon, Tolle et al. 1992; UNEP/SETAC

2005; ISO 2006). According to ISO 14040 standards (2006) a process LCA is conducted in four steps. The first step, goal and scope definition, sets up the boundary conditions of the system, establishing what will and will not be included in the assessment. This step also defines a functional unit for the system in order to standardize the results and enable comparison with other products or processes. The second step, Life Cycle Inventory (LCI), includes the collection of raw data for the system inputs and outputs. Life Cycle Impact Assessment (LCIA) is the third step where environmental impacts are calculated from the inventory data. In this step, the inventory is aggregated into impact categories, such as global warming or acidification. The fourth and final step is improvement and interpretation, where the LCA and results are analyzed for areas of improvement.

As data availability and modeling tools have become more advanced, the effectiveness of using LCA to assess service industries has significantly improved. Historically the value of traditional process based LCA has been limited due to quality and availability of data, difficulty in determining system boundaries, and practicality associated with time constraints, all of which contributed questions about its suitability for analysis of service industries (Wong 2004). Another limitation to process LCA is the difficulty of including the Scope 3 emissions, which are the indirect emissions resulting from the companies' downstream value chains (e.g. the use and disposal of a product) (Ranganathan, Corbier et al. 2004). Scope 3 emissions have been shown to be a powerful contributor to corporations' environmental profiles (Huang, Weber et al. 2009). In the early stages of using process LCA to assess service industries Graedel developed and proposed the use of a streamlined LCA method (Graedel 1997). Streamlined, hybrid LCA will be used within the proposed research.

An alternative, economic input-output (EIO) based LCA was developed in part to address some of the issues encountered by process LCA (Hendrickson 1998). EIO-LCA combines environmental data with an economic input-output (I-O) model to determine primary energy and environmental loadings associated with producing a product. EIO-LCA has also been used to assess the impacts of services (Rosenblum, Horvath et al. 2000; Suh, Lenzen et al. 2003), however it has limitations due to its high levels of aggregation, and potential uncertainty (Lenzen 2000; Bilec 2007) and thus more effective as a high level screening tool.

The use of a hybrid based LCA technique offers the ability to combine the strengths of both the process and I-O based LCA approaches and navigate some of the issues associated with each (Suh, Lenzen et al. 2004; Bilec, Ries et al. 2006; Horvath 2006; Suh 2006). Hybrid LCA offers flexibility in the inventory portion of the assessment helping with boundaries and data collection. This proves valuable when working with service industries since not all inputs have directly associated mass or energy values. Recently hybrid LCA has been proposed and successfully used to assess the impacts of select service sector based companies within Europe and the US (Junnila 2006; Junnila 2007).

Aside from the tools and methods above, there has been little done to quantify the impacts of consulting service industries. With respect to hospital services, there have been some previous applications of life cycle based methods to analyze hospital waste disposal methods, the global warming potential of anaesthetic gases, or the purchasing of medical equipment (Kümmerer, Dettenkofer et al. 1996; Ison and Miller 2000; Zhao, Van Der Voet et al. 2009; Sulbaek Andersen, Sander et al. 2010). Existing healthcare studies have been limited in their level of completeness and in the environmental impacts considered. A 2001 Ecological Footprint of a Vancouver based hospital found that the running the facilities and operations for roughly a year requires almost 720 times the land-space on which the hospital is located (Germain 2002). In 2009 Dartmouth-Hitchcock released an Eco-Health Footprint Calculator Tool which runs input information such as products, energy, waste, transportation, food water, and built land, through Economic Input-Output LCA methodology to quantify the amount of equivalent land required, in global acres, to support the facility (Maverick Lloyd Foundation 2009). A problem with reducing environmental impacts to a single unit is that ecological footprints overlook the nuances of environmental issues and lose the depth and robustness of a complete study. There have been some studies on the treatment and assessment of medical waste, but the majority of it focuses on pharmaceuticals (Castensson 2008; Gunnarsson and Wennmalm 2008).

There have also been efforts to improve the sustainability of food services using life cycle based methods, however, the majority of the efforts focus on greening the supply chain and food sources (organic agriculture, food miles, food choice impact) rather than the operations of the food service establishment (Jungbluth, Tietje et al. 2000; Heller and Keoleian 2003; Weber and Matthews 2008; Xue and Landis 2010). There have been initiatives to improve the sustainability of operations in large scale food service providers, such as college dining halls, but there is less of a push for smaller eateries. The only assessment framework of note is the “NAMA Sustainability Assessment Tool” provided by the National Automatic Merchandising Association, which serves as little more than a reference guide (National Automatic Merchandising Association 2011). The framework also focuses more on supply chain management rather than the direct impacts of the service. Quantitative environmental evaluation of the impacts of these services is necessary to help transform them into sustainable industries.

2.2.2 Waste Audit

Waste streams from service industries can vary significantly depending upon the type of services provided. For example, the primary wastes generated from office and retail settings would likely be cardboard or paper, while waste from hospitals can be comprised of multiple materials, including hazardous wastes. In order to accurately quantify the impacts of waste from service industries, the amount and types of waste must be quantified. A primary method for assessing the makeup of waste generated from an industry is a waste audit. A waste audit is a systematic approach to quantifying the generation and management of waste. Waste audits are typically viewed as the first step in creating more effective waste management and recycling strategies. Waste audits have been conducted in a variety of settings, including industrial, university, and even dental care (Farmer, Stankiewicz et al. 1997; Dowie, McCartney et al. 1998; Smyth, Fredeen et al. 2010). There have been studies that have focused on the waste management practices of healthcare and hospitals as a whole, but they have been primarily in Europe and Asia, where waste management policies may be different (Woolridge, Morrissey et al. 2005; Zhao, Van Der Voet et al. 2009).

2.3 SERVICE INDUSTRY WASTE STREAMS AND DISPOSAL

There are a number of methods of waste disposal utilized by service industries. The primary methods are landfilling, recycling, incineration, and composting. Landfilling is by far the most common disposal method with more that than 54% of MSW being disposed of in this method.

Recycling accounts for about 33% of waste disposal and combustion an additional 12%. Although not every material is suitable for each disposal method, each method has its associated benefits and detractions.

The waste disposal processes for consulting industries are relatively straightforward. On the contrary, due to the diverse and potentially harmful nature of waste produced from hospital operations, the waste disposal processes are less clear (Meaney and Cheremisihoff 1989; James 2010; Prem Ananth, Prashanthini et al. 2010; Jang 2011). Regulation of medical waste first came to realization due to media coverage of waste items washing up on beaches in the late 1980's (Rutala and Mayhall 1992). Although multiple studies have shown that medical waste can safely be landfilled or recycled, and poses virtually no threat to human health, the media attention demanded a response (Rutala and Mayhall 1992). The federal and state government's response ranged from heavy regulation to none at all, and gave regulatory oversight to multiple different regulatory agencies, thus creating a great deal of uncertainty (NY Department of Health 2007). The overlap by the regulatory agencies can make it difficult to understand the exact waste disposal requirements potentially resulting in dramatic increases in materials being landfilled or incinerated. Historically, many hospitals incinerated waste on-site, helping to eliminate concerns and uncertainty with disposal beyond the employees handling the waste safely. More recently, the EPA has established guidelines for the processes and emissions associated with on-site incineration, providing a driving force for hospitals to shift this process to off-site commercial incinerators (United States Environmental Protection Agency 2006). The shift to off-site disposal methods coupled with the increased diversity of medical waste streams has continued to complicate the disposal process. Although medical waste may be handled differently than the waste of other service industries, the end of life processes are essentially the same. The following section details the primary waste disposal methods for US service industries.

Landfilling

Landfilling is the primary disposal method in the US. The number of landfills has decreased significantly in the past 20 years, however the size and scale of the remaining landfills has increased greatly. The amount of waste placed in MSW landfills annually increased from 209 Tg to 297 Tg between 1990 and 2009 (EPA 2011). Landfills also account for the third highest source of methane emissions in the US, and a continual rise in CH_4 emissions is being observed even as the quantity of methane being collected and combusted has steadily increased (EPA 2011). Another issue with landfills is the location and transportation distances necessary for the deposit of MSW. As of 2009 there were still 1,908 MSW landfills, the majority of which are located in the South and West (EPA 2010). The smallest number of landfills is in the Northeast, which is where a large portion of the US population resides. Due to the desire of people not to have landfills in their living area, as well as a lack of available space, MSW often travels long distances before its end of life, increasing the impacts associated with disposal (Brambilla Pisoni, Raccanelli et al. 2009). Additionally, landfilling can have significant environmental impacts on nearby groundwater sources from landfill leachate and runoff (Howard, Eyles et al. 1996; van Vossen 2010).

Recycling

Recycling is the second most common method of MSW disposal in the US. The recycling rate of MSW has increased from 10% in the 1980’s to almost 34% in 2009 (EPA 2010). There have been significant strides in the US to increase the amount of recycling;

however there are still a number of obstacles to overcome to optimize the recycling programs in the US, including issues with quality control, separation technology, and governmental legislation (Reuter, Boin et al. 2004). The EPA estimates that the recycling rate for metals is just above 34%, and only 7% of plastics are recycled, leaving significant room for improvement (EPA 2010). Recycling these materials can have dramatic effects on improving the environmental performance. In particular, recycling metals reduces or displaces the need for mining, offsets a number of primary production steps, and also limits the amount of landfilled waste (Dubreuil, Young et al. 2010).

Incineration

Currently about 11.9% of MSW is incinerated with energy recovery. This method of disposal offers advantages of producing energy from waste and decreasing land space that would typically be taken up by landfilling the waste. However, incineration also results in the release of harmful emissions (Kaplan, Ranjithan et al. 2009). Incineration also removes the products from usable forms, eliminating the potential for recycling or potential landfill mining to recover valuable resources.

2.4 ORGANIZATION OF THESIS

Chapter 3 addresses Objective 1, which is the development and application of the framework for assessing the impacts of service industries. The framework is developed and applied to an engineering consulting firm to determine the aspects of a service firm with the greatest environmental implications, including transportation, energy use, and waste management. This work has been accepted and will be published in the *Journal of Cleaner Production.*

Objective 2 is the evaluation of organizational behaviors regarding environmental sustainability. This objective evaluates the behaviors associated with associated with waste disposal, energy management, and transportation, and is addressed primarily in chapter 4. Chapter 4 evaluates employee and management response to new initiatives aimed at reducing the impacts of waste production and energy consumption in an office setting. Additionally, Chapter 3 evaluates and presents methods for reducing the environmental impacts from transportation and energy consumption on building premises through behavior change.

Objective 3, which is the identification of materials through multiple service industry waste streams, is addressed by chapter 3, but more so in Chapter 5. These chapters discuss the quantity and type of materials found from the consulting firm and a hospital OR respectively.

Finally, Objective 4, the best sustainability practices across services: transportation, energy consumption and waste management are addressed in the results sections of Chapters 3, 4, 5, and 6. Chapters 3 and 4 discuss best practices for services similar to consulting, while Chapter 5 examines ways to minimize the production and waste impacts from hospital procedures. Chapter 6 offers recommendations and strategies to reduce the environmental impacts across the services.

3.0 THE APPLICATION OF A MULTI-FACETED APPROACH FOR EVALUATING AND IMPROVING THE LIFE CYCLE ENVIRONMENTAL PERFORMANCE OF SERVICE INDUSTRIES

The following chapter is a reproduction of an article that has been accepted in the *Journal of Cleaner Production* with the citation:

Shrake, Scott O., Melissa M. Bilec, and A.E. Landis (2011). "The application of a multi-faceted approach for evaluating and improving the life cycle environmental performance of service industries." Journal of Cleaner Production, *accepted*

The article appears as submitted following the peer-review for the *Journal of Cleaner Production.* Supporting Information submitted with the *Journal of Cleaner Production* appears in Appendix A.

3.1 ABSTRACT

Service industries continue to be to be a driving force economically, both within the US and globally, yet their environmental impacts still tend to be overlooked. This article presents a hybrid life cycle assessment case study to assess and quantify the life cycle impacts of an engineering service firm. The data for the hybrid LCA of the firm's activities and operations was collected for one fiscal year, from January 2009 to December 2009. Data collection methods include an energy audit, personnel survey, and assessment of waste management practices. The results of the case study show that the impacts of employee travel and transportation as well as the building premises are the major contributors to the environmental impact of a service industry (40% and 24% of GWP, respectively) and should be the areas targeted for improvements to reduce life-cycle impacts of similar service firms. The study also reveals that in order to make specific targeted reductions to a firm's life-cycle impacts, more in depth evaluation of certain activities, such as workstation energy consumption, can be essential to identifying unnecessary wastes of resources.

3.2 INTRODUCTION

In the United States alone, service industries account for nearly 76% of the total Gross Domestic Product (BEA 2011). Although the economic impacts of services are apparent, the environmental impacts of service industries are generally not as well known and are often overlooked (Rosenblum, Horvath et al. 2000). While service industries may seem more environmentally friendly than manufacturing industries, service industries require significant flows of material and energy. These material and energy flows result in environmental impacts which are directly attributable to the upstream and downstream effects of the activities of service industries (Suh 2006). The majority of environmental regulation focuses on industries with more visible environmental impacts, such as manufacturing or mining, as their environmental effluents are generally obvious. The tendency to overlook the environmental loadings associated with service industries is likely due to their lack of point source emissions. This paper presents a framework for quantifying the life-cycle environmental impacts of an engineering consulting service firm, details improvements to reduce the largest impacts, and evaluates the implementation of the improvements.

There are a disparate number of tools and methods that could be applied to assess the environmental performance of service industries. These methods include: the Greenhouse Gas Protocol (GHG Protocol) from the World Resource Institute, Publicly Available Specification (PAS) 2050 from the British Standards Institute, ISO 14064 from the International Organization for Standardization (ISO), and the method of composed of financial statements (MC3) from Spain (World Resource Institute 2004; ISO 2006; BSI 2008; Carballo-Penela and Doménech 2010). The GHG Protocol is one of the most widely recognized tools for evaluating the environmental performance of governments and businesses, but it is limited strictly to the quantification of GHGs and overlooks other environmental impacts, such as eutrophication or smog. Similarly, ISO 14064 is a specification regarding the guidance of quantifying and reporting GHG emissions only. PAS 2050 and MC3 are both life cycle assessment (LCA) based approaches for evaluating the impacts of goods or organizations.

LCA is a method used to quantify the environmental impacts of a given product, process, or service throughout its entire life cycle from raw materials extraction to end of life (ISO 2006). Multiple organizations have established guidelines for performing detailed LCAs including the US Environmental Protection Agency (USEPA), the Society for Environmental Toxicologists and Chemists (SETAC), ISO, and American National Standards Institute (ANSI) (Fava, Denison et al. 1991; Vigon, Tolle et al. 1992; UNEP/SETAC 2005; ISO 2006). PAS 2050 is a process LCA based tool that, similar to the tools above, calculates a carbon footprint (CF) for a product or process. MC3 is described as an organization based LCA tool, also with the goal of assessing the CF of goods and businesses (Carballo-Penela and Doménech 2010). MC3's approach calculates the CF of a corporation through assessing financial records and converting all of the products consumed by a company into mass units by using the specific product average price in the period under study (i.e. monetary unit/kg). The reliance on financial records helps to more quickly assess a business or products environmental impacts, but again focuses solely on carbon footprinting. Other LCA tools exist, such as SimaPro and GABI; while these tools are often used for products, they can be applied to service industries (PE INTERNATIONAL 2011; Pré Consultants 2011).

Although historically used to assess products or processes often related to manufacturing, there are a handful of LCAs of service industries in the literature. The applicability of traditional process LCA to assessing service industries has been questioned due to data availability, difficulty in setting and determining system boundaries, and practicality associated with time constraint (Graedel 1997; Wong 2004). The issues of determining system boundaries make it difficult to capture the Scope 3 emissions, i.e. the indirect emissions that result from the companies' upstream and downstream supply chains (Ranganathan, Corbier et al. 2004). The impacts of Scope 3 emissions have been shown to be a large contributor to service companies' environmental profiles, often accounting for more than 75% of an industry's carbon footprint (Huang, Weber et al. 2009; Downie and Stubbs 2011). Although data availability and modeling have improved, the effectiveness of process LCA can still be limited when used to assess service industries, due to the complexity of the evaluated services and the difficulty of attributing impacts to the monetary flows that propel service industry revenue.

Economic Input-Output Life Cycle Assessment (EIO-LCA), an alternative or supplement to process LCA, was developed in part to address some of the issues of process LCA (Hendrickson 1998). EIO-LCA combines environmental data with an economic input-output (I-O) model to determine primary energy, economic, and environmental releases associated with producing a product. EIO-LCA has also been used to assess the impacts of services, as it is better suited to deal with the impacts of financial flows to capture the Scope 3 emissions (Rosenblum, Horvath et al. 2000; Suh, Lenzen et al. 2003). However, it too, has limitations associated with high levels of aggregation, as well as potential uncertainty and thus, is often used as an effective high level screening tool (Lenzen 2000; Bilec 2007).

Hybrid LCA offers the ability to combine the strengths of both process and I-O based LCA approaches in order to avoid some of the issues associated with both methods (Bilec, Ries et al. 2006; Horvath 2006; Suh 2006). Hybrid LCA allows for flexibility within the inventory of the assessment, which aids in setting appropriate boundaries and data collection. Hybrid LCA is often used to assess production of products such as laptops, incorporating economic data where process manufacturing or material data is unavailable or proprietary (Deng, Babbitt et al. 2011).

The flexibility of hybrid LCA has proven to be valuable when working with assessing impacts of companies, since not all of the inputs have directly accountable mass and energy values. Hybrid LCA has been used to assess marine shipping services companies and found that the majority of impacts result from direct operations, but that the supply chain has significant impacts (Ewing, Thabrew et al. 2011). Hybrid LCA has also been utilized to evaluate the impacts of ambulance services in Australia, again finding that direct impacts from fuel use and manufacturing were major components of the life cycle impact, but indirect impacts also contributed significantly(Brown, Buettner et al. 2012). Most similar to this study, Junilla et al. used hybrid LCA to assess the impacts of select service sector based companies (e.g. banking and consulting) within Europe and the US (Junnila 2006; Junnila 2007). The method presented and utilized in this research takes a similar approach to that used by Junilla et al, in evaluating and reducing the environmental impacts of service industries, and the findings of this study are compared to Junnila's findings.

