

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

## **Executive Summary**

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## **ABSTRACT**

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.

This research consisted of three major steps. It identified incremental first costs related with LEED IEQ. 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 presents some degree of validation to occupant well-being and productivity improvement claims in green buildings and provides the basis for further research and validation.

## **ACKNOWLEDGEMENT**

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## **INTRODUCTION**

The construction industry has been undergoing the transition towards the development of a more sustainable/green built environment. Existing knowledge of the industry's environmental impact and the rising concern for sustainability has provided significant impetus to the green building movement. This movement gained further momentum with the development of marketable green certification systems such as LEED<sup>®</sup> (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).

Among several benefits hypothesized from green buildings, occupant well-being and productivity improvements generate substantial interest in building green (Turner Construction 2005) and contribute the largest share of possible economic gains from green buildings (Kats 2003). Such benefits are primarily attributed to better indoor environments in green buildings (Pillai and Syal 2006). However, there remains a need to validate these benefits through actual observations.

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. From a building owner or investor's perspective,

improved well-being and productivity conditions and the possible life cycle economic gains in green buildings 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.

## **RESEARCH OVERVIEW**

This research attempts to quantify occupant well-being and productivity benefits in LEED offices through a case study based approach and provides an economic validation using the Life Cycle Cost Analysis (LCCA) framework. The overall goal is to demonstrate the economic benefits of green buildings based on occupant well-being and productivity.

The research objectives include:

1. Identify IEQ related processes/items responsible for incremental first cost in LEED offices.
2. Determine annual benefits from occupant well-being and productivity improvements resulting from the move to LEED offices.
3. Determine life cycle economic impact of LEED-IEQ based on inputs from objectives 1 and 2.

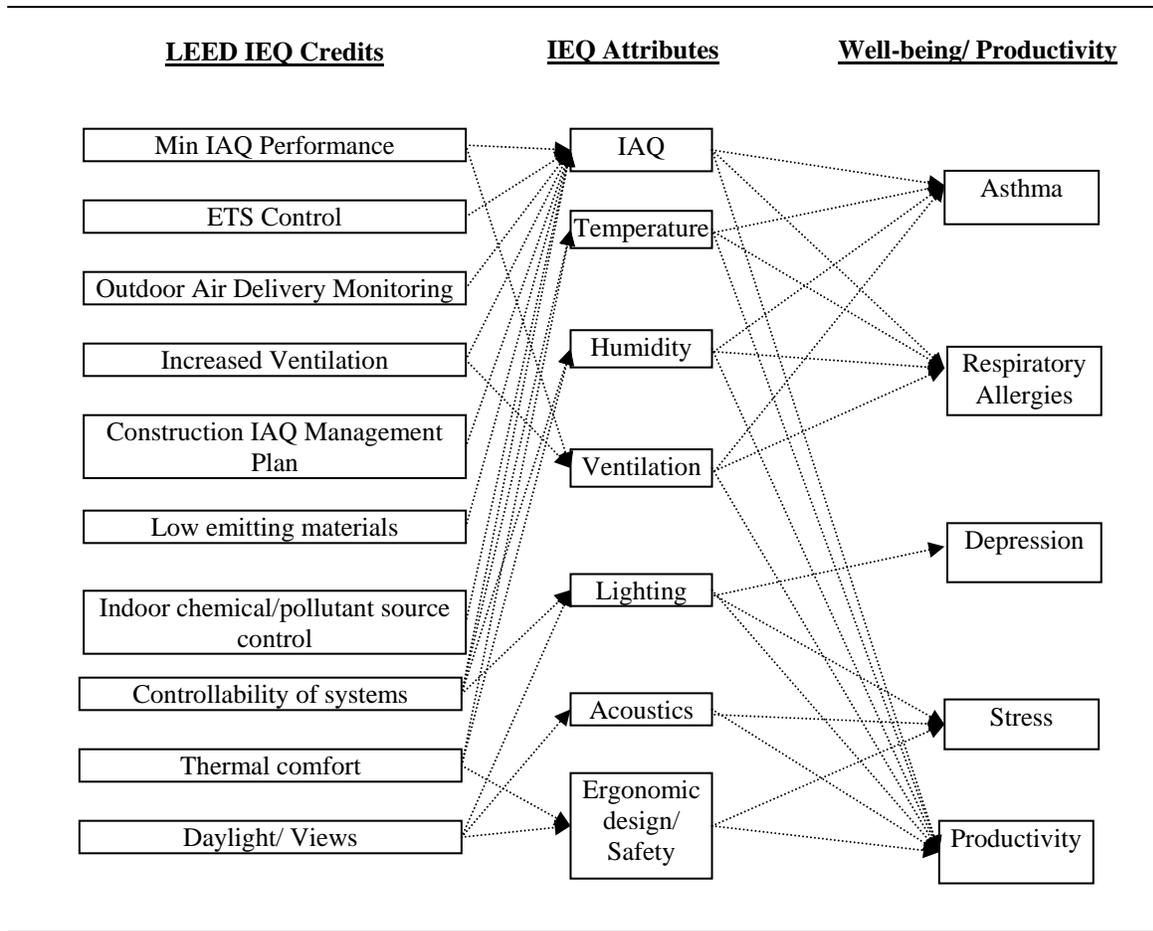
Literature assists in identifying certain occupant well-being and productivity conditions, which may be influenced by building indoor environments. These include:

