The DEVELOPMENT OF GREEN BUILDING PERFORMANCE ASSESSMENT TOOL (GBPAT)

by

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EXECUTIVE SUMMARY

This dissertation consists of two studies: (1) establishment of an evaluation tool framework to determine the proper investment to make the building LEED-certified with the consideration of the initial investment cost using the statistical analyses of integrated Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) and (2) development of a Green Building Performance Assessment Tool (GBPAT). Nine LEED-certified buildings built at the University of Wisconsin-Madison were used for the study. The overall dissertation was initiated to mitigate a significant problem of the LEED certification system, that it cannot reflect cost effectiveness. Thus, the first research component was designed to determine whether the earned points on the LEED certification system are correlated with the incremental investment as the cost premium for green building.

The first research effort demonstrated that the initial incremental investment was not closely related with the earned points on Energy & Atmosphere (EA) and Water Efficiency (WE) credits but was clearly related with energy-related points. The sustainable items that lead to the increased initial construction costs were mainly related to energy savings, as anticipated. In addition, seven LEED buildings showed the affordable Discounted Payback Period (DPP) depending on the level of LEED certification while the other two buildings had higher DPP in the Gold and Platinum levels of LEED, which means over incremental investments along with unfulfilled DPP.

The Cost Effectiveness Index (CEI) proposed in this study was found to represent the net savings of the life cycle costs and cost effectiveness for a green building better than LEED. LCA and LCCA methods would be adopted for GBPAT to address these issues. Generally, LCCA methods have proven to be a good approach to assess the financial impact for building construction. However, formal techniques are limited to the evaluation of building performance with respect to environmental and social responsibility.

GBPAT would provide the information that helps all participants, such as building owners, building managers, building occupants, and society who are involved and impacted by building performance. They have their own demands on the information of building performance, such as affordable financial investment, expected financial benefits, lower environmental impacts, and better indoor environment. The objectives of the second study were to:

- Develop a green building performance assessment tool (GBPAT) that embodies economic feasibility based on an integrated LCA and LCCA method;

- Develop the expert system consisting of plug-in software and a user-friendly Graphic User Interface (GUI) that allows easy of input data and information for a proposed building;

- Establish more accurate building performance index (BPI) and cost effectiveness index (CEI) based on cost and financial benefits (B/C) analysis; and

- Provide essential economic assessment methods, such as net savings (NS), saving to investment ratio (SIR), adjusted internal rate of return (AIRR) and expected payback period for application of green features on buildings.

Users should be able to make a strategic decision to evaluate various alternative designs or retrofitting schemes for sustainable building. Moreover, applying social costs to total LCC of green building would lead to a reduction in environmental burden to society and significantly improve indoor environmental quality affecting the health of occupants since users are able to recognize that these social costs may impact the entire building LCC.

ACKNOWLEDGEMENT

Completing my PhD degree is probably the most challenging activity of my whole life. The best moments of my doctoral journey have been shared with many people. It has been a great privilege to spend several years in the Environment and Resources program at University of Wisconsin-Madison, and its members will always remain dear o me.

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based on Integrated LCA and LCCA

ABSTRACT

Since the Leadership in Energy and Environmental Design (LEED) Certification was established in 1993, many buildings have been certified in the United States (U.S.). Although the performance of LEED-certified buildings has been studied with comparison to the conventional buildings, few studies have been conducted to evaluate whether the higher incremental investment guarantees higher points in LEED certification. LEED credits related to energy and water consumption savings were correlated with the initial incremental costs spent for the application of sustainable items constructed in nine LEED-certified buildings at the University of Wisconsin-Madison campus. Besides, the discounted payback period (DPP) used widely for the decision-making of project investors were compared with the incremental investments in order to check if the investment made to obtain LEED certification is affordable to achieve their expectations.

Low correlation was found between the earned points on energy & atmosphere (EA) and water efficiency (WE) credits and the initial incremental investment, but relatively high correlation coefficient for energy-related points versus the initial incremental investment was found. The sustainable items that lead to the increased initial construction costs were mainly related to energy savings, as anticipated. Seven LEED projects showed an affordable DPP depending on the level of LEED certification while others had higher DPP at the Gold and Platinum levels of LEED, implying excess incremental investments along with unfulfilled discounted payback period. The cost effectiveness index (CEI) proposed in this study was found to represent the net savings of the life cycle costs and cost effectiveness for a green building better than LEED.

CHAPTER 1. INTRODUCTION

1.1 Background

Green building construction is a dynamic, rapidly growing and evolving field, driven by a confluence of rising public concerns about global climate change, cost and availability of energy sources, and the impact of the built environment on human health and performance (USGBC Research Committee, 2007). Green and sustainable buildings result from the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life cycle from design to construction, operation, maintenance, renovation and demolition [U.S. Environmental Protection Agency (EPA), 2011]. The accurate building performance evaluation (BPE) and the energy performance simulation (EPS) must be preceded in order for a commercial building to be considered green, sustainable and optimized. In the field of green building construction, there are already several types of green building rating systems for BPE, such as LEED, BREEAM, GBCC, Green Globes, and Energy Star.

According to the definition of the assessment of building performance by U.S. DOE, the evaluation of building performance involves the assessment of the extent to which a given building has met its design goals for resource consumption and occupant satisfaction. It is based on feedback and evaluation at every phase of building delivery, ranging from strategic planning to occupancy, throughout the building's life cycle (Preiser and Vischer 2004). LEED certification was established in 1998 as "a voluntary, consensus-based national standard to support and validate successful green building design, construction, and operations" (ICF Consulting, 2003). This national green building certification system was formed by the U.S. Green Building Council (USGBC) and is designed to offer third-party building certification, professional design guidelines and accreditation services (ICF Consulting, 2003). Although this is one of the independent Building Performance Rating (BPR) systems for green buildings, LEED system has outweighed since there is awareness that LEED buildings are efficient in terms of energy and water consumption. However, Scofield (2009) claimed that there was no evidence that LEED Certification collectively lowered either site or source energy for office buildings after comparing energy consumption between LEED buildings and Commercial Building Energy Consumption Survey (CBECS) buildings. Keil (2008) stated that LEED became expensive, slow, confusing and unwieldy and seemed to focus on points, not environmental nor financial benefits. Although there have been several studies to estimate the benefit and cost for the LEED-certified buildings, few studies were conducted on the correlation between the earned points from the system of LEED certification and incremental investments since there is lack of related information and data. Therefore, several studies have been performed on the life cycle costs analysis for LEED buildings.

1.2 Problem Statement

Although the LEED Certification system was developed based on the consideration of reducing environmental impacts, it is also shown that economic aspect can be reflected since the energy consumption is directly related to the energy cost. Especially, the points on EA credit 1, which intends to achieve increased energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use, estimate the degree of improvement to reduce energy costs (USGBC, 2009). Table 1.1 shows a percent improvement in the proposed building performance rating compared with the baseline building performance rating per ASHRAE Standard 90.1-2004 by a whole building project simulation using the BPR method in Appendix G of the Standard.

Table 1.1. Possible points on EA Credit 1 (optimized energy performance)

New Building	Renovations	Points	
10.5%	3.5%	1	Mandatory Points
14%	7%	2	
17.5%	10.5%	3	
21%	14%	4	
24.5%	17.5%	5	
28%	21%	6	
31.5%	24.5%	7	
35%	28%	8	
38.5%	31.5%	9	
42%	35%	10	

Although this is one of the independent BPR systems for green buildings, LEED system has been used most widely since LEED buildings are known to be efficient in terms of energy and water consumption. However, Scofield (2009) claimed that there was no evidence that LEED certification collectively lowered either site or source energy for office buildings after comparing energy consumption between LEED buildings and CBECS buildings. Keil (2008) stated that LEED became expensive, slow, confusing and unwieldy and seemed to focus on points, not environmental nor financial benefits.

For example, having a few hundred-dollar bike racks and a multimillion-dollar low energy air conditioning system both get one point. In addition, basic certification (LEED-certified level) is too low a hurdle to merit the green stamp of approval. In addition, energy and water reductions cannot be reflected accurately. Furthermore, each of building performance rating systems provides different assigned points to evaluating categories, such as energy, environment, IAQ and social aspect. It can cause that the building archives certainly different results on building performance evaluated by another BPR system, thus it makes users confused whether theirs buildings are really sustainable.

Although there have been several studies to estimate the benefit and cost for the LEED-certified buildings, few studies were conducted on the correlation between the earned points from the system of LEED certification and incremental investments due to lack of related information and data. Therefore, several studies have been performed on the life cycle costs analysis for LEED buildings.

In the perspective of life cycle assessment (LCA), LEED system is sufficient to assess the building performance. However, there are several questions whether LEED-certified buildings are more cost-effective than the conventional building. According to Menassa (2011), four of eleven LEED projects had lower electricity consumption savings than their counterpart non-LEED-certified buildings and other LEED-certified buildings did not meet the expected savings of over 30%. Therefore, it is necessary to check the incremental investment versus savings of green building achieving LEED certification when the decision is made on whether the incremental investment is appropriate depending on the level of LEED.

In order to assess the cost effectiveness for LEED-certified buildings, the integrated LCA and life cycle cost assessment (LCCA) were used to reflect environmental impacts to life cycle costs in the estimation of social costs. Recently, an integrated LCA and LCCA approach has been employed to consider user cost and environmental impact cost. Chan et al. (2008) discussed that an integrated LCA and LCCA method should be employed for a road construction project when evaluating infrastructure sustainability, alternative materials, and designs using environmental, economic, and social indicators.

1.3 Research Objectives

This study was started with the question whether LEED certification system reflects cost effectiveness well that has been raised in the field of green building evaluation. As mentioned in the problem statement, it is deficient in the studies analyzing the cost effectiveness of LEED-certified buildings comparing to conventional buildings since there has been no consensus to assess the cost effectiveness for LEED certification system. Until now, previous studies have been focused on energy and water reduction of LEED buildings comparing with counterparts which build in similar size and area. Even though there are a few studies on cost effectiveness of the implementation of LEED system on the buildings, there is no approach to analyze the correlation between the earned points on LEED credits associated energy and water reduction and incremental investment which need to apply the sustainable items for LEED system.

The following three questions are raised in this research:

(1) Is the incremental investment proportional to green building performance?

(2) How much incremental investment is affordable for LEED certification depending on levels?

(3) Does LEED Certification system reflect the cost effectiveness?

Therefore, the following objectives for this research were defined:

- Investigate the relationship between LEED credits related to energy and water consumption savings and the initial incremental costs.
- Determine the discount payback period (DPP) is affordable as an indicator for the cost effectiveness of green buildings.
- Determine the most appropriate index reflecting the net savings of the life cycle costs and cost effectiveness at once.

1.4 Research Methodology

The research followed the five steps as shown in Figure 1.1.

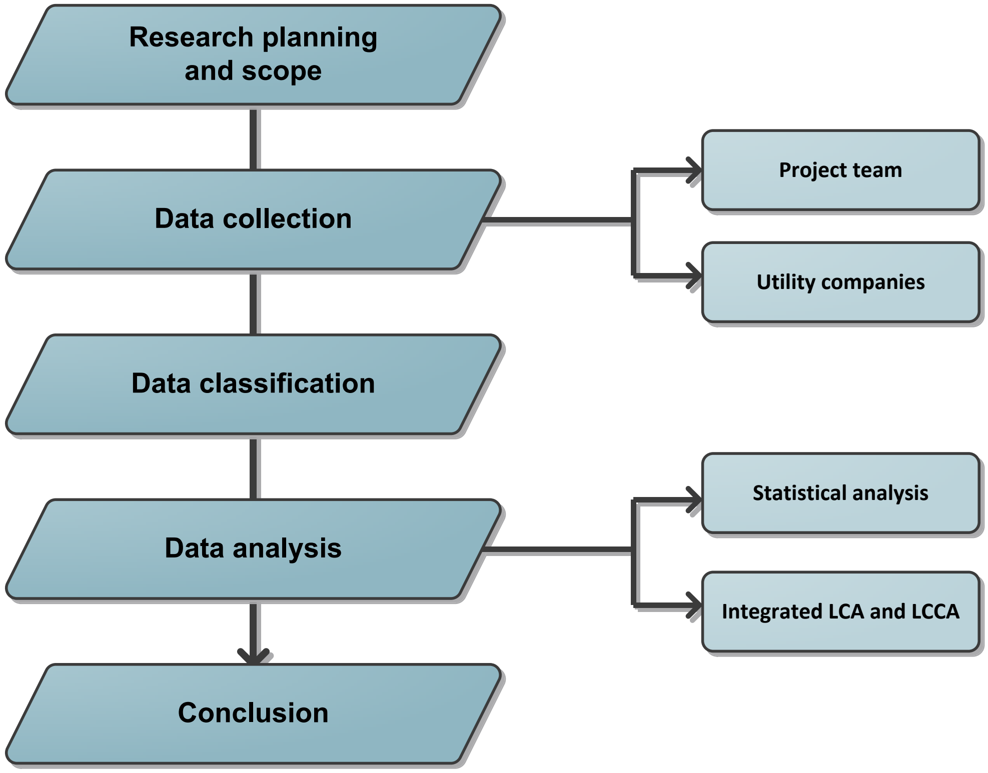


Figure 1.1 The procedure of the research

Extensive data were obtained from University of Wisconsin-Madison Capital Planning Development (UW-CPD) to evaluate the feasibility of cost effectiveness. UW-CPD is the office that manages the design and construction of all projects on the campus. Out of the 15 building projects that are in the process of acquiring LEED certification or have already achieved so far, nine LEED-certified buildings were chosen for the study based on the availability of the full data set and ease of data accessibility.

The data gathering process of LEED-certified buildings is needed to simulate both the proposed building model and the baseline building model. The information on LEED certification, level of LEED certification, LEED templates, and energy and water simulation results were collected. The energy and water simulation data were also compared with each corresponding building design, such as baseline building design and proposed building design. To accurately estimate the cost of energy and water, the practical rates of energy and water were provided by utility companies, such as Madison Gas and Electricity (MG&E) and Madison Water Utility.

Statistical analysis and integrated LCA and LCCA method were used for the study. Correlation coefficients and statistical hypothesis tests were used for statistical analysis. Correlation coefficients are generally referred to Pearson's R, which measures the strength and direction of the linear relationship between two variables. The correlation coefficient, R, can be in the range of -1 to +1. The R value close to -1 or +1 refers to high correlation while that close to zero means low correlation. As a statistical hypothesis test, paired t-test was used to verify the hypothesis and the significance of p-value at the confidence level of 95%.

To check if there is a relationship between the whole life cycle costs associated with social costs and the points on the credits related energy and water consumption, the integrated LCA and LCCA approach was used for the nine LEED-certified buildings. The proposed sustainable building design was compared with the baseline building design to evaluate LCC. For the evaluation of the integrated LCA and LCCA approach for LEED-certified buildings, existing supplementary measures were also applied to the analysis phase of green building performance. According to Fuller and Petersen (1995), the supplementary measures are net savings (NS), the savings-to-investment ratio (SIR), adjusted internal rate of return (AIRR), and discounted payback period (DPP).

CHAPTER 2. LITERATURE REVIEW

2.1 Previous Studies on Cost-Effectiveness of LEED Certification

LEED certification was established in 1998 as “a voluntary, consensus-based national standard to support and validate successful green building design, construction, and operations” (ICF Consulting, 2003). This national green building certification system was formed by the U.S. Green Building Council (USGBC) and is designed to offer third-party building certification, professional design guidelines and accreditation services (ICF Consulting, 2003). LEED certification is aimed to evaluate building performance with certain points that can be achieved by fulfilling their own requirements and the checklists. The number of LEED certifications have rapidly grown since it was announced in early 2000 with more than 40,000 commercial and industrial projects (Katz, 2012). According to Nelson et al. (2010), the main reasons for these building owners and building managers to aquire LEED certification are to have energy efficient and sustainable designs in their buildings considering social responsibility and reputational issues, to lower operating costs related with energy and water consumptions, and to achieve higher occupant productivity.

So far, the studies associated with improved performance, which is generally shown as energy and water reductions, improved indoor environmental quality (IEQ), higher productivity and so on, have been conducted. The U.S. Good Energies (2008) found that the incremental investment of the LEED buildings was less than 2% while the energy saving was 33% from the evaluation of 146 LEED-certified buildings. In addition, over 50% of the LEED-certified buildings were able to recover the incremental investments within five years through only the energy and water reduction. Moreover, the report by Capital E (2003) claimed that the average incremental investment was 1.84% and the average savings of total energy consumptions was 36%. Turner and Frankel (2008) evaluated LEED building energy use intensity (in kBtu/sf/yr) using the data from all national building stock which comes from the CBECS and for all 121 LEED buildings. The median measured EUI was 69 kBtu/sf, which is 24% below the CBECS national average for commercial building stock. Figure 2.1 shows the median EUIs by certification level and the individual measured EUIs for each of 100 participating buildings.

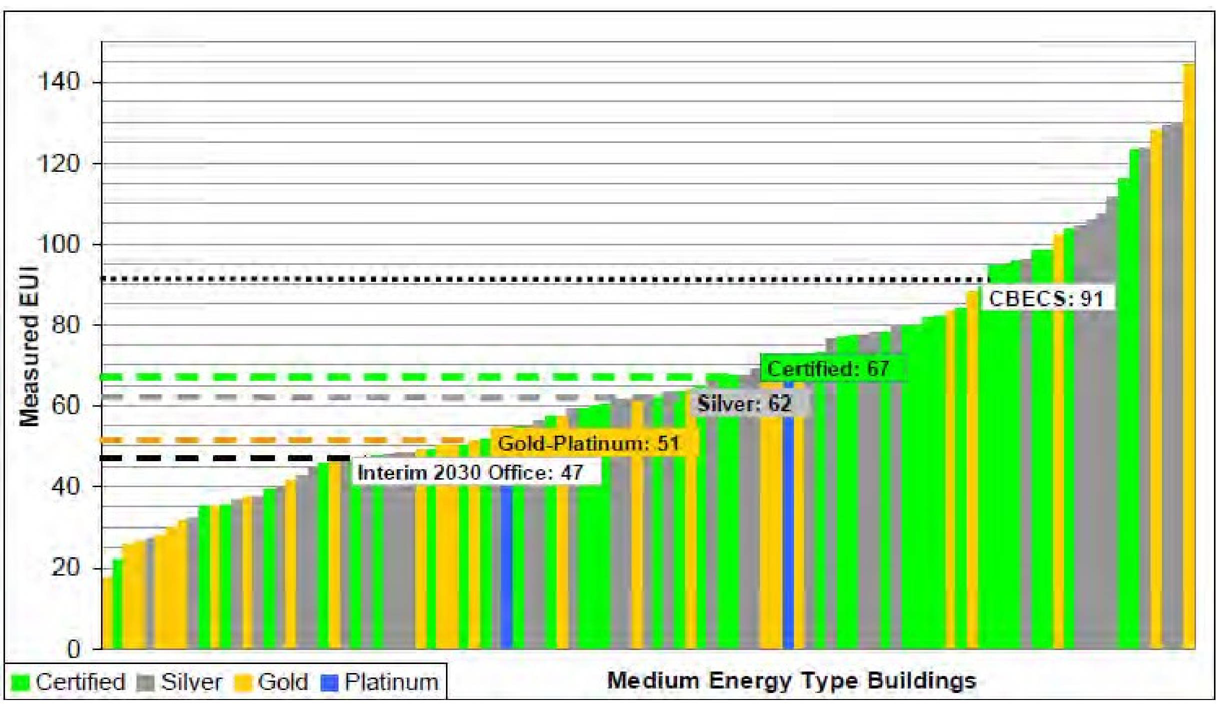


Figure 2.1 EUI (kBut/sf) distributions (Turner and Frankel, 2008)

The studies above also found that the incremental costs occurred to implement sustainable items for improving performance as a hard cost or to just achieve LEED certification as a soft cost. According to Kats et al. (2003), while some of the green premium costs are related to materials, the majority of the increase in total construction cost was due to the increased architectural and engineering design, modeling and integrate sustainable building practices into projects, such as advanced daylighting, thermal technologies, and photovoltaic systems. The average percent cost premiums increased by getting different LEED levels by Kats et al. (2003) are shown in Figure 2.2. However, Steven Winter Associates (2004) showed that the construction costs increased by 8.1% for the application of LEED certification with Gold level while the Certified and Silver level had minimal impacts.

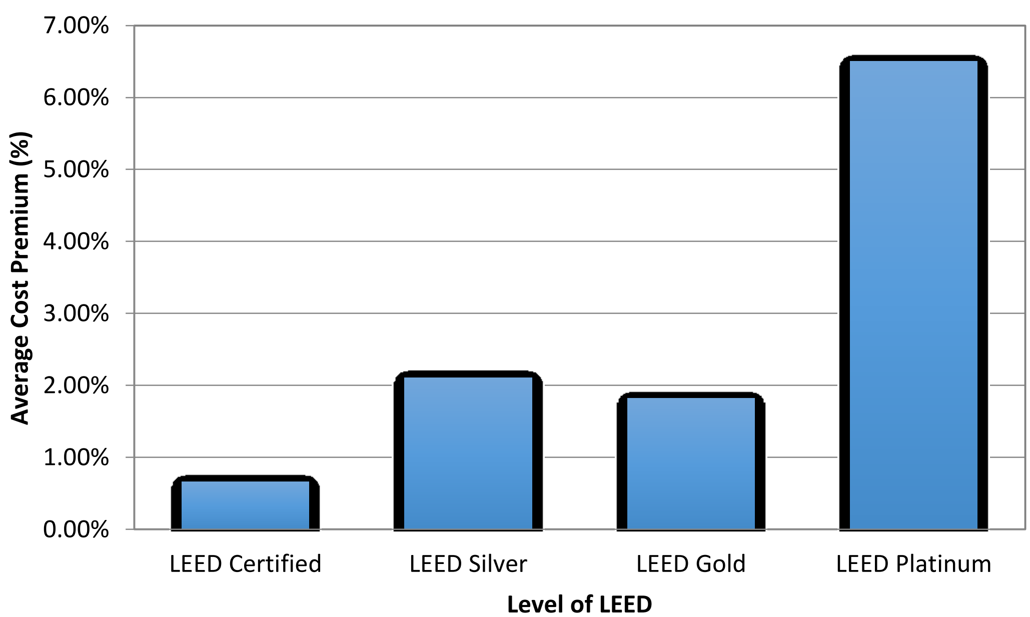


Figure 2.2 Average cost premium depending on level of LEED (Kats et al. 2003)

Although the LEED system is able to conduct the comprehensive assessment for green buildings, there are some controversies in terms of the cost effectiveness. According to Udall (2005), LEED projects increase the initial cost of a building due to the registration fee with the USGBC typically \$0.32~0.54/m^2 (\$0.03~0.05/ft^2) and 1~2% of the construction cost for the upgraded material and building systems. The LEED system is costly and time consuming as it has no cost and financial benefit evaluation (Schendler and Udall, 2005). Besides, Malkin (2005) argued that most people wanted to see quantitative data that shows the savings of energy use and cost but LEED did not meet the expectation. Newsham et al. (2009) insisted that 28~35% of LEED buildings save more energy than their conventional counterparts although LEED-certified buildings use 18~39% less energy per floor area than conventional counterparts. According to Menassa (2011), four of eleven LEED projects had lower electricity consumption savings than their counterpart non-LEED-certified buildings and other LEED-certified buildings did not meet the expected savings of over 30% as shown in Figure 2.3. In Menassa's study, the important finding is that there is not strong correlation between the earned points on EA credits and percent electricity savings.

Moreover, Scofield (2009) found that smaller LEED buildings had relatively lower purchased energy intensity (relative to non-LEED buildings) while larger buildings showed less savings, implying that higher investments for LEED certification might not be able to guarantee the sustainable building. According to Stephens (2013), LEED certification does not mean that a building has increased energy performance by default and seeking more energy performance points lead to greater energy performance. In addition, LEED has different weighting points that a building can achieve in different categories, such as sustainable site, energy and water usages, environmental protection, and indoor environmental quality (IEQ). Finally, the affordable investment to obtain the LEED certification at a target level is important since the excessive investment to obtain higher level of LEED certification regardless of the cost might not be most sustainable or economical.

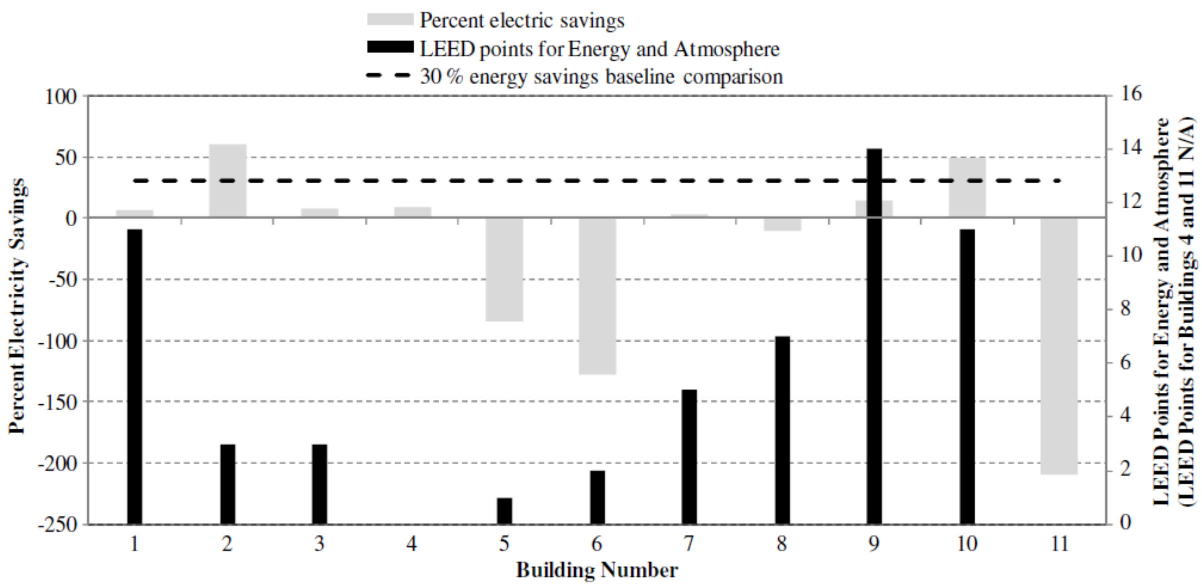


Figure 2.3 Percent electricity savings versus LEED points for Energy and Atmosphere (Menassa, 2012)

2.2 Evaluation of Integrated LCA and LCCA

Furthermore, building products have a relatively long service life and many factors involved during the building life cycle that makes it difficult to predict what actually happens during the life cycle, especially in the operation phase (Thomas, 1999). With the increased concern for the built environment among the public, governmental regulation and the aspiration towards a sustainable society forced to evaluate various methods or technologies for the environmental assessment of the activities of the building sector as well as the valuation in the whole process (Guoguo, 2008). Both LCA and LCCA measure costs and environmental impacts of the whole building. It is necessary to find a feasible way of incorporating them together to accommodate both economic and environmental elements (Jaein, 2006). Goh and Yang (2010) presented a new approach to an existing LCCA method that estimates all sustainability criteria including agency cost, social cost, and environmental cost into entire life cycle costs. Kats (2003) analyzed 24 buildings that achieved LEED certification in terms of sustainable bottom lines, such as economy, environment, and human based on LCCA.

Both LCC and LCA measure costs and environmental impacts of whole building, respectively. It is necessary to find a feasible way of incorporating them together to accommodate both economic and environmental elements (Jaein, 2006). Goh and Yang (2010) presented new approach to an existing LCCA method that estimates all sustainability criteria including agency cost, social cost, and environmental cost into entire life cycle costs. As the more detailed attempt for integrating LCA and LCC, Kats (2003) analyzed 24 buildings that achieved LEED certification in terms of sustainable bottom lines, such as economy, environment, and human. Contrary to other approaches, Kats analyzed LCC based on LCA, which means that all assigned indicators for environmental and social impacts were generated in a cost value. Table 2.1 shows the assessment of 24 LEED-certified buildings analyzed by the integrated LCA and LCCA method.

Table 2.1 The assessment of LEED-certified buildings (Kats, 2003)

Categories	20-Year NPV (per ft^2)
Energy Value	$5.79
Emissions Value	$1.18
Water Value	$0.51
Waste Value (Construction only)-1 year	$0.03
Commissioning O&M Value	$8.47
Productivity and Health Value (Certified and Silver)	$36.89
Productivity and Health Value (Gold and Platinum)	$55.33
Less Green Cost Premium	$4
Total 20-Years NPV (Certified and Silver)	$48.87
Total 20-Years NPV (Gold and Platinum)	$67.37

CHAPTER 3. Methodology

3.1 Data Gathering

Extensive data of LEED-certified institutional buildings were obtained from University of Wisconsin-Madison Capital Planning Development (UW-Madison CPD) to evaluate the feasibility of cost effectiveness. Nine LEED-certified buildings on the campus were chosen for the study. The information on LEED certification, level of LEED Certification, LEED templates, energy and water simulation results were collected. The list of the requested data to UW-Madison CPD was as follows:

- gbXML (green building XML) file or BIM (Building Information modeling) file along with building components and costs data if available
- Total estimated construction costs using company's own cost data or commercial costs reference, without documentation fees and taxes
- Building energy and water simulation modeling files (operating for EnergyPlus, DOE-2, eQuest, or other energy or water simulation modeling software)
- Prototype building or baseline building models (as baseline building performance) – company's own data or other source (e.g., ASHRAE 90.1 prototype building model)
- Financial cost information – discount rate (interest rate) and escalation rate if available
- Average energy and water consumption – monthly and yearly

- Peak energy and water billing rate if applied
- LEED or other green building certification scores with detailed points description

The energy and water simulation data were also compared with each corresponding building design, such as baseline building design and proposed building design. In terms of the construction estimates as an initial investment, UW-Madison CPD provided two types of cost estimates: (1) the formation phase estimate without the reflection of the sustainable items to improve energy and water efficiencies and to reduce the environmental impacts and (2) the system development estimate reflecting the sustainable items. In addition, the construction cost is only considered on the total project cost excepting soft costs along with a design cost, incentives, and the costs for LEED certification since this research focused on the incremental initial investment due to the application of the sustainable items to the proposed building design. It is necessary to have the economic factors to conduct LCCA. In this study, 30-year life span was used because the economic factors, such as long-term discount rates and escalation rates are not easy to predict accurately. Depending on the types of energy resources, several elements can impact the escalation rate of energy price. It is difficult to obtain the accurate escalation rate of energy prices. Finally, this research adopted the Uniform Present Value (UPV) of the Federal Energy Management Program (FEMP) to adjust the energy and water price depending on annual discount rate and escalation rate.

3.1.1 Project Descriptions

In order to determine the correlation of the cost effectiveness and LEED system, the data related to LEED-certified buildings was provided by UW-Madison CPD. The detailed project descriptions for nine LEED-certified buildings at the campus of University of Wisconsin-Madison are summarized in Table 3.1.

Table 3.1 The summary of the detailed project descriptions for nine LEED buildings

Name of projects	Purpose of projects	Year of occupancy	Investment (construction)	Size (ft^2)	Full Time Equivalent
Wisconsin Energy Institute	Research centers	2013	$47,792,534	107,018	227
UW-Medical Foundation Centennial Building	Faculty offices	2010	$35,492,731	130,000	485
Lakeshore Residence Hall	Campus housing	2013	$10,378,957	64,209	187 (Residents)
Wisconsin Institute for Discovery	Research centers	2011	$144,205,940	327,615	415
Wisconsin Institutes for Medical Research	Research centers	2013	$157,064,548	265,118	-
Education Building	Instructional spaces	2010	$21,883,436	100,345	178
Union South	Student Union	2011	$76,500,000	276,664	103
School of Human Ecology	Instructional spaces	2013	$35,422,258	201,623	256
School of Nursing	Instructional spaces	2014	$40,020,479	166,536	140

These building projects have achieved LEED Certification ranging from silver level to platinum level and they were usually built as the laboratory or institution. The incremental investment was made to achieve higher energy and water savings. In order to evaluate the relationship between the incremental investment and the economic benefits during the operation phase of building projects, the points associated with the credits on the categories of Energy & Atmosphere (EA) and Water Efficiency (WE) were investigated, especially optimized energy performance (EA credit 1), on-site renewable energy (EA credit 2), water efficient landscaping (WE credit 1), innovative wastewater technologies (WE credit 2), and water use reduction (WE credit 3). Note that the points earned on these credits can be acquired depending on the degree of the performance related to how much the building project can reduce the consumption of energy and water. The initial incremental investment is closely related with the application of high-performed systems to reduce energy and water usages. The information of nine LEED Certified buildings is summarized in Table 3.2.

The initial incremental investment is closely related with the application of high-performed systems to reduce energy and water usages. As shown in Table 3.2, Education Building owning platinum level received the highest total points while Lakeshore Residence Hall with silver level had the least points. The premium (%) refers to the initial incremental investment, i.e., the difference between the formation phase estimate for the baseline building design and the system development estimate for the proposed building design. The premium is calculated as follows:

$$\text{Premium (\%)} = \frac{\text{Development estimate} - \text{Formation phase estimate}}{\text{Formation phase estimate}} \times 100 \qquad (3.1)$$

Table 3.2 The information of the UW-Madison projects acquiring LEED Certification

Name of LEED Projects	Level of LEED	Size (ft^2)	EA Credits (EAc1, EAc2)		WE Credits (WEc1, WEc2, WEc3)			Total Credits (EA plus WE)	Premium (%)
Wisconsin Energy Institute	Gold	107,018	11	0	4	0	2	17	2.6
UW-Medical Foundation Centennial Building	Gold	130,000	13	0	4	0	3	20	1.63
Lakeshore Residence Hall	Silver	64,209	5	1	4	0	0	10	3.5
Wisconsin Institute for Discovery	Gold	327,615	7	0	2	1	4	14	1.3
Wisconsin Institutes for Medical Research	Gold	265,118	6	0	4	0	4	14	1.2
Education Building	Platinum	100,345	15	0	2	0	4	21	5.8
Union South	Gold	276,664	11	0	4	0	2	17	4.6
School of Human Ecology	Silver	201,623	13	0	4	0	2	19	0.9
School of Nursing	Gold	166,536	9	0	4	0	3	16	2.1

3.1.2 Baseline Building Model and Proposed Building Model

To check if there is the relationship between whole life cycle costs and the points on the credits related to energy and water consumption, the integrated LCA and LCCA method was used for the nine LEED-certified buildings. Furthermore, two building models are required to identify how much the savings can be achieved from implementation of sustainable items. These two building designs were created under the same condition, such as building size, location, number of full-time employees, and building operation time. For the sustainable items, the baseline building designs and proposed building designs were estimated in compliance with two standards, such as ASHRAE 90.1 (Energy Standard for Building except Low-Rise Residential Building) and Energy Policy Act (EPAct) 1992 for plumbing fixture flow rate. Building envelopes, HVAC systems, serviced hot water system, power systems, and lighting systems were designed for appropriate performance following ASHRAE 90.1. The description of the two building models is illustrated in Figure 3.1.

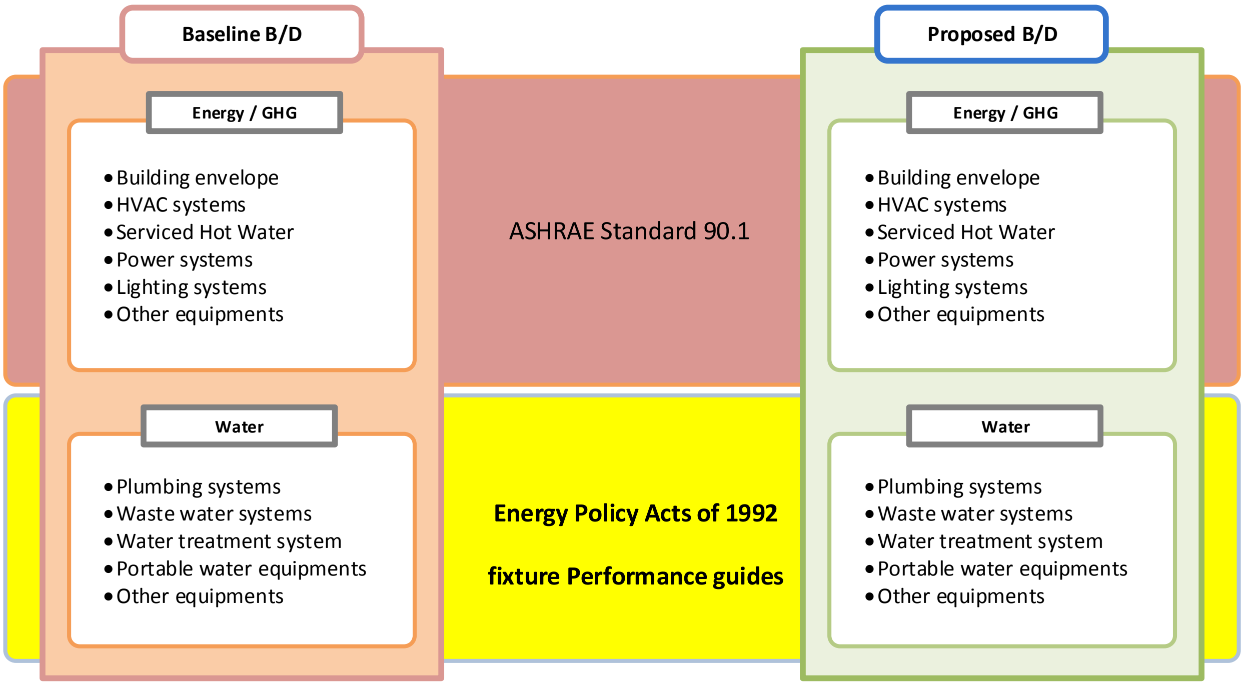


Figure 3.1 Two building models under ASHRAE 90.1 and EPAct 1992

In order to create a baseline building model in terms of energy efficiency, ASHRAE Standard 90.1 for a building energy design is used. ASHRAE Standard 90.1 standard presents minimum requirements for energy efficient designs of green buildings. Thus, it provides the strategies to improve energy and water cost saving. ASHRAE has published this standard per every three years and hence the upgrade version of ASHRE Standard 90.1 has showed improved energy saving performance as shown in Figure 3.2.

While the water systems regarding water supply, the treatment of waste water, and plumbing systems were designed in compliance with EPAct 1992. In terms of water efficiency on green buildings, the U.S. DOE provided Energy Policy Act of 1992 fixture performance requirements as a baseline of building water plumbing systems.

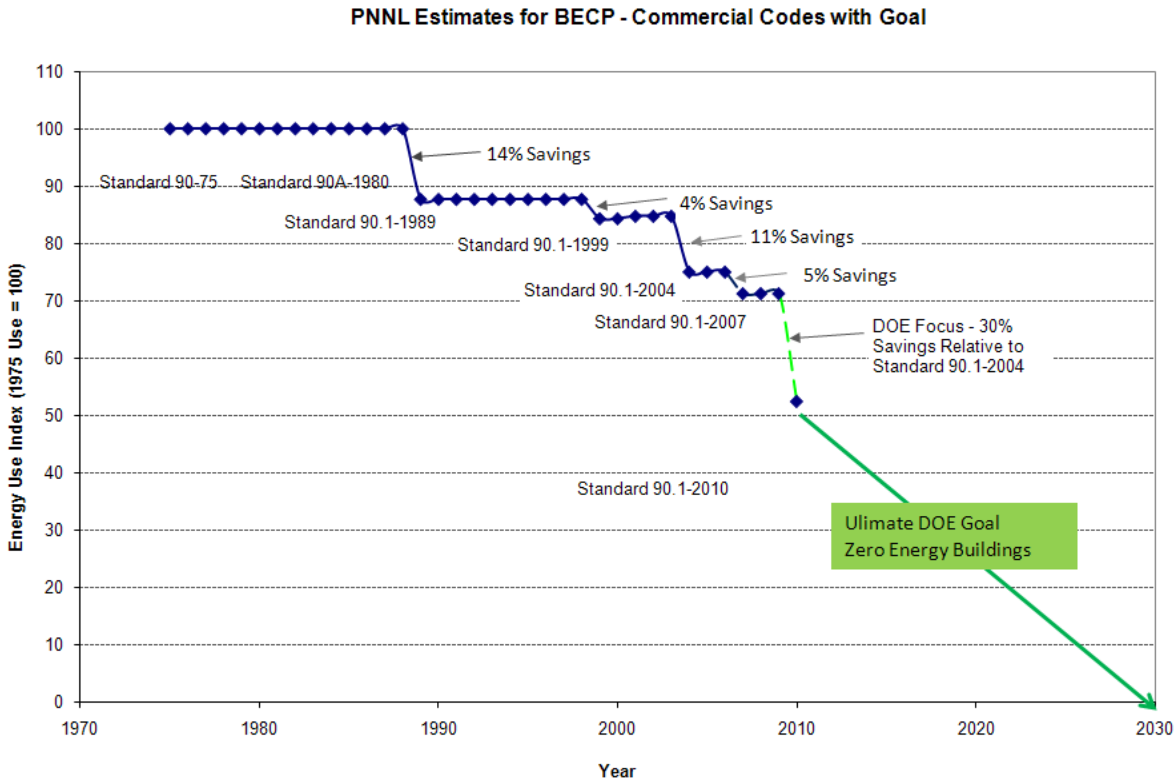


Figure 3.2 ASHREA 90.1 standard energy efficiency (U.S. DOE, 2011)

In the case of LEED certification, the building models that meet the fixture performance requirements on Energy Policy Act of 1992 are used as a baseline building model that can be compared with a proposed building model in order to measure the water efficiency. Thus, the parts of water plumbing and wastewater systems for the baseline building would be designed under the compliance of Energy Policy Act of 1992 fixture performance requirements.

Compared with baseline building designs, most LEED buildings adopted sustainable items, such as green roof, energy recovery wheels, low-flow lavatory faucets, etc. As examples, the

Wisconsin Institute for Discovery saves the energy for heating water by constructing geothermal energy system which requires higher initial costs while School of Human Ecology acquired Silver level of LEED mainly employed the sensing technologies that reduce energy and water consumptions with lower initial investments. For reducing or no-irrigation, most buildings implemented stormwater management system or landscaping that required no water, and to reduce the potable water, several sustainable technologies, such as low-flow shower heads, dual flushing toilet, grey and rain water re-use systems and etc. Two building designs, the baseline building design and the proposed building design, were used to evaluate LCC. The comparisons of two building designs for nine building projects are summarized in Table 3.3.

Among nine projects, Lakeshore Residence Hall, Education Building, Union South and School of Nursing invested 2% of the initial costs additionally by installing green roofs and water-reuse systems. Most building projects purchased renewable energy sources, especially electricity that is produced by renewable resources, such as solar, wind and landfill gas from the local area. In addition, the full points were earned on the water efficient landscaping with vegetated plants required no irrigation system and on the use of the sensors to detect daylight and occupant's motions. Besides these applications, several energy and water saving technologies illustrated in above were used to reduce energy and water usages and were reflected in energy and water simulations.

Table 3.3 Comparison of Baseline building versus proposed building

Name of LEED Projects	Baseline Building	Proposed Building
Wisconsin Energy Institute	ASHRAE 90.1 2007, EPAct 1992	Renewable sources, chill beams, Floor-to-ceiling windows, low-flow shower heads, dual flushing toilets
UW-Medical Foundation Centennial Building	ASHRAE 90.1 2004, EPAct 1992	Renewable sources, Daylight sensors, plants with no required irrigation, stormwater management
Lakeshore Residence Hall	ASHRAE 90.1 2007, EPAct 1992	Renewable sources, solar panels, low-flow shower heads dual flushing toilets
Wisconsin Institute for Discovery	ASHRAE 90.1 2004, EPAct 1992	Geothermal energy system, dual flushing toilets, low-flow urinal, grey water re-use, rainwater re-use
Wisconsin Institutes for Medical Research	ASHRAE 90.1 2004, EPAct 1992	Renewable sources, dual flushing toilets, low-flow urinal
Education Building	ASHRAE 90.1 2004, EPAct 1992	Green roof, energy recovery wheels, renewable sources, grey water re-use, rainwater re-use
Union South	ASHRAE 90.1 2007, EPAct 1992	Vertical sun louvers, Daylight sensors, renewable sources, vegetated green roof, stormwater management, rainwater re-use
School of Human Ecology	ASHRAE 90.1 2004, EPAct 1992	Daylight sensors, renewable sources, green roof, energy recovery wheel, occupancy sensors, tankless electric water heaters, low-flow water urinal, low-flow lavatory faucets
School of Nursing	ASHRAE 90.1 2007, EPAct 1992	Green roof, energy recovery wheels, low-flow shower heads, dual flushing toilets

3.2 Methods of Data Analysis

In this research, the statistical analyses and the calculation of supplementary measures were conducted in order to identify the correlation between the earned points on WE and EA, and to evaluate the cost effectiveness for nine LEED projects. The process of data analysis was followed as shown in Figure 3.3.

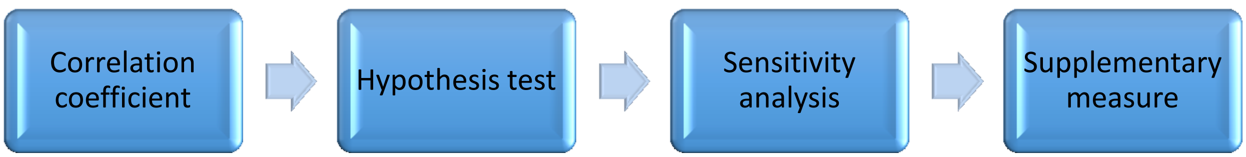


Figure 3.3 The process of data analysis

3.2.1 Statistical Analysis

In order to identify the correlation between earned points on EA credits and WE credits and the initial incremental investments, the correlation coefficient (R) and paired t-test were used with a 0.05 significant level. In statistics, the Pearson product-moment correlation coefficient refers to the correlation coefficient which is a measure of the linear correlation between two variables. The pearson correlation coefficient is calculated as follows:

$$\mathrm{R} = \frac{\Sigma(x_i - \bar{x})\,(y_i - \bar{y})}{\sqrt{\Sigma(x_i - \bar{x})^2}\,\sqrt{\Sigma(y_i - \bar{y})^2}} \quad (3.2)$$

where R = correlation coefficient;

$\bar{x}$ = the mean of x variable; and

$\overline{y}$ = the mean of y variable.

The correlation coefficient, R, can be in the range of -1 to +1. An R value close to -1 or +1 refers to higher correlation while that close to zero means low correlation. Generally, the R value can be analyzed per the ranges shown in Table 3.4.

Table 3.4 The general analysis of the R value

Range of R value	Analysis
-1.0 ~ -0.7	Strong negative linear correlation
-0.3 ~ -0.7	Distinct negative linear correlation
-0.1 ~ -0.3	Weak negative linear correlation
-0.1 ~ 0.1	Ignorable linear correlation
0.1 ~ 0.3	Weak positive linear correlation
0.3 ~ 0.7	Distinct positive linear correlation
0.7 ~ 1.0	Strong positive linear correlation

For this statistical analysis, the R statistical program was utilized. "R" is a free software environment for statistical computing and graphics and it is widely used among statisticians and data miners for developing statistical software (Fox et al. 2005). The statistical dispersion of the plots shows the correspondence of the earned points on the EA credits, WE credits and total credits which sum up the points from EA credits and WE credits, and the initial incremental investments for nine LEED-certified buildings. In order to identify whether the R value showing the correlation has the significance or not, the statistical hypothesis test was conducted. In general, the hypothesis test is the use of statistics to determine the probability that a given hypothesis is true. First, it is assumed that the population distribution is normal and the paired t-test was adopted in order to check the significance of the p-value for this hypothesis. For the paired t-test, the null hypothesis and its rejection were established as follows:

$$\begin{aligned} &H_0 : \text{Correlation Coefficient is zero } (R = 0), \text{ if the p-value} \geq 0.05 \\ &H_1 : \text{Correlation Coefficient is not zero } (R \neq 0), \text{ if the p-value} < 0.05 \end{aligned} \tag{3.2}$$

3.2.2 Supplementary Measures and Indexes

In order to determine whether the LEED-certified buildings can save LCC compared with conventional buildings, the integrated LCA and LCCA approach was used with the nine LEED-certified buildings on the University of Wisconsin-Madison campus. Along with the existing method for the estimate of LCC, environmental burdens as social costs, specifically the costs of GHG emission during only the building operation phase and waste water disposal were considered and reflected. The factors of the integrated LCA and LCC can be expresses as follows:

$$\begin{aligned} \text{Life Cycle Cost} = \text{Initial investment} &+ \textstyle\sum_{N=1}^{n} \text{Energy cost} + \sum_{N=1}^{n} \text{Water cost} \\ &+ \textstyle\sum_{N=1}^{n} \text{GHGs cost} + \sum_{N=1}^{n} \text{Water disposal cost} \\ &+ \textstyle\sum_{N=1}^{n} \text{Maintenance cost} + \text{Replacement cost} \end{aligned} \tag{3.3}$$

The rates of energy sources, the rate of portable water, landscaping and water disposal, and the maintenance costs were obtained from UW-Madison CPD, Wisconsin Department of Administration, and West Campus Cogeneration Facility (WCCF). The cost of the Carbon Dioxide Equivalent (CO_2E) was estimated from Harvard University's Life Cycle Cost Program. Annually-recurring costs, such as energy cost, water cost, GHG cost, water disposal cost and maintenance cost were estimated with Uniform Present Value (UPV). One-time costs including initial investment and replacement cost were converted to net present value in a 2009 dollar.

