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LIFE CYCLE COST ANALYSIS OF OCCUPANT WELL-BEING AND PRODUCTIVITY IMPACTS IN LEED® OFFICES

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LIFE CYCLE COST ANALYSIS OF OCCUPANT WELL-BEING AND PRODUCTIVITY IMPACTS IN LEED® OFFICES

By

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ABSTRACT

LIFE CYCLE COST ANALYSIS OF OCCUPANT WELL-BEING AND PRODUCTIVITY IMPACTS IN LEED® OFFICES

By

Amanjeet Singh

The rising concern for sustainability has provided significant impetus to the green building movement. Its future, however, may depend on substantiation of the widely claimed green benefits. While significant improvements in occupant well-being/productivity in green buildings have long been hypothesized, the precise quantification of such improvements remains fuzzy. This research analyzes occupant well-being and productivity related costs and benefits in LEED offices using the Life Cycle Cost Analysis (LCCA) framework and a case study based approach.

Incremental first costs related with LEED IEQ were identified. Changes in the occupants' well-being and productivity were determined using occupant surveys. Using the IEQ related incremental costs and occupant well-being and productivity based benefits, LCCA calculations were performed. It was determined that life cycle benefits far exceed the incremental costs, indicating economically viable investments. This research provides some degree of validation to occupant well-being and productivity improvement claims in green buildings and provides the groundwork for further research and validation.

To Daarji
My Idol, My Hero

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

The concept of sustainability has been establishing a strong foothold in recent times, with efforts ranging from reducing air emissions from our industrial processes to lowering our energy consumption, and much more. Likewise, the construction industry has been undergoing the transition towards the development of a more sustainable/green built environment. Traditionally, construction had been a major contributor in environmental degradation in terms of material and energy consumption as well as waste and pollution generation (Mago 2007, Kibert 2005, USDOE 2007). Existing knowledge of such negative environmental impacts and the rising concern for sustainability provided the perfect setting for the steady growth of the green building movement, which gained further momentum with the development of marketable green certification systems such as LEED® (Leadership in Energy and Environmental Design) developed by the US Green Building council (USGBC 2008a).

LEED rating systems provide guidance for development of sustainable design and construction strategies and award certification for utilizing such strategies, thus deeming the buildings as green. LEED and green building supporters claim potential benefits of utilizing such green strategies for environmental, social, and economic gains, while uncertainties regarding such benefits often invite criticism (Bowyer 2007, Scheuer and Keoleian 2002). Anticipations of incremental costs and uncertainties surrounding the long-term benefits of green building may prove to be a challenge for further growth of the sustainable/green building movement.

1.2 NEED STATEMENT

The need for this research is twofold. First, there is a need to verify claims related with occupant well-being and productivity improvements in green buildings, since these claims hold a significant share among the expected benefits from green built environments. In addition, it is vital to elucidate the economic impacts of green buildings to ensure the long-term sustainability of the green building movement.

1.2.1 Occupant Well-being and Productivity Benefits in Green Buildings

Green buildings have been touted to provide occupant well-being and productivity benefits (USGBC 2008b). Such claims have generated substantial interest in building green, both for improving occupant well-being/productivity as well as for the anticipated economic gains (Turner Construction 2005). These claims however, seem to be based on mere hypothesis of projected green building benefits rather than the actual gains observed during the buildings' operational life.

Often, such well-being and productivity improvement claims are a result of far reaching conclusions based on gross nationwide data and significant assumptions (Fisk and Rosenfeld 1997; Kats 2003; SBW 2003). Limited researches have attempted to validate such claims through actual case-study observations. Such well-being and productivity savings may form a substantial part of the potential economic benefits from green buildings, which makes it even more significant to validate these hypotheses.

1.2.2 Ensuring Long-term Sustainability of the Green Building Movement

Building projects often imply significant economic investments. Building green may require utilizing building materials, methods, and technologies, which are different from those typically used for conventional projects. Several authors have also identified the need to re-assess the overall project procurement approach, in order to attain maximum efficiency in green building projects (Kats 2003, Lapinski et al. 2006, Mago 2007). Green buildings may, therefore, be viewed as alternative investments, compared with conventional building projects. While the green building industry hypothesizes the potential for improved life cycle economic performance in these buildings (USGBC 2008b), there is a need to provide validation to such claims by analyzing the actual performance of green buildings.

It is also significant to understand that while green buildings may incur incremental costs during the project procurement phase, the anticipated benefits are spread over their much longer operational life. The incremental upfront costs and economic uncertainties in the long-term have sometimes been criticized as significant hurdles to the growth of the green building movement (Kats 2003).

While rise in market demand for green buildings may assist in limiting the incremental cost, there remains a need to elucidate the long-term economic impact of building green in order to assist informed decision making from the investor's perspective.

LEED office buildings provide an opportunity to assess such green building well-being and productivity claims. This may be achieved by studying occupant well-being and productivity changes as they move from conventional (non-LEED) to LEED offices. This study design is based on an intervention type-prospective cohort study approach, as discussed in epidemiological literature (Hennekens and Buring 1987). Occupant well-being and productivity improvements have been associated with better IEQ in LEED buildings (Pillai 2006). Hence, such improvements may be equated against any incremental costs required to attain LEED-IEQ credits.

From a building owner's/investor's perspective, improved well-being/productivity conditions and the possible life cycle economic gains in green offices provide sufficient motive to conduct such assessment. If these life cycle gains meet the economic expectations from green buildings, such validation may help in providing further impetus to green building initiatives. Overall, this research may help in removing a significant hurdle to the growth of the green building movement and assist the construction industry's initiative for a sustainable future.

1.3 RESEARCH GOAL AND OBJECTIVES

The goal of this research is to demonstrate the economic benefits of green buildings based on occupant well-being and productivity. The following objectives and work steps have been outlined to achieve this goal:

Objective 1: Identify IEQ related processes/items responsible for incremental first cost in LEED offices.

1. Review literature related with Green Building and IEQ (GB-IEQ), Built Environment and Occupant Well-being/Productivity (BE-OWP), and Life Cycle Cost Analysis (LCCA).
2. Identify relationships between building IEQ and well-being/productivity.
3. Determine LEED-IEQ credits that may impact occupant well-being/ productivity.
4. Identify case studies where occupants move from conventional (non-LEED) to LEED offices.
5. Review case study LEED documentation for the IEQ credits identified in step 3, to hypothesize design/construction processes/items that may result in incremental first costs.
6. Obtain feedback from constructors to finalize the hypothesized processes/ items.
7. Summarize IEQ related processes/items causing incremental first cost in LEED offices.

Objective 2: Determine annual benefits from occupant well-being and productivity improvements, resulting from the move to LEED offices.

8. Review existing occupant surveys seeking input regarding well-being and productivity.
9. Develop and conduct pre-move occupant survey.
10. Develop and conduct post-move occupant survey.
11. Analyze responses from both surveys together to determine changes in occupant well-being and productivity.
12. Summarize annual benefits from occupant well-being and productivity improvements.

Objective 3: Determine life cycle economic impact of LEED-IEQ, based on inputs from objectives 1 and 2.

13. Monetize findings from step 7 to determine incremental first cost of LEED IEQ.
14. Monetize findings from step 12 to determine annual $ benefit from improved occupant well-being and productivity.
15. Determine LCCA method, variables, and develop analysis worksheet.
16. Perform LCCA calculations to determine net life cycle economic impact, based on incremental cost input from step 13 and annual $ benefits from step 14.
17. Summarize uncertainties associated with LCCA findings.

The above outline presents key work steps conducted to attain the research objectives. The detailed methodology discussion is presented in Chapter 3.

1.4 RESEARCH SCOPE AND LIMITATIONS

This study focuses on determining the life cycle economic impact of improved occupant well-being and productivity, resulting from the move to LEED office environments. The study scope and limitations are defined below.

1. The study scope is limited to evaluating the economic performance of LEED offices based only on IEQ related incremental costs and occupant well-being/productivity related benefits. Other variables affecting life cycle economic performance, such as energy, operation and maintenance, replacement and salvage of indoor equipment, employee turnover rates, liability-related costs, etc. are not studied.
2. The economic analysis is performed from the investor's (building owner's) perspective.
3. The benefit-analysis is based on 2 case study projects in Michigan. The findings represent benefits that may be attained by comparable occupant populations under similar conditions, while wider-scale generalization may require further case study analysis.
4. This research utilizes self-perceived well-being and productivity data, collected through pre-move (while occupants work in non-LEED offices) and post-move (after occupants move to LEED offices) occupant surveys. Both these surveys gather data based on 4-week snapshots. This study

assumes inputs attained during these snapshots as representative of typical occupant conditions throughout the study life.

5. The recent move to a new building may have a temporary effect on the occupants' well-being/productivity. Hawthorne effect (Romm and Browning 1994) explains temporary changes in people's behavior or performance as a response to a change in the environment. Although the Hawthorne theory has been disputed (Adair 1984; Diaper 1990; Gottfredson 1996; Rice 1982; Wickstrom and Bendix 2000), the uncertainty in long-term benefits presented by this theory may only be eliminated by continuing this research over a longer timeframe.
6. This research assumes that all well-being/productivity benefits result from improved IEQ in LEED buildings. Influence of other LEED credits and other external influences (outside the building) are disregarded.

Several limitations identified above result from the limited timeframe and sample size (only two case studies) for this study. Further research based on a longer timeframe and increased number of case studies may assist in eliminating some of these limitations.

1.5 PROJECT OUTPUTS/RESEARCH CONTRIBUTION

The following outputs would be developed from this research:

Objective 1: Identify IEQ related processes/items responsible for incremental first cost in LEED offices.

1. A structure identifying the relationships between LEED IEQ credits and occupant well-being/productivity.
2. Matrices identifying LEED IEQ related processes/items with potential incremental first costs.

Objective 2: Determine annual benefits from occupant well-being and productivity improvements, resulting from the move to LEED offices.

3. Occupant surveys addressing well-being and productivity related data collection.
4. Summary of annual benefits from occupant well-being and productivity improvements.

Objective 3: Determine life cycle economic impact of LEED-IEQ, based on inputs from objectives 1 and 2

5. Matrices summarizing incremental cost estimates related with LEED IEQ credits.
6. Table summarizing annual US$ benefits from occupant well-being and productivity improvements.
7. Summarized Life Cycle Cost Analysis (LCCA) calculations.

Overall, this research provides a framework for future assessments of occupant well-being and productivity benefits in green buildings.

1.6 Chapter Summary

This chapter provided an overview of the research need and presented the goal, objectives, scope and key limitations anticipated at the start of this research. The discussion presented in this chapter has been refined throughout the conduct of this research.

The next chapter provides a discussion of the literature reviewed for this research. This review assisted in finalizing the research methodology, which is presented in Chapter 3. Chapter 4 presents the data collection and primary analysis, while the economic analysis of these findings is presented in Chapter 5. Chapter 6 summarizes the research conclusions and presents directions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 CHAPTER OVERVIEW

This Chapter presents an overview of the literature reviewed for this research. Three categories of literature were identified for review. Figure 2.1 presents the structure of the literature review.

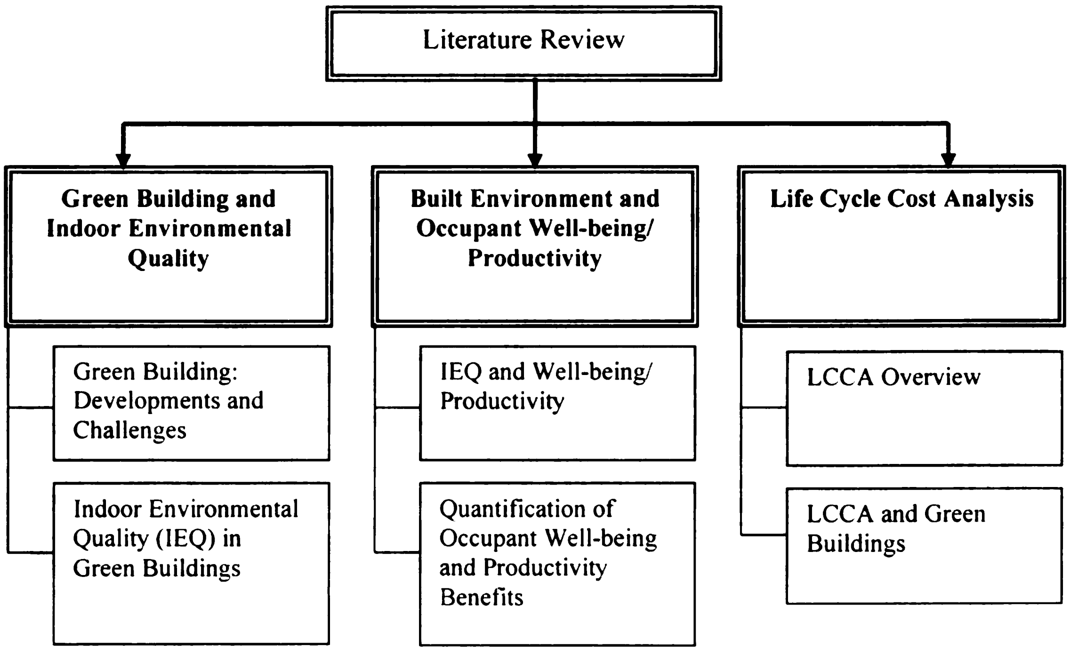

Figure 2.1: Literature Review Structure

The first category, Green Building and Indoor Environmental Quality, presents an overview of green building and LEED-NC® green building guidelines. Also presented here, is a discussion of the roadblocks in the green building movement and the need for quantification of the potential well-being and productivity benefits resulting from improved indoor environments in green buildings.

The next category of review, Built Environment and Occupant Well-being/ Productivity, provides an overview of potential well-being/productivity effects of the built environment. Several publications that have attempted to quantify the affect of building Indoor Environmental Quality (IEQ) on occupant well-being and productivity/performance are discussed in this segment.

The first two review categories lead to the overarching research hypothesis that indoor environments in green buildings can lead to significant well-being and productivity improvements, which may provide substantial economic benefits during the operational life of the building. To test this hypothesis, an economic evaluation needs to be performed that would weigh occupant well-being and productivity-based benefits resulting from green building indoor environments, against incremental costs involved with incorporating the related green building strategies. This requires a review of the third literature category, Life Cycle Cost Analysis (LCCA). An overview of LCCA is presented, followed by recent LCCA studies in the green building domain.

2.2 GREEN BUILDING AND INDOOR ENVIRONMENTAL QUALITY (IEQ)

The construction industry has been undergoing a transition towards development of green/sustainable built environments in recent times. Samaras (2004: Referenced in Mago 2007) attributes this transition to construction being the foremost contributor of detrimental impacts on the environment. At a global scale, our construction practices consume 10% of the world's freshwater, 25% of the wood harvest, and are responsible for 40% of material and energy flows (Kibert 2005). "Further, 8-20% of the total municipal solid waste is attributable to construction operations" (Mago 2007). While the green building movement has grown, it has also faced criticism often arising out of economic uncertainties (Wolff 2006, Syphers et al. 2004, Kats 2003).

2.2.1 Green Building: Developments and Challenges

The green building movement gained momentum on the premise of attaining integrated environmental, social, and economic improvements over the buildings' operational life spans. This growth has also lead to the development of various green building standards/assessment systems/benchmarking tools. LEED-NC (Leadership in Energy and Environmental Design for New Construction), developed by US Green Building Council (USGBC 2008a) is the most widely accepted assessment system in the US (Fowler and Rauch 2006, Syal et al. 2007).

LEED standards assess buildings on five main categories of impact; site selection and development, indoor environmental quality, water efficiency, energy efficiency, and materials selection. Buildings are certified as green at various levels depending on the points achieved in these categories. The LEED rating system utilizes a whole system approach to minimize environmental damage while enhancing occupant well-being and productivity (USGBC 2008b).

Even as the green building movement has grown and LEED has made a significant marketplace for itself, the challenge to further enhance this movement needs to be addressed to ascertain a sustainable future. Ever since their inception, LEED buildings have faced some opposition owing to anticipations of incremental first costs (Kats 2003). Besides, the precise quantification of the widely claimed green benefits remains fuzzy. This is evident in a large number of publications trying to elucidate the cost-benefits of green buildings (Kats 2003, SWA 2004, Langdon 2004 and 2007, Stegall 2004, Syphers et al. 2004, SBW 2003).

While the green building movement was initiated by environmental concerns, it is evident that in the present context the expectations from these buildings exceed merely environmental interests. About 80% of the respondents in a public survey expressed interest in building green for health and productivity related benefits (Turner 2005). Other researches conclude that about 89% of building life cycle costs (in commercial offices) are attributable to employee costs (Kats 2003), which clearly establishes substantial economic gains by improving occupant well-being/productivity. It seems necessary given the above discussion that the impact of green buildings on occupant well-being and productivity be quantified.

2.2.2 Indoor Environmental Quality (IEQ) in Green Buildings

Research suggests that people in the United States tend to spend 80-90% of their time indoors (Singh 1996, Klepeis et al. 2001, Pillai 2006) while studies also argue that "pollution levels indoors may often be higher than those outdoors" (Hoskins 2003, USEPA 1987). This summarizes the significance of improving building indoor environments to enhance "occupant health, comfort, morale, productivity, and overall well-being" (Singh 1996).

IEQ improvements form one of the focus areas of green building. LEED-NC ascribes about 20% of the total points (15/69 total) in the IEQ category. The IEQ credits included in LEED-NC have been presented in Table 2a. These are based on American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards and consensus-based criteria on design and construction applications (Syal et al. 2008). Pillai (2006) identified building IEQ attributes that affect occupant health as indoor air quality (IAQ), temperature, humidity, ventilation, lighting, acoustics and ergonomic design/safety. These attributes have been linked with the LEED IEQ credits in Table 2.1.

Table 2.1: LEED-NC IEQ Credits and related IEQ attributes (LEED-NC 2007)

Credit No.	Points	Credit Description	IEQ Attribute
Prereq. 1	-	Minimum IEQ Performance	IAQ, Ventilation
Prereq. 2	-	Environmental Tobacco (ETS) Smoke Control	IAQ
Credit 1	1 pt.	Outdoor Air Delivery Monitoring	IAQ
Credit 2	1 pt.	Increased Ventilation	IAQ, Ventilation
Credit 3	2 pts	Construction IAQ Management Plan : 3.1 Construction; 3.2 Occupancy	IAQ
Credit 4	4 pts	Low Emitting Materials: 4.1 Adhesives and Sealants; 4.2 Paints and Coats; 4.3 Carpet Systems; 4.4 Composite Wood and Agrifiber Products	IAQ
Credit 5	1 pt.	Indoor Chemical and Pollutant Source Control	IAQ
Credit 6	2 pts	Controllability of Systems: 6.1 Lighting; 6.2 Thermal Comfort	Lighting, Temperature, Humidity
Credit 7	2 pts	Thermal Comfort: 7.1 Design; 7.2 Verification	Temperature, Humidity
Credit 8	2 pts	Daylight and Views: 8.1 Daylight 75% of Spaces; 8.2 Views for 90% of Spaces	Lighting

These IEQ credits reflect the bulk of occupant well-being and productivity concerns addressed in LEED buildings. In order to comprehend potential well-being/productivity benefits that may be attained from improved IEQ in LEED buildings, it is necessary to understand the general relationships between building IEQ and occupant well-being/productivity. The next category of review, builds on such literature.

2.3 BUILT ENVIRONMENT AND OCCUPANT WELL-BEING/PRODUCTIVITY

Various aspects of the built environment have the potential to affect the overall well-being of its occupants. Pillai (2006) explored potential health effects of design and construction improvements based on various LEED-NC categories. Holden (2007) summarized further linkages between occupant health and LEED based design and construction strategies.

Several other publications have explored such relationships between various aspects of buildings and occupant health in the past, especially those among building IEQ and occupant health and productivity (Singh 1996, Hoskins 2003, Fisk and Rosenfeld 1997, Fisk 2000, May 2006, IOM 2000, Seppanen et al. 2004, Wargocki et al. 2000). The next section presents an overview of such literature.

2.3.1 IEQ and Well-being/Productivity

Health (well-being) has a multidimensional perspective and may be defined as a "state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO 2007). Physical health includes "conditions related with specific illnesses and the functioning of a person's body systems" (Adkins et al. 2000) while psychological health comprises of "the attitudes and feelings one has about various life domains, including work" (Spector 2006).

Among various physical health effects of the built environment, asthma and respiratory allergies have been considered among the five most significant health conditions causing sick leaves among US workforce (USA Today 2008). Improvements in these conditions have the potential to provide significant economic gains (Fisk 2000, Fisk and Rosenfeld 1997). Together asthma and respiratory allergies account for 27 lost work days per year to each affected employee. Allergic disorders affect more than 35 million people with upper respiratory systems each year in the US (Syal 2008).

As per a 2005 study, about 54% of all people diagnosed with asthma (total 22.2 million were diagnosed with asthma) in the US were of working age (Moorman et al. 2007). Literature is rich with studies that demonstrate an association between asthma/respiratory allergy problems and workplace exposures to such allergens (Cirla 2005, Spengler and Sexton 1983, Goe et al. 2004, Burr et al. 2008, Henneberger et al. 2005, Schleiff et al. 2003). Fisk (2000) argues that the design of workplaces can promote or reduce allergens and irritants, which can trigger symptoms of allergies and asthma.

Psychological health includes issues such as anxiety, depression, and stress and may also be described in positive ways such as feelings of confidence, energy, and generally being in good spirits (Spector 2006). Among psychological health effects, depression has been observed among the most significant chronic conditions causing worker absenteeism in the United States (USA Today 2008, Burton and Conti 1999). Studies have found depression as causing the highest productivity loss among several health effects in work environments (Hemp 2004, Wang et al. 2004). Existing research provides some evidence of improved productivity/performance among workers as well as students resulting from improved lighting, view, ventilation, and air temperature conditions (HMG 1999, HMG 2003).

Pillai (2006) categorized IEQ attributes with potential health impacts through an extensive literature review. A discussion of these IEQ attributes and their possible effects on occupant well-being/productivity is provided below (Modified from Pillai 2006).

1. Indoor Air Quality: Indoor air has been defined as the air within a building occupied for a period of at least one hour by people of varying states of health (Pillai 2006). The 70's energy crisis is often held responsible for poor IAQ as it triggered development of tighter building envelopes (Hoskins 2003). The US Department of Health (1999) attributes the rise in indoor air pollution and associated health problems to reduced ventilation and increased use of synthetic building materials. NIOSH (Pillai 2006) also attributes majority of IAQ problems to inadequate ventilation (53% cases), and indicates other causes of such problems as inside contaminant source (15%), outside contaminant source (10%), microbial growth (5%), and building materials (4%).

   Indoor air pollutants (IAP) may be categorized as chemical and biological. Chemical pollutants may include volatile organic compounds (VOCs), asbestos, radon, carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxides (NOx), respirable suspended particulates (RSPs), construction chemicals, ozone, unpleasant odors, and lead. Biological pollutants may include molds, dust mites, animals, cockroaches, endotoxins, houseplants, pollen, and other infectious agents (IOM 2000, Pillai 2006).

Among chemical pollutants, IOM (2000) found evidence of relationships of certain RSPs (for example: Environmental tobacco smoke), NOx emissions, and formaldehyde among chemical pollutants, with asthma exacerbations. Among biological pollutants, the report identified such relationships with molds, dust mites, certain animals (dog, cat), birds, and some infectious agents (*Rhinovirus, Chlamydia pneumoniae, Mycoplasma pneumoniae, Respiratory Syncytial Virus*).

Literature also identifies Radon as a cancer risk (May 2006, Pillai 2006). NOx, CO emissions and RSPs have been associated with various respiratory allergies and sick building syndrome (SBS) symptoms (Pillai 2006, Holden 2007, Jaakkola et al. 1994, Skov et al. 1990). DTIR (1995: Referenced in Pillai 2006) links ozone to eye irritations and respiratory infections while lead is associated with slow mental development, learning and behavioral problems, damage to nervous and reproductive systems and high blood pressure (Pillai 2006).

Pillai (2006) argues that most of these IAQ problems can be significantly reduced by adequate outdoor ventilation and maintaining appropriate temperature and humidity levels. Other publications have also established the health and/or productivity benefits of improved ventilation rates (Fisk 2000, IOM 2000, Wargocki et al. 2000, May 2006), temperature

(Seppanen et al 2004, Spengler and Sexton 1983), and humidity levels (Holden 2007).

2. Temperature: "Room temperature has potential impacts on prevalence of SBS symptoms and occupant satisfaction with air quality" (Pillai 2006). High temperatures are associated with the prevalence of sick building syndrome while low temperatures can induce temporary deterioration in the "dexterity of hands" (Seppanen et al. 2002). Seppanen et al. (2004) also found a relationship between rise in temperature (above 25° C) and productivity decrement in typical office environments. Nielsen (2002) argues that temperature plays a crucial role in the growth of molds. Temperature also has a role in the off-gassing from building materials (USEPA 2005).

3. Humidity: Various publications discuss significant associations between humidity levels and concentrations of indoor air pollutants (Nielsen 2002, Arens and Baughman 1996, Fisk and Rosenfeld 1997, IOM 2000). Correlations between humidity levels and health effects are often found to be building-specific (Pillai 2006). Arens and Baughman (1996) identified the factors affecting humidity/moisture related health effects as; outdoor climate, surface properties encountered across rooms and HVAC ducts, water in cooling and humidification systems, intermittency of operation in cooling systems, and other moisture sources like rain penetration, rising

damp, and plumbing leaks. Temperature, humidity, and air movement often interact (Pillai 2006). In very humid conditions, the temperature appears to be warmer than it would be in drier air (LHC 1990: Referenced in Pillai 2006).

4. Ventilation: Ventilation is used to bring outdoor air to the inside and remove or dilute indoor air pollutants. The air supplied can be entirely outdoor air or be mixed with re-circulated return air (Pillai 2006). Seppanen et al. (1999) considers the relationship between ventilation rates and occupant health as indirect. Studies show that health and perceived air quality will usually improve with increased outside air ventilation (Seppanen et al. 2002). NIOSH investigators have found a majority of IEQ problems caused by ventilation system deficiencies and overcrowding (NIOSH 2005).

5. Lighting: Lighting is a significant factor in the indoor environment however limited research has been conducted in the area of health effects of lighting in the context of design and construction of buildings (Pillai 2006). Daylight has the potential to reduce the incidence of health problems caused by the rapid fluctuations in artificial lighting (Boyce and Hunter 2003). Studies suggest that classrooms without daylight may upset the basic hormone pattern of children and influence their ability to concentrate

or cooperate or affect their performance negatively (Plympton et al. 2000, Fisk 2000).

The amount of light we need in an indoor environment varies on the type of surfaces, the individual's vision, and the type of task being done (Pillai 2006). Glare, flicker, lack of contrast, inadequate illumination or unsuitable spot lighting can all lead to health problems and discomfort (Pillai 2006). Romm and Browning (1994) found substantial productivity improvements and reduced absenteeism rates with improved lighting conditions in eight work environment case studies.

6. Acoustics: Noise problems indoors may be related to outdoor sources, indoor sources or bad acoustics. Excessive exposure to noise can result in hearing loss, which could become permanent after continued exposure (Pillai 2006). Noise has the potential to mask important sounds and disrupt communication. The effects can vary from a slight irritation to a serious safety hazard involving an accident or even a fatality because of the failure to hear the warning sounds of imminent danger (Suter 1991). Noise that is too loud for comfort is intrusive whether it is a single, unexpected sound or a continuous one (LHC 1990: Referenced in Pillai 2006).