1. Physical well-being: Asthma and respiratory allergies
2. Psychological well-being: Depression and stress
3. Productivity and performance

Asthma and respiratory allergies have been considered among the five most significant health conditions causing sick leaves among US workforce (USA Today 2008). 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 (Korkmaz et al. 2009). Literature is rich with studies that demonstrate an association between asthma or 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).

Among psychological health conditions, 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 also provides some evidence of direct improvements in productivity/performance among workers as well as students resulting from improved lighting, view, ventilation, and air temperature conditions (HMG 1999, HMG 2003).

Pillai and Syal (2006) categorized IEQ attributes with potential health impacts through an extensive literature review. Using these attributes, relationships between LEED IEQ credits and the selected well-being and productivity conditions were summarized, as shown in Figure 1.



**Figure 1: LEED IEQ-Occupant Well-being/Productivity Structure**

All LEED IEQ credits were found to have potential relationships with the selected well-being and productivity conditions. Therefore, all LEED-IEQ credits were included in the study scope. Next, two case studies in Michigan were identified where occupants either were planning to move or had recently moved from conventional offices to LEED offices. Incremental costs for LEED IEQ credits attained in the new offices were determined.

Changes in occupant well-being and productivity were assessed using an intervention type- prospective cohort study design, as defined in Epidemiological literature (Hennekens and Buring 1987). 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.

Data for determining such changes in well-being and productivity was collected through pre-move (While occupants worked from conventional buildings) and post-move (after occupants moved to LEED buildings) occupant surveys. Table 1 presents an overview of the case studies and occupant surveys.

**Table 1: Case Studies and Occupant Surveys Overview**

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

Findings from the occupant surveys were monetized and weighed against the incremental costs for LEED IEQ using an LCCA framework. Within the research

limitations/uncertainties, it was found that benefits from improved occupant well-being and productivity significantly outweigh incremental costs for LEED IEQ.

## **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. Study scope**

- a The study scope is limited to evaluating the economic performance of two case study LEED office buildings based only on IEQ related incremental costs and occupant well-being and 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 part of the scope.
- b The economic analysis is performed from the investor's (building owner's) perspective.

### **2. Incremental cost input limitations/uncertainties**

- a Certain LEED credits result from building decisions that are primarily driven by other concerns. For example, both case studies use under floor air distribution (UFAD) systems, which assist in achieving certain LEED credits. However, these systems were incorporated due to architectural

concerns. Hence, no incremental costs were attributed to such LEED requirements.

- b Certain cost items accounted for as part of 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. Such costs are 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.

### 3. Benefit input limitations/uncertainties

- a Occupant productivity findings are based on self-reported perceptive responses.
- b Benefits reported by the survey respondents (n) based on 4-week snapshots are assumed to be representative for the entire organizations' population (N) over the study life.
- c The recent move to a new building may have a temporary effect on the occupants' well-being/productivity as explained by the Hawthorne effect (Romm and Browning 1994). 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 may only be eliminated by continuing this research over a longer timeframe.