According to Fuller and Petersen (1995), the supplementary measures are Net Savings (NS), the Savings-to-Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), and Simple Payback (SPB). Net Savings (NS) measures a variation of the net benefits of economic performance of a building project, which can be computed from the difference between present value benefits and present value costs over the designed study period. Net Savings (NS) for building-related projects can be estimated as follows (Fuller and Petersen, 1995):

$$\mathrm{NS}_{\mathrm{A:BC}} = (\Delta\mathrm{E} + \Delta\mathrm{W} + \Delta\mathrm{OM}\&R) - (\Delta\mathrm{I}_{\mathrm{O}} + \Delta\mathrm{Repl} - \Delta\mathrm{Res}) \tag{3.4}$$

where $\mathrm{NS}_{\mathrm{A:BC}}$ = Net Savings, operation-related savings minus additional investment costs for the alternative relative to the baseline;

$\Delta\mathrm{E}$ = Savings in energy costs attributable to the alternative;

$\Delta\mathrm{W}$ = Savings in water costs attributable to the alternative;

$\Delta\mathrm{OM\&R}$ = Savings in operation, maintenance and replacement costs;

$\Delta\mathrm{I}_{\mathrm{O}}$ = Additional initial investment cost required for the alternative relative to the baseline;

$\Delta\mathrm{Repl}$ = Additional capital replacement costs; and

$\Delta\text{Res} = \text{Additional residual value.}$

SIR is a measure of economic performance for a project alternative that expresses the relationship between its savings and its increased investment cost as a ratio (Fuller and Petersen, 1995). SIR is a variation of the B/C ratio for use when benefits occur primary a reductions in operation-related costs and like the NS measure, SIR is a relative measure of performance. SIR for building-related projects can be estimated as follows (Fuller and Petersen, 1995):

$$\text{SIR}_{\text{A:BC}} = \frac{\Delta\text{E}+\Delta\text{W}+\Delta\text{OM}\&R}{\Delta\text{I}_\text{O}+\Delta\text{Repl}-\Delta\text{Res}} \tag{3.5}$$

where $\text{SIR}_{\text{A:BC}}$ = Ratio of operational savings to investment=related additional costs;

computed for the alternative relative to the baseline;

ΔE = Savings in energy costs attributable to the alternative;

ΔW = Savings in water costs attributable to the alternative;

$\Delta\text{OM}\&R$ = Savings in OM&R costs;

ΔI_O = Additional initial investment cost required for the alternative relative to the baseline;

ΔRepl = Difference in capital replacement costs; and

$\Delta\text{Res} = \text{Difference in residual value.}$

AIRR is a measure of the annual percentage yield from a project investment over the study period and it is a relative measure of cost effectiveness. Thus, AIRR and SIR are correspondingly related to BPI and CEI in GBPAT. In addition, these supplementary measures must be computed with respect to a designated base case, which means that the same start date, study period, and discount rate must be applied for both the baseline and the alternative. The simplified formula for AIRR is as follows (Fuller and Petersen, 1995):

$$\mathrm{AIRR} = (1 + \mathrm{r})\ \mathrm{SIR}^{\frac{1}{\mathrm{N}}} - 1 \tag{3.6}$$

where r = the reinvestment rate; and

N = the number of years in the study period.

Simple Payback (SPB) measures the time required to recover the initial investment cost. Thus, SPB is expressed as the number of years elapsed between the beginning of the service period and the time at which cumulative savings are just sufficient to offset the incremental initial investment cost of the project (Fuller and Petersen, 1995). In general, SPB is best used as a screening method for identifying single project alternatives that are clearly economical when the time and expense of a full LCCA are not warranted. Payback formula for building-related project is as follows (Fuller and Petersen, 1995):

$$\sum_{\mathrm{t}=1}^{\mathrm{y}} \frac{(\Delta\mathrm{E}+\Delta\mathrm{W}+\Delta\mathrm{OM}\&R-\Delta Repl+\Delta Res)}{(1+\mathrm{d})^{\mathrm{t}}} \geq \Delta\mathrm{I}_{\mathrm{O}} \tag{3.7}$$

where $\Delta\mathrm{E}$ = Savings in energy costs attributable to the alternative;

$\Delta\mathrm{W}$ = Savings in water costs attributable to the alternative;

$\Delta\mathrm{OM}\&R$ = Savings in OM&R costs;

$\Delta\mathrm{Repl}$ = Difference in capital replacement costs;

$\Delta\mathrm{Res}$ = Difference in residual value;

d = Discount rate; and

ΔI_O = Additional initial investment cost.

Among supplementary measures, the payback period is defined as the expected number of years required to recover the original investment and is the ratio of the incremental investment to the decreased annual operating cost. If all factors are held constant, the project with a shorter payback period is considered as the better project since the investor can recover the capital invested in a shorter period of time (Brigham and Ehrhardt, 2005). Besides, shorter payback period means greater liquidity of the project. The payback period without the reflection of time value of money is referred to simple payback period (SPP) while the payback period with time value of money is defined as discounted payback period (DPP). According to studies by MHTN Architects and American Chemistry Council (2009), the cost premium (%) depending on the level of LEED Certification ranged from 0 to 8.5% while discounted payback period varied from four to eight years as shown in Table 4.

The discounted payback period is calculated as follows (Fuller and Petersen, 1995):

$$\text{Discounted Payback Period (DPP)} = \frac{\ln[\frac{CF}{CF-P\times r}]}{\ln(1+r)} \tag{3.8}$$

where CF = cash flow and

r = discount rate.

Table 3.4 Suggested cost premium and discount payback period (MHTN Architects and American Chemistry Council)

	LEED-certified	LEED Silver	LEED Gold	LEED Platinum
Cost Premium	0 ~ 2.5%	0 ~ 3.3%	0.3 ~ 5%	4.5 ~ 8.5%
Discount Payback Period (estimated)	4 years	5 years	6 years	8 years

In order to assess green building performance that is represented with the integrated LCA and LCCA method, the system of the performance index or metrics would be necessary as the comparison of the proposed building's LCC relative to baseline building is insufficient for the user to understand easily. Building performance metrics are intended to explicitly represent the performance objectives for a building project, using quantitative criteria, in dynamic, structured format (Hitchcock et al., 2002). In the field of a green building project, the energy use intensity (EUI) is usually used as energy efficiency metrics and the representative green building rating systems (LEED, BREEAM, etc.) provide the appropriate points or credits. With the integrated LCA and LCCA that comprise initial costs and future costs for two building models, the building performance index (BPI) is provided with numerical scales to help the user in using the simulation results produced through all process of integrated LCA and LCCA.

For BPI, the integrated LCA and LCCA method for baseline building and proposed building can be compared. Once each of the advanced LCCs for two building simulation models is obtained, BPI in GBPAT can be calculated as follows:

$$\frac{\text{Reference B/D LCC} - \text{Proposed B/D LCC}}{\text{Reference B/D LCC}} \times 100 = \text{Relative BPI} \tag{3.9}$$

To establish BPI for assessing green building performance, LCC for the baseline building simulation model is deemed as a basis. In contrast, the difference between LCCs for the baseline and proposed building models are considered as a practical improved building performance.

In addition, the cost effectiveness index (CEI) is needed with respect to cost-benefit. The information on the ratio of the investments for a green building and the integrated LCA and LCCA method during the operation of a green building must be provided to the user. Although BPI can represent overall greenness and sustainability of the proposed building that the user customizes, it is limited to the analysis of the investment versus cost saving that the user expects. Thus, this research provides two types of indexes: advanced BPI to evaluate the overall green building performance and cost effectiveness index (CEI) to identify the feasibility of investments for more green building projects

Economic benefit-cost ratios have been developed for various criteria to help the developers and designers to identify the economic impact and cost effectiveness of an environmental assessment scheme (Chau, 2000). With the comprehensive green building assessment tools based on the life cycle assessment method that considers only environmental impacts, the building project participants, such as owners, project managers, designers, and general and sub-contractors, are difficult to evaluate the information regarding cost effectiveness for application of green building technologies. Thus, CEI is provided for users to easily catch the feasibility of the investments for green building technologies to their building projects. To represent practical

CEI, it can be calculated by the proportion of incremental rate, not simulated LCC of building models. In addition, CEI in GBPAT is created by only the comparison between initial and future costs for each of the baseline building model and the proposed building model since it represents the ratio of initial costs as an investment to future costs as a cost saving, and it is only the comparison to assess the improvements of the proposed building model from the baseline building model. Hence, with these premises, the following equation can be established:

$$\text{Cost Effectiveness Index} = \frac{\frac{\text{Baseline}\,\frac{\text{B}}{\text{D}}\text{future cost} - \text{Proposed}\frac{\text{B}}{\text{D}}\,\text{future cost}}{\text{Baseline B/D future cost}}}{\frac{\text{Proposed B/D initial cost} - \text{Baseline B/D initial cost}}{\text{Baseline B/D initial cost}}} \tag{3.10}$$

In Equation 3.10, the part of a numerator is intended as the incremental rates of cost saving and a denominator is to present the incremental rates of the investments for the green features on the proposed building model. Also, all of incremental rates for the investments and cost savings are shown in a finite decimal or a minus decimal in the case of decreased building performance.

Finally, by comparing LCCA supplementary measures illustrated above, specifically BPI and CEI in GBPAT, BPI and CEI can be the principal indicators for assessing green building performance.

CHPATER 4. DATA ANALYSIS AND RESULTS

4.1 Analysis of Feasibility Test for Cost-Effectiveness of LEED-Certification

The initial statistical analysis was performed using the correlation coefficient. It was shown that there was a weak correlation between the earned points on WE and EA credits, and the incremental investments. Among the earned points on WE, EA and total credits, and the points on EA credits, the relatively higher correlation coefficient for energy-related points compared with the initial incremental investment indicates that the sustainable items that increase the initial construction costs are mainly related to energy savings. On the other hand, all of nine LEED projects were analyzed to be cost effective on 30 years life span with various levels of savings. Depending on the degree of incremental investment, the benefits analyzed by the integrated LCA and LCCA method may vary. Furthermore, it was found that the discount rate and escalation rate as the financial factors are most significant impact to total LCC from sensitivity analysis.

4.1.1 Statistical Analysis Results

In order to identify the correlation between earned points on EA credits and WE credits and the initial incremental investments, the statistical analysis of the correlation coefficient (R) and paired t-test were implemented with a 0.05 significance level. Using R statistical software, theses statistical analyses were conducted. The correlation coefficients were 0.1849, 0.4597 and -0.4059 for the earned points of total credits, EA credits, and WE credits, respectively. As these R values are compared with the reference in Table 3.4, R values can be analyzed in the positive or negative linear correlation. However, the relationships between EA points and premium and between WE points and premium were not strong as seen in Figure 4.1. Thus, the R^2 values for both cases were 0.1689 and 0.1645, respectively, indicating a low correlation as illustrated in Table 3.4.

In the case of the correlation between the total points on EA and WE credits, and cost premium, the R value was 0.1849, again showing the weak correlation. In addition, it was difficult to find the trend from the plots since they were scattered as seen in Figure 4.2. In order to determine whether the R^2 values have the significance, as mentioned in Section 3.2.1 Statistical Analysis, the hypothesis test was needed so the paired t-test was conducted with using R statistical software as well.

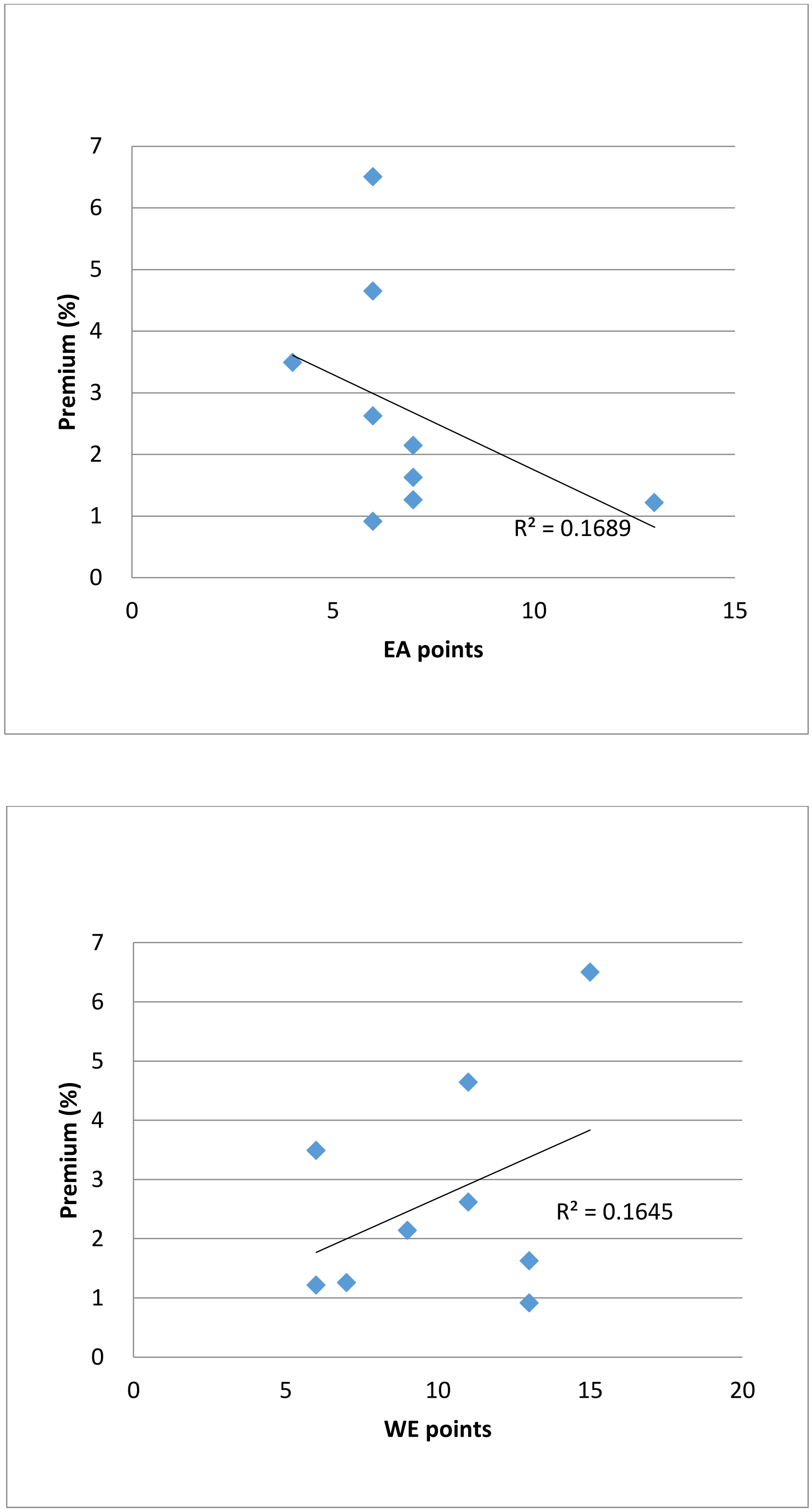


Figure 4.1 Plots for the earned points and cost premium with the trendline

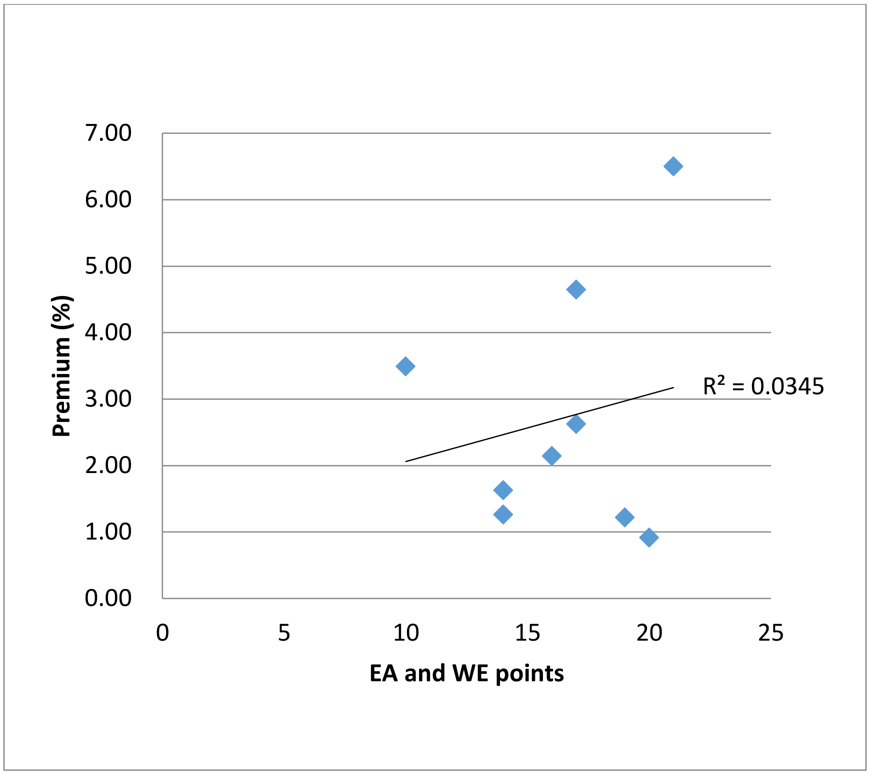


Figure 4.2 Plot for the earned points and cost premium with the trendline

Table 4.1 shows the results of paired t-test. All the correlation coefficients had higher p-values of 0.6337, 0.2783, and 0.9385 at the significant level of 95%, indicating that the null hypothesis that the correlation coefficient is zero cannot be rejected. Therefore, it was shown that the correlations between the earned points on EA, WE, and total points summing up on EA and WE, and cost premium were practically weak although the correlation for EA and WE existed to a certain degree. In addition, it implies that the higher initial incremental investment for improving energy and water reduction does not guarantee higher performance for energy and water usages. The relatively higher correlation coefficient for energy-related points versus the initial incremental investment indicates that the sustainable items that increase the initial construction costs are mainly related to energy savings.

Table 4.1 Summary of Correlation Coefficient and P-value

	Correlation Coefficient	P-value
Premium vs Total credits	0.1849825	0.6337
Premium vs EA credits	0.459737	0.2783
Premium vs WE credits	-0.4059737	0.2131

4.1.2 Results of Integrated LCA and LCCA

Using the integrated LCA and LCCA approach, the feasibility test was conducted for nine LEED-certified buildings. The total LCC reflecting the social costs related to environmental impact was estimated by analyzing the data provided by UW-Madison CPD, design firms, and utilities companies. The total LCC for nine LEED projects was preceded with the same procedure. The procedure with the Wisconsin Institute for Discovery (WID) project is illustrated below.

The WID building had been constructed for four years from planning to occupancy with the investment of over $140 million. Before the building was occupied, it had successfully received LEED certification at the gold level. In addition, through applying several innovated and efficient items including the solar hot water heater, increased ventilation system, geothermal heat exchange system, etc. the initial investments were increased. The breakdown of the initial construction costs for the WID project and baseline building project as a baseline building model were provided by the project manager at CPD and are summarized in Table 4.2 as an example.

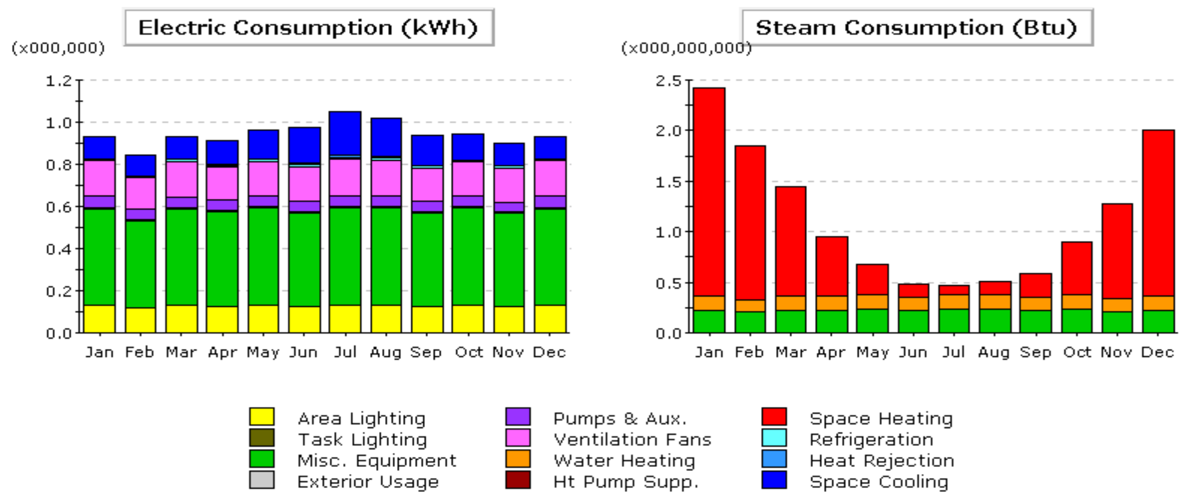
Table 4.2 Breakdown of initial construction costs for WID and baseline building

Construction cost summary	Baseline building estimate	WID project estimate
Site work	$7,609,100	$6,263,891
Foundation/Substructure	$9,249,510	$9,212,908
Superstructure	$16,389,550	$17,091,322
Enclosure	$19,782,594	$17,953,195
Interior construction	$27,975,790	$29,153,312
Equipment	$6,866,439	$7,302,294
Conveying Systems	$1,296,110	$1,741,142
Plumbing	$7,042,629	$7,617,059
Fire protection	$1,241,127	$1,368,349
HVAC	$20736,531	$20,318,528
Electrical	$18,215,709	$19,915,074
Controls	$0	$0
General requirements	$7,979,069	$8,268,866
Total construction cost	$144,384,159	$146,205,940

The WID building project was able to accomplish energy savings of 68%, water reduction of 78%, and improved IEQ. Although the initial construction cost ($538/Gross square feet) was relatively high compared with the other similar building projects, green building performance is shown in this project due to more savings of future costs occurring from energy and water consumption, GHG emission and black water disposal, and occupant health.

Energy simulation for WID project and baseline building project was conducted with the eQuest program based on DOE-2.2 simulation engine and Midwest weather data was applied. Through the energy simulation of eQuest, annual energy consumption and peak energy demand depending on energy resources (e.g., electricity, natural gas, and purchased steam) along with monthly usages are provided. Figure 4.3 shows the simulation result for the WID building project by eQuest software.

Thus, the detailed information of energy consumption with the energy rate supplied by the power plant company can be transferred to annual energy costs as an annually recurring present value. Affiliated engineers from the architect firm for the WID project had been modeling for both proposed building and baseline building based on the minimum requirement of ASHRAE Standard 90.1.



Electric Consumption (kWh x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.11	0.10	0.11	0.11	0.14	0.17	0.21	0.18	0.14	0.12	0.11	0.11	1.61
Heat Reject.	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.03
Refrigeration	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.10
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.17	0.15	0.17	0.16	0.17	0.16	0.17	0.17	0.16	0.16	0.16	0.17	1.98
Pumps & Aux.	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.59
Ext. Usage	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08
Misc. Equip.	0.46	0.41	0.46	0.45	0.46	0.44	0.46	0.46	0.44	0.46	0.44	0.46	5.41
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.13	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	1.54
Total	0.93	0.84	0.93	0.91	0.96	0.98	1.05	1.02	0.94	0.94	0.90	0.93	11.34

Gas Consumption (Btu x000,000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	2.06	1.53	1.08	0.59	0.31	0.14	0.10	0.14	0.23	0.52	0.93	1.64	9.26
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.14	0.13	0.14	0.14	0.14	0.13	0.14	0.14	0.13	0.14	0.13	0.14	1.65
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.22	0.20	0.22	0.23	0.23	0.21	0.23	0.23	0.21	0.23	0.21	0.22	2.66
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	2.42	1.85	1.45	0.96	0.68	0.48	0.47	0.51	0.58	0.89	1.27	2.00	13.57

Figure 4.3 The energy simulation result of WID building project by eQuest software

Table 4.3 Comparison of annual energy costs reflecting peak-time energy demand.

Energy type	Baseline building		Proposed building	
	Energy use	Cost	Energy use	Cost
Electricity	11,384,250 kwh	$770,906	8,075,500 kwh	$546,784
Purchased chilled water	0 ton hrs	0	251,058 ton hrs	$17,574
Purchased steam	13,728 MBtu	$103,923	11,604 MBtu	$87,842
Sub-total	52,572 (MBtu/year)	$874,829	42,170 (MBtu/year)	$652,200
Solar hot water	0	0	-17 MBtu	- $128
Geo-thermal heat pump	0	0	- 2,720 MBtu	- $5,181
Total	52,572 (MBtu/year)	$874,829	39,433 (MBtu/year)	$646,891

As shown in Table 4.3, annual total energy costs can be estimated. It can be seen that the proposed building model for WID building project can save the energy consumption by $200,000 annually by alternative components. Moreover, PSJ Engineering Company for water plumbing contractor of the WID building project simulated the water usages as summarized in

Table 4.4. A significant water saving was anticipated from innovative wastewater technologies, such as grey water reuse and rain water reuse systems.

Table 4.4 The comparison of water usages between baseline and proposed building models

Baseline building-Annual water consumption	1,197,127 gal/year	1600 CCFs/year
Proposed building-Annual water consumption	902,085 gal/year	1206 CCFs/year
Total annual non-potable water consumption	642,600 gal/year	859 CCFs/year
Total water saving	78.3%	

Finally, the costs of GHG emission can be generated by computing GWP. The prices of the purchased steam provided by the local power plant company are summarized in Table 4.5.

Table 4.5 GHG emission amounts and carbon dioxide costs

	Baseline building	Proposed building
Annual electricity consumption, kWh	11,384,250 kWh	8,075,500 kWh
CO_2E, lbs	12,750,360 lbs	9,044,560 lbs
CO_2E, ton	5,783 ton	4,103 ton
CO_2E cost, $	$86,745	$61,545

First, the total LCC was estimated using the integrated LCA and LCCA method. With respect to the triple sustainable bottom lines (economy, environment, and society), the integrated LCA and LCCA method can compare the performance of a green building with the baseline building in a monetary unit. Generally, the life cycle of commercial building for calculating LCC is 20 years and 25 years even though the most commercial building is maintained well beyond that period. For the perspective of building owners and managers, the consideration of life cycle over 30 years is limited as the increment of future costs are exponentially higher than the increment of investment costs over time. The appropriate life span of green building should be within 25 years. Both the total life cycle costs estimated by the integrated LCA and LCCA method for baseline and proposed building models are summarized in Tables 4.6 and 4.7.

Table 4.6 Total LCC for baseline and proposed buildings (20 and 25 years)

Categories	Baseline building		Proposed building	
	20 years	25 years	20 years	25 years
Construction cost	$144,384,158	$144,384,158	$146,205,940	$146,205,940
Maintenance cost	$13,124,151	$16,134,909	$11,418,012	14,037,371
Energy costs	$14,228,525	$17,376,429	$10,570,224	$12,908,769
Water costs	$213,669	$260,941	$119,907	$146,435
CO2 emission costs	$1,217,593	$1,486,972	$913,287	$1,115,342
Water disposal costs	$304,214	$371,518	$170,711	$208,479
Total costs	$165,938,044	$170,706,602	$162,857,149	$166,541,045

The total LCC for two models are estimated with discount rate of 3.0% and escalation rate of 2.0%. The life spans of 20, 25, 30 and 50 years were used to compare the difference of the assessment of green building performance by changing expected life cycle of building. For the expected life cycles of 20 and 25 years, the net savings (the difference between the total LCCs of baseline and proposed building models) were approximately $4,100,000 and $5,500,000, respectively.

Table 4.7 Total LCC for baseline and proposed buildings (30 and 50 years)

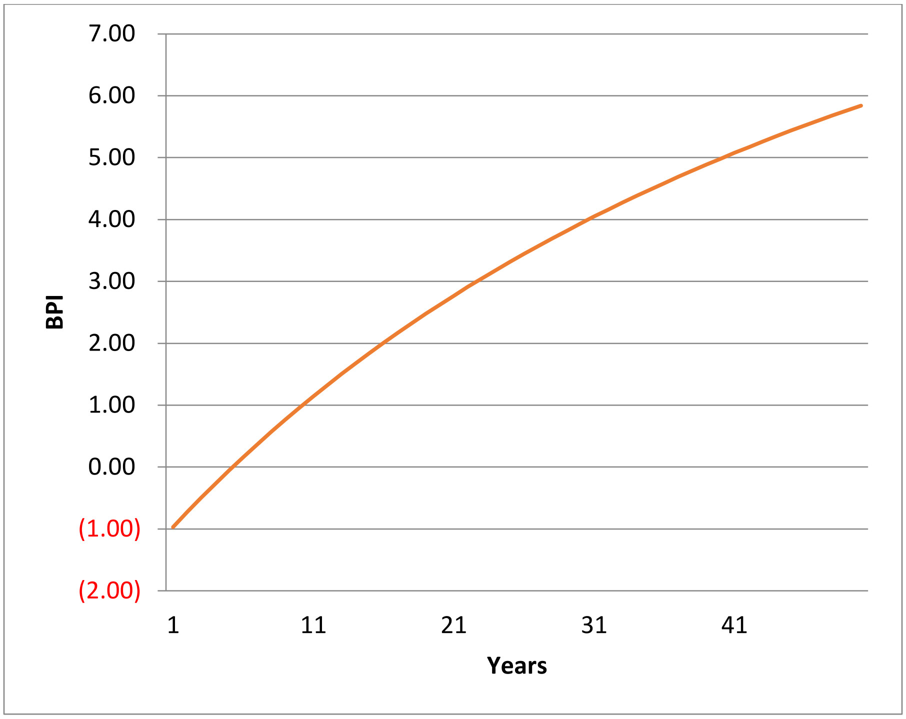
Categories	Baseline building		Proposed building	
	30 years	50 years	30 years	50 years
Construction cost	$144,384,158	$144,384,158	$146,205,940	$146,205,940
Maintenance cost	$19,044,741	$29,740,793	$16,568,924	$22,874,490
Energy costs	$20,368,344	$30,987,202	$14,752,119	$22,443,008
Water costs	$57,562	$88,327	$12,483	$19,155
CO_2 emission costs	$1,742,216	$2,650,505	$1,294,713	$1,969,701
Water disposal costs	$72,750	$111,634	$15,777	$24,210
Total costs	$185,669,722	$207,962,620	$178,849,959	$196,536,506

However, it might be only under 2% of the increment of the total LCC based on the baseline building model for the 20-year life cycle since the initial investment costs affected the total LCCs of both the baseline and proposed building models. However, the other supplementary measures of LCCA methods showed higher performance index compared with BPI and CEI. Table 4.8 illustrates the results of LCCA for the WID building with discount rate of 3.0% and escalation rate of 2.0%.

Table 4.8 The results of LCCA for the WID project

Duration	Net saving	Net saving ($/ft^2)	SIR	AIRR	DPP (less than)	BPI	CEI
20 Years	$4,191,499	12.94	3.30	0.09	6	2.42	16.63
25 years	$5,534,840	16.89	4.04	0.09	6	3.08	16.61
30 years	$6,819,813	$20.82	4.74	0.08	6	3.67	16.59
50 years	$11,426,114	$34.88	7.27	0.07	6	5.49	16.51

By analyzing the values of SIR and AIRR, the WID building can be shown as the cost-effective project since the SIR value of 3.30 is greater than 1 and AIRR of 0.09 (9%) exceed the discount rate of 3.0%. However, the net savings of $12.94 and $16.89 still do not meet the average savings of LEED-certified buildings with silver level. In addition, the values of two indexes and three supplementary measures over 50 years are shown in Figures 4.4 and 4.5.



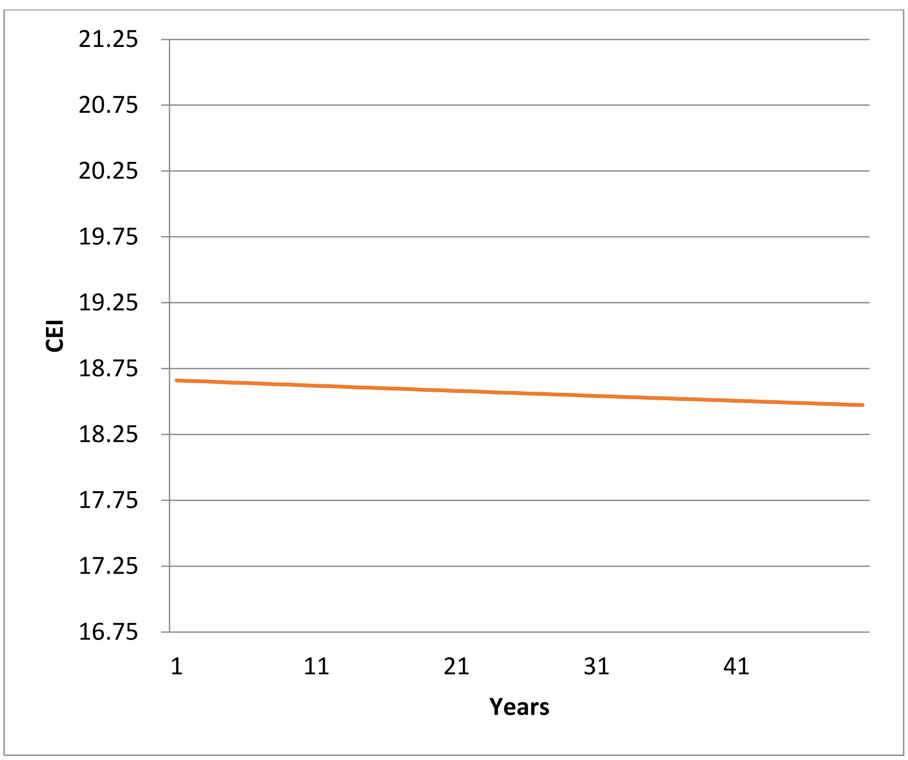
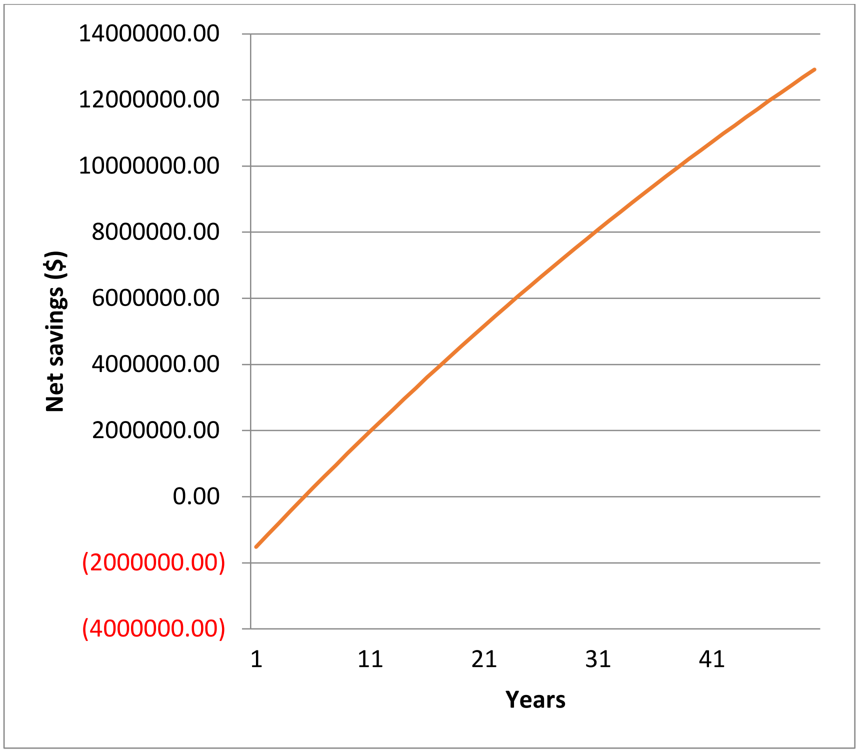


Figure 4.4 BPI and CEI for the WID building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31
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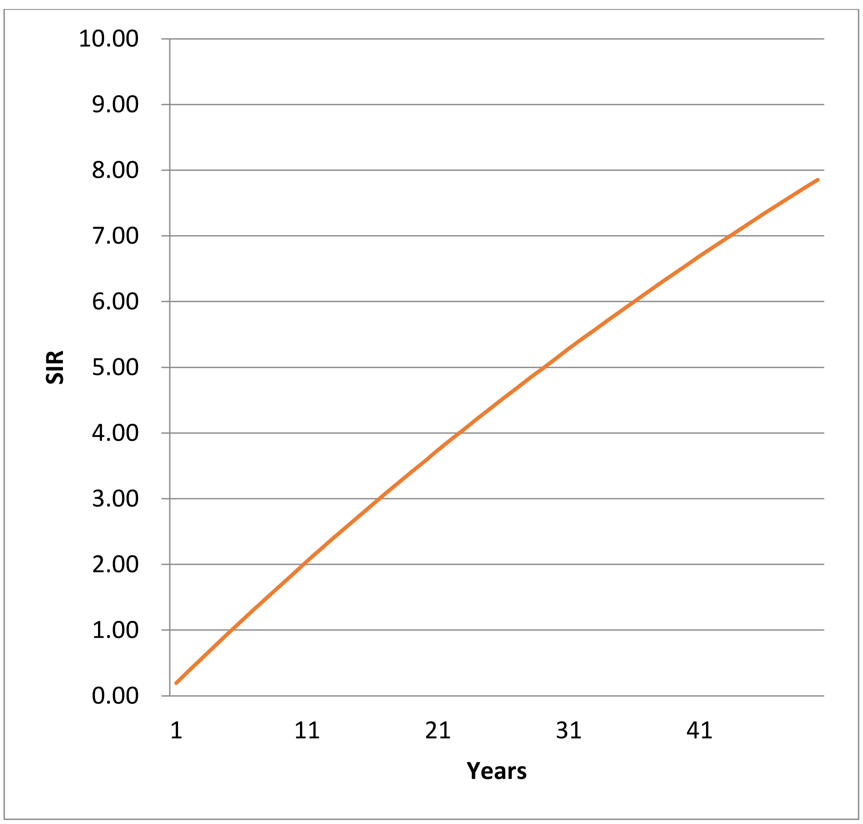
Years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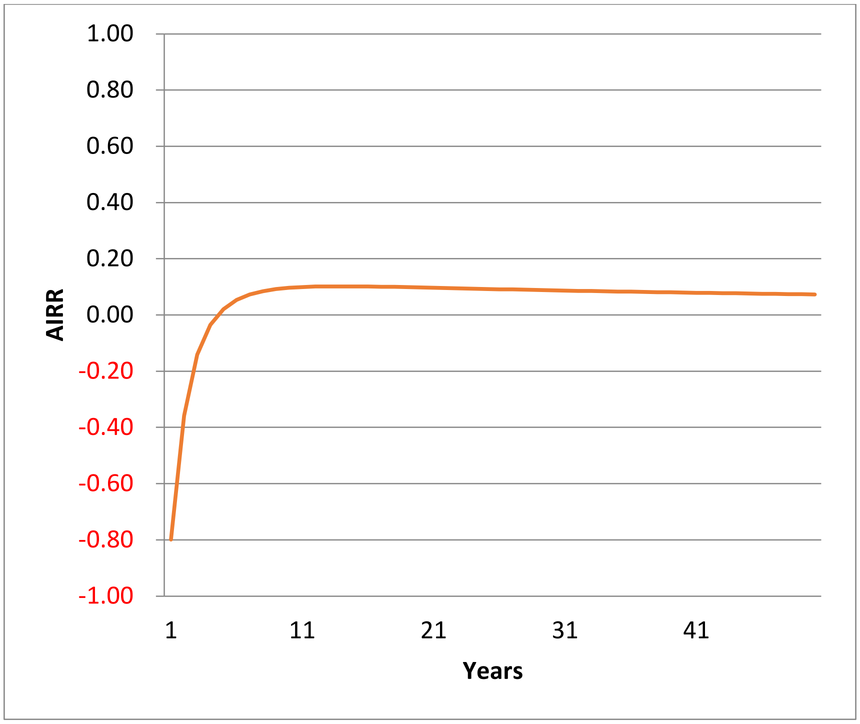


Figure 4.5 Net saving, SIR and AIRR in GBPAT for the WID building

As shown in Figure 4.4, the values of CEI decreased slightly over the 50-year life span while BPI and other three supplementary measures increased continuously. Therefore, CEI seems to be the indicator of green building performance regardless of the length of life cycle and it can show the B/C ratio in the initial stage of building project. Moreover, through analysis of AIRR as shown in Figure 4.5, the payback period can be analogized by determining the inflection point on the graph line of AIRR, which is between 5 and 8.

The other eight LEED projects were tested for the feasibility of cost effectiveness with the same procedure as the WID project. The integrated LCA and LCCA results analyzed by the supplementary measures and discounted payback period are summarized in Table 4.9.

Table 4.9 Life cycle costs Analysis of UW-Madison projects acquiring LEED Certification (20 years life span)

Name of LEED Projects	Net saving ($)	Net saving ($/$\mathrm{ft}^2$)	SIR	AIRR	DPP (less than)	BPI	CEI	Premium (%)
Wisconsin Energy Institute	3,592,939	33.57	4.20	0.11	5	6.20	10.15	2.62
UW-Medical Foundation Centennial Building	1,638,904.95	12.61	3.35	0.11	5	3.47	12.56	1.63
Lakeshore Residence Hall	833,610.53	12.98	3.38	0.09	6	5.30	3.72	3.49
Wisconsin Institute for Discovery	4,191,499.50	12.79	3.30	0.09	6	2.42	16.33	1.26
Wisconsin Institutes for Medical Research	4,857,297.98	18.32	3.58	0.10	6	2.62	15.08	1.21
Education Building	135,774.01	1.35	1.10	0.06	12	2.82	4.21	5.82
Union South	1,423,575.58	5.15	1.50	0.08	13	1.75	11.04	4.64
School of Human Ecology	2,033,313.18	10.08	7.34	0.14	3	4.30	7.75	0.91
School of Nursing	2,052,554.85	12.32	3.45	0.18	6	3.84	15.08	2.14

For the 20-year life span, all LEED-certified buildings are shown to be cost effective through the analysis of the supplementary measures and indexes provided by this research. The detailed summaries of total LCC for all LEED projects are attached in Appendix 4.1.

All nine LEED-certified buildings resulted in positive net savings and other indexes within 30 years of life span while two projects (Education Building and Union South) performed comparably lower net savings and values on the supplementary measures.

In terms of payback period, the expected DPP of Lakeshore Residence Hall, Education Building and Union South exceeded the average DPP presented by MHTN Architects and American Chemistry Council (2004) while DPP of the other buildings are within the average. For Lakeshore Residence Hall, longer DPP might be affected largely by relatively higher incremental investment (3.49%) that is out of the range of the cost premium (0 ~ 3.3%) even though it has relatively higher net savings ($12.98/ft^2). On the other hand, Education Building and Union South showed relatively lower performance in the net savings and all supplementary measures along with two indexes. Thus, their incremental investment would be shown as the excessive investment although they comparably achieved more points on the credits of EA and WE. Moreover, the correlation between DPP and the incremental investments was significant considering the higher t-value of 4.917, R^2 value of 0.0.742 and lower p-value of 0.0017 at the 95% significant interval as shown in Figure 4.6. Therefore, using the linear regression shown in Figure 4.6, the affordable incremental investment would be estimated.

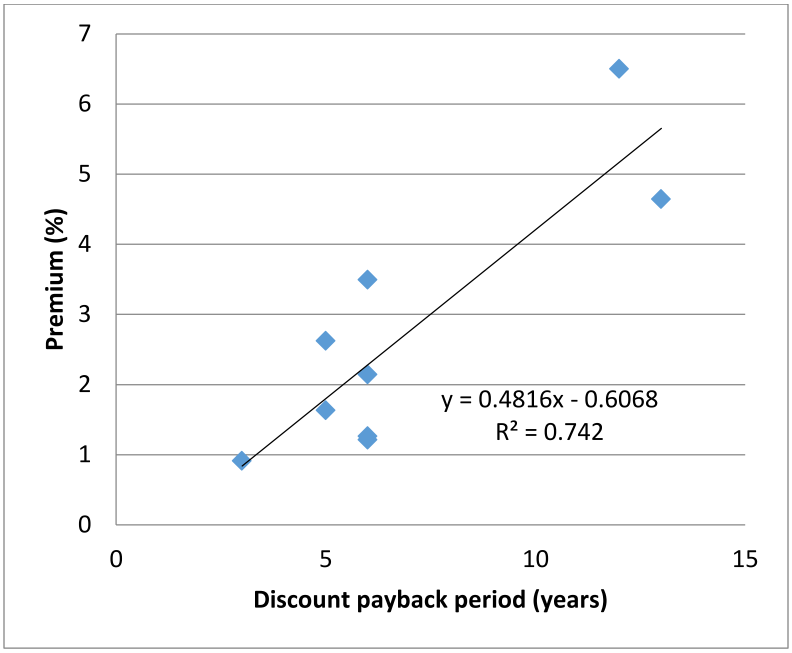


Figure 4.6 Correlation between cost premium and DPP

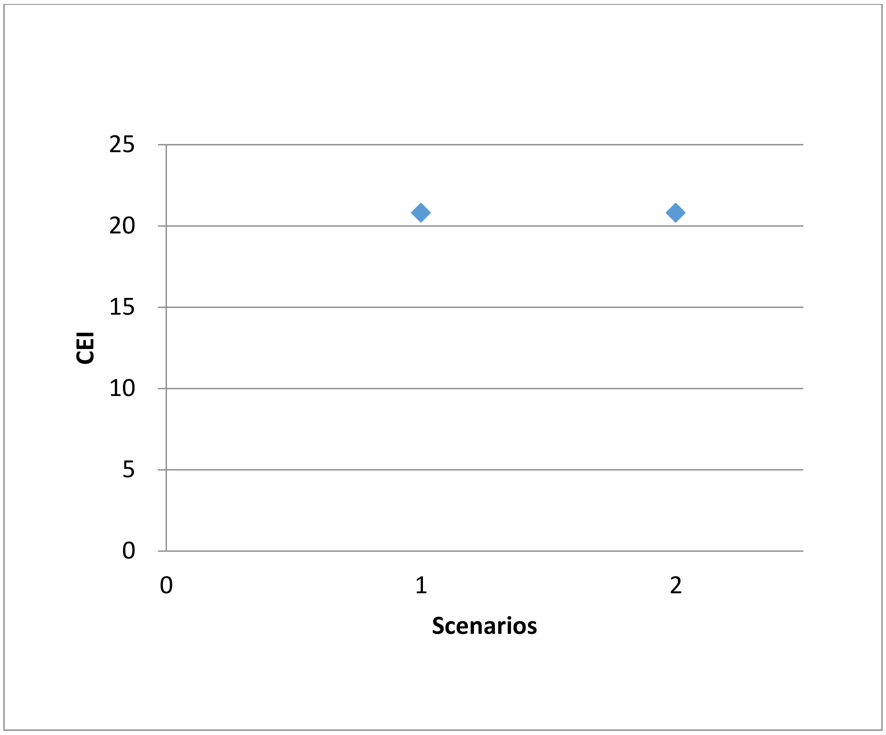
4.1.3 Sensitivity Analysis

The sensitivity analysis method was conducted to evaluate the effect of financial factors in the output of a LCCA. By controlling the general variables, such as discount rate, and escalation rate, the changes of the comparable indexes and the supplementary measures were investigated. Depending on the variables, total three scenarios were taken into account and the characteristics of the scenarios are summarized in Table 4.10.

Table 4.10 Summary of three scenarios for sensitivity analysis in GBPAT

# of Scenarios	Condition	Purpose
Scenario 1	Discount rate 3%, escalation rate 2%	Baseline
Scenario 2	Discount rate 3%, escalation rate 4%	Increased escalation rate
Scenario 3	Discount rate 5%, escalation rate 2%	Increased discount rate

Scenario 1 is the baseline for all sensitivity analysis when the total LCC is compared. Thus, each scenario from 2 to 8 was compared with Scenario 1. By comparing Scenarios 1 to 3 under the condition of adjusted discount rate, the impact of the discount rate to total LCC can be analyzed. Finally, the results of this sensitivity analysis showed that higher discount rate lead to smaller total LCC and net savings, which means the impact of increased discount rate is negative, while CEI is steady maintained regardless changing discount rate. Figures 4.7 and 4.8 show the results of the sensitivity analysis for the impact of discount rate on total LCC.