This research focuses on asthma, respiratory allergies (physical health), depression, and stress (psychological health), as well as direct productivity improvements from LEED based IEQ changes. Figure 2.2 presents relationships between LEED IEQ credits and these selected well-being/ productivity attributes, as found in literature.

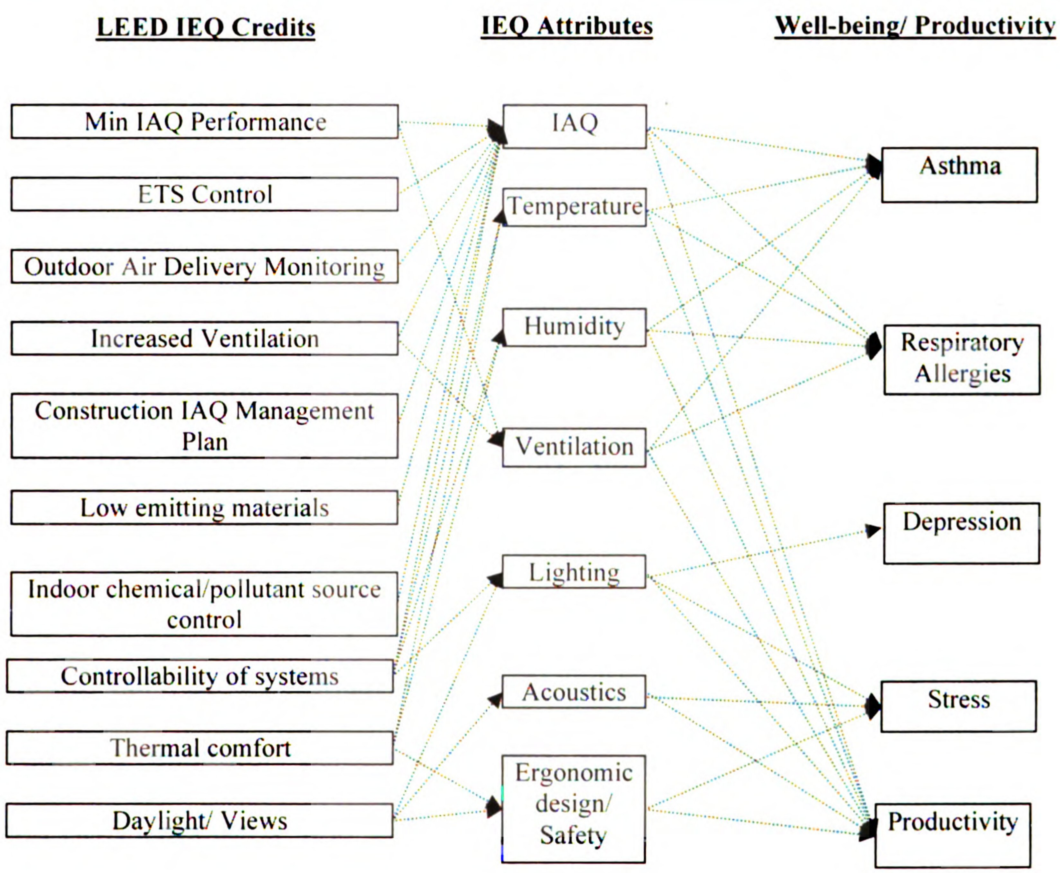

Figure 2.2: LEED IEQ-Occupant Well-being/Productivity Structure

This structure helps in identifying potential LEED-IEQ credits related with occupant well-being/productivity attributes of interest (AOI). All LEED IEQ credits were found to have such relationships. Hence all LEED-IEQ credits were included in the study scope.

2.3.2 Quantification of Occupant Well-being and Productivity Benefits

The effect of improved IEQ conditions on well-being and productivity/ performance may be felt in our daily work lives. Various studies have investigated these relationships in distinct work environments. Burton et al. (2001) found a 10% performance reduction among telephone customer service workers facing allergy problems as compared to healthy workers. Hemp (2004) reported a 9.3% average productivity loss due to respiratory allergies and asthma related conditions. Wargocki et al. (2000) estimated a 2% productivity improvement in typical office tasks resulting from improvements in ventilation rates in three independent experiments, while Seppanen et al. (2004) established a relationship of 2% decrement in work performance per °C increase in temperature above 25° C.

Fisk (2000) estimated potential annual economic gains ranging US$7- 18 billion from reduced respiratory diseases, asthma, and allergies; US$10-30 billion from reduced SBS symptoms; and $20-160 billion from direct improvements in worker performance across United States. Romm and Browning (1994) also found significant economic benefits from improved productivity, improved work quality, reduced defects, reduced absenteeism, and increased sales in several case studies, resulting from IEQ improvements.

Pillai (2006) identified some potential design and construction strategies based on LEED-NC IEQ credits that could be useful in reducing certain health problems (asthma and allergies, SBS conditions). Similarly, IEQ improvement strategies may be devised for improving other well-being/productivity conditions. While the possibility of substantial economic gains upon implementing such healthy building strategies is evident, these may require an incremental investment (SBW 2003, SWA 2004), which is often a significant consideration when making building decisions. In order to assist investors in making better informed decisions, it is necessary to elucidate the long-term economic impacts of incorporating these strategies (Kats 2003). This warrants the need for conducting a life cycle cost analysis.

2.4 LIFE CYCLE COST ANALYSIS (LCCA)

This category presents an overview of life cycle cost analysis and its applicability to the current research. Also discussed here are recent LCCA related publications in the green building domain.

2.4.1 LCCA Overview

Life cycle cost analysis has been defined as an "economic assessment of competing alternatives, considering all significant costs over the economic life of each alternative" (Kirk and Dell'Isola 2008). It enables an investor to make decisions based on costs and benefits throughout the economic life of an investment. In the building industry this economic life may include:

1. Initial costs for design and construction of buildings.
2. Costs incurred during the operational life of the building.

3. End of life or demolition costs.

Historically, building decisions have been based in initial investments. Bull (1993) suggests that the realization of building operational costs having significant budget impacts in 1930's helped in transforming this economic decision making process towards a more long-term approach. In the present context, with employee costs being 90% of building life-cycle costs (Kats 2003), any savings among such employee costs could result in substantial life cycle gains. Such savings must be included in present day economic assessments of buildings.

Various sources provide information regarding several economic analysis methods in the building industry (Wolff 2006, Bull 1993, Dell'Isola and Kirk 1981, Ruegg and Marshall 1990). Among these, simple payback, net present value, and internal rate of return have been consistently discussed in building economics literature. These are summarized below.

1. Simple payback enables a user to calculate the expected time period for availing the investment returns. This method does not account for time related variations (discounting, inflation) in costs. This is often viewed as a significant limitation (Norris 2001, Woodward 1997). Although simple payback is commonly used as a coarse filter to eliminate unrealistic options, it is not recommended for detailed economic analysis to support decision making (Bull 1993).

2. Net present value (NPV) permits discounting the total investment throughout the building life to its present value. Such overall investment results may then be compared among competing alternatives and the least overall cost option may be selected. NPV accounts for time related changes in the value of money by utilizing the concepts of discounting and inflation. It is primarily useable when comparing alternatives, and not to assess the investment value for a single scheme (Bull 1993).

3. Internal rate of return (IRR) considers all benefits during the investment life as earnings and permits calculation of these as interest earned. This interest rate can then be compared with the expected returns for alternative investments to determine the economic feasibility of the investment. Like NPV, IRR is also a discounted cash flow technique, which implies that it accounts for time value of money.

Other commonly used LCCA methods are based on minor modifications of the above methodologies.

4. The annualized value method uses the NPV result and amortizes it over the study period. This is useful in comparing product alternatives with differing lifetimes or when addressing non-recurring costs.

5. Discounted payback allows incorporating time related cost variations in the simple payback methodology. This method utilizes annualized inputs for assessment of the time period expected for investment returns.

6. Benefit-cost ratio (B/C ratio) allows separate calculation of life cycle costs and benefits while incorporating the discount rate, and inflation rate. A net ratio of benefits/costs greater than 1 reveals a favorable investment and that less than 1 reveals a potential loss. This method also includes discounting future costs to their present value and may be considered as part of the NPV umbrella. The same method is often called cost-benefit ratio in literature.

Recent green building literature is rich with benefit-cost evaluations. While most of these studies discuss potential economic gains from improved occupant health and productivity, they either refrain from quantifying such gains (Stegall 2004, SWA 2004) or base the calculations on gross nationwide data and assumptions (Kats 2003, SBW 2003). The following section summarizes some of these publications.

2.4.2 LCCA and Green Buildings

Kats (2003) compared economic data for 33 LEED projects with hypothetical non-LEED buildings. This study used an NPV analysis with a 5% discount rate and 2% inflation. The authors argue that these are representative of rates used by public sector entities and in line with common inflation projections. The research team gathered actual cost data for the LEED projects and generated incremental cost reports based on extensive discussions and interviews with building industry professionals. An average 2% incremental investment for LEED buildings was established.

Data on utility savings and waste reduction was obtained from USGBC databases and economic impacts were calculated using typical utility costs and landfill diversion impacts for the State of California. However, no case study specific data was gathered for estimating well-being and productivity impacts of these buildings. These well-being/productivity benefits were assumed, based on existing literature (Fisk and Rosenfeld 1 997). The authors argued that such benefits were conservatively estimated; however, in context of their overall findings these form about 70% of the total estimated benefits from LEED buildings.

In a study at Carnegie Mellon, Stegall (2004) conducted the economic assessment of a new LEED-Silver residence hall facility considering the incremental investment, and the annual energy cost savings. This study also established a 2% incremental cost for the LEED building. Once again, the author collected actual cost data for the new facility and conducted interviews with the university project managers and architects to compare costs with similarly built conventional buildings. The annual energy costs were determined to be about

22% lesser than a similar facility based on the university's typical design and construction approach. The author did not conduct an overall life cycle cost analysis to determine the net economic implications. In addition, the quantification of improved well-being and/or productivity gains is missing, even though the author discussed the potential for such benefits in the conclusions.

A study conducted for the Seattle office of Sustainability and Environment (SBW 2003) quantified benefit-cost ratios of incorporating LEED in two state buildings. The study assumed a 25-year life cycle, two discount rate scenarios of 2% and 6% and an inflation rate of 2.8%. The authors identified three separate benefit-cost ratios based on varying benefit considerations:

1. Primary benefit-cost: These include direct observable financial impacts such as additional costs for bike racks, benefits due to reduced energy consumption etc.
2. Primary and secondary benefit-cost: These include less observable impacts such as productivity gains.
3. All benefit-cost: These include citywide effects, such as utility incentives that may pay for conservation measures.

This study found a 1.2% incremental cost for LEED buildings and established benefit-cost ratios of 0.78-1.11, 1.49-2.16, 1.19-1.72 for the respective case scenarios. Once again, the study establishes significant gains based on improved occupant well-being and productivity but these numbers are based on statewide data regarding general productivity-health relationships, existing nationwide research, and the authors' assumptions instead of live case study analysis. None of the studies summarized above considered a case study-based approach for well-being/productivity analysis.

Rocky Mountain Institute (Romm and Browning 1994) found energy savings, and quantified the productivity gains from 8 separate work-environment case studies with lighting upgrades. They however, did not link such gains to improved health conditions. A recent University of Pittsburgh study (Ries et al. 2006) determined a benefit-cost ratio of 1.7 from a live case study where occupants from a manufacturing facility moved to a new LEED building. Among the two components of manufacturing plant workers and office employees, the study accounted for absenteeism for all workers, while productivity gains were calculated only for manufacturing workers based on increased production data. The authors restrained from quantifying any health/productivity effects for the associated office employees.

Several other initiatives have focused on establishing only the initial cost effects of LEED buildings, rather than the complete life cycle cost analysis. The GSA LEED cost study (SWA 2004) was commissioned to determine incremental costs for incorporating LEED in existing GSA building standards. The study established average cost premiums ranging from 0-8.5% for incorporating LEED for various building scenarios.

Langdon (2004) established a 0-3% incremental investment for LEED buildings based on a comparative analysis of 45 LEED and another 93 similar non-LEED facilities. Upon a second review (Langdon 2007) the same team determined no significant cost premiums for LEED facilities. They compared cost data from 83 LEED and 138 non-LEED academic, laboratory, library, community centers, and ambulatory care facilities. The authors attributed this variation to the changing markets, and project teams incorporating sustainability concerns in their initial budgets. They also discuss that building costs and incremental investments are very specific to the projects and generalizing them may not be appropriate. This further strengthens the need for conducting case study based life cycle cost analysis rather than utilizing macro-level data.

2.5 CHAPTER SUMMARY

This Chapter presented an overview of the existing literature under three categories, Green Building and IEQ, Built Environment and Occupant Well-being/Productivity, and Life Cycle Cost Analysis. Literature presents strong evidence of relationships between indoor environments and occupant well-being/productivity. Although several authors hypothesize substantial economic benefits from improvements in occupant well-being and productivity in LEED offices, resulting from better IEQ (Fisk and Rosenfeld 1997, Kats 2003, SBW 2003), literature presents limited case study-based evidence of such improvements. However, outside the scope of LEED-related literature, studies have demonstrated such improvements in occupant well-being and productivity resulting from IEQ improvements (Burton et al. 2001, Hemp 2004, Romm and Browning 1994, Seppanen et al. 2004, Wargocki et al. 2000).

Occupant well-being and productivity improvements in LEED buildings have often been considered intangible/ difficult to measure, especially in office settings (Kats 2003, Ries et al. 2006, SBW 2003). The possibility of large economic benefits related with such improvements warrants a need for better quantification of such improvements.

CHAPTER 3

METHODOLOGY

3.1 CHAPTER OVERVIEW

This Chapter presents a discussion of the research methodology. After identifying the research objectives and scope, a four-phase approach was followed. These phases include literature review, data collection and analysis, life cycle cost analysis, and interpretation. Figure 3.1 presents an overview of this methodology.

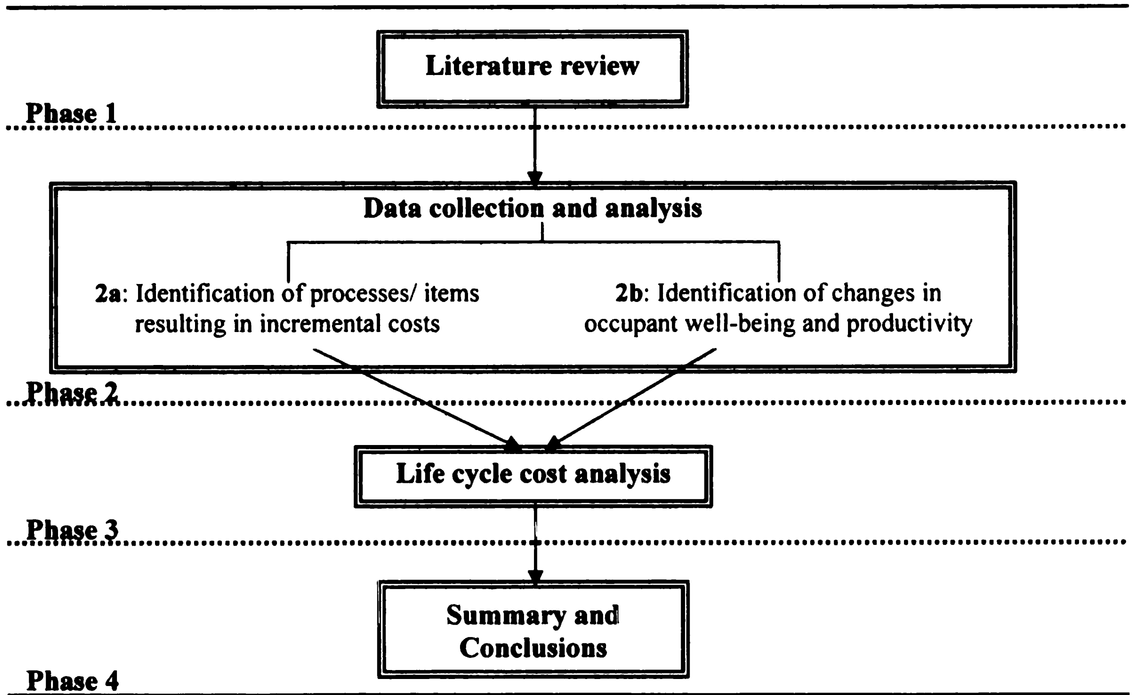

Figure 3.1: Methodology Overview

Phase 1 included a review of relevant literature. This review, presented in Chapter 2, assisted in summarizing existing research in this area. Phase 2 included collection and primary analysis of the research data. This was sub-divided in phase 2a that dealt with identification of processes/items resulting in incremental costs, and phase 2b that addressed changes in occupant well-being and productivity. The work done in this phase is presented in Chapter 4. Phase 3 included economic analysis of the phase 2 outputs from an LCCA perspective to determine the net benefit-cost ratio for the investment (i.e. constructing the building based on LEED® IEQ credits). The work performed in Phase 3 is presented in Chapter 5. Finally, the overall research conclusions forming phase 4 are presented in Chapter 6. The methodology used for each phase is elaborated in the following sections.

3.2 PHASE 1: LITERATURE REVIEW

The literature review conducted to develop the necessary background for this research provided input for several steps in the following phases. Figure 3.2 presents the phase 1 methodology.

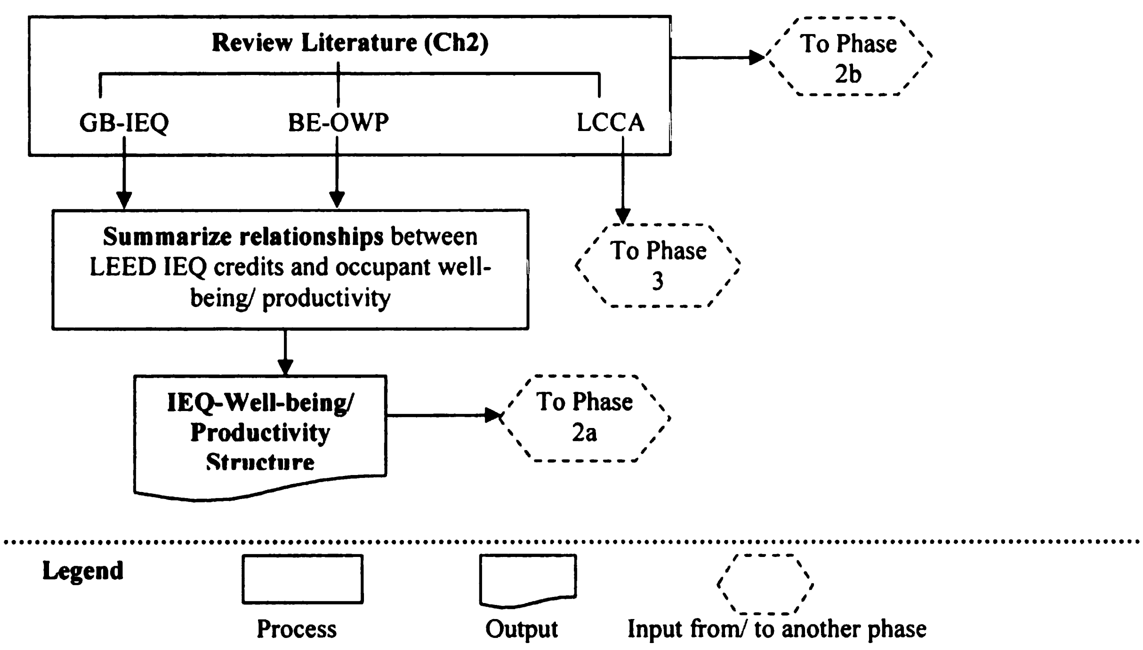

Figure 3.2: Phase 1 Methodology

Based on the research objectives, three categories of literature were identified for review. These include Green Building and Indoor Environmental Quality (GB-IEQ), Built Environment and Occupant Well-being/Productivity (BE-OWP), and Life Cycle Cost Analysis (LCCA). The GB-IEQ literature was reviewed to develop an understanding of current green building trends and challenges with a focus on IEQ aspects of LEED buildings. The BE-OWP review focused on linking building IEQ aspects with selected occupant well-being and productivity attributes. Among several physical/psychological health conditions, four were selected for assessment in this research. These four attributes of interest (AOI) are:

1. Physical well-being attributes
    a. Asthma
    b. Respiratory allergies
2. Psychological well-being attributes
    a. Depression
    b. Stress

In addition, the direct effects of IEQ on productivity were also studied. Next, relationships between LEED IEQ credits and these AOI and productivity were summarized in the IEQ- Well-being/Productivity structure, presented as Figure 2.2 in Chapter 2. This structure identifies relationships between LEED IEQ credits and occupant well-being and productivity. This input is useful for the identification of processes/items causing incremental cost in phase 2a.

LCCA literature was reviewed to develop an overall understanding of the subject, to select an analysis method for this research, and to identify the economic analysis variables and data requirements. This background assisted with planning the phase 3 LCCA as well as phase 2 data collection. The literature review is presented in Chapter 2. The literature reviewed in phase 1 helped extensively in refining the research objectives and methodology.

3.3 PHASE 2: DATA COLLECTION AND ANALYSIS

Phase 2 includes the data collection and analysis conducted to provide input for LCCA in phase 3. The research data was collected from two case studies. The following sections provide insight into the scope of data collection and the case studies used in this research.

3.3.1 Scope of Data Collection

The data required for this initiative included two major components:

1. Data for identifying processes/items causing incremental cost among LEED-IEQ credits.
2. Data for evaluating changes in occupant well-being/productivity, as a result of moving to an office with LEED-IEQ.

This data was collected from selected case-study projects. Identification of processes/items causing incremental cost was conducted under phase 2a and evaluation of changes in occupant well-being was conducted under phase 2b.

3.3.2 Case Studies

Two case-study offices were identified where occupants were either planning to move or had recently moved from conventional offices to new LEED facilities. The other selection criteria were, ease of accessibility and the organizations' willingness to participate in the research initiative. To maintain confidentiality, these have been referred to as Case Studies one and two (CS1, CS2) throughout this publication.

CS1 was a 60 (approximately) employee organization in Michigan. The company had recently moved to a new office that was awarded LEED Platinum ratings under both the CS 2.0 (LEED- Core and Shell) and CI 2.0 (LEED- Commercial Interiors) rating systems. CS2 was a 200 (approximately) employee organization, also in Michigan. Most occupants were slated to move to a newly constructed office building expecting a LEED Silver rating under the NC2.1 (LEED- New Construction) rating system. The study sample included all employees from CS1 and about 90% employees from CS2 (The other employees from CS2 organization were expected to continue operations in the old building).

Contact persons were identified within both case study organizations and among the constructors involved with these projects. Initial meetings were held with each of the contact persons to establish partnerships, provide an overview of the project objectives, and discuss their potential roles in the study. Since this research required communication with a large population, a separate e-mail account was set up with access restricted to the research team. All communication related with this project was channeled through this e-mail account.

The selected case studies provide variety in terms of population size as well as the level of LEED rating (Platinum vs. Silver) and the certification system (CI/CS vs. NC). This allowed assessment in varying circumstances thus providing depth to the analysis. After finalizing case studies and developing the communication channels, data collection and primary analysis were performed under the two parallel paths presented as phase 2a and 2b.

3.3.3 Phase 2a: Processes/Items Resulting in Incremental Costs

Literature presents evidence of the existence of incremental costs for LEED buildings. However, the values of incremental costs identified in literature vary considerably and such findings are often loaded with uncertainties. These uncertainties arise from approaches comparing LEED buildings to either hypothetical non-LEED buildings (Kats 2003, Stegall 2004) or to existing buildings that may not always be comparable (Langdon 2004, Ries et al. 2006, SWA 2004). In addition, these studies typically focus on evaluating overall incremental cost for LEED buildings, while the focus of the current research is to assess only building IEQ-related cost (and benefit) impacts. These concerns directed the research team to develop an alternative approach for assessment of the incremental cost for LEED-IEQ credits incurred on the case study projects.

The IEQ-Well-being/Productivity structure presented as Figure 2.2 identifies all LEED IEQ credits as possibly affecting occupant well-being/productivity. These credits were analyzed to identify processes/items resulting in incremental costs. LEED credits are awarded upon a review of project documentation, which provides input regarding how the requirements for each credit were achieved. A review of such documentation provides information regarding design and construction strategies used to attain the credits, thus offering an insight into processes/items influencing the first cost for the project. Figure 3.3 presents the methodology used for this phase.

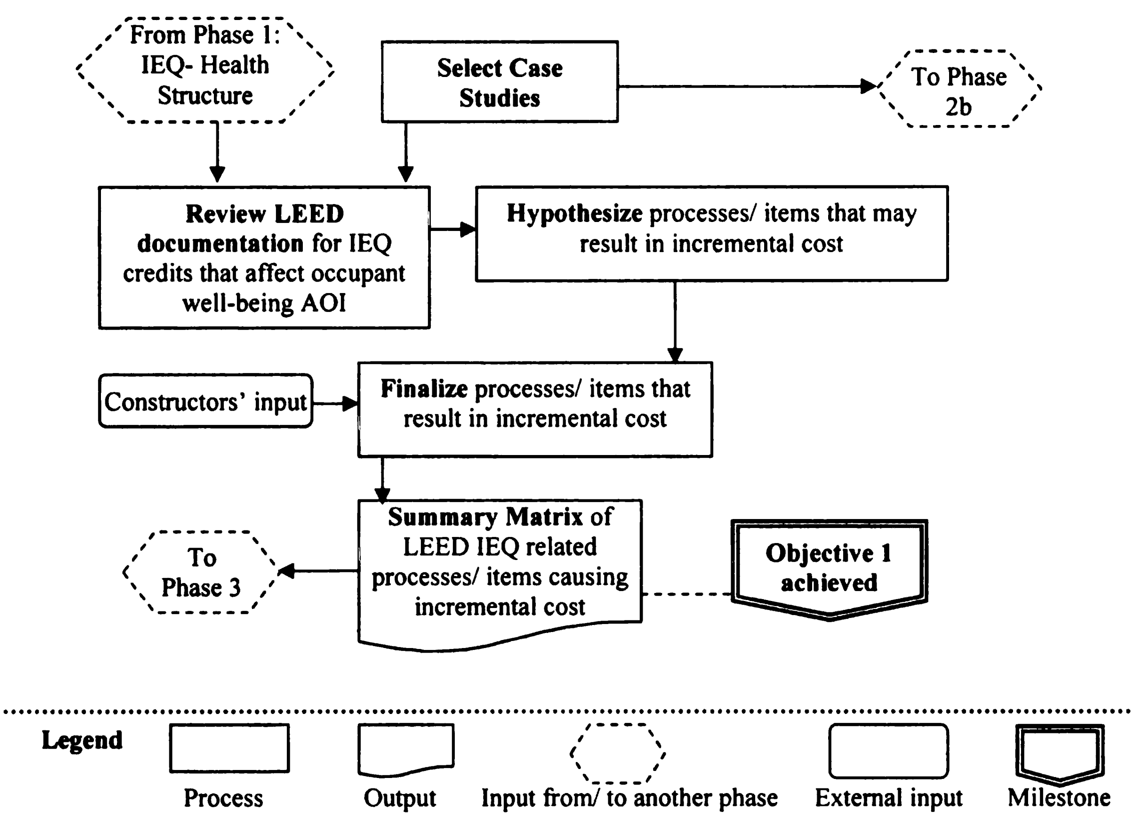

Figure 3.3: Phase 2a Methodology

The researchers reviewed LEED IEQ documentation from the case studies to hypothesize processes/items that may be different from conventional (non-LEED) building projects. This documentation included LEED templates and submittals furnished by the case study design/construction teams for USGBC review. Next, feedback was obtained from the constructors to finalize such processes/items, which had not been used for their non-LEED projects. The constructors were asked to reject the hypothesized items as causing incremental cost if these formed part of the local building codes, or if these had become market standards or were being used for most projects over the past 5-6 years. This feedback was obtained through personal discussions, and e-mail communication.