3.3 APPROACH AND DATA COLLECTION

The goal of this paper is to develop a framework to assess the environmental impacts of service sectors. A hybrid LCA of an engineering consulting firm was conducted to establish the framework and identify major environmental impacts of a service industry. The hybrid LCA approach was selected for its ability to attribute life cycle impacts to monetary flows, which a major portion of the life cycle inventory inputs consisted of. The economic data collected from financial records complimented the process data, and provided a more refined picture than would be possible with process or EIO-LCA alone. Using the results from the LCA, improvements were identified and implemented.

The case study evaluated Gewalt Hamilton Associates Incorporated (GHA), a civil and environmental engineering and consulting firm. GHA is headquartered in the suburbs of Chicago and supports a full time staff of 75 employees as well as 10-20 seasonal interns. GHA had no specific existing environmental sustainability programs, however it had expressed a desire to improve the sustainable performance of their operations. Data for the hybrid LCA of GHA's activities and operations was collected for one fiscal year, from January 2009 to December 2009. Additionally, follow up data to monitor the effectiveness of the facility and program improvements was collected as the changes were implemented, and again one month after implementation to assess the impact of the improvements.

3.3.1 Data Collection and Hybrid LCA Framework

For organizational purposes, five categories of the engineering company's activities were defined: *purchased services, building premises, travel and transportation, office and field equipment*, and *office supplies* as illustrated in **Figure 2**. The scope of the hybrid LCA included all of the material, waste, and energy flows as well as monetary flows for fiscal year 2009 – salary was excluded as it was determined to be outside of the scope of the study; and GHA had little control over how employee salary was spent. Different data collection approaches for each category were employed to obtain the necessary LCI data to construct a hybrid LCA. Table 1 summarizes the process data sources and assumptions. Where process data or inventory were unavailable, EIO-LCA was used. All of the data assessed using EIO-LCA was collected from financial records and general ledger data, and was then matched to the corresponding sectors designated by the North American Industry Classification System (NAICS), summarized in Table A.1 in Appendix A. The NAICS classification system is the method for classifying businesses in order to collect and assess data related to the US economy and its performance.

The data collected for the hybrid LCA is discussed in more detail in subsequent sections. Primarily, data was obtained from financial records, utility bills, billable miles and related services, solid waste, personnel survey, and an energy audit. The personnel survey obtained information on employee commuting habits and workspace energy use habits. The energy audit collected plug load data for office equipment, quantified employee electricity use, and modeled the building premises and its components to generate the energy profile and consumption of the building facilities. The model was validated by comparing the model results to the actual energy consumption acquired from the utility bills for the office during the corresponding time period.

Inputs to the EIO-LCA model included monetary values, the data for which were collected from purchase orders, receipts, and accounting records and were adjusted for inflation by converting to 2002 dollars. The monetary values were converted to 2002 dollars because the most up to date EIO-LCA model relies on the 2002 purchaser and producer benchmark models and to ensure accuracy, values should be converted to the value of the currency during that time period (Carnegie Mellon University Green Design Institute 2011). The monetary values were then evaluated using the 2002 purchaser price model, as GHA was the purchaser of the goods or services represented by the data. An inherent limitation of EIO-LCA is the increased uncertainty with converting from 2009 values to 2002 values as environmental impact and process demands can change significantly. While the increased uncertainty is not as significant in industries where processes are stable, it can be more pronounced with respect to rapidly evolving industries such as electronics and computer manufacturing (Carnegie Mellon University Green Design Institute 2011). Whether from process or EIO sources, all inventory data was evaluated using the Tool for the Reduction and Assessment of Chemicals and other environmental Impacts v3 life cycle impact assessment tool (Bare, Norris et al. 2003).

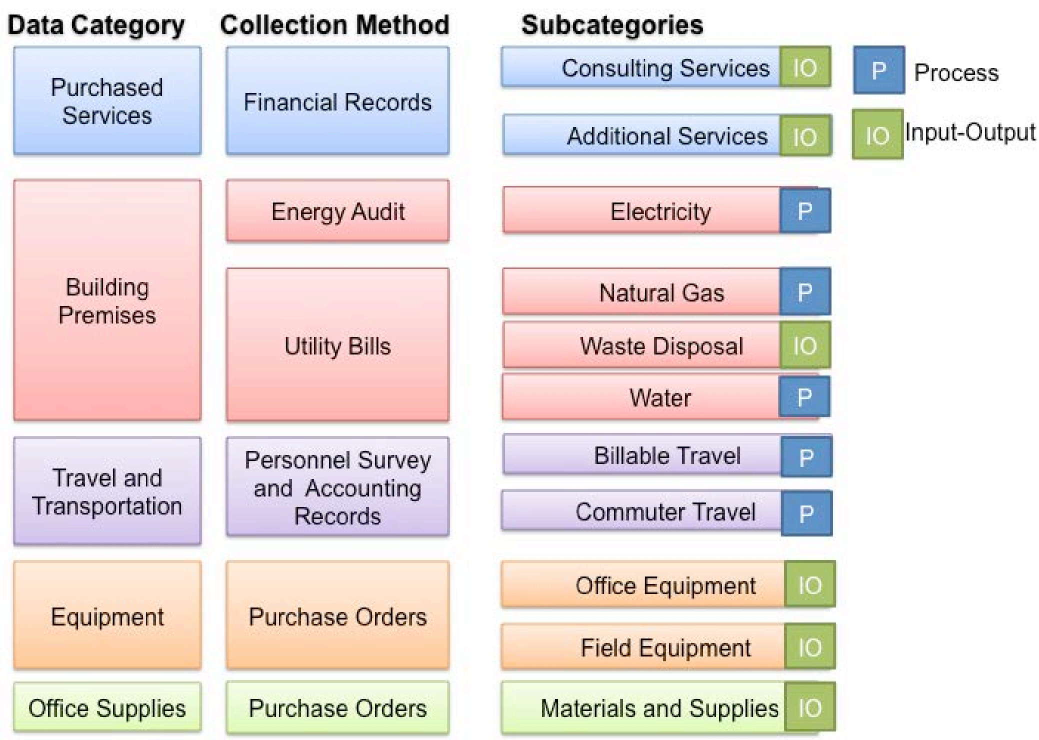

Figure 2. Framework for life cycle environmental assessment of the impacts of one year of operation for a service based industry, an engineering firm

Table 1. Process life cycle inventory data sources and assumptions

Data Category	Sub category	Primary Data Source	Upstream LCI Source	Notes/Assumptions
Building Premises	Electricity	Ulitliy Records, EPA	Franklin 2003, USLCI	Used electricity generation mix for Chicago area found from EPA eGRID.
	Natural Gas	Utility Records	Franklin 1998	All natural gas was assumed to be used for building heating.
	Water	Utility Records	Wastewater - ecoinvent 2.0 Water - ecoinvent 2.0	Irrigation water not considered returned for wastewater treatment. All other water considered returned to system for wastewater treatment
Travel and Transportation	Commuter	Personnel Survey	ecoinvent 2.0	5% ethanol blend. Fuel consumption calculated through dividing total distance commuted annually by fuel efficiency to obtain volume of fuel consumed.
	Billable	Mileage Logs	ecoinvent 2.0	5% ethanol blend. Fuel consumption calculated through dividing total distance billed to clients annually by vehicle fuel efficiency to obtain volume of fuel consumed.

The LCI data for the *purchased services* category was collected from accounting entries. Purchased services consisted of services purchased from other service companies such as consulting services. Consulting services included accounting, legal, and insurance services, where the service provided typically involved non-material flows. Additional services were services that typically had more obvious physical inputs, such as shipping and courier services, equipment rentals, and repairs and maintenance. Data inputs to EIO-LCA are summarized in Table A.1 in Appendix A.

The *building premises* category consisted of all energy, waste, and water use on site, and all operations directly related to the office space and its daily operations. Energy used to regulate the temperature of the building, electricity to power the equipment, potable water, wastewater, water treatment, and waste disposal services were included in the hybrid LCA. The LCI data for energy consumption was collected from utility bills from the providers of electricity and natural gas while energy consumption for specific activities was collected via the energy audit (described in more detail in section 2.3). Employees' energy usage was assessed through the personnel survey and plug load monitoring, which are discussed in section 3.2 and 3.3 respectively. The electricity generation mix for Chicago was obtained from United States

Environmental Protection Agency's (US EPA) Emissions & Generation Resource Integrated Database (eGRID) (US EPA 2011). The upstream LCI data for the electricity consumption was acquired from the USLCI eastern US mix for electricity which was adjusted to match the electricity mix for Chicago (Franklin Associates Ltd 2003). For life cycle modeling, all of the natural gas was used for space conditioning and assumed to be combusted in an 80% efficient furnace from the early 1990's, consistent with that used on GHA's building premise and the upstream impacts were obtained from Franklin databases (Franklin Associates 1998; US EIA 2010). The impacts associated with the construction of the building itself were not directly included in this analysis, but have been shown in the past to typically account for between 8-20% of the buildings' lifetime impacts depending upon impact category (Bilec, Ries et al. 2010).

The amount of water used and wastewater generated in the building premises category (subcategory 'water' in **Figure 2**) were collected from utility invoices. The water use consisted of both landscape irrigation and potable water. As wastewater effluents are typically not monitored for commercial settings, the quantity of potable water used on site was also assumed to be the quantity of wastewater generated. All water consumed from the potable water was deemed to have returned to the system and to be treated as wastewater. Irrigation water, however, was not included in the quantity of wastewater generated. The upstream impacts for the water treatment and transportation to the user were obtained from ecoinvent v2.0 (lthaus H.-J. 2007). The upstream impacts for wastewater treatment were obtained from a moderately large wastewater treatment facility (71,000 per capita equivalents) similar to the one used to treat GHA's wastewater and applicable to US treatment standards (Classen M. 2007).

The upstream impacts of the solid, municipal waste flows (subcategory 'waste disposal' in Fig. 1) from the building premises were obtained from EIO-LCA data, summarized in Table

A.1 in Appendix A. Additionally, over a month long time frame, the waste and recycling bins on the premises were visually inspected each evening to determine the approximate amount of each type of waste. GHA had a 2 cubic yard (1.53 cubic meter) dumpster that was collected 3 times a week, and two 128 gallon (485 liter) recycling containers that were collected twice per week. The waste and recycling flows were qualitatively evaluated by estimating how full the containers were, as well as what general type of material (e.g. paper, cardboard, plastic, food waste) went into each container.

Travel and transportation was organized in two distinct subcategories: 'billable' business travel and employee 'commuter' travel. Business travel consisted of any travel that was billed to a client, as well as employee travel to conferences or meetings. This data was collected from company mileage logs and accounting records. Employee commuting consisted of employee travel between the building premises and their residences and was not billable. This data was collected from mileage logs (for employees who used company vehicles for commuting) and a personnel survey (described in further detail in section 3.2). From the personnel survey, distances from employee residences to the building premise and mode, miles per gallon (if primary mode was personal automobile), and frequency were collected to determine the environmental impact of employee commuting. The process data for upstream impacts of fuel combustion was obtained from ecoinvent v.2.0 (Frischknecht, Jungbluth et al. 2005; Frischknecht et al. 2007; Jungbluth N. 2007). A representative fuel blend of 5% ethanol was selected because Illinois gasoline blends typically contain ethanol but cannot exceed 10% unless labeled (EIA 2012). LCA results include the impacts from the fuel consumption only from the cradle through combustion, and not associated infrastructure.

The *equipment* category included all field and office equipment needed for daily operations such as vehicles purchased for site work, surveying and construction management equipment, desktops, laptops, printers, copy machines, telephones, faxes, and all other office equipment that use electricity within the building premise. LCI data for both of these categories were collected from accounting records and invoices and was assessed using EIO-LCA; data inputs to EIO-LCA are summarized in Table A.1 in Appendix A.

Office supplies comprised the final category and were defined as items such as envelopes, paper products, and writing utensils. This data was also collected through purchase orders and records. The associated data and NAICs codes used within EIO-LCA for this category are summarized in Table A.1 in Appendix A.

3.3.2 Personnel Survey

To model the commuter habits and modes of transportation, as well as workplace habits and preferences of the employees, a personnel survey (included in Appendix B) was developed and distributed. The survey was reviewed by Institutional Review Board (IRB) and was deemed exempt. The survey was distributed to all employees through email. Employees were able to respond to the survey either through email, or, to retain anonymity, through a drop box located in the office. The response rate of the survey was 84%, with 63 respondents of a possible 75. The survey assessed commuter habits (which contributed to the LCI data for the travel and transportation category), building and personal energy use, and waste disposal habits.

3.3.3 Energy Audit

GHA's energy use within the building premises was evaluated through an energy audit. The energy audit collected energy consumption data on individual employee and business wide activities. The total actual energy consumption for the building was collected from utility invoices, while the building systems were simulated using the Quick Energy Simulation Tool (eQUEST) to determine the distribution of energy consumption by end use. Comparing the results from the simulation to the actual energy use reflected by GHA's utility invoices for the same time period validated the eQUEST model.

Employee energy usage was tracked by fitting all devices consuming electricity in five employee workstations every week for 5 weeks with P4400 Kill a Watt® electricity monitors to measure electricity consumed during the weeklong period. The electricity monitors are capable of quantifying and displaying the cumulative electricity use of electric equipment, as well as providing instantaneous electricity consumption data. The employees were aware of the purpose of the meters and were instructed to maintain their usual work habits and to not alter their normal routines. The power meters were checked multiple times a day, including once when the employee first entered their workstation at the beginning of the day, and again immediately before the employees' departure at the end of the day. In this manner, 32% of employees' electricity consumption was collected, and the data was assumed to be representative of all employees. All other electricity using devices on the building premises were also monitored for two week intervals with Watt-meters including: printers, copy machines, fax machines, servers, kitchen equipment, and electric heaters.

The results of the electricity monitoring from the energy audit were used in conjunction with architectural drawings to develop the eQUEST energy model. Lighting, HVAC, and other energy using systems were also included in the eQUEST model; actual lighting and window types were confirmed by a visual inspection of the building and updated within eQUEST where any deviations from the architectural drawings occurred.

3.4 RESULTS AND DISCUSSION

3.4.1 Life cycle assessment results

The hybrid LCA included all energy, material, and economic flows for the fiscal year, January through December, of 2009. Life cycle impact assessment results acidification, ecotoxicity, eutrophication, human health noncancer, photochemical smog, and human health cancer are illustrated in Figure 3. Greenhouse gas emission results are illustrated separately in Figure 4 (and further in Appendix C) to graphically show greater granularity in contributing sectors. With respect to Figure 3, the included LCIA results show that the impacts associated with travel and transportation as well as the building premises are responsible for the majority of Scope 3 life-cycle environmental impacts. The travel and transportation category is the most significant contributor to every impact category except acidification and photochemical smog. The impacts from transportation result from the consumption of petroleum-based fuels, specifically gasoline. The building premises category is the largest contributor to acidification and photochemical smog primarily due to the electricity production mix for Chicago, 72% of their electricity is obtained from coal fired power plants (US EPA 2011).

The purchased services, equipment, and office supplies categories typically accounted for less than 10% of the total impact in each category, with one exception; purchased services contributed approximately 31% to the overall human health noncancer impacts. There was not one sector or process that contributed significantly to noncancer impacts from purchased services; over 25 sectors contributed fairly equally to this result, none of which constituted over 6% of the total noncancer impacts.

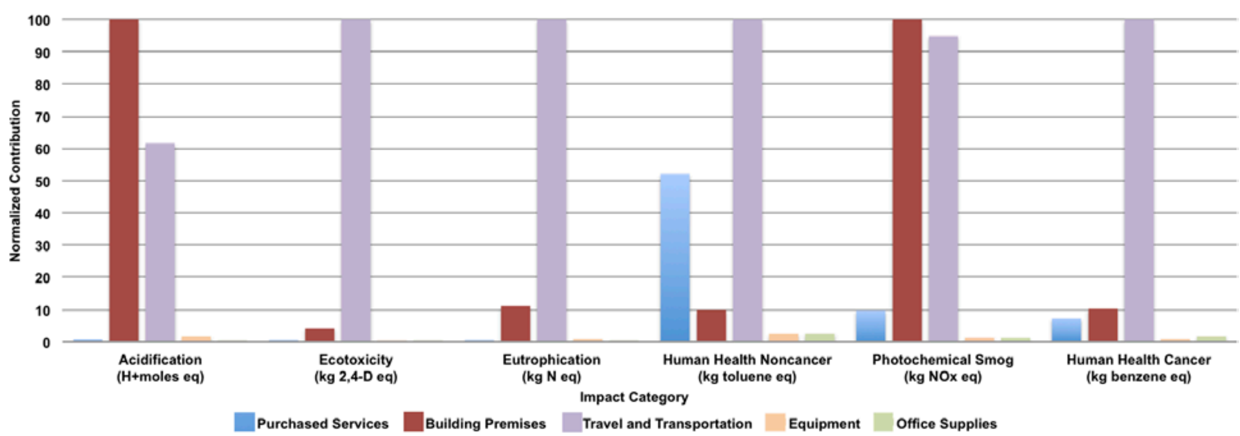

Figure 3. Normalized hybrid life cycle assessment results for one year of operations of a service industry, an engineering consulting firm

Figure 4 displays the life-cycle greenhouse gas emissions for GHA during fiscal year 2009. The travel and transportation category is the most significant contributor to the GHG emissions, accounting for nearly 40% of the company's entire GHG releases while Building Premises and Purchased Services each accounted for about 24% of the GHGs, respectively. The equipment and office supplies categories combined to account for about 10% of the total GHG profile. As shown in the breakdown of contributions from different sectors to GHG emissions in

Figure 4, power generation and supply was a significant contributor to the GHG emissions for purchased services and building premises categories, while gasoline fuel combustion constituted over 97% of GHG emissions resulting from the travel and transportation category. The main factors influencing these impacts and suggested improvements are discussed in detail in subsequent sections.