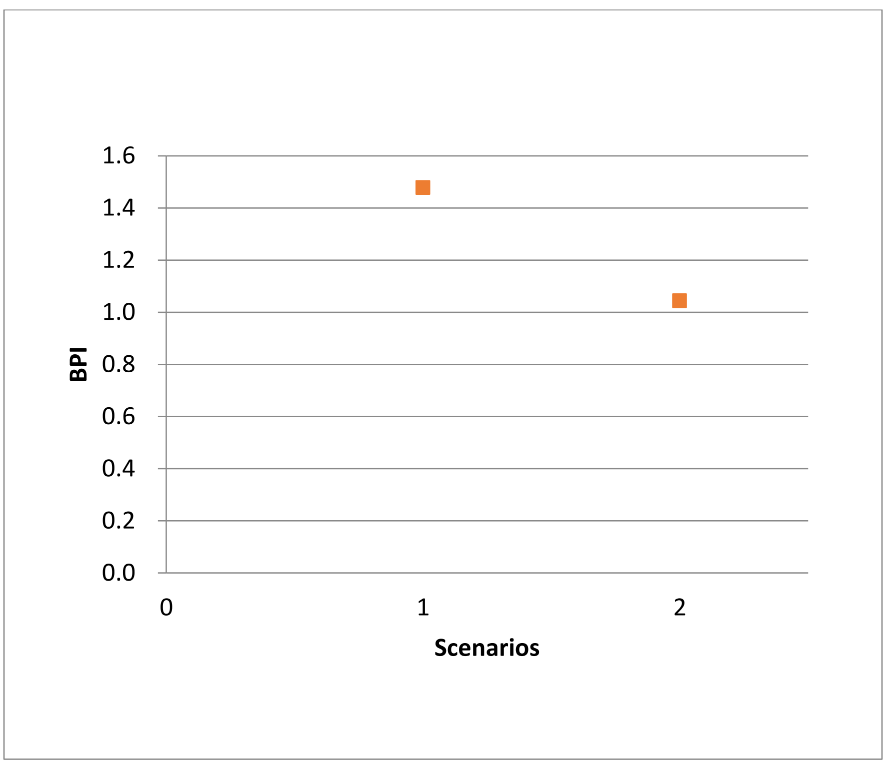
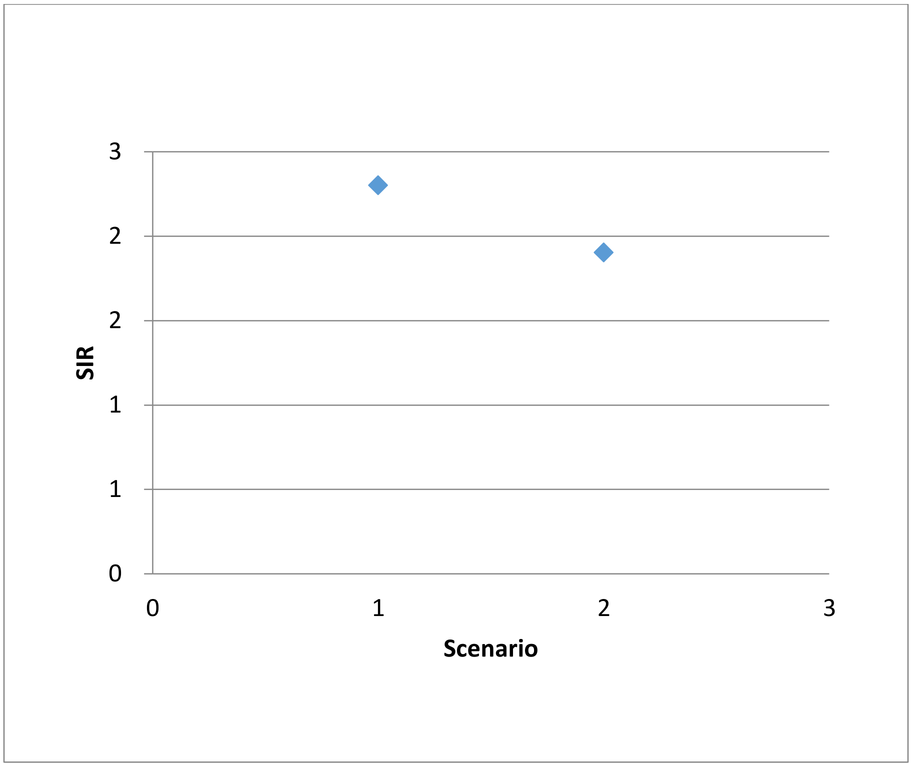


Figure 4.7 BPI and CEI on sensitivity analysis for impact of discount rate


SIR
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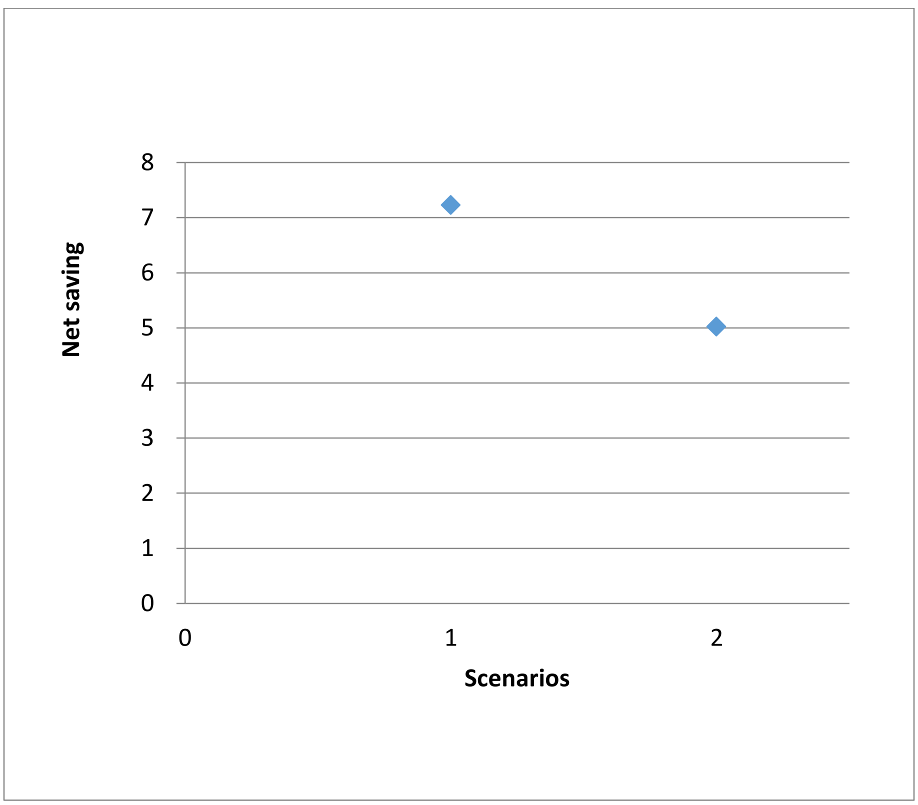
Scenario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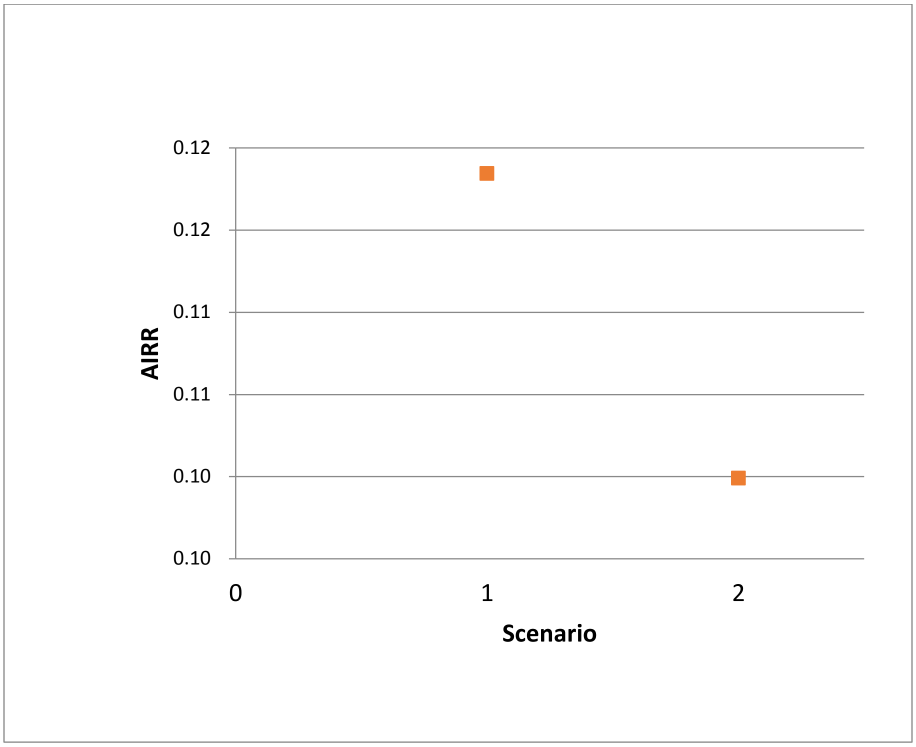

Figure 4.8 The supplementary measures on sensitivity analysis for impact of discount rate

Depending on other variables for sensitivity analysis, two indexes and three supplementary measures are responded with different sensitivity. Table 4.11 summarizes the correlation of sensitivity depending on variable in GBPAT.

Table 4.11 the correlation of sensitivity depending on variable in GBPAT

Variables	Net savings	SIR	AIRR	BPI	CEI
Discount rate	Inverse	Inverse	Inverse	Inverse	Steady
Escalation rate	Proportional	Proportional	Proportional	Proportional	Steady

Comparing the detailed analysis of the sensitivity by two factors such as discount rate and escalation rate to total LCC, the variations of total LCC depending on Scenarios 2 and 3 were investigated for all LEED projects as shown in Table 4.12. Although the total LCC for all LEED projects are sensitive by the changes of discount rate and escalation rate, the escalation rate (Scenario 2) impacts a few more than the discount rate (Scenario 3) in average 0.2%. According to life cycle costing manual (1995), a uniform present value (UPV) transferring future cost to present costs consists of the combination of the discount rate and escalation rate as follows:

$$\text{Present cost} = \text{A} \sum_{t=1}^{n} \left(\frac{1+e}{1+d}\right)^{t} \qquad (4.1)$$

where A = annual recurring cost;

t = life span;

d = discount rate; and

e = escalation rate.

As shown in Equation 4.1, the escalation rate is placed in the numerator while the discount rate is in the denominator. Since increasing the numerator is more effective than increasing the denominator in terms of increasing the overall UPV value, it implies that changing the escalation rate is more sensitive than the discount rate to impact to total LCCs.

Table 4.12 Variations depending on scenarios

	Variation by Scenario 2	Variation by Scenario 3
WEI	0.0167	0.0143
UW-MFC	0.0106	0.0091
Lakeshore	0.0131	0.0117
WID	0.0090	0.0076
WIMR	0.0081	0.0066
Education B/D	0.0107	0.0090
South union	0.0077	0.0062
School of H/E	0.0107	0.0092
School of Nursing	0.0115	0.0098

4.2 Analysis of Cost-Effectiveness Indexes

4.2.1 Evaluation of Indexes and Supplementary Measures

In order to determine the appropriate index representing the cost effectiveness for LEED-certified buildings, the statistical analyses of the correlation coefficient and p-values in the mutual relationship of initial incremental investments, net saving, SIR, AIRR, BPI and CEI were performed and summarized in Table 4.13.

Table 4.13 Summary of Statistical Analysis for Life Cycle Costs Analysis

	Correlation coefficient	P - value
Premium vs SIR	-0.7449699	0.02127
Premium vs AIRR	-0.5934998	0.09203
Premium vs BPI	-0.4679264	0.204
Premium vs CEI	-0.8280916	0.005837
CEI vs SIR	0.6536856	0.05619
BPI vs SIR	0.619586	0.07514
Net savings vs SIR	0.3698321	0.3273
CEI vs BPI	0.4525073	0.2213
CEI vs Net savings	0.7284605	0.02602
Net savings vs BPI	0.7579049	0.01797

First, SIR and CEI values with the higher correlation coefficient (-0.74496699 and -0.8280916) and lower p-values (0.02127 and 0.005837) at a significant level of 95%, were most relative with the initial incremental investment as an initial cost while the others were not appropriate to represent the mutual relationship of the cost effectiveness as the higher p-values at the significant level of 95% were not able to reject the null hypothesis (R = 0). Comparing CEI with SIR, CEI values were more sensitive than SIR values in terms of net savings ($\$/ft^2$) while SIR values had a weak correlation with net savings ($\$/ft^2$). This means that CEI values were more appropriate to respond to both integrated LCA and LCCA, and the initial incremental investment. On the other hand, BPI is closely correlated with net savings on the integrated LCA and LCCA method but seems to be in short of representing the initial incremental investment. Thus, BPI may not be suitable as the index of the cost effectiveness. It can be concluded that CEI is more suitable index representing the net savings of the life cycle costs and cost effectiveness at once.

Table 4.14 SIR and CEI for WID and UW-MFC buildings at different life spans

Projects	Wisconsin Institute for Discovery (WID)		UW-Medical Foundation Centennial (UW-MFC)	
Life Span	SIR	CEI	SIR	CEI
20 years	3.30	16.63	3.89	11.05
25 years	4.04	16.61	4.75	11.04
30 years	4.74	16.59	5.59	11.04
50 years	7.27	16.51	8.57	11

As the advantage of CEI, it is possible that CEI shows the cost effectiveness as comparing the LCC of the projects which are analyzed in different life span which means the cost effectiveness of the projects can be compared regardless the life span. Table 4.14 shows the comparison of SIR and CEI as a cost effectiveness index for WID and UW-Medical Foundation Centennial (UW-

MFC) buildings for 20, 25, 30, and 50 years of life span.

For example, for UW-MFC, the SIR value was lower at 20-year life span of WID (3.30) than at 30-year life span (5.59) even though the SIR value was slightly higher for WID than UW-MFC at the same life span. However, the CEI value was constant in terms of the cost effectiveness regardless of life span. For WID, the CEI value was higher at 20 year life span (16.63) than for UW-FMCE at 30-year life span (11.04). Therefore, CEI appears to be very helpful in comparing the cost effectiveness for alternative design incorporating the sustainable items with different life span or whole LCC analyzed in a different life span. In addition, with the results of the correlation between the incremental investment and CEI for nine LEED projects, the regression analysis was tested as shown in Figure 4.9.

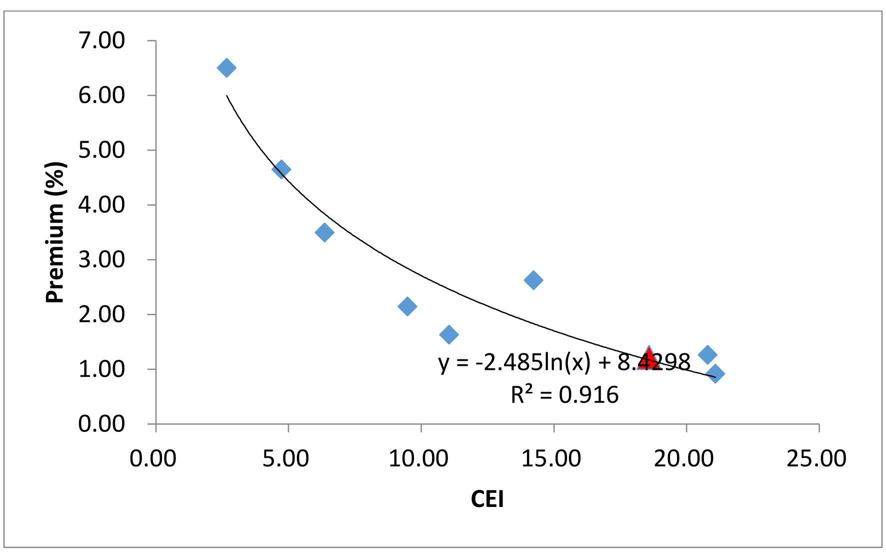

Figure 4.9 Correlation between the incremental investment and CEI with the trendline

The logarithmic function for this regression analysis follows below:

$$y = -2.485\ln(x) + 8.4298 \quad (4\text{-}2)$$

where x = CEI and

y = incremental investment (%).

As shown in Figure 4.9, the projects with higher incremental investment show lower level of CEI as CEI is very sensitive to initial investment. Using this regression analysis, it is possible to determine the correlation of the cost effectiveness between incremental investment and building performance. It is also helpful to evaluate the appropriate incremental investments depending on the level of LEED, building size, the purpose of building, etc.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Although there are several studies regarding the building performance on LEED certification system, the detailed comparison between the earned points in LEED and the incremental investment for improved building performance has not been studied extensively. Using the extensive data obtained for nine LEED-certified buildings constructed at the University of Wisconsin-Madison from 2008 to 2013, the relationship between the LEED points and the incremental investment cost was investigated using statistical methods and supplementary measures such as net saving, Saving Investment Ratio (SIR), and Adjusted Internal Rate of Return (AIRR).

The correlation between the earned points on EA and WE credits in LEED Certification system and the initial incremental investment was found to be weak, implying that higher initial incremental investments for improved energy and water reduction does not always guarantee better performance for energy and water usages. It was also found that the relatively higher correlation coefficient for energy-related points versus the initial incremental investment indicates that the sustainable items that increase the initial construction costs are mainly related to energy savings. In the analysis of LCC, all nine LEED-certified buildings resulted in positive net savings and other indexes within 50 years of life span while the expected discounted payback periods of Lakeshore Residence Hall, Education Building and Union South exceeded the average DPP for LEED-certified buildings depending on the level of system. It is possible to determine the reasonable incremental investment by analyzing the correlation between DPP and cost premium.

In addition, CEI was found to be a more reliable index for the evaluation of the cost effectiveness than other supplementary measures. CEI appears to be most suitable in comparing the cost effectiveness for alternative design incorporating the sustainable items with different life span or whole LCC analyzed in a different life span. However, CEI would be adopted with other supplementary measures and BPI in order to fully assess the practical benefits of LEED-certified buildings. If more data can be obtained and analyzed to determine the relationship between CEI and the incremental investment, the range of the appropriate incremental investments can be provided depending on the purposed of buildings, size, location, and the level of LEED.

5.2 Recommendation and Future Research

Nine buildings evaluated in this study are educational buildings. Thus, the study results may not be the same for commercial buildings. Thus, it is recommended that more buildings should be investigated because the educational buildings have specific characteristics and it is difficult to gather the essential data, such as a real energy and water consumption and a maintenance cost since the usages bill of the institutional buildings are generally estimated in the sum of the total bills for the whole buildings on a campus, not each building.

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Appendixes

Appendix 4.1 The detailed summaries of total LCC for all LEED projects

Project 1. Wisconsin Energy Institute

Total LCC for baseline and proposed buildings (20, 25, 30, and 50 years)

Categories	**Baseline building**			
Life span	**20years**	25years	30years	50years
Construction cost	**$42,809,242.00**	$42,809,242.00	$42,809,242.00	$42,809,242.00
Maintenance cost	**$4,287,106.65**	$5,270,594.27	$6,221,113.57	$9,715,062.54
Energy costs	**$9,888,358.63**	$12,073,378.43	$14,154,369.00	$21,533,625.74
Water costs	**$15,837.61**	$19,381.37	$22,772.98	$34,944.51
CO_2 costs	**$894,481.41**	$1,092,133.99	$1,280,376.30	$1,947,889.30
Water disposal costs	**$20,016.66**	$24,495.50	$28,782.05	$44,165.27
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$57,915,042.97**	**$61,289,225.56**	**$64,516,655.90**	**$76,084,929.37**

Categories	**Proposed building**			
Life span	**20years**	25years	30years	50 years
Construction cost	**$43,932,848.00**	$43,932,848.00	$43,932,848.00	$43,932,848.00
Maintenance cost	**$3,729,782.78**	$4,585,417.01	$5,412,368.81	$8,452,104.41
Energy costs	**$6,212,545.18**	$7,585,324.49	$8,892,745.51	$13,528,900.77
Water costs	**$10,608.45**	$12,982.15	$15,253.94	$23,406.75
CO_2 costs	**$422,911.61**	$516,361.93	$605,363.06	$920,963.80
Water disposal costs	**$13,407.68**	$16,407.73	$19,278.97	$29,583.05
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$54,322,103.70**	**$56,649,341.31**	**$58,877,858.29**	**$66,887,806.79**

Supplementary measures and indexes

Years	**Net saving**	S/F	**Net savings**	**SIR**	AIRR	**BPI**	**CEI**
1	(866,107)	107018	($8.09)	0.22917	-0.76	(1.99)	**11.95**
2	(611,021)	107018	($5.71)	0.46	-0.30	(1.37)	**11.95**
3	(358,325)	107018	($3.35)	0.68	-0.09	(0.79)	**11.94**
4	(107,996)	107018	($1.01)	0.90	0.00	(0.23)	**11.94**
5	139,987	107018	$1.31	1.12	0.05	0.30	**11.94**
6	385,648	107018	$3.60	1.34	0.08	0.81	**11.93**
7	629,008	107018	$5.88	1.56	0.10	1.30	**11.93**
8	870,089	107018	$8.13	1.77	0.11	1.77	**11.93**
9	1,108,913	107018	$10.36	1.99	0.11	2.22	**11.93**
10	1,345,500	107018	$12.57	2.20	0.11	2.65	**11.92**
11	1,579,873	107018	$14.76	2.41	0.12	3.07	**11.92**
12	1,812,051	107018	$16.93	2.61	0.12	3.47	**11.92**
13	2,042,056	107018	$19.08	2.82	0.12	3.86	**11.92**
14	2,269,908	107018	$21.21	3.02	0.11	4.23	**11.91**

15	2,495,628	107018	$23.32	3.22	0.11	4.59	**11.91**
16	2,719,235	107018	$25.41	3.42	0.11	4.93	**11.91**
17	2,940,750	107018	$27.48	3.62	0.11	5.27	**11.90**
18	3,160,193	107018	$29.53	3.81	0.11	5.59	**11.90**
19	3,377,583	107018	$31.56	4.01	0.11	5.90	**11.90**
20	3,592,939	107018	$33.57	4.20	0.11	6.20	**11.90**
21	3,806,281	107018	$35.57	4.39	0.11	6.50	**11.89**
22	4,017,628	107018	$37.54	4.58	0.10	6.78	**11.89**
23	4,226,998	107018	$39.50	4.76	0.10	7.05	**11.89**
24	4,434,411	107018	$41.44	4.95	0.10	7.31	**11.89**
25	4,639,884	107018	$43.36	5.13	0.10	7.57	**11.88**
26	4,843,437	107018	$45.26	5.31	0.10	7.82	**11.88**
27	5,045,086	107018	$47.14	5.49	0.10	8.06	**11.88**
28	5,244,851	107018	$49.01	5.67	0.10	8.29	**11.87**
29	5,442,749	107018	$50.86	5.84	0.09	8.52	**11.87**
30	5,638,798	107018	$52.69	6.02	0.09	8.74	**11.87**

31	5,833,014	107018	$54.50	6.19	0.09	8.95	**11.87**
32	6,025,416	107018	$56.30	6.36	0.09	9.16	**11.86**
33	6,216,021	107018	$58.08	6.53	0.09	9.36	**11.86**
34	6,404,845	107018	$59.85	6.70	0.09	9.56	**11.86**
35	6,591,905	107018	$61.60	6.87	0.09	9.75	**11.86**
36	6,777,219	107018	$63.33	7.03	0.09	9.94	**11.85**
37	6,960,801	107018	$65.04	7.20	0.09	10.12	**11.85**
38	7,142,670	107018	$66.74	7.36	0.09	10.29	**11.85**
39	7,322,841	107018	$68.43	7.52	0.08	10.46	**11.85**
40	7,501,329	107018	$70.09	7.68	0.08	10.63	**11.84**
41	7,678,151	107018	$71.75	7.83	0.08	10.79	**11.84**
42	7,853,323	107018	$73.38	7.99	0.08	10.95	**11.84**
43	8,026,861	107018	$75.00	8.14	0.08	11.11	**11.83**
44	8,198,778	107018	$76.61	8.30	0.08	11.26	**11.83**
45	8,369,092	107018	$78.20	8.45	0.08	11.40	**11.83**
46	8,537,817	107018	$79.78	8.60	0.08	11.55	**11.83**

47	8,704,967	107018	$81.34	8.75	0.08	11.69	**11.82**
48	8,870,559	107018	$82.89	8.89	0.08	11.82	**11.82**
49	9,034,606	107018	$84.42	9.04	0.08	11.96	**11.82**
50	9,197,123	107018	$85.94	9.19	0.08	12.09	**11.82**

Project 2. UW-Medical Foundation Centennial Building

Total LCC for baseline and proposed buildings (20, 25, 30, and 50 years)

Categories	**Baseline building**			
Life span	**20years**	25years	30years	50years
Construction cost	**$35,101,561.00**	$35,101,561.00	$35,101,561.00	$35,101,561.00
Maintenance cost	**$8,076,952.51**	$9,929,853.18	$11,720,641.22	$18,303,276.60
Energy costs	**$3,756,917.84**	$4,587,079.87	$5,377,717.72	$8,181,343.92
Water costs	**$26,811.79**	$32,811.08	$38,552.80	$59,158.22
CO2 costs	**$325,033.12**	$396,855.33	$465,258.07	$707,816.30
Water disposal costs	**$33,886.58**	$41,468.89	$48,725.68	$74,768.22
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$47,321,162.84**	**$50,089,629.36**	**$52,752,456.50**	**$62,427,924.26**

Categories	**Proposed building**			
Life span	**20years**	25years	30years	50 years
Construction cost	**$35,422,258.00**	$35,422,258.00	$35,422,258.00	$35,422,258.00
Maintenance cost	**$7,026,948.68**	$8,638,972.27	$10,196,957.86	$15,923,850.64
Energy costs	**$2,539,364.02**	$3,100,484.51	$3,634,889.94	$5,529,908.09
Water costs	**$16,473.11**	$20,662.10	$23,686.77	$36,346.69
CO2 costs	**$261,986.00**	$319,876.76	$375,011.33	$570,520.22
Water disposal costs	**$20,819.85**	$25,478.41	$29,936.96	$45,937.44
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$45,287,849.66**	**$47,527,732.05**	**$49,682,740.86**	**$57,528,821.08**

Supplementary measures and indexes

Years	Net saving	S/F	Net savings	SIR	AIRR	BPI	CEI
1	($193,318.70)	201623	($0.96)	0.40	-0.59	(0.54)	21.21
2	($67,012.83)	201623	($0.33)	0.79	-0.08	(0.18)	21.20
3	$58,229.91	201623	$0.29	1.18	0.09	0.16	21.19
4	$182,418.73	201623	$0.90	1.57	0.15	0.48	21.19
5	$305,562.75	201623	$1.52	1.95	0.18	0.80	21.18
6	$427,671.02	201623	$2.12	2.33	0.19	1.10	21.17
7	$548,752.51	201623	$2.72	2.71	0.19	1.39	21.17
8	$668,816.11	201623	$3.32	3.09	0.19	1.66	21.16
9	$787,870.63	201623	$3.91	3.46	0.18	1.93	21.16
10	$905,924.79	201623	$4.49	3.82	0.18	2.19	21.15
11	$1,022,987.25	201623	$5.07	4.19	0.17	2.43	21.14
12	$1,139,066.59	201623	$5.65	4.55	0.17	2.67	21.14
13	$1,254,171.30	201623	$6.22	4.91	0.16	2.90	21.13
14	$1,368,309.82	201623	$6.79	5.27	0.16	3.12	21.12
15	$1,481,490.48	201623	$7.35	5.62	0.16	3.33	21.12

16	$1,593,721.58	201623	$7.90	5.97	0.15	3.54	21.11
17	$1,705,011.30	201623	$8.46	6.32	0.15	3.74	21.10
18	$1,815,367.78	201623	$9.00	6.66	0.14	3.93	21.10
19	$1,924,799.08	201623	$9.55	7.00	0.14	4.12	21.09
20	$2,033,313.18	201623	$10.08	7.34	0.14	4.30	21.09
21	$2,140,918.00	201623	$10.62	7.68	0.13	4.47	21.08
22	$2,247,621.39	201623	$11.15	8.01	0.13	4.64	21.07
23	$2,353,431.11	201623	$11.67	8.34	0.13	4.80	21.07
24	$2,458,354.89	201623	$12.19	8.67	0.13	4.96	21.06
25	$2,562,400.35	201623	$12.71	8.99	0.12	5.12	21.05
26	$2,665,575.07	201623	$13.22	9.31	0.12	5.26	21.05
27	$2,767,886.55	201623	$13.73	9.63	0.12	5.41	21.04
28	$2,869,342.24	201623	$14.23	9.95	0.12	5.55	21.04
29	$2,969,949.50	201623	$14.73	10.26	0.12	5.69	21.03
30	$3,069,715.63	201623	$15.23	10.57	0.11	5.82	21.02
31	$3,168,647.89	201623	$15.72	10.88	0.11	5.95	21.02

32	$3,266,753.46	201623	$16.20	11.19	0.11	6.07	21.01
33	$3,364,039.44	201623	$16.68	11.49	0.11	6.20	21.01
34	$3,460,512.88	201623	$17.16	11.79	0.11	6.31	21.00
35	$3,556,180.79	201623	$17.64	12.09	0.11	6.43	20.99
36	$3,651,050.08	201623	$18.11	12.38	0.10	6.54	20.99
37	$3,745,127.62	201623	$18.57	12.68	0.10	6.65	20.98
38	$3,838,420.23	201623	$19.04	12.97	0.10	6.76	20.98
39	$3,930,934.64	201623	$19.50	13.26	0.10	6.86	20.97
40	$4,022,677.54	201623	$19.95	13.54	0.10	6.96	20.96
41	$4,113,655.56	201623	$20.40	13.83	0.10	7.06	20.96
42	$4,203,875.27	201623	$20.85	14.11	0.10	7.16	20.95
43	$4,293,343.18	201623	$21.29	14.39	0.10	7.25	20.95
44	$4,382,065.74	201623	$21.73	14.66	0.09	7.34	20.94
45	$4,470,049.36	201623	$22.17	14.94	0.09	7.43	20.94
46	$4,557,300.37	201623	$22.60	15.21	0.09	7.52	20.93
47	$4,643,825.05	201623	$23.03	15.48	0.09	7.60	20.92

48	$4,729,629.64	201623	$23.46	15.75	0.09	7.69	20.92
49	$4,814,720.31	201623	$23.88	16.01	0.09	7.77	20.91
50	$4,899,103.18	201623	$24.30	16.28	0.09	7.85	20.91

Project 3. Lakeshore Residence Hall

Total LCC for baseline and proposed buildings (20, 25, 30, and 50 years)

Categories	**Baseline building**			
Life span	**20years**	25years	30years	50years
Construction cost	**$10,028,756.00**	$10,028,756.00	$10,028,756.00	$10,028,756.00
Maintenance cost	**$2,572,191.88**	$3,162,267.91	$3,732,563.51	$5,828,874.12
Energy costs	**$1,857,575.81**	$2,268,042.30	$2,658,966.41	$4,045,195.34
Water costs	**$129,302.96**	$158,235.23	$185,925.36	$285,297.35
CO2 costs	**$985,577.50**	$1,203,359.48	$1,410,772.82	$2,146,266.92

Water disposal costs	**$163,421.96**	$199,988.54	$234,985.22	$360,578.37
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$15,736,826.11**	**$17,020,649.46**	**$18,251,969.32**	**$22,694,968.09**

Categories	**Proposed building**			
	20years	25years	30years	50 years
Construction cost	**$10,378,957.00**	$10,378,957.00	$10,378,957.00	$10,378,957.00
Maintenance cost	**$2,237,806.94**	$2,751,173.08	$3,247,330.25	$5,071,120.49
Energy costs	**$1,489,802.35**	$1,819,002.34	$2,132,529.06	$3,244,304.48
Water costs	**$96,276.66**	$117,819.11	$138,436.68	$212,427.28
CO2 costs	**$578,691.57**	$706,564.41	$828,349.21	$1,260,201.83
Water disposal costs	**$121,681.05**	$148,907.87	$174,965.78	$268,480.18
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00

Total costs	$14,903,215.57	$15,922,423.82	$16,900,567.98	$20,435,491.26

Supplementary measures and indexes

Years	**Net saving**	S/F	**Net savings**	**SIR**	AIRR	**BPI**	**CEI**
1	(285,891)	64209	($4.45)	0.18364	-0.81	(2.77)	**5.97**
2	(222,150)	64209	($3.46)	0.37	-0.38	(2.09)	**5.96**
3	(158,971)	64209	($2.48)	0.55	-0.16	(1.45)	**5.96**
4	(96,352)	64209	($1.50)	0.72	-0.05	(0.86)	**5.96**
5	(34,285)	64209	($0.53)	0.90	0.01	(0.30)	**5.96**
6	27,233	64209	$0.42	1.08	0.04	0.23	**5.96**

7	88,208	64209	$1.37	1.25	0.06	0.73	**5.96**
8	148,645	64209	$2.32	1.42	0.08	1.20	**5.96**
9	208,548	64209	$3.25	1.60	0.08	1.64	**5.95**
10	267,922	64209	$4.17	1.77	0.09	2.06	**5.95**
11	326,772	64209	$5.09	1.93	0.09	2.46	**5.95**
12	385,103	64209	$6.00	2.10	0.10	2.84	**5.95**
13	442,920	64209	$6.90	2.26	0.10	3.20	**5.95**
14	500,226	64209	$7.79	2.43	0.10	3.54	**5.95**
15	557,027	64209	$8.68	2.59	0.10	3.87	**5.95**
16	613,328	64209	$9.55	2.75	0.10	4.18	**5.94**
17	669,132	64209	$10.42	2.91	0.10	4.48	**5.94**
18	724,444	64209	$11.28	3.07	0.10	4.76	**5.94**
19	779,269	64209	$12.14	3.23	0.10	5.04	**5.94**
20	833,611	64209	$12.98	3.38	0.09	5.30	**5.94**
21	887,474	64209	$13.82	3.53	0.09	5.55	**5.94**
22	940,863	64209	$14.65	3.69	0.09	5.79	**5.94**

23	993,781	64209	$15.48	3.84	0.09	6.02	**5.94**
24	1,046,234	64209	$16.29	3.99	0.09	6.24	**5.93**
25	1,098,226	64209	$17.10	4.14	0.09	6.45	**5.93**
26	1,149,759	64209	$17.91	4.28	0.09	6.66	**5.93**
27	1,200,840	64209	$18.70	4.43	0.09	6.85	**5.93**
28	1,251,471	64209	$19.49	4.57	0.09	7.04	**5.93**
29	1,301,657	64209	$20.27	4.72	0.09	7.23	**5.93**
30	1,351,401	64209	$21.05	4.86	0.09	7.40	**5.93**
31	1,400,709	64209	$21.81	5.00	0.08	7.57	**5.92**
32	1,449,582	64209	$22.58	5.14	0.08	7.74	**5.92**
33	1,498,027	64209	$23.33	5.28	0.08	7.90	**5.92**
34	1,546,046	64209	$24.08	5.41	0.08	8.05	**5.92**
35	1,593,643	64209	$24.82	5.55	0.08	8.20	**5.92**
36	1,640,822	64209	$25.55	5.69	0.08	8.34	**5.92**
37	1,687,586	64209	$26.28	5.82	0.08	8.48	**5.92**
38	1,733,941	64209	$27.00	5.95	0.08	8.62	**5.92**

39	1,779,888	64209	$27.72	6.08	0.08	8.75	**5.91**
40	1,825,432	64209	$28.43	6.21	0.08	8.88	**5.91**
41	1,870,577	64209	$29.13	6.34	0.08	9.00	**5.91**
42	1,915,325	64209	$29.83	6.47	0.08	9.12	**5.91**
43	1,959,681	64209	$30.52	6.60	0.08	9.23	**5.91**
44	2,003,648	64209	$31.21	6.72	0.08	9.35	**5.91**
45	2,047,230	64209	$31.88	6.85	0.07	9.45	**5.91**
46	2,090,430	64209	$32.56	6.97	0.07	9.56	**5.91**
47	2,133,251	64209	$33.22	7.09	0.07	9.66	**5.90**
48	2,175,697	64209	$33.88	7.21	0.07	9.76	**5.90**
49	2,217,771	64209	$34.54	7.33	0.07	9.86	**5.90**
50	2,259,477	64209	$35.19	7.45	0.07	9.96	**5.90**

Project 4. Wisconsin Institutes for Medical Research

Total LCC for baseline and proposed buildings (20, 25, 30, and 50 years)

Categories	**Baseline building**			
Life span	**20years**	25years	30years	50years
Construction cost	**$155,179,773.42**	$155,179,773.42	$155,179,773.42	$155,179,773.42
Maintenance cost	**$10,620,541.78**	$13,056,956.88	$15,411,698.86	$24,067,334.01
Energy costs	**$17,250,482.77**	$21,062,303.09	$24,692,641.88	$37,565,935.22
Water costs	**$31,643.85**	$38,724.34	$45,500.84	$69,819.79
CO2 costs	**$1,925,976.88**	$2,351,557.89	$2,756,876.90	$4,194,150.61
Water disposal costs	**$39,993.67**	$48,942.47	$57,507.09	$88,243.04
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$185,048,412.37**	**$191,738,258.09**	**$198,143,998.99**	**$221,165,256.09**

Categories	**Proposed building**			
Life span	**20years**	25years	30years	50 years
Construction cost	**$157,064,548.00**	$157,064,548.00	$157,064,548.00	$157,064,548.00
Maintenance cost	**$9,239,871.35**	$11,359,552.48	$13,408,178.01	$20,938,580.59
Energy costs	**$12,594,448.00**	$15,377,429.41	$18,027,912.51	$27,426,607.36
Water costs	**$21,148.19**	$25,880.22	$30,409.09	$46,661.91
CO2 costs	**$1,244,370.31**	$1,519,337.46	$1,781,213.37	$2,709,833.41
Water disposal costs	**$26,728.53**	$32,709.19	$38,433.09	$58,974.52
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$180,191,114.38**	**$185,379,456.76**	**$190,350,694.06**	**$208,245,205.78**

Supplementary measures and indexes

Years	**Net saving**	S/F	**Net savings**	**SIR**	AIRR	**BPI**	**CEI**
1	(1,517,551)	265118	($5.72)	0.19	-0.80	(0.97)	**18.66**

2	(1,153,676)	265118	($4.35)	0.39	-0.36	(0.73)	**18.66**
3	(793,121)	265118	($2.99)	0.58	-0.14	(0.50)	**18.65**
4	(435,853)	265118	($1.64)	0.77	-0.04	(0.27)	**18.65**
5	(81,842)	265118	($0.31)	0.96	0.02	(0.05)	**18.64**
6	268,941	265118	$1.01	1.14	0.05	0.16	**18.64**
7	616,527	265118	$2.33	1.33	0.07	0.37	**18.64**
8	960,945	265118	$3.62	1.51	0.08	0.57	**18.63**
9	1,302,225	265118	$4.91	1.69	0.09	0.77	**18.63**
10	1,640,396	265118	$6.19	1.87	0.10	0.96	**18.62**
11	1,975,486	265118	$7.45	2.05	0.10	1.15	**18.62**
12	2,307,525	265118	$8.70	2.22	0.10	1.33	**18.62**
13	2,636,539	265118	$9.94	2.40	0.10	1.51	**18.61**
14	2,962,558	265118	$11.17	2.57	0.10	1.68	**18.61**
15	3,285,609	265118	$12.39	2.74	0.10	1.85	**18.60**
16	3,605,720	265118	$13.60	2.91	0.10	2.01	**18.60**
17	3,922,917	265118	$14.80	3.08	0.10	2.17	**18.60**

18	4,237,228	265118	$15.98	3.25	0.10	2.32	**18.59**
19	4,548,680	265118	$17.16	3.41	0.10	2.48	**18.59**
20	4,857,298	265118	$18.32	3.58	0.10	2.62	**18.58**
21	5,163,109	265118	$19.47	3.74	0.10	2.77	**18.58**
22	5,466,140	265118	$20.62	3.90	0.10	2.91	**18.58**
23	5,766,415	265118	$21.75	4.06	0.09	3.05	**18.57**
24	6,063,960	265118	$22.87	4.22	0.09	3.18	**18.57**
25	6,358,801	265118	$23.98	4.37	0.09	3.32	**18.57**
26	6,650,963	265118	$25.09	4.53	0.09	3.45	**18.56**
27	6,940,469	265118	$26.18	4.68	0.09	3.57	**18.56**
28	7,227,346	265118	$27.26	4.83	0.09	3.69	**18.55**
29	7,511,616	265118	$28.33	4.99	0.09	3.82	**18.55**
30	7,793,305	265118	$29.40	5.13	0.09	3.93	**18.55**
31	8,072,436	265118	$30.45	5.28	0.09	4.05	**18.54**
32	8,349,032	265118	$31.49	5.43	0.09	4.16	**18.54**
33	8,623,117	265118	$32.53	5.58	0.09	4.27	**18.54**

34	8,894,715	265118	$33.55	5.72	0.08	4.38	**18.53**
35	9,163,848	265118	$34.57	5.86	0.08	4.49	**18.53**
36	9,430,539	265118	$35.57	6.00	0.08	4.59	**18.52**
37	9,694,810	265118	$36.57	6.14	0.08	4.69	**18.52**
38	9,956,685	265118	$37.56	6.28	0.08	4.79	**18.52**
39	10,216,184	265118	$38.53	6.42	0.08	4.89	**18.51**
40	10,473,330	265118	$39.50	6.56	0.08	4.98	**18.51**
41	10,728,145	265118	$40.47	6.69	0.08	5.08	**18.51**
42	10,980,650	265118	$41.42	6.83	0.08	5.17	**18.50**
43	11,230,866	265118	$42.36	6.96	0.08	5.26	**18.50**
44	11,478,815	265118	$43.30	7.09	0.08	5.35	**18.49**
45	11,724,518	265118	$44.22	7.22	0.08	5.43	**18.49**
46	11,967,994	265118	$45.14	7.35	0.08	5.52	**18.49**
47	12,209,266	265118	$46.05	7.48	0.08	5.60	**18.48**
48	12,448,352	265118	$46.95	7.60	0.07	5.68	**18.48**
49	12,685,274	265118	$47.85	7.73	0.07	5.76	**18.48**

50	12,920,050	265118	$48.73	7.85	0.07	5.84	**18.47**

Project 5. Education building

Total LCC for baseline and proposed buildings (20, 25, 30, and 50 years)

Categories	**Baseline building**			
Life span	**20years**	25years	30years	50years
Construction cost	**$20,679,847.02**	$20,679,847.02	$20,679,847.02	$20,679,847.02
Maintenance cost	**$4,019,788.41**	$4,941,951.65	$5,833,202.28	$9,109,289.57
Energy costs	**$3,978,611.80**	$4,857,761.30	$5,695,054.31	$8,664,121.17
Water costs	**$20,799.06**	$25,452.97	$29,907.07	$45,891.58
CO2 costs	**$188,781.92**	$230,496.86	$270,225.73	$411,105.56
Water disposal costs	**$24,285.62**	$29,719.66	$34,920.40	$53,584.40
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$28,912,113.83**	**$30,765,229.45**	**$32,543,156.82**	**$38,963,839.31**

Categories	**Proposed building**			
Life span	**20years**	25years	30years	50 years
Construction cost	**$21,883,436.00**	$21,883,436.00	$21,883,436.00	$21,883,436.00
Maintenance cost	**$3,497,215.92**	$4,299,497.94	$5,074,885.98	$7,925,081.92
Energy costs	**$2,536,669.92**	$3,097,195.09	$3,631,033.56	$5,524,041.21
Water costs	**$11,417.09**	$13,971.73	$16,416.69	$25,190.96
CO2 costs	**$153,072.06**	$186,896.23	$219,110.02	$333,341.11
Water disposal costs	**$14,419.58**	$17,646.05	$20,733.99	$31,815.74
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$28,096,230.57**	**$29,498,643.03**	**$30,845,616.24**	**$35,722,906.95**

Supplementary measures and indexes

Years	**Net saving**	S/F	**Net savings**	**SIR**	AIRR	**BPI**	**CEI**
1	(1,093,759)	100345	($10.90)	0.09125	-0.91	(5.18)	**4.24**

2	(984,913)	100345	($9.82)	0.18	-0.56	(4.57)	**4.24**
3	(877,042)	100345	($8.74)	0.27	-0.33	(3.99)	**4.24**
4	(770,138)	100345	($7.67)	0.36	-0.20	(3.43)	**4.24**
5	(664,191)	100345	($6.62)	0.45	-0.12	(2.90)	**4.24**
6	(559,192)	100345	($5.57)	0.54	-0.07	(2.40)	**4.23**
7	(455,134)	100345	($4.54)	0.62	-0.04	(1.92)	**4.23**
8	(352,007)	100345	($3.51)	0.71	-0.01	(1.46)	**4.23**
9	(249,803)	100345	($2.49)	0.79	0.00	(1.02)	**4.23**
10	(148,513)	100345	($1.48)	0.88	0.02	(0.59)	**4.23**
11	(48,130)	100345	($0.48)	0.96	0.03	(0.19)	**4.23**
12	51,356	100345	$0.51	1.04	0.03	0.20	**4.23**
13	149,951	100345	$1.49	1.12	0.04	0.57	**4.22**
14	247,666	100345	$2.47	1.21	0.04	0.93	**4.22**
15	344,506	100345	$3.43	1.29	0.05	1.28	**4.22**
16	440,481	100345	$4.39	1.37	0.05	1.61	**4.22**
17	535,599	100345	$5.34	1.45	0.05	1.93	**4.22**

18	629,867	100345	$6.28	1.52	0.05	2.24	**4.22**
19	723,292	100345	$7.21	1.60	0.06	2.54	**4.22**
20	815,883	100345	$8.13	1.68	0.06	2.82	**4.21**
21	907,648	100345	$9.05	1.75	0.06	3.10	**4.21**
22	998,593	100345	$9.95	1.83	0.06	3.37	**4.21**
23	1,088,726	100345	$10.85	1.90	0.06	3.63	**4.21**
24	1,178,055	100345	$11.74	1.98	0.06	3.88	**4.21**
25	1,266,586	100345	$12.62	2.05	0.06	4.12	**4.21**
26	1,354,328	100345	$13.50	2.13	0.06	4.35	**4.21**
27	1,441,288	100345	$14.36	2.20	0.06	4.58	**4.21**
28	1,527,471	100345	$15.22	2.27	0.06	4.80	**4.20**
29	1,612,887	100345	$16.07	2.34	0.06	5.01	**4.20**
30	1,697,541	100345	$16.92	2.41	0.06	5.22	**4.20**
31	1,781,440	100345	$17.75	2.48	0.06	5.42	**4.20**
32	1,864,592	100345	$18.58	2.55	0.06	5.61	**4.20**
33	1,947,002	100345	$19.40	2.62	0.06	5.80	**4.20**

34	2,028,679	100345	$20.22	2.69	0.06	5.98	**4.20**
35	2,109,629	100345	$21.02	2.75	0.06	6.16	**4.20**
36	2,189,857	100345	$21.82	2.82	0.06	6.33	**4.19**
37	2,269,371	100345	$22.62	2.89	0.06	6.50	**4.19**
38	2,348,178	100345	$23.40	2.95	0.06	6.66	**4.19**
39	2,426,283	100345	$24.18	3.02	0.06	6.82	**4.19**
40	2,503,693	100345	$24.95	3.08	0.06	6.98	**4.19**
41	2,580,414	100345	$25.72	3.14	0.06	7.13	**4.19**
42	2,656,454	100345	$26.47	3.21	0.06	7.27	**4.19**
43	2,731,816	100345	$27.22	3.27	0.06	7.42	**4.19**
44	2,806,509	100345	$27.97	3.33	0.06	7.56	**4.18**
45	2,880,538	100345	$28.71	3.39	0.06	7.69	**4.18**
46	2,953,909	100345	$29.44	3.45	0.06	7.82	**4.18**
47	3,026,628	100345	$30.16	3.51	0.06	7.95	**4.18**
48	3,098,701	100345	$30.88	3.57	0.06	8.08	**4.18**
49	3,170,134	100345	$31.59	3.63	0.06	8.20	**4.18**

50	3,240,932	100345	$32.30	3.69	0.06	8.32	**4.18**

Project 6. Union south

Total LCC for baseline and proposed buildings (20, 25, 30, and 50 years)

Categories	**Baseline building**			
Life span	**20years**	25years	30years	50years
Construction cost	**$61,704,420.00**	$61,704,420.00	$61,704,420.00	$61,704,420.00
Maintenance cost	**$11,083,070.82**	$13,625,592.82	$16,082,884.81	$25,115,476.49
Energy costs	**$8,668,918.86**	$10,584,480.39	$12,408,841.65	$18,878,082.94
Water costs	**$42,107.93**	$51,529.81	$60,547.19	$92,908.01
CO2 costs	**$857,250.81**	$1,046,676.59	$1,227,083.76	$1,866,813.17
Water disposal costs	**$53,218.89**	$65,126.91	$76,523.70	$117,423.51
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00

Total costs	**$82,408,987.32**	**$87,077,826.53**	**$91,560,301.11**	**$107,775,124.12**

Categories	**Proposed building**			
Life span	**20years**	25years	30years	50 years
Construction cost	**$64,570,564.00**	$64,570,564.00	$64,570,564.00	$64,570,564.00
Maintenance cost	**$9,642,271.62**	$11,854,265.75	$13,992,109.78	$21,850,464.55
Energy costs	**$5,933,934.03**	$7,245,148.94	$8,493,936.65	$12,922,176.39
Water costs	**$28,685.07**	$35,103.52	$41,246.41	$63,291.48
CO2 costs	**$610,389.63**	$745,266.76	$873,722.36	$1,329,229.89
Water disposal costs	**$36,254.16**	$44,366.24	$52,130.04	$79,992.11
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$80,822,098.51**	**$84,494,715.21**	**$88,023,709.24**	**$100,815,718.42**

Supplementary measures and indexes

Years	**Net saving**	S/F	**Net savings**	**SIR**	AIRR	**BPI**	**CEI**
1	(2,624,380)	276664	($9.49)	0.08	-0.91	(4.18)	**4.66**
2	(2,384,737)	276664	($8.62)	0.17	-0.58	(3.73)	**4.66**
3	(2,147,198)	276664	($7.76)	0.25	-0.35	(3.30)	**4.65**
4	(1,911,743)	276664	($6.91)	0.33	-0.22	(2.89)	**4.65**
5	(1,678,352)	276664	($6.07)	0.41	-0.14	(2.50)	**4.65**
6	(1,447,009)	276664	($5.23)	0.50	-0.08	(2.12)	**4.65**
7	(1,217,694)	276664	($4.40)	0.58	-0.05	(1.76)	**4.65**
8	(990,389)	276664	($3.58)	0.65	-0.02	(1.41)	**4.65**
9	(765,076)	276664	($2.77)	0.73	-0.00	(1.07)	**4.65**
10	(541,737)	276664	($1.96)	0.81	0.01	(0.75)	**4.64**
11	(320,354)	276664	($1.16)	0.89	0.02	(0.44)	**4.64**
12	(100,911)	276664	($0.36)	0.96	0.03	(0.14)	**4.64**
13	116,611	276664	$0.42	1.04	0.03	0.15	**4.64**
14	332,228	276664	$1.20	1.12	0.04	0.43	**4.64**