The processes/items finalized above, represent design and construction work undertaken primarily to attain LEED certification. Costs associated with such work are specific to LEED buildings and considered incremental investments over conventional projects. This approach incorporates a review of the same information that is assessed by LEED reviewers for award of LEED credits. It eliminates the uncertainties resulting from comparing non-LEED buildings or those caused by using hypothetical scenarios. Estimation of incremental costs for the processes/ items identified above was undertaken under phase 3.

3.3.4 Phase 2b: Changes in Occupant Well-being and Productivity

Data collection for changes in occupant well-being falls within the scope of Epidemiological research. Epidemiology is defined as "the study of the distribution and determinants of disease frequency in human populations" (Hennekens and Buring 1987). The current research explores the effect of building indoor environment on disease frequency. This research fits an intervention type-prospective cohort study design within epidemiology.

Prospective cohort studies are used to determine changes in the people's health conditions by following them forward in time. In this research, the case study occupants were followed from their old (conventional) office through their move to the new LEED office, the move being viewed as an intervention. Typically, subjects in a cohort study are classified based on the presence or absence of exposure to some particular factor. In this research, that factor is the move to the new LEED office. However, only occupants moving to the LEED building were studied, while it was assumed that health conditions remain unaffected for occupants continuing work in the old office. Future initiatives may consider releasing this assumption by selecting case studies where comparable fractions of the sample population may be expected to continue operations in the old (non-LEED) office.

Pre-move (while occupants worked in non-LEED offices) and post-move (after occupants started working in LEED offices) occupant surveys were used to collect data regarding occupant well-being and productivity. Phase 2b includes development, administration, and analysis of these surveys to determine the annual benefits from changes in occupant well-being/productivity. Figure 3.4 presents the methodology used in this phase.

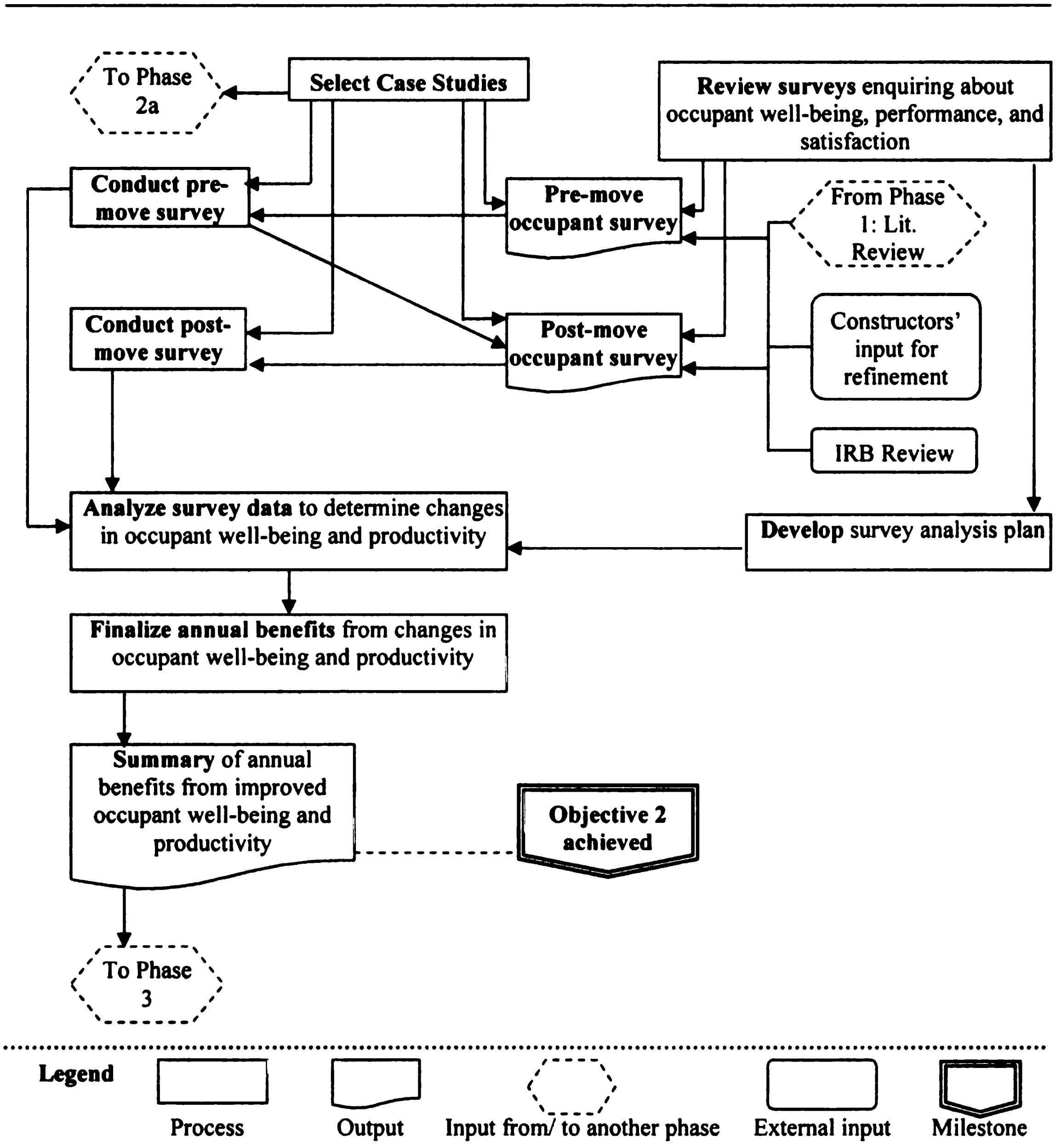

Figure 3.4: Phase 2b Methodology

3.3.4.1 Pre-move Occupant Survey

The primary objective of conducting the occupant surveys was to determine changes in occupant well-being/productivity upon moving from conventional to LEED offices. To attain this, data was collected under three key categories:

1. General occupant information: The general occupant information category included questions regarding demographic information and the occupants' workspace. Questions in this segment were based on building post-occupancy evaluation literature (CBE 2004, Fard 2006, Lee 2007, Prakash 2005, Ries et al. 2006).

2. Occupant well-being: Occupant well-being questions focused on the occupants' health background and their recent health conditions. Recent health conditions were studied over 4-weeks, similar to previous studies. Occupant well-being attributes and questions were defined using input from the BE-OWP and medical literature (Kessler et al. 2003, Kessler et al. 2004).

3. Work environment satisfaction: Work environment satisfaction questions focused on getting occupant feedback regarding their satisfaction with the office IEQ, and their perception of the effect of IEQ on their productivity. Questions in this category were based on building post-occupancy evaluation literature (CBE 2004, Fard 2006, Lee 2007, Prakash 2005, Ries et al. 2006).

Data from categories 2 and 3 provided the key input needed to evaluate occupant well-being/productivity-related changes in the work environment. In addition to these, data was collected under two other categories on an exploratory basis:

4. Productivity and performance: The productivity and performance category included questions seeking occupant perception regarding their performance, as a 4-week snapshot. This provided additional information regarding variation in perceived performance resulting from the move. These questions were based on the surveys reviewed in the earlier two categories.

5. Other effects of work environment: Questions in this category focused on getting occupant input regarding their general behavior/attitude, as well as environmental initiative, and their knowledge of green (LEED) buildings. This provided exploratory input regarding spill over effects of changes in the work environment on the occupants' attitude/lifestyle. These questions were based on social sciences literature (Dunlap et al. 2000, Stern et al. 1999). This data was collected as part of a larger research initiative (Syal et al. 2008) and has not been analyzed in this thesis.

For quality assurance of the survey data, questions seeking the respondents' confidence levels were built in with key survey questions. Eventually, occupant well-being responses with <50% confidence were eliminated from the analysis.

The draft pre-move survey was circulated to attain subject specific input, among associated researchers from Built Environment, Epidemiology, Industrial Psychology, and Behavioral Sciences. Feedback was also attained from the case study constructors and the university's Institutional Review Board (IRB).

The final version of this survey was then developed using an online survey tool (Survey Monkey 2008). The pre-move survey links were forwarded to the study population through e-mail with a 3 week response window and followed up with several participation reminders. The pre-move survey has been provided as Appendix A1.

The survey data was downloaded in MS Excel spreadsheets and coded per the analysis methodology discussed in section 3.3.4.3. A preliminary analysis was conducted to provide feedback for development of the post-move survey. This preliminary analysis suggested a drop in the respondents' interest as number of questions increased. Also through this preliminary analysis, the need to conduct separate surveys for the two case studies to facilitate the analysis was realized.

3.3.4.2 Post-move Occupant Survey

The post-move survey was condensed and developed as separate versions for each case study. Since the demographic and health background information was already attained, such questions were easily eliminated from the general occupant information and occupant well-being categories. Based on discussions with the research team, selected questions were eliminated from the other three categories as well. The post-move survey was administered in the same manner as the pre-move survey with a 2-week response window. The post-move survey has been provided as Appendix A2.

3.3.4.3 Analysis of Survey Data

Each response was accompanied by a unique ID and the respondent's full name. Based on name, pre-move and post-move IDs were correlated and names were removed from the analysis sheet to protect the respondents' privacy. Next, a coding plan was implemented to represent all responses as numerical values. Typically, single digit numerical values were used to code responses; however, responses such as age that already contained numerical values were not coded while those with a numerical range were coded as the range average (for example, range 1-5 was coded as 3). The complete survey coding plan is presented as Appendix A3.

An analysis plan was developed to identify the statistical analysis requirements for the research. This was finalized in consultation with a statistical consultant. Descriptive statistical methods including histograms and box plots were used for the basic analysis in all categories. Further analysis of occupant well-being and productivity data was performed using hypothesis testing (paired t-tests) in order to provide statistically relevant inputs for the economic analysis. The analysis plan has been summarized in Table 3.1.

Table 3.1: Occupant Survey Analysis Plan
(Pr: Pre-move data, Po: Post-move data)

Survey Category	Sub-categories	Objective of data collection	Analysis Method	References for Survey Development
General occupant information	Demographic information	To define the study sample.	Histograms (Pr)	CBE 2004, Fard 2006, Lee 2007, Prakash 2005, Ries et al. 2006
	Workspace definition		Histograms (Pr, Po)	
Occupant well-being	Health background	To define the study sample.	Histograms (Pr)	BE-OH literature review, Kessler et al. 2003 and 2004.
	Health snapshot	To determine changes in occupant well-being	Box plots (Pr vs. Po) Paired t-tests (Pr vs. Po)	
Work environment satisfaction	Satisfaction with various IEQ attributes	To identify changes in satisfaction	Box plots (Po-Pr)	CBE 2004, Fard 2006, Lee 2007, Prakash 2005, Ries et al. 2006
	Effect of IEQ on productivity	To determine changes in productivity	Box plots (Pr vs. Po) Paired t-tests (Pr vs. Po)	
Productivity and performance	Performance snapshot	To explore direct effects of the move on changes in performance	Box plots (Po-Pr)	Kessler et al. 2003 and 2004, Ries et al. 2006
	Initiative at work snapshot			
Other effects of work environment	General behavior/ attitude	To explore spill-over effects of the move on environmental leadership/ general attitude	Box plots (Po-Pr)	Dunlap et al. 2000, Stern et al. 1999
	Environmental leadership			
	Knowledge of green buildings			

Further discussion and findings from the phase 2b occupant survey analysis as well as the phase 2a incremental cost assessment have been provided in the next chapter.

3.4 PHASE 3: LIFE CYCLE COST ANALYSIS (LCCA)

Phase 3 includes monetization of phase 2 findings and an economic analysis using the LCCA approach. Figure 3.5 presents the phase 3 methodology.

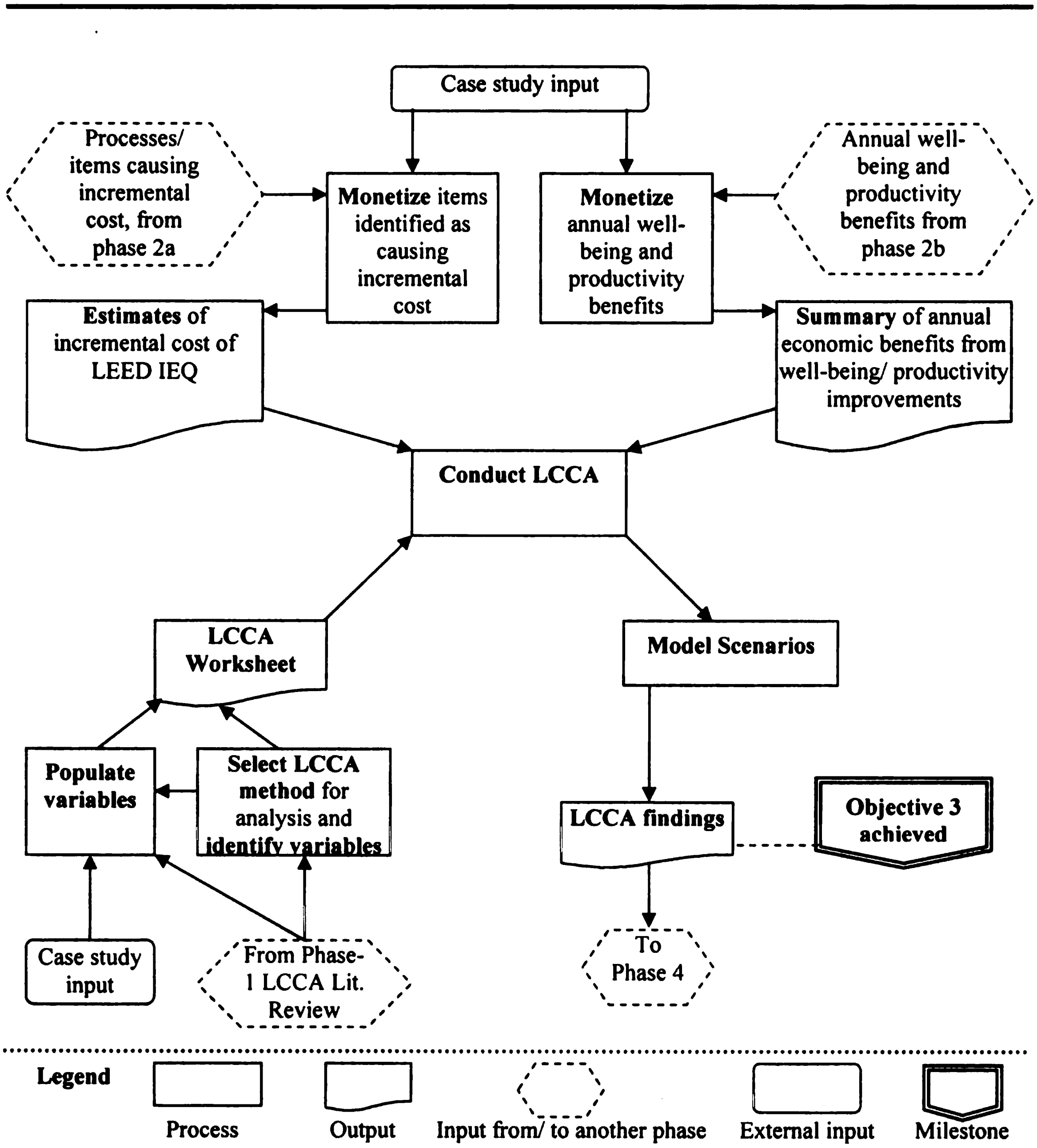

Figure 3.5: Phase 3 Methodology

The processes/items causing incremental cost, finalized in phase 2a, were monetized using input from the case study constructors and additional estimates from of-the-shelf cost manuals (Means 2007). The annual benefits attained through improved occupant well-being and productivity were monetized using employee wage information from case studies and typical industry wages.

LCCA-related literature review helped in determining the economic analysis methods for this research. Benefit-cost analysis methodology was selected as the primary analysis method, because of its wide application in existing green building studies. The three key variables identified from literature are study life, discount rate, and inflation rate. These were populated based on the literature review and with input from the case study decision makers. Next, an MS Excel worksheet was developed for conducting the LCCA calculations. Finally, LCCA calculations were performed using the monetized phase 2 outputs and analysis variables discussed above. Further discussion and findings from phase 3 are presented in Chapter 5.

3.5 PHASE 4: SUMMARY AND CONCLUSIONS

This phase includes presentation of overall research outputs and conclusions and identification of potential areas for future research. This discussion is as significant as the research findings because it provides a better understanding of the findings and may also assist in further development of this critical field.

3.6 CHAPTER SUMMARY

This chapter provided a discussion of the methodology adopted for this research. This overall methodology discussion and the supporting models form a key output of this research. These can provide guidance to future initiatives for exploring the impact of other LEED (or other similar green building rating systems) credits on occupant well-being, and application of economic analysis for quantifying benefits from changes in peoples' well-being/productivity. The next two chapters elaborate on research data collection and analysis.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 CHAPTER OVERVIEW

This Chapter presents a discussion of the data collection and analysis undertaken for this research. As discussed in the methodology, this data collection and analysis work forms phase 2 of the research and provides input for phase 3. Identification of processes/items causing incremental cost, conducted under phase 2a, is discussed in the next section. This is followed by phase 2b work addressing changes in occupant well-being and productivity resulting from the move to LEED® offices. Work related to monetization of the phase 2 findings forms part of phase 3 and is discussed in the next chapter.

4.2 PROCESSES/ITEMS RESULTING IN INCREMENTAL COSTS

Existing studies typically focus on evaluating overall incremental cost for LEED buildings, while the focus of the current research is to assess only building IEQ-related cost (and benefit) impacts. This research utilizes constructor-feedback for hypothesis validation to identify design and construction processes/items resulting in incremental costs in LEED buildings. An overview of this approach and key findings from the incremental cost assessment are discussed below.

4.2.1 Processes/Items Resulting in Incremental Costs: Approach

The IEQ credits attained on the case studies were analyzed for identification of processes/items resulting in incremental costs. Table 4.1 summarizes the IEQ credits attained on both case study projects.

Table 4.1: LEED IEQ Credits attained on Case Studies (Credits based on LEED-CI 2.0)
(Y: Credit attained; Y*: Similar credit attained; N: Not attained; NA: Credit not available for the LEED rating system pursued)

Credit No.	Credit Description	CS1	CS2
Prereq. 1	Minimum IEQ Performance	Y	Y
Prereq. 2	Environmental Tobacco (ETS) Smoke Control	Y	Y
Credit 1	Outdoor Air Delivery Monitoring	Y	Y*
Credit 2	Increased Ventilation	Y	Y*
Credit 3.1	Construction IAQ Management Plan : during construction	Y	Y
Credit 3.2	Construction IAQ Management Plan : before occupancy	N	Y
Credit 4.1	Low Emitting Materials: Adhesives and Sealants	Y	Y
Credit 4.2	Low Emitting Materials: Paints and Coatings	Y	Y
Credit 4.3	Low Emitting Materials: Carpet Systems	Y	Y
Credit 4.4	Low Emitting Materials: Composite Wood and Agrifiber Products	Y	N
Credit 4.5	Low Emitting Materials: Systems Furniture and Seating	Y	NA
Credit 5	Indoor Chemical and Pollutant Source Control	Y	Y
Credit 6.1	Controllability of Systems: Lighting	Y	Y*
Credit 6.2	Controllability of Systems: Temperature and Ventilation	Y	Y*
Credit 7.1	Thermal Comfort: Compliance	Y	N
Credit 7.2	Thermal Comfort: Monitoring	Y	N
Credit 8.1	Daylight and Views: Daylight 75% of Spaces	Y	Y
Credit 8.2	Daylight and Views: Daylight 90% of Spaces	Y	NA
Credit 8.3	Daylight and Views: Views for 90% of Seated Spaces	Y	N

It is evident that although the two case studies attempt different levels of LEED certification, both have tried to attain most of the IEQ credits. CS1 attained 18/19 CI 2.0 prerequisites and credits and CS2 attained 13/17 NC2.1 prerequisites and credits. The following steps summarize approach undertaken for identification of incremental cost processes/items:

1. Review of LEED requirements and documentation for the IEQ credits.
2. Development of hypothesis for potential cost impact items.
3. Hypothesis testing through constructors' feedback.
4. Finalization of processes/items resulting in incremental cost.

Figure 4.1 demonstrates this incremental first cost items identification approach using the example of LEED-IEQ credit 3.1 for CS1.

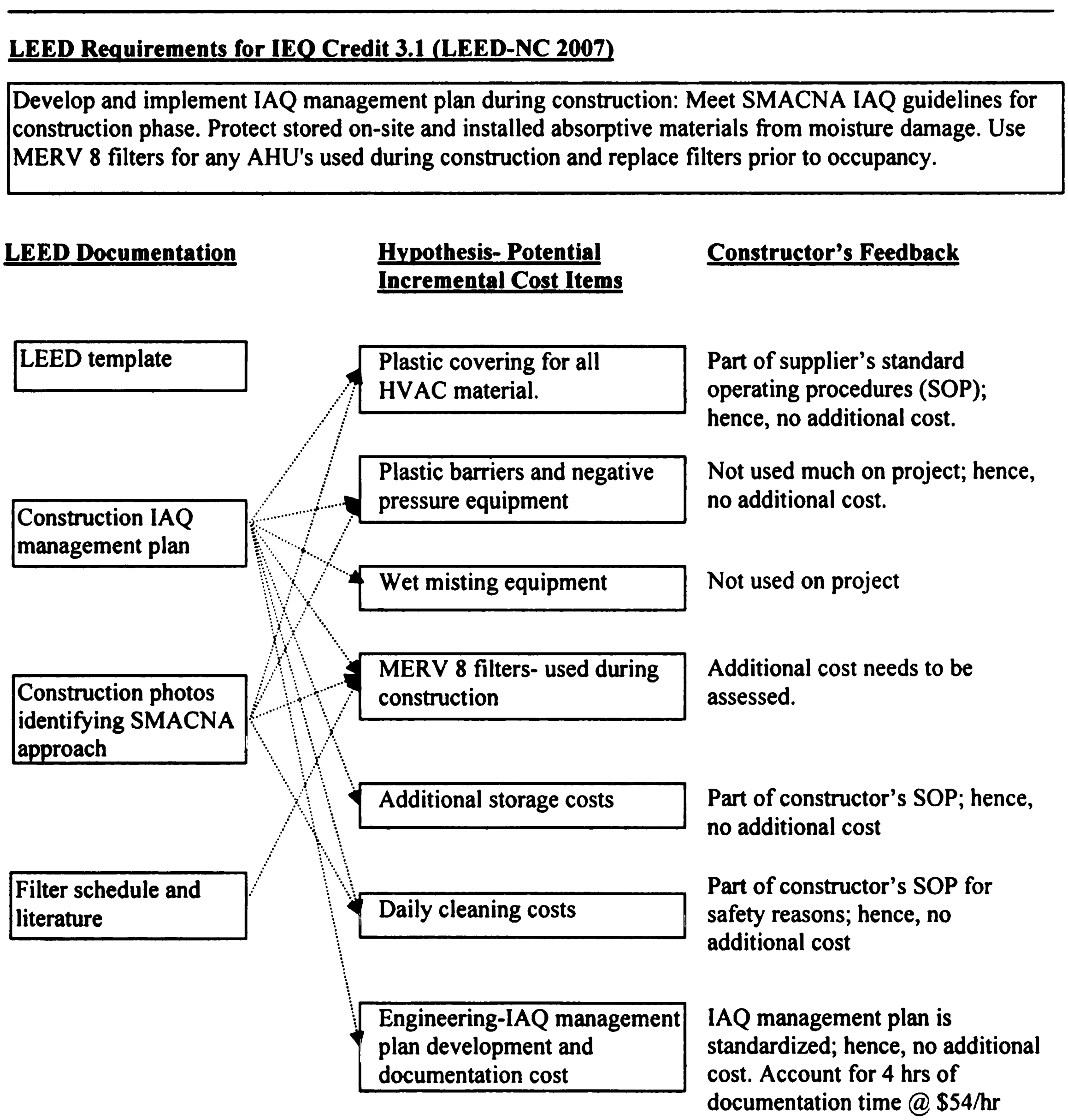

Figure 4.1:
Example Structure for Identification of Processes/ Items Causing Incremental Cost (LEED IEQ credit 3.1)

Documentation for EQ 3.1 included an IAQ management plan, construction photos, and HVAC filter schedule and literature. Based on a review of LEED requirements and this documentation, several potential items that may result in incremental cost were hypothesized. The relationships between LEED documentation and these hypothesized items have been depicted by arrows in Figure 4.1.

After the constructors' feedback, it was established that most of these items had been part of standard practices for recent construction projects. However, LEED documentation caused additional effort that was not necessarily representative of typical industry practices. Also, MERV 8 filters used during construction present a cost that may not be typically accrued on non-LEED construction projects. Similarly, incremental cost items were identified among all LEED-IEQ credits. The findings from this process are discussed below.

4.2.2 Processes/Items Resulting in Incremental Costs: Findings

The analysis from both case studies suggests that very few LEED-IEQ credits result in incremental hard costs. This is either a result of the local building codes having similar base requirements or such green practices having become part of standard industry practices. Some significant processes/items identified as causing incremental costs include:

1. MERV13 filters installed for building operation– CS1 and CS2 (LEED-CI 2.0 credit EQ5; LEED-NC 2.1 credit EQ3.1).

2. MERV8 filters used during the construction process for CS1 (LEED-CI 2.0 credit EQ3.1). Alternatively, temporary heating provided during the construction process for CS2.
3. Installation of a permanent outdoor air delivery monitoring system - CS1 (LEED-CI 2.0 credit EQ1). The CS2 constructor considered the CO2 monitoring equipment (LEED-NC 2.1 credit EQ1) as part of their standard construction practice.
4. High-performance glazing used for enhancing energy performance and maximizing daylight and views (LEED-NC 2.1 credit EQ8.1).
5. Indoor air quality testing before occupancy- CS2 (LEED-NC 2.1 credit EQ3.2)
6. Commissioning of IEQ systems- CS1 only. The CS2 constructor considered this as part of their standard construction practice.

In addition to the above, LEED-related coordination/documentation for all credits were also identified as accruing additional soft cost for both case studies. Monetization of such LEED-IEQ costs is presented in the next chapter. The following section presents a discussion of the changes in occupant well-being and productivity, resulting from the move to LEED offices, that may be attributable to IEQ credits.

4.3 CHANGES IN OCCUPANT WELL-BEING AND PRODUCTIVITY

Literature presents a need to quantify occupant well-being and productivity-based benefits in LEED offices. The current research utilizes a case study based approach using self-reported well-being and productivity metrics (occupant surveys). An overview of this approach and key findings from the related analysis are presented below.

4.3.1 Occupant Well-being and Productivity: Approach

Table 4.2 presents an overview of the case studies and occupant surveys.