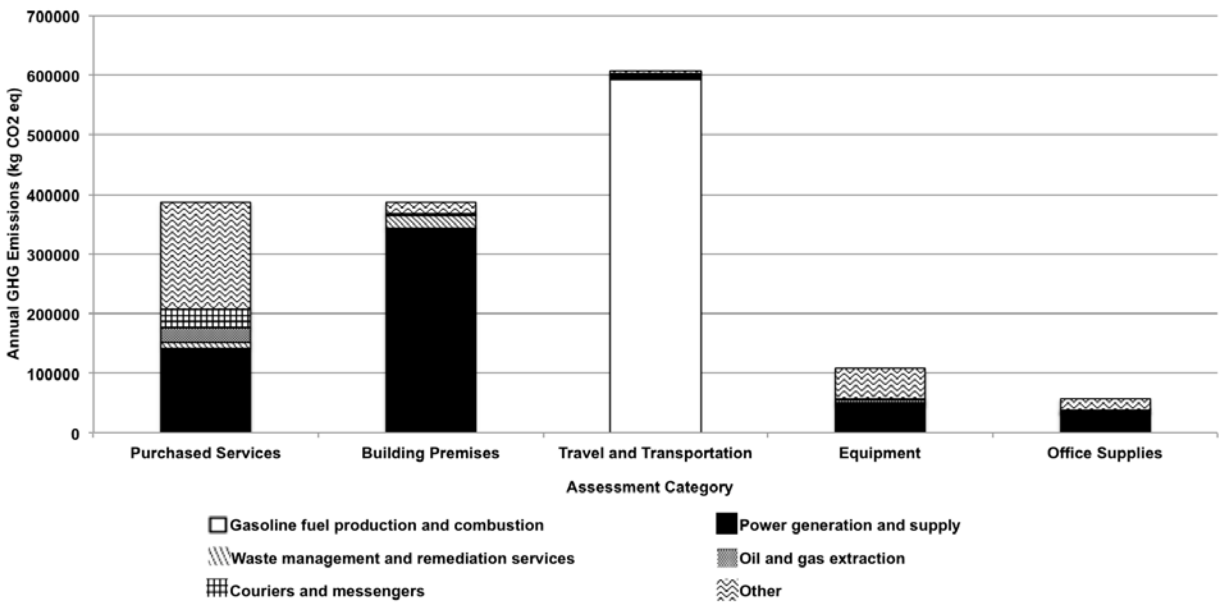

Figure 4. Greenhouse gas emissions for fiscal year 2009, only the top 5 total contributors are displayed while all other life cycle inventory contributions are contained in the group "Other." Table C.1. in Appendix A displays the total greenhouse gas emissions by Inventory item for the top contributors.

3.4.1.1 Building Premises and Energy Findings

Combining an energy audit with the hybrid LCA results revealed the amount of energy consumed on the building premises, the consumption profile, and impacts of the operation of the building. The building premises category accounted for about 24% of the overall GHG emissions

(Figure 4), in addition to contributing significantly to smog formation and acidification (Figure 3). These impacts are almost entirely due to power generation and supply; Chicago's electricity is derived primarily from coal. The results of the electricity consumption from the eQUEST model were within 2.5% of the actual consumption reported by the monthly utility bills. The building used 13.5 kilowatt-hours (kWh) per square foot (146 kWh per square meter) compared to a national median of 11 kWh per square foot (119 kWh per square meter), falling in the 65th percentile for buildings office buildings of similar type (US EIA 2010). Figure 5 shows the breakdown of all of the electricity used on the building premises by major type, and also shows that the greatest contributors are electrical equipment in the office and the office lighting. The percent of electricity used for office equipment was about 5% higher than the US national average for office buildings, and the percent of lighting was about 8% lower than the average (US EIA 2010). The building used 42.9 cubic feet of natural gas per square foot (517,000 Btu per square meter) for heating, also placing it at about the 65th percentile of similar buildings.

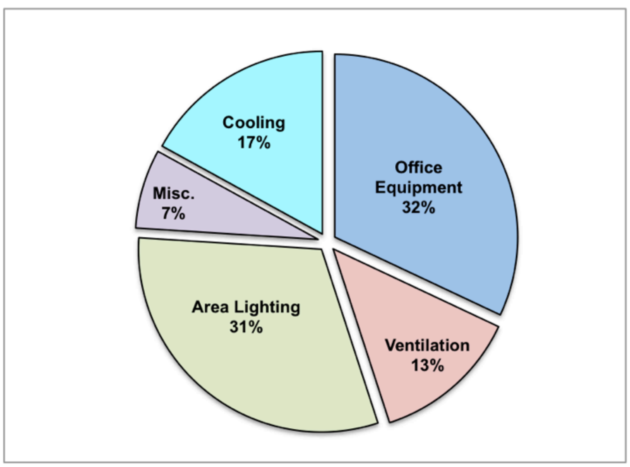

Figure 5. The on -site electricity use profile of an engineering consulting firm for fiscal year 2009.

The energy audit showed that the employee workstations accounted for 22-28% of monthly electricity use (consumption fluctuates seasonally; e.g. in the summer cooling increases). The employees were using nearly as much electricity when they were not in the office as when they were in the office. This electricity usage was typically due to the employees leaving equipment at their workstations powered on (e.g. lights, computers, and monitors) when out of the office and after business hours. The majority of the workstations did not have power saving options enabled, such as sleep and hibernate modes on computers. The plug load monitoring revealed a minimum of 2.0 kWh per workstation over a week and a max of 52.5 kWh per workstation-week, with the average employee workstation using 19 kWh per week. Employees with the same job responsibilities and working hours had a wide range of different energy use profiles. For example, two employees who were typically in the office early in the morning and in the field for the rest of the day had electricity consumption differences of a factor of 10. The employee who left his workstation running 100% of the time whether he was in the office or not used about 21 kWh per week, while the employee who had a similar workstation but powered down all equipment when leaving the building premises used only 2.6 kWh per week. In another case, one employee workstation alone accounted for 240 kWh per month, close to 2% of the company's electricity use for the month. The employee had 3 monitors, 3 computer towers, and multiple pieces of equipment charging with no hibernation or power saving features enabled.

3.4.1.2 Travel and Transportation Findings

Commuter and business travel contributed 40% to the business's GHG emissions (Figure 4) and contributed significantly to other impact categories (Figure 3). Although commuter travel accounted for about 22,500 (2.5%) more kilometers traveled than the billable travel, the billable travel accounted for 6% more of the life cycle impacts. In general, the vehicles used for employees for their daily commute were more efficient than the vehicles used for billable travel. The majority of the fleet vehicles used for billable travel were light duty trucks or Sport Utility Vehicles (SUVs) as most of the engineering consulting travel included driving on construction sites where passenger cars may not be suitable. Also of note was that male employees' commuter vehicles were less fuel-efficient (i.e. trucks and SUVs averaging 20 miles per gallon (mpg) (11.76 liters per 100km)) than female employee commuter vehicles, which averaged 23 mpg (10.2 liters per 100km). The fuel efficiencies were the actual efficiencies reported by the employees, unless the employee stated they "did not know" in which case EPA fuel efficiencies were obtained for their reported commuter vehicle.

The impacts of the location (e.g. city, suburb, rural) of the business can be critical to the commuter impacts. The survey revealed 65% of employees lived greater than 16 km from the office, and 40% of employees lived at least 32 km away from the office. GHA is headquartered in a suburb, and the average round trip commuting distance reported by employees in the personnel survey was 64 km, with no carpooling and less than 1% (by total commutes) use of public transportation. The only exception was an employee that reported commuting by bicycle about once a week. None of the employees reported using any degree of car-pooling.

3.4.1.3 Building Premises Waste Management Findings

Figure 4 shows that waste management and remediation services is 7% of the GHG emissions for GHA's building premises, and 3% of GHG emissions for purchased services. Although waste management was not the largest contributor to any of the impact categories, it still proved to be an area that could be easily improved with significant cost savings. The majority of the waste generated on site by GHA, about 85% by volume, was paper products or cardboard. As a design firm, GHA often produces design plans and construction drawings for clients. These plans can go through multiple iterations and revisions prior to the final result, and thus many copies of plans and drawings are printed for review prior to delivering the service to the client. The revision process at GHA was almost entirely done by hand on printouts. Once revisions were made, the marked up draft was placed in recycling or waste bins.

The visual inspection of the waste also revealed that essentially no recycling was actually occurring within GHA's office premises even though 30% of GHA's waste management bill was for recycling collection. On collection days, the 2 cubic yard (1.53 cubic meters) container used for waste disposal was full or overflowing, while the two 128 gallon (484.5 liters) containers used for recycling were generally empty. Despite the employees placing items in recycling containers within the building, the recycling was not making its way to the recycling containers outside of the building where a waste management company would collect them twice per week. The cleaning staff combined the office waste and recycling into the same container after business hours, and then placed everything into the 2 cubic yard (1.53 cubic meters) municipal solid waste dumpster outside the building where it was collected three times a week.

3.4.2 Validation of the hybrid LCA framework

Figure 6 shows the comparison between the results for the hybrid LCA and the results calculated from solely using EIO-LCA, where the firms' annual revenues (from fiscal year 2009) were adjusted to the 2002 Producer Price Index value and input into the architectural and engineering services sectors (sectors #54131-54138) of the EIO-LCA US national producer price model. The hybrid LCA presented within this paper resulted in higher impacts in every impact category except human health non-cancer and global warming potential. Acidification, ecotoxicity, and eutrophication had results that were between 89%-98% larger than what would be reported using solely EIO-LCA.

One of the differences between the hybrid LCA and EIO-LCA results is the number of compounds available in the process life cycle inventories. The hybrid LCA had significantly more substances contributing to the impact categories where the hybrid results were greater. The LCI generated using EIO-LCA has 465 emissions that can contribute to each of the impact categories, whereas the process LCA data has inventories that included hundreds to thousands of substances. For example, when comparing the LCI process data and EIO-LCA data for wastewater treatment, the process data included 654 inventory items compared to the 464 of EIO-LCA inventory. EIO-LCA acknowledges this as a limitation, and it is a result of industry data not being specifically available or no longer nationally collected to reduce the reporting burden on companies. Because of the reduced reporting, some data such as non-hazardous solid wastes, or non-toxic pollutants to water are not included in the EIO-LCA model and can cause lower reported impacts.

Additionally, the sector aggregation of EIO-LCA may have influenced the lower impacts in several of the categories. The "Architectural and engineering services" sector is comprised of multiple services, some of which fit the description of the services provided by GHA (e.g. Architectural Services (NAICS 54131), engineering services (NAICS 54133), and Drafting Services (NAICS 54134)) and others which have little nor no applicability to the services provided by GHA (e.g. Testing Laboratories (NAICS 54138), Building Inspection Services

(NAICS 54135), and Geophysical Surveying and Mapping Services (NAICS 54136). The aggregation of the services, although unavoidable when using EIO-LCA.net, can lead to over or under reporting emissions. While EIO-LCA can be an effective high-level screening tool, it can be difficult to get meaningful results for making specific improvements to a service industry using only EIO-LCA.

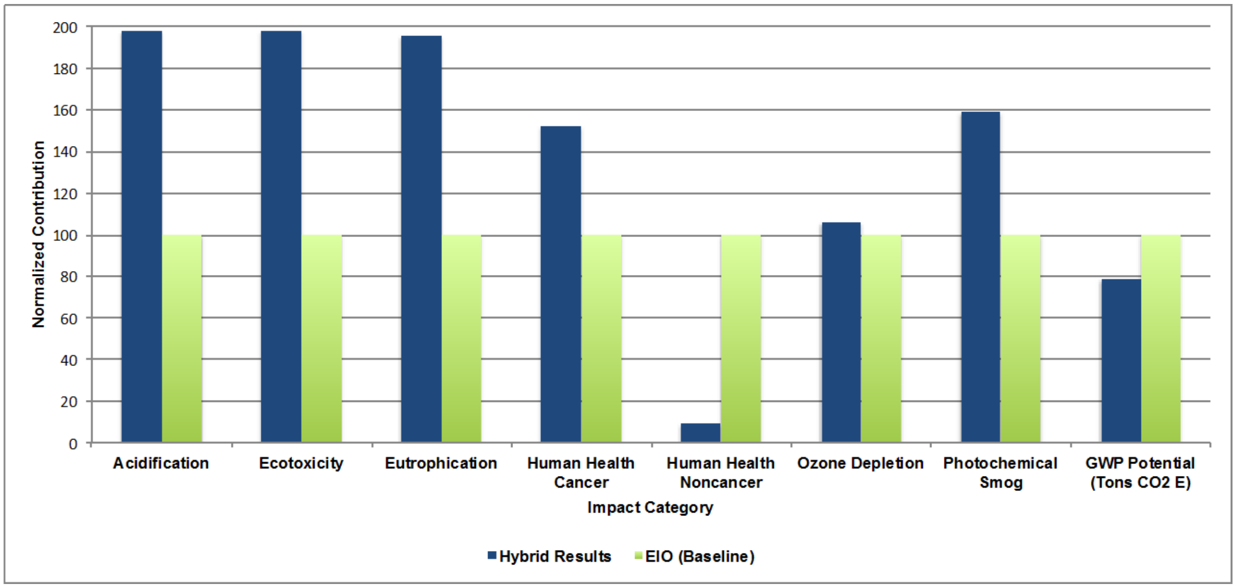

Figure 6. Comparison of hybrid and EIO-LCA results of the annual environmental impacts of an engineering service firm

The findings of this study are comparable to the LCA of European service industries by Junnila et al., however there are some significant differences. While Junnila's study employs different I-O tools than this study (2002 for this study vs. 1998 data in Junnila), and different LCIA methods than this study (TRACI for this study, European Commission guidelines for Junnila), the primary cause of the differences in results is the system of study, where activities during *travel and transportation* cause the major differences, not the framework. Additionally, Junnila's approach was more reliant on process LCA for the *office supplies* and *equipment* categories, however the results of the overall contribution of the two data categories negligible (less than 10%) in every impact category in both this study and Junnila's work (Junnila 2007).

The primary cause for the difference in the findings between the two studies is a result of the *travel and transportation* category. Contrary to Junilla's findings, the *travel and transportation* category was the most significant contributor in every impact category except acidification and photochemical smog. *Travel and transportation* accounted for between 38% and 91% of the impact in all categories, a range that was similar to the impacts of the building premises category in Junilla's study. Even when the impacts of the *building premise* are increased by 20% to include the impacts of the construction of the building, travel and transport still accounts for between 36%-90% of the impacts depending upon the category, and remains the most significant contributor in every category except acidification and photochemical smog.

The difference in the impacts of *travel and transportation* between this study and Junilla is likely caused by two primary contributing factors. First, GHA's location in a suburban setting with limited public transportation and an American infrastructure designed for automobiles results in a much larger use of personal vehicles than would be found in the European firms that Junnila assessed. The nature and intended market of the business also plays a strong role in determining the impacts of travel and transportation. As a company whose primary market is regional rather than international, the majority of GHA's transportation impacts for commuting and billable travel were almost entirely a result of personal or company automobile use. In contrast, the companies assessed by Junnila had a more international market, and the impact of air travel was higher in Junnila's case studies. GHA's primary market is within Illinois or the bordering states, and often the services provided by GHA require them to have employees on the customer's site, causing an increased amount of billable transportation by automobile.

Another interesting finding was the magnitude of the impacts of *purchased services* on GHA's GWP. Junnila found the median impact of purchased services to account for 8% of GWP, compared to an IO study that found a GWP contribution of 15% (Suh 2006). This study found that the *purchased services* of GHA accounted for 24% of the GWP. This contribution is a marked increase from previous research, and demonstrates the magnitude that *purchased services*, which are typically overlooked, can have on a company's life cycle impacts (Suh, Lenzen et al. 2003).

3.4.3 Improvements and implementation

The hybrid LCA revealed that the most effective areas to address for reducing environmental impacts were the *travel and transportation* and the *building premises* categories. The following sections detail improvements to the service companies' operations and building premises that will achieve reductions in environmental impacts resulting from these categories. In addition, GHA implemented several recommendations, and the magnitude of the decreased impacts is presented from a follow-up assessment.

3.4.3.1 Reducing Travel and Transportation

As *the* largest contributing category to the majority of the environmental impacts, reducing the *travel and transportation* should be a focus of any plan to improve GHA's sustainability. The end goal for reducing the impacts of commuter and billable transportation is to minimize the amount of fuel consumed, however the strategies to reach this goal are different between the two subcategories. In order to reduce commuter transportation programs such as flexible scheduling or telecommuting should be promoted. Studies have shown that implementing flexible scheduling, where employees can modify their schedules to either avoid the hours of most roadway congestion, or telecommuting, where employees can reduce their commuting to a four day work week instead of a 5 day work week have significant environmental impact reduction potential (Atkyns, Blazek et al. 2002). Although it has been shown that these practices merely shift the burden of some of the impacts and create other unintended impacts, the overall impacts from reducing commuting is greater than the increase in shifted impacts (Mokhtarian and Varma 1998). By instituting a telecommuting program, where employees can work one day from home, even at a 50% participation rate, GHA could reduce its environmental impacts by 4-10% depending on the impact category.

Shifting to more efficient fleet vehicles is the most effective way to reduce the impact of billable travel without altering business practices. The mean fuel efficiency of the fleet responsible for billable travel is 17 mpg. The fleet vehicles are generally phased out as they become obsolete, or as it becomes uneconomical to repair them. By switching to more fuel-efficient vehicles as older vehicles become phased out, GHA could reduce its fuel consumption by 15% annually, a savings of $19,500 per year assuming gasoline fuel prices of $3.50 per gallon ($1.08 per liter). Upgrading the obsolete standard trucks to Chevy Silverado Hybrid 4 wheel drive vehicles, and the light duty trucks to Toyota Tacoma 2 wheel drive vehicles, (the two trucks with the current highest fuel economies) GHA could increase it’s fuel efficiencies by 35% to 22 MPG (10.7 liters per 100km) (US EPA 2012). This would result in an overall reduction of 8-14% for depending on impact category.