15	545,959	276664	$1.97	1.19	0.04	0.70	**4.64**
16	757,819	276664	$2.74	1.26	0.05	0.96	**4.64**
17	967,825	276664	$3.50	1.34	0.05	1.22	**4.63**
18	1,175,995	276664	$4.25	1.41	0.05	1.46	**4.63**
19	1,382,344	276664	$5.00	1.48	0.05	1.70	**4.63**
20	1,586,889	276664	$5.74	1.55	0.05	1.93	**4.63**
21	1,789,646	276664	$6.47	1.62	0.05	2.15	**4.63**
22	1,990,631	276664	$7.20	1.69	0.05	2.36	**4.63**
23	2,189,859	276664	$7.92	1.76	0.06	2.57	**4.63**
24	2,387,348	276664	$8.63	1.83	0.06	2.77	**4.62**
25	2,583,111	276664	$9.34	1.90	0.06	2.97	**4.62**
26	2,777,165	276664	$10.04	1.97	0.06	3.16	**4.62**
27	2,969,525	276664	$10.73	2.04	0.06	3.34	**4.62**
28	3,160,207	276664	$11.42	2.10	0.06	3.52	**4.62**
29	3,349,224	276664	$12.11	2.17	0.06	3.69	**4.62**
30	3,536,592	276664	$12.78	2.23	0.06	3.86	**4.62**

31	3,722,326	276664	$13.45	2.30	0.06	4.03	**4.62**
32	3,906,440	276664	$14.12	2.36	0.06	4.19	**4.61**
33	4,088,949	276664	$14.78	2.43	0.06	4.34	**4.61**
34	4,269,867	276664	$15.43	2.49	0.06	4.49	**4.61**
35	4,449,208	276664	$16.08	2.55	0.06	4.64	**4.61**
36	4,626,987	276664	$16.72	2.61	0.06	4.78	**4.61**
37	4,803,217	276664	$17.36	2.68	0.06	4.92	**4.61**
38	4,977,912	276664	$17.99	2.74	0.06	5.06	**4.61**
39	5,151,086	276664	$18.62	2.80	0.06	5.19	**4.61**
40	5,322,753	276664	$19.24	2.86	0.06	5.32	**4.60**
41	5,492,926	276664	$19.85	2.92	0.06	5.45	**4.60**
42	5,661,617	276664	$20.46	2.98	0.06	5.57	**4.60**
43	5,828,842	276664	$21.07	3.03	0.06	5.69	**4.60**
44	5,994,612	276664	$21.67	3.09	0.06	5.81	**4.60**
45	6,158,940	276664	$22.26	3.15	0.06	5.92	**4.60**
46	6,321,840	276664	$22.85	3.21	0.06	6.04	**4.60**

47	6,483,324	276664	$23.43	3.26	0.06	6.14	**4.60**
48	6,643,404	276664	$24.01	3.32	0.06	6.25	**4.59**
49	6,802,094	276664	$24.59	3.37	0.06	6.36	**4.59**
50	6,959,406	276664	$25.15	3.43	0.06	6.46	**4.59**

Project 7. School of human ecology

Total LCC for baseline and proposed buildings (20, 25, 30, and 50 years)

Categories	**Baseline building**			
Life span	**20years**	25years	30years	50years
Construction cost	**$35,101,561.00**	$35,101,561.00	$35,101,561.00	$35,101,561.00
Maintenance cost	**$8,076,952.51**	$9,929,853.18	$11,720,641.22	$18,303,276.60
Energy costs	**$3,756,917.84**	$4,587,079.87	$5,377,717.72	$8,181,343.92
Water costs	**$26,811.79**	$32,811.08	$38,552.80	$59,158.22
CO2 costs	**$325,033.12**	$396,855.33	$465,258.07	$707,816.30
Water disposal costs	**$33,886.58**	$41,468.89	$48,725.68	$74,768.22
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$47,321,162.84**	**$50,089,629.36**	**$52,752,456.50**	**$62,427,924.26**

Categories	**Proposed building**			
Life span	**20years**	25years	30years	50 years
Construction cost	**$35,422,258.00**	$35,422,258.00	$35,422,258.00	$35,422,258.00
Maintenance cost	**$7,026,948.68**	$8,638,972.27	$10,196,957.86	$15,923,850.64
Energy costs	**$2,539,364.02**	$3,100,484.51	$3,634,889.94	$5,529,908.09
Water costs	**$16,473.11**	$20,662.10	$23,686.77	$36,346.69
CO2 costs	**$261,986.00**	$319,876.76	$375,011.33	$570,520.22
Water disposal costs	**$20,819.85**	$25,478.41	$29,936.96	$45,937.44
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$45,287,849.66**	**$47,527,732.05**	**$49,682,740.86**	**$57,528,821.08**

Supplementary measures and indexes

Years	Net saving	S/F	Net savings	SIR	AIRR	BPI	CEI
1	($193,318.70)	201623	($0.96)	0.40	-0.59	(0.54)	21.21

2	($67,012.83)	201623	($0.33)	0.79	-0.08	(0.18)	21.20
3	$58,229.91	201623	$0.29	1.18	0.09	0.16	21.19
4	$182,418.73	201623	$0.90	1.57	0.15	0.48	21.19
5	$305,562.75	201623	$1.52	1.95	0.18	0.80	21.18
6	$427,671.02	201623	$2.12	2.33	0.19	1.10	21.17
7	$548,752.51	201623	$2.72	2.71	0.19	1.39	21.17
8	$668,816.11	201623	$3.32	3.09	0.19	1.66	21.16
9	$787,870.63	201623	$3.91	3.46	0.18	1.93	21.16
10	$905,924.79	201623	$4.49	3.82	0.18	2.19	21.15
11	$1,022,987.25	201623	$5.07	4.19	0.17	2.43	21.14
12	$1,139,066.59	201623	$5.65	4.55	0.17	2.67	21.14
13	$1,254,171.30	201623	$6.22	4.91	0.16	2.90	21.13
14	$1,368,309.82	201623	$6.79	5.27	0.16	3.12	21.12
15	$1,481,490.48	201623	$7.35	5.62	0.16	3.33	21.12
16	$1,593,721.58	201623	$7.90	5.97	0.15	3.54	21.11
17	$1,705,011.30	201623	$8.46	6.32	0.15	3.74	21.10

18	$1,815,367.78	201623	$9.00	6.66	0.14	3.93	21.10
19	$1,924,799.08	201623	$9.55	7.00	0.14	4.12	21.09
20	$2,033,313.18	201623	$10.08	7.34	0.14	4.30	21.09
21	$2,140,918.00	201623	$10.62	7.68	0.13	4.47	21.08
22	$2,247,621.39	201623	$11.15	8.01	0.13	4.64	21.07
23	$2,353,431.11	201623	$11.67	8.34	0.13	4.80	21.07
24	$2,458,354.89	201623	$12.19	8.67	0.13	4.96	21.06
25	$2,562,400.35	201623	$12.71	8.99	0.12	5.12	21.05
26	$2,665,575.07	201623	$13.22	9.31	0.12	5.26	21.05
27	$2,767,886.55	201623	$13.73	9.63	0.12	5.41	21.04
28	$2,869,342.24	201623	$14.23	9.95	0.12	5.55	21.04
29	$2,969,949.50	201623	$14.73	10.26	0.12	5.69	21.03
30	$3,069,715.63	201623	$15.23	10.57	0.11	5.82	21.02
31	$3,168,647.89	201623	$15.72	10.88	0.11	5.95	21.02
32	$3,266,753.46	201623	$16.20	11.19	0.11	6.07	21.01
33	$3,364,039.44	201623	$16.68	11.49	0.11	6.20	21.01

34	$3,460,512.88	201623	$17.16	11.79	0.11	6.31	21.00
35	$3,556,180.79	201623	$17.64	12.09	0.11	6.43	20.99
36	$3,651,050.08	201623	$18.11	12.38	0.10	6.54	20.99
37	$3,745,127.62	201623	$18.57	12.68	0.10	6.65	20.98
38	$3,838,420.23	201623	$19.04	12.97	0.10	6.76	20.98
39	$3,930,934.64	201623	$19.50	13.26	0.10	6.86	20.97
40	$4,022,677.54	201623	$19.95	13.54	0.10	6.96	20.96
41	$4,113,655.56	201623	$20.40	13.83	0.10	7.06	20.96
42	$4,203,875.27	201623	$20.85	14.11	0.10	7.16	20.95
43	$4,293,343.18	201623	$21.29	14.39	0.10	7.25	20.95
44	$4,382,065.74	201623	$21.73	14.66	0.09	7.34	20.94
45	$4,470,049.36	201623	$22.17	14.94	0.09	7.43	20.94
46	$4,557,300.37	201623	$22.60	15.21	0.09	7.52	20.93
47	$4,643,825.05	201623	$23.03	15.48	0.09	7.60	20.92
48	$4,729,629.64	201623	$23.46	15.75	0.09	7.69	20.92
49	$4,814,720.31	201623	$23.88	16.01	0.09	7.77	20.91

50	$4,899,103.18	201623	$24.30	16.28	0.09	7.85	20.91

Project 8. School of nursing

Total LCC for baseline and proposed buildings (20, 25, 30, and 50 years)

Categories	**Baseline building**			
Life span	**20years**	25years	30years	50years
Construction cost	**$39,181,346.00**	$39,181,346.00	$39,181,346.00	$39,181,346.00
Maintenance cost	**$6,671,378.58**	$8,201,832.28	$9,680,982.36	$15,118,089.07
Energy costs	**$5,060,456.96**	$6,178,660.60	$7,243,626.34	$11,020,027.71
Water costs	**$30,267.08**	$37,039.51	$43,521.19	$66,782.06
CO2 costs	**$743,894.56**	$908,272.12	$1,064,823.64	$1,619,960.16
Water disposal costs	**$38,253.62**	$46,813.08	$55,005.06	$84,403.75
Occupant	**$0.00**	$0.00	$0.00	$0.00

satisfaction				
Total costs	**$51,725,596.79**	**$54,553,963.59**	**$57,269,304.59**	**$67,090,608.75**

Categories	**Proposed building**			
	20years	25years	30years	50 years
Construction cost	**$40,020,479.00**	$40,020,479.00	$40,020,479.00	$40,020,479.00
Maintenance cost	**$5,804,099.36**	$7,135,594.08	$8,422,454.65	$13,152,737.49
Energy costs	**$3,557,174.50**	$4,343,199.46	$5,091,801.62	$7,746,367.95
Water costs	**$19,173.69**	$23,463.91	$27,569.94	$42,305.32
CO2 costs	**$462,260.88**	$564,406.16	$661,688.28	$1,006,653.70
Water disposal costs	**$24,233.03**	$29,655.30	$34,844.78	$53,468.36
Occupant satisfaction	**$0.00**	$0.00	$0.00	$0.00
Total costs	**$49,887,420.46**	**$52,116,797.92**	**$54,258,838.28**	**$62,022,011.82**

Supplementary measures and indexes

Years	**Net saving**	S/F	**Net savings**	**SIR**	AIRR	**BPI**	**CEI**
1	(693,781)	166536	($4.17)	0.17322	-0.82	(1.74)	**10.02**
2	(549,705)	166536	($3.30)	0.34	-0.40	(1.36)	**10.02**
3	(406,892)	166536	($2.44)	0.52	-0.17	(0.99)	**10.02**
4	(265,332)	166536	($1.59)	0.68	-0.06	(0.63)	**10.01**
5	(125,012)	166536	($0.75)	0.85	-0.00	(0.29)	**10.01**
6	14,077	166536	$0.08	1.02	0.03	0.03	**10.01**
7	151,947	166536	$0.91	1.18	0.05	0.35	**10.00**
8	288,609	166536	$1.73	1.34	0.07	0.65	**10.00**
9	424,074	166536	$2.55	1.51	0.08	0.94	**10.00**
10	558,353	166536	$3.35	1.67	0.08	1.22	**9.99**
11	691,455	166536	$4.15	1.82	0.09	1.49	**9.99**
12	823,393	166536	$4.94	1.98	0.09	1.75	**9.99**
13	954,175	166536	$5.73	2.14	0.09	2.01	**9.99**
14	1,083,813	166536	$6.51	2.29	0.09	2.25	**9.98**

15	1,212,317	166536	$7.28	2.44	0.09	2.49	**9.98**
16	1,339,697	166536	$8.04	2.60	0.09	2.71	**9.98**
17	1,465,963	166536	$8.80	2.75	0.09	2.93	**9.97**
18	1,591,125	166536	$9.55	2.90	0.09	3.15	**9.97**
19	1,715,193	166536	$10.30	3.04	0.09	3.35	**9.97**
20	1,838,176	166536	$11.04	3.19	0.09	3.55	**9.97**
21	1,960,085	166536	$11.77	3.34	0.09	3.75	**9.96**
22	2,080,929	166536	$12.50	3.48	0.09	3.94	**9.96**
23	2,200,717	166536	$13.21	3.62	0.09	4.12	**9.96**
24	2,319,460	166536	$13.93	3.76	0.09	4.30	**9.95**
25	2,437,166	166536	$14.63	3.90	0.09	4.47	**9.95**
26	2,553,844	166536	$15.34	4.04	0.09	4.63	**9.95**
27	2,669,504	166536	$16.03	4.18	0.09	4.80	**9.95**
28	2,784,155	166536	$16.72	4.32	0.09	4.95	**9.94**
29	2,897,806	166536	$17.40	4.45	0.08	5.11	**9.94**
30	3,010,466	166536	$18.08	4.59	0.08	5.26	**9.94**

31	3,122,144	166536	$18.75	4.72	0.08	5.40	**9.93**
32	3,232,848	166536	$19.41	4.85	0.08	5.54	**9.93**
33	3,342,587	166536	$20.07	4.98	0.08	5.68	**9.93**
34	3,451,371	166536	$20.72	5.11	0.08	5.81	**9.93**
35	3,559,206	166536	$21.37	5.24	0.08	5.94	**9.92**
36	3,666,103	166536	$22.01	5.37	0.08	6.07	**9.92**
37	3,772,068	166536	$22.65	5.50	0.08	6.19	**9.92**
38	3,877,111	166536	$23.28	5.62	0.08	6.32	**9.92**
39	3,981,240	166536	$23.91	5.74	0.08	6.43	**9.91**
40	4,084,463	166536	$24.53	5.87	0.08	6.55	**9.91**
41	4,186,787	166536	$25.14	5.99	0.08	6.66	**9.91**
42	4,288,222	166536	$25.75	6.11	0.08	6.77	**9.90**
43	4,388,775	166536	$26.35	6.23	0.07	6.88	**9.90**
44	4,488,453	166536	$26.95	6.35	0.07	6.98	**9.90**
45	4,587,265	166536	$27.55	6.47	0.07	7.08	**9.90**
46	4,685,219	166536	$28.13	6.58	0.07	7.18	**9.89**

47	4,782,321	166536	$28.72	6.70	0.07	7.28	**9.89**
48	4,878,580	166536	$29.29	6.81	0.07	7.37	**9.89**
49	4,974,003	166536	$29.87	6.93	0.07	7.46	**9.89**
50	5,068,597	166536	$30.44	7.04	0.07	7.55	**9.88**

Development of Green Building Performance Assessment Tool (GBPAT)

based on the Integrated LCA and LCCA Approach

ABSTRACT

Green building construction is dynamic, rapidly growing and evolving due to the increased public concerns with global climate change, cost and availability of energy sources, and the impact of the built environment on human health and performance. This research is aim to address the issues raised on the green building performance rating systems. Existing building performance rating (BPR) systems are unable to provide the cost effectiveness for decision making about whether the proposed building is currently sustainable or should be renovated, such as affordable initial investment, net saving, payback period and so on. Each BPR system assigns different points to evaluating categories, such as energy consumption, environmental impact, indoor air quality, and social aspect because these assessment systems have their own formulas to give the assigned points to the performance results. In addition, the user must have the professional knowledge on the system to apply the existing BPE systems on green building project.

In this research, the integrated life cycle assessment (LCA) and life cycle cost analysis (LCCA) method was adopted as the green building performance assessment tool (GBPAT) to address these issues. GBPAT was presented in the versions of Microsoft Excel and stand-alone program programmed with C# language. The objectives of the development of GBPAT were to develop the green building performance assessment tool (GBPAT) embodying financial feasibility based on the integrated LCA and LCCA method and establish more reliable cost effectiveness index (CEI) based on cost and financial benefits (B/C) analysis.

With GBPAT, it is possible for the user to determine the cost-effectiveness for their project to be green. Also, in terms of the energy consumption, BLCC and other reference programs have no option to reflect the usages of the renewable energies earned from solar, geothermal and wind while GBPAT is capable of converting the amount of these renewable energies produced to the secondary energies, especially electricity and hot water. Therefore, GBPAT can estimate more reliable social costs spent by environmental impact. Finally, GBPAT provides the annual changes of the supplementary measures and indexes in order to identify the trend of the cost effectiveness for the target building over the life span and these results can be illustrated in the graphicall charts so that the user can easily understand although BLCC. Therefore, it is thought that GBPAT is more advanced LCCA and building performance evaluation program although it is not able to cover the occupant's satisfaction in the integrated LCA and LCCA approach.

CHAPTER 1. INTRODUCTION

1.1 Background

Green building is a dynamic, rapidly growing and evolving field, driven by a confluence of rising public concerns about global climate change, cost and availability of energy sources, and the impact of the built environment on human health and performance (Brage et al., 2007). Moreover, nationally and globally, buildings contribute significantly to energy consumption, as well as other environmental impacts, such as air pollution and solid waste generation (Scheuer and Keoleian 2002). In addition, the building sector has shown considerable interest in environmental issues since 1990s and the building sector is one of the key sectors in the pursuit of a sustainable society. Buildings account for approximately 40% of the total energy use, 12% of the total water consumption, 68% of the total electricity consumption, 38% of the total carbon dioxide emissions, and 60% of the total non-industrial waste generation in the United States (U.S.) (U.S. DOE, 2007).

Green and sustainable buildings are the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building’s life cycle from design to construction, operation, maintenance, renovation and demolition [U.S. Environmental Protection Agency (EPA), 2011]. In order for a commercial building to be green, sustainable and optimized, the accurate building performance evaluation (BPE) and the energy performance simulation (EPS) must be preceded. In the green building construction field, there are already several types of green building rating systems for BPE that assess commercial building performance, such as LEED, BREEAM, Green Globes, GBCC and Energy Star.

According to the definition of the assessment of building performance by U.S. DOE, evaluating building performance involves the assessment of the extent to which a given building has met its design goals for resource consumption and occupant satisfaction. It is based on feedback and evaluation at every phase of building delivery, ranging from strategic planning to occupancy, throughout the building's life cycle (Preiser and Vischer 2004).

1.2 Practical Problems

All goods are following in the order of building's life-cycle as shown in Figure 1.1. Thus, BPE is aimed to determine the ratio of output to input in each phase of life cycle. In building construction, input (goods) usually means materials, energy, human power, and land while output implies financial benefit, environmental impact, and occupant's satisfaction. The comprehensive BPE system should allow for the assessment of both input goods and output performance.

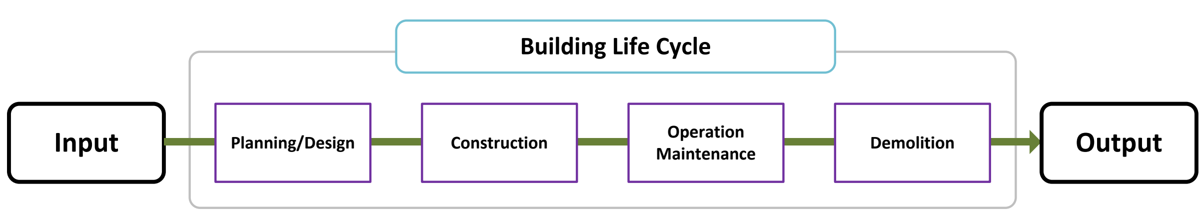


Figure 1.1 Conceptual framework for building performance throughout building life cycle

Among existing BPE systems, the building performance rating (BPR) system, Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) are most widely used. First, building rating systems are aimed to evaluate building performance with certain points that can be achieved by fulfilling their own requirements and the checklists. Comparison with other techniques can help the user in understanding how much their buildings are green and sustainable. Compared with existing BPE systems, the LCCA method is an economic evaluation technique that determines the total cost of owning and operating a building over its assumed life (Fuller and Petersen 1995). Although the formal LCCA method is aimed to assess all costs occurred during building construction, maintenance, operation, and demolition, it lacks the information regarding output performance, such as energy consumption, environmental impact, occupant satisfaction and so on. According to Kats (2003), decisions on the investment to a green building are typically based only on the initial costs plus, in some cases, a discounted value of lowered energy and water bills. Based on the literature review, there are some limitations associated with the use of existing LCCA models. These models tend to ignore social and environmental costs obviously because it is difficult to estimate such costs and the real values related with both are often disputed.

In the past, the existing green BPR systems had been aimed to offer limited information to only owners and building managers since buildings were considered as their own properties that provide the economic benefits. However, with increased awareness of green building construction and stringent regulations, the evaluation of building performance with social responsibilities was started. Thus, more improved BPE systems considering green and sustainability have been developed but they still have significant problems. As mentioned above, BPR systems are not capable of providing economic performance to all parties. Keil (2008), who works at Navigant that is partner with the U.S. EPA and U.S. DOE, asserted that LEED has become expensive, slow, confusing and unwieldy and it seems to focus on points, not environmental nor not financial benefits. For example, having a few hundred-dollar bike rack and a multimillion-dollar low energy air conditioning system both get one point. In addition, basic certification (LEED-certified level) is too low a hurdle to merit the green stamp of approval. In addition, it is limited that the exiting BPR systems provide accurate energy and water reduction. Furthermore, existing building performance rating systems provides different assigned points to evaluating categories, such as energy, environment, IAQ and social aspect. As a result, the building archives certainly different results of building performance evaluated by another BPR system, thus making users to confuse whether theirs buildings are really sustainable. Figure 1.2 shows the example of the different assigned points provided in representative BPR systems.

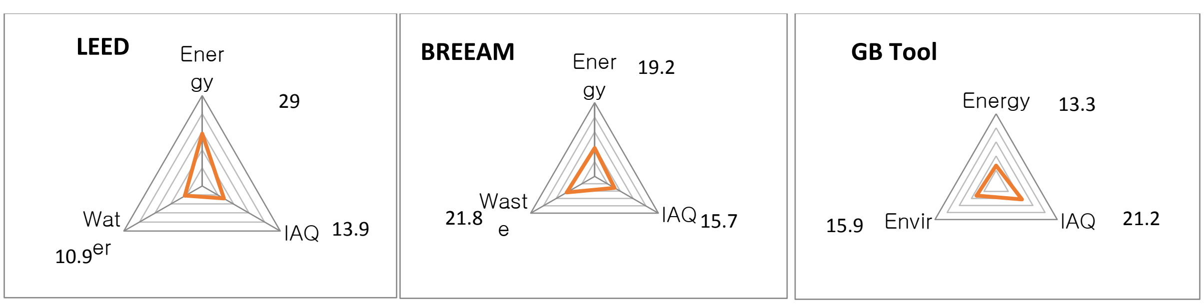


Figure 1.2 Assigned points to categories on each BPR systems

Finally, existing building rating systems can be a good model to evaluate building performance by comparing with other buildings. However, it failed to provide financial information. On the other hand, LCCA is a good tool to assess financial impact for building construction but formal techniques for LCCA are limited to the evaluation of building performance in the overall sustainability aspects of economy, environment, and human. In other fields, especially the road construction sector, an integrated LCA and LCCA approach has been started to consider user cost and environmental impact cost. Chan et al (2008) discussed that an integrated LAC and LCCA method should be taken into account for a road construction project when evaluating infrastructure sustainability, compared alternative materials, and designs using environmental, economic, and social indicators.

1.3 Research Objectives

Although existing green BPR systems have been developed and applied widely, they have certain limitations as illustrated in the problem statement. Thus, advanced green BPR systems must be developed to properly assess building performance with respect to sustainability that is based on triple bottom line: economy, environment, and human. In addition, the system must provide the information that helps all participants related and impacted by building performance. In the perspective of building construction, there are three parties evaluating building performance regarding sustainability, such as owners and building managers, building occupants, and society. Depending on participants on buildings, they have their own needs on the information of building performance and Figure 1.3 shows the needs for individual participants.

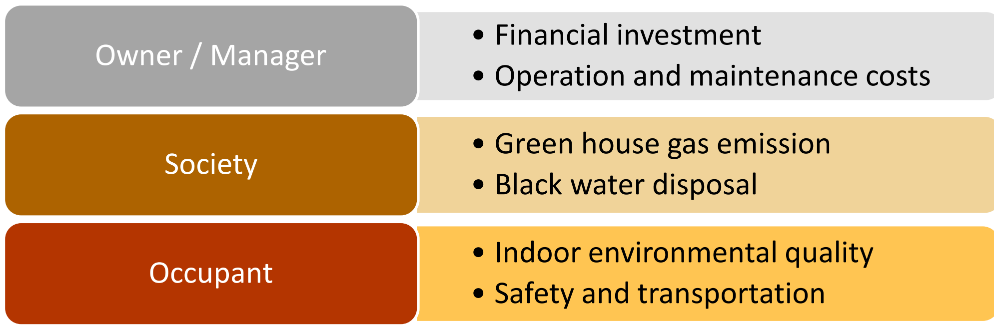


Figure 1.3 The needs for each of green building participants

In spite of certain improvements of the existing BPE systems, they could not satisfy all participants. Because of limited information and complicated system, the user is not able to conduct BPE without professional knowledge. The objectives of this study were to:

- Develop green building performance assessment tool (GBPAT) embodying financial feasibility based on the integrated LCA and LCCA method;
- Develop the expert system (stand-alone) with user-friendly Graphic User Interface (GUI) developed using C# programming language in order to easily input data and information;
- Establish more reliable cost effectiveness index (CEI) based on cost and financial benefits (B/C) analysis; and
- Present the appropriate initial investment depending on the level of LEED system and select the optimized design alternatives in terms of sustainability.

1.4 Research Methodology

There are hundreds of building performance evaluation tools that focus on different areas of sustainable development and are designed for different types of projects. These tools include life cycle assessment, life cycle costs, energy systems design, performance evaluation, productivity analysis, indoor environmental quality assessments, operations and maintenance optimization, whole building design and operations tools, and more (Fowler, 2006). For this research, the concept of the integrated LCA and LCCA approach comprising social and environmental impacts will be adopted. There are two costs: realization costs and non-realization costs on building construction and operation over its life cycle as owners' perspective. Here, the realization cost as an owner's perspective is the ownership cost that uses for building construction, operation and maintenance and demolition. In contrast, non-realization cost does not need to be paid by owners and building managers, such as social cost and occupant cost (user cost). Although building owners and building managers have not been responsible for these costs in the past, building occupants and society impacted by building performance have constantly paid these non-realization costs. Thus, formal BPE systems and LCCA methods had assessed only realization cost before 1990's because the users who wanted these systems were not interested in social costs. However, advanced BPE system should consider these indirect costs caused by operating buildings. Thus, realization and non-realization costs should be all estimated in GBPAT.

Next, the research strives to list the needs of all parties related in building performance from a social standpoint. As mentioned in the problem statement, owners, occupants and society are directly or indirectly correlated with building performance. In addition, GBPAT would provide information strongly related to the needs of three parties and building performance will be estimated with the ratio of input to output as shown in the Figure 1.4.

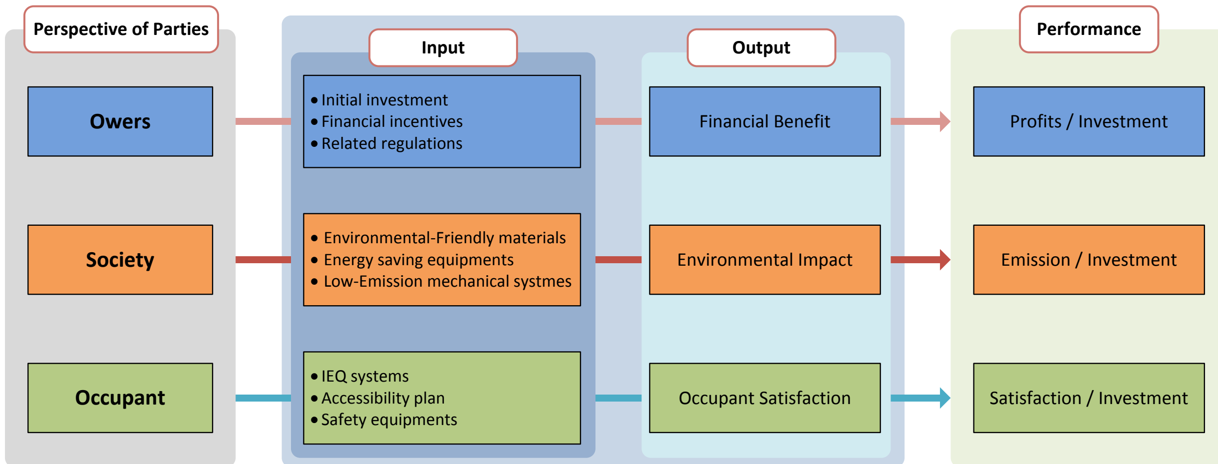


Figure 1.4 Input/output of GBPAT

As seen in Figure 1.4, for measuring performance, the information of an investment, profit, emission and occupant satisfaction is needed. Contrary to a financial investment, other outputs are not easily measured quantitatively so that the method of converting formless output to quantitative values is required as well as the integration of units. For solving these challenges, the monetary unit can be a good alternative since input information can be also provided in the cost values.

Even though building performance can be assessed quantitatively, it is limited to comprehensively evaluate how much a building is green and sustainable. Therefore, overall building performance will be provided with points that are generated by cost-based values. There are two ways to improve performance by (1) reducing costs and (2) maximizing benefits. To compare proposed building performance to baseline building performance, the two ways mentioned above will be considered together. Especially, the pivotal hypothesis in this research is that a total lower cost implies more green and sustainable building. Lastly, GBPAT is able to offer users more practical performance index generated with overall building life cycle costs.

Finally, with these all concepts, GBPAT was presented in the version of Microsoft Excel and the stand-alone program developed by C# programming language. As a prior version to check the validation of GBPAT, Microsoft Excel version was developed and then the stand-alone program by using C# programming language was made for directly operating GBPAT under the computer operating system (OS). Once GBPAT was developed in the stand-alone program, GBPAT was compared with well-known building life cycle cost (LCC) programs such as BLCC and Harvard Life Cycle Calculator in order to validate the benefits of GBPAT.

1.5 Expected Benefits

Developing GBPAT is expected to have several benefits. First, users are able to operate GBPAT without professional knowledge required and to use it with minimized information. The assessment methods for financial feasibility with final BPI reflecting entire building performance will be based on the estimation of building LCC. Through the results of the assessment by integrated LCA and LCCA, users should be able to make a strategic decision to sustain or change a building design in a case of new construction or determine whether their existing buildings should be renovated or retrofitted based on the final outcomes regarding specifically cost and financial benefits (B/C) analysis. Moreover, with the accumulated database in GBPAT, the optimized initial investment depending on the level of LEED or other BPR systems can be expected for the proposed building project.

Second, applying social costs, such as environmental costs and occupant’s health costs, to total

LCC for their green buildings would lead to the reduction of environmental burden of society and to significantly improve indoor environmental quality affecting the health of occupants since users are able to recognize that these social costs may impact the entire building LCC. The federal and state governments have encouraged the building owners to make their buildings to be more green and sustainable. Therefore, the experimental and comparable results from GBPAT will be useful to determine whether a building is green and sustainable along with comparable indexes.

CHAPTER 2. LITERATURE REIVEW

2.1 Existing BPE systems

The commercial building construction sector has recently begun to acknowledge their responsibilities for the environment, resulting in a shift in how buildings are designed, built, and operated (Smith et al., 2006). Since 1990s, conceptual BPE systems have been appeared with environmental approaches and these BPR systems were a guide to assess building performance with respect to green and sustainability, which means that buildings have to fulfill social responsibility as a social constituent, not as only owner's individual property. The first environmental certification system was created in 1990 in the UK, The Building Research Environmental Assessment Method (BREEAM). In 1998 the Leadership in Energy and Environmental Design (LEED) green building rating system was introduced based quite substantially on the BREEAM system and then, in 2005, the Green Building Initiative (GBI) launched Green Globes by adaption the Canadian version of BREEAM and distributing it in the U.S. market (Smith et al., 2006). The LEED Green Building Rating System is a voluntary rating system introduced in 2000 for developing high performance, sustainable buildings that are assessed by assigned points along six assessment area, such as sustainable sites, water efficiency, energy & atmosphere, materials & resources, indoor environmental air quality and innovation.

Even though these BPR systems are able to conduct the comprehensive assessment, however, they have significant limitations as mentioned in Chapter 1. According to “LEED is broken”, LEED system is costly and time consuming as it has no cost and financial benefit evaluation (Schendler and Udall 2005). In addition, Malkin (2005) argued that most people want to see quantitative data that shows they are saving energy use and cost but LEED does not meet the expectation. Newsham et al. (2009) insisted that 28~35% of LEED buildings save more energy than their conventional counterparts although LEED-certified buildings use 18~39% less energy per floor area than conventional counterparts. Moreover, according to Scofield (2009), the fact that smaller LEED buildings have relatively lower purchased energy intensity (relative to non-LEED building) while larger buildings show less savings is not just coincidental, which means that higher investments for LEED certification are not able to guarantee more sustainable buildings. Thus, existing BPR systems do not show the relationship between gaining more points and improving building performance. In addition, each of green BPR systems has different weighting points that building can achieve in sustainable categories, such as optimize site, energy use, environmental protection, indoor environmental quality (IEQ), etc. Table 2.1 shows their weighted points in accordance to Pacific Northwest National Laboratory (2006). Also, detailed information comparing representative BPR systems along with GBPAT are attached Appendix I.

Table 2.1 Comparison of weighted points for representative BPR systems

	Technical Content						
	Optimize site potential	Optimize energy use	Protect and conserve water	Use environmentally preferable products	Enhance IEQ	Optimize operational & maintenance practices	Other
BREEAM	15%	25%	5%	10%	15%	15%	15%
CASBEE	15%	20%	2%	13%	20%	15%	15%
GBTool	15%	25%	-	-	15%	15%	30%
Green Globes US	11.5%	36%	10$	10%	20%	-	12.5%
LEED	20%	25%	7%	19%	22%	-	7%

2.2 Comparison of LCA and LCCA

There are two kinds of life cycle technologies that are commonly used in environmental management, such as LCA and LCCA. LCA means product is followed from its "cradle" where raw materials are extracted from natural resources through production and use to its "grave", the disposal (Baumann, 2004). In fact, assessment of environmental impacts in the building sector is a quite complex work due to lack of a database. In addition, building products have a relative long service life and many actors involved during the building life cycle that makes it difficult to predict what actually happens during the life cycle, especially in the operation phase (Thomas, 1999). With the increased concern for the built environment among the public, governmental regulation and the aspiration towards a sustainable society has shown rising interest in methods or technologies for the environmental assessment of the activities of the building sector as well as the valuation in the whole process (Guoguo, 2008). In building sector, LCA is only used for evaluating the environmental impact from building, but nothing to do with decision making. Scheuer et al. (2003) defied that LCA is a process whereby the material and energy flows of a system are quantified and evaluated (Scheuer et al., 2003). General structure of LCA proposed by Bribián et al. (2009) is illustrated in Figure 2.1.

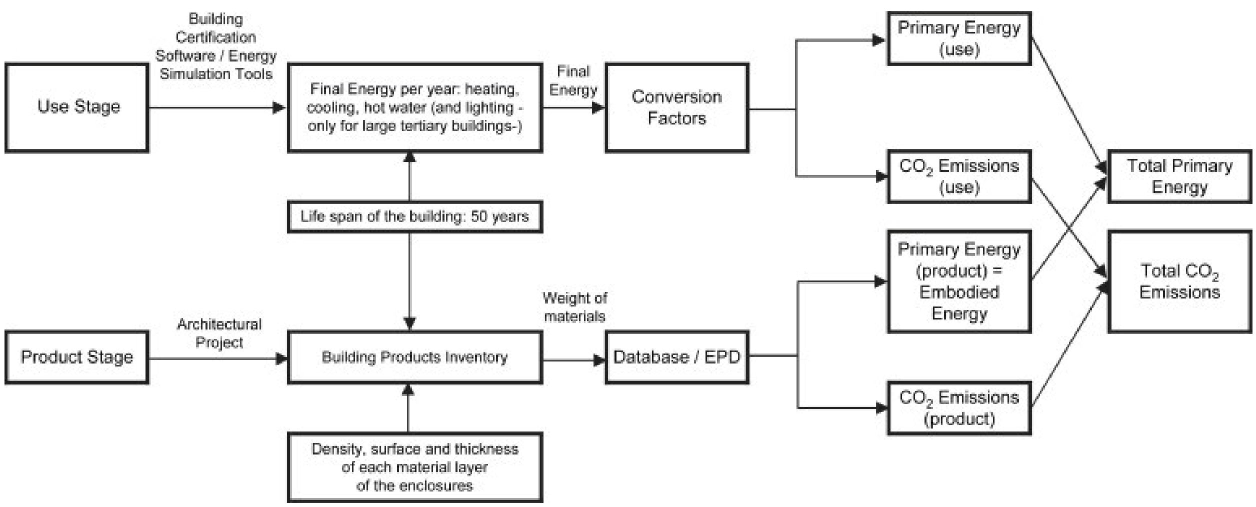


Figure 2.1 General structure of LCA methodology (Bribián et al., 2009)

On the other hand, LCCA is the technique to estimate the total cost of ownership. In the building and construction industry, LCCA is applied to quantifying costs of whole buildings, systems, and building components and materials. Fuller and Petersen (1995) define LCCA as an economic evaluation technique that determines the total costs of owning and operating a building over its assumed life. The technique can assist decision-making for building investment projects (Nelson, 2002). While there is no standardized methodology used for LCCA, basically all LCCA methods deal with costs, time, and interest rate, giving results in net present value or net present costs, annual cost or annual equivalent value or payback (Guoguo, 2008). In general, formal technology of LCCA method is estimated as follows (Fuller and Petersen, 1995):

$$\text{Life Cycle Cost} = \text{Initial investment} + \sum_{N=1}^{n} \text{Energy cost} + \sum_{N=1}^{n} \text{Water cost}$$

$$+ \textstyle\sum_{N=1}^{n} \text{Maintenance cost} + \text{Replacement cost} \ + \text{Demolition cost} \qquad (2.1)$$

The National Institute of Standards and Technology (NIST) Building Life Cycle Cost (BLCC) computer program provides economic analysis of proposed capital investments that are expected to reduce long-tern operating costs of buildings or building systems/components (Fuller and Petersen, 1995). Typically, BLCC is used to evaluate alternative designs that have higher initial costs but lower operating-related costs over the project life than the lowest-initial-cost design. Although BLCC is widely used in the field of a building and road construction, it does not reflect the externality costs including social cost related in environmental impact. In addition, BLCC program requires the users to input lots of information thus, it is not easy for the users who do not have the professional knowledge to use. For instance, the total LCC based on ASHRAE 90.1 standard (1999) is the energy and construction cost estimated by comparing the baseline building modeling with the sustainable building modeling. The baseline building intended to represent a typical new federal office building and the sustainable building was defined in terms of a number of improvements made to the base-case building. For estimates of PV for the LCC on both of buildings, only the investment cost, and energy costs were considered as an indicator. Figure 2.2 shows the stand-alone version of BLCC.

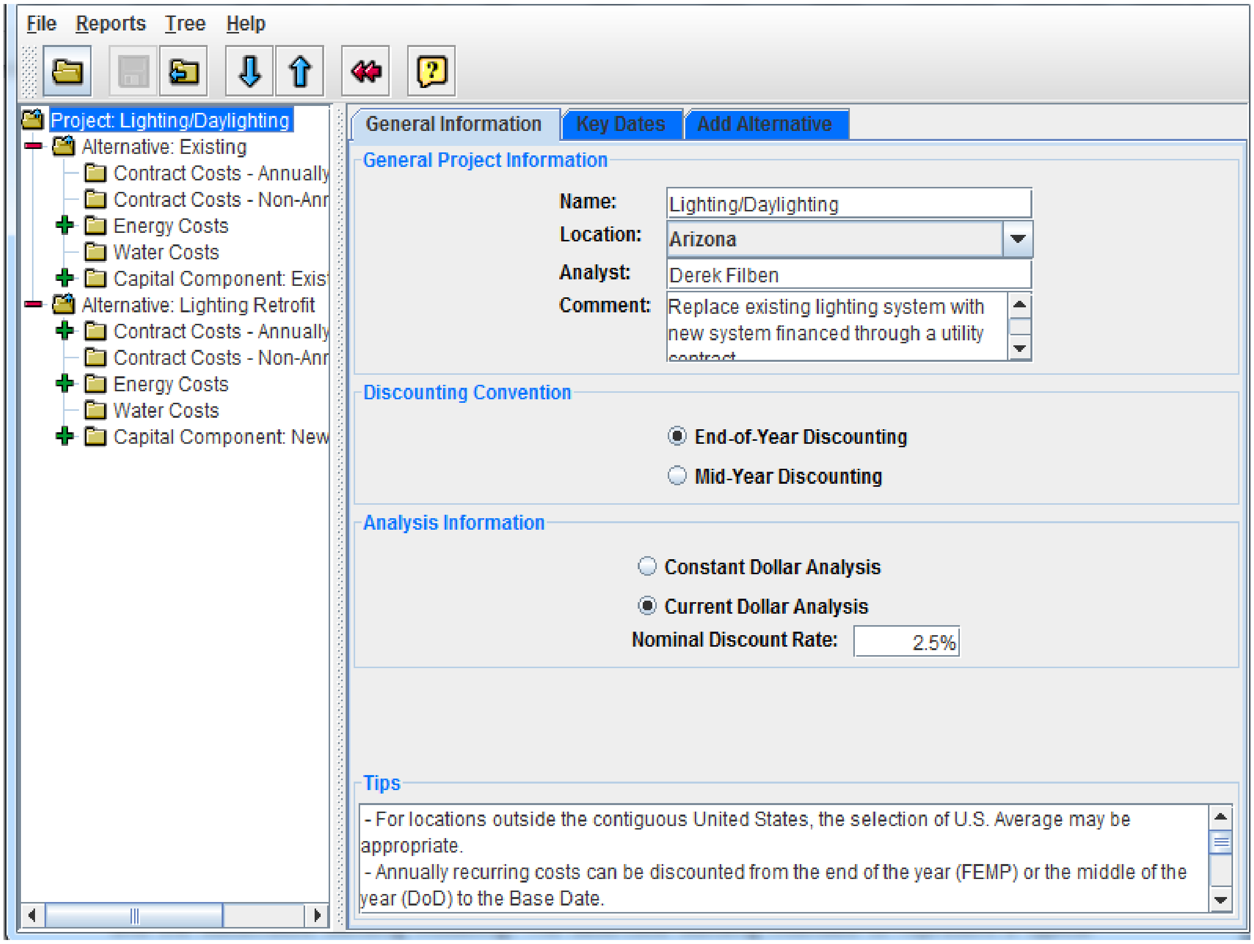


Figure 2.2 The stand-alone version of BLCC (program captured)

Table 2.2 illustrates the estimate of energy and construction estimate based on ASHRAE 90.1 1999. Both LCA and LCCA measure costs and environmental impacts of whole building, respectively. It is necessary to find a feasible way of incorporating them together to accommodate both economic and environmental elements (Jaein, 2006).

Table 2.2 Life Cycle Cost for the Base-case and Sustainable Building (ASHRAE 90.1, 1999)

Cost Element	Units	Base-Case Building	Sustainable Building	Difference (Sustainable-Base)	% Difference
Investment cost					
Total First cost	$	$2,400,000	$2,437,578	$37,578	1.6%
Present value (investment cost)	$	$2,400,000	$2,449,565	$49,565	2.1%
Annual energy costs					
Annual electricity cost	$/Yr	$9,123	$5,374	($3,749)	-41.1%
Annual natural gas cost	$/Yr	$2,249	$1,653	($595)	-26.5%
Annual fixed costs	$/Yr	$462	$462	$0	0.0%
Total annual energy cost	$/Yr	$11,843	$7,489	($4,345)	-36.7%
Present value of energy costs					
Present value (electricity cost)	$	$151,985	$89,525	($62,461)	-41.1%
Present value (natural gas cost)	$	$39,022	$28,690	($10,332)	-26.5%
Present value (fixed energy costs)	$	Not included	Not included	Not applicable	Not applicable
Present value (total energy cost)	$	$191,007	$118,214	($72,793)	-38.1%
Life Cycle Cost	$	$2,591,007	$2,567,780	($23,228)	-0.9%

Goh and Yang (2010) presented a new approach to an existing LCCA method that estimates all sustainability criteria including agency cost, social cost, and environmental cost into entire life cycle costs.

As the more detailed attempt for integrating LCA and LCC, Kats (2003) analyzed 24 buildings that achieved LEED certification in terms of sustainable bottom lines, such as economy, environment, and human. Contrary to other approaches, Kats' analysis was conducted by LCC based on LCA, which means all assigned indicators for environmental and social impacts are generated in a cost value. In the field of the transportation especially including roads and bridges construction, the investigation of the integrated LCA and LCCA approach has been raised up for last decade. Kendall et al. (2008) implemented the integrated LCA and LCCA model for concrete bridge deck applications in the sustainable perspective, and the model based on the integrated LCA and LCCA approach estimated total LCC which reflects social and user costs converted from environmental impacts [greenhouse gas (GHG) emission]. Figure 2.3 illustrates the flow diagram of the integrated LCA and LCCA model.

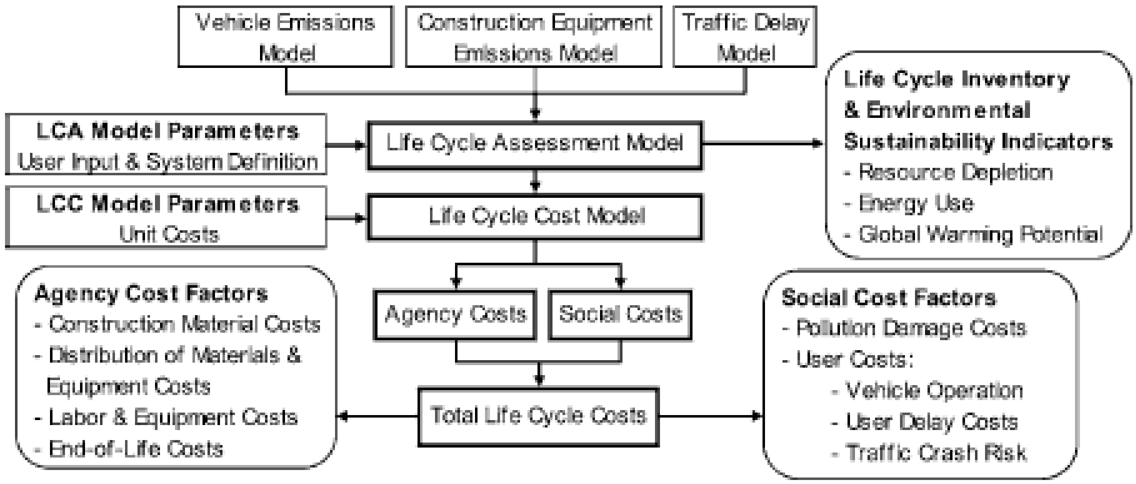


Figure 2.3 Integrated LCA and LCCA model flow diagram (Kendall et al., 2008)

CHAPTER 3. PROGRAM LOGIC FOR GREEN BUILDING PERFORMANCE ASSESSMENT TOOL (GBPAT)

3.1 Comprehensive Logic of GBPAT

This research for the development of GBPAT was proceded with five independent steps as shown in Figure 3.1. First, before starting the development, the investigation regarding the references and the similar programs was preceded in the step of the preparation. After the preparation, the overall logic for GBPAT was defined with the clear purposes for the development of GBPAT and the appropriate data and information to operate the program were collected in the next steps. In the development step, GBPAT was developed in the version of Microsoft Excel and the stand-alone program and these the feasibility of two versions were validated through the comparison of other programs.

Figure 3.1 The procedure of the development of GBPAT

Based on the formal green building rating systems, GBPAT is the advanced system that provides the financial feasibility based on the integrated LCA and LCCA method in order to help all participants who are related and impacted by building performance. While formal LCC gives users only limited cost information, GBPAT can provide advanced LCC information integrating existing life cycle cost along with potential costs related to environmental impacts and occupant's health and productivity.

Although Kats (2003) has published B/C analysis for the buildings with LEED certification, it is restricted to the information reflected to the check lists. Due to this major limitation, users are not able to get appropriate financial investment costs to earn green building recognition and it is too hard to compare a building of interest with the reference building in accordance of three aspects: economy, environment and human.

Contrary to existing BPE systems that consider only the aspect of environment, GBPAT would evaluate building performance through LCCA approach incorporating potential costs based on LCA. In order to estimate accurate LCC, GBPAT collects overall costs in accordance with two types of costs: initial and future costs. Figure 3.2 shows classification of initial and future costs. When it comes to the calculation of LCC, life cycle is usually referred to the study period. The study period for an LCCA is the time over that the costs and benefits related to a capital investment decision are of interest to the decision maker (Fuller, 1995). Within the study period, the planning and construction period and service period are included. The service period is defined as the period from the beginning date for service to the end date. In a simple LCCA, it may be convenient to assume that all initial investment costs are incurred during planning and construction period.