Table 4.2: Case Studies and Occupant Surveys Overview

	CS1	CS2
Building type, location	Office building, Michigan	Office building, Michigan
Total population (N)	56	207
LEED rating	Awarded LEED Platinum- CI2.0 and CS2.0	Registered for LEED Silver-NC2.1
Timing of the move	Occupants moved to LEED building around the start of research	Occupants moved to LEED building during the research
Pre-move survey: timing and response rate (n)	Survey conducted 3-4 months after the move. n= 33 (59%)	Survey conducted 1-2 months before the move. n= 142 (69%)
Post-move survey: timing and response rate (n)	Survey conducted 3-months after the pre-move. n= 32 (57%)	Survey conducted 1-2 months after the move. n= 113 (55%)

Occupant responses from pre-move (Pr) and post-move (Po) surveys were downloaded to MS Excel spreadsheets. These Pr and Po responses were correlated, coded, and copied to a unified analysis spreadsheet. Next, the data analysis was performed using MS Excel and Minitab 15 (Minitab 2008) software. Among the respondents (n), few provided information related with their well-being conditions (Pr 42% and Po 36% overall for CS1 and CS2). Due to such limited response, both case studies were analyzed collectively.

Basic analysis was performed using descriptive statistical methods such as histograms and box plots (Devore 2004), while hypothesis testing using paired t-tests (Devore 2004) was used for further analysis of occupant well-being and productivity-related data. While the basic analysis presents an overview of the occupant responses, hypothesis testing provides statistically significant inputs for the economic evaluation. The key findings from the occupant survey analysis are discussed below.

4.3.2 Occupant Well-being and Productivity: Findings

1. Occupant demographic information was collected during the pre-move survey while workspace-related information was collected during both surveys, as part of the general occupant information category. The objective of collecting such data was to provide a descriptive overview of the study population. Occupant responses in this category are summarized using histograms. Figure 4.2 presents an overview of the demographic information while workspace-related information is summarized in Figure 4.3.

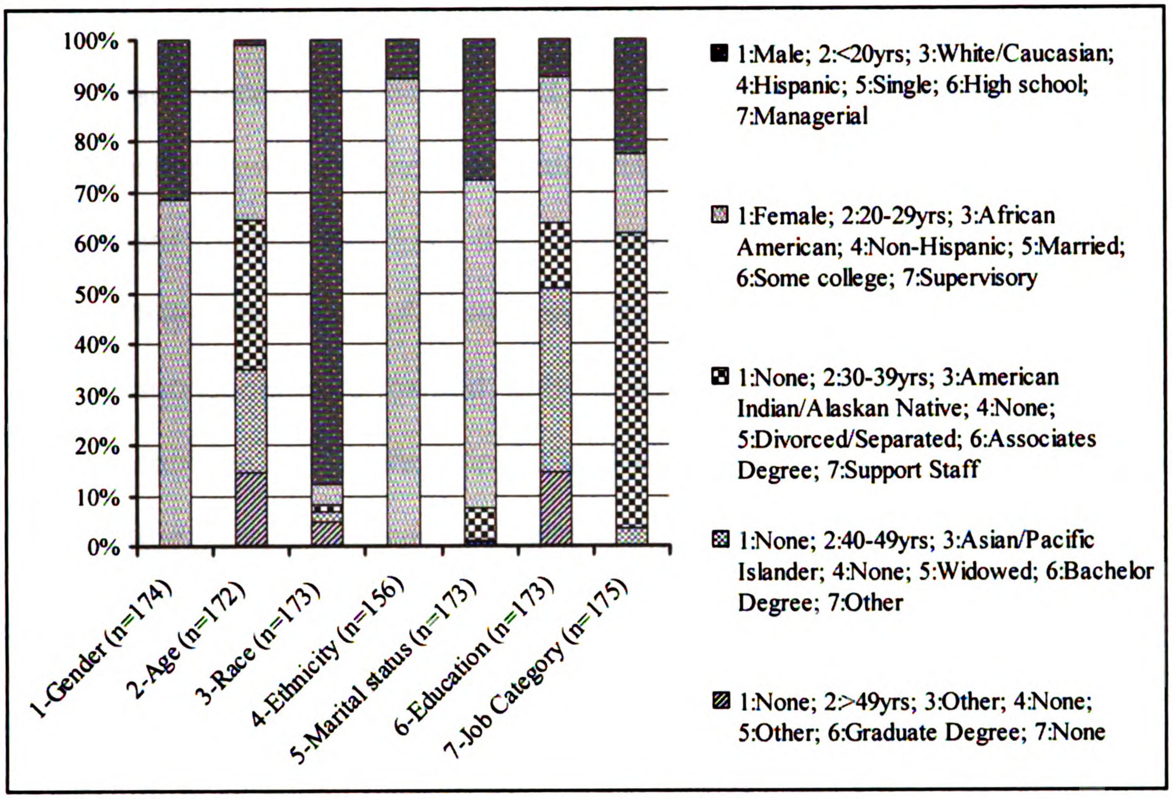

Figure 4.2: Demographic Information

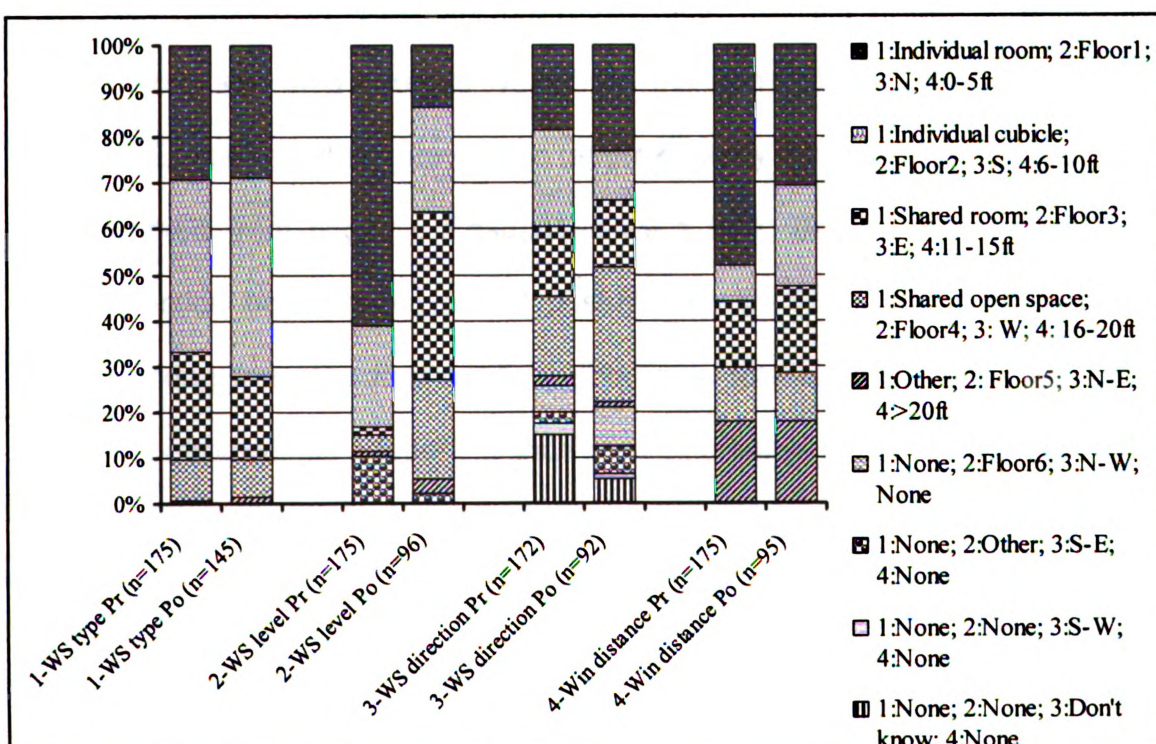

Figure 4.3: Workspace-related Information

Figure 4.2 shows that about 70% of the respondents were female; the respondents were fairly divided between age groups 20-29,30-39yrs with slightly fewer respondents divided among age groups 40-49 and >49yrs. More than 85% of the respondents identified themselves as White/Caucasian and more than 90% as Non-Hispanic. About 65% of the respondents were married, and the education category had fairly divided responses with more than 90% of the population having been through some level of college education. More than 55% of the respondents identified themselves as support staff while approximately 40% identified as holding supervisory or managerial positions.

Figure 4.3 shows that about 70% of the occupants work from individual rooms or cubicles both pre-move and post-move, while a greater percentage of occupants work from the upper floors (above floor 1) in LEED offices than previously (approximately 60% occupants pre-move worked from floor 1). Responses were fairly distributed for workspace direction both pre-move and post-move with >70% of the respondents working from the four cardinal directions. Interestingly, fewer occupants work from within a 5feet distance from external windows in LEED buildings (about 30%) than those in conventional buildings (about 48%), although a fairly similar percentage of occupants work from within 15feet of external windows both pre and post-move.

2. The occupant well-being survey category gathered information regarding the occupants' physical (Asthma and Respiratory Allergies) and psychological (Depression and Stress) conditions. Figure 4.4 shows that about 15% of the respondents had a medical history of asthma and a similar number have faced depression symptoms in the past, while nearly 30% respondents have been affected by various respiratory symptoms and about 35% have a history of stress-related conditions. This data was collected during the pre-move survey.

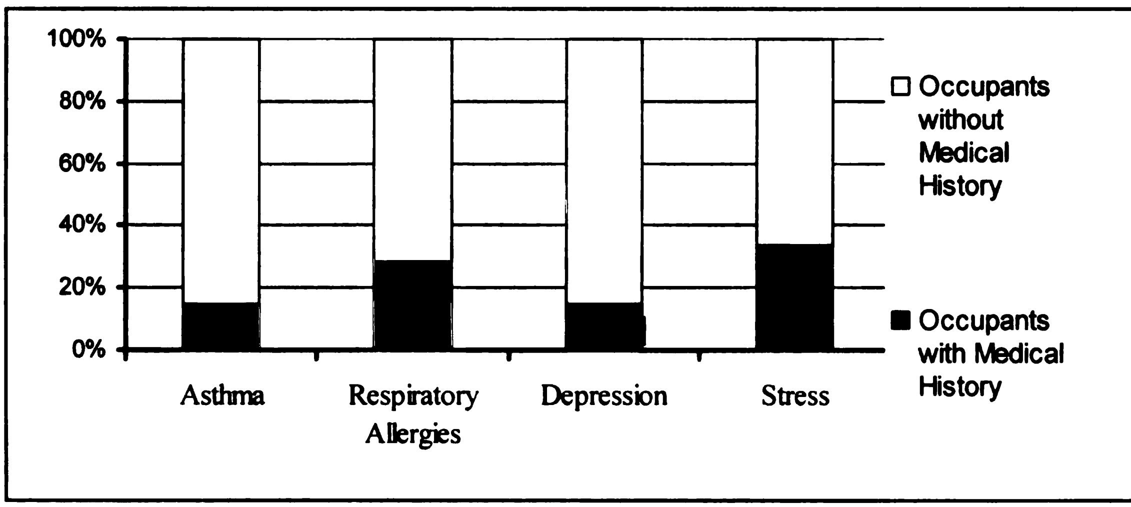

Figure 4.4: Occupants' Medical History (n=175)

The pre-move and post-move surveys provided data regarding occupant absenteeism and work-hours affected by the above health conditions over four-week snapshots. Due to a limited number of data points, the effects from asthma and respiratory allergies were clubbed together and similarly those from depression and stress were also clubbed. Health snapshot responses were accompanied by questions seeking respondents' confidence levels. All responses with <50% confidence were disregarded from the analysis. The box plots presented in Figures 4.5-4.8 summarize the health snapshot responses.

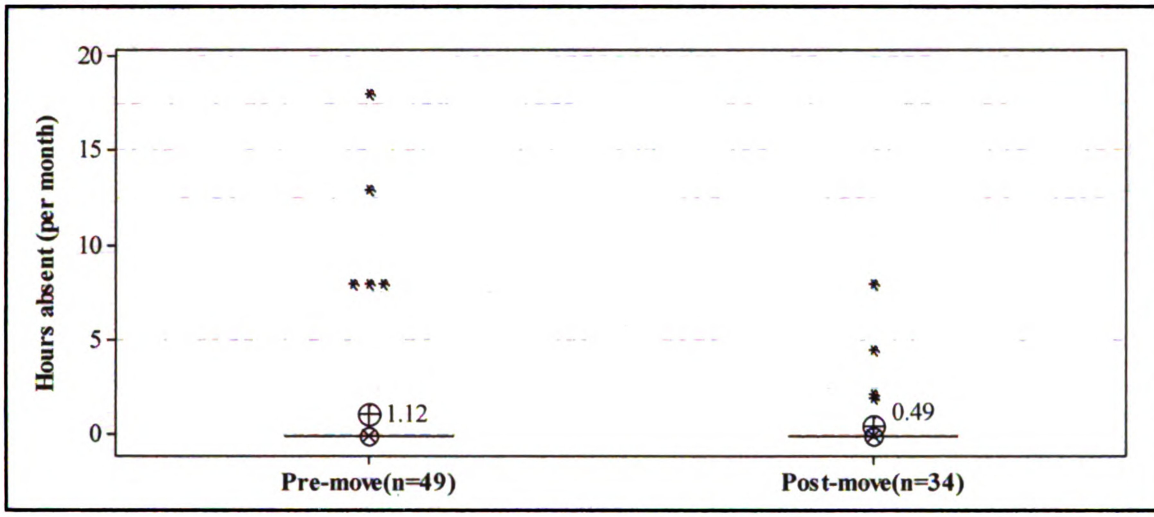

Figure 4.5: Hours Absent due to Asthma/Respiratory allergies
(*: Outlier; +: Mean-values shown; x: Median)

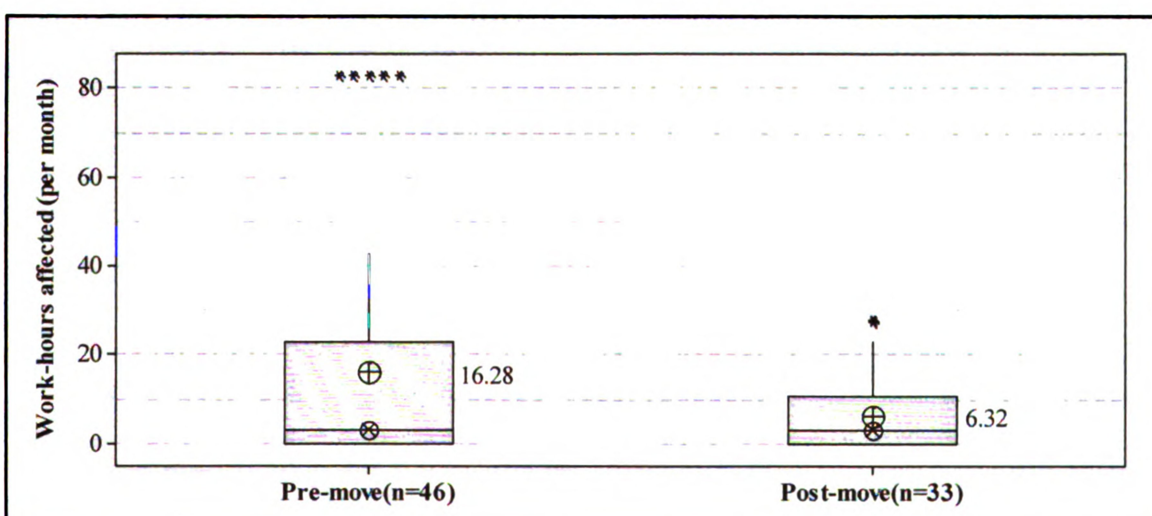

Figure 4.6: Work-hours Affected by Asthma/Respiratory Allergies
(*: Outlier; +: Mean-values shown; x: Median)

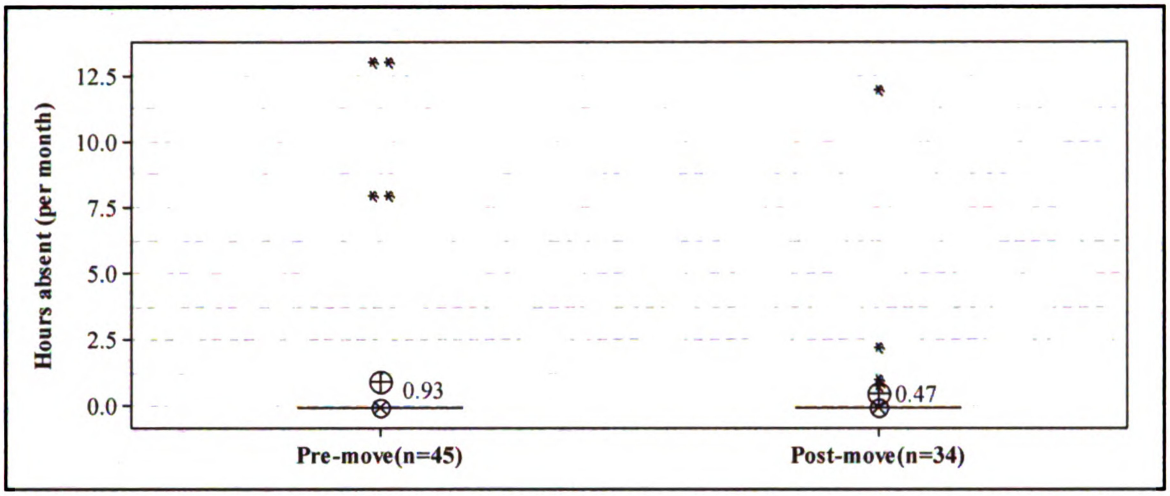

Figure 4.7: Hours Absent due to Depression/Stress
(*: Outlier; +: Mean-values shown; x: Median)

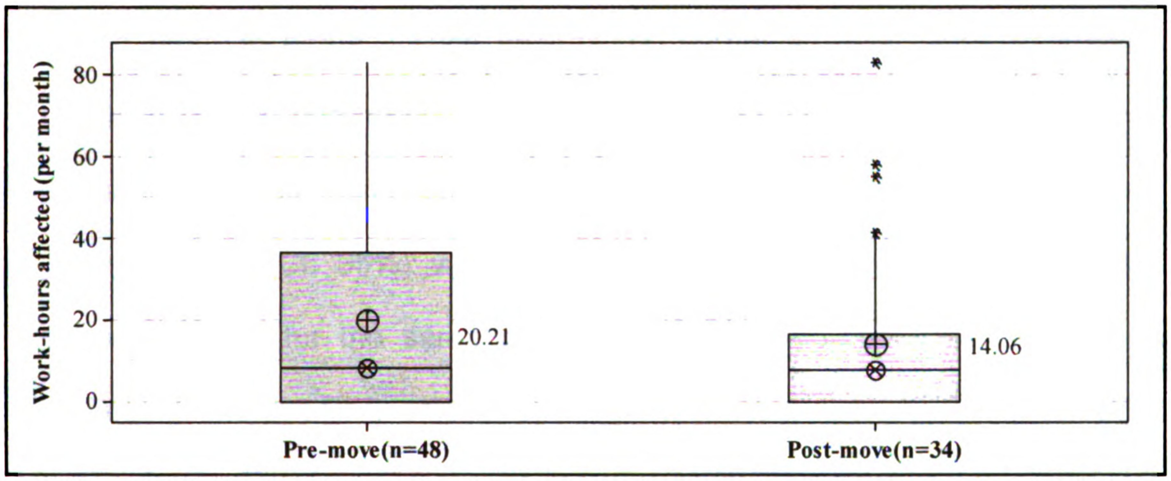

Figure 4.8: Work-hours Affected by Depression/Stress
(*: Outlier; +: Mean-values shown; x: Median)

For asthma/respiratory allergies, Figure 4.5 indicates a minor reduction in the mean value for hours absent (1.12 to 0.49), while a more substantial reduction in the mean value for the affected work-hours (16.28 to 6.32) is presented in Figure 4.6. For depression/stress-related conditions, Figure 4.7 shows a minor reduction in the mean value for hours absent (0.93 to

0.47), while a more substantial reduction in the mean value for the affected work-hours (20.21 to 14.06) is presented in Figure 4.8. These findings are based on all responses collected through pre-move and post-move surveys. Even though the above findings indicate reductions in average absenteeism and affected work-hours, such findings can only provide limited confidence for the economic analysis as they do not necessarily imply improvements in health conditions for the same respondents.

In order to address such uncertainty, further analysis using hypothesis testing was performed. Pre-move and post-move responses were paired and analyzed using lower-tailed, paired t-tests to determine statistically significant (CI: 95%) values of reduction in absenteeism and affected work-hours for the same respondents, resulting from improved health conditions in LEED offices. Lower-tailed tests provide fairly conservative estimates, and pairing results in better estimation of changes, as a mean of differences for the same occupants instead of a difference of means for the entire population. However, pairing of the data results in a limited data set for the analysis since all unpaired responses (where occupants responded only one out of the two surveys) have to be discarded.

This problem was addressed by including blank responses as a "0" value for occupants who had participated in both surveys and had provided input for well-being questions in at least one survey. This was possible since the well-being questions directed occupants to leave the fields blank if they had not faced such heath conditions during the snapshot period. Table 4.3 presents the findings from the occupant well-being paired t tests.

Table 4.3: Changes in Occupant Well-being upon Moving to LEED Offices
(d-value: mean difference of Pr-Po response; AB: Absenteeism; WH: Affected work-hours; W/MH: Occupants with medical history; W/O MH: Occupants without medical history; PR: Reduced productivity)

Lower tailed paired t-test					
		p-value	**d-value CI (95%)**	**n**	**Interpretation**
1. Asthma and Respiratory Allergies					
AB	All	0.115	-0.26	47	No significant finding
	W/MH	0.047	0.034	25	95% sure that value of mean (AB difference) is at least 0.034 hours/month for occupants with MH of Asthma/ Respiratory Allergies
WH	All	0.048	0.07	46	95% sure that value of mean (WH difference) is at least 0.07 hours/month for all occupants
	W/MH	0.02	2.35	27	98% sure that value of mean (WH difference) is at least 2.35 hours/month for occupants with MH
2. Depression and Stress					
AB	All	0.058	-0.18	46	No significant finding
	W/MH	0.102	-0.24	29	No significant finding
WH	All	0.047	0.17	51	95% sure that value of mean (WH difference) is at least 0.17 hours/month for all occupants
	W/MH	0.02	2.86	34	98% sure that value of mean (WH difference) is at least 2.86 hours/month for occupants with MH of Depression/ Stress
3. Overall effect of health					
AB	All	0.239	-0.44	109	No significant finding
PR	All	0.005	0.565	107	99% sure that value of mean (Productivity difference) is at least 0.565 % for all occupants

The t-tests indicate statistically significant values for mean reduction in work-hours affected by both sets of health conditions and a minor reduction in the absenteeism caused by asthma/respiratory allergies.

Overall, an improvement (0.565%) in the occupants' perceived productivity resulting from all health conditions was also found.

3. In the next survey category, work environment satisfaction, occupants were asked to rate their satisfaction level with their work environment IEQ attributes both pre-move and post-move (5-point scale, 5 being completely satisfied). IEQ attributes included temperature (TE), humidity (HU), air flow (AF), air quality (AQ), lighting (LI), daylight (DL), glare (GL), outside views (OV), noise level (NL), office furniture (OF), office computer (OC), and visual privacy (VP). Responses were paired and the difference (d) in satisfaction levels (Post-Pre) was determined. Figure 4.9 presents an overview of changes in occupant IEQ satisfaction using such difference values.

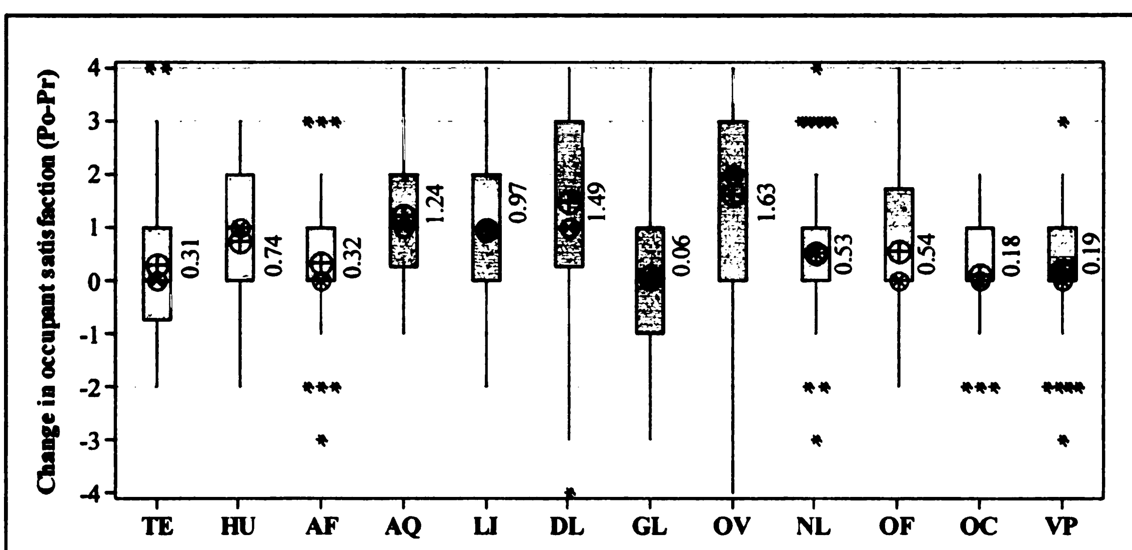

Figure 4.9: Change in Occupant IEQ satisfaction (n=68)
(*: Outlier; +: Mean-values shown; x: Median)

While mean occupant satisfaction with all IEQ attributes seems to have improved in LEED buildings, the most substantial improvement is seen in occupant satisfaction with the indoor air quality (AQ: mean d=1.2), daylight (DL: mean d=1.5), and outside views (OV: mean d=1.6).

Occupants were also asked to provide input regarding the effect of their workspace IEQ on their perceived productivity both pre-move and post-move. These responses are summarized in Figure 4.10a. Figure 4.10b presents box plots based on paired responses from the same respondents who provided Pr and Po inputs for IEQ satisfaction earlier (Figure 4.9).