- d 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, using mid-scale values for coding ranges, and using lower-tailed t-test values to represent average benefits.
- e Influences of other LEED credits as well as those unrelated to the building on occupant well-being and productivity are not explored in this research.
- f Occupant well-being conditions other than those studied in this research may also affect the research findings. For example, Sick Building Syndrome (SBS) has been previously discussed as another key occupant well-being condition affected by building IEQ (Pillai and Syal 2006).

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.

## **INCREMENTAL COST OF LEED-IEQ**

Incremental costs for LEED IEQ credits attained on the case study projects were determined by reviewing LEED documentation for such credits and through constructors' input. Table 2 summarizes the IEQ credits attained on the case study projects.

The following steps were undertaken to estimate the incremental cost of LEED IEQ, for the case study projects:

1. Documentation for LEED IEQ credits was reviewed

2. Design and Construction processes/items causing incremental cost were identified by the research team and finalized based on the feedback from the case study project teams
3. Incremental costs for the above processes/items were estimated
4. Summary matrices linking LEED IEQ credits, cost items, constructors' feedback, and incremental costs were developed

**Table 2: LEED IEQ Credits attained on Case Studies (Credits based on LEED-CI 2.0)**  
(Y: Exact or Similar Credit attained; N: Not attained or not available)

<b>Credit No.</b>	<b>Credit Description</b>	<b>CS1</b>	<b>CS2</b>
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	N
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	N
Credit 8.3	Daylight and Views: Views for 90% of Seated Spaces	Y	N

Table 3 presents a snapshot of the LEED IEQ cost estimate matrix developed for CS2.

**Table 3: Snapshot of LEED IEQ Cost Estimate Matrix (LEED IEQ credit 3.2- CS2)**

LEED Information Review			Hypothesis Formulation		Constructors' Feedback		Incremental Cost Estimation		
LEED Credit	LEED Req.	Docs. Reviewed	Potential Cost Impact Items		Cost items	Rationale	Hard Cost	Soft Cost	Notes
			Hard Cost	Soft Cost					
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	\$0.0	Subcontractor costs for air testing
				Engineering-planning for air-testing, document. cost	Coordination/doc. time	Time spent at constructors end for coordination/documentation	\$0.0	\$1,275	15 hrs of constructor's coordination/documentation time@ \$85/hr

The incremental costs for both case studies were determined to be approximately 2-2.5% (US\$2.3 to 2.6/ SF) of construction costs for typical office buildings in Michigan (Means 2007). About 85-90% of these were attributable to hard costs while the rest were coordination/documentation related soft costs. Some key example items resulting in 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.

The incremental costs found in this research compare well with few existing studies in this area. Kats (2003) had earlier found incremental costs for overall LEED credits for a mixed sample including 33 LEED buildings rated at LEED certified to platinum levels, 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.

## OCCUPANT WELL-BEING AND PRODUCTIVITY BENEFITS

This research utilizes pre-move and post-move occupant surveys to determine changes in occupant well-being and productivity resulting from improved IEQ in LEED offices. The occupant surveys were conducted online and data was analyzed using descriptive statistical methods such as histograms and box plots as well as hypothesis testing using paired t-tests (Devore 2004). Data regarding occupant medical history was collected during the pre-move survey; these findings are presented in Figure 2.