3.4.3.2 Improving Building Premise Energy Consumption

Electricity use within the building premises was one of the primary contributors to GHA's environmental impacts, and thus was a major target for improvements. As the major consumers of electricity, lighting and office equipment (i.e. employee workstations) were targeted in order to lower the energy used in the daily operations of the office space. The lamps and ballasts in use at GHA were the same ones that had been installed when the office premises were first constructed in 1990. These ballasts and the T12 light bulbs used in them are very inefficient when compared to the fluorescent ballasts, fixtures, and bulbs available today. By replacing all of the existing lamps and ballasts with more efficient fixtures and T8 lights, the resulting lighting system would decrease electricity consumption from lighting by 47-50% resulting in a savings of around 23,000 kWh (13% of annual electricity operation costs). The annual savings from reduced operating and maintenance costs, combined with incentives provided by the local power supplier to replace outdated technologies would result in a complete pay back of 2.5 years.

As the energy audit revealed, employee workstations accounted for 22-28% of the buildings' energy use, and provides a second major target for improvement in building electric use. By implementing a power saving initiative composed of standardizing computer power settings (e.g. screen brightness of all monitors was set to 30-50% and they were set to sleep after 5 minutes of inactivity, sleep mode was enabled on all computers after 7 minutes of inactivity), assuring lights and power drawing equipment are powered down prior to close of business, and encouraging employees to minimize their workstation electricity consumption, GHA would be able to decrease the electricity lost to powered on equipment that isn't being used, and minimize the difference in electricity use between employees with similar job responsibilities. The power saving initiative was implemented at GHA and resulted in decreases of 15-20% in off-hour energy consumption. This would result in a savings of about 4,000 kWh annually and have a payback of less than a year for the labor required to implement the power settings.

3.4.3.3 Improving Building Premise Waste Management

As a result of mishandling of the office municipal solid waste stream, a new waste reduction and recycling program was developed and implemented. The primary goals of the program were to minimize the amount of unnecessary paper waste produced and to ensure proper disposal of recyclable materials. By improving employee awareness and working with the custodial services, the program was able to successfully replace workspace waste bins with recycling bins, and limited the amount of waste bins to strategic areas located through out the building. This arrangement also made it more convenient and efficient for the custodial crew, eliminating the need to empty two bins per workspace, and making it less likely that they would combine the waste streams. The initiative has resulted in a decrease in the amount and frequency of waste to a third of its historic level, and increasing the overall waste recycling rate from essentially nothing to 75% of the waste stream. Moreover, this decrease in municipal solid waste generated and increase in recyclable materials saved GHA nearly $4,000 annually in waste service fees.

3.4.3.4 Realized Improvements to the Firm's Environmental Impacts

Figure 7 depicts the former, current, and potential reductions in GHA's environmental footprint as a result of the improvements discussed in sections 3.4.3.1, 3.4.3.2, and 3.4.3.3. The first column in each series represents GHA's baseline environmental impact, prior to the evaluation of the services. The second column demonstrates the actual reductions realized by GHA through implementing some of the improvements mentioned above. The third column in each series displays the potential reduction as a result of implementing all of the improvements recommended above.

Of the improvements detailed in sections 3.4.3.1 – 3.4.3.3, GHA chose to focus on the improvements with the least obstacles for implementation and shortest payback periods. GHA enacted all of the improvements outlined in sections 3.4.3.2 and 3.4.3.3 (e.g. lighting retrofit, energy reduction initiative, and waste reduction initiative) all of which had paybacks less than three years. After discovering the magnitude of impacts from travel and transport, GHA has expressed a commitment to further lower these impacts, for both economic (i.e. rising fuel prices) and environmental reasons. Reducing these impacts are long-term solutions (fleet turnover to more efficient vehicles) or more dramatic company culture shifts (flexible scheduling or telecommuting). GHA has implemented a program to include fuel efficiency as a selection criterion for future fleet vehicles, however rather than replace all of the fleet vehicles at the same time, they are purchasing vehicles with improved fuel economy as they phase out older vehicles. Flexible scheduling and telecommuting have not been implemented due to perceived potential difficulties as a result of the changes to company culture.

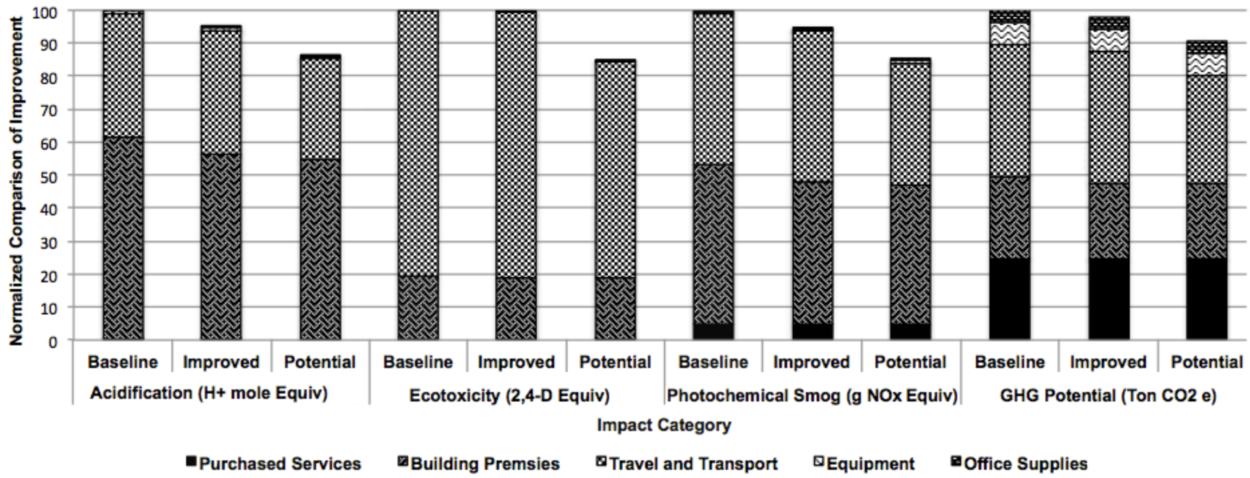

Figure 7. LCA impact reductions due to implemented projects and potential for improvement through reducing travel and transportation impacts. The Baseline column depicts GHA's life cycle impacts prior to implementing improvements. The Improved columns show the realized reduction in life cycle impacts as a result of improvements implemented (i.e. changing lighting from T12 to T8 bulbs and replacing ballasts, energy reduction initiative and waste reduction initiative). The Potential column includes the potential reduction in life cycle impacts realized by improving the fleet efficiency and implementing a 50% telecommuting program one day per week.

3.5 CONCLUSIONS

This study shows the value of developing a clear and complete picture of the impacts of a service industry. By utilizing the methods discussed in this paper, GHA gained a more comprehensive view of the scope of its activities and was able to efficiently and effectively work towards improving their long-term sustainability. Being able to discern and address the low hanging fruit provided GHA the ability to aggressively approach the improvements with short-term payback and develop strategies to address the recommendations with more long term paybacks such as improving the fuel efficiency of their fleet vehicles.

The study also found that the majority of the impacts of this service are associated with travel and transportation and the building premises. This finding is consistent with the findings of similar studies, although the magnitude of the impacts from business travel and employee commuting are noticeably greater than the findings of similar studies. Similar service industries looking to improve their environmental performance would do well to focus on improving the energy efficiency of their building premise and reducing the impacts of their travel and transportation. Minor and major improvements to the efficiencies of older business systems can have significant impacts on reducing the overall life cycle impacts of a service.

The impacts of service industries are far from negligible, and as this study has shown, there is room for improvement. *Purchased services* accounted for 24% of the firm's GHG emissions, improving the environmental performance of other service industries will have a compound effect and reduce the impacts of other industries as well. Based on the findings of this study and the work of Junnila, service industries could conduct a screening LCA by focusing first on the likely heavy hitters: their office and building energy use as well as their travel. Although this screening would be more time consuming than using strictly an EIO-LCA screening, the results would present a more thorough analysis and potentially offer more guidance with the best way to improve the environmental performance of the service industry.

This analysis focused on an engineering consulting firm, however, this approach is not limited to strictly engineering service firms. The inputs involved in the analysis are similar across most service industries, from accounting, to architecture, to consulting. The methods presented and used in this article can be applied to additional industries to improve long-term economic and environmental performance. Although the methods may need to be adjusted to address other services, the results show that it is an effective method for improving service industry sustainability from the bottom up.

4.0 EVALUATION OF THE RELATIONSHIP BETWEEN EMPLOYEES AND MANAGEMENT ON BUILDING ENVIRONMENTAL PERFORMANCE AND SUSTAINABILITY

4.1 ABSTRACT

As companies strive to adapt and improve the environmental performance and efficiency of their buildings through green building, they often overlook one of the most significant aspects of improvement: employee and management behavior. This oversight is interesting because the energy is used in buildings to support the occupants activity, so while efficient design is important in lowering energy use, it is the influence of the occupants, not just the building, which controls the buildings performance. This research evaluates the impacts of employee actions and discusses initiatives implemented by management to reduce energy and waste consumption in a 75 employee engineering consulting firm. The research presents the findings of an employee post occupancy survey, workstation electricity monitoring, and waste assessment conducted at the firm. This paper also presents the methods and approaches used by management to reduce

electricity consumption (13% decrease in non-business hour electricity use) and waste production (75% waste stream diversion).

4.2 INTRODUCTION

With the transition in businesses toward corporate social responsibility, companies are realizing the significant benefits of reduced operational costs from energy savings, improving supply chain management, and process optimization. Companies are allocating resources to find practical, effective, and efficient methods to improve environmental and economic performance. One common investment is in greening buildings and facilities, as evidenced by the increase in green building certifications such as of the United States Green Building Council Leadership in Energy and Environmental Design (LEED) building certification system, which has certified over two billion square feet of green construction (USGBC 2006; USGBC 2012).

The focus on improving the energy efficiency of buildings is warranted. Buildings accounted for 40% of energy use, and 73% of total electricity use (US DOE 2010). Further, according to the US Energy Information Administration (EIA), office buildings consume the most energy of all building types, and account for 17% of all commercial energy usage (US EIA 2010). Studies have shown that green building techniques can significantly lower energy consumption, having reductions of about 25-30% per square foot (Ries, Bilec et al. 2006; Turner 2008). Green building is gaining an increasing share of the new construction market, increasing from 2% of total non-residential construction in 2005 to between 28-35% in 2010, and projected to be 40-48% of new construction by 2015, a $145 billion opportunity (McGraw-Hill Construction 2010).

As businesses continue to push for reduction in energy, waste, and water use through green building, the actual operation of the building is often overlooked. Typically, building certification systems place the most emphasis on the energy modeling and materials selections of the building, rather than accounting for the impact from the operation of the facility and its occupants (Cole, Brown et al. 2010; Beauregard, Berkland et al. 2011). In summary, the greenest building at the end of construction will only continue to be a green building if the operation of the building is seriously considered, as studies have shown fluctuations of more than 50% from expected performance from energy modeling (Turner 2008). There is little available research documenting the impact of employees and management on building performance (Wener and Carmalt 2006). Multiple studies have shown the impacts of green buildings on employee performance, often resulting in perceived increases in productivity (Heerwagen 2000; Ries, Bilec et al. 2006; Steinberg, Patchan et al. 2009).

The decisions and interactions of the management and staff have a significant impact on the overall sustainability of a business, specifically when considering energy use, waste production, and impacts from commuting. With respect to the impacts of individuals on the environmental performance of buildings, research has shown that there exists knowledge gaps for occupants in key reduction areas (e.g. waste, energy, water) and that occupants' lack of knowledge of building systems negatively effect building performance (Steinberg, Patchan et al. 2009; McGraw-Hill Construction 2010). For example, as documented by Steinberg et al., occupants generally understand the impacts of waste reduction activities (e.g. recycling) and actively practice those techniques. However, occupants were less aware of the impacts of, and techniques for, reducing energy use (e.g. reducing monitor brightness, using computer and monitor power management settings, and using a laptop instead of a desktop). In order to improve the environmental performance of buildings and companies, building occupants and management need to be targeted.

The goal of this research was to quantitatively and qualitatively evaluate the implications of the interactions between an office building and its occupants. This research assessed the impacts of the employees on the environmental performance of the office building as well as the office buildings impact on employees' performance by using a personnel occupancy survey, energy audit, and waste production analysis. The article also examined the impact of management strategies and actively involving employees to improve corporate sustainability performance. Finally this study explored the benefits of empowering employees to achieve projects and initiatives.

4.3 METHODS

In order to determine the dynamics of the building/employee interactions, a case study was conducted on a mid-sized engineering consulting firm, Gewalt Hamilton Associates. The impacts of employees' decisions and energy consumption on the environmental impacts of service industries are often overlooked; this consulting firm offered the opportunity to evaluate both. GHA specializes in civil and environmental design, surveying, and inspection. The firm is located in the northwestern Chicago suburbs and consists of 75 full time employee equivalents.

The methods of the case study were a combination of a personnel occupancy survey, workstation electricity monitoring, and an employee and office waste assessment.

4.3.1 Personnel occupancy survey

A survey was developed and administered to gain qualitative and quantitative data regarding employee opinions and habits in a number of areas, including: commuter habits, workspace location, thermal comfort, lighting comfort, building and personal energy use, and waste disposal habits (see Appendix B). The survey was submitted for review by the Institutional Review Board (IRB) and was deemed not to need IRB approval due to it being an employee satisfaction survey. The survey also included open ended questions allowing employees to share their thoughts on what things they would like incorporated into their workplaces, how they would like to see the company improve its environmental performance, and the most effective means of communicating new initiatives.

The survey was distributed to the employees through email, and they were given the option to respond either through email, or through a drop box located in the office premises. The survey had a response rate of 84%, with 63 responses of a possible 75.

4.3.2 Workstation electricity monitoring

The employee workstations were fitted with electricity monitoring devices in order to quantitatively evaluate the electricity consumption and use profiles of the workstations. The workstations of four employees were evaluated for a period of one week, using the P4400 Kill a Watt ® electricity monitors to measure electricity consumption. After the week of electricity data collection (in October, 2010), the monitors were switched to four other workstations also for a one-week period. The electricity monitors were capable of quantifying and displaying the instantaneous electricity draw as well as calculating cumulative electricity consumption. In order to accurately reflect the employee electricity consumption patterns, the employees were made aware of the purpose of the monitor, but instructed to maintain their usual work habits and to not adjust their routine.

The electricity monitors were checked several times daily, including when the employees first entered the building, as well as prior to the employee departure at the end of the day. The electricity monitors were fitted to employees with different roles and job titles in order to obtain a representative sample of the total workplace. The weekly business, off-hour, and weekend use consumption patterns were then extrapolated to calculate a value for the monthly electricity consumption for the occupants. In this manner 21% of the employee workstation electricity consumption was collected. Additionally, after the initial monitoring and introduction of energy saving initiatives, two of the employee workstations were monitored to determine the reduction impacts from the energy reduction initiatives, which are discussed further in results and discussion.

4.3.3 Employee and office waste assessment

To evaluate the potential for reduction in waste production, as well as increase recycling, a waste assessment of the building premises was conducted. The waste was inspected over a month long time period. During this period the waste and recycling bins were visually inspected each evening to determine the types (e.g. paper, cardboard, plastic, food, etc…) and quantity (by volume) of waste produced by the building occupants. The waste was placed in a 2 cubic yard dumpster that had a collection frequency of three times per week, and the recycling receptacles consisted of two 128 gallon dumpsters that were collected twice per week. The waste assessment also evaluated the location and usage of the waste and recycling receptacles within the office premises to aide in determining optimal waste management strategies.

4.4 RESULTS AND DISCUSSION

At the conclusion of the initial assessment the ownership of the firm was presented with a report of the assessment findings. The report detailed recommendations to increase the sustainability of the company's operations, including employee and management strategies. The ownership met with the research team to determine which improvements they wanted to implement and discussed the strategies for the most efficient and effective transitions. The strategies implemented focused on some of the major impact areas including reducing non-business hour electricity consumption, improving building efficiency, and reducing waste generation. The following sections detail the findings of the assessment as well as the implemented improvements.

4.4.1 Workstation electricity monitoring

The results of the workstation electricity monitoring program revealed the impacts of employee behavior and knowledge on GHA's energy consumption. Figure 8 displays the expected monthly electricity use from the employee workstation electricity monitoring, broken down by employee position description. The results are arranged by job type to show the difference in energy consumption profiles between employees with similar responsibilities.

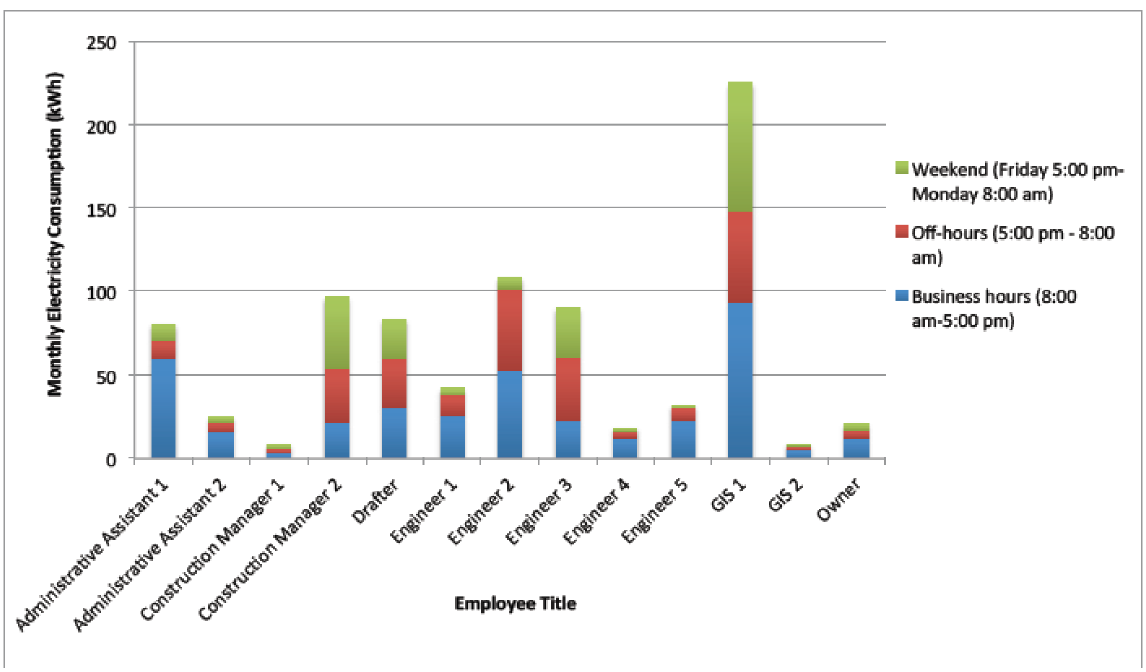

Figure 8. Employee monthly workstation electricity use by job title for an engineering consulting firm

The difference between the electricity consumption of employees with similar responsibilities was considerable. For example, Construction Manager 1 and Construction Manager 2, both construction managers with very similar schedules (typically mornings were spent in the office and afternoons were in the field) had dramatically different energy profiles. The primary difference between the two employees was the power settings of the workstations. Construction Manager 2's computer and monitors were on at all times (workday, off-hours and weekend), while Construction Manager 1 had energy saving features enabled. This same behavior of not powering off, or setting to hibernate mode is illustrated in the survey results shown in Figure 9. Off-hour and weekend electricity consumption accounts for almost 40% of GHA's electricity consumption. Three employees with the lowest electricity consumption all used laptops with external monitors as their primary computer as opposed to desktop towers.