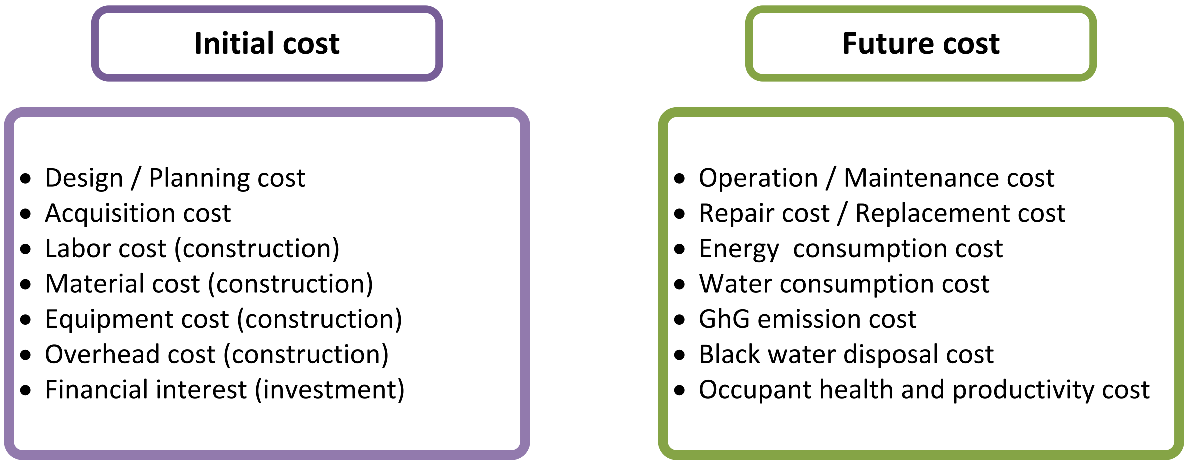


Figure 3.1 Classification of Initial and Future costs

Within the study period, the planning and construction period and service period are included. The service period is defined as the period from the beginning date for service to the end date. In a simple LCCA, it may be convenient to assume that all initial investment costs are incurred during planning and construction period.

Within the range of initial costs, there are several considerable components of initial costs, such as design/planning cost, acquisition cost (land), labor/materials/equipment costs, overhead costs, financial interests, etc. On the other hand, it is more complex to estimate future costs than initial costs since there are several factors that the user must take into account. In addition, an advanced LCC would add potential costs to the formal LCC and thus, a new approach is required.

The calculation method of the future cost in GBPAT would reflect the externality cost compared with the future cost on the formal LCCA method since the negative impacts occurred from operating buildings can be shifted to the society when environmental and human costs are not considered. According to the Energy Resources and Economics Workbook (2008), it can be easily proved as shown in Figure 3.3.

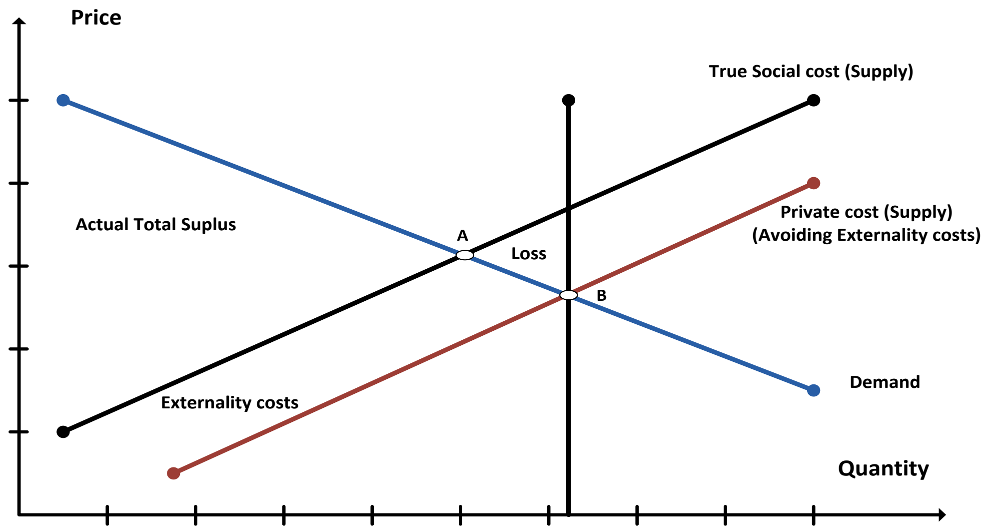


Figure 3.3 Loss in surplus from externalities (Sharten, 2008)

3.1.1 Application of the Integrated LCA and LCCA Approach to GBPAT

In the calculation method for LCC, all costs for a building project during the entire study period have to be discounted to their present value. GBPAT would apply two formulas: calculation of present value for one-time cost and annually recurring cost, to advanced LCC. First, the formula for one-time cost is used to calculate the cost that occurs intermittently, not continuously and this cost includes initial costs and replacement cost for specific equipment. The following formula can be used to calculate present value (PV) for one-time cost (Fuller and Petersen, 1995):

$$PV = F_t \times \frac{1}{(1+r)^t} \tag{3.1}$$

where PV = present value;

F_t = future value at the end of year, t; and

r = given discount rate.

The other formula is usually used to calculate PV for annually recurring cost. Thus, the general future costs along with environmental and human costs can be estimated. The following formula shows PV for annually recurring cost (Fuller and Petersen, 1995):

$$PV = A_O \times \sum_{t=1}^{n} \frac{1}{(1+r)^t} = A_O \times \frac{(1+r)^n - 1}{r(1+r)^n} \tag{3.2}$$

where PV = present value;

A_0 = annual recurring cost;

n = period of year; and

r = given discount rate.

Along with these formulas, initial and future costs can be estimated. As described previously, advanced LCC for GBPAT reflects all costs regarding three aspects: economy, environment, and human. The resources of costs and the study including each initial and service period need to be determined to calculate all costs. Figure 3.4 shows the comparison of the advanced LCC for GBPAT with the formal LCC.

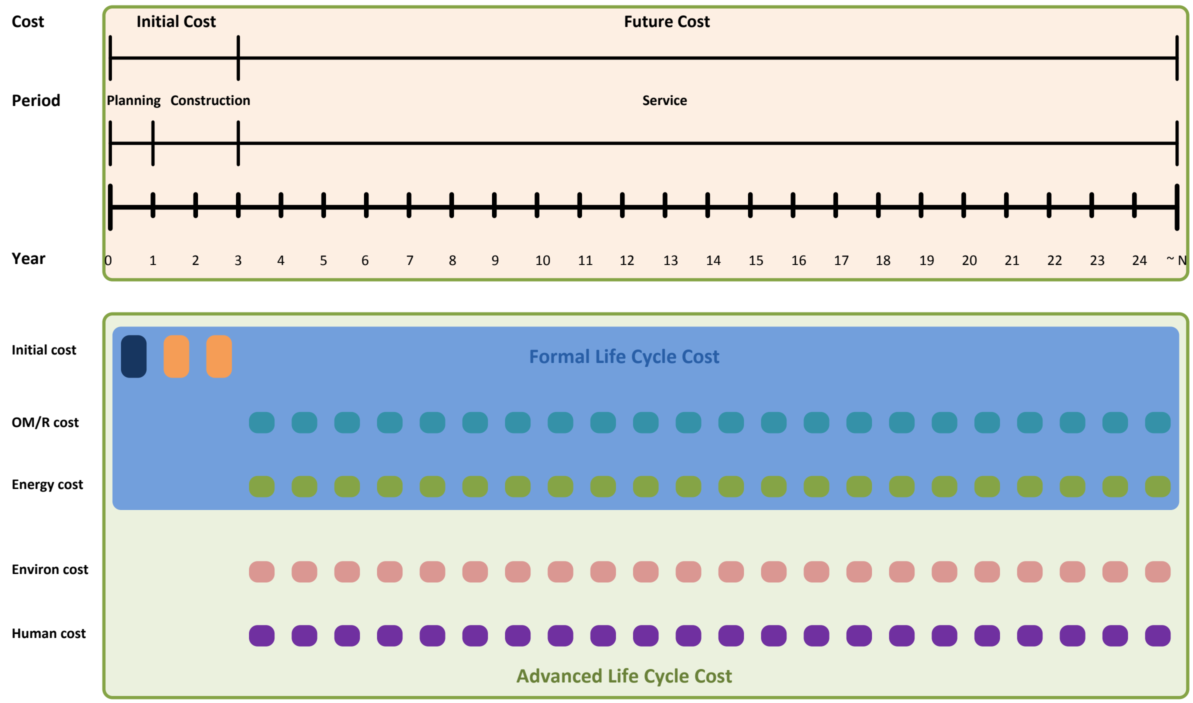


Figure 3.4 Comparison advanced LCC to formal LCC

Compared with the formal LCC, the advanced LCC for GBPAT takes into account externality costs that comprise environmental and human costs. As shown in Figure 3.3, initial costs occurred during planning and construction period are defined as one-time cost. Thus, PV adjusted by the discount rate is simply calculated. In contrast, all costs occurred or predicted during the service period are usually referred as an annually-recurring cost. Therefore, these costs can be estimated with the cumulative costs discounted to PV. Also, externality costs should be defined as future cost since these costs are excessively related to the performance of building operation. Hence, the following formula can be presented in GBPAT:

$$\text{Total LLC} = \left[\left\{ F_{\text{Iinitial}} \times \frac{1}{(1+r)^t} \right\} + \left\{ A_{\text{OM/R}} \times \sum_{t=1}^{n} \frac{1}{(1+r)^t} \right\} + \left\{ A_{\text{E/W}} \times \sum_{t=1}^{n} \frac{1}{(1+r)^t} \right\} + \left\{ A_{\text{Envir}} \times \sum_{t=1}^{n} \frac{1}{(1+r)^t} \right\} + \left\{ A_{\text{Human}} \times \sum_{t=1}^{n} \frac{1}{(1+r)^t} \right\} \right] \quad (3.3)$$

where $F_{Iinitial}$ = future cost for planning and construction (if new construction);

$A_{OM/R}$ = annual cost for operation, maintenance and repair;

$A_{E/W}$ = annual cost for energy and water consumption;

A_{Envir} = annual cost for environmental impacts; and

A_{Human} = annual cost for occupant health and productivity.

3.1.2 Conceptual Framework for GBPAT

The practical and affordable system logic is required in order to operate GBPAT. As illustrated in the previous chapter, GBPAT consist of the overall GUI including input and output interfaces, essential simulation software, and calculation programs. Moreover, the overall GUI controlling and managing entire system is connected to the engines/programs and data-base through programming language, such as visual basic. Figure 3.5 shows the conceptual framework explaining the overall system logic for GBPAT. As shown in Figure 3.5, the structure of GBPAT is largely divided into GUI, linked programs, and data-base. Once the data from the project specifications and building design is collected, users can enter the information and building design [computer-aided design (CAD) files] through the input interface. The input information and data are classified to convert to text files that can be readable for engines/programs. For the evaluation of sustainable and green buildings, GBPAT have two important programs, such as building energy simulation (BES) and cost estimate, along with two data-base sources widely used in the building simulation systems.

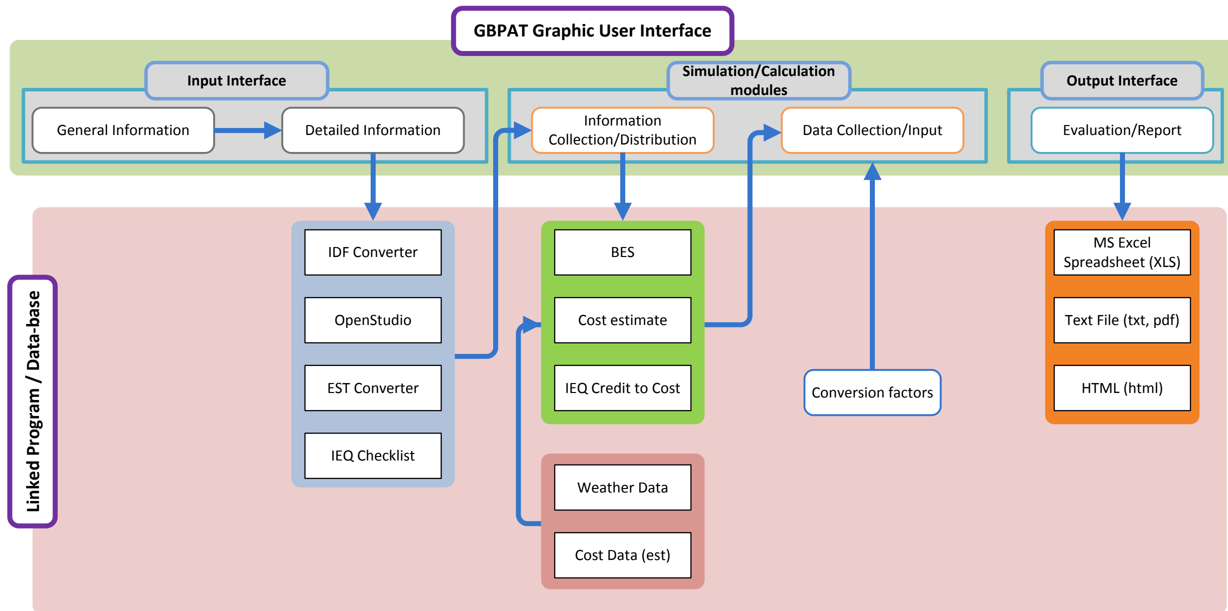


Figure 3.5 Conceptual framework of overall logic for GBPAT

Through the simulation/calculation modules within GBPAT, the data converted into unique text files would be distributed into each BES and cost estimate program. At once, each program imports weather data and cost data from data-base and then the simulation outcomes would be created from BES and cost estimate program.

In terms of programs, BES can only read the text file converted into the file name, Input Data File (IDF) and it provides the information of simulated energy and water consumption for a whole building or components of a building. The cost estimate is the necessary program to estimate construction cost for building project. In order for these programs to run, important data that can only be obtained from external data-base is absolutely needed. Thus, data-base for weather data provided by U.S. DOE and cost data from R.S.Means would be directly imported.

All simulation programs would export predicted outcome in text file or directly Microsoft Excel file (xls); thus, Microsoft Excel program is able to be the main server that collects all outcome information. With the results simulated and converted by the programs, GBPAT can sort the data in the aspects of sustainability bottom line, economy, environment, and human. Moreover, all data having different units, such as energy unit, cost unit, and credit unit, must be generated since GBPAT evaluates building performance in advanced BPI that takes into account the relationship among total LCCs for proposed, reference, and most efficient building. GBPAT collects all outcome data and then classify in the unit of building components since it must create alternative buildings that equip different building components, such as HVAC, electrical system, etc. The example of Microsoft Excel spreadsheet can be shown in Figure 3.6.

F13

	A	B	C	D	E	F
1						
2						
3					Air Handling Unit (AHU)	($)
4						
5				Reference (Baseline)	Proposed	Most-efficient (Optimum)
6						
7		Initial Cost (one-time)			15000	
8		Energy (annual)			1800	
9		Water (annual)			500	
10		OM/R (annual)			400	
11		Replacement (one-time)			0	
12						
13		Total economic cost			17700	
14						
15		GhG emission (annual)				
16		Carbon dioxide			150	
17		Methane			0	
18		Nitrous oxide			0	
19		Ozone			0	
20		Black water			70	
21						
22		Total environmental cost			220	
23						
24		Occupant satisfaction (annual)				
25		Occupant health			250	
26		Occupant productivity			400	
27						
28		Total human cost			650	
29						
30						
31		Total life cycle cost (LCC)			18570	
32						

Figure 3.6 The example of outcome for building components (Microsoft Excel spreadsheet)

Finally, the output interface simply shows the evaluation of green building performance with comparable indexes. In addition, there is the significant function to export the detailed evaluation data to other file forms, such as PDF (pdf) and HTML (html). Conceptual framework for GBPAT along with the detailed factors and indicators is attached in Appendix.

3.2 Integrated Graphical User Interface (GUI) for GBPAT

In programming, a GUI is a type of user interface that allows users to interact with image or icon rather than text commands. In order to use some program or system, the user is required to put the important information that operates them through specific program commands; however, these technical or professional commands prevent the user from using necessary programs due to inconvenience of use. Without the input of program commands directly, the use of images or icons that are pre-programmed by the program developers can encourage users to input data and information more easily as well as importing specific files formatted for other programs. Figure 3.7 shows the comparison text commands to GUI for building energy simulation software.

Especially, in the case of EnergyPlus, GUI is essential since EnergyPlus is the simulation engine, not integrated program including the user interface. A major barrier to the widespread adoption by practitioners of the U.S. DOE's EnergyPlus has been the lack of a comprehensive GUI that would make the program easy and efficient to use (See, 2011). Several products that adopted GUI have so far been developed by third parties from public and commercial sectors, such as

DesignBuilder, Easy EnergyPlus, EFEN, etc. Through investigation of these products using EnergyPlus simulation engine, the following common points were found:

- Efficiency and ease of use
- Data import from industry design applications, e.g., Building Information Models (BIM) and CAD
- Integration of BIM model data with Input Data File (IDF, EnergyPlus file format) model data
- Import of existing EnergyPlus data sets
- Interpretation of simulation results for individual runs
- Comparison of baselines and design alternatives
- Support of ASHRAD Standards or equipment data

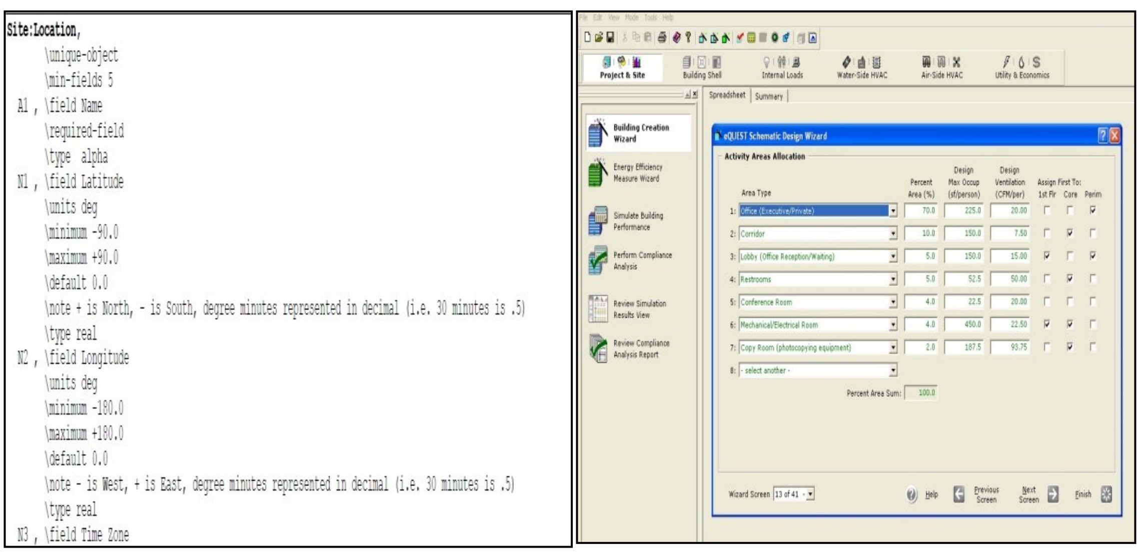


Figure 3.7 Comparison text commands to GUI for building energy simulation software

Furthermore, the overall GUI for GBPAT must minimize essential information and data in order for users to avoid duplicating input of information required for programs linked to overall GUI. To prevent from entering duplicated information and data into GUI, it is necessary to classify the set of information and data needed initially and the sets of information and data classified by similarity of their characteristics would be listed on the input interface.

In terms of simulation and calculation process, GUI has the clear purpose of transmitting classified and collected information along with certain data-base regarding weather and cost to the simulation and calculation programs correctly. However, simulation and calculation are performed by external programs just by linking to GUI of GBPAT, not the function of a normal interface; thus, the function of GUI on this process is to send the information or data in appropriate simulation and calculation programs.

Finally, along with the outcome formed by simulation and calculation process, output interface shows the outcome in the text form and graphical methods so that the user can understand the result more easily. Moreover, GBPAT exports the evaluation reports in various formats, such as the form of Microsoft Excel, PDF, and web page; thus, users are able to convert these outcome data into their preferred forms. Figure 3.8 shows the hierarchies of the GUI of GBPAT.

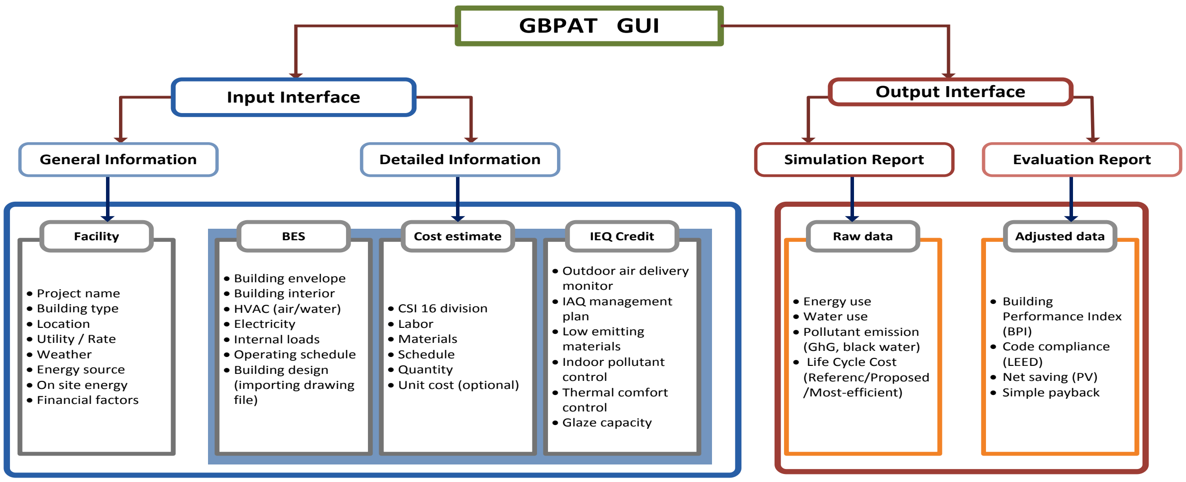


Figure 3.8 Hierarchies of GBPAT GUI

As shown in Figure 3.8, the first stage of GUI for GBPAT consists of two parts to enter general and detailed information related to the proposed building project. In terms of general information, users are asked to enter the information regarding building physical characteristics, such as project name, type, location, weather and occupant's number, and building economical characteristics, such as utility/rate, energy source, onsite energy, and financial factors (discount rate and escalation rate). The achieved information would be divided by simulation engines. Two simulation programs directly linked to GUI of GBPAT require specific information and data to run these engines. For operating the simulation files of BES and the results of cost estimate for baseline and proposed building models are needed.

After simulation and calculation, the GUI for GBPAT reports the accuracy and the detailed simulation outcomes in the text and graphical forms. From the simulation engines and the calculation program, raw output data for the proposed building project customized by users is presented by comparing to alternatives projects, such as the baseline building project and most efficient building project. Raw output data coming from the programs include cost information, energy and water consumption, and pollutant emission

However, it is difficult for users to understand why and how their buildings are sustainable and green from these raw output data; thus, the outcome must be adjusted and compared with existing methods. Simulated and calculated performance results should be compared with affordable index to evaluate accurate and reliable building performance, since users would like to determine how sustainable the building is compared with the baseline building. Furthermore, it would be helpful to estimate how much the building of interest can save money and how long it takes for a building owner to have the payback as a function of the output interface.

3.3 Characteristics of Building Energy Simulation (BES)

Since 1950s, a number of building energy simulation programs have been developed and used throughout the building energy community. The core tools in the building energy field are the whole-building energy simulation programs that provide users with key building performance indicators such as energy use and demand, temperature, humidity, and costs (Drury et al., 2005). Also, Drury’s research shows the overview of comparison of the feathers and capabilities of twenty major building energy simulation programs. For developing GBPAT, BES is the most important component operating the overall system and it must be satisfied with research requirements below:

- GUI feature
- Simulation of internal loads

- Supply of cost information (Construction cost, emission cost, etc.)
- User-defined coefficients (constants, equations, or correlations)
- Possibility of LCCA
- Input of location information (weather data, cost data, etc.)
- Database of information of reference building
- Building standard/code compliance (e.g., ASHREA 2009 version)

There are several BES systems available in the market and they have their own characteristics. Among them, four most used systems, BLAST, DOE-2.1E, eQuest, and EnergyPlus, were compared. The investigation of these systems is illustrated with respect to research requirements. Detailed description and relative comparison for those BES systems are attached in Appendix.

3.4 Essential Data-Base System

In order for GBPAT to operate, the simulation programs are needed to be linked directly to the GUI for GBPAT and to get the external data sets along with the conversion factors that are able to be saved in the independent data-base system. Among the representative simulation programs, some programs are equipped with their own data sets within the internal system or have to take external data sets for building simulation. For the operation of simulation and calculation programs for GBPAT, the essential data-base system is necessary. The fundamental concept of the essential data-base system consists of two main parts as shown in Figure 3.9.

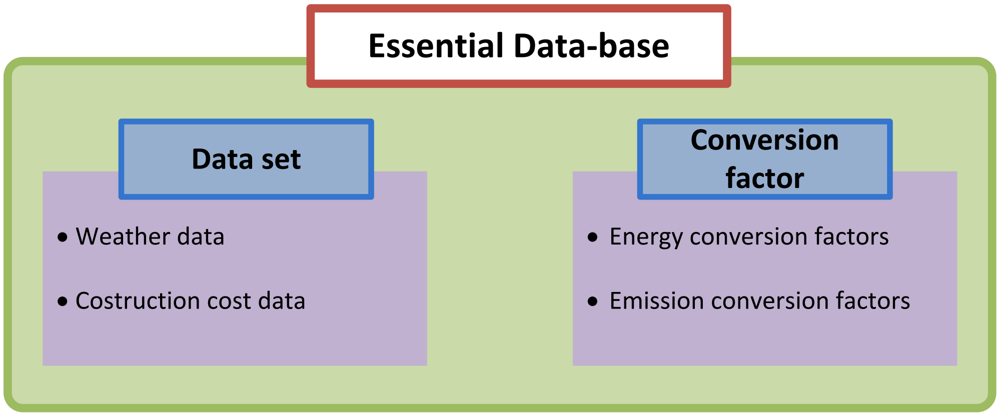


Figure 3.9 Fundamental concept of the essential data-base system

There are two parts that support the simulation programs and calculation process for GBPAT. First, the data set is needed to run the simulation program to generate the outcomes that result from the program operation with the collected data. The programs can bring essential data sets from open resources. Two simulation programs are not operational by themselves without the essential data sets since the building has been simulated in unique conditions, such as location, temperature, solar radiation, labor, materials, and so on. Thus, in order to revise the fixed operation results and to make the simulation programs adjusted for different conditions, the weather data set and construction cost data set are needed.

In terms of the conversion factors, the essential data-base system has a different concept to support simulation programs along with the calculation process. After the simulation programs produce the raw outcomes, the calculation process will be performed in order to create advanced building LCC. GBPAT needs to obtain the advanced building LCC from the raw outcomes that are presented in different units, such as the quantity of energy and waste emission. Several conversion factors are necessary to divert from the simulated raw value to cost unit. The conceptual framework that illustrates the correspondence of each data set and conversion factors to the simulation programs and calculation process is shown in Figure 3.10.

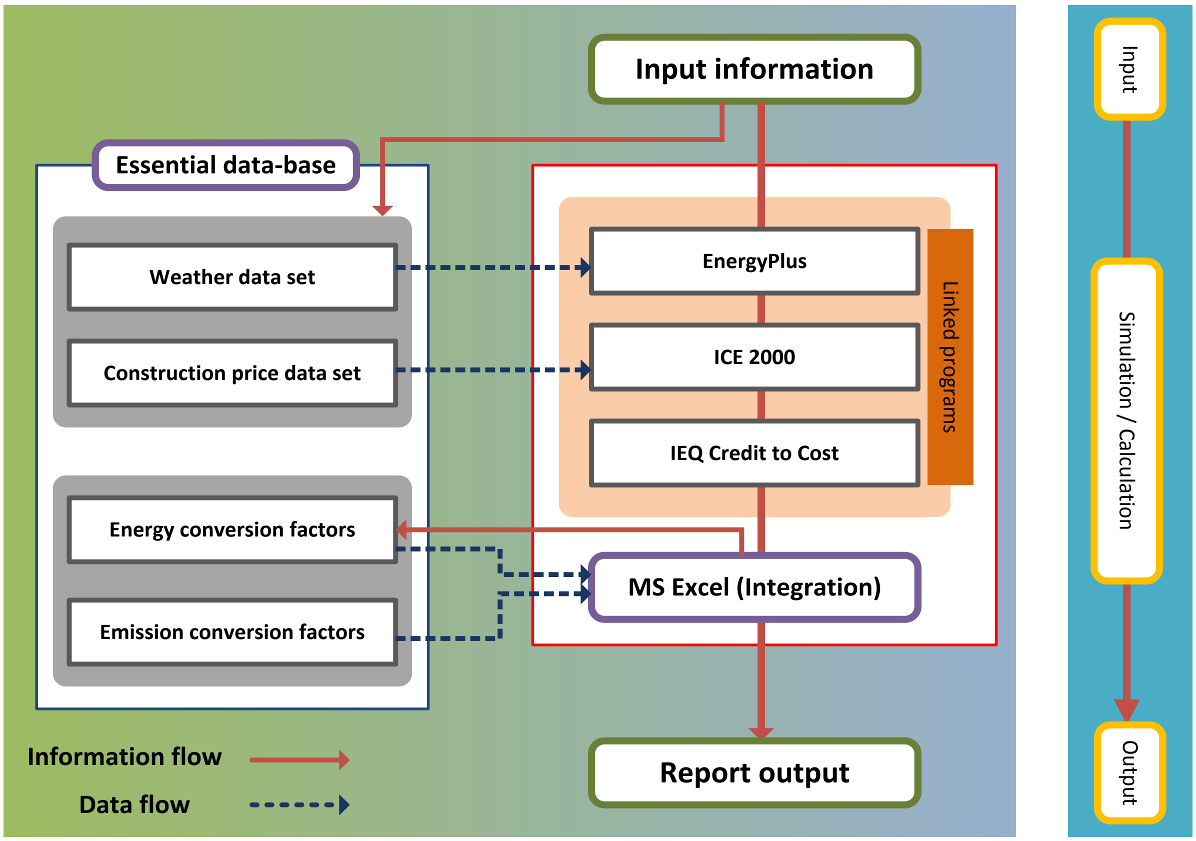


Figure 3.10 Correspondence of data-base and simulation/calculation process

3.4.1 Collection of Data Sets

GBPAT will link the external simulation programs that are BES for the simulation of building energy consumption along with waste emission and the cost estimate program for the estimation of initial costs including construction, design/planning cost, acquisition cost, overhead cost and so on. Because these programs operate with the consideration that the buildings have been constructed under different conditions, they are required to import the data sets having the function of the revision.

Over the past 20 years, several groups have developed weather data sets specifically designed for use in building energy simulations (Crawley, 1997). Typically, weather data sets contain dry bulb, wet bulb, dew point temperatures, wind direction, wind speed, barometric pressure, relative humidity, cloud cover, and a place holder for solar radiation. In case of BES, it has the weather data sets that U.S. DOE has provided. The weather data in BES is a simple text-based format, similar to the input data and output data files. The weather data format comprises basic location information regarding location, data source, latitude, longitude, time zone, elevation, peak heating and cooling design conditions, holidays, daylight saving period, typical and extreme periods along with Typical Meteorological Year 2 (TMY2) weather format that is able to cover 234 U.S locations. Figure 3.11 shows the process that imports weather data set manually in EnergyPlus.

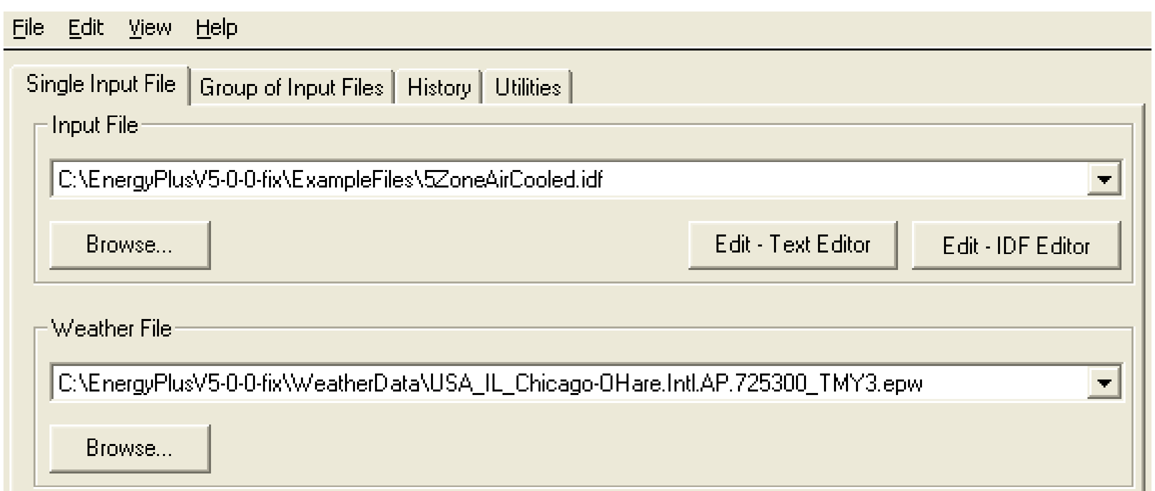


Figure 3.11 Import process of weather data set in EnergyPlus

From the results of the cost estimate program, GBPAT will obtain the building initial costs. In order to use the building estimation programs, several requisites related to project specifications, building design and construction unit price data are required prior to starting estimation. Like other building estimation programs, ICE 2000 as the cost estimate program does not have construction unit price data sets; thus, it is needed to bring the external data sets. RSMeans that is the major company offering accurate construction price data in a construction field has updated the unit price data sets annually. The construction price data sets offered by RSMeans will be equipped with the essential data-base system for users to directly assess ICE 2000 program without duplicating input information. Figure 3.12 shows the example of the construction price data set provided by RSMeans.

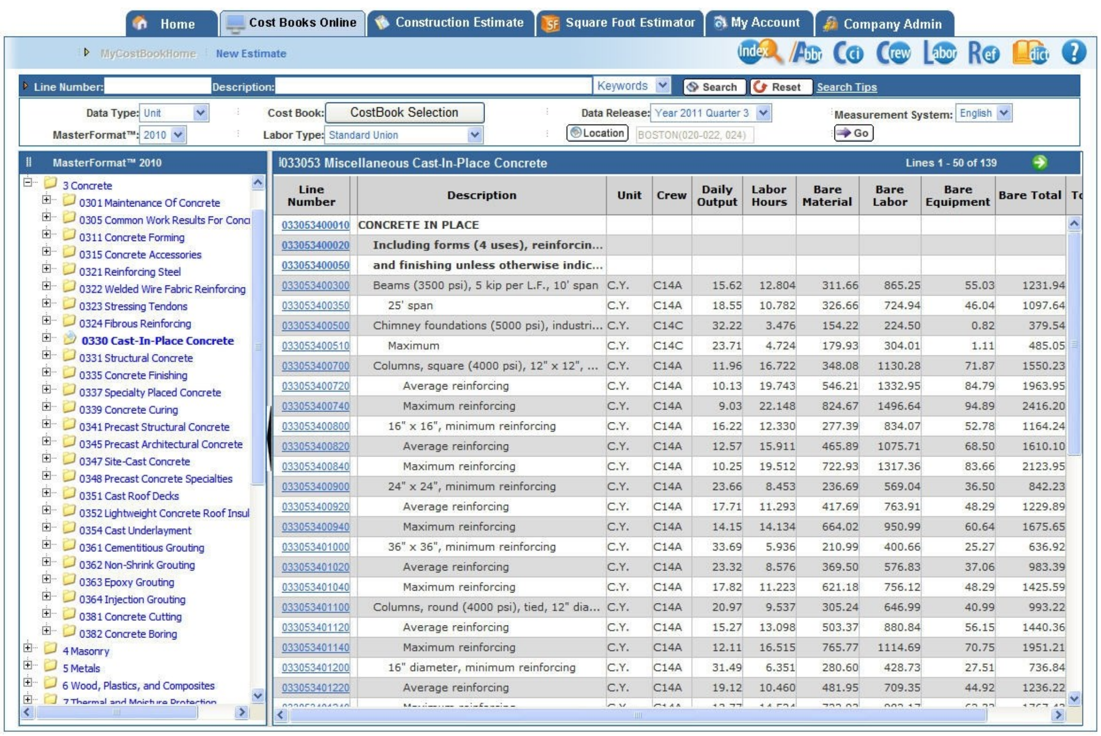


Figure 3.12 The example of construction price data set by RSMeans

3.4.2 Conversion Factors

The most important purpose of GBPAT is to evaluate building performance with cost unit in order to deal with the different simulation outcomes to a comparable index. To revise or convert the raw results (should be 'data set') created by the simulation programs along with required data sets, the external conversion factors that were presented by governments and research centers would be adopted into the essential data-base system in GBPAT. As the cost estimate program already provides outputs in a monetary unit, only the results simulated by BES will be modified. The quantity of energy usages simulated by BES would be presented in energy units, such as kilowatt-hour (kWh) and British thermal unit (BTU) depending on energy sources; thus, some conversion factors are needed to switch from energy to a monetary unit. In addition, with the estimations of building energy and water usages, GBPAT will be able to assess the quantity of waste emissions that are considered to assess negative environmental impacts. In terms of all these outcomes, they would be revised and converted in cost unit since the raw outcomes are presented in different unit (kWh, BTU, ton, and ft^3) depending on energy sources and emission types.

For future costs, the building operating costs including building utilities, such as energy and water consumptions, can be obtained by the simulation of BES. First, in terms of the conversion factor for the quantity of energy to a monetary unit, U.S Census Bureau and U.S DOE sponsored OpenEI publish the energy utility rates by states annually. In case of peak-time energy consumption, current BES programs automatically reflects the peak-time energy usages to total energy usages with weighting factors. In addition, since on-site renewable energy has no open data set to impose utility rate nationally, the quantity of renewable energy would be calculated as the deduction from total energy consumption by type of energy resource that is used in the building mechanical systems. For example, if the building has the photovoltaic panels to generate electricity for lighting systems, the total quantity of solar energy can deduct total quantity of electricity energy since it can save cost of building electricity utility. The data set provided by OpenEI is shown in Figure 3.13.

zip	compid	compname	comrate	indrate	resrate
27529	3046	Carolina Power &	74.34	57.46	90.23
73112	14063	Oklahoma Gas &	66.14	48.58	80.16
59037	12825	Clark Fork & Blacl	83.97	62.87	89.42
28705	3046	Carolina Power &	74.34	57.46	90.23
96134	14354	PacifiCorp.	59.39	40.36	69.43
8554	14940	PECO Energy Co	121.2	81.88	139.07
78832	3278	AEP Texas Centr	0	0	0
35459	195	Alabama Power C	81.85	49.23	89.32
78368	3278	AEP Texas Centr	0	0	0
67432	22500	Westar Energy In	0	0	0
24712	733	Appalachian Powe	52.6	36.59	58.52
72354	814	Entergy Arkansas	71.81	57.46	92.02

Figure 3.13 National electricity rate data set (OpenEL)

Within the essential data-base system in GBPAT, the significant conversion factors are used to switch the quantity of waste emission to cost unit. In case of gas emission, GHG emissions are usually considered as a key factor. Under the Koto Protocol, participating countries must decrease the quantity of GHG unless the country purchases the cap and trade of GHG, especially carbon dioxide. The GHG emission can be assessed in market price as social duty and thus, most LCC programs have reflected the GHG emission costs to total LCC recently. On the other hand, there is no published or provided data set to convert black water disposal to cost unit. In terms of social cost, the water bill already reflects the sewer cost. Therefore, the user would enter water and sewer utility rate manually on GUI for GBPAT.

There are two GHG emission types widely generated in a building operation, such as direct and indirect emissions. In general, direct emission is referred as emissions from on-site boilers used for heat and hot water, on-site electricity generation, including co-generation, industrial processes, and fugitive emissions. On the other hand, indirect emission means emissions from purchased electricity and steam generated off-site and consumed on-site. Thus, all of direct and indirect emissions would be considered and they all have to be converted to cost unit in GBPAT. In order to switch energy usages to cost unit, there are three conversion factors at three steps as shown in Figure 3.14.

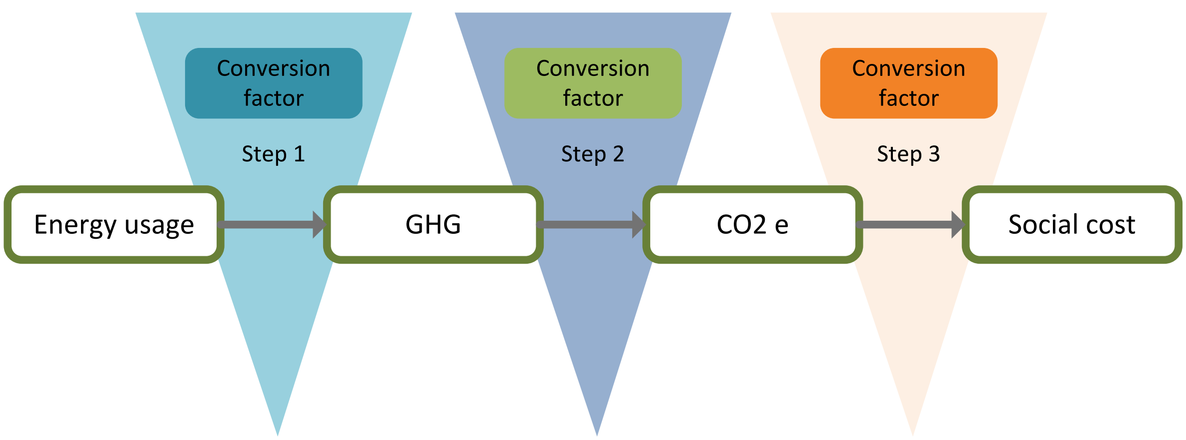


Figure 3.14 Conversion factors and process for estimating GHG emissions

First, depending on the types of energy sources, such as electricity, natural gas, coal, etc., the quantity of GHG emissions varies; thus, the conversion factors replace the quantity of each energy resource, especially electricity and natural gas, with the quantity of types of GHG emission. The major types of GHG consist of the following gases:

- CO_2 - carbon dioxide
- CH_4 - methane
- N_2O - nitrous oxide

These three gases account for 98% of total GHGs; thus, the assessment of their quantity can provide the degree of GHG emissions for building operation. U.S. Energy Information Administration (EIA) has published GHG emissions by fuel types. Next, with the revised data generated by the conversion factor in Step 1, CH_4, and N_2O would be switched to the quantity of CO_2 since only carbon can be assessed in cost unit. U.S. EPA provides – CO_2 equivalent factors that convert other GHGs to CO_2 values with the calculation of Global Warming Potentials (GWP). Table 3.1 shows the equivalent factors.

Table 3.1 CO_2 equivalent with GWP (U.S. EPA, 2007)

Chemical	Global Warming Potentials (GWP)
CO_2	1
CH_4	21
N_2O	310

Finally, the quantity of CO_2 equivalent revised from the quantity of different types of GHGs with the above conversion factors can be obtained. There are two approaches used widely to assess costs of CO_2 equivalent: that the assessment of carbon tax and the prediction of social cost of carbon (SCC). Nowadays, the U.S. Government has tried to pass the carbon tax to address the climate change issue. The carbon tax would be essential to reduce GHG emissions. Some researchers and U.S EPA present the initial rate of carbon tax and annual increments.

Table 3.2 Proposed carbon tax rate and annual increments

Proposal	Initial rate ($/T CO_2E)	Increase/year
Cantwell – Collins	$14 (±7)	6%
Krupnick: Waxman – Markey equiv.	$18	8%
U.S. EPA equiv (% increase)	$21.5	6%
U.S. EPA equiv (step increase)	$10	$3.5

The other approach is to assess the social cost of carbon. According to Greenstone (2010), the key step of the social cost of carbon (SCC) is to determine the monetized damages associated with an incremental increase in carbon emissions. Monetized estimates of the economic damages associated with CO_2 emissions allow the social benefits of regulatory actions that are expected to reduce these emissions to be incorporated into cost-benefit analyses.

The U.S. Government recently provided four SCC estimates for use of the conversion factors that are $5, $21, $35, and $65 depending on annual discount rates. The values of $21, $5, and $35 are associated with discount rates of 3%, 2.5%, and 5%, reflecting that much of the damages from climate changes are in the future (Greenstone, 2010). Especially, it is the SCC value for 95th percentile at a 3% discount rate; thus, $21 per ton of CO_2-equivalent emissions would be the central value. Table 3.3 classifies the SCC value with the discount rates.

Table 3.3 SCC values with discount rates

Fixed discount rates	Social cost of carbon (2007 $)
5%	$5
3%	$21
2.5%	$35

With these values of CO_2-equivalent emissions as a conversion factor, GHG emissions are able to be presented in a monetary value in GBPAT.

3.5 Estimation of occupant satisfaction in GBPAT

As mentioned in the previous chapters, green buildings are defined as ones that have significantly reduced or eliminated negative impacts on the environment and the occupants. According to EPA and the U.S. Consumer Product Safety Commission (1995), the people spend about 90% of their time indoors and thus indoor environmental quality is critical. The researchers also argue that pollution levels of indoors may be higher than those of outdoors (Hoskins, 2003). According to Singh et al., (2010), the effect of IEQ in office buildings on employee health, well-being, and productivity is an important topic on the evaluation of green building performance. Several studies have proved that controlling IEQ can negatively or positively affect occupant's physical health regarding Acute Respiratory Infects (ARIs) through poor air quality, extreme temperatures, excess humidity, and insufficient ventilation and psychological health regarding depression and stress through inadequate lighting, acoustics, and ergonomic design. By these risk factors as mentioned above, the studies have shown that employees with such adverse health conditions are absent frequently losing work hours and are less productive compared with green buildings with improved IEQ to conventional buildings.

Given the large impact of poor IEQ on the health and comfort of building occupants, it is not surprising that recent surveys of occupants suggest that IEQ is one of the most important factors of job satisfaction (Kats, 2003). According to the study that was conducted to 1800 office tenants by Building Owners and Managers Association(1999), the tenants put the highest importance to comfort features, including comfortable air temperature (95%) and indoor air quality (94%). The effects of air quality, humidify, lighting, temperature, views, and acoustics on building occupants have been studied so far. Through these effects on building occupants, changes in occupant's absenteeism and health symptoms of asthma, flu, colds and allergies regarding sick building syndrome (SBS) are created. The Center for Building Performance Diagnostics (CBPD) at Carnegie Mellon University investigated the several studies related to health and productivity impacts on building occupants as shown in Figure 3.15.

As shown in Figure 3.15, depending on the researchers, the different range of improvement rates can be presented since most studies are based on the survey, not the experimental method. According to the research from CBPD, improved IAQ, access to the natural environment and high performance lighting systems were able to increase the benefits of health and productivity on building occupants with average range from 3.3 % to 43%. However, there is limited data on health and productivity improvements in green buildings specifically since no agreement for evaluation of IEQ on the field of green building construction exists.

Figure 3.15 Health gains from improved indoor air quality (CBPD, 2007)

In terms of estimating health and productivity benefits on building occupants, there are few studies considering occupant health and productivity gains with economic benefits. One approach would involve assuming modest health improvements and estimating the monetary value of such improvements. Fisk (2002) divided the health benefits provided by better building with improved IEQ into four principal areas including acute respiratory illness, allergies and asthma, sick building syndrome symptoms, and direct productivity gains. Based on his approach that combined source of potential impacts with potential annual health costs, the potential health gain with economic impacts can be created as shown in Table 3.4.

Table 3.4 Estimated health benefits of green buildings

Potential impact	Estimate method	Present value of 20 years of impact	
		$/ft^2$	$/m^2$
Reduced health care costs for green building occupants and employers	Assumed 1% reduction of $3,000 per occupant in health care costs	$2.0	$0.19
Reduced respiratory infections, allergies, and asthma	Scaled-down national savings estimates	$1.0	$0.09
Productivity increases from improved work environment	Assumed 0.5% improvement, based on $50,000 in annual employee value	$13	$1.21
Productivity increases from reduced sick-building syndrome	Scaled-down national estimates	$12~35	$1.1148 ~ $3.2515

For instance, if the annual health cost was estimated to be $3,000 per occupant and diminished by 1% with improved IEQ, this improvement would be valued at $30 per employee in the first year, and the present value of a 1% reduction in health costs over 20 years would approximately $2/ft^2 under the assumption that the building area is 230 ft^2, discount rate is 7% and the annual increase in health care costs is 3%. However, it is hard to clearly distinguish the difference between the improved and poor IEQs; thus, the establishment for improved IEQ should be defined clearly in advance.

The other approach that was studied by Singh (2011) involved the use of the case studies to compare LEED-rated buildings with conventional buildings with using the IEQ related incremental costs and occupant well-being and productivity based benefit with LCCA framework. According to the study, "Life Cycle Cost Analysis of Occupant Well-being and Productivity in LEED offices" published by Michigan State University, all LEED IEQ credits were found to have potential relationships with the selected well-being and productivity conditions. Thus, the accomplishment of IEQ credits can be directly related to occupant's health conditions, and the well-being and productivity on LEED-certified building occupants can be assessed by pre- and post-occupant survey that asks occupants about health problems including asthma, respiratory allergies, depression and stress. Table 3.5 shows the annual economic benefits from occupant well-being and productivity improvement.While the first approach proposed by Fisk (2002) involves the estimation of the economic value of occupant well-being and productivity with the health care costs and annual employee value, the second approach above uses AWHs by improved IEQ with average hourly wages of occupants on green buildings as shown in Table 2.3. In addition, the research using this approach compared the economic value of occupant well-being and productivity with the incremental costs that were used to meet LEED IEQ requirements as the method of LCCA including benefit-cost ratio, payback period and rate of return. Although this study was the important step to evaluate occupant well-being and productivity with economic value, the relationship between LEED IEQ credits and the change of occupant's health and productivity costs is hard to validate.