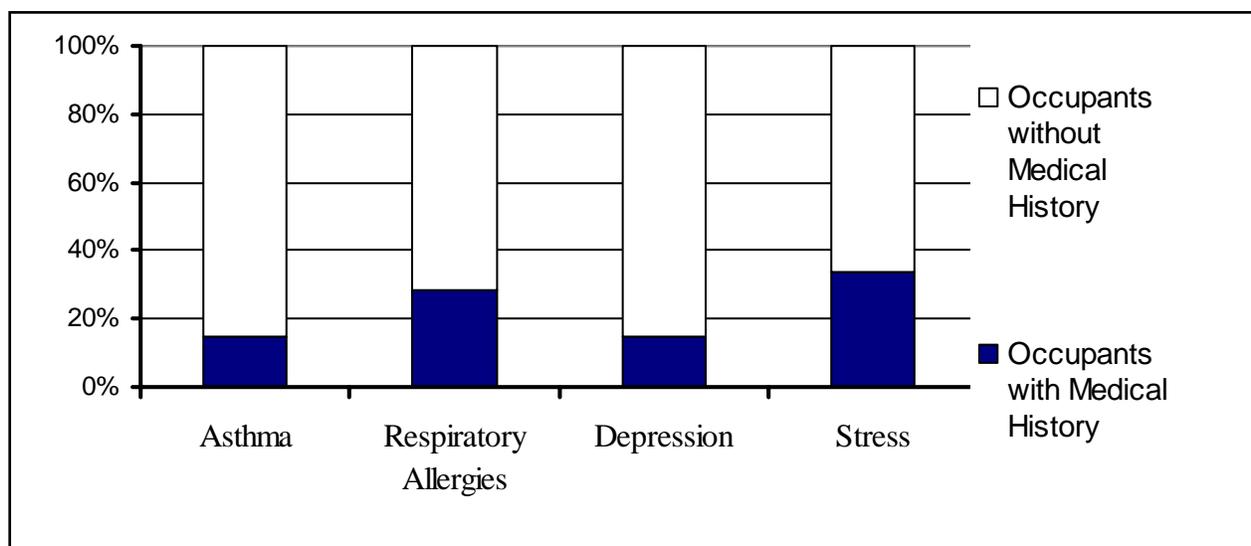
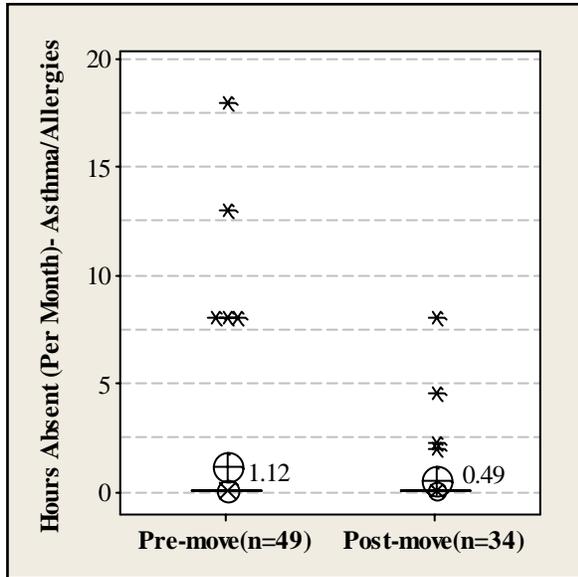


Figure 2: Occupants' Medical History (n=175)

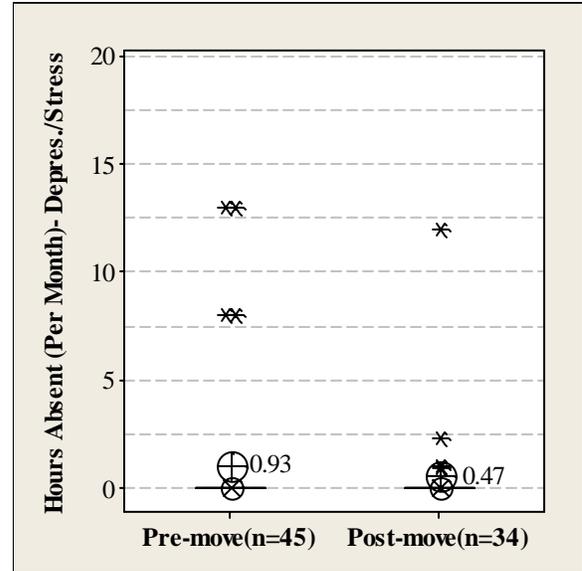
Approximately 18% of the occupants had a medical history of asthma, about 30% had a history of respiratory allergies, about 18% had a history of depression, and about 35% had faced stress-related conditions in the past.