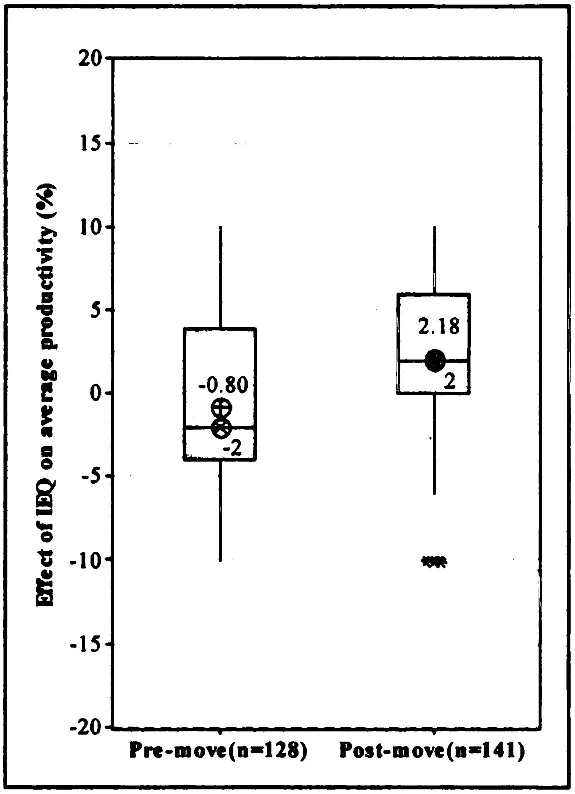

Figure 4.10a: Perceived Effect of IEQ on Productivity
(*: Outlier; +: Mean; x: Median)

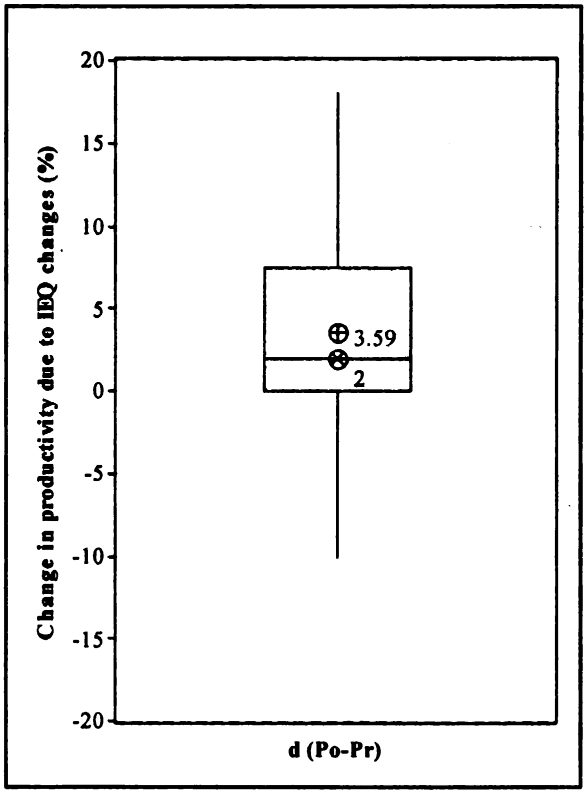

Figure 4.10b: Perceived Change in Productivity due to IEQ Changes (n=68)
(*: Outlier; +: Mean; x: Median)

Figure 4.10a reflects that on average the LEED office IEQ has a positive effect on the occupants' perceived productivity. The mean value for effect of office IEQ on average productivity has changed from -0.8% to +2.2%, i.e. approximately a 3% improvement; the median value also changed from -2% to +2 %.

Figure 4.10b presents an even higher mean improvement value (3.6%) for change in the perceived productivity. This is based on responses from the same population that indicated improved satisfaction levels with LEED office IEQ in Figure 4.9. This indicates the possibility of a correlation between improvements in perceived productivity and improvements in IEQ satisfaction. While scatter plots of perceived IEQ changes vs. changes in satisfaction with IEQ attributes do not reflect linear relationships, future researchers may explore such relationships based on other statistical models.

Similar to the occupant well-being analysis, lower-tailed, paired t-tests were conducted to determine statistically significant (CI: 95%) values of improvement in perceived productivity for the same respondents, resulting from improved IEQ in LEED offices. Also, in order to explore the effect of well-being conditions on the occupants' perceived productivity, such t-tests were performed using data from occupants with medical history of the well-being attributes of interest (AOI), as well as for those without such conditions. Table 4.4 presents the findings from these paired t-tests.

Table 4.4: Changes in Occupant Productivity upon Moving to LEED Offices
(d-value: mean difference of Po-Pr response; W/MH: Occupants with medical history; W/O MH: Occupants without medical history; PR: Productivity)

Lower tailed paired t-test					
		p-value	d-value CI (95%)	n	Interpretation
1. Overall effect of IEQ on Productivity					
PR	All	0.000	2.599	86	Almost certain that value of mean (Productivity difference) is at least 2.6% for all occupants
PR	W/MH	0.000	2.875	52	Almost certain that value of mean (Productivity difference) is at least 2.875% for occupants with MH of at least one well-being AOI.
PR	W/o MH	0.006	1.01	34	99% sure that the value of mean (Productivity difference) is at least 1.01% for occupants without MH of all of the well-being AOI

These t-tests indicate statistically significant values for mean improvement in occupant productivity (2.6%) resulting from the move to LEED offices for all occupants. For occupants with medical history of at least one well-being AOI this mean improvement was found to be slightly higher (2.9%) while a lower improvement value (1.01%) was determined for occupants without medical history of all of the well-being AOI.

4. In the next survey category, productivity and performance, occupants were asked to rate their performance over a 4 week snapshot during both the pre-move and post-move surveys (5 point scale, 5 being most preferable). Performance was defined by four attributes including quantity of work (Work-Qty), quality of work (Work-Qlty), customer service provided

to internal clients (CS-Int), and customer service provided to external clients (CS-Ext). The difference (d) in performance attributes (Po-Pr) was determined. Figure 4.11 presents an overview of changes in such performance attributes.

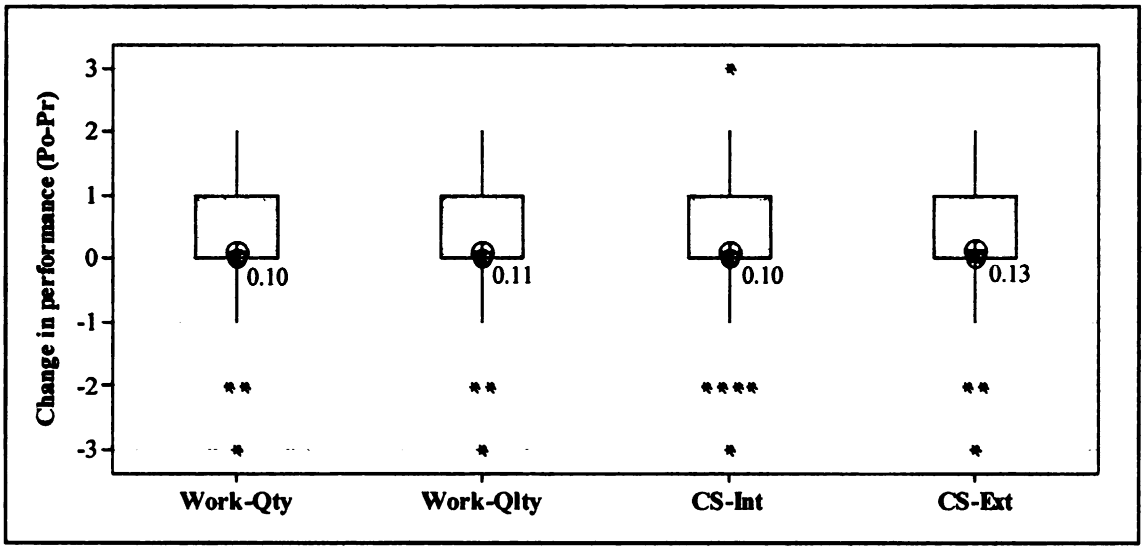

Figure 4.11: Change in Perceived Performance (n=105)
(*: Outlier; +: Mean-values shown; x: Median)

Figure 4.11 reflects mild improvements in the mean values for all performance attributes resulting from the move to LEED offices, however these changes are not as substantial as those seen for IEQ satisfaction questions.

4.3.3 Annual Benefits from Occupant Well-being and Productivity

The primary goal of the occupant survey analysis was to provide annual benefit input for phase 3. The researchers hypothesized, that the move to LEED offices would improve productivity and reduce absenteeism among occupants. While reduction in absenteeism is expected to result from improved occupant well-being alone, the productivity improvement may include benefits resulting from changes in well-being or directly from improved IEQ (Fisk and Rosenfeld 1997).

Within the scope of this research, improvements in occupant productivity resulting from improved well-being form a sub-set of overall improvements in occupant productivity resulting from better IEQ. Hence, using a 2.6% change in productivity from better IEQ (Table 4.4) along with a 0.57% productivity improvement from improved well-being (Table 4.3) would lead to double-counting of the productivity benefits. Therefore, the overall productivity improvement from IEQ was discounted to 2.03% (2.6%-0.57%) and used along with other benefits determined from the well-being AOI earlier. This productivity improvement was finally converted to additional work-hours offered by occupants toward their respective organizations.

The reduction in the absenteeism value was directly used to calculate annual work-hours gained per employee due to the respective health conditions. However, conversion of affected work-hours (WH) included an additional step. Occupant well-being questions also collected data for perceived productivity loss during these affected work hours for the respective health conditions. Such productivity data was clubbed from both surveys and analyzed using lower-tailed one-sample t-tests (Devore 2004). The mean productivity loss during work-hours affected by asthma/respiratory allergies was found to be at least 4.75% and for depression/stress as 5.90%. These mean productivity loss values were used for calculation of the lost work-hours per employee. Table 4.5 summarizes the final benefit outputs from the survey analysis, useable for the phase 3 LCCA.

Table 4.5: Annual Occupant Well-being and Productivity Benefits in LEED Offices
(d-value: mean difference of Po-Pr response; AB: Absenteeism; WH: Affected work-hours; PR: Productivity; W/MH: Occupants with medical history; W/O MH: Occupants without medical history)

Source of improvement	Additional calculations	Resultant benefit/year
1. Reduction in Asthma/ Respiratory Allergies		
AB is reduced by 0.034hrs/month for W/MH	None	Additional 0.41 work-hours for each occupant W/MH
WH is reduced by 2.35hrs/month for W/MH	@4.75%productivity loss, 2.35 WH (d) accounts for a gain of 0.112hrs/month	Additional 1.34 work-hours for each occupant W/MH
2. Reduction in Depression/Stress		
WH is reduced by 2.86hrs/month for W/MH	@5.90%productivity loss, 2.86 WH (d) accounts for a gain of 0.17hrs/month	Additional 2.02 work-hours for each occupant W/MH
3. Improvement in productivity		
PR d value=2.599% for all occupants	Discount 0.565% improvement resulting from well-being; PR=2.03% For each month averaging 160 work-hours a 2.03% improvement equals 3.25 additional work-hours	Additional 38.98 work-hours for each occupant

Improvements in asthma/respiratory allergy conditions seem to provide 1.75 (0.41+1.34) additional work hours/year to each employee with a medical history of such conditions. Similarly, occupants with a medical history of depression/ stress seem to gain 2.02 additional work hours/year due to reductions in such conditions. Perceived improvements in productivity seem far more substantial. All occupants seem to gain approximately 39 additional work hours/year from direct productivity improvements (unrelated to well-being conditions).

The above findings provide the benefits input for LCCA. These findings have been monetized in the next chapter.

4.4 CHAPTER SUMMARY

This chapter provided a detailed discussion of the phase 2 analysis approach and presented the findings from the analyzed data. It seems likely that the case study organizations may attain substantial benefits through improvements in occupant well-being and productivity in LEED offices. However, economic justification of the incremental investment for incorporating LEED-based IEQ strategies remains to be undertaken. Phase 3 provides such economic justification through a life cycle cost analysis approach, as presented in the next chapter.

CHAPTER 5

LIFE CYCLE COST ANALYSIS

5.1 CHAPTER OVERVIEW

This Chapter presents a discussion of the life cycle cost analysis (LCCA) work undertaken as research phase 3. This phase includes monetization of phase 2 outputs and conduct of the LCCA. The following section elaborates the approach and findings from monetization of phase 2 outputs. The LCCA approach including method selection, variables, and calculation worksheet has been outlined next. This is followed by a discussion of LCCA findings and the uncertainties associated with these findings.

5.2 MONETIZATION OF PHASE 2 OUTPUTS

The previous chapter elaborated on phase 2 work. Phase 2a concluded with identification of processes/items resulting in incremental costs, and phase 2b ended with a summary of additional work hours (benefits) available to case study occupants through improved well-being and productivity each year. These phase 2 outputs have been monetized in this section to provide input data for LCCA.

5.2.1 Monetization of Processes/Items Resulting in Incremental Costs

Processes/Items including labor, material, equipment etc. were categorized as hard costs. These were monetized using inputs from case study constructors and estimation using of-the-shelf cost references (Means 2007). Others items requiring engineering/documentation etc. were categorized as soft costs. These were monetized using the constructors' estimates of time invested in such documentation and hourly cost estimates. Cost estimates were added to the matrices developed in phase 2a. Table 5.1 presents a snapshot of the final LEED-IEQ cost estimate matrix developed for CS1.

Table 5.1: Snapshot of LEED IEQ Cost Estimate Matrix (LEED IEQ credit 3.1- CS1)

LEED Information Review			Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit	LEED Req.	Docs. Reviewed	Potential Cost Impact Items: Hard Cost	Potential Cost Impact Items: Soft Cost	Cost items	Rationale	Hard Cost	Soft Cost	Notes
EQ3.1: Construction IAQ management plan- during construction	Develop and implement IAQ management plan during construction: Meet SMACNA IAQ guidelines for construction phase. Protect stored on-site and installed absorptive materials from moisture damage. Use MERV 8 filters for any AHU's used during construction and replace filters prior to occupancy.	LEED template, Construction IAQ management plan, Construction photos identifying SMACNA approach. Filter schedule and literature.	Plastic covering for all HVAC material.		Disagree	Part of supplier's Standard Operating Procedure (SOP)	$0.0	$0.0	
			Plastic barriers and negative pressure equipment, Wet misting.		Disagree	Not used on project	$0.0	$0.0	
			MERV 8 filters used during construc.		Agree-MERV 8 filters		$0.0	$0.0	MERV8 filter cost not assessed- these are assumed to be used during operations for other buildings. MERV13 filters cost for operations in the case study assessed under EQ5
			Additional storage costs.		Disagree	Part of constructor's SOP	$0.0	$0.0	
			Daily cleaning costs.		Disagree	Part of constructor's SOP for safety reasons	$0.0	$0.0	
				Engineer.-IAQ managem. plan develop. and document. cost	Doc. only	Standardized IAQ management plan used , hence no substantial engineering work	$0.0	$216.0	4hrs documentation time @$54/hr (constructor's input)

Note: Cost inputs from constructors were assumed to represent 2008 values, as discussed in Section 5.5.

These matrices follow a similar layout to the first cost assessment structure presented in Figure 4.1 in the previous chapter. In these matrices, the information reviewed for each IEQ credit is linked with hypothesized incremental cost items, the related feedback obtained from constructors, and the incremental cost estimates. Complete cost estimate matrices are provided in Appendix B. Some key findings from the LEED IEQ cost estimate matrices are discussed next.

CS1 incurred an incremental cost of approximately $40,000 for LEED-IEQ including $33,500 (85%) in hard costs and the rest as soft costs. This amounts to $2.34/SF for the 16,900 gross square feet (GSF) space. The total incremental cost for CS2 was determined to be approximately $454,591, including $417,491 (92%) in hard costs and the rest as soft costs. This amounts to $2.6/SF for the 174,750 GSF space. The above findings amount to about 2.1% (CS1) and 2.4% (CS2) of average costs for construction of office buildings in Michigan (Means 2007).

Kats (2003) had earlier found incremental costs for overall LEED credits (for a mixed sample including 33 LEED buildings rated at different LEED levels, certified to platinum) as approximately $4.00/SF amounting to 2% incremental investment. Stegall (2004) also established a 2% incremental investment for a LEED-Silver facility, while SBW (2003) found a 1.2% increment for 2 LEED buildings. SWA (2004) found an overall incremental cost of $11.00/SF for LEED-Gold rated office buildings amounting to an 8.5% increment. Langdon (2004 and

2007) reported a reduction in LEED-related incremental costs from 0-3% in 2004 to almost negligible increments in 2007.

Although the above studies vary in their findings of incremental cost amounts, they generally indicate increments ranging from 1-3% of project costs for all LEED credits. Our findings suggest that a substantial portion of such first cost increments may be attributable to IEQ-related credits.

5.2.2 Monetization of Occupant Well-being and Productivity Findings

The annual resultant benefits (additional work hours) from improved occupant well being and productivity improvements presented in Table 4.4 were monetized using employee wage inputs from case studies and typical industry wages.

The occupant demographic information gathered during the pre-move survey provided the respondent job category breakup among managerial/supervisory and support staff categories. Typical employee income ranges for these categories were obtained from case studies and industry averages. Average hourly wages (WA) considering all occupants were computed for each case study. These were used to determine the dollar value of phase 2b benefits. These calculations have been summarized in Tables 5.2a and 5.2b.

Table 5.2a: Calculation of Average Hourly Wage (WA)

	Support Staff Category		Managerial Staff Category		
	Av. Annual Income (CS input)	**% Population** (Pr Survey)	**Av. Annual Income** (CS input)	**% Population** (Pr Survey)	**Overall Average Hourly Wage (WA)** ∑(Av Category Income x % Population)/2080 hrs
CS1	$35,500	22%	$72,500	78%	$30.94
CS2	$41,655	69%	$108,500	31%	$29.99

Table 5.2b: Annual Economic Benefits from Occupant Well-being and Productivity Improvements

(WA: Average hourly wage; AWH: Additional work hours; $O: Dollar benefit per occupant; W/MH: Occupants with medical history; n': Number of occupants extrapolated from Pre-move respondent sample using total CS population; Pr: Pre-move survey)

	AWH	CS1	CS2
Average hourly wage- WA (from Table 5.2a)		$30.94	$29.99
AWH from reduced Asthma/Allergies per year (from Table 4.4)	1.75		
$ Benefit/occupant- $O (WA x AWH)		$54.15	$52.48
Applicable occupants-n' (extrapolated from W/MH in Pr Survey)		20	69
Monetized benefit/year (n' x $O)		$1,103	$3,596
AWH from reduced Depression/Stress per year (from Table 4.4)	2.02		
$ Benefit/occupant- $O (WA x AWH)		$62.50	$60.58
Applicable occupants-n' (extrapolated from W/MH in Pr Survey)		15	85
Monetized benefit/year (n' x $O)		$955	$5,122
AWH from improved Productivity per year (from Table 4.4)	38.98		
$ Benefit/occupant- $O (WA x AWH)		$1,206.13	$1,168.97
Applicable occupants- n' (Total CS Population)		56	207
Monetized benefit/year (n' x $O)		$67,543	$241,976
Total $ benefit/ year from improved occupant well-being and productivity		**$69,601**	**$250,694**

Table 5.2a presents the calculation of average hourly wage (WA) using percent of respondents among each category and typical annual income for such categories. Using these WA values the additional work hours (AWH) found in phase 2b were monetized for each occupant ($O) in Table 5.2b.

Next, the number of applicable occupants (n') was calculated by extrapolating the percent of relevant respondent population from the pre-move survey to account for the total sample population. For example, only 33 among 56 CS1 occupants responded to the pre-move survey. Among these about 36% responded as having a medical history of Asthma/Allergies. Hence an n' of 20 (36% of 56) occupants was determined. Finally, the total annual $ benefit was calculated using the annual benefit per occupant ($O) and number of applicable occupants (n').

For CS1, the total annual benefit was computed to be $69,601 and for CS2 it was determined as $250,694. The larger benefit value in CS2 is primarily attributable to a much larger occupant population. About 97% of the total benefits for both case studies are attributable to direct occupant productivity improvements and the rest result from improved occupant well-being. These benefit values, along with the incremental first costs determined in the previous section, provide the data input for LCCA. The next sections elaborate on the LCCA approach and findings and present the associated uncertainties.

5.3 LIFE CYCLE COST ANALYSIS: APPROACH

The literature presented LCCA applications for studying the economic viability of several green building investments. While these studies have limited focus on evaluating occupant well-being/productivity related impacts, they certainly provide overall directions for approaching LCCA, selecting the analysis method, and help in identifying data requirements and key analysis variables. The following discussion provides further insight into this overall LCCA approach and highlights some key analysis decisions.

5.3.1 LCCA Method Selection

Chapter 2 provided an overview of some commonly used LCCA methods. These include:

1. Simple payback.
2. Net present value.
3. Internal rate of return.
4. Annualized value.
5. Discounted payback.
6. Benefit-cost analysis.

Several existing green building-related LCCA studies have used benefit-cost analysis as the LCCA method of choice (Kats 2003, Ries et al. 2006, Romm and Browning 1994, SBW 2003). This method addresses the time-related variations in costs by incorporating concepts such as discounting and inflation. It provides a simple indicator of favorability of the economic investment (favorable investments are those where benefit-cost ratio is greater than 1) based on the selected variables.

For the current research, benefit/cost analysis has been used as the primary cost analysis method in order to allow comparisons of the research findings with existing green building LCCA literature. In addition, payback period (simple payback) and the rate of return (internal rate of return) will be calculated to provide additional decision support metrics for the investors.

5.3.2 LCCA Variables

Three LCCA variables were identified through literature. These include:

1. Study period (SP): This is the duration for which the study is conducted. Costs and benefits accrued within this period are used as inputs for the analysis. The United States General Services Administration (GSA) recommends limiting the SP for LCCA calculations to a maximum of 25 years (GSA 2003). Dell'Isola and Kirk (1981) as well as Gardi (2003) recommend using an SP of 25-40 years. Kats (2003) used 20 years; SBW (2003) used 25 years, while Ries et al. (2006) used an assumed 50 year building life as the study period. For the current research, the researchers finalized a 25 year study period for the base scenario.

2. Inflation rate (IR): This is the rate at which costs are expected to escalate over the study period. United States inflation data (Inflationdata 2008) since 1997 suggests an average annual inflation rate ~2.74%, while this number is ~3.33% for the last 5 years. Kats (2003) used 2%, SBW (2003) used 2.8%, while Gardi (2006) used 2-6% inflation rates for various analysis components. For the current research, a 3% inflation rate was finalized for the base scenario.

3. Discount rate (DR): This rate represents a reduction in the value of money over the study life. Gardi (2003) recommends using "cost of borrowing money" as an indicator to select the appropriate discount rate. Dell'Isola and Kirk (1981) recommend using either the "minimum acceptable rate of return" for the investor or the "current borrowing rate of interest" to determine the discount rate. In a recent green building-related LCCA application, Gardi (2006) used a 7.75% discount rate. Other researchers have used discount rates of 5% (Kats 2003), 7% (Ries et al. 2006), as well as 2% and 6% (SBW 2003). For the current research, a 6% discount rate was finalized for the base scenario.

5.3.3 LCCA Worksheet

After identifying the LCCA method and the base scenario variables, an MS Excel worksheet was developed to assist in performing the LCCA calculations. This worksheet is presented as Table 5.3.

Table 5.3: Life Cycle Cost Analysis Worksheet

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$0.00	Study Period- SP (Yrs)	0
Annual Benefit- Be (Table 5.2b)	$0.00	Inflation Rate- IR (%)	0.0%
		Discount Rate- DR (%)	0.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	0.00
Present worth of Annuity Factor (PWA)		(Co/Be)	0.00
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$0
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	0
Payback Period (PB)- in years		Co/Be	0.0
Rate of Return (RR)		Determined using PWA tables using PWA	0.00%

The worksheet comprises of four sections. These are:

1. LCCA Inputs: This includes the Incremental Cost (Co) and Annual Benefit (Be) inputs for LCCA. For the current research, the incremental first cost for LEED-IEQ provides a one-time cost input, while the occupant well-being and productivity improvements provide annually recurring benefits.

2. LCCA Variables: This includes the Study Period (SP), Inflation Rate (IR), and Discount Rate (DR), as previously discussed.

3. LCCA Mid-Points: A Present Worth (PW) factor is determined from published PW tables (Dell'Isola and Kirk 1981) using the LCCA variables. This PW is used to compute the Present Value of Life Cycle Benefits (PVB). Since incremental costs are incurred only once at the start of the

study period, PV for these is not computed. The Present Worth of Annuity (PWA) is also calculated from the LCCA inputs. PWA is used to determine the Rate of Return (RR).

4. LCCA outputs: This includes the final computation step and presents the findings from the analysis. Benefit-Cost ratio (B/C) is computed using Co and PVB. A Benefit/Cost greater than 1 represents an economically viable investment.

   The Payback Period (PB) and Rate of Return (RR) provide additional decision support metrics for the investor. PB is calculated using Co and Be. An acceptable payback period is specific to the investor's expectations.

   RR is determined using PWA value, published PWA tables (Dell'Isola and Kirk 1981) and adjusting for inflation. Instead of assuming a discount rate to extrapolate costs and benefits over the study period, this method assists in determining the expected returns on investment for the given study period. An RR greater than the investors typical returns, represents an economically viable investment.

The above discussion outlines the overall cost analysis approach and presents some key assumptions/decisions for this research. This discussion may assist readers in developing a better understanding of the economic analysis and minimize any ambiguity in the research findings.

5.4 LCCA: FINDINGS

Based on the approach highlighted in the previous section, LCCA calculations were performed for the base scenario. In addition, three alternative scenarios were modeled by adjusting the analysis variables based on the literature review and case study feedback. The four scenarios include the following variables:

1. Base Scenario: SP=25years, IR=3%, DR=6%
2. Scenario 1(Increase in inflation): SP=25years, IR=6%, DR=6%.
3. Scenario 2 (Higher discount rate): SP=25years, IR=3%, DR=8%.
4. Scenario 3 (Shorter study period): SP=15years, IR=3%, DR=6%.

LCCA findings from all scenarios have been summarized in table 5.2 below. LCCA worksheets for all scenarios have been presented in Appendix C.

Table 5.4: Life Cycle Cost Analysis Findings

Scenario	Case Study	Benefit/Cost Ratio	Payback Period (yrs)	Rate of Return (%)
Base Scenario (SP= 25yrs ; IR=3%; DR=6%)				
	CS 1	30.9	0.6 yrs	167%
	CS 2	9.7	1.8 yrs	50%
Scenario 1 (SP= 25yrs ; IR=6%; DR=6%)				
	CS 1	44.0	= Base Scenario	= Base Scenario
	CS 2	13.8	= Base Scenario	= Base Scenario
Scenario 2 (SP= 25yrs ; IR=3%; DR=8%)				
	CS 1	25.2	= Base Scenario	= Base Scenario
	CS 2	7.9	= Base Scenario	= Base Scenario
Scenario 3 (SP= 15yrs ; IR=3%; DR=6%)				
	CS 1	21.1	= Base Scenario	= Base Scenario
	CS 2	6.6	= Base Scenario	= Base Scenario

For the base scenario, life cycle benefits exceed the incremental costs approximately by factors of 31 and 10 for CS1 and CS2 respectively. The benefits seem to payback for the incremental costs within about 7 months of occupancy for CS1 and in less than 2 years for CS2. The rates of return on LEED-IEQ investment are in the order of 167%/year for CS1 and 50%/year for CS2. These findings imply a high feasibility of the economic investment.

Other LCCA scenarios were modeled to gain a preliminary insight into the sensitivity of research findings to changes in LCCA variables. Future researchers may use Monte Carlo Simulation (Huijbregts et al. 2003) to model the economic risk associated with these findings by using a wider spectrum of LCCA variables. It may be noted that PB and RR calculations are based on first year costs and benefits only and remain unaffected by changes in LCCA variables.

Scenario 1 addresses an increase in inflation. The 6% inflation rate used in this scenario is higher than the largest monthly inflation (5.6%) reported over the last 10 years (Inflationdata 2008). For this scenario, the B/C increases to about 44 and 14 for CS1 and CS2 respectively, increasing the economic feasibility of the investment. Scenario 2 models a higher discount rate (8%) representing higher expectations of returns on the investment. This causes the B/C to reduce to 25 for CS1 and 8 for CS2. Scenario 3 models a shorter study period (15 years). This reduces the B/C ratio to 21 and 7 for CS1 and CS2 respectively. Each of these scenarios, still represent a highly beneficial economic investment.

Among previous green building related LCCA studies, Kats (2003) found an average B/C ratio in the range of 15-16, SBW (2003) found B/C ranging approximately 1 to 2, and Ries et al. (2006) determined a B/C of 1.7. Romm and Browning (1994) determined a 1 year payback for improved workplace lighting conditions. While all these studies indicate higher benefits than costs, they vary in the scale of their findings primarily due to the scope of the benefits evaluated. The current research focuses on benefits resulting from occupant well-being and productivity that have sometimes been conservatively quantified in these studies.