Table 3.5 Annual economic benefits from occupant well-being and productivity improvements (Singh, 2011)

	AWH	CS 1	CS 2
Average hourly wage- WA		$30.94	$29.99
AWH from reduced Asthma/Allergies per year	1.75		
$ Benefit/occupant - $0c (WA x AWH)		$54.15	$52.48
Applicable occupant number – n' (W/MH)		20	69
Monetized benefit/year (n' x $0c)		$1,103	$3,596
AWH from reduced Depression/Stress per year	2.02		
$ Benefit/occupant - $0c (WA x AWH)		$62.50	$60.58
Applicable occupant number – n' (W/MH)		15	85
Monetized benefit/year (n' x $0c)		$955	$5,122
AWH from improved Productivity per year	38.98		
$ Benefit/occupant - $0c (WA x AWH)		$1,206.13	$1,168.97
Applicable occupant number – n' (W/MH)		56	207
Monetized benefit/year (n' x $0c)		$67,534	$241,976
Total $ benefit/year from improved occupant well-being and productivity		$69,601	$250,694

(AWH is Additional Work Hour)

While literature provides sufficient background to hypothesize such well-being and productivity benefits as a result of improved IEQ in buildings (Newsham et al., 2009). Although there are some approaches on estimating economic value for occupant health and productivity on green building with improved IEQ, the quantitative method for assessing indoor environment quality can be switched directly to economic value due to lack of data-base and agreement of the field.

3.6 Creation of Comparable Building Simulation Models for GBPAT

In order to evaluate green building performance, GBPAT provides the comparable performance index that has 1 to100 scale. According to Bordass (2002), the relative benchmarks are referred as a benchmark that provides a more closely related, comparatives measure for a similar, clearly defined or reference building type, such as a standard or prestige office building. From the initial stage of GBPAT to final evaluation and the report process, there are three simulation building models that are created by GBPAT complying with the standards of green buildings, such as ASHRAE Standard 90.1 and LEED certification system. The benchmarks are needed to compare how much green and sustainable the projected building that the user customizes will be. Especially, both the baseline benchmark as the lowest index and the most green and sustainable benchmark as a highest one are required to develop the BPI along with the score of 1 to 100 that is widely accepted, easy to understand and comparative. If there exists only the bottom-line on BPI for the green BPE, the scale of the BPI cannot be limited since the green performance of the projected building can be compared with only the baseline building.

On GBPAT, two building simulation models, baseline building and proposed building, are created by the user entering the general and detailed information of the building of the interest, such as building types, building location, building size, building envelope, lighting systems, HVAC systems, SWH system, etc. On the other hand, the simulation model for the proposed building is created by the user's input directly; the baseline building model for the baseline would be generated by the collection of the most similar reference buildings that correspond to the proposed building under three major conditions, such as building type, building location, and building size. In order for GBPAT to create comparable indexes, the standards for green building strategies related to how to make green building are adopted. It means that the baseline building that only meets the minimum requirements in terms of three sustainable aspects for green buildings that shows higher cost-effective performance along with higher environmental and social performance are simulated for the proposed buildings that the user customizes to be compared and evaluated with a numerous scale.

In order to create a baseline building model in terms of energy efficiency, ASHRAE Standard 90.1 for a building energy design was used. ASHRAE Standard 90.1 standard presents minimum requirements for energy efficient designs of green buildings. Thus, it provides the strategies to improve energy and water cost saving. ASHRAE has published this standard per every three years and hence the upgrade version of ASHRE Standard 90.1 has showed improved energy saving performance as shown in Figure 3.16.

U.S. DOE expects that the building that meets ASHRAE Standard 90.1 2010 can save approximately 30% of the total energy consumption and costs for the building that was built with ASHRAE Standard 90.1 2004. LEED certification and Energy Star building rating system have used ASHRAE 90.1 2004 as a prerequisite standard of building energy simulation. Both methods give the points related to energy performance comparing the proposed building with the reference building that is designed by ASHRAE 90.1 standard 2004. U.S. DOE provides the 90.1 prototype building models that were developed by Pacific Northwest National Laboratory (PNNL). The 90.1 prototype building models that cover 80% of the commercial building floor area in the U.S. for new construction include 16 building types in 17 climate locations for each version of ASHRAE 90.1 Standard 2004, 2007, and 2010 (U.S. DOE, 2011).

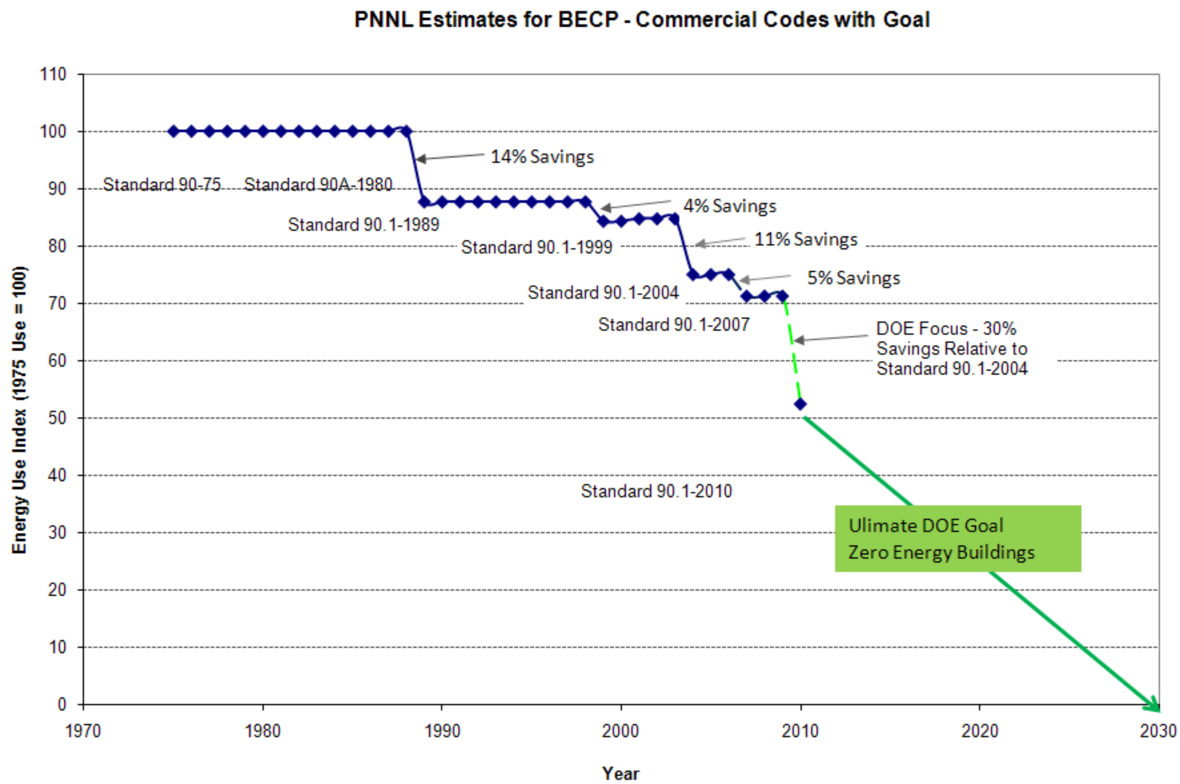


Figure 3.16 ASHREA 90.1 standard energy efficiency (U.S. DOE, 2011)

For LEED certification, building energy simulation to evaluate building energy consumption and costs is conducted by comparing with building energy models designed by ASHRAE Standard 90.1 (2004). The appropriated points can be achieved depending on which percentage the building models might save energy consumption and costs against the baseline building similar to ASHRAE 90.1 prototype building models. In addition, ASHRAE Standard 90.1 (2010) and ASHRAE Advanced Energy Design Guides show that the buildings with these standards are capable of achieving approximately 30~50% improved energy performance more than the building with ASHRAE Standard 90.1 (2004).

The building that meets the requirements for ASHRAE Standard 90.1 (2010) and ASHRAE Advanced Energy Design Guides would obtain full points regarding energy efficiency of building performance. On the other hand, the prototype building modeled by ASHRAE Standard 90.1 (2004) can be used as the baseline building to measure the improvement of building energy efficiency. Although building energy simulation does not correctly correspond with actual building performance due to several potential factors, such as building types, building characteristics and occupant's behaviors, these reference buildings that are designed with the building standards are needed to evaluate and compare conditioned building performance to baseline or efficient basis. Moreover, the consideration of environmental impacts, such as GHG emissions, as a viewpoint of sustainability of building performance can be handled with ASHRAE Standard 90.1 since the standard deals with the power systems as a factor of direct emission and the entire energy use systems on a green building as a factor of indirect emission.

Although ASHRAE Standard 90.1 is able to manage the minimum requirements for building energy performance, it is insufficient to cover other aspects of building performance regarding building water efficiency and Indoor Environmental Quality (IEQ). In terms of water efficiency on green buildings, the U.S. DOE provided Energy Policy Act of 1992 fixture performance requirements as a baseline of building water plumbing systems. In the case of LEED certification, the building models that meet the fixture performance requirements on Energy Policy Act of 1992 are used as a baseline building model that can be compared with a proposed building model in order to measure the water efficiency. Thus, the parts of water plumbing and wastewater systems for the reference building and in GBPAT would be designed under the compliance of Energy Policy Act of 1992 fixture performance requirements.

For ASHRAE Standard 90.1 and Energy Policy Acts of 1992, they are not sufficient enough to fully expect IEQ performance on a reference building model. Thus, additional IEQ requirements are required to improve occupant’s health and productivity for operating IEQ credit to cost calculation. Therefore, for baseline building model, it assumes that the model has no extra credit related to IEQ critical factors, such as outdoor air delivery monitor, increased ventilation system, indoor pollutant source control, etc. that are able to improve occupant’s health and productivity. Finally, the reference building model can be designed with the integration of ASHRAE Standard 90.1 and Energy Policy Acts of 1992 fixture performance guides as shown in Figure 3.17. The baseline building model must be created under the same conditions from the proposed building model, such as building size, building operating schedule, number of occupants, and internal loads (personal electricity instruments) in order to eliminate other variables that impact on building performance.

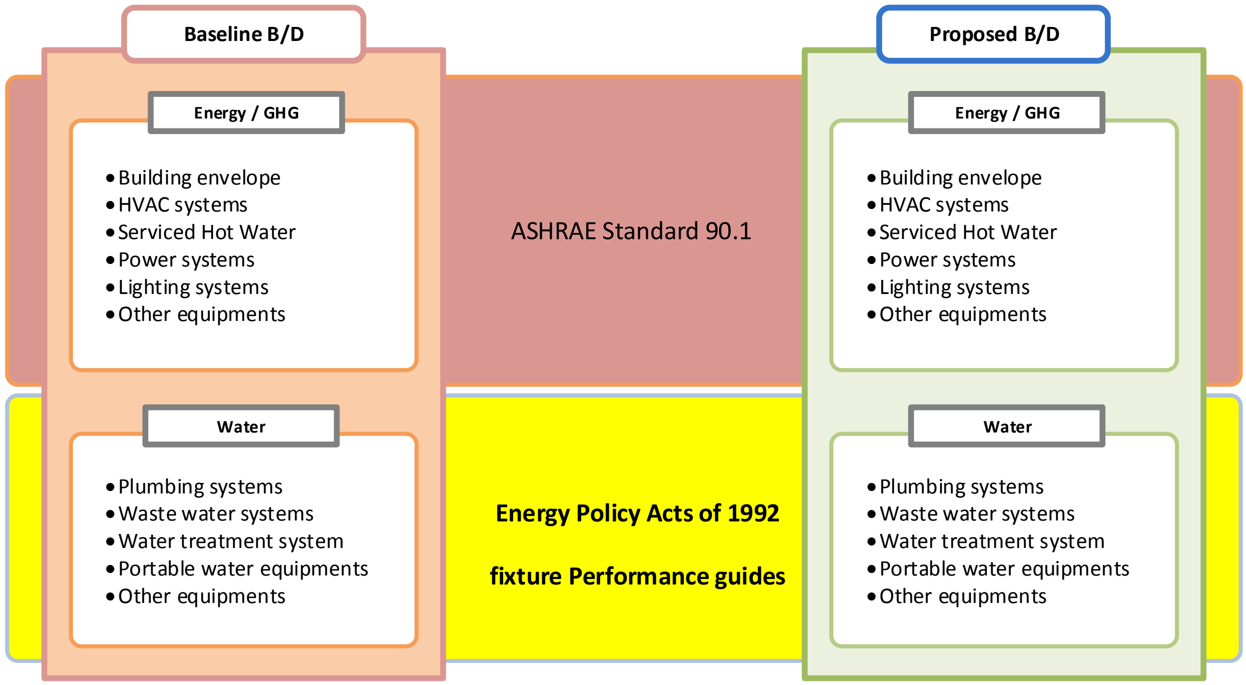


Figure 3.17 The creation of building simulation models with ASHRAE 90.1 and Energy Policy Acts of 1992

3.6.1 Building Performance Index (BPI) and Cost-Effectiveness Index (CEI)

In order to assess green building performance that is represented with the integrated LCA and LCCA method, the system of the performance index or metrics would be necessary as the comparison of the proposed building's LCC relative to baseline building is insufficient for the user to understand easily. Building performance metrics are intended to explicitly represent the performance objectives for a building project, using quantitative criteria, in the dynamic, structured format (Hitchcock et al., 2002). In the green building project, the energy use intensity (EUI) is usually used as energy efficiency metrics and the representative green building rating systems (LEED, BREEAM, etc.) provide the appropriate points or credits. Using the integrated LCA and LCCA approach that comprises initial costs and future costs for two building models, the BPI for GBPAT is provided with numerical scales to help the user in using the simulation results produced through all process of GBPAT.

In addition, the cost effectiveness index should be needed with respect to cost-benefit. As a significant purpose of this research, the information regarding the ratio of the investments for a green building and the integrated LCA and LCCA method during the operation of a green building must be provided to the user. Although BPI in GBPAT can represent overall greenness and sustainability of the proposed building that the user customizes, it is limited to the analysis of the investment versus cost saving that the user expects. Thus, GBPAT will provide two types of indexes: advanced BPI to evaluate the overall green building performance and CEI to identify the feasibility of investments for more green building projects.

For BPI in GBPAT, the integrated LCA and LCCA results for reference building and proposed building were compared. Once each of the advanced LCCs for two building simulation models is obtained, BPI in GBPAT can be calculated as follows:

$$\frac{\text{Reference B/D LCC} - \text{Proposed B/D LCC}}{\text{Reference B/D LCC}} \times 100 = \text{Relative BPI} \qquad (3.4)$$

To establish BPI for assessing green building performance, the LCC for the reference building simulation model is deemed as a basis. In contrast, the difference between the LCC for the reference and the proposed building models is considered as a practical improved building performance.

For example, it assumes that there are two LCCs for each of reference building and proposed building models through the simulation and calculation processes in GBPAT, which are \$176/ft^2/year and \$122/ft^2/year,. They assumed that LCCs for each of three buildings can be created under the premise that if buildings are more green and sustainable, buildings spend less money. Moreover, the difference between the LCCs of the reference building model and the proposed building model can be calculated to be \$54/ft^2/year and hence, \$54/ft^2/year is the practical improved performance. Through these calculation processes, the advanced BPI for the proposed building model that the user would like to simulate is estimated to be 30.7% and thus 31st percentile. In addition, this BPI point can be intended to be placed at the 31st percentile of high performance among the green buildings that follows ASHREA Standard 90.1.

Economic benefit-cost ratios have been developed for various criteria to help the developers and designers to identify the economic impact and cost effectiveness of an environmental assessment scheme (Chau, 2000). With the comprehensive green building assessment tools based on the life cycle assessment method that considers only environmental impacts, the building project participants, such as owners, project managers, designers, and general and sub-contractors, are difficult to understand the information regarding cost effectiveness for application of green building technologies. Thus, GBPAT provides CEI for users to easily catch the feasibility of the investments for green building technologies to their building projects. To represent practical CEI, it would be calculated by the proportion of incremental rate, not simulated LCC of building models. In addition, CEI in GBPAT is created by only the comparison between initial and future costs for each of the reference building model and the proposed building model since it represents the ratio of initial costs as an investment to future costs as a cost saving, and it is only the comparison to assess the improvements of the proposed building model more than the reference building model as a baseline. Hence, with these premises, the following equation can be established:

$$\text{Cost Effectiveness Index} = \frac{\frac{\text{Reference B/D future cost of the reference building}}{\text{Reference B/D future cost}}}{\frac{\text{Proposed B/D initial cost} - \text{Reference B/D initial cost}}{\text{Reference B/D initial cost}}} \quad (3.5)$$

In Equation 3.5, the part of the numerator is intended as the incremental rates of cost saving and the denominator is to present the incremental rates of the investments for the green features on the proposed building model. Also, all of incremental rates for the investments and cost savings are shown in a finite decimal or a minus decimal in the case of decreased building performance. For validation of BPI and CEI in GBPAT, existing supplementary measures are also applied to analysis phase of green building performance. According to Fuller and Petersen (1995), the supplementary measures are Nest Savings (NS), the Savings-to-Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), and Simple Payback (SPB).

CHAPTER 4. EMBODIMENT OF GBPAT

4.1 Procedure of development for GBPAT

GBPAT was developed following the procedures shown in Figure 4.1. Initially, the major objectives described in Section 1.3 were established by conducting literature review and evaluating the comparable programs, such as BLCC and Harvard LCC calculator. There are a few LCC programs presented in the commercial and institutional field for the building sector

Once the conceptual framework regarding GUI, input and output, linked programs, database, etc. is established, the initial program was developed using Microsoft Excel program in order to confirm whether the program logic and the calculation methods can estimate the total LCC based on the integrated LCA and LCCA approach as expected. Moreover, the Microsoft Excel version of GBPAT was used to compare to the results by the stand-alone version of GBPAT.

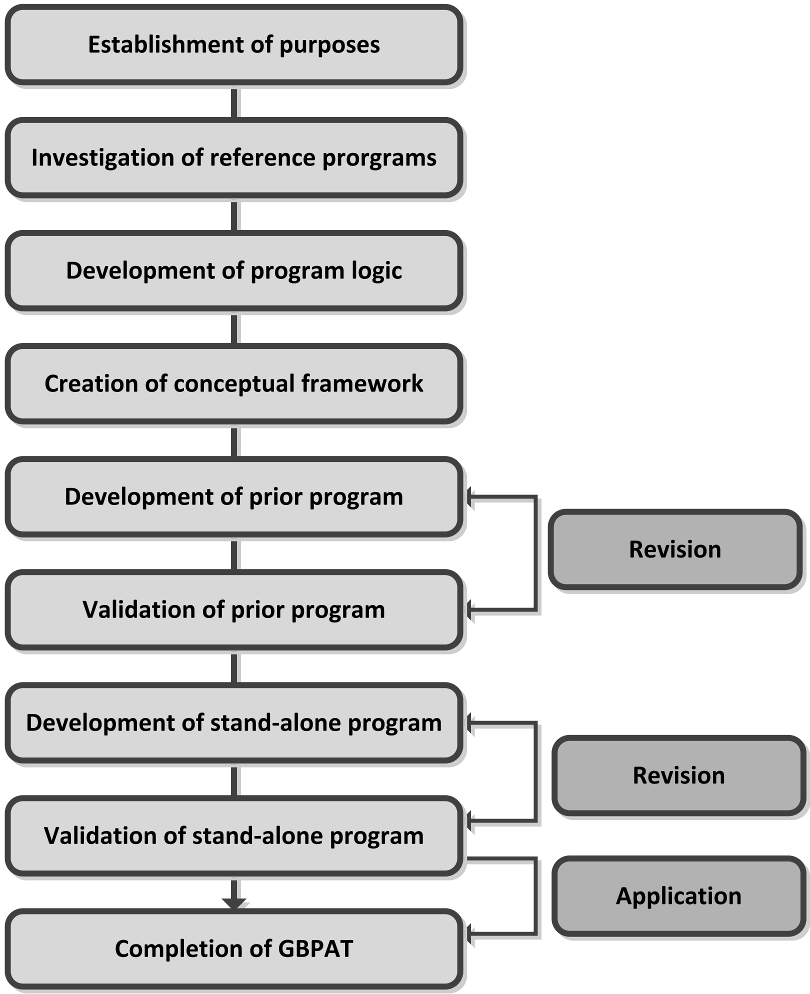


Figure 4.1 Detailed procedures for the development of GBPAT

After Microsoft Excel version of GBPAT is validated and refined, the stand-alone GBPAT program was developed using visual C# program. Along with all functions on Microsoft Excel version of GBPAT, the stand-alone program of GBPAT was made for the fulfillment of the GUI which is independently operating under Windows OS. Finally, GBPAT developed in the stand-alone version was validated by comparing the result from Microsoft Excel version with that from the existing LCC programs.

4.2 Programming of GBPAT

As mentioned in the previous section, GBPAT was embodied in the two versions which were developed using Microsoft Excel and Visual C# express. While those two versions were made with same program logic and the operation progress of the program, the stand-alone program by Visual C# express has only GUI and the database which is required for the simulation programs. The program processing of GBPAT is preceded in following steps as shown in Figure 4.2.

Figure 4.2 The five steps of the program processing in GBPAT

The project information, data, equations, conversion factors and indexes are needed to run GBPAT. The first data input is the information regarding the baseline and proposed building models for the project. Therefore, categorizing the input factors that are mandatory information was the most significant step in the development of GBPAT. There are three parts on the input interface for GBPAT: the general information, financial factors and detailed information. First, the general information part requires the building characteristics, level of LEED, expected life span, operation days, etc. Once the general information is provided, GBPAT analyzes the comparable performance with other projects that are classified as a similar project. The user interface of the required general information in GBPAT is shown in Figure 4.3. The Microsoft Excel version of GBPAT is attached in Appendix 4.1 and the coding of the stand-alone version using C# language is attached in Appendix 4.2.

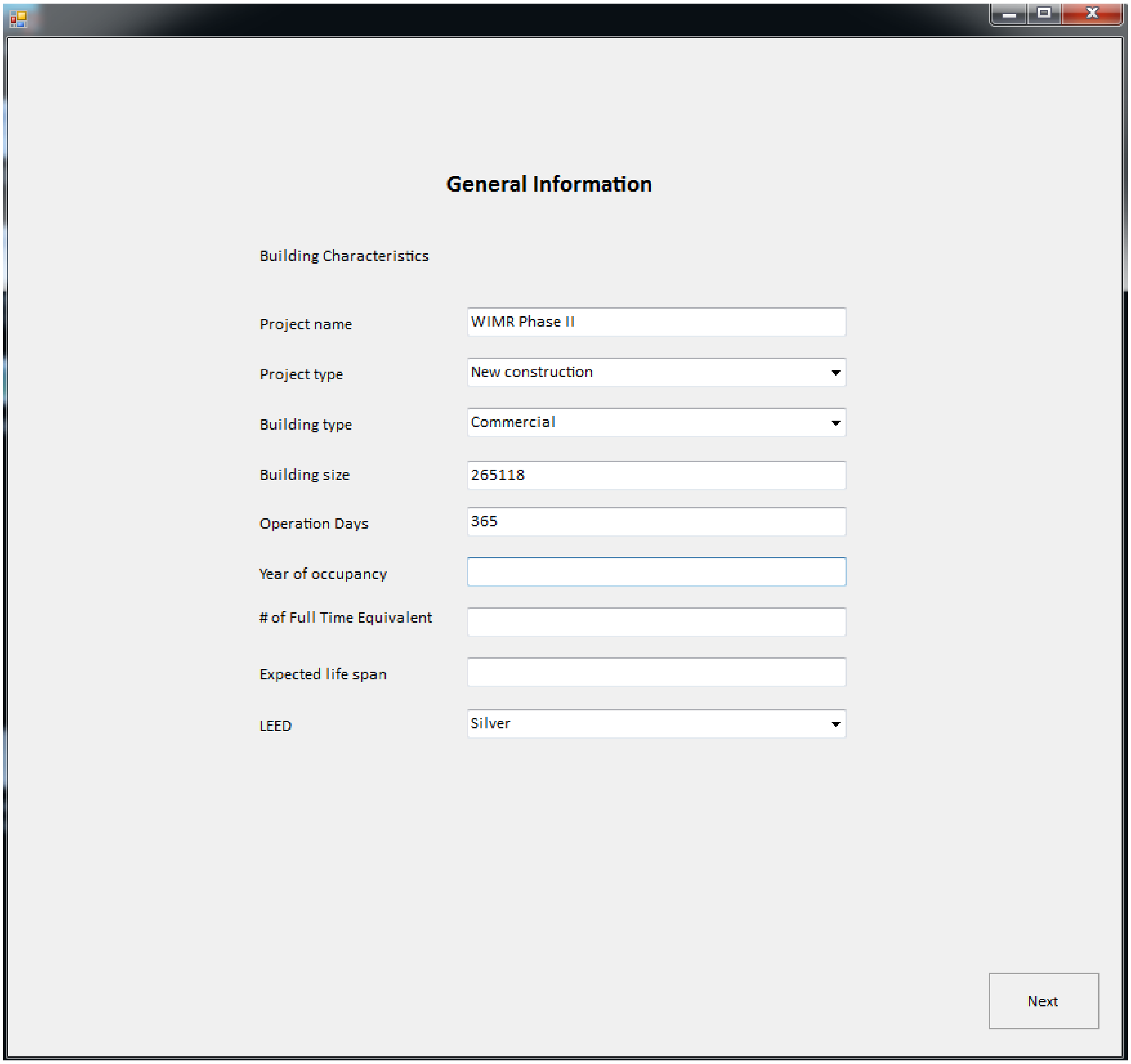


Figure 4.3 User interface of the general information (Stand-alone version)

Next, the future costs are required to convert the present value in the course of estimating the total LCC. The uniform present value (UPV) transferring future costs to present costs consists of the combination of the discount rate and escalation rate as follows (Life cycle costing manual 1995):

$$\text{Present cost} = \text{A} \sum_{t=1}^{n} \left(\frac{1+e}{1+d}\right)^{t} \quad (4.1)$$

where A = annual recurring cost;

t = life span;

d = discount rate; and

e = escalation rate.

Therefore, it is necessary to have escalation rates for energy, water, emissions and maintenance costs to calculate the UPVs. Figure 4.4 shows the input interface for the discount rate and the escalation rates in GBPAT.

Finally, the previous input interfaces are the first step to prepare for the total LCC, whereas the input interface for the detailed information regarding the initial investments, energy consumption, and water consumption is to estimate the expected total LCC. Before estimating the future costs that consist of the costs of energy, water, emission, maintenance, and occupant health, the initial investments of the baseline and proposed building models must be entered. The initial investment costs mean only the construction costs since it would be compared with the sustainable items making the building project to be green. Moreover, the initial investment for baseline building model is the cost estimate for the building project designed under ASHRAE Standard 90.1 and EPAct of 1992 as mentioned in Section 3.6. By entering the initial investment costs for the baseline and proposed building models, the cost premium can be calculated. The input interface of the initial investment costs is shown in Figure 4.5.

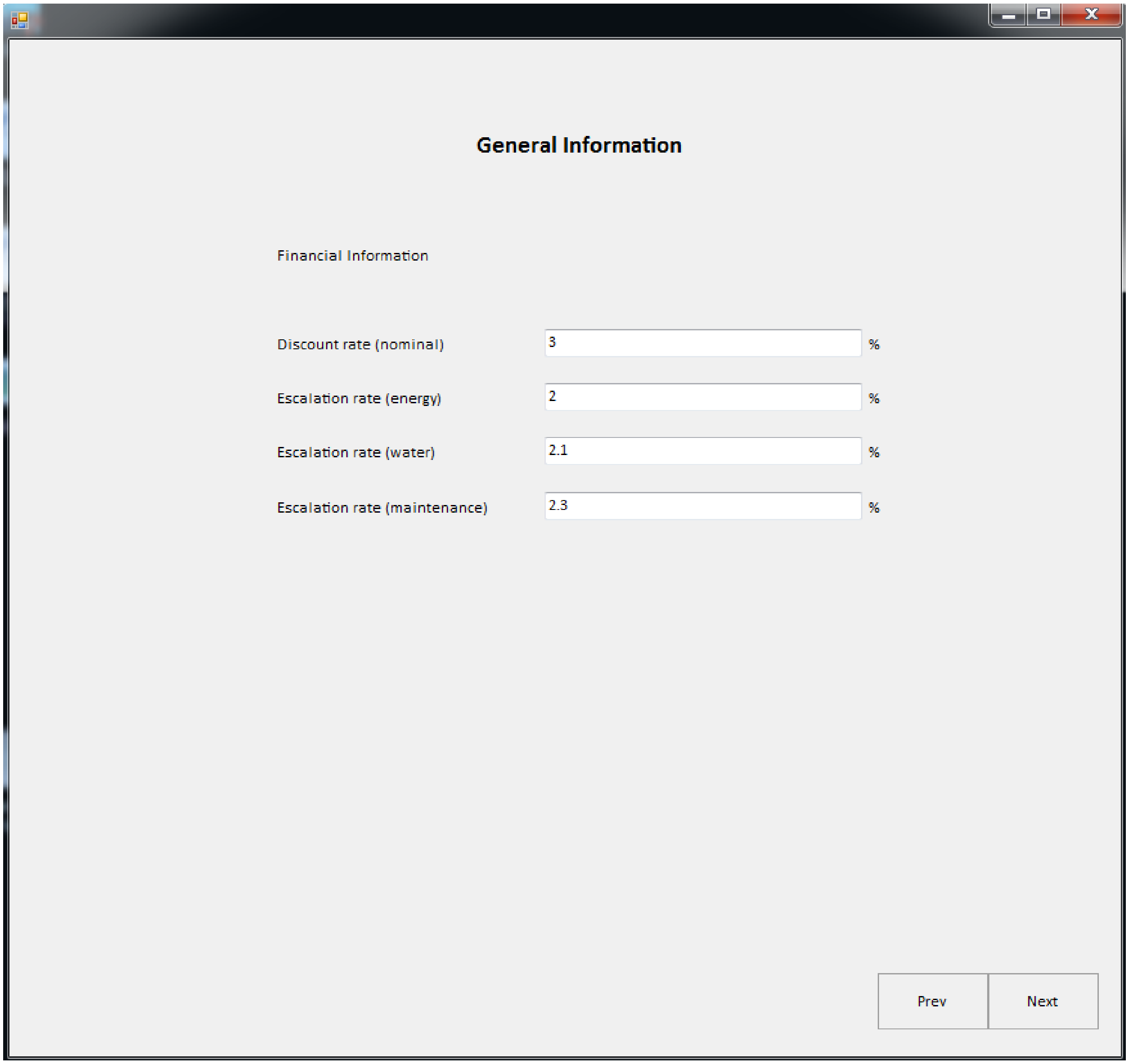
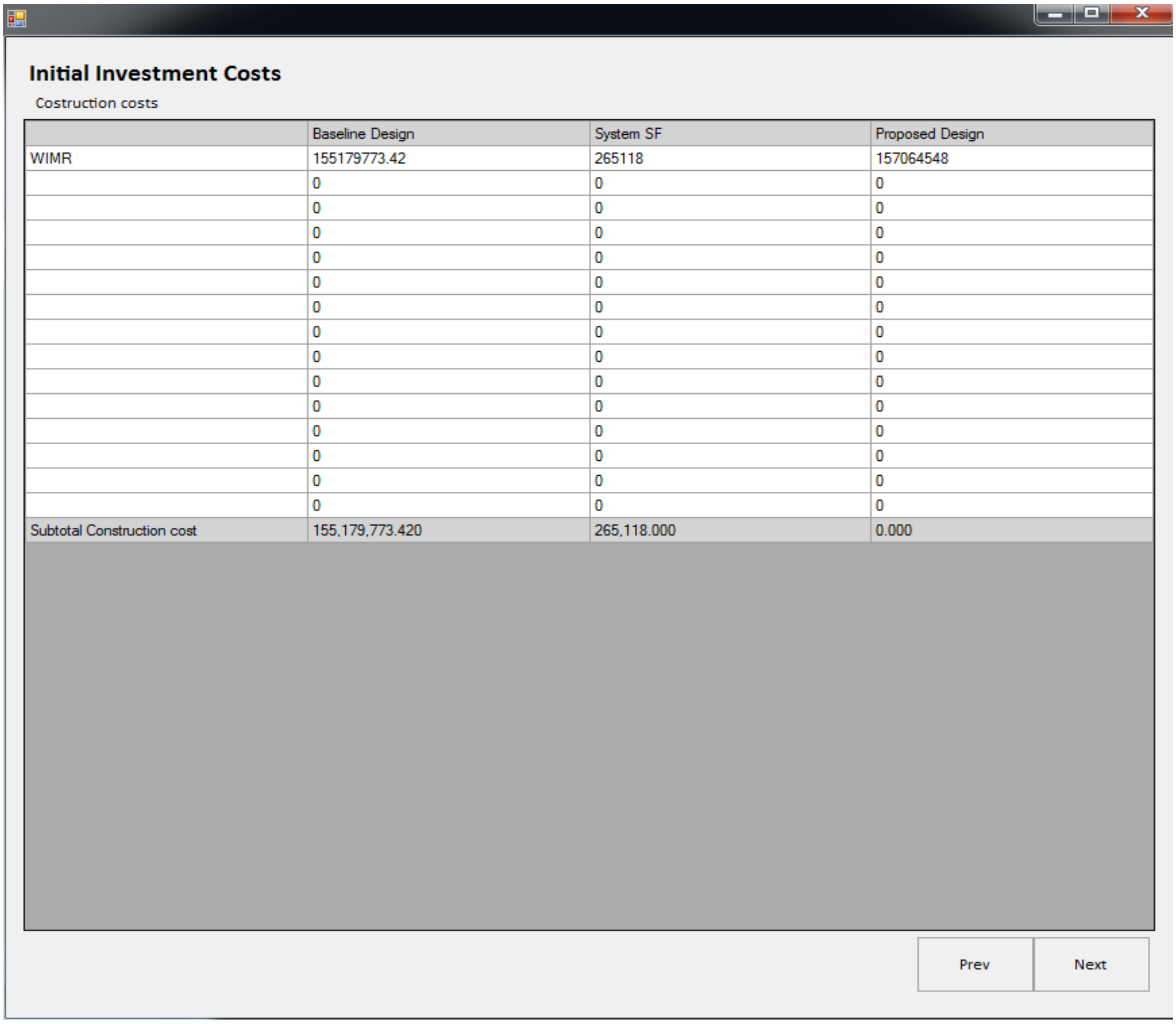


Figure 4.4 the input interface for the discount rate and the escalation rates



Initial Investment Costs

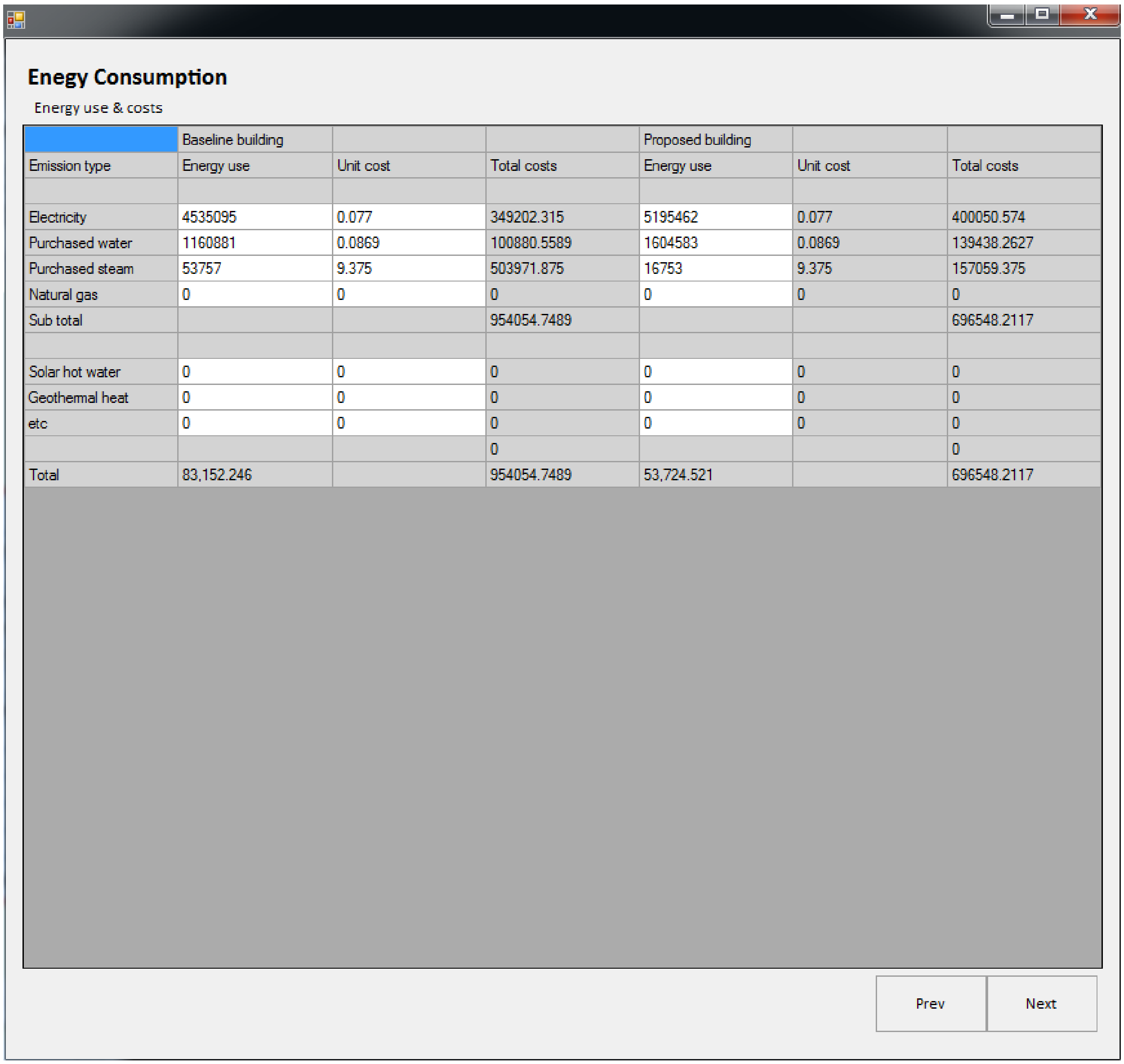
Costruction costs

	Baseline Design	System SF	Proposed Design
WIMR	155179773.42	265118	157064548
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
Subtotal Construction cost	155,179,773.420	265,118.000	0.000

Prev Next

Figure 4.5 The input interface of the initial investment costs

With the results of BES, users are able to input the estimated energy consumption depending on the general energy resources, such as electricity, purchased water (chilled water), purchased steam, and natural gas. In addition, the renewable energy resources earned from solar, geothermal, wind, etc., are available to reflect the total energy consumption by subtracting the earned energy resources from the aggregate total of the general energy consumption. In terms of the unit costs of energy consumption depending on the type of energy, the energy rates provided by the Wisconsin utility companies, such as Madison Gas and Electricity (MG&E), and Madison Water Utility are pre-loaded in GBPAT and the energy rates are able to be customized by users as well. The input interface for the energy consumption is shown in Figure 4.6.



	Baseline building			Proposed building		
Emission type	Energy use	Unit cost	Total costs	Energy use	Unit cost	Total costs
Electricity	4535095	0.077	349202.315	5195462	0.077	400050.574
Purchased water	1160881	0.0869	100880.5589	1604583	0.0869	139438.2627
Purchased steam	53757	9.375	503971.875	16753	9.375	157059.375
Natural gas	0	0	0	0	0	0
Sub total			954054.7489			696548.2117
Solar hot water	0	0	0	0	0	0
Geothermal heat	0	0	0	0	0	0
etc	0	0	0	0	0	0
			0			0
Total	83,152.246		954054.7489	53,724.521		696548.2117

Figure 4.6 The input interface of the energy consumption

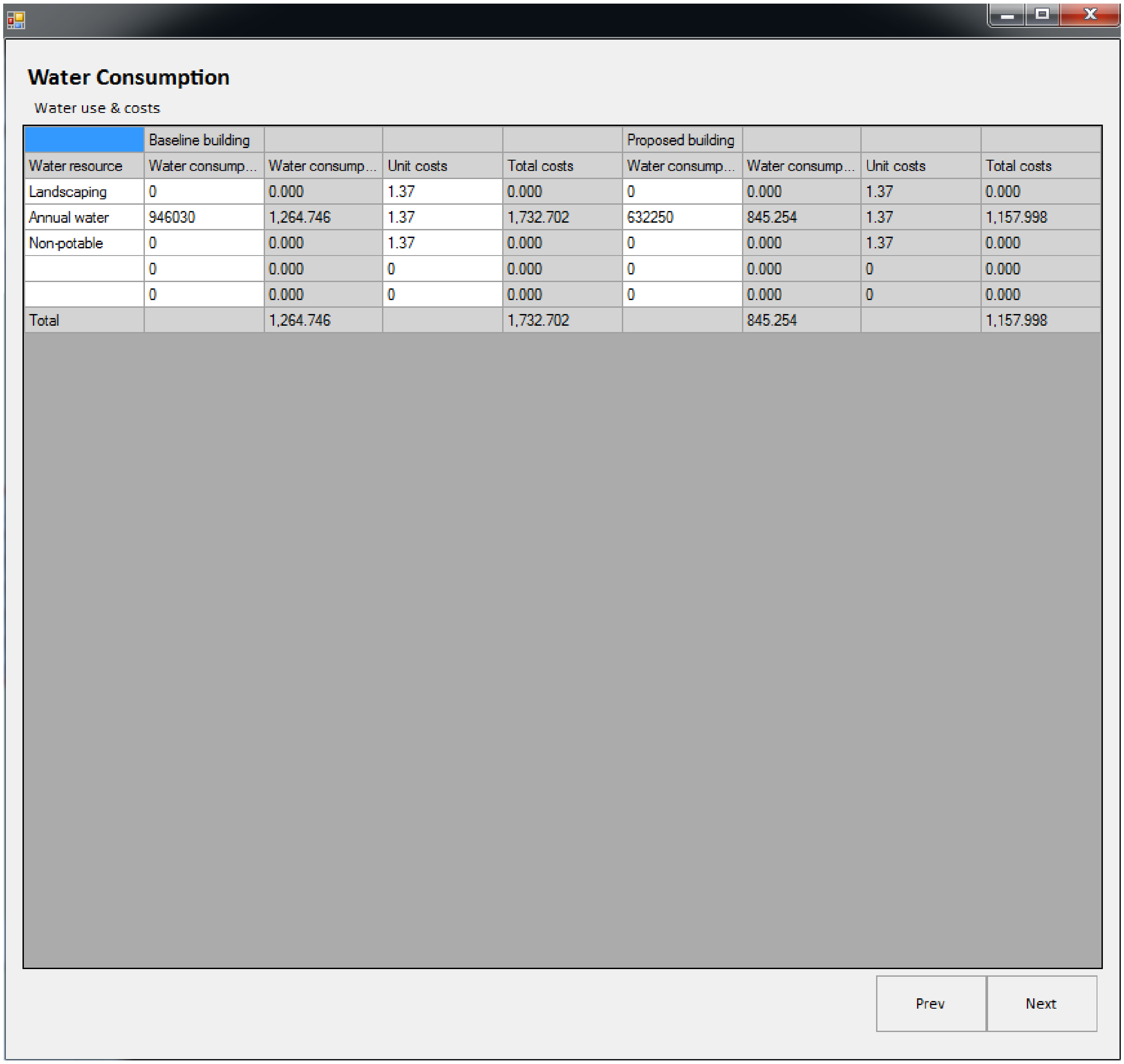
In the input interface for the energy consumption, the total energy use which is located in the last line of the table presents in the unit of the British thermal unit (MMBTU) while other energy consumption should be entered in the other SI units, such as kilowatt hours (kwh), therm, and ton hours (refrigeration) thus following equation is required to convert the other energy units to MMBTU (NIST,2008):

$$\text{Total energy consumption (MMBTU)} = \text{Electricity (kWh)} \times 0.00341$$
$$+ \text{Purchased water (ton hours)} \times 0.012 + \text{Purchased steam (MMBTU)} \quad (4.1)$$
$$+ \text{Natural gas (Therm)} \times 0.1$$

The annual water consumption costs for the baseline and the proposed building models were estimated based on the EPAct of 1992 (Jonathan G. Koomey et al., 1995). To simulate the total water consumption, the flush fixture data, flush rate, full time equivalent, the flow fixture data and flow rate are required. Also, the following conversion factor to generate gallon to a hundred cubic feet (ccf) is pre-loaded in GBPAT (NIST, 2008):

$$\text{Hundred cubic feet (ccf)} = \text{gallon} \div 748 \quad (4.2)$$

The input interface for the water consumption is shown in Figure 4.7.



	Baseline building				Proposed building			
Water resource	Water consump...	Water consump...	Unit costs	Total costs	Water consump...	Water consump...	Unit costs	Total costs
Landscaping	0	0.000	1.37	0.000	0	0.000	1.37	0.000
Annual water	946030	1,264.746	1.37	1,732.702	632250	845.254	1.37	1,157.998
Non-potable	0	0.000	1.37	0.000	0	0.000	1.37	0.000
	0	0.000	0	0.000	0	0.000	0	0.000
	0	0.000	0	0.000	0	0.000	0	0.000
Total		1,264.746		1,732.702		845.254		1,157.998

Figure 4.7 The input interface for the water consumption

The computation method for the carbon dioxide equivalent (CO_2E) is illustrated in Section 3.4.2 in detail and the rate of the water disposal was obtained from Wisconsin Water Utility. Therefore, the users need to provide only the rates of CO_2E and water disposal rate. These input values are automatically brought from the previous interface. The input interface of the emission and water disposal is shown in Figure 4.8.

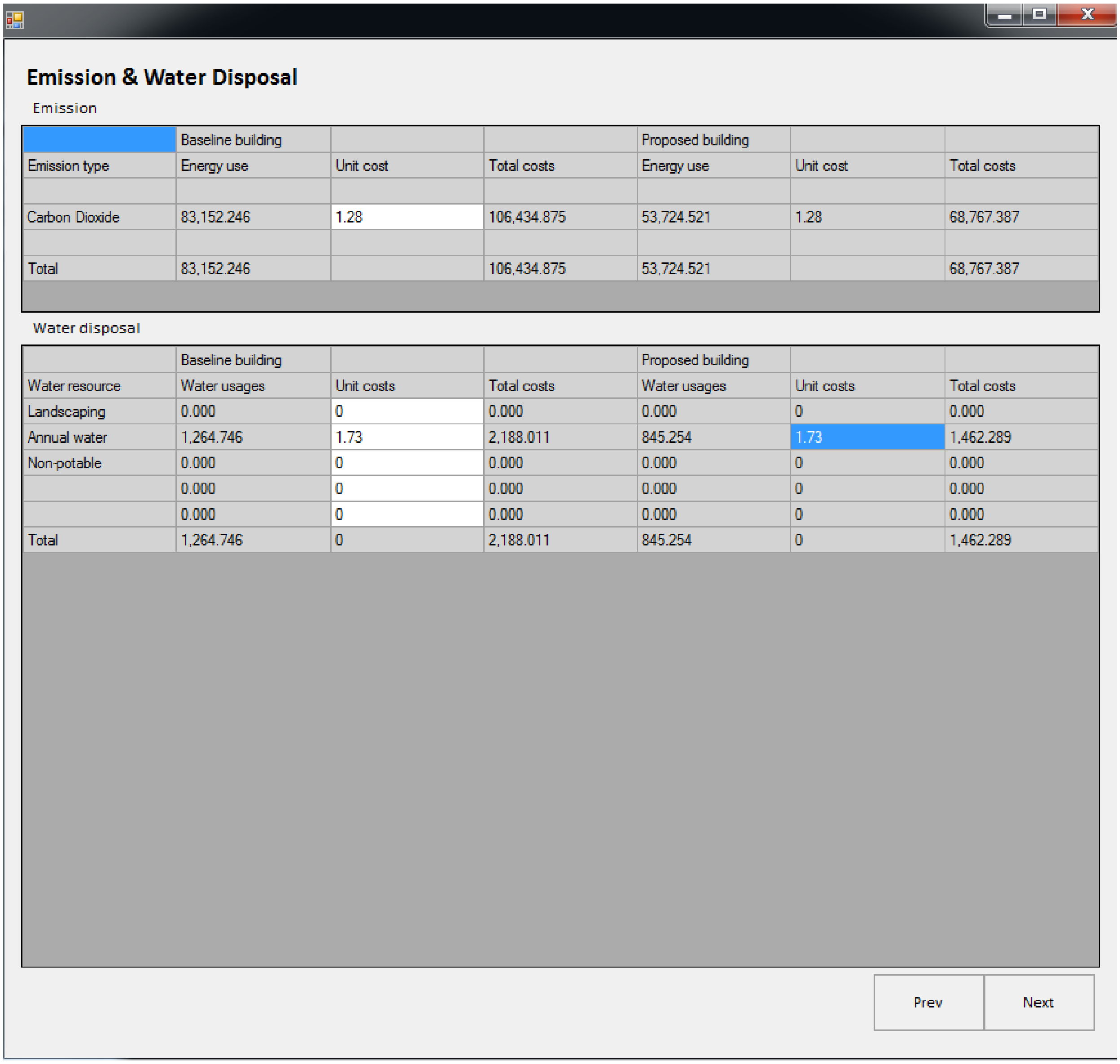


Figure 4.8 The input interface for the emission and water disposal

Moreover, in the input interface for the emission and water disposal, users are able to customize the rate of CO_2E and water disposal. From the database of LABARRE Associates, the annual maintenance costs depending on building types can be obtained and building life span need to be entered. Therefore, based on the building size and the building type provided in the general information part, the annual maintenance cost is calculated and printed in the input interface of the building maintenance as shown in Figure 4.9.