The findings in Figure 8 are interesting when combined with the survey findings related to energy behaviors summarized in Figure 9, which shows the response to questions targeting how quickly employees' computers and monitors enter sleep mode (or turn off) after leaving the office. Almost all of the respondents (81% for computers and 98% for monitors) stated that their equipment powered down within an hour (Figure 9). However, 38% employee workstations had their off-hour and weekend consumption exceed their business hour consumption (Figure 8). Upon further inquiry, many of the employees relayed that they either did not know how to change the power saving settings, or believed that screen savers resulted in the same energy saving effect as powering down the computer.

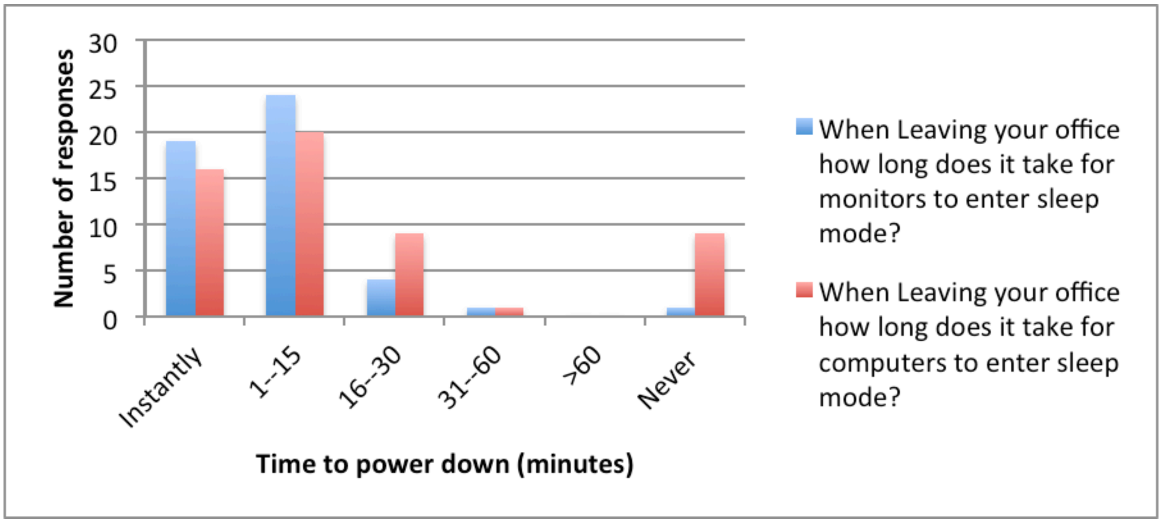

Figure 9. Employee response to personnel survey addressing the current power setting options for their respective computer equipment

4.4.2 Workstation energy reduction

The large variability in the workstation energy consumption of individuals with the same responsibilities lead management to develop office wide workstation standards to help reduce unnecessary electricity consumption during non-business hours. The primary focus of the workstation electricity reduction entailed educating employees on the impact of the wasted electricity and the savings potential of enabling power saving settings on the computers as well as reducing monitor brightness. The management recommended implementing the following workstation computer settings on every employee's computer and offered IT support to make the appropriate changes: computer monitors sleep after 5 minutes of inactivity, computers to sleep after 7 minutes of inactivity, and finally, enabling hibernation (shutting down hard disks) after 30 minutes of inactivity. The management also suggested decreasing monitor brightness to the minimum level necessary without impairing visual comfort or job performance. The suggested workstation electricity settings resulted in an off-hour energy reduction of 81% for the employees monitored before and after the initiative as shown in Figure 10. These strategies also resulted in an average decrease in the buildings overall off-hour electricity consumption of 13%.

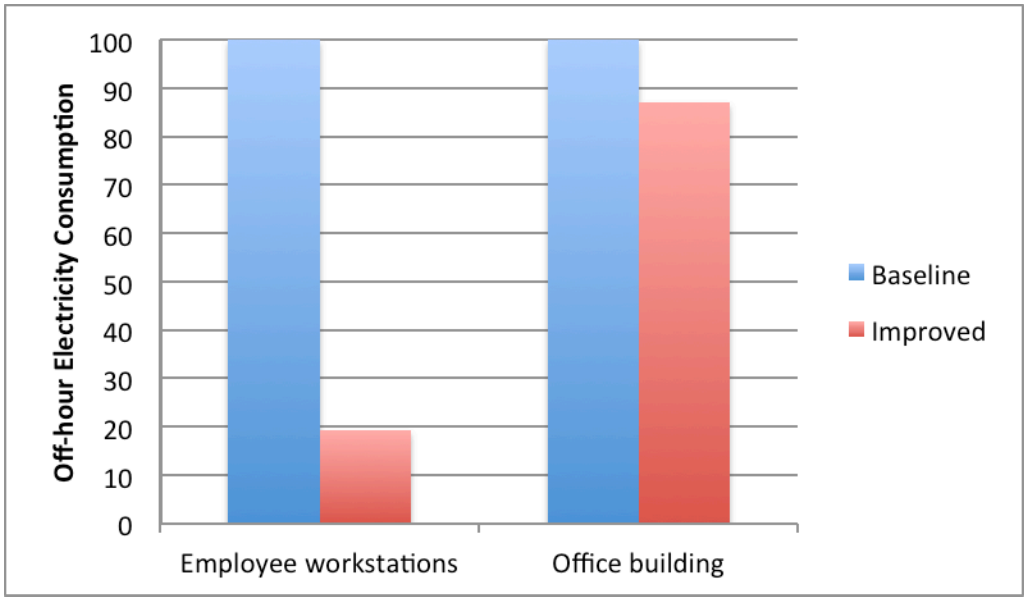

Figure 10. Resulting decrease in off-hour electricity consumption due to employee workstation reduction initiative (e.g. implementing power saving settings such as sleep mode and reducing screen brightness)

4.4.3 Waste assessment findings

The waste assessment revealed the inefficiency of the building waste management, as well as insight into employee waste management practices. Regarding recycling, the receptacles outside the building premise were essentially unutilized. Although recycling bins were located throughout the office, and employees would place recyclables within the office recycling bins, the two recycling dumpsters outside were empty. The cleaning staff had been combining the contents of the waste and recycling bins in the office into the same waste stream, and disposing both streams only into the municipal solid waste (MSW) dumpster. This resulted in an overflow of waste in the dumpster (or the need to store waste in the office storage area) on Mondays, Wednesdays, and Fridays until the waste was hauled away on those evenings. The waste overflow was occurring while the 2 recycling dumpsters remained empty, even though GHA was paying for the recycling dumpsters to be emptied 2 times per week, without actually receiving the benefit of the service.

The survey results provide insight into obstacles for improving recycling efficiency from the employee perspective. Table 2 shows the self-reported respondent response for the frequency of employees choosing to recycle items that were recyclable. The reported rates appeared to be higher than would be expected by viewing contents and quantities contained in the waste and recycling bins within the office premises. The recycling receptacles in the office were used, but generally only about 25% full, while most of the wastebaskets were filled or overflowing with paper products. The waste assessment revealed that approximately 85% of the waste produced on-site was recyclable, primarily in the form of paper, cardboard, or plastics. The rest of the waste stream was composed of primarily non-recyclable food waste and containers. The survey results for the product types or materials that they typically recycled are illustrated in Table 2. The "Other" category included items such batteries, steel cans, and shipping materials.

The survey also asked employees what their motivation was when they chose not to recycle materials that were recyclable. The most common reason given was that of laziness, followed by questions of the recyclability of an item or access to recycling receptacles (Table 1).

Table 2. Employee responses to recycling tendencies. Employees were allowed one response and the values represent number of respondents out of 63 total respondents

How often do you recycle items that are recyclable?						
Always	**Somewhat often**	**Often**	**Not often**	**Never**	**No response**	
26	22	3	0	0	12	
If you choose not to recycle, what is the main reason for not doing so?						
Laziness	**Not sure of recyclablility**	**No receptacle available**	**Forget**	**Other**	**No response or N/A**	
7	4	4	2	1	45	
Which materials do you typically recycle in the office (mark all that apply)?						
Paper	**Cardboard**	**Plastics**	**Glass**	**Aluminum cans**	**Other**	**No response**
49	28	39	22	36	3	11

4.4.4 Waste management program improvements

As a result of the waste assessment and survey findings, management developed a multifaceted approach to reduce waste production and improve recycling. The three aspects of the waste reduction initiative included: improving awareness of the recyclability of items, improving communication with the cleaning staff, minimizing waste production through reducing unnecessary printing, and reducing the frequency of the waste pickups. Based on input from the employees and the cleaning staff, management implemented only recycling bins at employee workstations, while wastebaskets were placed in strategic locations throughout the office. All of the recycling receptacles were marked with a white bag, while the waste receptacles were marked with the traditional gray garbage bag. In order to announce the initiative, a short meeting was held detailing the purpose of the initiative, explaining the changes to waste handling, addressing what materials could and could not be recycled, and highlighting the waste reduction and cost savings potential of the program. Finally, a flyer was emailed to employees in order to reinforce the details of the new program and serve as a reference sheet for which materials and items should be recycled.

Having the cleaning staff involved was an integral part of the success of the initiative, as they were responsible for where the recycled materials were ultimately placed. The management met with the cleaning staff to inform them of the new waste management strategies and to determine what steps could be taken to ease the transition for the cleaning staff. The cleaning staff stated that the replacement of the waste bins with recycling bins, and concentrating the waste receptacles in strategic areas would actually improve their efficiency, limiting the time spent collecting the materials.

From a management standpoint, the initiative has been viewed as a success. The initiative has resulted in a decrease in the amount and frequency of waste collection to one third of its historic levels. The recycling initiative has also increased the overall recycling rate from essentially nothing to about 75% (by volume) of the current waste stream. Moreover, the firm's reduction in its solid waste generation and increase in recyclable materials has saved it nearly $4,000 annually in waste service fees.

From an employee standpoint, the majority expressed positive opinions of the recycling initiative. In a survey question administered after the introduction of the waste initiative regarding the effectiveness of the waste initiative and means for improvement, 57% of respondents expressed that were content or happy with the initiative (Table 3). Many of the write in responses reflected a sense of relief or optimism that the company was beginning to take steps towards improving their environmental impacts. Of those indicating that there was room for improvement; most suggested the need for more wastebaskets, or a need to improve the program through increased participation or improved labeling. In order to accommodate these concerns, more wastebaskets were added in the areas that people expressed the need for them, and the recycling bins were more clearly marked with large painted recycling logos as well as overhead signs explaining the purpose of each receptacle.

Table 3. Employee response to survey question regarding effectiveness of waste management initiative

Employees were allowed one response and the values represent number of respondents out of 63 total respondents

What are your opinions on the new recycling program, and what suggestions do you have for improvement?					
Positive opinions	Need more wastebaskets	Indifferent	Too early to tell	Mark cans more clearly	Need to improve participation
27	8	3	2	3	4

An interesting result of the waste initiative was the way in which employees adapted to the replacement of the wastebasket in their workspace. While 8 employees mentioned the need for a wastebasket in their workspace, more employees commented on the fact they were surprised that they enjoyed getting up to dispose of waste that was not recyclable, giving them a break and chance to stretch. Those that missed their wastebasket compensated by using small waste receptacles at their desk that they would empty in the strategically placed wastebaskets when needed.

4.4.5 Thermal comfort survey results

The impacts of the building components and envelope were a focus of the personnel survey. With respect to thermal comfort, 19.5% of respondents expressed a degree of dissatisfaction with the overall thermal comfort (Table 4). To account for seasonal variability, the employees were asked about thermal comfort during both warm and cool weather. Twenty three percent of respondents were dissatisfied during warmer months (53% of which were male) and 26% of respondents were dissatisfied during cooler weather (53% of which were female). When asked if thermal comfort had an effect on the job performance, 29% responded that the temperature somewhat interfered with their ability to perform their job, while nearly 8% said that it strongly interfered. The remaining 65% said that thermal comfort either had no effect (42%) or enhanced (23%) their productivity.

Table 4. Employee perception of building thermal comfort. Employees were allowed one response and the values represent number of respondents out of 63 total respondents

Thermal Comfort	**Very Satisfied**	**Somewhat Satisfied**	**Satisfied**	**Somewhat Unsatisfied**	**Very Unsatisfied**	**No Response**
Overall thermal comfort	11	12	18	9	1	12
Warm weather comfort	13	9	17	10	2	12
Cool weather comfort	11	7	20	10	3	12
	Strongly Enhances	**Somewhat Enhances**	**No Effect**	**Somewhat Interferes**	**Strongly interferes**	**No Response**
Percieved impact on productivity	1	10	21	15	4	12

As a result of the complexity of the buildings HVAC layout and system controls there was significant inefficiency due to operator error. The building was composed of 5 separately controlled HVAC, each with its own thermostat control, and designated to condition different spaces within the building. However, the thermostats did not always control the temperature of the areas that they were closest to, creating confusion and inefficient HVAC use. For example, if an occupant would express dissatisfaction with the thermal comfort in their work area and ask for the temperature to be adjusted, the management would adjust the thermostats closest to the employee workspace. However, the adjusted thermostat controlled only the temperature in the private offices adjacent to the area, and not the space where the occupant complaint initiated. The adjustment would result in no discernible temperature change for the occupant in the common space while creating uncomfortable conditions for the occupants of the private offices.

There were times that different thermostats were set to heat and cool the building simultaneously, resulting in unnecessary energy use. This finding corroborates previous research of employees poor system comprehension resulting in sub-optimal building system performance (McGraw-Hill Construction 2010). As a result, color coded graphics of the building spaces denoting which areas were conditioned by each thermostat were placed by the thermostats to help inform the occupants of the workings of the building systems.

4.4.6 Perceived visual comfort survey results

Employees were asked about visual comfort of their workspaces. Only 10% of the respondents expressed that the lighting and visual comfort in their workspace was unsatisfactory, however about 21% expressed that the lighting somewhat interfered with their ability to effectively complete their work (see Table 5). None of the respondents in private or shared offices (about 25% of total staff) expressed issues with visual discomfort. The respondents in private offices had more control of their lighting than employees in the central portion of the building (open floor plan with cubicles). Of the respondents in the main office area, 7 expressed the lighting was too bright, 1 expressed it was too dim, and 3 responded with glare. Prior to this study, the active lights in each lighting fixture were modified (e.g. bulbs removed) to attempt to address visual concerns.

Table 5. Employee perception of visual comfort Employees were allowed one response and the values represent number of respondents out of 63 total respondents

Lighting and Visual Comfort	**Very Satisfied**	**Somewhat Satisfied**	**Satisfied**	**Somewhat Unsatisfied**	**Very Unsatisfied**	**No Response**
Lighting in Workspace	14	8	24	5	0	12
Visual Comfort	9	13	24	4	1	12
	Strongly Enhances	**Somewhat Enhances**	**No Effect**	**Somewhat Interferes**	**Strongly interferes**	**No Response**
Effect on Job Performance	2	10	28	10	1	12

4.4.7 Employee visual comfort improvements

In order to improve visual comfort and decrease electricity costs, the company installed a lighting retrofit, upgrading the lights from T12 to T8 and replacing the ballasts since the building's construction in 1990. This retrofit resulted in a 48% reduction in electricity consumption from lighting with a 2.5 year payback due to increased electricity cost savings and incentives from the power supplier to replace outdated lighting technologies. Although there has not been a follow up survey since the completion of the retrofit, the management staff has said that the feedback from employees has been almost entirely positive, with reduced complaints of glare.

Lighting occupancy sensors were installed to improve the perceived and actual building energy efficiency. The sensors were used to curb wasted electricity used to light rooms that were less frequently occupied (e.g. the printer and server rooms, supply storage areas, the kitchen and dining areas, and the restrooms) where lights previously remained on almost at all times. The sensors were also installed after the survey, however they have been viewed by management as less successful than other initiatives due to difficulties with adjusting them to be set for the proper durations; for example, employees have complained about the lights turning off in the dining areas due to them not moving enough to keep the sensors activated. There have also been issues with lights staying on longer than necessary, and longer than they may have without the sensors, in the areas that employees typically walk in and out of quickly, such as the supply storage. The effectiveness of lighting occupancy sensors to accurately reflect occupant behavior is common issue, however with adjustable sensors this problem can be alleviated to some degree (Garg and Bansal 2000).

4.4.8 Employee attitudes toward building efficiency

Employees were asked to gauge the efficiency of the building and its systems. More than half of the respondents believed the building was either somewhat (47%) or very (9%) inefficient (Table 6). In follow up questioning, the occupants primary complaints regarding the inefficiency of the building were related to the building envelope and lighting (efficiency as opposed to thermal comfort). Many of the employees verbally complained of noticeable air leaks in multiple locations from the building’s exterior. These leaks were present for a number of years, however they were overlooked, ignored, and even compensated for by the use of space heaters in individual workstations.