5.5 UNCERTAINTIES ASSOCIATED WITH LCCA FINDINGS

The above findings indicate substantial economic incentive in investing in LEED-IEQ, received through improved occupant well-being and productivity. While the above findings are based on a research methodology developed upon extensive labor and rigorous review, several uncertainties exist. Highlighting these uncertainties is significant to assist the readers in gauging the validity and associated risk of these findings as well as for further development of this critical research area. Some key uncertainties have been discussed below:

1. Cost input uncertainties
    a Often, building decisions are not solely driven by LEED requirements; in such cases attributing incremental costs to LEED becomes challenging. For example both case studies used under floor air distribution (UFAD) systems instead of conventional overhead HVAC systems. While this assisted these projects in

achieving certain LEED credits, the constructors' input suggested that this decision was driven by other concerns (for example, architectural). Such costs were not accounted for in this research

b Certain cost items accounted for under LEED-IEQ credits, also assist attaining other LEED credits. For example, substantial incremental costs were estimated for high-performance glazing for CS2, while incorporating this glazing also resulted in achieving credit EA1. Since other LEED categories were not studied in this research, all such costs were attributed to LEED-IEQ

c Costs estimated using Means (2007) were extrapolated to 2008 Michigan-specific estimates while cost inputs received from the constructors were assumed to represent 2008 estimates, as these inputs were received in 2008.

d Hypothesis development for identifying incremental cost items was based on a review of LEED documentation. Certain cost items not evident in such documentation may have been missed

In addition, the constructors' bias to justify LEED investments or loss of information due to miscommunication may also have affected the incremental cost assessment. However, these uncertainties form part of most researches that involve external feedback and are assumed to have limited significance.

2. Benefit input uncertainties

   a Occupant productivity benefits provide the majority of the total life cycle benefits in this research. However, such productivity is based on self-reported perceptive responses. While such perception-based surveys have been extensively used in post-occupancy evaluation literature, their validity may need to be explored through further research

   b Benefits attained by the survey respondents (n) were assumed to be representative for the entire organizations' population (N)

   c Benefits were determined from two 4-week snapshots; it can not be claimed that these snapshots would have comprehensively captured the annual effects of occupant well-being and productivity conditions

   d The recent move to a new building may have a temporary effect on the occupants' well-being/productivity. Hawthorne effect (Romm and Browning 1994) explains temporary changes in people's behavior or performance as a response to a change in the environment. Although the Hawthorne theory has been disputed (Adair 1984; Diaper 1990; Gottfredson 1996; Rice 1982; Wickstrom and Bendix 2000) , the uncertainty in long-term benefits presented by this theory may only be eliminated by continuing this research over a longer timeframe e Decisions made during data coding and analysis may result in some uncertainties. Some of these decisions include; using occupant well-being responses with >50% confidence, coding blank responses as 0 in limited cases, cropping upper scale values, and using mid-scale values for coding ranges. Also, lower-tailed t-test benefit values were used for the economic evaluation; average benefits may be higher

In addition, influences of other LEED credits as well as those unrelated to the building on occupant well-being and productivity were not explored. Such external influences may be explored in further research to fully understand the relationship of building IEQ and occupant well-being/ productivity.

3. Other uncertainties

a Changing the LCCA variables can affect the final results. While multiple scenarios were modeled during LCCA to limit this uncertainty, it is not completely eliminated

b Occupant well-being conditions other than those studied in this research may also affect the LCCA findings. Sick Building Syndrome (SBS) has been previously discussed as another key occupant well-being condition impacted by building IEQ (Pillai 2006). While data for some SBS symptoms was collected during occupant surveys, it has not been assessed in this thesis

Overall, improvements in occupant well-being/productivity may also provide several trickle-down benefits. These may include reduced liability from improved well-being, reduction in company-wide medical insurance premiums, increased client database resulting from improved marketability, benefits from reduced employee turnover rates etc. Such effects have not been accounted for in this research, while these may add significantly to the overall economic benefits.

5.6 CHAPTER SUMMARY

This Chapter provided a discussion of phase 3 approach and the related findings. In this chapter, the phase 2 outputs were monetized to provide incremental cost and annual economic benefit inputs for LCCA, and the LCCA approach and calculations were presented. Completion of phase 3 also marks the completion of the final research objective.

Within the research limitations, the findings indicate that the case study organizations are on track to attain significant economic benefits. This may provide some economic validity to LEED-IEQ investments. However, several uncertainties remain to be addressed before such investments may be comprehensively justified. These uncertainties provide opportunities for further research.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 OVERVIEW

This research analyzed occupant well-being and productivity related costs and benefits in LEED® offices, using the LCCA framework and a case study based approach. In this research, LEED IEQ related design and construction processes/items resulting in incremental first costs were identified, and their incremental costs were estimated. Occupants from the selected case studies were followed through their move from conventional to LEED offices. Changes in their well-being and productivity were assessed using data from occupant surveys, and these findings were monetized. Finally, a benefit-cost analysis was performed setting LEED IEQ related incremental costs against occupant well-being and productivity benefits. It was determined that life cycle benefits far exceed the incremental costs, indicating an economically viable investment.

The research need, goal, objectives and key work steps, scope and overall limitations were presented in Chapter 1. Chapter 2 presented a summary of the literature. Chapter 3 outlined the 4-phase research methodology. Data collection and primary analysis was presented in Chapter 4, and LCCA work was summarized in Chapter 5.

This chapter summarizes the overall research outputs and conclusions. This discussion forms phase 4 and marks the completion of this initiative. The next section summarizes the work performed for each objective and presents the related outputs. This is followed by a discussion of the research conclusions and inferences. Finally, potential areas of future research are presented.

6.2 SUMMARY OF OBJECTIVES ACHEIVED

The goal of this research was to demonstrate the economic benefits of green buildings based on occupant well-being and productivity. This section summarizes the work performed to achieve the research objectives.

6.2.1 Objective 1: Identify IEQ related processes/items responsible for incremental first cost in LEED offices

The work performed to attain Objective 1 is divided among research Phases 1 and 2a. This is presented in Chapters 2 and 4. Following is a discussion of the work performed under the key work steps.

1. Review literature related with Green Building and IEQ (GB-IEQ), Built Environment and Occupant Well-being/Productivity (BE-OWP), and Life Cycle Cost Analysis (LCCA).

   Literature related with the above categories was reviewed under phase 1 and summarized in Chapter 2. GB-IEQ literature provided an overview of green building, LEED-NC guidelines, and the need for quantification of the well-being and productivity benefits. BE-OWP literature provided an overview of potential well-being/productivity effects of the built environment and assisted in identification of physical/psychological health attributes for assessment. LCCA literature assisted in developing an approach for the economic analysis and provided insight into existing LEED-related LCCA studies.

2. Identify relationships between IEQ and well-being/productivity

   The GB-IEQ and BE-OWP literature provided such overview. This discussion is included in Chapter 2.

3. Determine LEED-IEQ credits that may impact occupant well-being/ productivity.

   Potential relationships between LEED IEQ credits and selected occupant well-being and productivity attributes were identified based on the literature review. These are presented in Figure 2.2, LEED IEQ-Occupant Well-being/Productivity Structure, in Chapter 2. All IEQ credits were found to have such relationships.

4. Identify case studies where occupants move from conventional (non-LEED) to LEED offices.

   The research team identified two case studies in Michigan where occupants were slated to move or had recently moved from conventional offices to LEED facilities. Overview of the selected case studies is provided in Chapter 3.

5. Review case study LEED documentation for the IEQ credits identified in step 3 to hypothesize design and construction processes/items that may result in incremental first costs.

   Access to case study LEED online documentation was obtained with assistance from the constructors involved with these projects. This documentation was reviewed, and potential items/processes causing incremental cost were hypothesized.

6. Obtain feedback from constructors to finalize the hypothesized processes/ items.

   Input was obtained from constructors through personal discussions/e-mail communication. Hypothesized items identified as Standard Operating Procedures (SOPs) or part of local building code requirements etc. were rejected for incremental cost estimation.

7. Summarize IEQ related processes/items causing incremental first cost in LEED offices.

   The work done in steps 5 and 6 was summarized in matrices presented in Appendix B1. This step marks the completion of the first research objective as well as phase 2a.

6.2.2 Objective 2: Determine annual benefits from occupant well-being and productivity improvements resulting from the move to LEED offices

The work performed to attain Objective 2 forms research Phase 2b. This is presented in Chapter 4. Following is a discussion of the work performed under the key work steps.

8. Review existing occupant surveys seeking input regarding well-being and productivity.

   Surveys from building post occupancy evaluation literature, medical (public health) literature, and social sciences literature were studied to identify useful questions and analysis methods.

9. Develop and conduct pre-move occupant survey.

   The pre-move occupant survey was developed with demographic, well-being, productivity/performance, and few exploratory questions. The survey was conducted online. Discussion regarding development and conduct of the pre-move survey is provided in Chapter 3, and the complete survey is provided as Appendix A1.

10. Develop and conduct post-move occupant survey.

   A preliminary analysis of responses from the pre-move survey was conducted and the required adjustments were made to the post-move survey. The survey was conducted online. The complete survey is provided as Appendix A2.

11. Analyze responses from both surveys together to determine changes in occupant well-being and productivity.

    A survey analysis plan was developed. This is presented as Table 3.1 in Chapter 3. Next, responses were coded based on a survey coding plan, presented as Appendix A3. Finally, the responses were analyzed using MS Excel and Minitab 15 software. Detailed discussion of the survey analysis is provided in Chapter 4.

12. Summarize annual benefits from occupant well-being and productivity improvements.

    Annual benefits from improved occupant well-being and productivity (additional work hours available to occupants), as determined from the survey analysis, are presented in Table 4.5 in Chapter 4. This step marks the completion of the second research objective as well as phase 2b.

6.2.3 Objective 3: Determine life cycle economic impact of LEED-IEQ, based on inputs from objectives 1 and 2

The work performed to attain Objective 3 forms research Phase 3. This is presented in Chapter 5. Following is a discussion of the work performed under the key work steps.

13. Monetize findings from step 7 to determine incremental first cost of LEED IEQ.

LEED IEQ related processes/items identified as having incremental first cost were monetized using input from constructors and additional estimating efforts. Estimates of overall incremental cost of LEED IEQ were developed. These are presented in Appendix B2.

14. Monetize findings from step 12 to determine annual $ benefit from improved occupant well-being and productivity.

    The additional work hours determined in step 12 were monetized using employee wage inputs from case studies and typical industry wages. These calculations and outputs are presented in Tables 5.2a and b in Chapter 5.

15. Determine LCCA method, variables, and develop analysis worksheet.

    The LCCA method (benefit-cost analysis) and variables were identified using input from the literature review (step 1) and with inputs from case studies. Four scenarios were developed by adjusting the variables. An MS Excel based worksheet was developed to perform the required calculations. This worksheet is presented as Table 5.3 in Chapter 5.

16. Perform LCCA calculations to determine net life cycle economic impact, based on incremental cost input from step 13 and annual $ benefits from step 14.

LCCA calculations were performed using inputs from steps 13 and 14 and based on the approach and worksheet finalized in step 15. The findings are summarized in Table 5.4 in Chapter 5 and all LCCA worksheets are provided in Appendix C.

17. Summarize uncertainties associated with LCCA findings.

    A structured discussion of the uncertainties associated with the LCCA findings is provided as Section 5.5 in Chapter 5. This step marks the completion of the final research objective as well as phase 3.

The final research phase includes presentation of overall research outputs and conclusions and identification of potential areas for future research. This is provided in the current chapter.

6.3 OBSERVATIONS REGARDING DATA COLLECTION

Detailed analysis of the pre-move and post-move occupant surveys presents some directions to improve their effectiveness. These are summarized below:

1. Include'0' values for well-being questions: Occupants were asked to leave certain questions blank if they had not faced the related health problems during the snapshot period. It is uncertain whether such blank responses can be viewed as a '0' or if the occupants chose to not respond to these questions. Allowing a '0' response to these questions, in future surveys, will assist in eliminating this uncertainty.

2. Gather demographic, medical background information: Demographic and medical background information was gathered only during the pre-move survey. Hence, such data is missing for occupants who did not participate during the pre-move. Since improvements in well-being conditions vary significantly based on the occupants' medical history, such data needs to be gathered in future surveys.
3. Club asthma and respiratory allergies, and depression and stress: While well-being data was gathered separately for all occupant conditions, asthma and respiratory allergy-related responses were analyzed together and similarly depression and stress-related responses were analyzed together. Such data may be collected together as well, for ease of analysis.
4. Condense surveys further: A large amount of exploratory data gathered during occupant surveys was not analyzed in this thesis. Either such exploratory questions can be eliminated from future surveys or analysis methods should be determined to analyze such data.

6.4 CONCLUSIONS AND INFERENCES

The literature review led to the overarching research hypothesis that indoor environments in green buildings can lead to significant well-being and productivity improvements, which may provide substantial economic gains during the operational life of the building. Within the research limitations, our findings provide some validation to this overall hypothesis. Other conclusions are provided below:

1. Incremental costs in LEED buildings: Our findings indicate that LEED buildings still incur some incremental costs. While some of the hard costs may reduce with increased market penetration, documentation-related soft costs may continue to exist.
2. Occupant well-being and productivity benefits in LEED buildings: Our findings indicate improvements in the physical and psychological well-being conditions as well as the occupant productivity after moving to LEED offices. These findings represent well-being/productivity gains as observed by the case study occupants.
3. Benefit/Cost of improved IEQ: From the long-term economic perspective, benefits attained from improved occupant well-being and productivity significantly outweigh the incremental costs associated with IEQ improvements.

Few other inferences may be drawn, based on the research findings. These are presented below:

1. Benefits from occupant well-being/productivity may exceed overall incremental cost for all LEED credits: Literature indicates overall incremental costs for LEED buildings ranging from 0-8.5% (Kats 2003, Stegal 2004, SBW 2003, SWA 2004, Langdon 2004 and 2007). For typical office buildings in Michigan, the maximum 8.5% increment would amount to approximately $9.30 of the typical construction cost per square feet (square feet cost estimated from Means 2007).

If occupant well-being and productivity benefits determined in this research are attained by other offices in Michigan, this would translate to a B/C ratio ranging from 3 to 8 (using the base scenario PVB). Hence, benefits from occupant well-being and productivity alone may outweigh the overall incremental costs from LEED buildings, from the LCCA perspective.

2. Large state-wide gains possible from improved occupant well-being: In a state-wide survey (Cook 2006), Michigan residents between 18 and 64 years old reported approximately 2.2 days/month of activity limitations on average caused by poor physical or mental (psychological) health conditions. These included day to day activities such as "self-care, work, or recreation."

Our findings indicate 4.75% to 5.9% of average productivity loss during hours affected by certain health conditions (Asthma, Respiratory allergies, Depression, and Stress). Extrapolating the research findings for Michigan, using a low end 4.75% productivity loss, and assuming that a third of the 2.2 days represent work hours, the findings indicate approximately 0.84 lost work hours/employee/month.

Another survey (Census 2005) identifies about 5.03 million people among the labor force in Michigan earning approximately $25,000/year (About $13/hr) on average. Using 0.84 lost work hours, this amounts to about

50.7 million lost work hours/year or roughly $660 million/year of possible losses across Michigan, incurred solely due to lost work hours from poor health conditions. A 0.565% productivity improvement, as found through survey analysis (Table 4.3: productivity improvement from improved well-being in LEED offices) would translate to savings of roughly $6.5 million/year throughout Michigan. These substantial benefits may be attained by improving the IEQ of our buildings.

The above conclusions and inferences indicate substantial economic value for improving building IEQ by investing in green (LEED) buildings, both from the individual investors' as well as the policymakers' perspective.

6.5 AREAS OF FUTURE RESEARCH

While the research findings indicate significant benefits of investing in LEED buildings, some uncertainties need to be addressed for further progress of this research area. These uncertainties provide challenges as well as opportunities for further research. Some key research directions are presented below:

1. Long-term follow up on occupants' well-being and productivity changes over the study life, especially by selecting case studies where comparable occupant populations continue to stay in conventional buildings: Further research may focus on prospective cohort study designs with case and control group populations (Hennekens and Buring 1987) to compare changes in occupant well-being/productivity conditions for occupants who move to LEED buildings with those who continue to stay in conventional

buildings. Also, a longer research period with multiple pre-move and post-move surveys would assist in increasing confidence in the research findings.

2. Economic risk assessment based on LCCA uncertainties: Further research may use Monte Carlo simulation (Huijbregts et al. 2003) to model the wide range of LCCA uncertainties and determine the economic risk associated with the investment. If a low risk is determined, it may provide additional confidence in the economic investment.
3. Explore comprehensive benefit/cost of LEED including all credits as well as all costs and benefits throughout the study life: This research developed a methodology for assessment of LEED costs and benefits related with IEQ credits and occupant well-being/productivity. This methodology may be expanded further to address life cycle costs and benefits from all LEED credits.
4. Development of a comprehensive sustainability decision-making framework using environmental, social, and economic impacts: This research focused on assisting decision-making for LEED IEQ related investments using an economic framework. However, the focus of sustainability includes environmental, social, and economic concerns. There is a need to develop a comprehensive sustainability decision-making framework to assist investors/policymakers in making better-informed sustainable investment decisions.

5. Explore spill-over effects of the move to LEED buildings on occupants' life style and behavior: The exploratory data gathered as part of the surveys was focused on spill-over effects on the occupants' life style and behavior from changes in the work environment or their well-being. Such spill-over effects have been discussed in literature (Bianchi et al. 2005, Lambert 1990, Wharton and Erickson 1993, Greenhaus and Bentell 1985, Major and Germano 2006). However, not much research seems to have focused on such effects in the context of green building environments. These impacts remain to be explored.

This research is among some initial efforts directed towards providing economic validation to occupant well-being and productivity gains in green (LEED) buildings through a case study-based approach. Within the research limitations/ uncertainties, the findings impart some degree of substantiation to such well-being/productivity improvement claims. However, expecting this initial effort to comprehensively validate such benefits would be unreasonable.

Continuing research exploring life cycle economic impact of occupant well-being and productivity benefits in LEED buildings may provide additional confidence to these research findings. The researchers hope that this initiative would assist in providing the groundwork for such future efforts and assist long-term sustainability of the green building movement.

APPENDICES

APPENDIX A

OCCUPANT SURVEYS

Appendix A1
Pre-move Occupant Survey[1]

[1] Content reformatted to meet thesis publication requirements.

Survey Consent Form

We, in Construction Management and related disciplines at Michigan State University, are conducting research on the impact of improved indoor environments from LEED/ Green office buildings on occupants. This project is funded by the Environmental Research Initiative at MSU and is submitted for further funding to the National Science Foundation. You are being asked to participate in this project as an occupant having recently moved/ planning to move to a LEED ("Leadership in Energy and Environmental Design" rating system) office.

The main theme of this research is to evaluate changes in occupant well being, performance, and behavior after moving into LEED/ Green office environment. Occupant surveys will be conducted every 3-6 months over the next 3 years, to understand the occupants' perception of the effects of this new office environment on themselves, and employee records will be studied for attendance and performance. Each survey will take 20-30 minutes to complete. You may also be contacted for further participation in focus groups (every 3-6 months over the next 3 years) to elaborate and discuss your opinions and recommendations. All information collected through these surveys and focus groups would be kept confidential in the Principal Investigator's office and would be accessible only to the research team involved with this project and would be used to achieve the study objectives as well as for written or oral reports and published papers. Your name will be kept confidential in all public references to this research and your confidentiality will be protected to the maximum extent allowable by law (unless the interviewee agrees for us to use his/her name and/or professional affiliation in the study). There are no known risks associated with participation in the study. As a possible benefit of your participation, you could gain a better understanding of your work environment and this work may help advance the sustainable building movement in society.

Your assistance is voluntary i.e., you may choose not to participate at all, or refuse to participate in certain procedures or answer certain questions or discontinue your participation at any time without consequence. One copy of this document will be kept together with our research records at Michigan State University for 3 years after the project completion. As a participant you may request a copy for your records. If at any time, you would like to discuss questions regarding this research, you may do so by contacting Dr. Matt Syal, Construction Management, Michigan State University at (517)-432-2951. Also, If you have any questions or concerns about your role and rights as a research participant, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Director of MSU's Human Research Protection Program, Dr. Peter Vasilenko, at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 202 Olds Hall, MSU, East Lansing, MI 48824.

***1. I voluntarily agree to participate in this study and give permission to access my records.**

No

Yes, Please print your full name

____

***2. I volunteer the name of my professional affiliation to be used for publishing the study results.**

No

Yes, Please print your full name

____

Section 1: General Information

1. What is your Gender?

Male

Female

2. What is your Age in years?

[ ]

3. What is your Race?

White/Caucasian

American Indian/Alaskan Native

Black/African American

Asian/Pacific Islander (Asian American)

Other (please specify)

[ ]

4. What is your Ethnicity?

Hispanic

Non-Hispanic

5. What is your Marital status?

Single

Divorced/ Separated

Married

Widowed

Other (please specify)

[ ]

6. What is your highest level of education?

High School

Associate Degree

Graduate Degree

Some College

Bachelor Degree

Other (please specify)

[ ]

7. What is your job category?

Managerial/ Executive

Support staff

Supervisory/ Technical

Other (please specify)

8. What is your job title?

9. What kind of work space do you currently have?

Individual room

Individual cubicle

Shared room/ cubicle

Shared open space

Other (Please Specify)

10. How many people do you share your work space with?

11. How large is your workspace? (Sq ft estimate)

12. How satisfied are you with your work space size?

	To no extent	To some extent	To a moderate extent	To a large extent	To a very large extent
Rate your satisfaction level	O	O	O	O	O

13. Which floor in your building is your work space located?

First Floor Second Floor Third Floor

Fourth Floor Fifth Floor Sixth Floor

Other (Please Specify)

14. What direction in your building is your workspace located? (Pick single or multiple options as applicable)

North South East West Don't know

15. How far is your work space from the nearest window?

0-5ft 11-15ft >20ft

6-10ft 16-20ft

16. How many hours each week do you typically spend at your workspace?

17. How many total hours each week do you spend in your office building?

18. How long have you worked at your present workspace?

Years

Months

19. How long have you worked in this building?

Years

Months

Section 2: Occupant Well-being

1. Do you currently smoke?

Yes   No

2. How many cigarettes do you typically smoke each week?

1-5   15-20
6-10   >20
11-15

3. How long have you been smoking?

Years [ ]
Months [ ]

4. Listed below are some common health problems. Please answer the following questions.

	Do you have a medical history of this problem?	Are you currently on medication for this problem?
Asthma		
Respiratory allergies		
Sore throat/ Cough/ Common cold		
Breathing difficulty		
Hypertension		
Cardiovascular diseases		
Irritation- eyes/ nose/ throat/ skin		
Headache/ Fatigue/ Dizziness		
Visual discomfort/ Eye strain		
General discomfort		
Anxiety		
Depression		
Stress		
Lack of confidence		
Lack of motivation		
Low energy level		
Other lung diseases (Please specify below)		

5. Please answer the following questions if you have experienced these health problems in the last 4 weeks.

'Note: If you did not experience some of these health problems in the last 4 weeks, please leave those rows blank.'

	How many days did you face this health problem during the last 4 weeks?	How many hours were you absent from work due to this health problem during the last 4 weeks?	While at work, how many hours did you face this health problem during the last 4 weeks?	During these affected hours while at work, how did your productivity change?
Asthma aggravation				
Respiratory allergies				
Sore throat/ Cough/ Common cold				
Breathing difficulty				
Hypertension				
Cardiovascular diseases				
Irritation- eyes/ nose/ throat/ skin				
Headache/ Fatigue/ Dizziness				
Visual discomfort/ Eye strain				
General discomfort				
Anxiety				
Depression				
Stress				
Lack of confidence				
Lack of motivation				
Low energy level				
Other lung diseases (Please specify below)				

6. How much confidence do you have in your answers in the above question?

91-100%	81-90%	71-80%	61-70%	51-60%	41-50%	31-40%	21-30%	11-20%	1-10%	0%
○	○	○	○	○	○	○	○	○	○	○

7. How was your overall productivity affected during the last 4 weeks due to all health problems selected in question 1 above?

0% No effect on productivity	7-8% Less productive	15-16% Less productive
1-2% Less productive	9-10% Less productive	17-18% Less productive
3-4% Less productive	11-12% Less productive	19-20% Less productive
5-6% Less productive	13-14% Less productive	Overall productivity was reduced by >20%

8. In the last 4 weeks, how many hours were you absent from work because of all health problems selected in question 5 above?

0	31-40	71-80
1-10	41-50	>80
11-20	51-60	
21-30	61-70	

9. If you selected 'Asthma' or 'Respiratory allergies' in question 5 above, do you think that the indoor environment of your office triggers your symptoms?

Yes No Don't Know

10. What aspects of your office indoor environment trigger your respiratory symptoms? (Pick all that apply)

Furniture	Ceilings	Air quality
Carpet/ Floors	Temperature	Don't know
Paint/ Walls	Humidity	
Others (please specify)		

11. How much confidence do you have in your answers in the above question?

91-100%	81-90%	71-80%	61-70%	51-60%	41-50%	31-40%	21-30%	11-20%	1-10%	0%
○	○	○	○	○	○	○	○	○	○	○

Section 3: Work Environment Satisfaction

1. Listed below are some aspects of your office indoor environment. Please rate your current satisfaction level, their importance to your satisfaction, and your personal control over these.