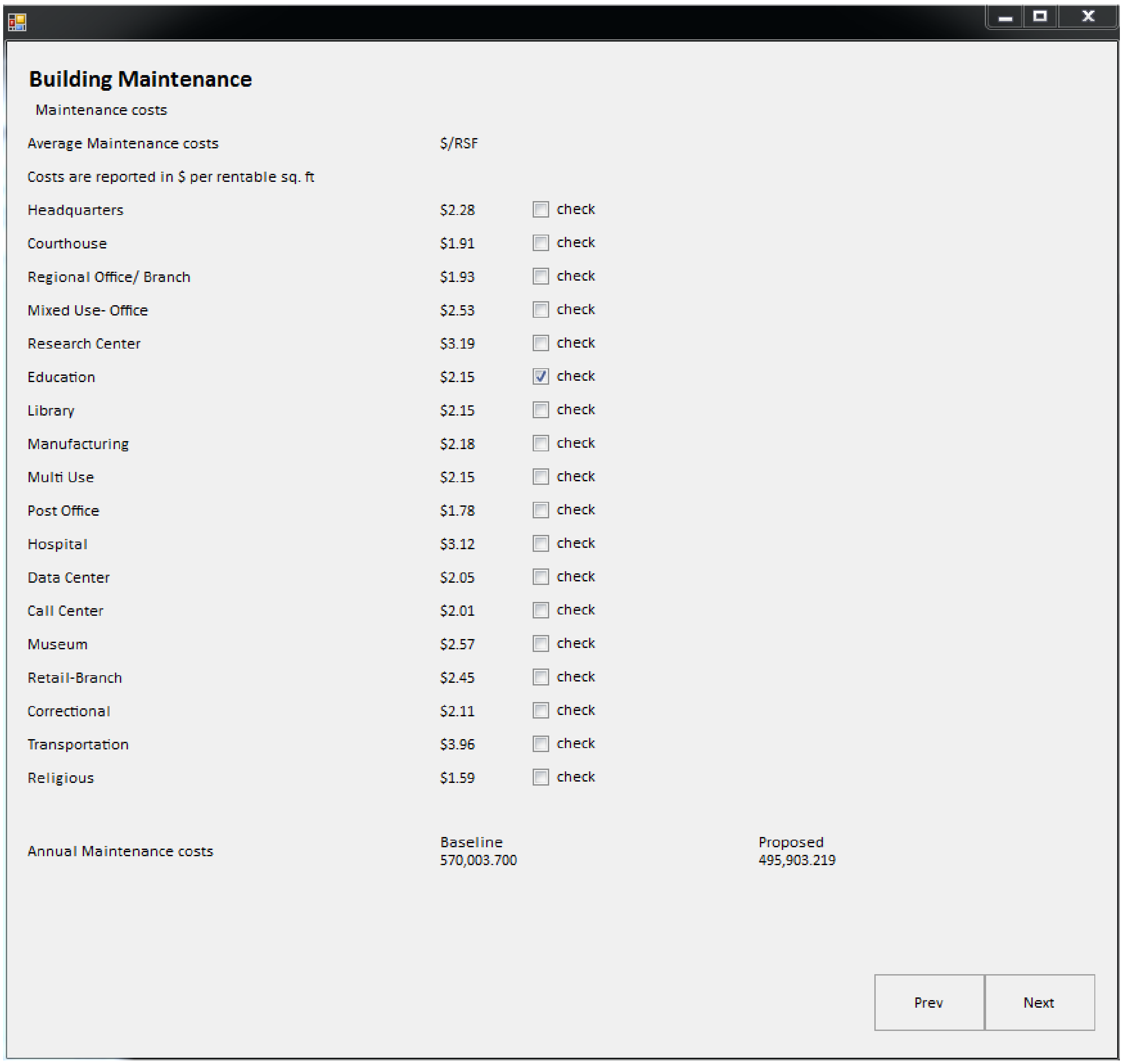


Figure 4.9 The input interface for the building maintenance

Although several studies were conducted on the occupant satisfaction impacted by building performance, there is no consensus to estimate the occupant's benefits earned from the improvement of the indoor environmental quality. Consequently, the savings of the occupant health costs can be estimated and reflected optionally in GBPAT if the users would like to assess the degree of the occupant satisfaction in the health costs that are usually calculated with the full time equivalent in the proposed building model. Figure 4.10 shows the input interface for the occupant health costs in GBPAT.

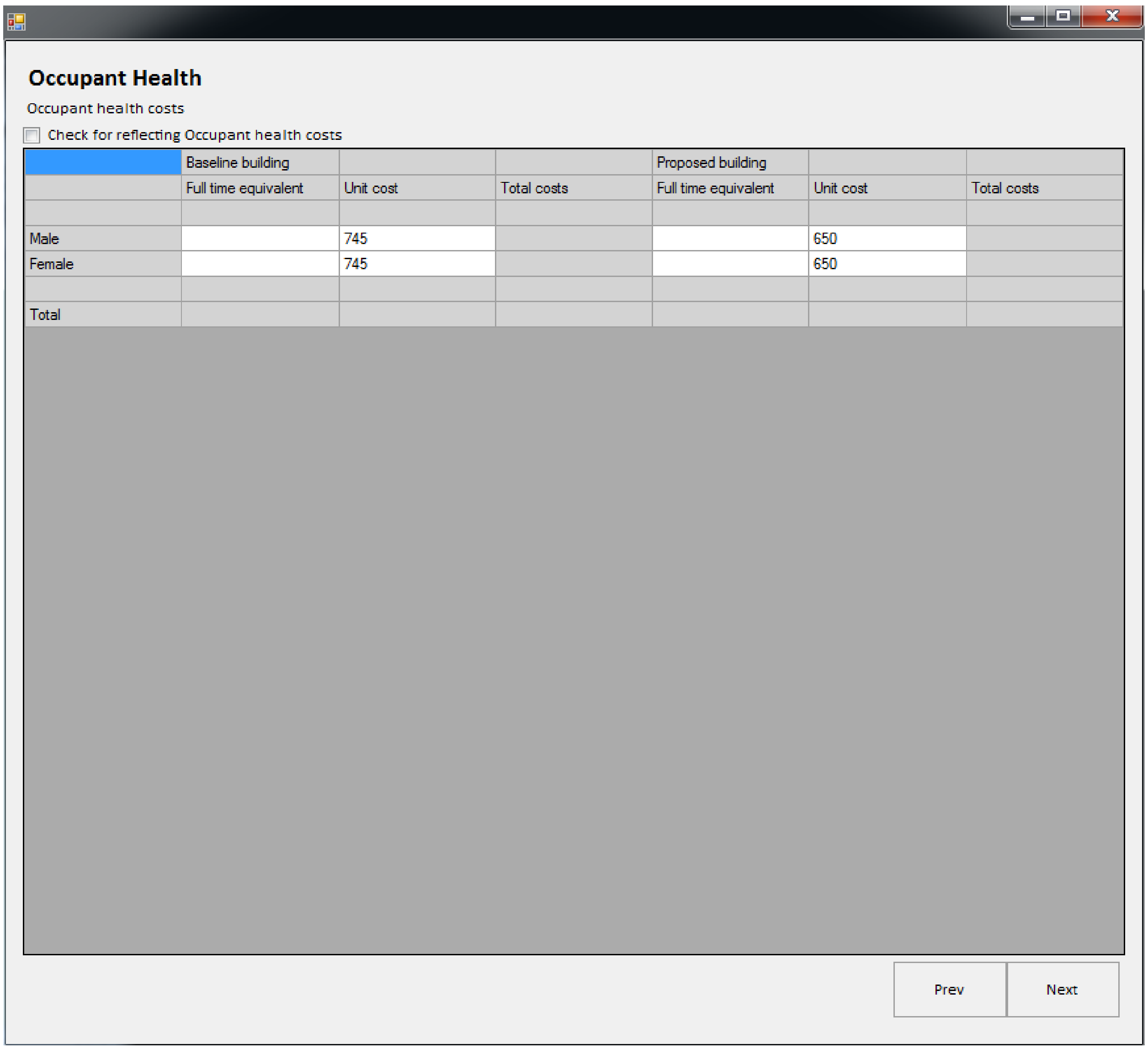
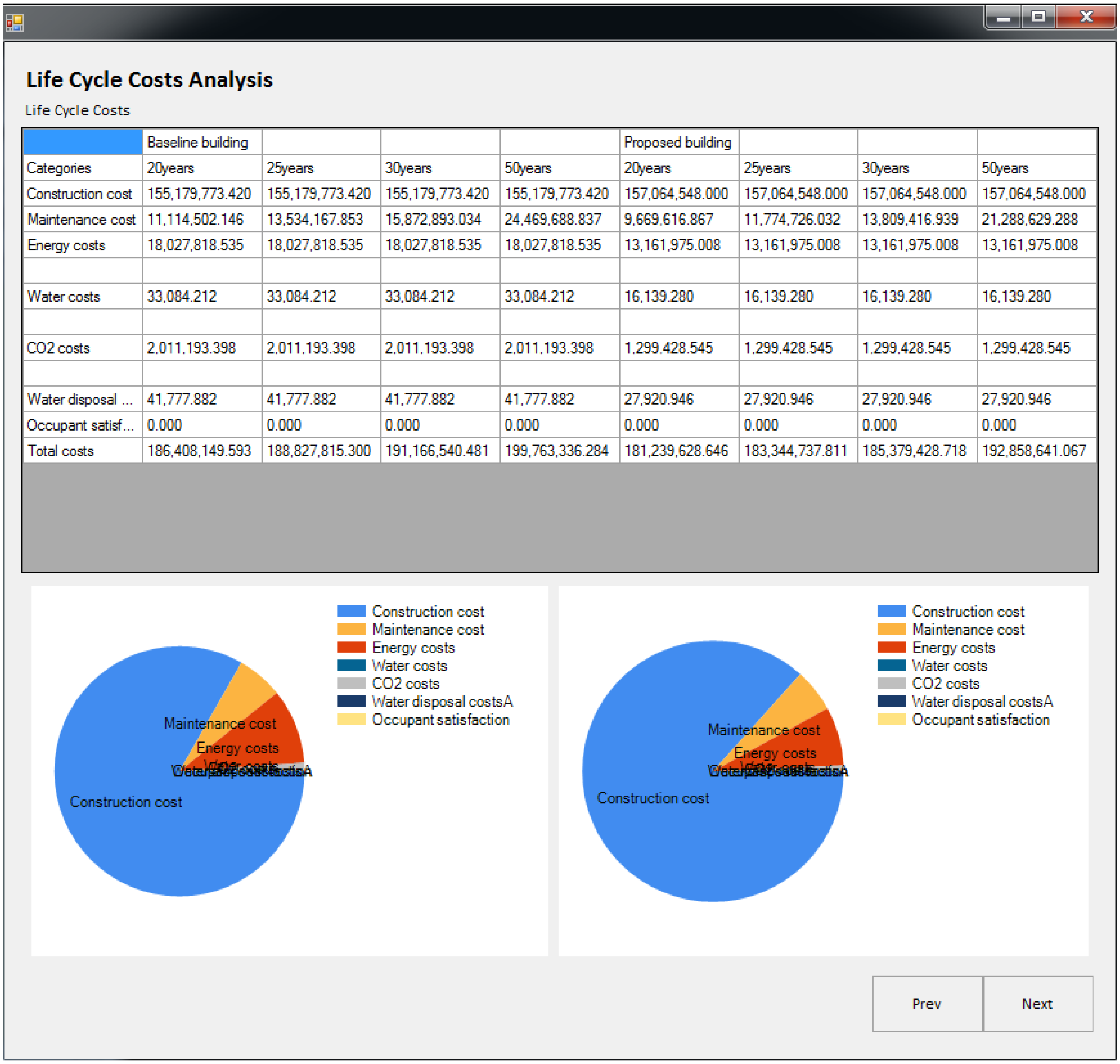


Figure 4.10 The input interface for the occupant health costs

Once the input data are entered, GBPAT shows the results related to the life cycle costs analysis for the baseline and proposed building models for 20, 25, 30, and 50 years, respectively. As described previously, the total LCC includes the initial investment, maintenance costs, energy and water costs, emission and water disposal costs, and occupant health costs (optional) in terms of sustainability. From the results of the total LCC at four life spans, the users are able to determine whether the proposed building model is more sustainable than the baseline building model based on the existing standards or not. If the total LCC for the proposed building model is less than the total LCC for the baseline building model, this implies that the proposed building is more economical and sustainable, while the opposite case means that the proposed building is less economical and may not be sustainable. At the same time, with the pie charts showing the compositions of costs, it is possible to assess which cost items can be saved over the life span. The output interface for the life cycle costs analysis is shown in Figure 4.11.

In order to check the cost-effectiveness and sustainability, GBPAT provides the green premium (%) and the proportion of the total LCC in terms of the sustainability. The green premium and sustainability check are shown in Figure 4.12. The green premium of the proposed building model is compared with the baseline building model in the table format along with the levels of LEED certification system classified based on the reference premium ranging from 0 to 8.5%. Also, the total LCC is analyzed in three categories of the sustainable perspective, such as economy, environment and human and illustrated in the pie charts.



Life Cycle Costs Analysis

Life Cycle Costs

	Baseline building				Proposed building			
Categories	20years	25years	30years	50years	20years	25years	30years	50years
Construction cost	155,179,773.420	155,179,773.420	155,179,773.420	155,179,773.420	157,064,548.000	157,064,548.000	157,064,548.000	157,064,548.000
Maintenance cost	11,114,502.146	13,534,167.853	15,872,893.034	24,469,688.837	9,669,616.867	11,774,726.032	13,809,416.939	21,288,629.288
Energy costs	18,027,818.535	18,027,818.535	18,027,818.535	18,027,818.535	13,161,975.008	13,161,975.008	13,161,975.008	13,161,975.008
Water costs	33,084.212	33,084.212	33,084.212	33,084.212	16,139.280	16,139.280	16,139.280	16,139.280
CO2 costs	2,011,193.398	2,011,193.398	2,011,193.398	2,011,193.398	1,299,428.545	1,299,428.545	1,299,428.545	1,299,428.545
Water disposal ...	41,777.882	41,777.882	41,777.882	41,777.882	27,920.946	27,920.946	27,920.946	27,920.946
Occupant satisf...	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total costs	186,408,149.593	188,827,815.300	191,166,540.481	199,763,336.284	181,239,628.646	183,344,737.811	185,379,428.718	192,858,641.067

Figure 4.11 The output interface for LCCA

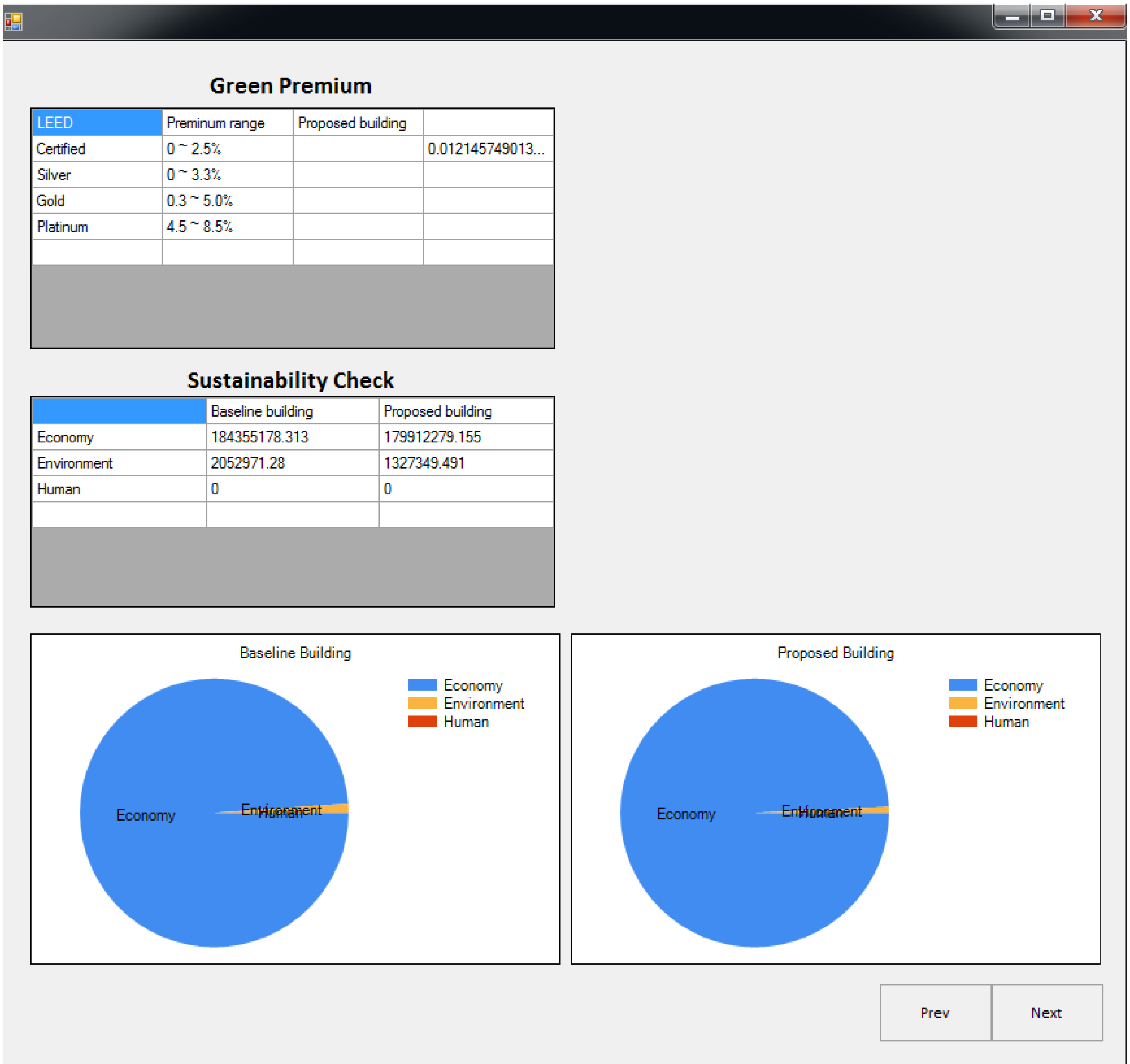


Figure 4.12 The output interface for the green premium and sustainability check

Moreover, GBPAT presents the supplementary measures including net saving, SIR, AIRR along with BPI and CEI that are illustrated in Section 3.6.1, in the form of the line chart. From the line charts, the discounted payback period (DPP) can be estimated and the point starting the net savings can be determined. In addition to analyzing the supplementary measures, the project can be compared with other projects using BPI and CEI as illustrated. Figure 4.13 shows the output interface for the line charts showing the supplementary measures and two indexes throughout the life span in GBPAT.

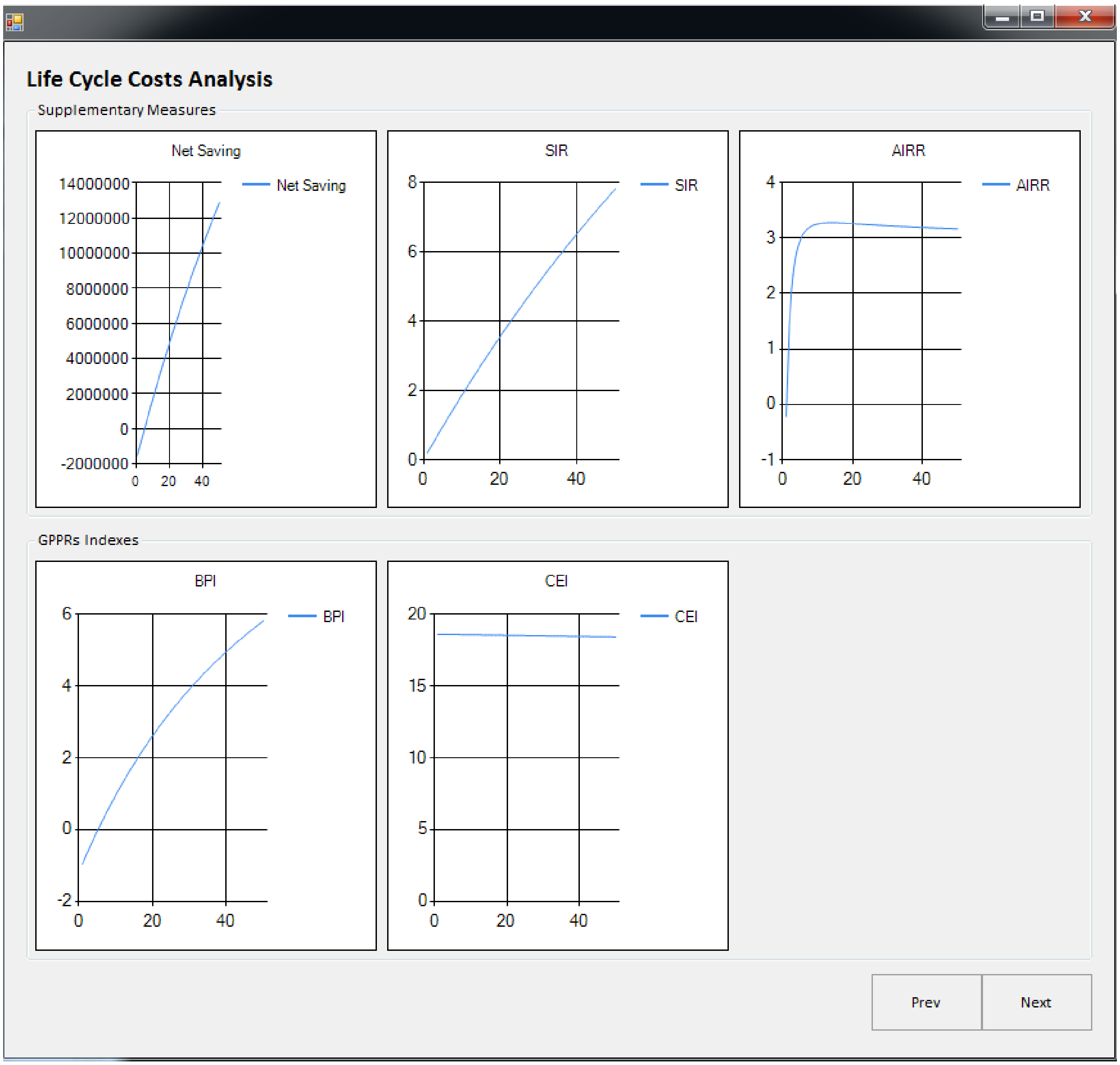
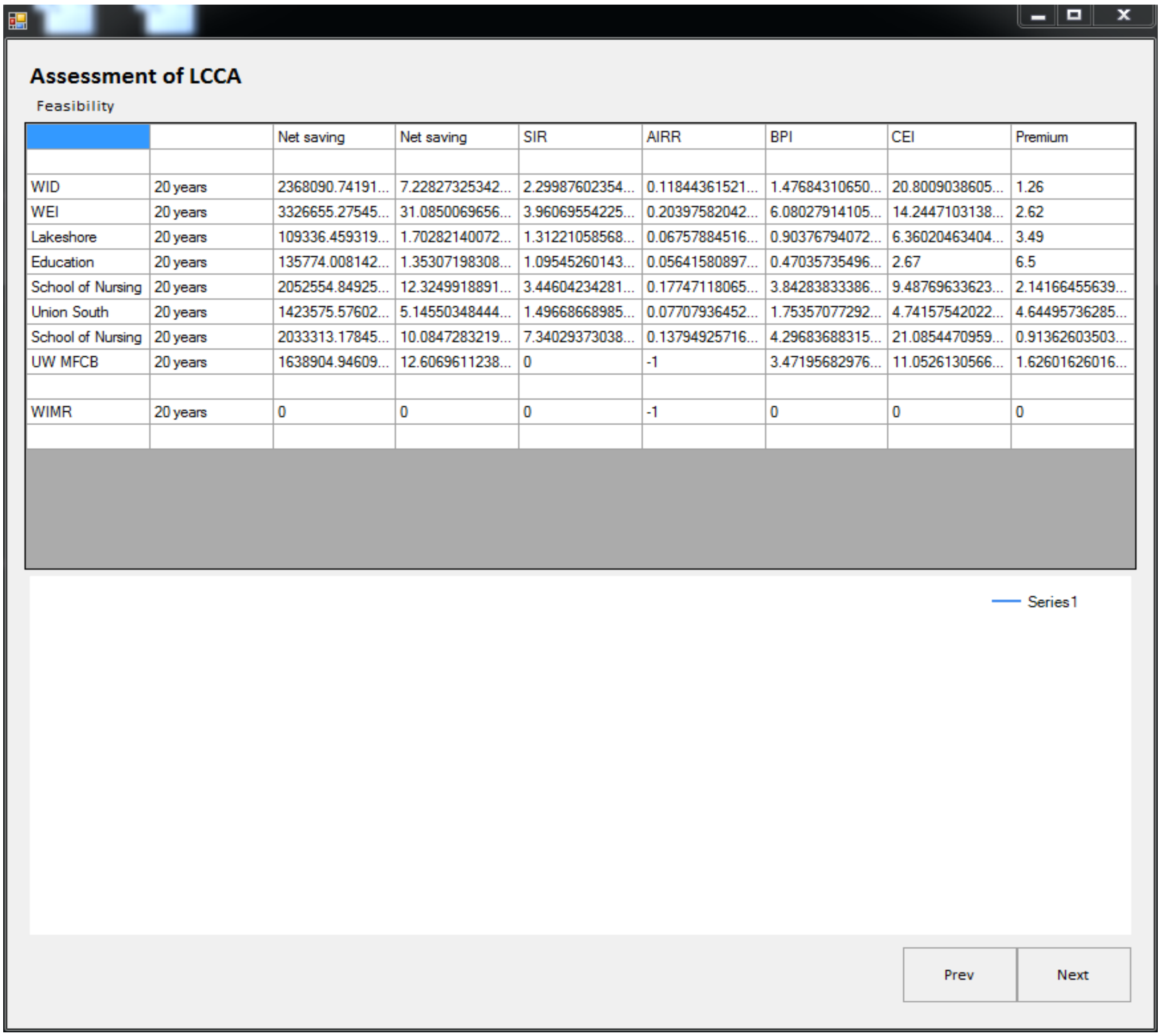


Figure 4.13 The output interface for the supplementary measures and indexes

Finally, the proposed building model can be compared with the analyses of the total LCC for nine LEED projects in order to identify the feasibility of the incremental investment. In addition, it is possible to determine whether the green premium is within appropriate range by comparing with the similar projects in the respective of a building type, building size, location and the level of LEED certification. The output interface of the assessment of LCCA is shown in Figure 4.14.



		Net saving	Net saving	SIR	AIRR	BPI	CEI	Premium
WID	20 years	2368090.74191...	7.22827325342...	2.29987602354...	0.11844361521...	1.47684310650...	20.8009038605...	1.26
WEI	20 years	3326655.27545...	31.0850069656...	3.96069554225...	0.20397582042...	6.08027914105...	14.2447103138...	2.62
Lakeshore	20 years	109336.459319...	1.70282140072...	1.31221058568...	0.06757884516...	0.90376794072...	6.36020463404...	3.49
Education	20 years	135774.008142...	1.35307198308...	1.09545260143...	0.05641580897...	0.47035735496...	2.67	6.5
School of Nursing	20 years	2052554.84925...	12.3249918891...	3.44604234281...	0.17747118065...	3.84283833386...	9.48769633623...	2.14166455639...
Union South	20 years	1423575.57602...	5.14550348444...	1.49668668985...	0.07707936452...	1.75357077292...	4.74157542022...	4.64495736285...
School of Nursing	20 years	2033313.17845...	10.0847283219...	7.34029373038...	0.13794925716...	4.29683688315...	21.0854470959...	0.91362603503...
UW MFCB	20 years	1638904.94609...	12.6069611238...	0	-1	3.47195682976...	11.0526130566...	1.62601626016...
WIMR	20 years	0	0	0	-1	0	0	0

Figure 4.14 The output interface of the assessment of LCCA

4.3 Validation of GBPAT

Once the stand-alone version of GBPAT was developed using Visual C# Express (C# programming language), the validation of the program of GBPAT was conducted by comparing the results with the Microsoft Excel version and BLCC that is the most well-known LCC program in the building field. First, the total LCCs of the nine LEED projects at the campus of UW-Madison were estimated individually using GBPAT in two versions and the results of the total LCCs were validated for the accuracy.

The output interfaces of life cycle costs analysis in GBPAT, green premium and sustainability check, and the line charts of supplementary measures and indexes were carefully checked. Since the total LCC varies sensitively with the discounted rate and the escalation rate, the validation of each LEED project was performed at the discount rate of 3% and the escalation rates of energy cost, water cost and maintenance of 2.1%, 2.2%, and 2.3% in the two versions of GBPAT. The two versions of GBPAT showed exactly the same outputs. Thus, it can be said that the stand-alone version of GBPAT operates correctly. Figures 4.15 and 4.16 show the output interfaces for the LCCA in the Microsoft Excel and stand-alone versions of GBPAT for the WEI project.

Life Cycle Costs Analysis

Life Cycle Costs

Categories	Baseline building					Proposed building			
	20years	25years	30years	50years		20years	25years	30years	50 years
Construction cost	$42,809,242.00	$42,809,242.00	$42,809,242.00	$42,809,242.00		$43,932,848.00	$43,932,848.00	$43,932,848.00	$43,932,848.00
Maintenance cost	$4,287,106.65	$5,270,594.27	$6,221,113.57	$9,715,062.54		$3,729,782.78	$4,585,417.01	$5,412,368.81	$8,452,104.41
Energy costs	$9,888,358.63	$12,073,378.43	$14,154,369.00	$21,533,625.74		$6,212,545.18	$7,585,324.49	$8,892,745.51	$13,528,900.77
Water costs	$15,837.61	$19,381.37	$22,772.98	$34,944.51		$10,608.45	$12,982.15	$15,253.94	$23,406.75
CO2 costs	$894,481.41	$1,092,133.99	$1,280,376.30	$1,947,889.30		$422,911.61	$516,361.93	$605,363.06	$920,963.80
Water disposal costs	$20,016.66	$24,495.50	$28,782.05	$44,165.27		$13,407.68	$16,407.73	$19,278.97	$29,583.05
Occupant satisfaction	$0.00	$0.00	$0.00	$0.00		$0.00	$0.00	$0.00	$0.00
Total costs	$57,915,042.97	$61,289,225.56	$64,516,655.90	$76,084,929.37		$54,322,103.70	$56,649,341.31	$58,877,858.29	$66,887,806.79

Figure 4.15 the output interfaces for life cycle costs analysis (Microsoft Excel version)

Life Cycle Costs Analysis

Life Cycle Costs

	Baseline building				Proposed building			
Categories	20years	25years	30years	50years	20years	25years	30years	50years
Construction cost	42,809,242.000	42,809,242.000	42,809,242.000	42,809,242.000	43,932,848.000	43,932,848.000	43,932,848.000	43,932,848.000
Maintenance cost	4,486,499.561	5,463,226.093	6,407,280.029	9,877,477.802	3,903,254.618	4,753,006.701	5,574,333.625	8,593,405.688
Energy costs	10,333,944.704	10,333,944.704	10,333,944.704	10,333,944.704	6,492,492.909	6,492,492.909	6,492,492.909	6,492,492.909
Water costs	16,558.508	16,558.508	16,558.508	16,558.508	8,095.856	8,095.856	8,095.856	8,095.856
CO2 costs	934,058.512	934,058.512	934,058.512	934,058.512	441,623.688	441,623.688	441,623.688	441,623.688
Water disposal ...	20,909.648	20,909.648	20,909.648	20,909.648	14,005.831	14,005.831	14,005.831	14,005.831
Occupant satisf...	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total costs	58,601,212.933	59,577,939.465	60,521,993.401	63,992,191.174	54,792,320.902	55,642,072.985	56,463,399.909	59,482,471.972

Figure 4.16 the output interfaces for life cycle costs analysis (Stand-alone version)

In addition, in order to confirm the accuracy of the total LCC, the line charts of the supplementary measures and indexes were checked in the two versions of GBPAT. From the comparison of the line charts, it can be said that GBPAT in the stand-alone version operates accurately. Figures 4.17 and 4.18 show the output interface for the line charts of the supplementary measures and indexes in the Microsoft Excel and the stand-alone versions.

The stand-alone version of GBPAT was also compared with the Building Life Cycle Cost (BLCC) program developed by National Institute of Standards and Technology (NIST). There are some difficulties for the user who is not the experts in the fields of building finance and energy to use the BLCC program. First, the user must enter many parameters to estimate the total LCC. For example, in order to input all cost factors, each escalation rate for all required cost parameters is not easy to obtain and accurately estimate the lone-term escalation rates for all energy and water.

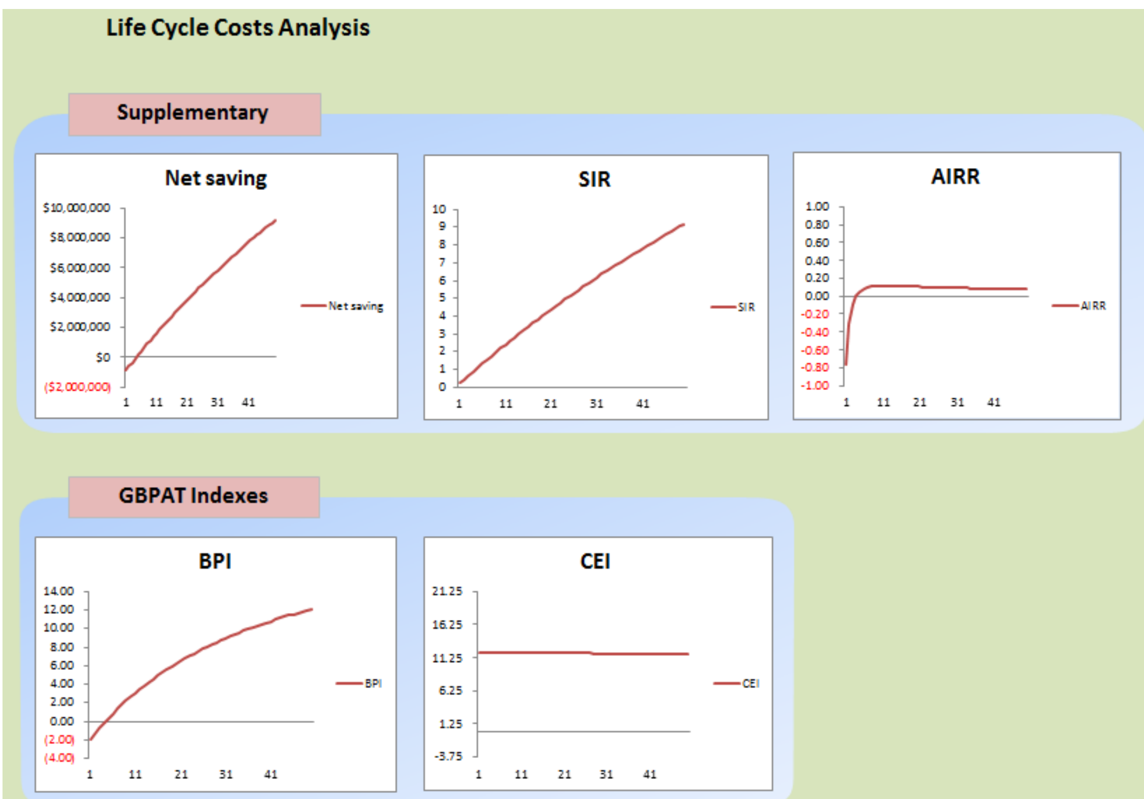


Figure 4.17 The output interface for the line charts of the supplementary measures and indexes

(Microsoft Excel version)

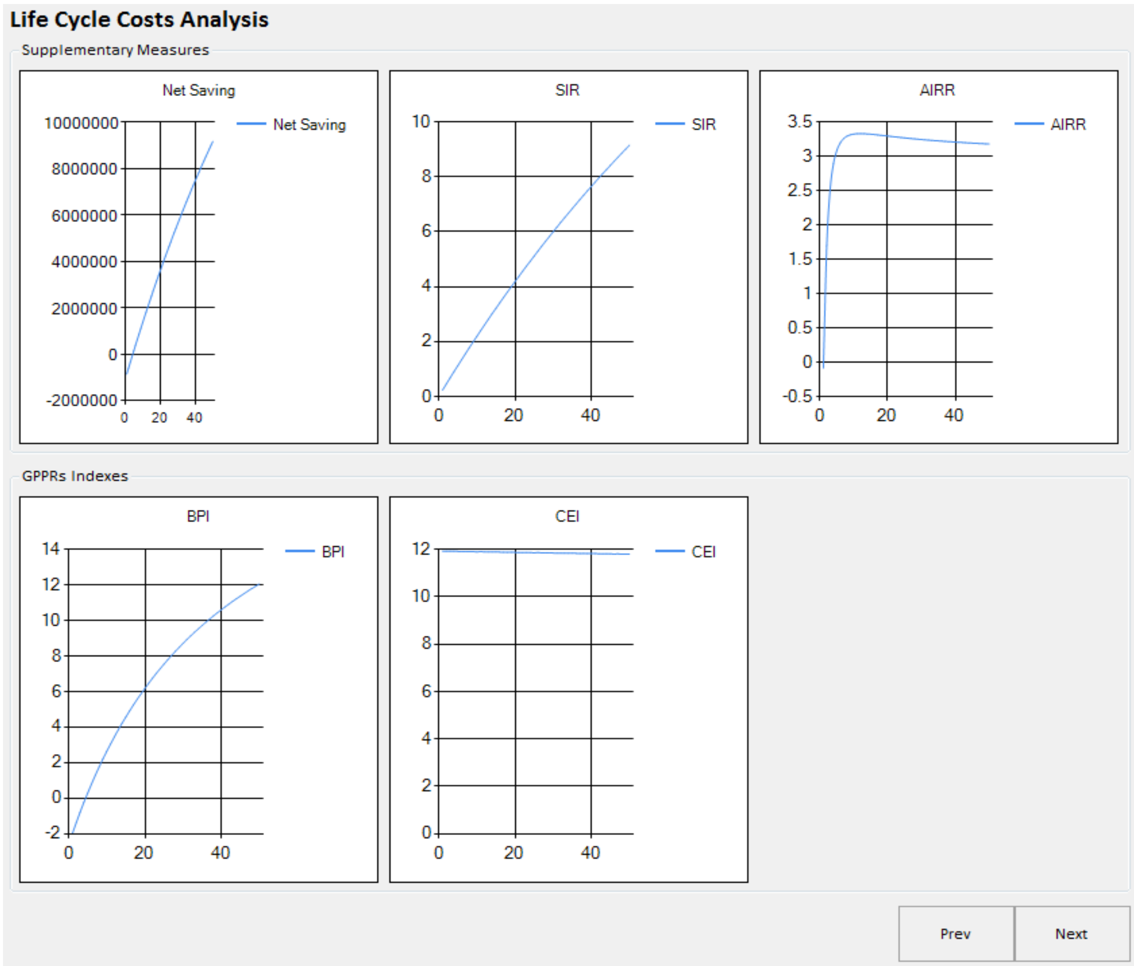


Figure 4.18 The output interface for the line charts of the supplementary measures and indexes

(Microsoft Excel version)

Next, in terms of the energy consumption depending on energy resources, there is no option to enter the secondary energies such as chilled water and purchased steam. Currently, most building energy simulation programs provide the energy consumption as the secondary energy, not energy sources like coal, fuel oil and petroleum gas. Therefore, the users have to convert the amount of energy sources from the consumption of the secondary energy. Figure 19 shows the input categories for energy consumption on BLCC program.

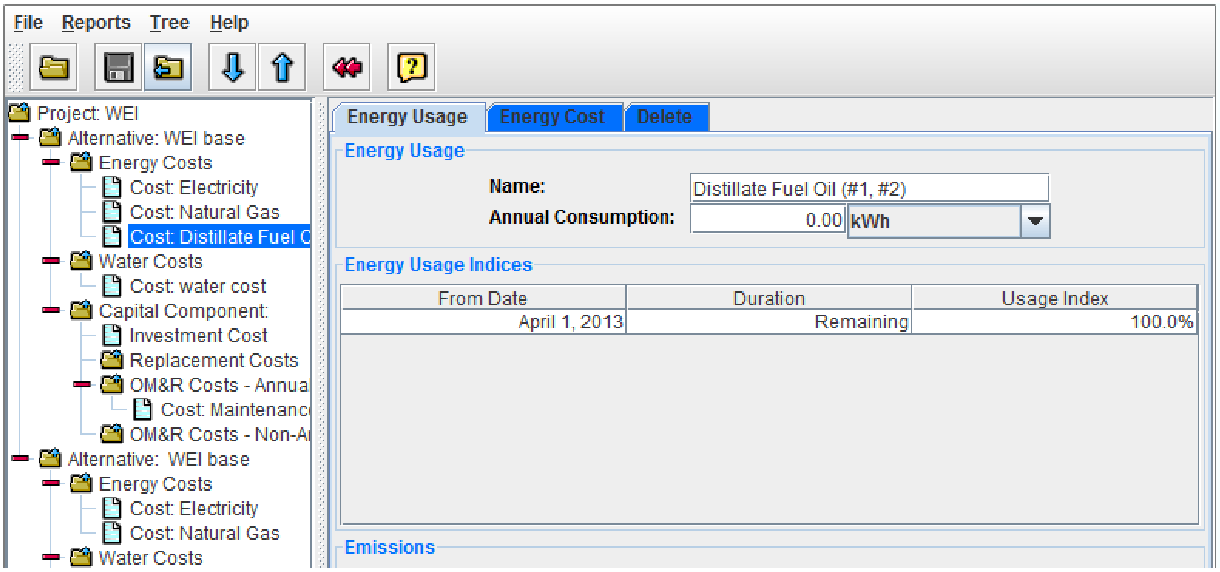


Figure 4.19 The input categories for energy consumption in the BLCC program

When the total LCC was compared, the results including net savings, SIR and AIR were slightly different since the total LCC by the BLCC program does not reflect the emission costs. The BLCC program only presents the amounts of the GHG emission, not the social costs. Therefore, BLCC does not seems to satisfy the trend that the LCC method reflect the environmental impact to the total LCC as the concept of the integrated LCA and LCCA approach. The total LCC subtracting the emission costs in BLCC were close to the total LCC from GBPAT. Thus, the total LCC and analysis using GBPAT is thought to be more thorough and thus accurate. Green buildings can achieve better performance when GBPAT is used to assess the various alternatives for sustainability. The detailed results estimated by BLCC are attached in Appendix 4.2. Table 4.1 illustrates the results of the total LCC estimated by GBPAT and BLCC.

Table 4.1 The results of the total LCC estimated by GBPAT and BLCC

Categories	GBPAT	BLCC
Life span (years)	20	20
Discount rate (%)	3.0	3.0
Escalation rates (%)	2.0, 2.1, 2.3	2.0, 2.1, 2.3
Total LCC ($)	56,152,636	57,915,042
Net savings($)	3,009,608	3,592,939
SIR	3.68	4.20
AIRR	9.93	11
DPP (years)	6	5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Although the importance of the integrated life cycle analysis (LCA) and life cycle cost analysis (LCCA) approach in the building sector has been raised up for a past decades, there has been no attempt to develop the LCCA program converting the environmental impact to a financial value since there is an uncertinity regarding the economical costs of the environmental burden to the society. However, through the development of advanced building energy simulation programs and the investigations in terms of social costs of GHG emission, the green building performance evaluation systems including sustainbility have been presented for the green building field. In contrast, the exting green building performance rating system (GBPRs) have been foucused on the environmental impacts; thus, they could not provide the cost effectiveness to the potential owner who are willing to construct the building to be green while more financial intensives are achieve. Therefore, it was necessary to develop the green building performance evaluation system providing total LCC reflecting social costs for the environmental impact produceda by a building project.

This study has conducted to develop the expert system with GUI called 'the Green Building Performance Assessment Tool' (GBPAT) based on the integrated LCA and LCCA approach considering sustainability. From the extensive literature review and and assessing the advantages and disadvantages of the reference programs such as BLCC and Harvard building life cycle cost calculator, the expert system of GBPAT was developed to overcome shortfalls of existing programs in the two versions using Microsoft Excel and Visual C# Express. GBPAT was validated by comparing the stand-alone version using C# language to Microsoft Excel version and the functionality of the stand-alone version of GBPAT was evaluated with the results of the stand-alone version of BLCC.

With the development of the expert system, GBPAT, it is possible for the user to determine the cost effectiveness of the green building. Moreover, GBPAT requires less information than BLCC and is capable of accepting the amount of energy consumption in the secondary energy while the user have to convert the secondary energy such as chilled water and purchased steam to energy resources such as coal, natural gas, and oil in BLCC. Also, in terms of the energy consumption, BLCC and other reference programs have no option to reflect the usages of the renewable energies earned from solar, geothermal and wind while GBPAT is capable of converting the amount of the renewable energies produced to the secondary energies, especially electricity and hot water. Thus, GBPAT can estimate more reliable social costs spent by environmental impact because these newable energies produce no environmental impact. Finally, GBPAT provides the annual changes of the supplementary measures and indexes in order to identify the trend of the cost effectiveness for the target building over the life span and these results are shown in the graphicall form so that the user can easily understand the building although BLCC and other similar program show only the results of the cost-effectiveness in the point of end year without the graphicall charts. Therefore, it is thought that

GBPAT is more advanced LCC program although it is not able to cover all indicators in the integrated LCA and LCCA approach.

5.2 Recommendation and Future Research

It is difficult to link the expert system with the building energy simulation program due to the complexity of importing the results of the BES programs to the input interface of GBPAT and arranging the mendatory information earned from the results of the BES programs in the right place of GBPAT. Additionally, because of the lack of the data regarding the occupant's health costs impacted by the indoor environmental quality in the green building, GBPAT was not fully able to cover the occupant satisfaction as the significant aspect of sustainability. Therefore, the following recommendations were made for the furture study:

- It is necessary develop the integrated expert system linking LCA program, BES, and cost estimate program as an object-orinted program.
- There is a need to incorporate GBPAT in Building Information Modeling (BIM) software for the assessment of the green building performance with the respect to sustainability from the early stage of a building project.
- It is necessary to collect more information on the correlation between the changes of the occupant health costs and the environmental quality to include the sustainability aspect more realistically and accurately to the BPE system.