Table 6. Employees perception of building envelope and systems efficiency; the two half responses show a response that indicated an employee felt the building efficiency was between the two categories. Employees were allowed one response and the values represent number of respondents out of 63 total respondents

In your opinion, considering energy use, how efficient is this building?						
Very Efficient	Somewhat Efficient	Efficient	Somewhat Inefficient	Very Inefficient	Don't know or Unsure	No Response
0	7	23	22.5	4.5	1	5

4.4.9 Building Efficiency Improvements

The management also addressed the perceived inefficiency of the building envelope by caulking all exterior windows to reduce air infiltration. By using a caulking agent to seal these breaches, the issues with drafts and energy wasted to condition the building were minimized. Although it is difficult to determine the exact energy savings and resultant return on investment (ROI) from this improvement, the US EPA has found that the payback is typically less than a year even when accounting for parts and labor (US EPA 2011).

4.4.10 Employee suggestions

In order to determine the best method to inform employees of new initiatives as a result of the case study, the survey included a question to determine what delivery method would employees thought would be the most effective. The choices for the survey included: short meeting, emailed notification, memo placed in employee mailboxes, hanging memos, or 'other' with room for a write in suggestion. Table 7 shows that the preferred methods for informing employees would be an emailed notification (33%) or a short meeting (29%). Multiple respondents suggested that the combination of emails and following up with a short meeting or a short meeting followed by emails explaining the reasons for the initiatives.

Table 7. Method to inform employees of new initiatives. Employees were allowed multiple responses and the values represent number of respondents out of 63 total respondents

In your opinion what are the most effective methods for informing employees of new initiatives such as the recycling program?					
Short Meeting	Emailed Memo	Hanging Memo	Reminders	Mailbox Memo	Kitchen Door Memo
24	28	16	8	5	4

The employees were also offered an opportunity to detail the types of programs or improvements they would like to see with respect to the office premises and the company's environmental initiatives. The suggested improvements ranged from small scale with easy implementation (e.g. installing lighting motion sensors, patching leaks in building envelope, promoting double sided printing, and composting programs) to larger projects with potentially high capital costs (e.g. installing a green roof, installing permeable pavers, on site renewable energy production, and switching to hybrid vehicles). The most common suggestions aside from reducing printing or increasing recycling were closely related to the type of projects the engineering firm had experience in designing, such as rain gardens and green roofs, summarized in Table 8. The employees and management viewed the potential installation of these options as an opportunity to improve their environmental performance and demonstrate the breadth and quality of their services.

Table 8. Employee survey response to open-ended question involving improving company environmental performance. Employees were allowed multiple responses and the values represent number of respondents out of 63 total respondents

Do you have any recommendations for what you would like to see incorporated with respect to environmental improvements?										
Rain garden	Green roof	Motion sensors for lighting	Reduce printing and paper waste	Improve vehicle fuel efficiency/ car pooling	Low maintenance landscaping	Improve building envelope	Permeable pavers	Increased natural lighting	Other	No response
6	4	4	4	3	2	2	2	2	9	25

4.5 CONCLUSION

The shift towards designing more sustainable corporations and building/occupant interactions goes beyond the design and construction of the building. While designing buildings to be greener or more efficient is essential, it is only part of the battle to reduce wasted energy and resources. The results of this research revealed the implications of the interaction between the occupants and the building; the building can have as much of an impact on the occupants' performance as the occupants' behaviors can have on the building's performance.

This article shows that having a knowledgeable and engaged workforce is key to improving economic and environmental performance. Increasing occupant awareness of how the building systems function, as well as raising awareness of the impacts that occupant decisions and habits can have on the buildings performance, is imperative for meaningful waste and energy reduction initiatives. Further, having a management staff that creates targeted, effective, and understandable improvements has direct results on reducing wasteful occupant behaviors, as was shown through the workstation energy use and office waste reductions. By creating a sense of employee ownership of initiatives, and proper occupant education, businesses can tackle the most difficult design feature: occupant behavior.

5.0 EVALUATING THE LIFE CYCLE IMPACTS OF SINGLE-USE DISPOSABLE MEDICAL PRODUCTS: FOCUS ON HYSTERECTOMY PROCEDURES IN A U.S. HOSPITAL SETTING

5.1 ABSTRACT

As the methods of performing surgical procedures have changed, so to have the environmental impacts of the procedures. Significant advancements in medicine within the past century, and with those advancements have come successes and consequences, both intentional and unintentional. These advancements have come with an increasing reliance on disposable medical equipment of all types, and hospitals are one of the greatest contributors to landfilled waste within the United States. This study used a waste audit and life cycle assessment (LCA) to evaluate the environmental impacts of the disposable products used in four hysterectomy procedures. The results show a direct relationship the relative age of the surgery and the increase in waste and environmental impacts. The results also showed that the impacts for production of the disposable products far outweighed the end of life impacts, accounting for 87% - 98% of life cycle greenhouse gas emissions.

5.2 INTRODUCTION

The healthcare sector generates a large amount of waste, which, in turn, affects human health. It has been estimated that American health facilities are responsible for the landfilling and incineration of over 3.4 billion pounds of waste annually (EPA 2005; Diconsiglio 2008). Although the amount of waste generated in operating rooms (ORs) varies drastically between individual hospitals, ORs are found to account for between 20-73% of hospital waste streams (Goldberg, Vekeman et al. 1996; U. S. Air Force Institute for Environment Safety and Occupational Health Risk Analysis 2001; Lee, Ellenbecker et al. 2002).

A large amount of healthcare waste is from single-use disposable items, which are a significant cost in a sector whose expenditures already account for 17% of the United States gross domestic product (Schaer, Koechli et al. 1995; Adler, Scherrer et al. 2005; BEA 2011). The reliance on disposable products has been the result of multiple factors, including: advances in technology and plastics manufacturing, quest for improved sterility, ease of use and disposal, improved turn around in operating room, and reduction in short term costs (Greene 1986). The impacts of medical waste, beyond concerns for potential disease transmission, are becoming more apparent. A burgeoning field set on reducing these long-term environmental impacts is developing methods and best practices to assess and ameliorate the impacts at multiple levels (Townend and Cheeseman 2005; Allen 2006; Zimmer and McKinley 2008; Kwakye, Brat et al. 2011; Brown, Buettner et al. 2012; Shrake, Thiel et al. 2012).

The first major study addressing the waste quantity and contents of various surgeries was conducted by Tieszen et. al, which reported the waste from five unique surgeries (Tieszen and Gruenberg 1992). More recently, a study was conducted evaluating the waste from two procedures involving knee joints, finding an average of 30.0 and 33.2 lbs. of waste generated per procedure (Lee and Mears 2012). Both of the studies demonstrated the potential reduction of waste through process improvement and increasing recycling, but stopped short of demonstrating the environmental impacts of the products being used in surgery.

Life cycle assessment (LCA), a sustainability quantification tool, is used in this paper to assess the impacts of various facets of healthcare. The impacts of disposable and reusable medical materials and equipment have recently been brought to the spotlight. Some studies compare individual items that were traditionally laundered and reused with their disposable counterparts, such as surgical gowns and laparotomy pads (Kümmerer, Dettenkofer et al. 1996; Overcash 2012). More recently, the focus has gone beyond textiles to analyze more complex medical equipment as well as instrument reprocessing and reuse (Adler, Scherrer et al. 2005; US Food and Drug Administration (FDA) 2009; Zhong, Alfa et al. 2009; Eckelman, Mosher et al. 2012; McGain, McAlister et al. 2012).

Larger-scope studies, focused on the impacts of hospital operating rooms, show that multiple components of medical procedures have significant impacts, including: facility systems, materials, and procedure itself (Campion, Thiel et al. 2012). Even the aspects of a procedure which may be commonly overlooked are found to have significant impacts, such as anesthetic gases, housekeeping routines, and potentially inefficient drug delivery methods (Karlsson and Öhman 2005; Sherman and Ryan 2010; Sherman, Le et al. 2012).

Multiple studies show critical links between human health effects and use and disposal of medical products. For example, a primary disposal method for medical waste is incineration, a process that results in the release of emissions such as particulate matter and organic pollutants (Zhao, Van Der Voet et al. 2009; Yan, Li et al. 2011). The production and disposal (life cycle) of single-use medical products creates a feedback loop with respect to patient health, as shown in Figure 11.

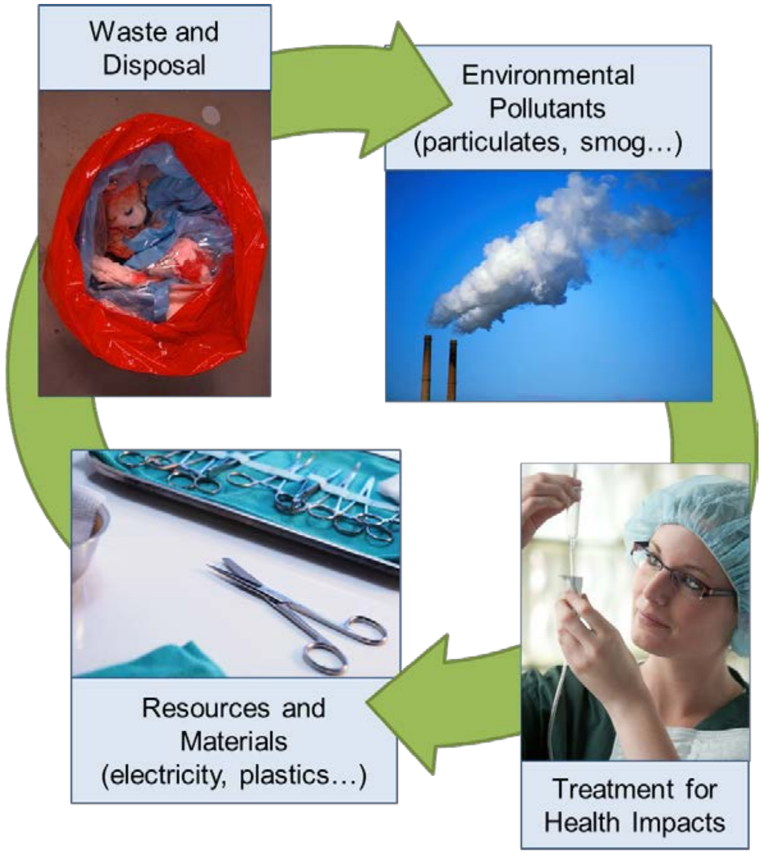

Figure 11. The figure displays the positive feedback loop demonstrated between medical waste production and human health impacts

This study aims to quantify the life cycle impacts of medical waste of single-use products entering waste streams of an illustrative medical procedure. Through a sensitivity analysis, the changes in environmental impacts associated with material consumption and disposal were examined as a result of technological advancements in procedure methods. The illustrative medical procedure, a hysterectomy, was selected for multiple reasons: frequency, variability in invasiveness, technological advancement, and data availability. With about 600,000 procedures performed annually in the United States, hysterectomies are one of the most common procedures involving women of reproductive age (Whiteman, Hillis et al. 2008). Additionally, there are four primary methods of performing a hysterectomy: abdominal, vaginal, laparoscopic, and robotic, each with varying degrees of invasiveness and patient recovery rates. This research was conducted in conjunction Obstetrics and Gynecology staff at the Magee-Womens Hospital (Magee) of the University of Pittsburgh Medical Center (UPMC).

5.3 METHODS

The case study approach was used in this research to evaluate the impacts of disposable medical products. Life cycle assessment was used to calculate the environmental impacts of the production and end of life for the discarded medical products. In order to evaluate the quantity and type of medical products present in the waste streams of the respective hysterectomy procedure (abdominal, vaginal, laparoscopic, and robotic), detailed waste audits were conducted. The waste audit was used a primary proxy for all the inputs and outputs associated with the procedure.

5.3.1 Case study

In order to determine the impacts of disposable medical products, the research team evaluated the waste produced from 60 hysterectomy procedures – 15 cases per surgery type. The research was conducted between July 2011 and June 2012. The case study consisted of a waste audit and life cycle assessment.

5.3.2 Waste Audit

To quantify and characterize the products and materials entering Magee's municipal solid waste and recycling streams, detailed waste audits were conducted. The audits involved data collection from individual patients' medical cases; therefore, the project team applied for and received Institutional Review Board (IRB) approval under 45 CFR 46.110.(4) and 45 CFR 46.110.(5) (IRB#: PRO11010250). Researchers participating in the sorting also completed University of Pittsburgh's Environmental Health and Safety Bloodborne Pathogen Training and wore personal protective equipment (PPE).

Patients undergoing vaginal, abdominal, laparoscopic, or robotic hysterectomies for non-cancer related reasons were identified and approached for participation in the study. Once a patient consented to participate in the study, researchers conducted a visual inspection of the OR prior to the surgery to ensure all previously generated waste was eliminated. Immediately following the surgery, the municipal solid waste (MSW) and recycling was collected, labeled with the case identification number, and moved to a secure storage location for sorting.

Recycling. The research team weighed the total quantity of recycling and MSW from each case before physically sorting the collected waste. The total weight included any fluids produced or acquired during surgery. The recycling was divided and weighed in the following categories: Plastic #5, Plastic #1, Plastic #6, and inappropriate materials or materials which are not actually recyclable but were found in the recycling stream.

Municipal solid waste. The MSW was divided and weighed according to the following method. Researchers separated the items according to material type. MSW items that were wet or contained fluids were initially counted rather than weighed. The material weights for clean, dry samples of the counted materials were taken and subsequently attributed to each case. The weighing of dry samples was done to eliminate potential inaccuracies due to fluid weight to ensure an accurate estimate of the material production impacts. Medical products found in MSW which were composed of multiple materials, such as grounding pads, cautery pens, and insuflators, were also counted. Locum "mixed material" items were later disassembled in a controlled laboratory setting and component materials were weighed to estimate the impacts associated with each case.

MSW which was not wet or composed of mixed material were sorted into the following material categories: gowns and drapes, cotton, blue wrap, gloves (sorted by color), rubber, hard plastic (generally #5), soft or thin-film plastic, Styrofoam, polyurethane foam or foam rubber, cardboard and paperboard, glass, paper, aluminum, metal (stainless steel), syringes, and wood. Any MSW that was too soiled to be removed from the collection bags were labeled as "miscellaneous," photographed, and weighed as a whole. Miscellaneous represent less than 2% of the average total weight of all cases.

Sharps. Sharps are products such as scalpels, needles, or other items that are capable of causing wounds or punctures while being handled. In order to estimate the impacts associated with the "sharps" waste stream, "peel packs" were sorted out of the MSW. These are paper labels affixed to the packaging of electrical tools which are used to operate on the patient (e.g. Trocars). The paper labels are disposed of into the MSW stream, while the electrical tools themselves are sent into the sharps stream. While the research team was unable to safely assess the sharps stream, using representative peel packs to count the number of tools used during each surgery gave an accurate estimate of the amount of waste being directed to this stream. Due to their physical complexity, the environmental impacts of the production of these electrical tools were analyzed based on cost data provided by Magee. For this study there was no safe way to track needle use so they were not considered in the Sharps category.

5.3.3 Life Cycle Assessment

This research used a hybrid life cycle assessment to evaluate the environmental impacts of the disposable materials. Hybrid LCA combines aspects of process LCA and Economic Input-Output Life Cycle Assessment (EIO-LCA) in order to address issues that may be encountered using each method alone (Lenzen 2002; Bilec, Ries et al. 2006). Hybrid LCA allows for inventory flexibility, aiding in the setting of system boundaries and data collection (Suh, Lenzen et al. 2003). The functional unit for this LCA was a single hysterectomy. Study boundaries were limited to the production and disposal of all single-use materials used in the operating room (OR) during a single procedure, from the beginning of surgery preparation in the OR until the patient left the room post-operation.

The following sections detail the assessment methods for the production and end of life of the disposable equipment.

5.3.3.1 Production / Process LCA

Using material quantities measured during the waste audits, LCI processes were selected based on the following approach: US database, USLCI, was given first preference (NREL 2010), ecoinvent was selected if USLCI did not contain the needed process (Frischknecht, Jungbluth et al. 2005). Finally, if neither USLCI nor ecoinvent contained suitable unit processes, another database was chosen based on comparison between the material type and the database process description. Because gowns, drapes, and bluewrap represented a significant portion by weight of each case, ecoinvent's polypropylene process was modified to account for special manufacturing of this spunbond-meltblown-spunbond (SMS) material (Ponder 2009). Much of the production

The production impacts of the single-use items were calculated using process LCA for all materials except the complex, electrical tools used in robotic and laparoscopic surgeries. Environmental impacts of these tools were calculated using their purchasing price and EIO-LCA, as described in the section below.

Table 9: Life cycle inventory material and database selection for material production of disposable medical products

Material	Product Examples	Material Production	
		LCI Database	**Database Process Name**
Cotton	Masks, blue towels, laparotomy pads, cotton swabs	ecoinvent	Textile, woven cotton, at plant/GLO U
PVC	IV bags and tubing	USLCI	Polyvinyl chloride resin, at plant/RNA
HDPE	Trays, caps	USLCI	High impact polystyrene resin, at plant/RNA
LDPE	Packaging, wrappers	USLCI	Low density polyethylene resin, at plant/RNA
PU Foam	Patient head support, equipment cover	ecoinvent	Polyurethane, flexible foam, at plant/RER S
PP	Surgical gowns, bluewrap, drapes	ecoinvent (modified)	SMS PP Disposable Gown - Ponder w/ energy
Styrofoam	Trays	ecoinvent	Polystyrene, general purpose, GPPS, at plant/RER U
Stainless Steel	Tool parts	ELCD	Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304 RER S
Aluminum	Lids on anesthetic bottles, tools, wrappers	USLCI	Aluminum, secondary, shape casted/RNA
Rubber / Isoprene / Neoprene	Gloves, arm ties	ecoinvent	Synthetic rubber, at plant/RER U
Nitrile	Gloves	USLCI	Polybutadiene, at plant/RNA
Paper	Labels and packaging	ecoinvent	Kraft paper, bleached, at plant/RER U
Paperboard	Packaging	ecoinvent	Solid bleached board, SBB, at plant/RER U
Glass	Anesthetic bottles	ecoinvent	Packaging glass, white, at plant/CH S
Wood	Tongue depressors	USLCI	Plywood, at plywood plant, US SE/kg/US
Complex materials (laparoscopic)	Laparoscopic instruments, accessories, and ports	EIO-LCA	Complex materials
Complex materials (robotic)	Robotic instrument attachments, accessories, and ports	EIO-LCA	Complex materials

The production impacts of the complex medical equipment were calculated using EIO-LCA due to the proprietary nature and associated difficulty in modeling of medical device manufacturing. The inputs for the EIO-LCA model were collected from Magee hospital purchase orders, detailing the price paid per unit for each piece of medical equipment used in the cases. The monetary values were converted from 2012 dollars to 2002 dollars, the basis for the most recent EIO-LCA model (Carnegie Mellon University Green Design Institute 2011). It is worth noting that while this monetary conversion is necessary to ensure accuracy, it does not completely overcome an inherent limitation of EIO-LCA - its reliance on historical values where process demands and environmental impacts can change significantly.