	How satisfied are you?	How important is this to your overall satisfaction?	Do you have control over this?
Temperature			
Humidity			
Air flow speed			
Air quality			
Lighting			
Daylight			
Glare			
Outside views			
Noise levels			
Office furniture ergonomics			
Office computer			
Visual privacy			
Other- Specify below			

2. Do you think that the indoor environment of your office affects your performance?

Yes   No   Don't Know

3. How does the indoor environment of your current workspace affect your typical performance/ productivity?

-10% or worse: Reduced productivity	-8%	-6%	-4%	-2%	0%: No affect on productivity	+2%	+4%	+6%	+8%	+10% or better: Improved productivity
○	○	○	○	○	○	○	○	○	○	○

4. How much confidence do you have in your answers in the above question?

91-100%	81-90%	71-80%	61-70%	51-60%	41-50%	31-40%	21-30%	11-20%	1-10%	0%
○	○	○	○	○	○	○	○	○	○	○

Section 4: Productivity and Performance

1. Rate your personal performance based on the following attributes for the last 4 weeks.

	Performed at a much lower level than the standards set for my job	Performed at a somewhat lower level than the standards set for my job	Performed at a level that meets the standards set for my job	Performed at a somewhat higher level than the standards set for my job	Performed at a much higher level than the standards set for my job
Quantity of work produced	○	○	○	○	○
Quality of work produced	○	○	○	○	○
Customer service provided (to those within my organization)	○	○	○	○	○
Customer service provided (to those outside my organization)	○	○	○	○	○

2. To what extent in the last 4 weeks have you done the following?

	To no extent	To some extent	To a moderate extent	To a large extent	To a very large extent
Implemented strategies that have improved ways to do your job	○	○	○	○	○
Created better processes and routines in your department	○	○	○	○	○
Came up with new ideas to improve the work processes in your area	○	○	○	○	○
Done things to help others do their job better	○	○	○	○	○
Helped others in ways so that people feel this is a good place to work	○	○	○	○	○
Helped others who had work related problems	○	○	○	○	○
Taken fewer off task breaks while at work	○	○	○	○	○
Tended to complain about work to colleagues	○	○	○	○	○
Tended to make a mountain out of molehills	○	○	○	○	○
Tended to complain about work to colleagues	○	○	○	○	○
Obeyed company rules and regulations throughout the day	○	○	○	○	○

Section 5: Other affects of work environment

1. How satisfied are you with your life in general?

	Strongly disagree	Mildly disagree	Unsure	Mildly agree	Strongly agree
In most ways my life is close to my ideal	○	○	○	○	○
The conditions of my life are excellent	○	○	○	○	○
I am satisfied with my life	○	○	○	○	○
So far, I have gotten the important things I want	○	○	○	○	○
If I could live my life over. I would change almost nothing	○	○	○	○	○

2. Given an opportunity how likely are you to make a special effort to do the following?

	To no extent	To some extent	To a moderate extent	To a large extent	To a very large extent
Consider buying Energy Star appliances at home	○	○	○	○	○
Consider buying water saving fixtures at home	○	○	○	○	○
Consider buying LEED/ Green home for your next house	○	○	○	○	○
Buy products made from recycled materials	○	○	○	○	○
Buy household chemicals such as cleaning solutions that are environmentally friendly	○	○	○	○	○
Buy organic fruits and vegetables	○	○	○	○	○
Avoid buying products from a company that you know may be harming the environment	○	○	○	○	○

3. Please answer the following about your current commuting habits

	Never	Sometimes	Averagely	Mostly	Always
Do you currently carpool to get to work?	○	○	○	○	○
Do you currently use public transport to get to work?	○	○	○	○	○
Do you currently bike/ walk to work?	○	○	○	○	○
Do you currently drive a low-emitting and fuel-efficient vehicle to get to work?	○	○	○	○	○

4. Rate the following statements

	To no extent	To some extent	To a moderate extent	To a large extent	To a very large extent
I would be willing to pay higher taxes in order to protect the environment	○	○	○	○	○
I would be willing to accept cuts in my standard of living to protect the environment	○	○	○	○	○
I would be willing to pay higher prices in order to protect the environment	○	○	○	○	○
In the last twelve months, have you read any newsletters, magazines or other publications written by environmental groups?	○	○	○	○	○
In the last twelve months, have you signed a petition in support of protecting the environment?	○	○	○	○	○
In the last twelve months, have you given money to an environmental group?	○	○	○	○	○
In the last twelve months, have you written a letter or called your member of Congress or another government official to support strong environmental protection?	○	○	○	○	○
In the last twelve months, have you read any newsletters, magazines or other publications written by environmental groups?	○	○	○	○	○
In the last twelve months, have you boycotted or avoided buying the products of a company because you felt that company was harming the environment?	○	○	○	○	○
In the last twelve months, have you voted for a candidate in an election at least in part because he or she was in favor of strong environmental protection?	○	○	○	○	○

5. Are you a member of any group whose main aim is to preserve or protect the environment?

Yes No

6. Do you agree or disagree to the following?

	Strongly disagree	Mildly disagree	Unsure	Mildly agree	Strongly agree
We are approaching the limit of the number of people the earth can support	○	○	○	○	○
Humans have the right to modify the natural environment to suit their needs	○	○	○	○	○
When humans interfere with nature it often produces disastrous consequences	○	○	○	○	○
Human ingenuity will insure that we do not make the earth unlivable	○	○	○	○	○
Humans are severely abusing the environment	○	○	○	○	○
The earth has plenty of natural resources if we just learn how to develop them	○	○	○	○	○
Plants and animals have as much right as humans to exist	○	○	○	○	○
The balance of nature is strong enough to cope with the impacts of modern industrial nations	○	○	○	○	○
Despite our special abilities humans are still subject to the laws of nature	○	○	○	○	○
The so called "ecological crisis" facing humankind has been greatly exaggerated	○	○	○	○	○
The earth is like a spaceship with very limited room and resources	○	○	○	○	○
Humans were meant to rule over the rest of nature	○	○	○	○	○
The balance of nature is very delicate and easily upset	○	○	○	○	○
Humans will eventually learn enough about how nature works to be able to control it	○	○	○	○	○
If things continue on their present course, we will soon experience a major ecological catastrophe	○	○	○	○	○

7. Have you received any information/ education from your company about LEED/ green building?

Yes No

8. Please provide a short description of what information has your company shared about LEED/ green building.

Thanks for your participation in this pre-move survey. We would forward further surveys for your new LEED building in the near future.

Sustainable Built Environment Research Team (SBER)
Michigan State University

Appendix A2

Post-move Occupant Survey[1]

[1] Content reformatted to meet thesis publication requirements.

Survey Consent Form

Continuing with our endavor to explore the impact of LEED office environment on occupant health and performance, the Sustainable Built Environement Researchers urge you to participate in this post-move occupant survey. You are being approached to take part in this survey as an occupant having recently moved to a LEED ("Leadership in Energy and Environmental Design" rating system) office.

The main theme of this research is to evaluate changes in occupant well being, performance, and behavior after moving into LEED/ Green office environment. Occupant surveys may be conducted every 3-6 months over the next 3 years, to understand the occupants' perception of the effects of this new office environment on themselves, and employee records will be studied for attendance and performance. Each survey will take 20-30 minutes to complete. You may also be contacted for further participation in focus groups (every 3-6 months over the next 3 years) to elaborate and discuss your opinions and recommendations. All information collected through these surveys and focus groups would be kept confidential in the Principal Investigator's office and would be accessible only to the research team involved with this project and would be used to achieve the study objectives as well as for written or oral reports and published papers. Your name will be kept confidential in all public references to this research and your confidentiality will be protected to the maximum extent allowable by law (unless the interviewee agrees for us to use his/her name and/or professional affiliation in the study). There are no known risks associated with participation in the study. As a possible benefit of your participation, you could gain a better understanding of your work environment and this work may help advance the sustainable building movement in society.

Your assistance is voluntary i.e., you may choose not to participate at all, or refuse to participate in certain procedures or answer certain questions or discontinue your participation at any time without consequence. One copy of this document will be kept together with our research records at Michigan State University for 3 years after the project completion. As a participant you may request a copy for your records. If at any time, you would like to discuss questions regarding this research, you may do so by contacting Dr. Matt Syal, Construction Management, Michigan State University at (517)-432-2951. Also, If you have any questions or concerns about your role and rights as a research participant, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Director of MSU's Human Research Protection Program, Dr. Peter Vasilenko, at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 202 Olds Hall, MSU, East Lansing, MI 48824.

***1. I voluntarily agree to participate in this study and give permission to access my records.**

- No
- Yes, Please print your full name

Section 1: General Information

1. What kind of work space do you currently have?

Individual room
Individual cubicle
Shared room/ cubicle
Shared open space
Other (Please Specify)

2. How large is your workspace? (Sq ft estimate)

3. How satisfied are you with your work space size?

	To no extent	To some extent	To a moderate extent	To a large extent	To a very large extent
Rate your satisfaction level	○	○	○	○	○

4. How many people do you share your work space with?

5. Which floor in your building is your work space located?

First Floor
Second Floor
Third Floor
Fourth Floor
Fifth Floor
Sixth Floor
Other (Please Specify)

14. What direction in your building is your workspace located? (Pick single or multiple options as applicable)

North
South
East
West
Don't know

15. How far is your work space from the nearest window?

0-5ft
11-15ft
>20ft
6-10ft
16-20ft

18. How long have you worked at your present workspace?

Years [ ]

Months [ ]

19. How long have you worked in this building?

Years [ ]

Months [ ]

Section 2: Occupant Well-being

1. Please answer the following questions if you have experienced these health problems in the last 4 weeks. 'Note: If you did not experience some of these health problems in the last 4 weeks, please leave those rows blank.'

	How many days did you face this health problem during the last 4 weeks?	How many hours were you absent from work due to this health problem during the last 4 weeks?	While at work, how many hours did you face this health problem during the last 4 weeks?	During these affected hours while at work, how did your productivity change?
Asthma aggravation				
Respiratory allergies				
Sore throat/ Cough/ Common cold				
Breathing difficulty				
Hypertension				
Cardiovascular diseases				
Irritation- eyes/ nose/ throat/ skin				
Headache/ Fatigue/ Dizziness				
Visual discomfort/ Eye strain				
General discomfort				
Anxiety				
Depression				
Stress				
Lack of confidence				
Lack of motivation				
Low energy level				
Other lung diseases (Please specify below)				

[ ]

2. How much confidence do you have in your answers in the above question?

91-100%	81-90%	71-80%	61-70%	51-60%	41-50%	31-40%	21-30%	11-20%	1-10%	0%
O	O	O	O	O	O	O	O	O	O	O

3. How was your overall productivity affected during the last 4 weeks due to all health problems selected in question 1 above?

0% No effect on productivity
1-2% Less productive
3-4% Less productive
5-6% Less productive
7-8% Less productive
9-10% Less productive
11-12% Less productive
13-14% Less productive
15-16% Less productive
17-18% Less productive
19-20% Less productive
Overall productivity was reduced by >20%

4. Over the last 4 weeks, how many hours were you absent from work because of all health problems selected in question 1 above?

0
1-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
>80

5. If you have 'Asthma' or 'Respiratory allergies,' what aspects of your office indoor environment trigger your respiratory symptoms? (Pick all that apply)

Furniture
Carpet/ Floors
Paint/ Walls
Ceilings
Temperature
Humidity
Air quality
Don't know
Others (please specify)

6. How much confidence do you have in your answers in the above question?

91-100%	81-90%	71-80%	61-70%	51-60%	41-50%	31-40%	21-30%	11-20%	1-10%	0%
O	O	O	O	O	O	O	O	O	O	O

Section 3: Work Environment Satisfaction

1. Listed below are some aspects of your office indoor environment. Please rate your current satisfaction level, their importance to your satisfaction, and your personal control over these.

	How satisfied are you?	How important is this to your overall satisfaction?	Do you have control over this?
Temperature	▼	▼	▼
Humidity	▼	▼	▼
Air flow speed	▼	▼	▼
Air quality	▼	▼	▼
Lighting	▼	▼	▼
Daylight	▼	▼	▼
Glare	▼	▼	▼
Outside views	▼	▼	▼
Noise levels	▼	▼	▼
Office furniture ergonomics	▼	▼	▼
Office computer	▼	▼	▼
Visual privacy	▼	▼	▼
Other- Specify below	▼	▼	▼

2. How does the indoor environment of your current workspace affect your typical performance/ productivity?

-10% or worse: Reduced productivity	-8%	-6%	-4%	-2%	0%: No affect on productivity	+2%	+4%	+6%	+8%	+10% or better: Improved productivity
○	○	○	○	○	○	○	○	○	○	○

Section 4: Productivity and Performance

1. Rate your personal performance based on the following attributes for the last 4 weeks.

	Performed at a much lower level than the standards set for my job	Performed at a somewhat lower level than the standards set for my job	Performed at a level that meets the standards set for my job	Performed at a somewhat higher level than the standards set for my job	Performed at a much higher level than the standards set for my job
Quantity of work produced	○	○	○	○	○
Quality of work produced	○	○	○	○	○
Customer service provided (to those within my organization)	○	○	○	○	○
Customer service provided (to those outside my organization)	○	○	○	○	○

Section 5: Other affects of work environment

1. Given an opportunity how likely are you to make a special effort to do the following?

	To no extent	To some extent	To a moderate extent	To a large extent	To a very large extent
Consider buying Energy Star appliances at home	○	○	○	○	○
Consider buying water saving fixtures at home	○	○	○	○	○
Consider buying LEED/ Green home for your next house	○	○	○	○	○
Buy products made from recycled materials	○	○	○	○	○
Buy household chemicals such as cleaning solutions that are environmentally friendly	○	○	○	○	○
Buy organic fruits and vegetables	○	○	○	○	○
Avoid buying products from a company that you know may be harming the environment	○	○	○	○	○

2. Please answer the following about your current commuting habits

	Never	Sometimes	Averagely	Mostly	Always
Do you currently carpool to get to work?	○	○	○	○	○
Do you currently use public transport to get to work?	○	○	○	○	○
Do you currently bike/ walk to work?	○	○	○	○	○
Do you currently drive a low-emitting and fuel-efficient vehicle to get to work?	○	○	○	○	○

3. Have you received any information/ education from your company about LEED/ green building?

Yes No

8. Please provide a short description of what information has your company shared about LEED/ green building.

Thanks for your participation in this post-move occupant survey. We may conduct further surveys, as needed in the near future.

Sustainable Built Environment Research Team (SBER)
Michigan State University
sbercm@msu.edu

Appendix A3

Survey Response Coding Plan[2]

[2] Data not analyzed in this thesis was typically not coded. Hence, the coding plan does not represent such data.

Table A3: Survey Response Coding Plan

Short question title	Survey (Pr/ Po)	Response	Code
Section 1: General Information			
Gender	Pr	Male	1
		Female	2
Race	Pr	White/Caucasian	1
		Black/African American	2
		American Indian/Alaskan Native	3
		Asian/Pacific Islander (Asian American)	4
		Other	5
Ethnicity	Pr	Hispanic	1
		Non-Hispanic	2
Marital status	Pr	Single	1
		Married	2
		Divorced/ Separated	3
		Widowed	4
		Other	5
Education	Pr	High school	1
		Some college	2
		Associates Degree	3
		Bachelor Degree	4
		Graduate Degree	5
		Other	6
Job Category	Pr	Managerial/ Executive	1
		Supervisory/ Technical	2
		Support staff	3
		Other	4
Work space type	Pr, Po	Individual room	1
		Individual cubicle	2
		Shared room/ cubicle	3
		Shared open space	4
		Other	5
Work space size satisfaction	Pr, Po	To no extent	1
		To some extent	2
		To a moderate extent	3
		To a large extent	4
		To a very large extent	5
Work space level	Pr, Po	First Floor	1
		Second Floor	2
		Third Floor	3
		Fourth Floor	4
		Fifth Floor	5
		Sixth Floor	6
		Other	7

Table A3: Survey Response Coding Plan (continued from previous page)

Short question title	Survey (Pr/ Po)	Response	Code
Work space direction	Pr, Po	North	1
		South	2
		East	3
		West	4
		NE	5
		NW	6
		SE	7
		SW	8
		Don't know	9
Distance from window	Pr, Po	0-5ft	3
		6-10ft	8
		11-15ft	13
		16-20ft	18
		>20ft	23
Section 2: Occupant Well-being			
Smoke	Pr	No	1
		Yes	2
Cigarettes/ week	Pr	1-5	3
		6-10	8
		11-15	13
		16-20	18
		>20	23
Have medical history	Pr	Yes	1
		No	2
Medical history- on medication	Pr	Prescribed	1
		Over the counter	2
		None	3
Health snapshot- days affected	Pr, Po	1-2	1.5
		3-4	3.5
		5-6	5.5
		7-8	7.5
		9-10	9.5
		11-12	11.5
		13-14	13.5
		15-16	15.5
		17-18	17.5
		19-20	19.5
		>20	23
Health snapshot- hours absent	Pr, Po	0	0
		1-5	3
		6-10	8
		11-15	13
		16-20	18
		21-25	23
		26-30	28
		31-35	33
		36-40	38
		>40	43

Table A3: Survey Response Coding Plan (continued from previous page)

Short question title	Survey (Pr/ Po)	Response	Code
Health snapshot- work hours affected	Pr, Po	0	0
		1-5	3
		6-10	8
		11-15	13
		16-20	18
		21-25	23
		26-30	28
		31-35	33
		36-40	38
		41-45	43
		46-50	48
		51-55	53
		56-60	58
		61-65	63
		66-70	68
		71-75	73
		76-80	78
		>80	83
Health snapshot- productivity reduction	Pr, Po	0%	0
		1-5%	3
		6-10%	8
		11-15%	13
		16-20%	18
		21-25%	23
		26-30%	28
		31-35%	33
		36-40%	38
		41-45%	43
		46-50%	48
		>50%	53
Confidence level (Same codes used for all confidence related questions)	Pr, Po	91-100%	95
		81-90%	85
		71-80%	75
		61-70%	65
		51-60%	55
		41-50%	45
		31-40%	35
		21-30%	25
		11-20%	15
		1-10%	5
		0%	0

Table A3: Survey Response Coding Plan (continued from previous page)

Short question title	Survey (Pr/ Po)	Response	Code
Overall productivity reduction	Pr, Po	0%	0
		1-2%	1.5
		3-4%	3.5
		5-6%	5.5
		7-8%	7.5
		9-10%	9.5
		11-12%	11.5
		13-14%	13.5
		15-16%	15.5
		17-18%	17.5
		19-20%	19.5
		>20%	20
Overall absence	Pr, Po	0	0
		1-10	5.5
		11-20	15.5
		21-30	25.5
		31-40	35.5
		41-50	45.5
		51-60	55.5
		61-70	65.5
		71-80	75.5
		>80	80
Does IEQ affect respiratory symptoms?	Pr	Yes	1
		No	2
		Don't Know	3
IEQ aspects that affect respiratory symptoms	Pr, Po	Furniture	1
		Carpet/ Floors	2
		Paint/ Walls	3
		Ceilings	4
		Temperature	5
		Humidity	6
		Air quality	7
		Others	9
		Don't know	8
Section 3: Work Environment Satisfaction			
IEQ aspects- satisfaction	Pr, Po	Not satisfied	1
		Below average satisfaction	2
		Average satisfaction	3
		Above average satisfaction	4
		Completely satisfied	5
IEQ aspects- significance	Pr, Po	Not significant	1
		Below average significance	2
		Average significance	3
		Above average significance	4
		Completely significant	5

Table A3: Survey Response Coding Plan (continued from previous page)

Short question title	Survey (Pr/ Po)	Response	Code
IEQ aspects- control	Pr, Po	Full Control	1
		Partial Control	2
		None	3
Does IEQ affect performance?	Pr	Yes	1
		No	2
		Don't Know	3
Work space IEQ- productivity effect	Pr, Po	-10% or worse productivity reduction	-10
		-8%	-8
		-6%	-6
		-4%	-4
		-2%	-2
		0% no effect on productivity	0
		+2%	2
		+4%	4
		+6%	6
		+8%	8
		+10% or better productivity improvement	10
Section 4: Productivity and Performance			
Performance snapshot questions	Pr, Po	Much lower performance	1
		Somewhat lower performance	2
		Performance per standards	3
		Somewhat higher performance	4
		Much higher performance	5
Section 5: Other affects of work environment			
Purchasing intent	Pr, Po	To no extent	1
		To some extent	2
		To a moderate extent	3
		To a large extent	4
		To a very large extent	5
Commuting habits	Pr, Po	Never	1
		Sometimes	2
		Averagely	3
		Mostly	4
		Always	5

APPENDIX B

LEED IEQ Incremental Cost Matrices

B1: LEED IEQ Processes/ Items Causing Incremental Costs

B2: LEED IEQ Incremental Cost Estimates

Appendix B1

LEED IEQ Processes/ Items Causing Incremental Costs

Table B1.1: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 1

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
Pr1	Min IAQ Performance	**Meet ASHRAE** 62-2004 IAQ requirements for Mech Vent. Buildings	LEED template, Airflow calculations	Engineering-airflow calculations, and document. cost	Engineering is part of Standard operating procedures (SOP) for the Architect/Engineer (A/E)
Pr2	ETS Control	Non-smoking building, exterior **designated smoking areas** at least 25 feet away from entries, outdoor air intakes and operable windows	LEED template, narrative, dwg	Engineering-drawing preparation, and document. Cost	Documentation only. No substantial cost for engineering work
EQ1	Outdoor air delivery monitoring	**Outdoor airflow measurement device** capable of measuring the minimum outdoor airflow rate at all expected system operating conditions within 15% of the design minimum outdoor air rate	LEED template, Narrative, dwgs, Equipment documentation	CO_2 sensors	Agree- CO_2 sensors
				Other system changes	Overhead flow (OHF) sensors
				Additional Engineering-system design, and document. cost	Engineering is part of SOP for under-floor air distribution (UFAD) system
EQ2	Increased Ventilation	Increase **breathing zone ventilation rates by at least 30% above ASHRAE** 62.1-2004	LEED template, Narrative, Ventilation rate calculations	Additional cost for increased capacity of AHU's	Part of SOP to meet Michigan mechanical code (It is more stringent than ASHRAE 62-2004)
				Engineering-airflow calculations, and document. cost	Engineering is part of A/E's Standard operating procedures (SOP)

Table B1.1: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
EQ3.1	Construction IAQ management plan- during construction	**Develop and implement IAQ management plan** during construction: Meet SMACNA IAQ guidelines for construction phase. Protect stored on-site and installed absorptive materials from moisture damage. Use MERV 8 filters for any AHU's used during construction and replace filters prior to occupancy.	LEED template, Construction IAQ management plan, Construction photos identifying SMACNA approach. Filter schedule and literature.	Plastic covering for all HVAC material.	Part of supplier's SOP
				Plastic barriers and negative pressure equipment, Wet misting.	Not used on project
				MERV 8 filters used during construction.	Agree-MERV 8 filters
				Additional storage costs.	Part of constructor's SOP
				Daily cleaning costs.	Part of constructor's SOP for safety reasons
				Engineering-IAQ management plan development, and document. cost	Standardized IAQ management plan used , hence no substantial engineering work
EQ4.1	Low-Emitting Materials, Adhesives and Sealants	Meet **SCAQMD and Green Seal requirements for material VOC limits**	LEED template, material literature (brochures/ MSDS/supplier submittals)	Premium cost for VOC free materials	These have become the industry standard, hence no premium
				Engineering-modifying specs to include VOC free materials, and document. cost	Part of standard specifications, hence no engineering work

Table B1.1: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
EQ4.2	Low-Emitting Materials, Paints and Coatings	Meet **SCAQMD and Green Seal requirements for material VOC limits**	LEED template, material literature (brochures)	Premium cost for VOC free materials	These have become the industry standard, hence no premium
				Engineering-modifying specs to include VOC free materials, and document. cost	Documentation only. Part of standard specifications, hence no engineering work
EQ4.3	Low-Emitting Materials, Carpet Systems	Carpet systems must **meet Green Label Plus requirements**. Carpet pad must meet CRI Green Label requirements.	LEED template	Premium cost for VOC free materials	These have become the industry standard, hence no premium
				Engineering-modifying specs to include VOC free materials, and document. cost	Documentation only. Part of standard specifications, hence no engineering work
EQ4.4	Low-Emitting Materials, Composite Wood and Laminate Adhesives	Composite wood and agrifiber products, including core **materials, must contain no added urea-formaldehyde resins.** Laminate Adhesives must contain no urea-formaldehyde.	LEED template, material literature (MSDS/supplier submittals)	Premium cost for Urea-formaldehyde free materials	These have become the industry standard, hence no premium
				Engineering-modifying specs to include urea-formaldehyde free materials, and document. cost	Part of standard specifications, hence no engineering work

Table B1.1: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
EQ4.5	Low-Emitting Materials, Systems Furniture and Seating	All systems furniture and seating must be **Greenguard Indoor Air Quality Certified**	LEED template, furniture Greenguard certificates	Premium cost for Greenguard labeled furniture	These have become the industry standard, hence no premium
				Engineering-modifying specs to include Greenguard labeled furn., and document. cost	Documentation only. No substantial engineering work
EQ5	Indoor Chemical and Pollutant Source Control	Employ **permanent entryway systems** to capture dirt, particulates, etc. from entering the building at all high-volume exterior entryways. Provide **segregated areas with separate outside exhausts** (operating under negative pressure compared with surrounding spaces) for spaces with hazardous gasses or chemicals. Provide containment drains for disposal of any hazardous liquid wastes. Provide **MERV 13 filters** for regularly occupied spaces	LEED template, Narrative, HVAC system technical data (filters info)	Permanent entryway systems	Part of good design practice- SOP for A/E
				MERV 13 filters for AHUs	Agree-MERV 13 filters
				Material/ installation related cost-to segregate haz. spaces	Nothing substantial- only a small pantry/ copy space
				Engineering-to segregate haz. Spaces, and document. cost	Documentation only. Part of good design practice- SOP for A/E
EQ6.1	Controllability of Systems, Lighting	Provide **lighting controls for 90% occupants**, and all shared multi-occupant spaces	LEED template, narrative, task lighting dwgs	Additional task lighting, controls	Ambient lighting was minimized. Controls are part of good design practice- SOP for A/E
				Engineering- system design, dwgs etc., and document. cost	Documentation only. SOP for A/E

Table B1.1: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
EQ6.2	Controllability of Systems, Temperature and Ventilation	Provide **thermal and ventilation controls for 50% of the space occupants and all multi-occupant spaces**. Operable windows if used instead of individual controls should meet ASHRAE 62-2004 requirements	LEED template, narrative, dwgs showing individual controls	Additional diffusers for individual control, sensors, system changes	SOP for UFAD system
				Engineering- system design, and document. Cost	Documentation only. SOP for UFAD system design
EQ7.1	Thermal Comfort, Compliance	**Meet ASHRAE 55-2004** requirements	LEED template, narrative, system dwgs	Overall HVAC system changes	These are in line with code requirements, hence SOP
				Engineering- system design, and document. cost	Documentation only. SOP for HVAC system design
EQ7.2	Thermal Comfort, Monitoring	Provide **permanent monitoring system** and process for corrective action to ensure performance per ASHRAE 55-2004	LEED template, narrative, system dwgs	Sensors, BM system, overall HVAC system changes	Sensors only, BM systems are common practice now
				Engineering- system design, and document. cost	Documentation only. Common practice, hence part of SOP
EQ8.1 & EQ8.2	Daylight and Views, Daylight 90% of Spaces	For **90%** of all regularly occupied **areas,** achieve a **Daylight Factor of 2% and provide glare control devices** to ensure daylight effectiveness.	LEED template, narrative, glazing factor calculations, dwgs	May result in planning fewer workstations than typical buildings	Planning was based on the company's work culture- not constrained by LEED requirements
				Cost for extra external glazing than usual, glass partitions	Exterior windows were already available in the original facade, glass partitions were estimated as similar cost to usual systems
				Engineering-design, calculations etc., and document. Cost	Documentation only

Table B1.1: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
EQ8.3	Daylight and Views, Views for 90% of Seated Spaces	Achieve **direct line of sight to the outdoor environment for building occupants in 90%** of all regularly occupied areas.	LEED template, calculations, dwgs	Engineering-design, calculations etc., and document. Cost	Documentation only
Other cost items					Cost for commissioning IEQ systems
					Cost for LEED-CS documentation
				Labor Burden for documentation work	

Table B1.2: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 2

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
Pr1	Min IAQ Performance	Meet ASHRAE 62-1999 IAQ requirements for Mech Vent. Buildings	LEED template, Airflow calculations, Code requirements (Mich, Ashrae 62-1999)	Engineering-airflow calculations, and document. cost	Documentation only. No additional engineering effort.
Pr2	ETS Control	Non-smoking building, exterior designated smoking areas away from entries and operable windows	LEED template, employment policies	Document. cost	10-15 hrs spent mainly at the owner's end due to LEED website technical issues.
EQ1	CO2 monitoring	Install permanent CO2 monitoring system- CO2 differentials per ASHRAE 62-2001 requirements	LEED template, Narrative, dwgs	CO2 sensors	No cost. SOP for constructor
				Other HVAC system changes	SOP for constructor, nothing extra worth attributing to LEED
				Additional Engineering- system design, and document. cost	Documentation only. SOP for A/E. No additional engineering effort.