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. The effects from asthma and respiratory allergies were analyzed together and similarly those

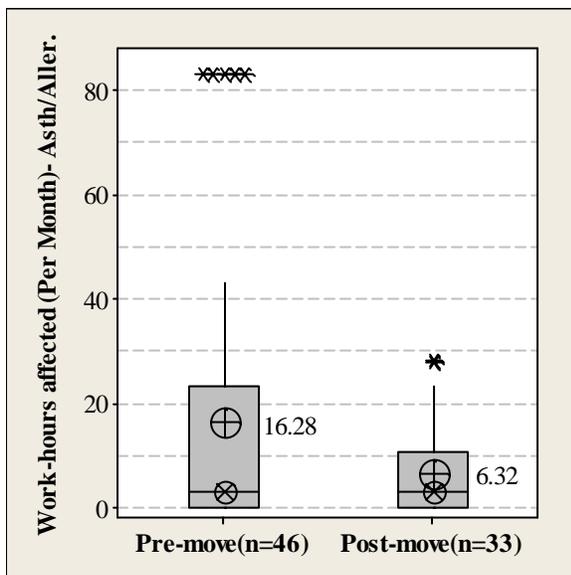
from depression and stress were also studied together. The box plots presented in Figures 3a-3d summarize the health snapshot responses.



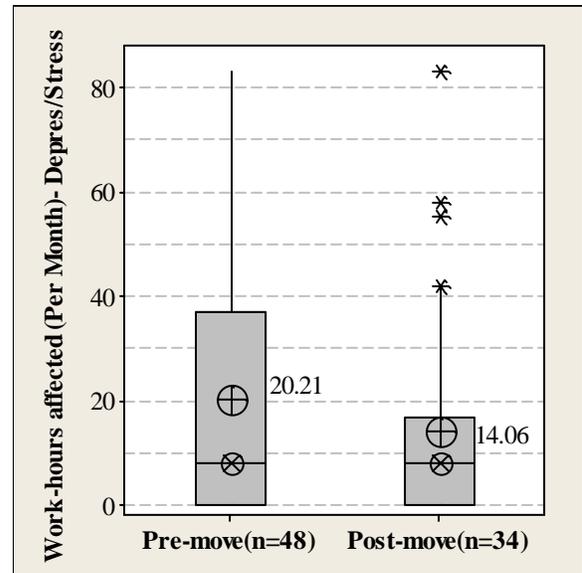
3a



3b



3c



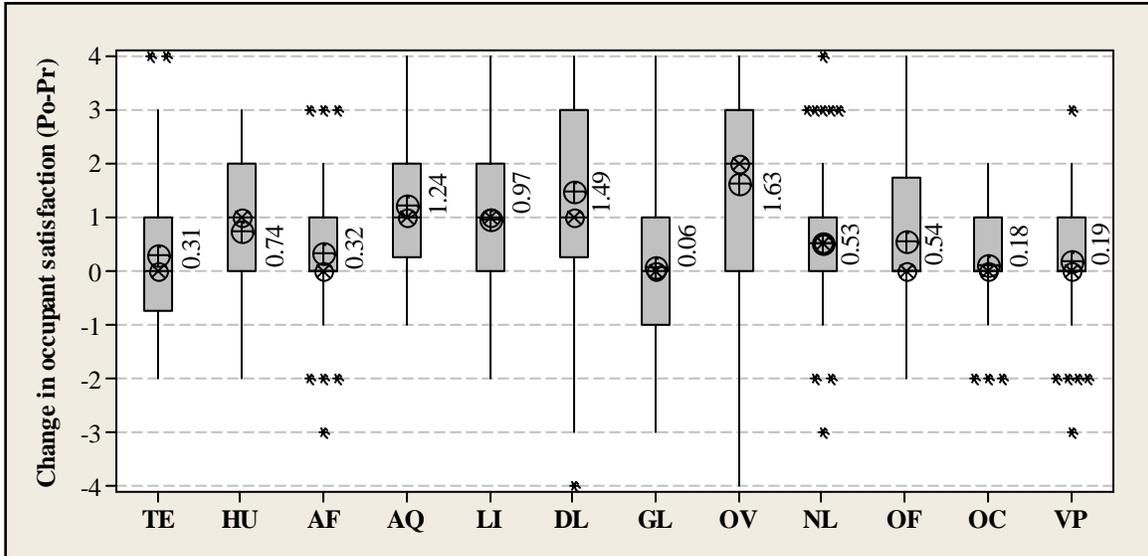
3d

**Figure 3: Changes in occupant well-being resulting from the move**  
 3a- Hours absent/month due to asthma/respiratory allergies; 3b- Hours absent/month due to depression/stress; 3c- Work-hours affected/month due to asthma/respiratory allergies; 3d- Work-hours affected due to depression/stress  
 (\*: Outlier; +: Mean-values shown; x: Median)