The monetary values were evaluated using the purchaser price model, as the prices were reflective of what the hospital paid, and not the cost to the manufacturer. The value was assessed using the corresponding sectors designated by the North American Industry Classification System (NAICS). The NAICS classification system is the method for classifying businesses in order to collect and assess data related to the US economy and its performance. For the complex medical devices, NAICS sector 339112 Surgical and Medical Instrument Manufacturing was selected. Whether from process or EIO sources, all inventory data was evaluated using the Tool for the Reduction and Assessment of Chemicals and other environmental Impacts v3 life cycle impact assessment tool (Bare, Norris et al. 2003)

5.3.3.2 End of Life LCA

The life cycle impacts for the disposal of the waste and recycling were assessed using both process and EIO-LCA. The impacts from the MSW were assessed using solely process LCA, and were assessed using information from ecoinvent and the European Life Cycle

Database (ELCD) 2.0 (see Table 2). Inert materials that did not have appropriate environmental impact information available through databases were lumped into one category and evaluated using ecoinvent inert landfilled data. The recycled materials were evaluated using ecoinvent recycling data for polyethylene, polypropylene and polystyrene.

Table 10. Life cycle inventory of material and database selection for municipal solid waste end of life

Material	Product Examples	Municipal Solid Waste	
		LCI Database	**Database Process Name**
Cotton	Masks, blue towels, laparotomy pads, cotton swabs	ELCD	Textile, woven cotton, at plant/GLO U
PVC	IV bags and tubing	ecoinvent	Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH S
HDPE/LDPE	Trays, caps, Packaging, wrappers	ecoinvent	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH S
PU Foam	Patient head support, equipment cover	ecoinvent	Disposal, polyurethane, 0.2% water, to sanitary landfill/CH S
PP	Surgical gowns, bluewrap, drapes	ecoinvent	Disposal, polypropylene, 15.9% water, to sanitary landfill/CH S
Styrofoam	Trays	ecoinvent	Disposal, polystyrene, 0.2% water, to sanitary landfill/CH S
Stainless Steel	Tool parts	ecoinvent	Disposal, steel, 0% water, to inert material landfill/CH S
Aluminum	Lids on anesthetic bottles, tools, wrappers	ecoinvent	Disposal, aluminum, 0% water, to sanitary landfill/CH S
Paper	Labels and packaging	ecoinvent	Disposal, paper, 11.2% water, to sanitary landfill/CH S
Paperboard	Packaging	ecoinvent	Disposal, packaging cardboard, 19.6% water, to sanitary landfill/CH S
Glass	Anesthetic bottles	ecoinvent	Disposal, glass, 0% water, to inert material landfill/CH S
Wood	Tongue depressors	ecoinvent	Disposal, wood untreated, 20% water, to sanitary landfill/CH S
Other Inert Products	Rubber / Isoprene / Neoprene	ecoinvent	1 kg Disposal, inert waste, 5% water, to inert material landfill/CH U (of project Ecoinvent unit processes)

Due to the complexity and difficulty modeling the processing of the sharps waste handling, it was evaluated using EIO-LCA. The per kilogram cost of hauling, treatment, and disposal for the sharps waste stream was obtained through Magee's contracted waste management company. The corresponding cost was assessed through impacts of *Waste management and remediation services* (NAICS sector 562000) which includes the processing of sharps designated medical equipment. The transportation impacts were calculated using distances from the hospital facility to the landfill and recycling facilities and using waste hauling quantity data provided by facility management. All transportation impacts were calculated using ecoinvent data.

5.4 RESULTS AND DISCUSSION

5.4.1 Waste generation and recycling

Over 602kg of municipal solid waste was sorted for this study. The MSW generated from the hysterectomy procedures ranged from a minimum of 5.9kg to a maximum of 14.6kg (Figure 12). The waste produced by each surgery type followed the relative age of the practice of each surgery, with vaginal hysterectomies having the smallest MSW generated on average (mean and median), and robotic having the largest MSW generation (mean and median). The weight of recycled materials can also be seen in Figure 12, with vaginal having the smallest quantity of recycled materials on average, and laparoscopic having the greatest amount of recycled materials on average. As a percentage of total waste generated, the recycling rate of abdominal hysterectomies averaged the highest at 9%, while robotic hysterectomies averaged the lowest at 6%.

The variability found in the waste production of each of the four surgeries can also be seen in Figure 12, specifically in abdominal and laparoscopic. Variability could not be directly attributed to any single factor with any statistical significance. There were indications that the surgeon performing the procedure had an impact on the amount of MSW generated, however there was insufficient data to draw any statistically significant conclusions correlating the performing surgeon to the MSW.

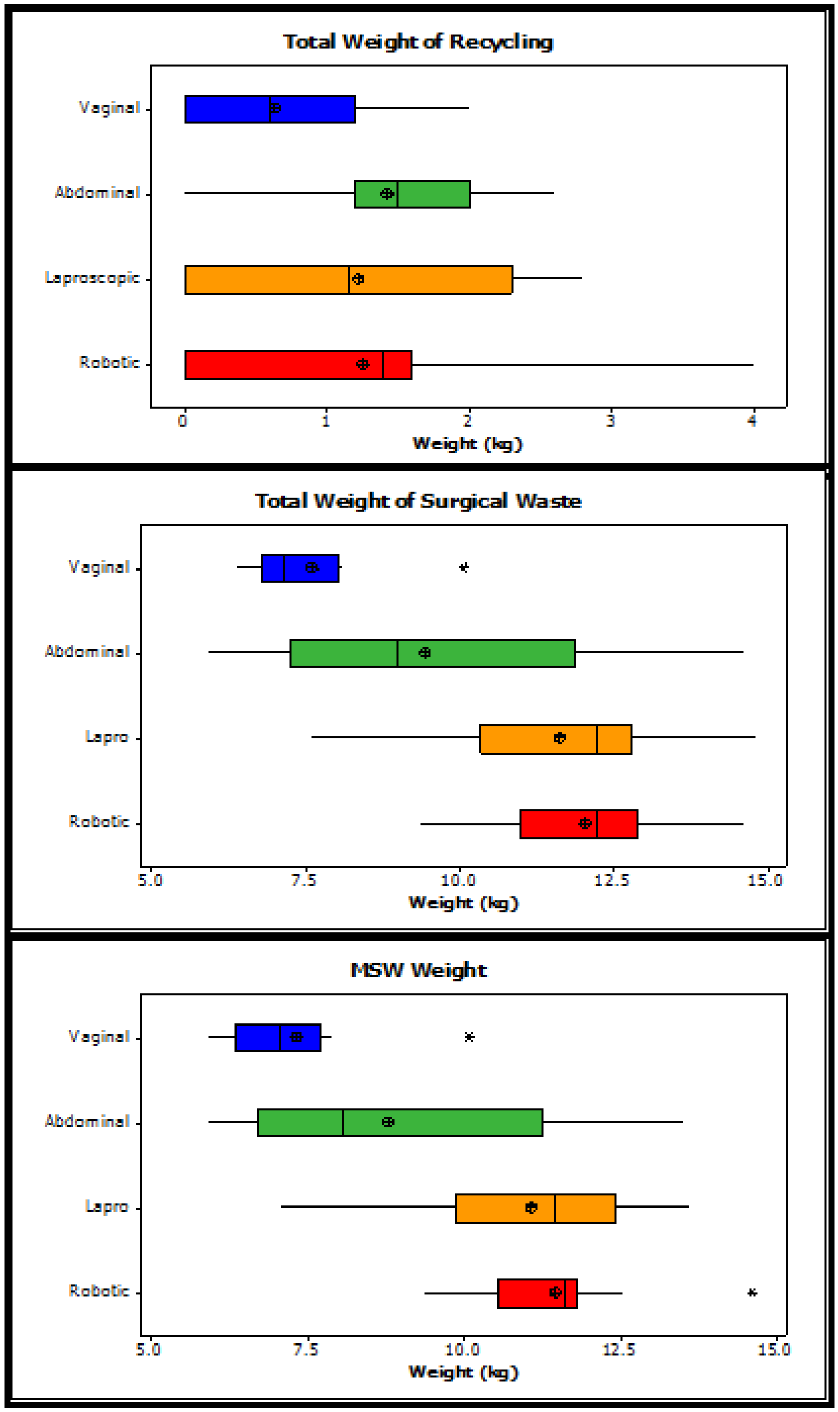

Figure 12. Weight of recycled materials (top), total materials disposed (middle), and municipal solid waste (bottom). The bullets represent the mean waste generated per procedure while the asterisks represent outliers; both outliers are due to complications in the procedures that can be expected.

The material composition of the MSW varied significantly between the surgeries as demonstrated in Figure 13. The largest contributing material by weight was the spun-melt-spun (SMS) polypropylene material, which is the primary material used in the fabrication of disposable gowns, drapes, and bluewrap. The second most common material was polyvinyl chloride, the primary material used in much of the tubing. Paper, the third most common material by weight, was primarily a result of packaging for medical equipment and supplies, which also accounted for nearly all of the soft plastic. The prevalence of high-density polyethylene (hard plastics) was due to the used for collection and storage of equipment and fluids, syringes, and components of disposable equipment. The cotton, more common in abdominal procedures, was primarily a component of disposable towels and pads, primarily used for fluid collection. The towels were the item that was most commonly found unused in the waste stream. Also of note is the relative uniformity the weight of the gloves. The quantity of gloves (polyisoprene, nitrile, neoprene) validates the waste audit by confirming the number of people present during the surgery, a number that should, and did, remain consistent between surgery types.

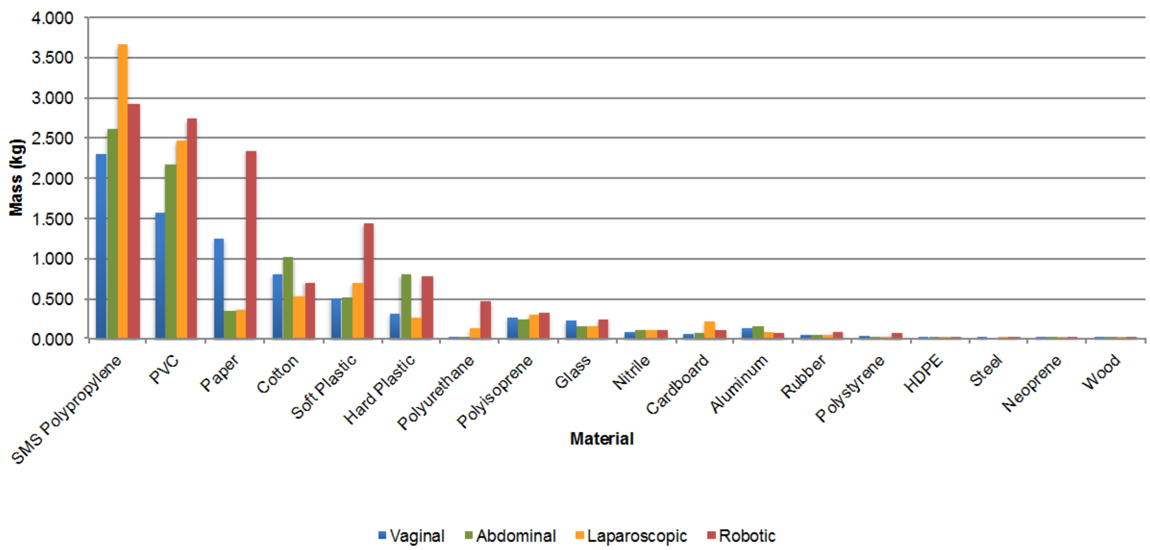

Figure 13. Mean municipal solid waste composition by material type for each procedure (Vaginal, Abdominal, Laparoscopic, Robotic)

An interesting finding of the waste audit was the prevalence of both unused items and improperly disposed reusable items. The most commonly unused items were the cotton blue towels, which were found unused in 55% of cases. At least one reusable stainless steel items in the MSW in 7 of the 60 cases were found, in most cases the tools were table clamps.

5.4.2 Life cycle impacts

The life cycle impacts are broken into two parts, the material production and the end of life. The impacts for the respective parts are presented in the subsequent sections.

5.4.2.1 Material production

For laparoscopic and robotic surgeries, the production of complex instruments account for over 75% of the impacts in the categories of global warming potential, human health carcinogenics, ozone depletion, smog, and cumulative energy demand, see Figure 14. The impacts for the complex instruments were evaluated using EIO-LCA, making it difficult to determine the exact "hot-spots" responsible for the significance of the impacts. The sectors that had the largest contribution with respect to GHG emissions were: *Power generation and supply, Iron and steel mills, Lime and gypsum product manufacturing, Oil and gas extraction, Truck transportation, Other basic organic chemical manufacturing,* and *Plastics material and resin manufacturing.* These sectors most significant contributors to the other impact categories as well. The *Power generation and supply* and *Truck transportation* sectors were the two largest contributors for Acidification, Respiratory effects, and Smog. However, with respect to Non carcinogenics, the *Waste management and remediation services* and *Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying* sectors accounted for 75% of the impacts from the medical devices.

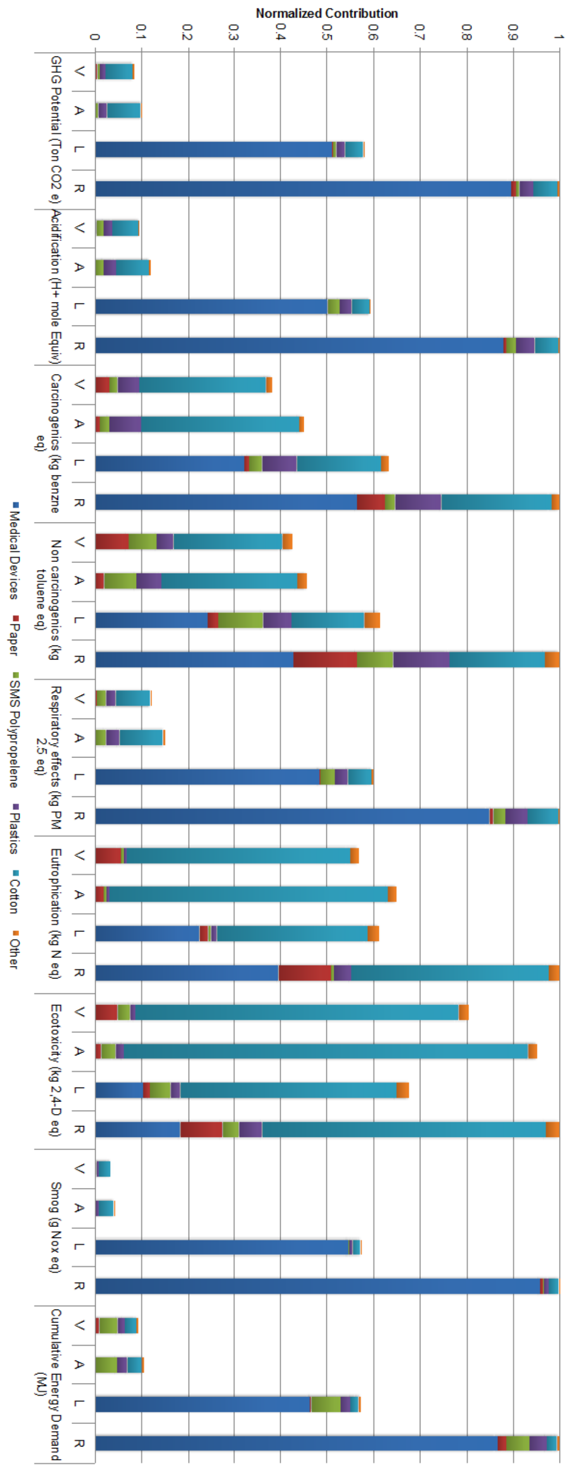

Figure 14. Environmental Impacts: Production phase of single-use disposable products by procedure type (Vaginal, Abdominal, Laparoscopic, and Robotic)

The production of cotton items accounts for more than 50% of the environmental impacts for every impact category, and nearly 30% of the cumulative energy demand associated with the production of single-use materials in vaginal and abdominal hysterectomies. Cotton is also a significant contributor to laparoscopic and robotic hysterectomies in the categories of acidification, respiratory effects, eutrophication, and ecotoxicity. Though cotton only represents 6% of laparoscopic and robotic, 10% of vaginal, and 12% of abdominal hysterectomy MSW by weight, the impacts associated with cotton farming, fertilizers, pesticides, and textile manufacturing are an order of magnitude greater than the impacts associated with the extraction and manufacturing of plastic products.

While not utilizing the complex instruments of laparoscopic and robotic surgeries, abdominal hysterectomies use a larger percentage of cotton in the form of blue OR towels, laparotomy pads, and gauze. Literature suggests the reuse of cotton-based products such as laparotomy pads may reduce the environmental impacts, water consumption, and energy demands of medical procedures (Kümmerer, Dettenkofer et al. 1996).