Table B1.2: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 2 (continued from previous page)

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
EQ2	Ventilation Effectiveness	Meet Ashrae 129-1997 air change effectiveness (Eac) requirements	LEED template, Narrative, Drawings, UFAD system-engineering literature	Additional cost for increased capacity of AHU's	SOP for UFAD system, no cost attributable to LEED
				Engineering-airflow calculations and dwgs, and document. cost	Documentation only. SOP for A/E for UFAD systems.
EQ3.1	Construction IAQ management plan- during construction	Develop and implement IAQ management plan during construction: Meet SMACNA IAQ guidelines for construction phase. Protect stored on-site and installed absorptive materials from moisture damage. Use MERV 8 filters for any AHU's used during construction and replace filters with MERV 13 prior to occupancy.	LEED template, Construction IAQ management plan, Construction photos identifying SMACNA approach.	Plastic covering for all HVAC material.	SOP for suppliers, no additional cost
				MERV 8 filters used during construction.	Building HVAC system was not used during construction.
				Additional storage costs.	SOP for constructor's QA/QC, no additional cost
				Daily cleaning costs.	Cost for separate cleaning sub; however, this was part of constructor's safety/quality initiative
				MERV 13 filters for AHUs	Yes, cost incurred. Though this was part of owner's commitment to create a healthy work environment
				Engineering-IAQ management plan development, and document. cost	Documentation only. Part of constructor's SOP

Table B1.2: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 2 (continued from previous page)

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
EQ3.2	Construction IAQ management plan- before occupancy	Conduct IAQ testing per US EPA requirements	LEED template, air testing results, narrative	Cost for air testing	Yes, cost incurred. Also incurred to establish the change in IEQ from old to new bldg.
				Engineering-planning for air-testing, document. cost	Time spent at constructors end for coordination/ documentation
EQ4.1	Low-Emitting Materials, Adhesives and Sealants	Meet SCAQMD requirements and Bay Area AQM District regulations for material VOC limits	LEED template, material literature	Premium cost for VOC free materials	Uncertain. Few adhesives/ sealants may still have such cost
				Engineering-modifying specs to include VOC free materials, and document. cost	Time spent at constructors end for coordination/ documentation
EQ4.2	Low-Emitting Materials, Paints and Coatings	Meet Green Seal requirements for material VOC limits	LEED template, material literature	Premium cost for VOC free materials	These materials are market standards now, no additional cost.
				Engineering-modifying specs to include VOC free materials, and document. cost	Time spent at constructors end for coordination/ documentation
EQ4.3	Low-Emitting Materials, Carpet	Carpet systems must meet CRI Green Label IAQ test program.	LEED template, material literature	Premium cost for VOC free materials	These materials are market standards now, no additional cost.
				Engineering-modifying specs to include VOC free materials, and document. cost	Time spent at constructors end for coordination/ documentation

Table B1.2: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 2 (continued from previous page)

LEED Information Review				Hypothesis Formulation	Constructors' Feedback
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
EQ5	Indoor Chemical and Pollutant Source Control	Employ permanent entryway systems to capture dirt, particulates, etc. from entering the building at all high-volume exterior entryways. Provide segregated areas with separate outside exhausts (operating under negative pressure compared with surrounding spaces) for spaces with hazardous gasses or chemicals. Provide containment drains for disposal of any hazardous liquid wastes.	LEED template, material technical specs (EQ4.1-4.4 materials)	Permanent entryway systems	SOP for constructor, no additional cost
				Material/ installation related cost-to segregate haz. spaces	No high volume copying etc- no significant effort to achieve this credit; hence, no additional cost
				Engineering-to segregate haz. Spaces, and document. cost	Documentation only. No substantial engineering effort.
EQ6.2	Controllability of Systems, non-perimeter spaces	Provide airflow, temp, and lighting controls for 50% occupants in non-perimeter, regularly occupied spaces	Documentation not available	Additional lighting, controls	No substantial hard costs attributable to this credit
				Engineering- system design, dwgs etc., and document. cost	Documentation only. No additional engineering effort.
EQ8.1	Daylight and Views, Daylight 75% of Spaces	For 75% of all regularly occupied areas, achieve a Daylight Factor of 2%.	LEED template, narrative, glazing factor calculations, dwgs	May result in planning fewer workstations than typical buildings	Planning was not driven by LEED, should not attribute additional cost.
				Additional Cost for high performance external glazing	Yes, cost incurred. Though this was part of owner's commitment to create a more satisfactory work environment and helped in reduction in energy costs.
				Engineering-design, calculations etc., and document. Cost	Time spent at constructors end for coordination/ documentation

Table B1.2: LEED IEQ Processes/ Items Causing Incremental Costs- Case Study 2 (continued from previous page)

LEED Information Review			Hypothesis Formulation	Constructors' Feedback
LEED Credit	LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Processes/ Items	
Other cost items				Additional A/E cost for documentation/ coordination/ engineering effort for overall IEQ credits
				Additional A/E initial time spent for finalizing credits to pursue
				Temporary heating costs in lieu of using building HVAC system during construction
			IEQ Commissioning related costs	Part of constructor's SOP, no cost attributable to LEED

Appendix B2

LEED IEQ Incremental Cost Estimate

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
Pr1	Min IAQ Performance	**Meet ASHRAE** 62-2004 IAQ requirements for Mech Vent. Buildings	LEED template, Airflow calculations		Engineering-airflow calculations, and document. cost	Documentation only	Engineering is part of Standard operating procedures (SOP) for the Architect/Engineer (A/E)	$0	$108	2hrs documentation time @$54/hr (constructor's input)
Pr2	ETS Control	Non-smoking building, exterior **designated smoking areas** at least 25 feet away from entries, outdoor air intakes and operable windows	LEED template, narrative, dwg		Engineering-drawing preparation, and document. Cost	Documentation only	No substantial cost for engineering work	$0	$54	1hrs documentation time @$54/hr (constructor's input)
EQ1	Outdoor air delivery monitoring	**Outdoor airflow measurement device** capable of measuring the minimum outdoor airflow rate at all expected system operating conditions within 15% of the design minimum outdoor air rate	LEED template, Narrative, dwgs, Equipment documentation	CO_2 sensors		Agree- CO_2 sensors		$15,000	$0	10CO2 sensors @ $1,500 each
				Other system changes		Overhead flow (OHF) sensors		$7,000	$0	2OHF sensors @ $3,500 each
					Additional Engineering-system design, and document. cost	Documentation only	Engineering is part of SOP for under-floor air distribution (UFAD) system	$0	$216	4hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ2	Increased Ventilation	**Increase breathing zone ventilation rates by at least 30% above ASHRAE 62.1-2004**	LEED template, Narrative, Ventilation rate calculations	Additional cost for increased capacity of AHU's		Disagree	Part of SOP to meet Michigan mechanical code (It is more stringent than ASHRAE 62-2004)	$0	$0	
					Engineering-airflow calculations, and document. cost	Documentation only	Engineering is part of A/E's Standard operating procedures (SOP)	$0	$108	2hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review			Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit	LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
			Hard Cost	Soft Cost					
EQ3.1 Construction IAQ management plan- during construction	**Develop and implement IAQ management plan** during construction: Meet SMACNA IAQ guidelines for construction phase. Protect stored on-site and installed absorptive materials from moisture damage. Use MERV 8 filters for any AHU's used during construction and replace filters prior to occupancy.	LEED template, Construction IAQ management plan, Construction photos identifying SMACNA approach. Filter schedule and literature.	Plastic covering for all HVAC material.		Disagree	Part of supplier's SOP	$0	$0	
			Plastic barriers and negative pressure equipment, Wet misting.		Disagree	Not used on project	$0	$0	
			MERV 8 filters used during construction.		Agree-MERV 8 filters		$0	$0	MERV8 filter cost not assessed. Instead full MERV13 filters cost assessed under EQ5
			Additional storage costs.		Disagree	Part of constructor's SOP	$0	$0	
			Daily cleaning costs.		Disagree	Part of constructor's SOP for safety	$0	$0	
				Engineering-IAQ man. plan dev, and document. cost	Documentation only	Standardized IAQ management plan used , hence no substantial engineering work	$0	$216	4hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ4.1	Low-Emitting Materials, Adhesives and Sealants	Meet **SCAQMD and Green Seal requirements for material VOC limits**	LEED template, material literature (brochures/ MSDS/supplier submittals)	Premium cost for VOC free materials		Disagree	These have become the industry standard, hence no premium	$0	$0	
					Engineering- modifying specs to include VOC free materials, and document. cost	Documentation only	Part of standard specifications, hence no engineering work	$0	$432	8hrs documentation time @$54/hr (constructor's input)
EQ4.2	Low-Emitting Materials, Paints and Coatings	Meet **SCAQMD and Green Seal requirements for material VOC limits**	LEED template, material literature (brochures)	Premium cost for VOC free materials		Disagree	These have become the industry standard, hence no premium	$0	$0	
					Engineering- modifying specs to include VOC free materials, and document. cost	Documentation only	Part of standard specifications, hence no engineering work	$0	$216	4hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items: Hard Cost	Potential Cost Impact Items: Soft Cost	Cost items	Rationale	Hard Cost	Soft Cost	Notes
EQ4.3	Low-Emitting Materials, Carpet Systems	Carpet systems must **meet Green Label Plus requirements**. Carpet pad must meet CRI Green Label requirements.	LEED template	Premium cost for VOC free materials		Disagree	These have become the industry standard, hence no premium	$0	$0	
					Engineering-modifying specs to include VOC free materials, and document. cost	Documentation only	Part of standard specifications, hence no engineering work	$0	$108	2hrs documentation time @$54/hr (constructor's input)
EQ4.4	Composite Wood and	Composite wood and agrifiber products, including core **materials, must contain no added urea-formaldehyde resins.** Laminate Adhesives must contain no urea-formaldehyde.	LEED template, material literature (MSDS/supplier submittals)	Premium cost for Urea-formaldehyde free materials		Disagree	These have become the industry standard, hence no premium	$0	$0	
					Engineering-modifying specs to include urea-formaldehyde free materials, and document. cost	Documentation only	Part of standard specifications, hence no engineering work	$0	$216	4hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ4.5	Low-Emitting Materials, Systems Furniture and Seating	All systems furniture and seating must be **Greenguard Indoor Air Quality Certified**	LEED template, furniture Greenguard certificates	Premium cost for Greenguard labeled furniture		Disagree	These have become the industry standard, hence no premium	$0	$0	
					Engineering- modifying specs to include Greenguard labeled furn., and document. cost	Documentation only	No substantial engineering work	$0	$432	8hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ5	Indoor Chemical and Pollutant Source Control	Employ **permanent entryway systems** to capture dirt, particulates, etc. from entering the building at all high-volume exterior entryways. Provide **segregated areas with separate outside exhausts** (operating under negative pressure compared with surrounding spaces) for spaces with hazardous gasses or chemicals. Provide containment drains for disposal of any hazardous liquid wastes. Provide **MERV 13 filters** for regularly occupied spaces	LEED template, Narrative, HVAC system technical data (filters info)	Permanent entryway systems		Disagree	Part of good design practice- SOP for A/E	$0	$0	
				MERV 13 filters for AHUs		Agree-MERV 13 filters		$10,000	$0	MERV13 filters for 2 AHUs for a total cost of $20,000- Allocate half, since only half of CS building is part of research scope
				Material/ installation related cost-to segregate haz. spaces		Disagree	Nothing substantial- only a small pantry/ copy space	$0	$0	
					Engineering- to segregate haz. Spaces, and document. cost	Documentation only	Part of good design practice- SOP for A/E	$0	$216	4hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ6.1	Controllability of Systems, Lighting	Provide **lighting controls for 90% occupants**, and all shared multi-occupant spaces	LEED template, narrative, task lighting dwgs	Additional task lighting, controls		Disagree	Ambient lighting was minimized. Controls are part of good design practice- SOP for A/E	$0	$0	
					Engineering- system design, dwgs etc., and document. cost	Documentation only	SOP for A/E	$0	$324	6hrs documentation time @$54/hr (constructor's input)
EQ6.2	Controllability of Systems, Temperature and Ventilation	Provide **thermal and ventilation controls for 50% of the space occupants and all multi-occupant spaces**. Operable windows if used instead of individual controls should meet ASHRAE 62-2004 requirements	LEED template, narrative, dwgs showing individual controls	Additional diffusers for individual control, sensors, system changes		Disagree	SOP for UFAD system	$0	$0	
					Engineering- system design, and document. Cost	Documentation only	SOP for UFAD system design	$0	$216	4hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ7.1	Thermal Comfort, Compliance	**Meet ASHRAE 55-2004** requirements	LEED template, narrative, system dwgs	Overall HVAC system changes		Disagree	These are in line with code requirements, hence SOP	$0	$0	
					Engineering-system design, and document. cost	Documentation only	SOP for HVAC system design	$0	$216	4hrs documentation time @$54/hr (constructor's input)
EQ7.2	Thermal Comfort, Monitoring	Provide **permanent monitoring system** and process for corrective action to ensure performance per ASHRAE 55-2004	LEED template, narrative, system dwgs	Sensors, BM system, overall HVAC system changes		Sensors only	BM systems are common practice now	$0	$0	CO2 and OHF sensors were assessed under EQ1 earlier.
					Engineering-system design, and document. cost	Documentation only	Common practice, hence part of SOP	$0	$108	2hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ8.1 & EQ8.2	Daylight and Views, Daylight 90% of Spaces	For **90%** of all regularly occupied **areas,** achieve a **Daylight Factor of 2% and provide glare control devices** to ensure daylight effectiveness.	LEED template, narrative, glazing factor calculations, dwgs	If achieving this credit resulted in planning fewer workstations than typical buildings- there may be a cost		Disagree	Planning was based on the company's work culture- not constrained by LEED requirements	$0	$0	
				Cost for extra external glazing than usual, glass partitions		Disagree	Exterior windows were already available in the original facade, glass partitions were estimated as similar cost to usual systems	$0	$0	
					Engineering- design, calculations etc., and document. Cost	Documentation only		$0	$540	10hrs documentation time @$54/hr (constructor's input)

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ8.3	Daylight and Views, Views for 90% of Seated Spaces	Achieve **direct line of sight to the outdoor environment for building occupants in 90%** of all regularly occupied areas.	LEED template, calculations, dwgs	Covered in EQ 8.1 & 8.2 above	Engineering-design, calculations etc., and document. Cost	Documentation only		$0	$216	4hrs documentation time @$54/hr (constructor's input)
Other cost items						Cost for commissioning IEQ systems		$1,500	$0	30% of total commissioning cost allocated to IEQ systems (constructor's input)
						Cost for LEED-CS documentation		$0	$702	2hrs additional documentation time@$54/hr for LEED-CS IEQ credits (13 points). Allocate half, since only 3 of 6 floors in case study building are being assessed in the research

Table B2.1: LEED IEQ Incremental Cost Estimate- Case Study 1 (continued from previous page)

LEED Information Review			Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit	LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
			Hard Cost	Soft Cost					
Other Cost Items			Labor Burden for documentation work				$0	$1,247	30% of documentation-related soft cost
Total incremental cost for LEED IEQ							$39,537.20		Hard cost- $33,500; Soft cost- $6037.20
Incremental cost of LEED IEQ/ SF							$2.34		16,900 GSF registered with LEED

Table B2.2: LEED IEQ Incremental Cost Estimate- Case Study 2

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
Pr1	Min IAQ Performance	Meet ASHRAE 62-1999 IAQ requirements for Mech Vent. Buildings	LEED template, Airflow calculations, Code requirements (Mich, Ashrae 62-1999)		Engineering-airflow calculations, and document. cost	Doc. Only.	No additional engineering effort.	$0	$0	A/E Doc. related soft cost assessed as a lump sum.
Pr2	ETS Control	Non-smoking building, exterior designated smoking areas away from entries and operable windows	LEED template, employment policies		Document. cost	Doc. Only.	10-15 hrs spent mainly at the owner's end due to LEED website technical issues.	$0	$425	Assuming constructor spent 5 hrs or so.
EQ1	CO2 monitoring	Install permanent CO2 monitoring system-CO2 differentials per ASHRAE 62-2001 requirements	LEED template, Narrative, dwgs	CO2 sensors		Disagree	SOP for constructor	$0	$0	
				Other HVAC system changes		Disagree	SOP for constructor, nothing extra worth attributing to LEED	$0	$0	
					Additional Engineering-system design, and document. cost	Doc. Only.	SOP for A/E. No additional engineering effort.	$0	$0	A/E Doc. related soft cost assessed as a lump sum.

Table B2.2: LEED IEQ Incremental Cost Estimate- Case Study 2 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ2	Ventilation Effectiveness	Meet Ashrae 129-1997 air change effectiveness (Eac) requirements	LEED template, Narrative, Drawings, UFAD system-engineering literature	Additional cost for increased capacity of AHU's		Disagree	SOP for UFAD system, no cost attributable to LEED	$0	$0	
					Engineering-airflow calculations and dwgs, and document. cost	Doc. Only.	SOP for A/E for UFAD systems.	$0	$0	A/E Doc. related soft cost assessed as a lump sum.

Table B2.2: LEED IEQ Incremental Cost Estimate- Case Study 2 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ3.1	Construction IAQ management plan- during construction	Develop and implement IAQ management plan during construction: Meet SMACNA IAQ guidelines for construction phase. Protect stored on-site and installed absorptive materials from moisture damage. Use MERV 8 filters for any AHU's used during construction and replace filters with MERV 13 prior to occupancy.	LEED template, Construction IAQ management plan, Construction photos identifying SMACNA approach.	Plastic covering for all HVAC material.		Disagree	SOP for suppliers, no additional cost	$0	$0	
				MERV 8 filters used during construction.		Disagree	Building HVAC system was not used during construction.	$0	$0	Refer 'other cost items' at the end for temporary heating costs
				Additional storage costs.		Disagree	SOP for constructor's QA/QC, no additional cost	$0	$0	
				Daily cleaning costs.		Agree	Cost for separate cleaning sub; however, this was part of constructor's safety/quality initiative	$30,838	$0	Subcontractor costs attributed to LEED requirements
				MERV 13 filters for AHUs		Agree	Yes, cost incurred. Though this was part of owner's commitment to create a healthy work environment	$33,600	$0	MERV 13 filters- $2,700/ unit x 6 units instead of $100/ unit Merv 7 filters. Additional $3,000/unit to adapt MERV 13 filter stacks

Table B2.2: LEED IEQ Incremental Cost Estimate- Case Study 2 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ 3.1 (Cont.)					Engineering- IAQ management plan development, and document. cost	Doc. Only.	Part of constructor's SOP	$0	$1,275	15 hrs of constructor's documentation time @ $85/hr
EQ3.2	Construction IAQ management plan- before occupancy	Conduct IAQ testing per US EPA requirements	LEED template, air testing results, narrative	Cost for air testing		Agree	Also incurred to establish the change in IEQ from old to new bldg.	$8,870	$0	Subcontractor costs for air testing
					Engineering- planning for air-testing, document. cost	Coordination/ doc. time	Time spent at constructors end for coordination/ documentation	$0	$1,275	15 hrs of constructor's coordination/ documentation time@ $85/hr

Table B2.2: LEED IEQ Incremental Cost Estimate- Case Study 2 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ5	Indoor Chemical and Pollutant Source Control	Employ permanent entryway systems to capture dirt, particulates, etc. from entering the building at all high-volume exterior entryways. Provide segregated areas with separate outside exhausts (operating under negative pressure compared with surrounding spaces) for spaces with hazardous gasses or chemicals. Provide containment drains for disposal of any hazardous liquid wastes.	LEED template, material technical specs (EQ4.1-4.4 materials)	Permanent entryway systems		Disagree	SOP for constructor, no additional cost	$0	$0	
				Material/ installation related cost-to segregate haz. spaces		Disagree	No high volume copying etc- no significant effort to achieve this credit; hence, no additional cost	$0	$0	
					Engineering- to segregate haz. Spaces, and document. cost	Doc. Only.	No substantial engineering effort.	$0	$0	A/E Doc. related soft cost assessed as a lump sum.

Table B2.2: LEED IEQ Incremental Cost Estimate- Case Study 2 (continued from previous page)

LEED Information Review				Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit		LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
				Hard Cost	Soft Cost					
EQ6.2	Controllability of Systems, non-perimeter spaces	Provide airflow, temp, and lighting controls for 50% occupants in non-perimeter, regularly occupied spaces	Documentation not available	Additional lighting, controls		Disagree	No substantial hard costs attributable to this credit	$0	$0	
					Engineering-system design, dwgs etc., and document. cost	Doc. Only.	No additional engineering effort.	$0	$0	A/E Doc. related soft cost assessed as a lump sum.
EQ8.1	Daylight and Views, Daylight 75% of Spaces	For 75% of all regularly occupied areas, achieve a Daylight Factor of 2%.	LEED template, narrative, glazing factor calculations, dwgs	If achieving this credit resulted in planning fewer workstations than typical buildings- there may be a cost		Disagree	Planning was not driven by LEED, should not attribute additional cost.	$0	$0	

Table B2.2: LEED IEQ Incremental Cost Estimate- Case Study 2 (continued from previous page)

LEED Information Review			Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit	LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
			Hard Cost	Soft Cost					
EQ8.1 (Cont.)			Additional Cost for high performance external glazing		Agree	Yes, cost incurred. Though this was part of owner's commitment to create a more satisfactory work environment and helped in reduction in energy costs.	$270,000	$0	45,000SF of glazing at $6/SF difference in costs for conventional vs. high performance glazing estimated from constructor's input and Means (2007).
				Engineering-design, calculations etc., and document. Cost	Doc. Only.	Time spent at constructors end for coordination/ documentation	$0	$1,063	10-15 hrs of constructor's coordination/ documentation time@ $85/hr

Table B2.2: LEED IEQ Incremental Cost Estimate- Case Study 2 (continued from previous page)

LEED Information Review			Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit	LEED Requirements	LEED Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
			Hard Cost	Soft Cost					
Other cost items					Additional A/E cost for documentation/ coordination/ engineering for overall IEQ credits		$0	$14,000	Lump sum amount- part of A/E fee
					Additional A/E initial time spent for finalizing credits to pursue		$0	$13,750	110 hrs of A/E's coordination/ doc. time@ $125/hr
					Temporary heating costs in lieu of using building HVAC system during construction		$74,183	$0	$44,000 for gas for the temporary heating units and $30,183 for the actual temporary heating and humidification units.
			IEQ Commissioning related costs		Disagree	Part of constructor's SOP	$0	$0	
Total incremental cost for LEED IEQ							**$454,591.00**		Hard cost- $417,491; Soft cost- $37,100
Incremental cost of LEED IEQ/ SF							**$2.60**		174,750 GSF registered with LEED

APPENDIX C

Life Cycle Cost Analysis (LCCA) Worksheets

C1: LCCA Worksheets- Base Scenario

C2: LCCA Worksheets- Scenario 1

C3: LCCA Worksheets- Scenario 2

C3: LCCA Worksheets- Scenario 3

Appendix C1

LCCA Worksheets- Base Scenario

Table C1.1: LCCA Worksheet- Base Scenario (CS1)

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$39,537.20	Study Period- SP (Yrs)	25
Annual Benefit- Be (Table 5.2b)	$69,601.00	Inflation Rate- IR (%)	3.0%
		Discount Rate- DR (%)	6.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	17.58
Present worth of Annuity Factor (PWA)		(Co/Be)	0.57
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$1,223,586
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	30.9
Payback Period (PB)- in years		Co/Be	0.6
Rate of Return (RR)		Determined using PWA tables using PWA	167.0%

Table C1.2: LCCA Worksheet- Base Scenario (CS2)

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$454,591.00	Study Period- SP (Yrs)	25
Annual Benefit- Be (Table 5.2b)	$250,694.00	Inflation Rate- IR (%)	3.0%
		Discount Rate- DR (%)	6.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	17.58
Present worth of Annuity Factor (PWA)		(Co/Be)	1.81
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$4,407,201
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	9.7
Payback Period (PB)- in years		Co/Be	1.8
Rate of Return (RR)		Determined using PWA tables using PWA	50%

Appendix C2

LCCA Worksheets- Scenario 1

Table C2.1: LCCA Worksheet- Scenario 1 (CS1)

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$39,537.20	Study Period- SP (Yrs)	25
Annual Benefit- Be (Table 5.2b)	$69,601.00	Inflation Rate- IR (%)	6.0%
		Discount Rate- DR (%)	6.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	25.00
Present worth of Annuity Factor (PWA)		(Co/Be)	0.57
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$1,740,025
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	44.0
Payback Period (PB)- in years		Co/Be	0.6
Rate of Return (RR)		Determined using PWA tables using PWA	167.0%

Table C2.2: LCCA Worksheet- Scenario 1 (CS2)

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$454,591.00	Study Period- SP (Yrs)	25
Annual Benefit- Be (Table 5.2b)	$250,694.00	Inflation Rate- IR (%)	6.0%
		Discount Rate- DR (%)	6.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	25.00
Present worth of Annuity Factor (PWA)		(Co/Be)	1.81
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$6,267,350
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	13.8
Payback Period (PB)- in years		Co/Be	1.8
Rate of Return (RR)		Determined using PWA tables using PWA	50%

Appendix C3

LCCA Worksheets- Scenario 2

Table C3.1: LCCA Worksheet- Scenario 2 (CS1)

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$39,537.20	Study Period- SP (Yrs)	25
Annual Benefit- Be (Table 5.2b)	$69,601.00	Inflation Rate- IR (%)	3.0%
		Discount Rate- DR (%)	8.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	14.30
Present worth of Annuity Factor (PWA)		(Co/Be)	0.57
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$995,434
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	25.2
Payback Period (PB)- in years		Co/Be	0.6
Rate of Return (RR)		Determined using PWA tables using PWA	167.0%

Table C3.2: LCCA Worksheet- Scenario 2 (CS2)

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$454,591.00	Study Period- SP (Yrs)	25
Annual Benefit- Be (Table 5.2b)	$250,694.00	Inflation Rate- IR (%)	3.0%
		Discount Rate- DR (%)	8.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	14.30
Present worth of Annuity Factor (PWA)		(Co/Be)	1.81
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$3,585,426
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	7.9
Payback Period (PB)- in years		Co/Be	1.8
Rate of Return (RR)		Determined using PWA tables using PWA	50%

Appendix C4

Table C4.1: LCCA Worksheet- Scenario 3 (CS1)

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$39,537.20	Study Period- SP (Yrs)	15
Annual Benefit- Be (Table 5.2b)	$69,601.00	Inflation Rate- IR (%)	3.0%
		Discount Rate- DR (%)	6.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	12.01
Present worth of Annuity Factor (PWA)		(Co/Be)	0.57
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$836,186
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	21.1
Payback Period (PB)- in years		Co/Be	0.6
Rate of Return (RR)		Determined using PWA tables using PWA	167.0%

Table C4.2: LCCA Worksheet- Scenario 3 (CS2)

LCCA Inputs		LCCA Variables	
Incremental Cost- Co (Appendix B2)	$454,591.00	Study Period- SP (Yrs)	15
Annual Benefit- Be (Table 5.2b)	$250,694.00	Inflation Rate- IR (%)	3.0%
		Discount Rate- DR (%)	6.0%
LCCA Mid-Points		**Source**	**Value**
Present Worth Factor (PW)		(Determined from Present Worth tables using LCCA variables)	12.01
Present worth of Annuity Factor (PWA)		(Co/Be)	1.81
Present Value of Life Cycle Benefits (PVB)		(Be x PWF)	$3,011,838
LCCA Outputs		**Source**	**Value**
Benefit-Cost Ratio (B/C)		PVB/Co	6.6
Payback Period (PB)- in years		Co/Be	1.8
Rate of Return (RR)		Determined using PWA tables using PWA	50%

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