These box plots indicate the following reductions in the mean absenteeism and affected work hours, after the move to LEED buildings:

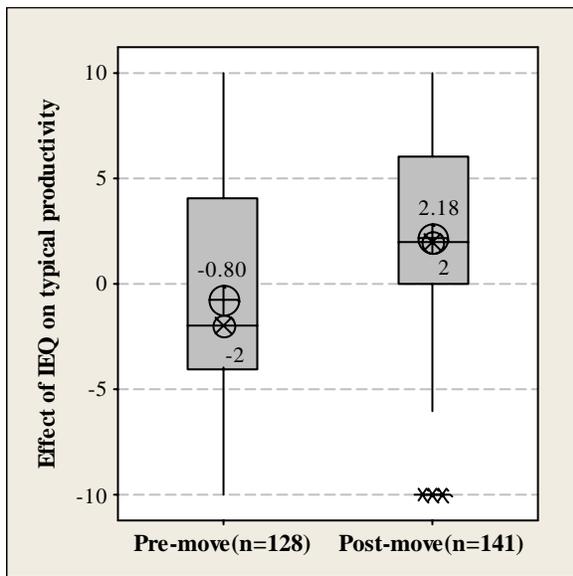
- a. For asthma/respiratory allergies, the mean hours absent/month/occupant reduced from 1.12 to 0.49
- b. For depression/stress, the mean hours absent/month/occupant reduced from 0.93 to 0.47
- c. For asthma/respiratory allergies, the mean work hours affected/month/occupant reduced from 16.28 to 6.32
- d. For depression/stress, the mean work hours affected/month/occupant reduced from 20.21 to 14.06

In the pre-move (Pr) and post-move (Po) surveys, occupants were asked to rate their satisfaction level with their work environment IEQ attributes (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 (Po-Pr) were determined. Figure 4 presents improvements in mean occupant satisfaction with all IEQ attributes after the move to LEED buildings. The most substantial improvements are seen in occupant satisfaction with AQ (d=1.2), DL (d=1.5), and OV (d=1.6).



**Figure 4: Change in Occupant IEQ satisfaction (n=68)**  
 (\*: Outlier; +: Mean-values shown; x: Median)

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 5.



**Figure 5: Perceived Effect of IEQ on Productivity**  
 (\*: Outlier; +: Mean; x: Median)

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%; the median value also changed from -2% to +2 %.

Overall, the above findings indicate improvements in the average well-being, satisfaction, and productivity for the respondent population, after moving to LEED offices. Next, paired t-tests were conducted to determine statistically significant improvements in occupant well-being and productivity conditions. Key findings from this analysis are presented in Table 4.

**Table 4: Summary of Occupant Well-being and Productivity Benefits**

(d-value: mean difference of Pre-Post response; W/MH: Occupants with medical history; CI-95%: 95% or greater statistical confidence; n= number of respondents)

Affected Occupants		d-value CI (95%); Lower-tailed t-tests	n	Interpretation (Minimum average gains)	Additional Calculations	Resultant Benefit per Year
<b>1. Asthma and Respiratory Allergies</b>						
Absenteeism	W/MH	0.034	25	Absenteeism is reduced by 0.034hrs/month for occupants W/MH	None	Additional 0.41 work-hours for each occupant W/MH
Affected Work-hours	W/MH	2.35	27	2.35fewer work-hours are affected each month for occupants 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
<b>2. Depression and Stress</b>						
Affected Work-hours	W/MH	2.86	34	2.86fewer work-hours are affected each month for occupants 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
<b>3. Productivity</b>						
Direct Productivity Improvement	All	2.03	86	Average occupant productivity is improved by 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

The above findings (resultant benefits/year) were monetized using typical employee salary inputs from the case studies. Average hourly wages (WA) considering all

occupants were computed for each case study (WA for CS1=\$30.94, for CS2=\$29.99).

Table 5 presents these monetization-related calculations for the above findings.