5.4.2.2 Disposable material end of life

The EOL impacts from the disposal of the materials are a combination of the impacts from the MSW, recycling, and sharps waste streams. Figure 15 displays the environmental impacts associated with the waste streams of each procedure. In nearly all categories the impacts from the MSW exceeded that of the other waste streams. It can be seen in Figure 15 that the impacts appear to be directly related to the quantity of waste produced, with Robotic having the largest environmental impacts across all categories except Carcinogenics and Non

Carcinogenics, both categories having laparoscopic as the largest contributor. The total quantity was responsible for the magnitude of the impacts because the majority of the impacts in nearly every category were a result of transportation. For example, with respect to GHG's, transportation accounted for 67% of laparoscopic impacts, 58% of abdominal impacts, and 50% of robotic and vaginal impacts. In all of the other categories except for Eutrophication and Ecotoxicity, the transportation impacts accounted for greater than 90% of the total environmental impacts.

While total quantity of waste did account for the majority of the impacts, the composition of the waste also played a large role. Most of the materials in the waste stream would be considered inert materials, and thus have a smaller impact with the impact categories used in this research since there is little degradation and material breakdown in a land fill setting. However, procedures where paper, cotton, and cardboard constituted a larger portion of the waste stream had larger impacts. For example, the laparoscopic and robotic procedures had similar quantities of total waste generated, but the GHG emissions from the average laparoscopic procedure were only 40% less than that of robotic. The major difference was that the average robotic procedure had nearly 2.3 kgs of paper waste compared to about .3kgs of paper waste in the laparoscopic waste stream. Paper waste accounted for 32% of GHG emissions for the robotic procedure and 23% of the GHG emissions for the vaginal procedure. Additionally, cotton, most prevalent in the abdominal procedure, was responsible for 19% of the GHG emissions for the procedure.

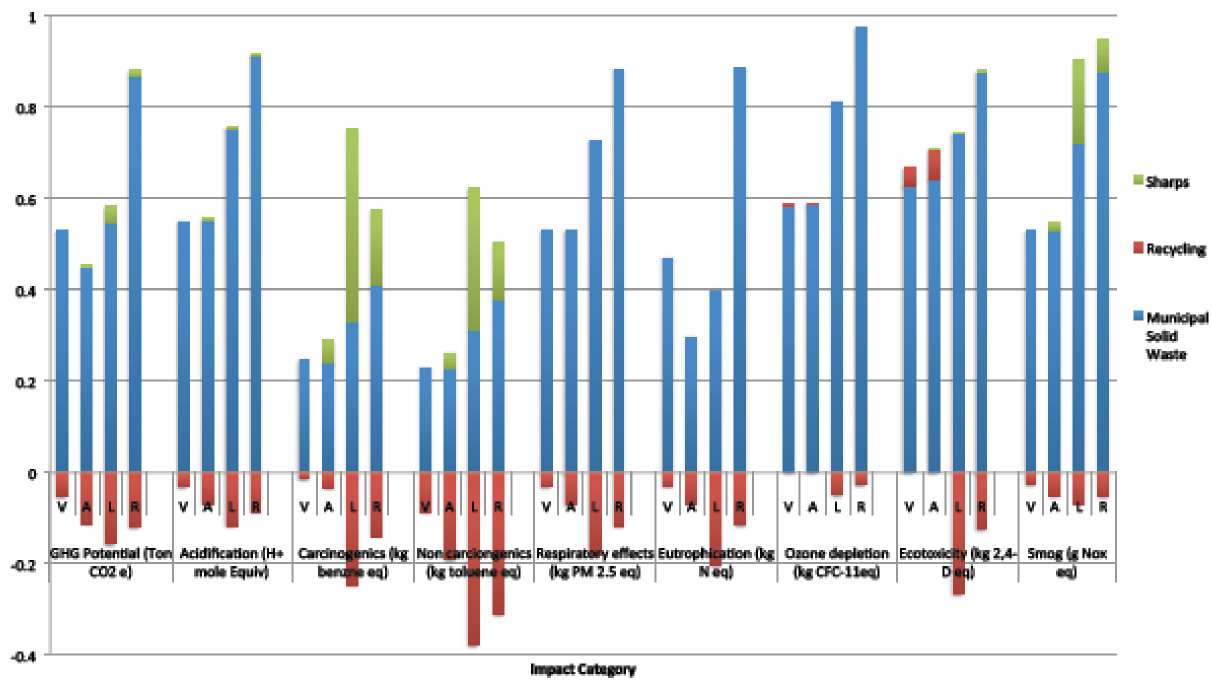

Figure 15. Environmental impacts: End of life of single, use disposable products by procedure type (Abdominal, Vaginal, Laparoscopic, and Robotic)

5.4.2.3 Combined life cycle impacts

With respect to the complete life cycle, the production of the disposable materials far outweighed the end of life impacts. With respect to robotic and laparoscopic, the end of life is less than 7% in every impact category, a trait that holds with true with vaginal and abdominal for every category except GHG potential (12% for vaginal), Smog (18% and 15% respectively), and Ozone depletion (31% and 32% respectively). The results show that the impacts of production should not be overlooked while selecting material equipment. Further, the significance of the production suggests that employing the use of reusable or multiple-use medical tools and supplies could greatly reduce the environmental impacts associated with surgeries, a finding supported by recent literature (Eckelman, Mosher et al. 2012; Grimmond and Reiner 2012).

Although the end of life impacts are less than production, the study found room for improvement in waste handling and processing. For example, reducing the amount of unused materials, and properly sorting the items that were found in MSW that could be recycled could have significant improvements. Further, the recycling of medical waste can offset negative environmental impacts through reducing the primary energy demands of the production of equipment and tools for other industries and can also be economical for a hospital depending on the cost of MSW and medical waste disposal over the cost of recycling (Lee, Ellenbecker et al. 2002; Gaiser, Cheek et al. 2004; Karlsson and Öhman 2005; McGain, Clark et al. 2008; McGain, Hendel et al. 2009; McGain, White et al. 2012).

5.5 CONCLUSION

There has been a lot of attention paid to the production, treatment, and disposal of medical waste since the 1980's, and while medical waste production needs to be reduced, this research found that the best way to reduce those impacts may be evaluating disposable medical product production. The impacts from the production of the medical products far outweighed the impacts from their treatment and disposal. While not unexpected, somewhat alarming is that the more recent the development and practice of the surgical procedure, the greater the quantity of waste produced, and life cycle impacts from the disposable equipment and materials used in that procedure. The increase in waste from the newer procedures demonstrates the potential negative implications of the shift towards disposal that has become prevalent in the healthcare and hospital system. While human health outcomes and patient recovery times are always the paramount concern, the advancement of medical technologies clearly results in tradeoffs with environmental and cost concerns.

This research also demonstrated the need for increased visibility in the manufacturing of medical equipment. The manufacturing of the electrical medical equipment was the largest contributor to nearly every impact category. While EIO-LCA use is widely accepted, it does not provide the level of detail for production improvements that process LCA does. In order to reduce the manufacturing impacts having access to reliable process data to identify the hotspots in production is imperative.

Similar to other sectors, it appears that the best way to minimize the environmental impacts from the manufacturing and waste treatments of medical equipment is to focus on the prevention of the waste itself through process improvements and best practice considerations. While this research is only a snapshot of the total environmental implications of our growing healthcare sector, it demonstrates the importance of continuing to evaluate health, cost, and environmental impacts associated with healthcare.

6.0 CONCLUSIONS

6.1 SUMMARY

The focus of this research was to assess and evaluate the environmental impacts of service industries, no simple task when considering the expanse, variety, and complexity of the industries that are considered service sector industries. While this research was not capable of determining all of the impacts associated with every industry, it did focus on identifying the impacts of two major sectors, professional services and healthcare. This research was motivated, in part, by the assumption that service sector industries were underperforming environmentally due to lack of regulation and lack of information regarding the expanse of a services environmental footprint, assumptions that were validated in regards to the findings of this research.

The framework presented in Chapter 3 is a powerful method for improving environmental performance. The application of the methods and techniques discussed in the framework will result in a clearer picture of the expanse of a services impacts and reveal the aspects of the service that are most responsible for the industries environmental impacts. The clearer picture allows for the development and evaluation of targeted strategies for improvement, rather than a simple trial-and-error approach. The potential benefits of the improvements can be evaluated using the same framework to determine whether the resulting improvement strategies are worth the investment. The life cycle framework is applicable to all service industries, and provides a valuable resource for industries looking to improve their environmental performance.

Due to the diverse nature of services provided by service sector industries, it is impossible to develop one standard or recommendation that would act as a cure-all to reduce the environmental impacts of service sector industries. However, there are likely commonalities across industries that provide similar services, and the impacts of each sector should be evaluated to improve information and develop best practice standards for each sector. For example, although consulting firms may vary by size, market, and service provided, it is likely that the top contributors to their environmental footprint would be similar to those found in the engineering firm evaluated in Chapter 3. Reducing the energy intensiveness of the activities associated with transportation and the building premises should be the concentration of a firm looking to reduce its environmental impacts.

Chapters 3 and 4 established the implications of the actions of staff and management on a services environmental performance. The impact of, and variability found in, the electricity consumption of employee workstations demonstrated the magnitude that even simple changes such as standardizing power settings can have on reducing a services electricity consumption. Building users and occupants are ultimately in control of consumption and disposal methods for a service industry - their potential for reducing environmental impacts cannot be undervalued.

Another aspect that should be considered by all services was the significance of frontend improvements on environmental performance. In the evaluation of both healthcare and professional services the impacts from the end of life were dramatically lower than the impacts of reducing consumption. As demonstrated in Chapter 5, the life cycle impacts from the raw materials and production of the medical products accounted for greater than 90% of the life cycle impacts. Focusing on reducing consumption on the frontend outweighed any effects from treatment or mitigation strategies after consumption. Improved supply chain management, informed purchasing, and reducing reliance on single use disposable items are essential in impact reduction. Single use disposables serve a valuable function, however the reliance on single use items and the associated trade-offs compared to their reusable counterparts need to be considered..

While the shift towards a service economy is often viewed as a positive environmentally, this shift has also resulted in the development of a myriad of new issues to be addressed and potential trade-offs to be evaluated. Life cycle assessment presents a valuable tool for improving the clarity of the major environmental loadings that result from the operations of service industries. The continued application of LCA to services presents a real opportunity to develop targeted and effective solutions for improving service industry sustainability.

6.2 RECOMMENDATIONS FOR FUTURE WORK

This research has contributed to the currently small amount of literature evaluating the impacts of service industries. The potential for improvement and impact reduction through the continued evaluation of service industries is prevalent. One of the future goals of this research is to continue to streamline the framework presented in Chapter 3, to make it more easily usable and accessible to industries of all size. While professional services and healthcare sectors are an important aspect of our economy, the scope of this research needs to continue expand and be applied to other services, such as: food service, retail, tourism, and professional sports.

APPENDIX A

ECONOMIC INPUT-OUTPUT LIFE CYCLE ASSESSMENT DATA

Table A.1. North American Industry Classification System (NAICS) codes used for upstream EIO-LCA data

Data Category	NAICS Sector	NAICS Codes
Purchased Services	Accounting and bookkeeping	54121
	Advertising and related	54181-54189
	Architectural and engineering services	54131-54138
	Automotive equipment rental	53211-5321209
	Automotive repair and maintenance	81111
	Civic, social, pro	81392
	Couriers and messengers	4921101
	Directory, mail	51114-511199
	Food service & drink	722211-722333
	Grant making, giving	813211-813319
	Insurance carriers	52411-52413
	Legal services	54111
	Management consulting	54161
	Nondepository credit	52221
	Office administrative	561100
	Other amusement	71391
	Other educational services	61141
	Photographic services	54192
	Printing	32311
	Spectator sports	711211
	Telecommunications	517211
Building Premises	Real estate	53111-53139
	Service to buildings and	56171-561719
	Waste management	562111
Travel and Transportation	Automobile parking garages	812930
	Hotels, motels, casinos	72111 & 72112
Equipment	Electronic equipment repair	811211
	Software Publishes	511200
	Electronic Computer Manufacturing	334111
Office Supplies	General and consumer goods	53221
	Retail trade	44111-45431

APPENDIX B

EMPLOYEE PERSONNEL SURVEY

1. Individual Information:
   1.1) What is your Gender? Male___ Female____
   1.2) How long have you been working in your present workspace?
   Less than 3 months ___ 3-6 months____ 6 months- 1 year____ Greater than 1 year____
2. Transportation:
   2.1) How many miles do you travel to work (one-way)? Less than 5____ 6-10____ 11-20____ 21-30___
   Over 30____
   2.2) What is your **primary** mode of transportation to work? Personal Car___ Company Car___ Bike___ Bus___
   Car pool___ Walk___ Other (please specify)________________________
   2.3) Do you have a secondary mode of transportation, and if so how often do you use it? ___________________
   ____
   2.4) If you car pool, to what extent? Do you car pool with a coworker or with someone at another location?
   How far is this location from the office? ____
   2.5) What type of vehicle do you drive (make, model, year)? ____
   2.6) About how many Miles per Gallon (MPG) does your vehicle get if use it for commuting to work? __________
3. Workspace Location Information (see map on reverse for directional office layout)
   3.1) In which area of the building is your workspace? N___ S___ E___ W___ Mid___
   3.2) Which direction is the nearest set of windows to your workspace? N___ S___ E___ W___
   3.3) Are you within 15 feet of an exterior wall? Y____ N____
   3.4) Which best describes your personal workspace? Enclosed office___ Private cubicle____ Shared cubicle___
   Other(explain)______________________________________
4. Thermal Comfort
   4.1) How satisfied are you **generally** with the temperature in your workspace?
   Very Satisfied Somewhat Satisfied Satisfied Somewhat Unsatisfied Very Unsatisfied
   4.2) How satisfied are you with the temperature of your work area during **warmer** weather?
   Very Satisfied Somewhat Satisfied Satisfied Somewhat Unsatisfied Very Unsatisfied
   4.3) How satisfied are you with the temperature of your work area during **cooler** weather?
   Very Satisfied Somewhat Satisfied Satisfied Somewhat Unsatisfied Very Unsatisfied
   4.4) Overall does the thermal comfort enhance or interfere with your ability to get your job done?
   Strongly Enhances Somewhat Enhances Enhances Somewhat Interferes Strongly Interferes
   4.5) Additional comments: ____
5. Lighting
   5.1) How satisfied are you with the amount of light in your workspace?
   Very Satisfied Somewhat Satisfied Satisfied Somewhat Unsatisfied Very Unsatisfied
   If you are unsatisfied what are the causes (too bright/dim)? _________________________________
   5.2) How satisfied are you with the visual comfort of the lighting (Glare, reflections, etc.)
   Very Satisfied Somewhat Satisfied Satisfied Somewhat Unsatisfied Very Unsatisfied
   Overall does the lighting quality enhance or interfere with your ability to get your job done?
   Strongly Enhances Somewhat Enhances Enhances Somewhat Interferes Strongly Interferes
6. Building Features and Energy Usage:
   In your opinion, considering energy use, how efficient is this building?
   Very Efficient Somewhat Efficient Efficient Somewhat inefficient Very inefficient
   6.1) When leaving your workspace how long does it take for your monitor(s) to go to sleep:
   Instantly (I turn it off) _____ 1-15 minutes______ 16-30 minutes_____ 31-60 minutes____ More than 60
   minutes____ Never_______
   6.2) When leaving your workspace how long does it take for your computer to go to sleep:

Instantly (I turn it off) _____ 1-15 minutes______ 16-30 minutes_____ 31-60 minutes____ More than 60 minutes____ Never_______

6.3) Do you have all electricity consuming devices plugged into a power strip? Yes____ No____

6.4) What Devices do you currently have plugged into an outlet within your workspace (list all): ______________
____

7. Waste Disposal Habits

7.1) How often do you recycle items that are recyclable? Always____ Somewhat Often____ Often____ Not very often____ Never______

7.2) If you choose not to recycle what is the main reason for not doing so? _______________________________
____

7.3) Do you have a recycling receptacle in your workspace? Yes______ No_____

7.4) Which materials do you typically recycle in the office (mark all that apply)? Paper_____ Cardboard______ Plastics (#'s 1-5)______ Glass______ Aluminum Cans_____
Other materials (please specify)________________________________

7.5) What are your opinions on the new GHA recycling program, and what suggestions do you have for improvement? ____
____

7.6) In your opinion, what are the most effective methods for informing people about new initiatives such as the recycling program (For example: short meeting, emailed memo, hanging flyers, etc...)? _________________
____

What sort of things would you like to see incorporated into the building/ office premises (if any):
____

Do you have any other recommendations for things you would like to see GHA incorporate with respect to environmental improvements? What other ideas/visions do you have for GHA's commitment to sustainability?
____
____
____

APPENDIX C

GREENHOUSE GAS EMISSIONS FOR FISCAL YEAR 2009

Table C.1. Top contributors to the overall greenhouse gas emissions from fiscal year 2009 (kg CO_2 e)

Life cycle inventory	Purchased Services	Building Premises	Travel and Transportation	Equipment	Office Supplies
Gasoline fuel production and combustion	0	0	593504	0	0
Power generation and supply	142468	343950	7704	47096	33575
Waste management and remediation services	9437	21506	456	1742	1325
Oil and gas extraction	24592	2405	476	4773	2187
Couriers and messengers	29764	0	0	2287	1570
Architectural and engineering services	25862	0	0	0	0
Petroleum refineries	16606	1116	233	2886	1234
Truck transportation	10254	587	136	5345	1915
Air transportation	13249	613	101	2877	574
Iron and steel mills	10254	642	89	5263	906
Coal mining	4800	1434	214	1579	953
Paper mills	8775	0	153	0	0
Retail Trade	0	0	0	2187	4474
Pipeline transportation	4682	789	140	0	592
Cement manufacturing	5000	495	0	0	0
State and local government passenger transit	4710	0	0	0	0
Telecommunications	4701	0	0	0	0
Real Estate	0	3503	0	0	0
Wholesale Trade	0	0	0	2786	0
Semi conductor	0	0	0	2604	0
Hotels and motels, including casino hotels	0	0	1833	0	0
Other	70508	9464	1532	26561	8137

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