**Table 5: Annual Economic Benefits from Occupant Well-being and Productivity Improvements**  
(AWH: Additional work hours; WA: Average hourly wage; \$Oc: Dollar benefit per occupant; W/MH: Occupants with medical history; n': Number of applicable occupants; Pr: Pre-move survey)

	AWH	CS1	CS2
Average hourly wage- WA		\$30.94	\$29.99
AWH from reduced Asthma/Allergies per year (from Table 4)	1.75		
\$ Benefit/occupant- \$Oc (WA x AWH)		\$54.15	\$52.48
Applicable occupants-n' (extrapolated from W/MH in Pr Survey)		20	69
Monetized benefit/year (n' x \$Oc)		\$1,103	\$3,596
AWH from reduced Depression/Stress per year (from Table 4)	2.02		
\$ Benefit/occupant- \$Oc (WA x AWH)		\$62.50	\$60.58
Applicable occupants-n' (extrapolated from W/MH in Pr Survey)		15	85
Monetized benefit/year (n' x \$Oc)		\$955	\$5,122
AWH from improved Productivity per year (from Table 4)	38.98		
\$ Benefit/occupant- \$Oc (WA x AWH)		\$1,206.13	\$1,168.97
Applicable occupants- n' (Total CS Population)		56	207
Monetized benefit/year (n' x \$Oc)		\$67,543	\$241,976
<b>Total \$ benefit/ year from improved occupant well-being and productivity</b>		<b>\$69,601</b>	<b>\$250,694</b>

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 US\$ benefit was calculated using the annual \$ benefit per occupant (\$Oc) and number of applicable occupants (n').

The total annual benefits for CS1 amount to US\$ 69,601 (\$4.12/SF) and for CS2 these amount to US\$ 250,694 (\$1.43/SF). 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 US\$ benefit values, along with the incremental first costs determined in the previous section, provide the data input for LCCA.

### **LIFE CYCLE COST ANALYSIS (LCCA)**

Among several LCCA methods, Benefit-Cost (B/C) analysis was selected for the economic evaluation. This method has been previously used in green building related LCCA studies (Ries et. al 2006, SBW 2003). It addresses the time-related variations in costs by incorporating discounting and inflation; this method provides a simple indicator of favorability of the economic investment (favorable investments are those where benefit-cost ratio is greater than 1). In addition, simple payback and internal rate of return calculations were performed to provide additional decision support metrics for the investors.

Key LCCA variables that need to be addressed for performing the cost analysis include:

1. Study Period (SP): The duration for which the analysis is conducted.
2. Inflation Rate (IR): The rate at which costs are expected to escalate over the study period.
3. Discount Rate (DR): The expected rate of return on investment.

Based on typical values used in literature and feedback from case studies, these variables were populated and multiple analysis scenarios were modeled. An MS Excel-based LCCA worksheet was developed to assist with performing the calculations. An example of this worksheet using the CS1 base scenario is presented in Table 6.

**Table 6: Life Cycle Cost Analysis Worksheet (CS1 Base Scenario)**

LCCA Inputs		LCCA Variables	
Incremental Cost- Co	\$39,537.20	Study Period- SP (Yrs)	25
Annual Benefit- Be	\$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%

The base scenario uses SP=25yrs, IR=3%, and DR=6%. For CS1, this scenario results in B/C ratio of 30.9. In addition, based on the first year benefits a payback period of about 7 months and a rate of return of 167% were found. For CS2 these findings amount to B/C of 10, PB <2yrs, and RR of 50%.

Other LCCA scenarios were modeled to gain a preliminary insight into the sensitivity of research findings to changes in LCCA variables. The B/C findings from all scenarios are summarized in Table 7. Each of these scenarios represent highly beneficial economic investment.

**Table 7: LCCA Findings**  
 (SP: study perios, IR: inflation rate, DR: discount rate)

LCCA Scenario	Benefit/Cost Ratios (Approximated)	
	CS1	CS2
Base Scenario (SP= 25yrs ; IR=3%; DR=6%)	31	10
Scenario 1 (SP= 25yrs ; IR=6%; DR=6%)	44	14
Scenario 2 (SP= 25yrs ; IR=3%; DR=8%)	25	8
Scenario 3 (SP= 15yrs ; IR=3%; DR=6%)	21	7

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.

**SUMMARY AND CONCLUSIONS**

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. 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 economically viable investments.

Overall, improvements in occupant well-being and 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.

The above discussion indicates substantial economic value for improving building IEQ by investing in green buildings, both from the individual investors' as well as the policymakers' perspective. 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.

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