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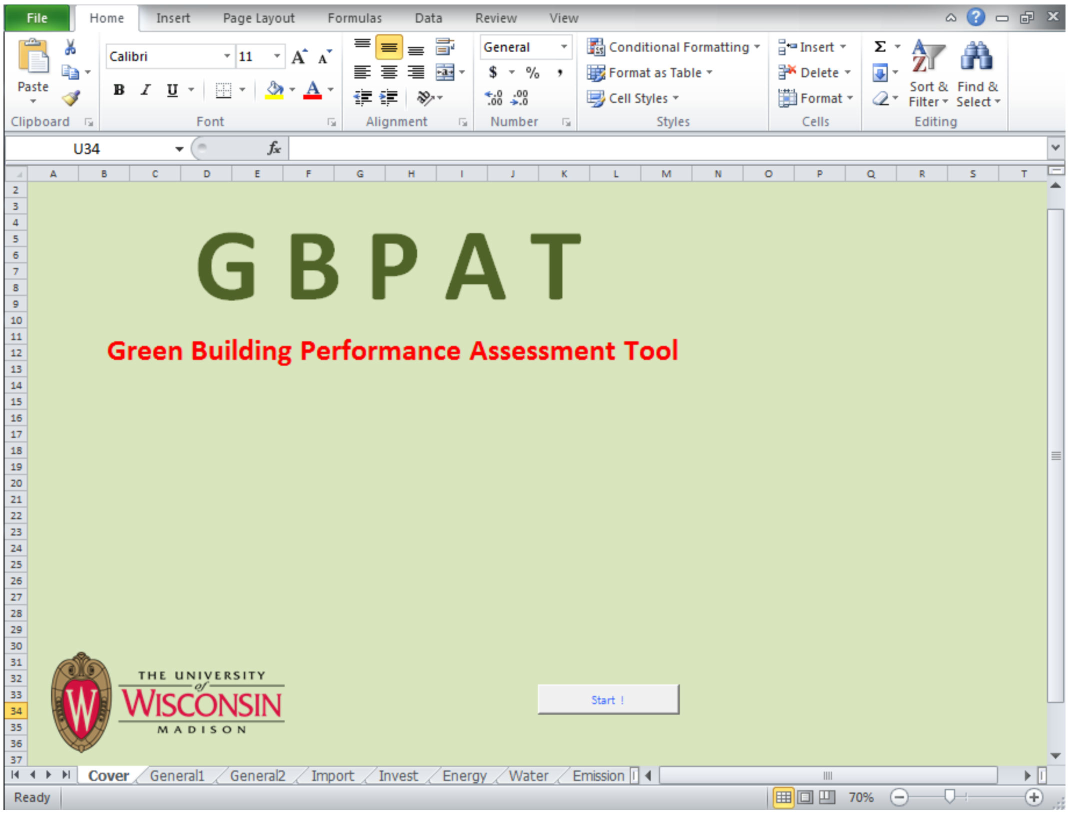
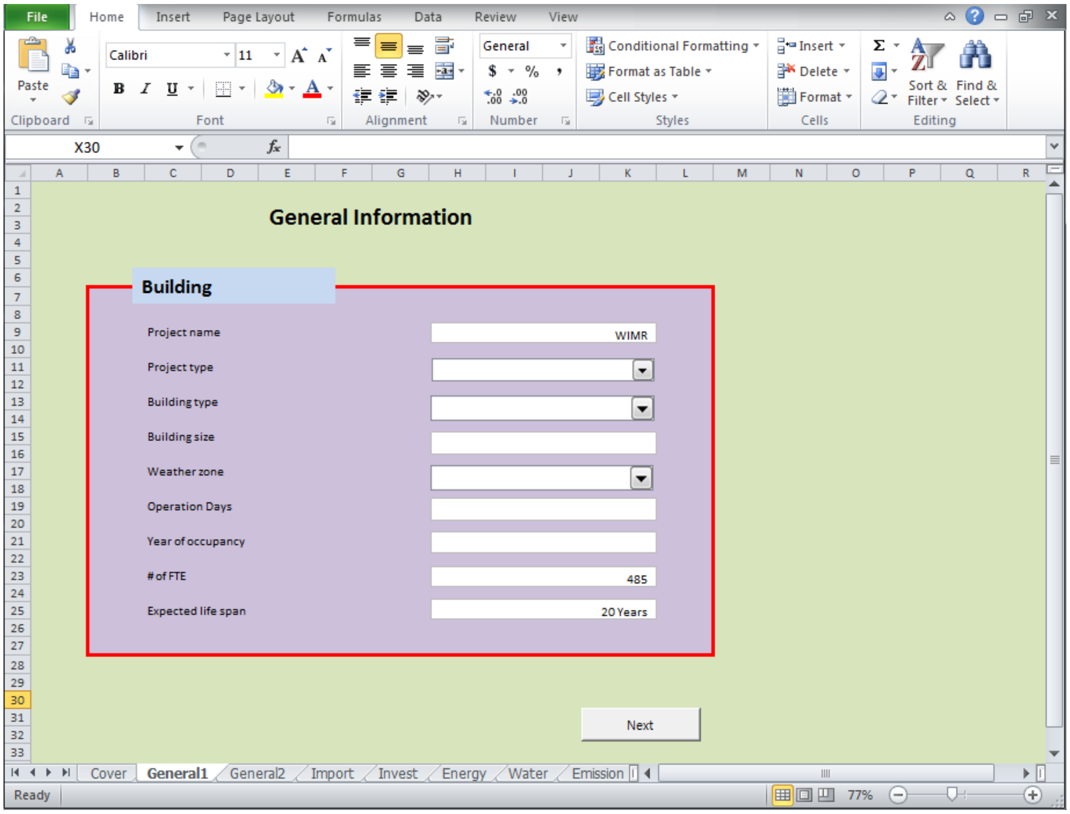
Appendixes

Appendix 4.1. The progress of the operation of GBPAT in Microsoft Excel version




General Information
Building
Project name
WIMR
Project type
Building type
Building size
Weather zone
Operation Days
Year of occupancy
# of FTE
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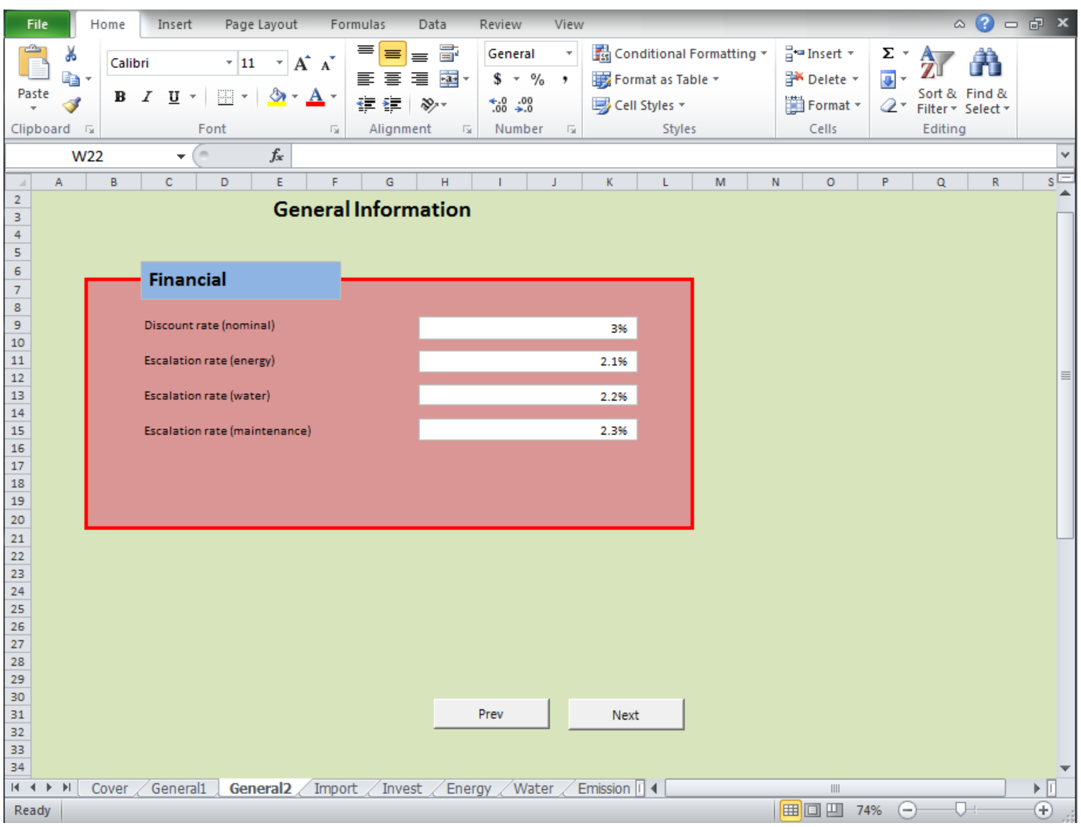
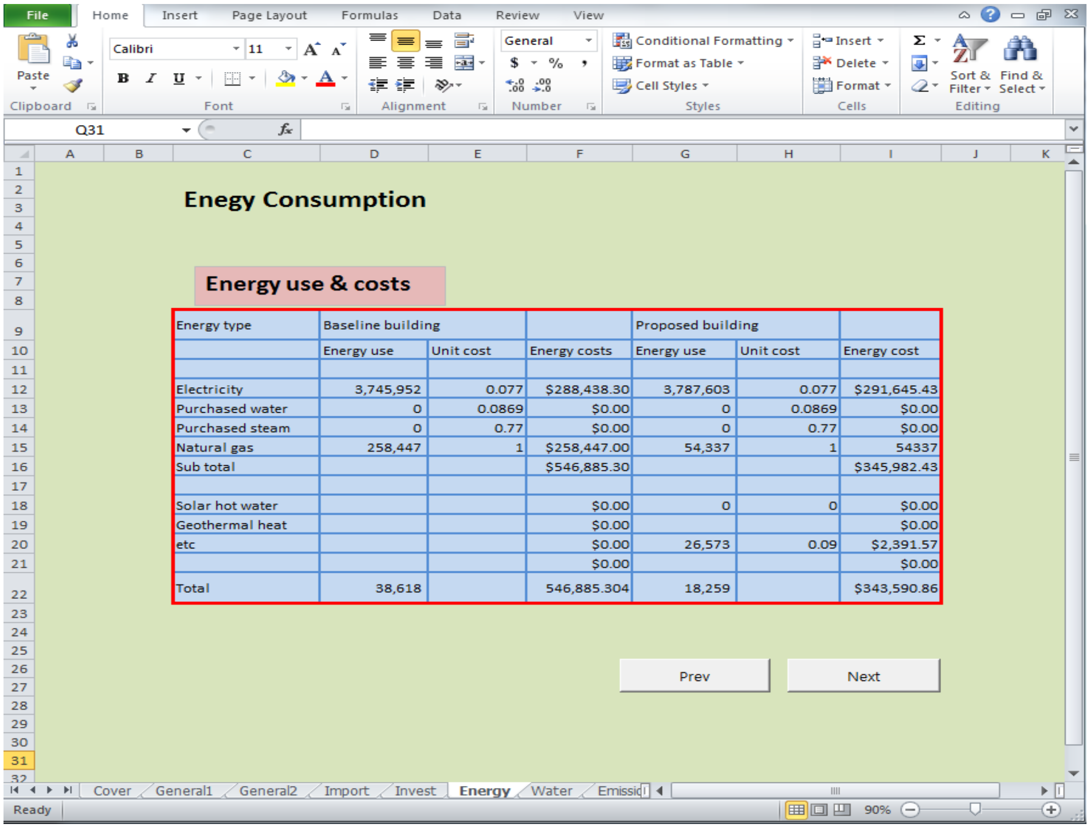
Expected life span
20 Years
Next
Cover
General1
General2
Import
Invest
Energy
Water
Emission

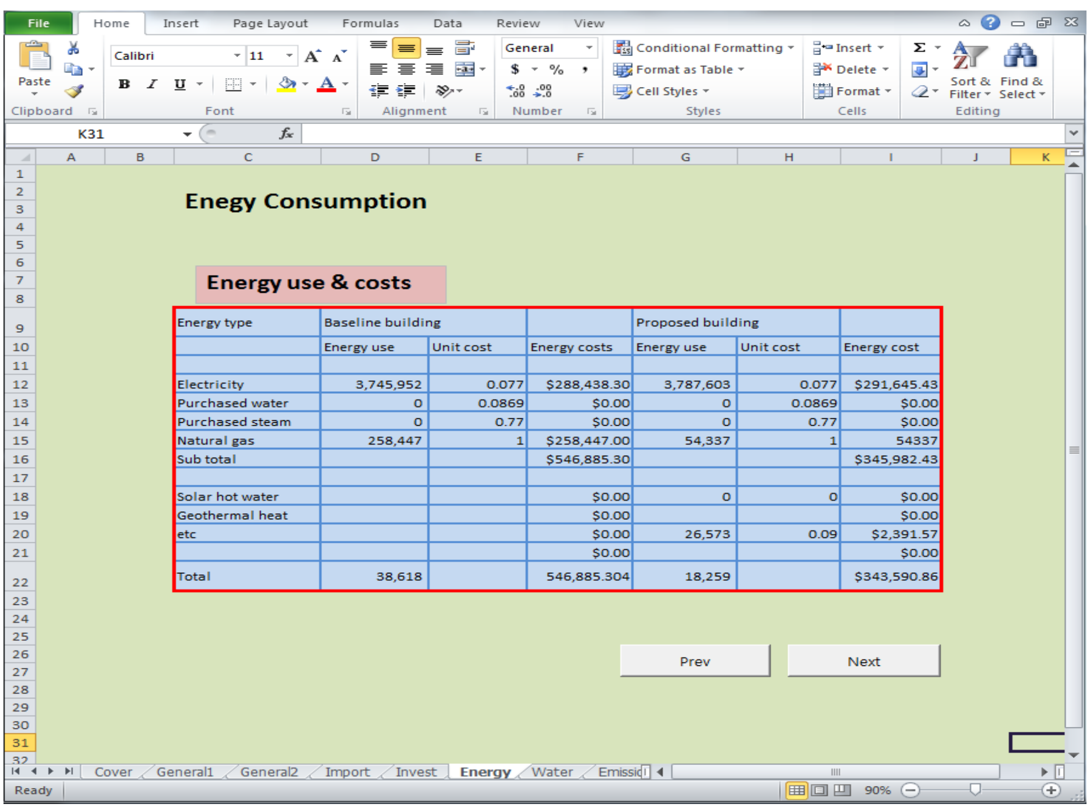

General Information
Financial
Discount rate (nominal)
3%
Escalation rate (energy)
2.1%
Escalation rate (water)
2.2%
Escalation rate (maintenance)
2.3%
Prev
Next
Cover
General1
General2
Import
Invest
Energy
Water
Emission



Enegy Consumption

Energy use & costs

Energy type	Baseline building			Proposed building		
	Energy use	Unit cost	Energy costs	Energy use	Unit cost	Energy cost
Electricity	3,745,952	0.077	$288,438.30	3,787,603	0.077	$291,645.43
Purchased water	0	0.0869	$0.00	0	0.0869	$0.00
Purchased steam	0	0.77	$0.00	0	0.77	$0.00
Natural gas	258,447	1	$258,447.00	54,337	1	54337
Sub total			$546,885.30			$345,982.43
Solar hot water			$0.00	0	0	$0.00
Geothermal heat			$0.00			$0.00
etc			$0.00	26,573	0.09	$2,391.57
			$0.00			$0.00
Total	38,618		546,885.304	18,259		$343,590.86



Enegy Consumption

Energy use & costs

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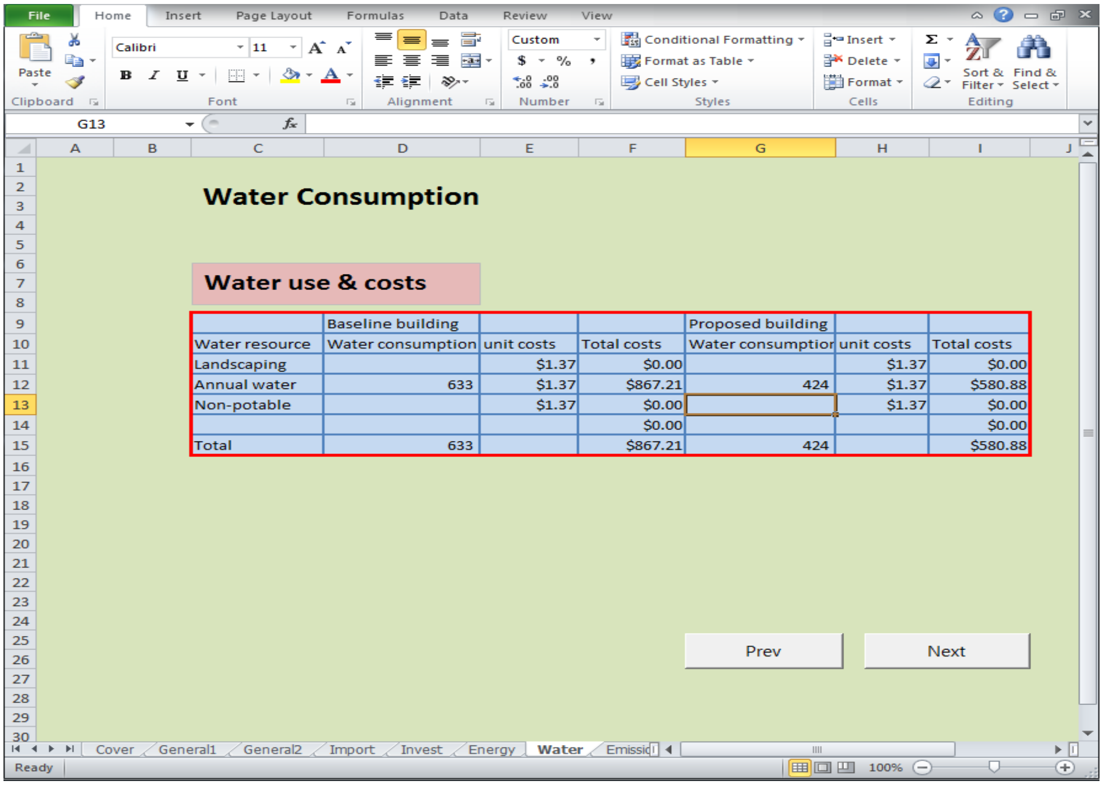
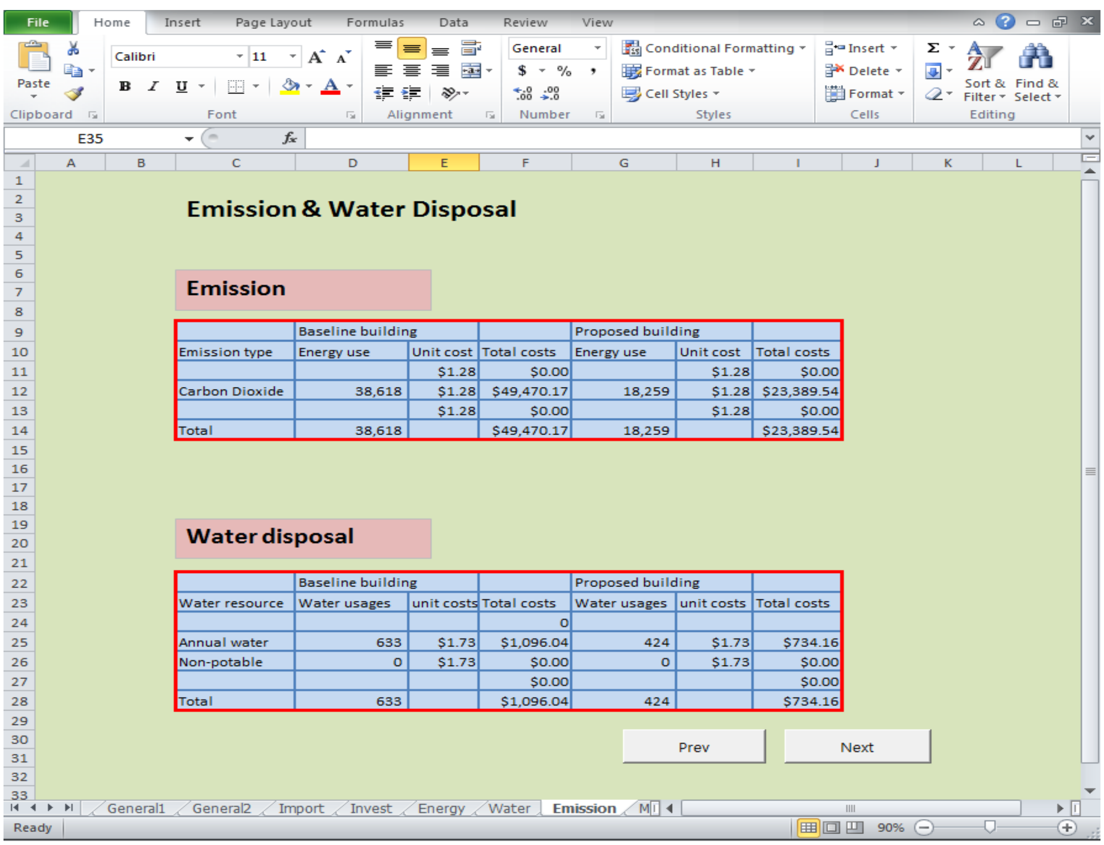
Purchased steam	0	0.77	$0.00	0	0.77	$0.00
Natural gas	258,447	1	$258,447.00	54,337	1	54337
Sub total			$546,885.30			$345,982.43
Solar hot water			$0.00	0	0	$0.00
Geothermal heat			$0.00			$0.00
etc			$0.00	26,573	0.09	$2,391.57
			$0.00			$0.00
Total	38,618		546,885.304	18,259		$343,590.86



Water Consumption

Water use & costs

	Baseline building			Proposed building		
Water resource	Water consumption	unit costs	Total costs	Water consumptior	unit costs	Total costs
Landscaping		$1.37	$0.00		$1.37	$0.00
Annual water	633	$1.37	$867.21	424	$1.37	$580.88
Non-potable		$1.37	$0.00		$1.37	$0.00
			$0.00			$0.00
Total	633		$867.21	424		$580.88



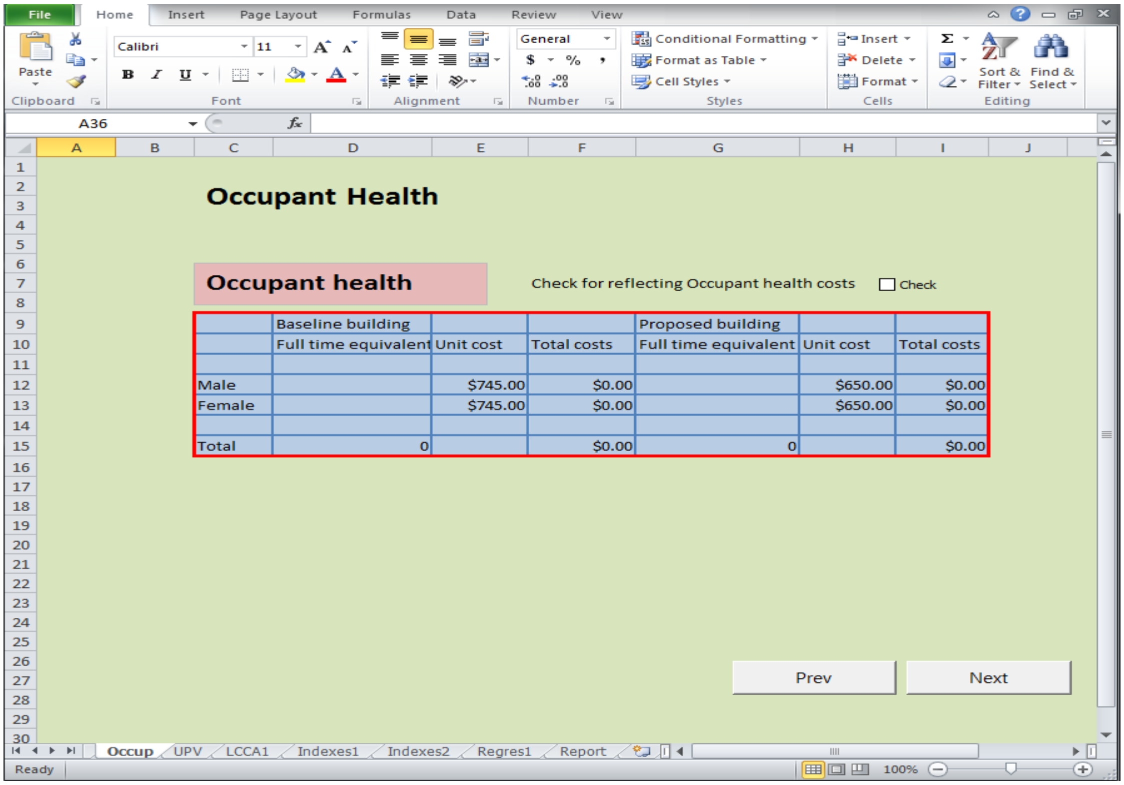
Emission & Water Disposal

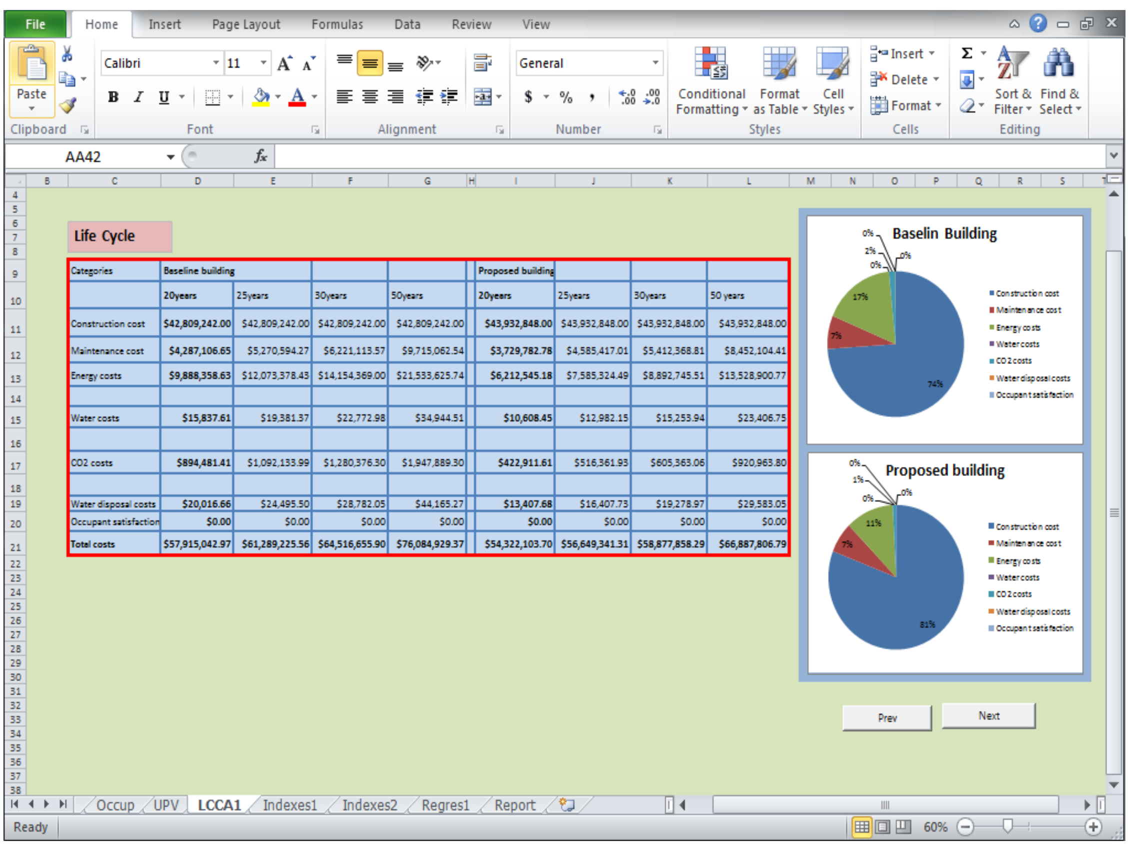
Emission

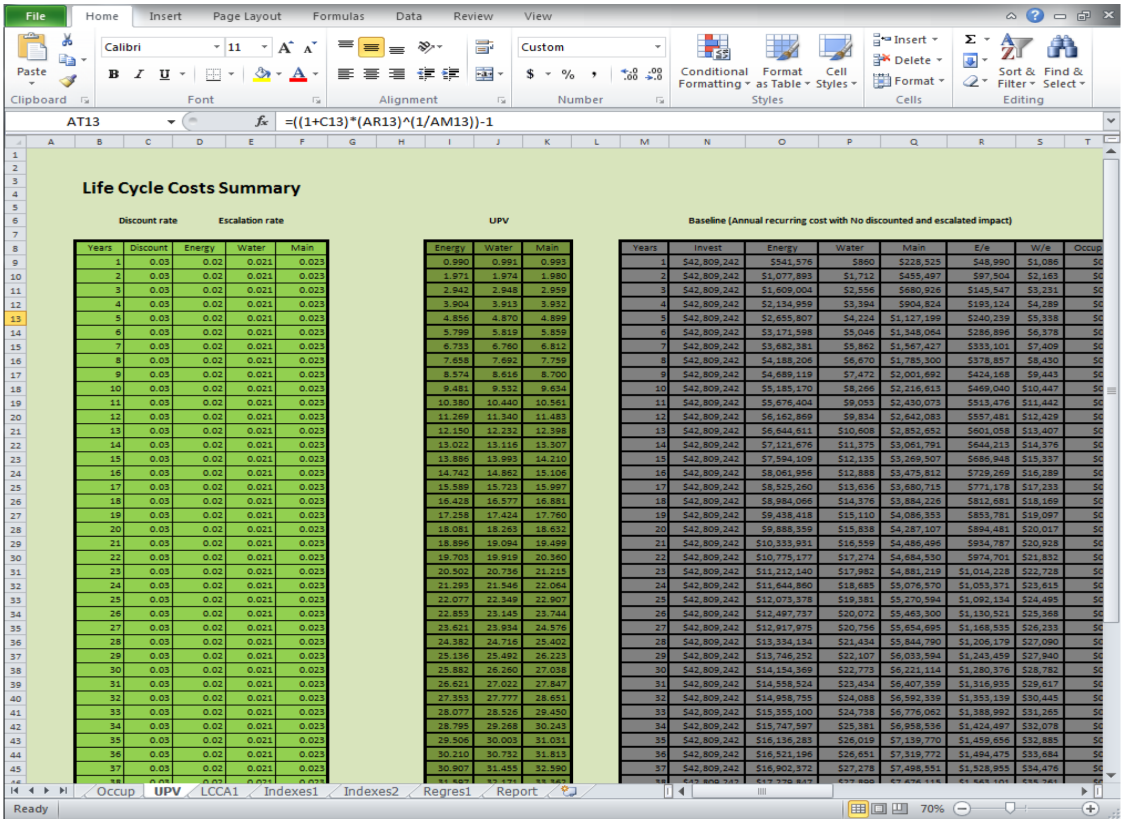
	Baseline building			Proposed building		
Emission type	Energy use	Unit cost	Total costs	Energy use	Unit cost	Total costs
		$1.28	$0.00		$1.28	$0.00
Carbon Dioxide	38,618	$1.28	$49,470.17	18,259	$1.28	$23,389.54
		$1.28	$0.00		$1.28	$0.00
Total	38,618		$49,470.17	18,259		$23,389.54

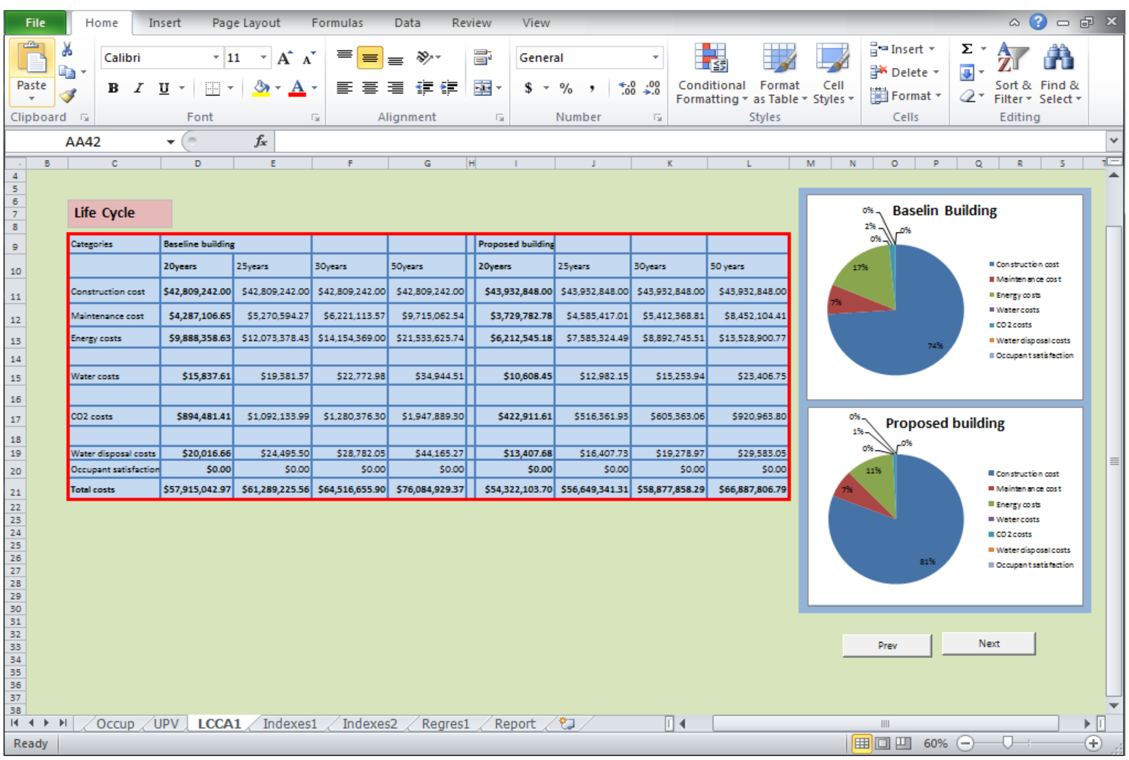
Water disposal

	Baseline building			Proposed building		
Water resource	Water usages	unit costs	Total costs	Water usages	unit costs	Total costs
			0			
Annual water	633	$1.73	$1,096.04	424	$1.73	$734.16
Non-potable	0	$1.73	$0.00	0	$1.73	$0.00
			$0.00			$0.00
Total	633		$1,096.04	424		$734.16

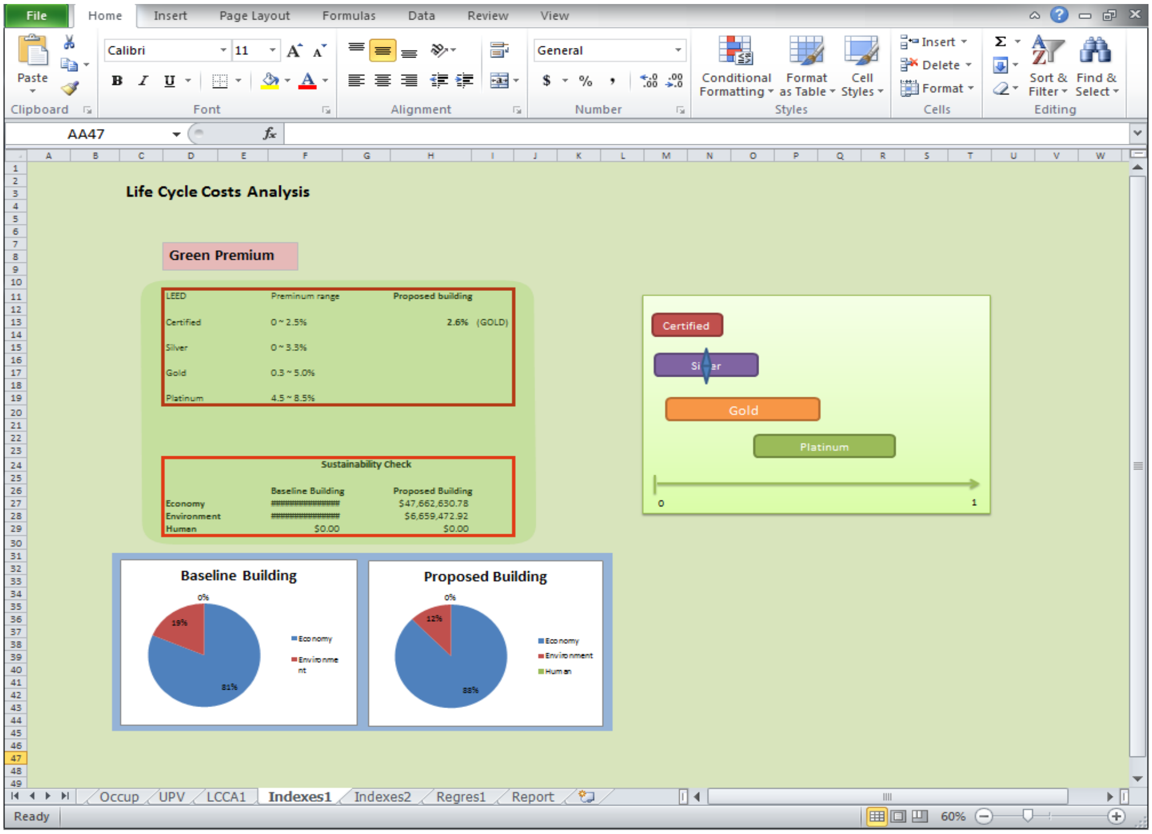

Occupant Health
Occupant health
Check for reflecting Occupant health costs
Check
Baseline building
Proposed building
Full time equivalent
Unit cost
Total costs
Full time equivalent
Unit cost
Total costs
Male $745.00 $0.00 $650.00 $0.00
Female $745.00 $0.00 $650.00 $0.00
Total 0 $0.00 0 $0.00
Prev
Next
Occup
UPV
LCCA1
Indexes1
Indexes2
Regres1
Report
Ready
100%

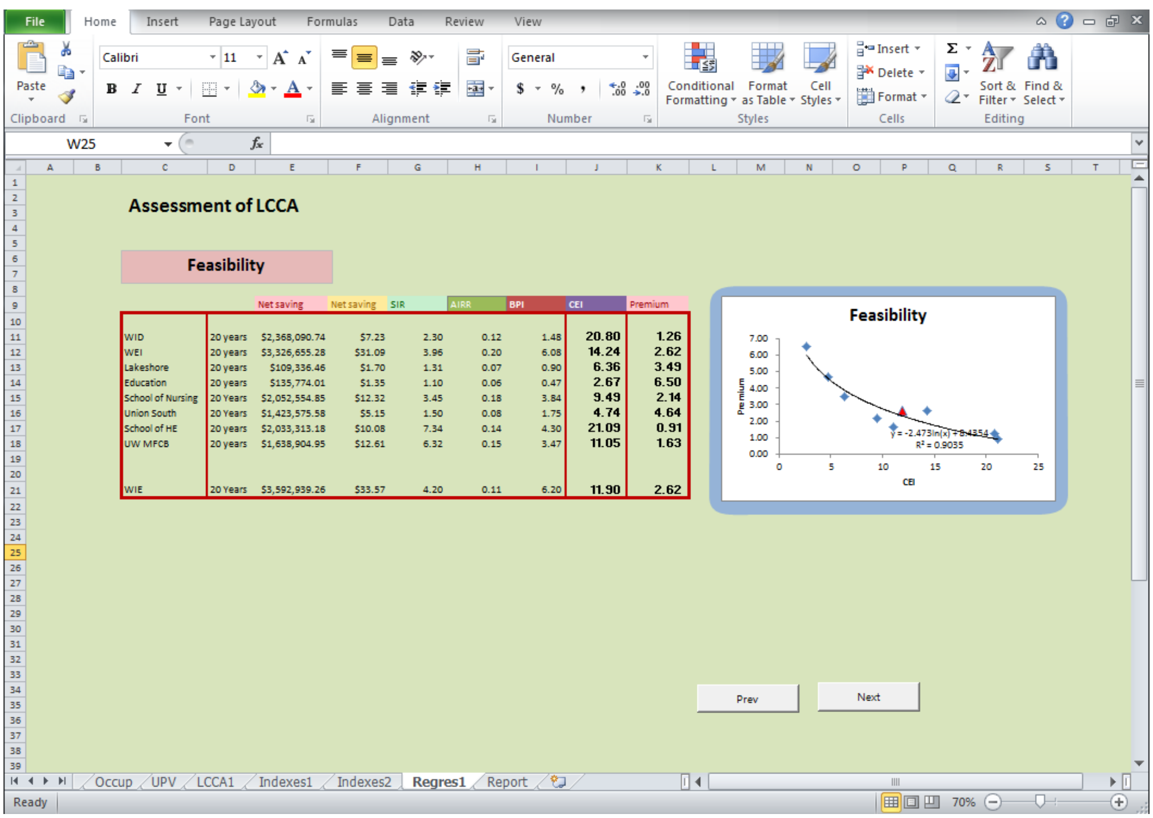

Life Cycle
Categories
Baseline building
Proposed building
20years
25years
30years
50years
20years
25years
30years
50 years
Construction cost $42,809,242.00 $42,809,242.00 $42,809,242.00 $42,809,242.00 $43,932,848.00 $43,932,848.00 $43,932,848.00 $43,932,848.00
Maintenance cost $4,287,106.65 $5,270,594.27 $6,221,113.57 $9,715,062.54 $3,729,782.78 $4,585,417.01 $5,412,368.81 $8,452,104.41
Energy costs $9,888,358.63 $12,073,378.43 $14,154,369.00 $21,533,625.74 $6,212,545.18 $7,585,324.49 $8,892,745.51 $13,528,900.77
Water costs $15,837.61 $19,381.37 $22,772.98 $34,944.51 $10,608.45 $12,982.15 $15,253.94 $23,406.75
CO2 costs $894,481.41 $1,092,133.99 $1,280,376.30 $1,947,889.30 $422,911.61 $516,361.93 $605,363.06 $920,963.80
Water disposal costs $20,016.66 $24,495.50 $28,782.05 $44,165.27 $13,407.68 $16,407.73 $19,278.97 $29,583.05
Occupant satisfaction $0.00 $0.00 $0.00 $0.00 $0.00 $0.00 $0.00 $0.00
Total costs $57,915,042.97 $61,289,225.56 $64,516,655.90 $76,084,929.37 $54,322,103.70 $56,649,341.31 $58,877,858.29 $66,887,806.79
Baselin Building
Proposed building
Prev
Next
Occup
UPV
LCCA1
Indexes1
Indexes2
Regres1
Report
Ready
60%





Categories	Baseline building				Proposed building			
	20years	25years	30years	50years	20years	25years	30years	50 years
Construction cost	$42,809,242.00	$42,809,242.00	$42,809,242.00	$42,809,242.00	$43,932,848.00	$43,932,848.00	$43,932,848.00	$43,932,848.00
Maintenance cost	$4,287,106.65	$5,270,594.27	$6,221,113.57	$9,715,062.54	$3,729,782.78	$4,585,417.01	$5,412,368.81	$8,452,104.41
Energy costs	$9,888,358.63	$12,073,378.43	$14,154,369.00	$21,533,625.74	$6,212,545.18	$7,585,324.49	$8,892,745.51	$13,528,900.77
Water costs	$15,837.61	$19,381.37	$22,772.98	$34,944.51	$10,608.45	$12,982.15	$15,253.94	$23,406.75
CO2 costs	$894,481.41	$1,092,133.99	$1,280,376.30	$1,947,889.30	$422,911.61	$516,361.93	$605,363.06	$920,963.80
Water disposal costs	$20,016.66	$24,495.50	$28,782.05	$44,165.27	$13,407.68	$16,407.73	$19,278.97	$29,583.05
Occupant satisfaction	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total costs	$57,915,042.97	$61,289,225.56	$64,516,655.90	$76,084,929.37	$54,322,103.70	$56,649,341.31	$58,877,858.29	$66,887,806.79


Life Cycle Costs Analysis
Green Premium
LEED
Premium range
Proposed building
Certified
0 ~ 2.5%
2.6% (GOLD)
Silver
0 ~ 3.5%
Gold
0.3 ~ 5.0%
Platinum
4.5 ~ 8.5%
Sustainability Check
Baseline Building
Proposed Building
Economy
$47,662,630.78
Environment
$6,659,472.92
Human
$0.00
$0.00
Certified
Gold
Platinum
Baseline Building
Proposed Building
Occup
UPV
LCCA1
Indexes1
Indexes2
Regres1
Report


Assessment of LCCA
Feasibility
Net saving
Net saving
SIR
AIRR
BPI
CEI
Premium
WID 20 years $2,368,090.74 $7.23 2.30 0.12 1.48 20.80 1.26
WEI 20 years $3,326,655.28 $31.09 3.96 0.20 6.08 14.24 2.62
Lakeshore 20 years $109,336.46 $1.70 1.31 0.07 0.90 6.36 3.49
Education 20 years $135,774.01 $1.35 1.10 0.06 0.47 2.67 6.50
School of Nursing 20 Years $2,052,554.85 $12.32 3.45 0.18 3.84 9.49 2.14
Union South 20 Years $1,423,575.58 $5.15 1.50 0.08 1.75 4.74 4.64
School of HE 20 years $2,033,313.18 $10.08 7.34 0.14 4.30 21.09 0.91
UW MFCB 20 years $1,638,904.95 $12.61 6.32 0.15 3.47 11.05 1.63
WIE 20 Years $3,592,939.26 $33.57 4.20 0.11 6.20 11.90 2.62
Feasibility
Premium
CEI
R² = 0.9035
Prev
Next
Occup
UPV
LCCA1
Indexes1
Indexes2
Regres1
Report

Appendix 4.2 The detailed results for WEI project by BLCC program

NIST BLCC 5.3-13: Detailed LCC Analysis

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\Users\YOUNGJUNYOO\Desktop\WEI.xml
Date of Study:	Wed Jan 01 23:10:11 CST 2014
Analysis Type:	FEMP Analysis, Energy Project
Project Name:	WEI
Project Location:	Wisconsin
Analyst:	
Base Date:	April 1, 2013
Service Date:	April 1, 2013
Study Period:	20 years 0 months (April 1, 2013 through March 31, 2033)
Discount Rate:	3%

Discounting Convention: End-of-Year

Discount and Escalation Rates are REAL (exclusive of general inflation)

Alternative: WEI base

Initial Cost Data (not Discounted)

Initial Capital Costs

(adjusted for price escalation)

Initial Capital Costs for All Components: $42,809,242

Component:

Cost-Phasing

Date	**Portion**	**Yearly Cost**
April 1, 2013	100%	$42,809,242
	------------	------------
Total (for Component)		$42,809,242

Energy Costs: Electricity

(base-year dollars)

Average	**Average**	**Average**	**Average**

Annual Usage	Price/Unit	Annual Cost	Annual Demand	Annual Rebate
3,745,952.0 kWh	$0.07700	$288,438	$0	$0

Energy Costs: Natural Gas

(base-year dollars)

Average Annual Usage	Price/Unit	Average Annual Cost	Average Annual Demand	Average Annual Rebate
258,447.0 Therm	$1.00000	$258,447	$0	$0

Energy Costs: Distillate Fuel Oil (#1, #2)

(base-year dollars)

Average Annual Usage	Price/Unit	Average Annual Cost	Average Annual Demand	Average Annual Rebate
0.0 kWh	$0.00000	$0	$0	$0

Water Costs: water cost

(base-year dollars)

Average Annual Usage	Average Disposal	Annual	Average Annual

Water	Units/Year	Price/Unit	Units/Year	Price/Unit	Cost
@ Summer Rates	633.0 CuFt	$1.37000	633.0 CuFt	$1.73000	$1,962
@ Winter Rates	0.0 CuFt	$0.00000	0.0 CuFt	$0.00000	$0

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs	$42,809,242	$2,877,738
Energy Costs		
Energy Consumption Costs	$9,020,008	$606,346
Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$9,020,008	$606,346
Water Usage Costs	$15,997	$1,075

Water Disposal Costs	$20,201	$1,358
Operating, Maintenance & Repair Costs		
Component:		
Annually Recurring Costs	$4,287,188	$288,195
Non-Annually Recurring Costs	$0	$0
	------------	------------
Subtotal (for OM&R):	$4,287,188	$288,195
Replacements to Capital Components		
Component:	$0	$0
	------------	------------
Subtotal (for Replacements):	$0	$0
Residual Value of Original Capital Components		
Component:	$0	$0

	------------	------------
Subtotal (for Residual Value):	$0	$0
Residual Value of Capital Replacements		
Component:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0
Total Life-Cycle Cost	$56,152,636	$3,774,712

Emissions Summary

Energy Name	Annual	Life-Cycle
Electricity:		
CO2	3,141,604.11 kg	62,823,480.86 kg
SO2	11,167.46 kg	223,318.67 kg
NOx	4,369.88 kg	87,385.57 kg
Natural Gas:		

CO2	1,365,208.50 kg	27,300,432.19 kg
SO2	11,017.66 kg	220,323.10 kg
NOx	1,609.02 kg	32,175.90 kg
Distillate Fuel Oil (#1, #2):		
CO2	0.00 kg	0.00 kg
SO2	0.00 kg	0.00 kg
NOx	0.00 kg	0.00 kg
Total:		
CO2	4,506,812.60 kg	90,123,913.06 kg
SO2	22,185.13 kg	443,641.78 kg
NOx	5,978.89 kg	119,561.47 kg

Alternative: WEI base

Initial Cost Data (not Discounted)

Initial Capital Costs

(adjusted for price escalation)

Initial Capital Costs for All Components: $43,932,848

Component: Copy of:

Cost-Phasing

Date	Portion	Yearly Cost
April 1, 2013	100%	$43,932,848
	------------	------------
Total (for Component)		$43,932,848

Energy Costs: Electricity

(base-year dollars)

Average		Average	Average	Average
Annual Usage	**Price/Unit**	**Annual Cost**	**Annual Demand**	**Annual Rebate**
3,787,603.0 kWh	$0.07700	$291,645	$0	$0

Energy Costs: Natural Gas

(base-year dollars)

Average		Average	Average	Average

Annual Usage	Price/Unit	Annual Cost	Annual Demand	Annual Rebate
54,337.0 Therm	$1.00000	$54,337	$0	$0

Water Costs: water cost

(base-year dollars)

	Average Annual Usage		Average Disposal		Annual Average Annual
Water	**Units/Year**	**Price/Unit**	**Units/Year**	**Price/Unit**	**Cost**
@ Summer Rates	424.0 CuFt	$1.37000	424.0 CuFt	$1.73000	$1,314
@ Winter Rates	0.0 CuFt	$0.00000	0.0 CuFt	$0.00000	$0

Life-Cycle Cost Analysis

	Present Value	Annual Value
Initial Capital Costs	$43,932,848	$2,953,270
Energy Costs		
Energy Consumption Costs	$5,456,072	$366,770

Energy Demand Charges	$0	$0
Energy Utility Rebates	$0	$0
	------------	------------
Subtotal (for Energy):	$5,456,072	$366,770
Water Usage Costs	$10,715	$720
Water Disposal Costs	$13,531	$910
Operating, Maintenance & Repair Costs		
Component: Copy of:		
Annually Recurring Costs	$3,729,861	$250,730
Non-Annually Recurring Costs	$0	$0
	------------	------------
Subtotal (for OM&R):	$3,729,861	$250,730
Replacements to Capital Components		

Component: Copy of:	$0	$0
	------------	------------
Subtotal (for Replacements):	$0	$0

Residual Value of Original Capital Components

Component: Copy of:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0

Residual Value of Capital Replacements

Component: Copy of:	$0	$0
	------------	------------
Subtotal (for Residual Value):	$0	$0

Total Life-Cycle Cost	$53,143,027	$3,572,399

Emissions Summary

Energy Name	Annual	Life-Cycle
Electricity:		
CO2	2,476,317.80 kg	49,519,576.13 kg
SO2	12,478.07 kg	249,527.29 kg
NOx	3,695.69 kg	73,903.71 kg
Natural Gas:		
CO2	287,027.26 kg	5,739,759.35 kg
SO2	2,316.40 kg	46,321.67 kg
NOx	338.29 kg	6,764.80 kg
Total:		
CO2	2,763,345.06 kg	55,259,335.48 kg
SO2	14,794.47 kg	295,848.96 kg
NOx	4,033.98 kg	80,668.51 kg

Appendix 4.3 The codeing of the stand-along version of GBPAT using C# language

GBPAT program coding (using Visual C# Express)

```
using System;
using System.Collections.Generic;
using System.Text;
using System.Windows.Forms;

using System.Windows.Forms.DataVisualization.Charting;

namespace GBPAT
{
   public class clsDataGridView_Setting
   {
      public static void Setting_DataGridView_Regres1(DataGridView dg, DataGridView dgUPV,
DataGridView dgInvest)
      {
         // 해¨ª더¥o Hidden
         dg.RowHeadersVisible = false;      // row
         dg.ColumnHeadersVisible = false;   // col

         // 길¾©¡이I 설ù©ø정¢´
         dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
         dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

         // col Setting
         dg.Columns.Add("COL_1", "");
         dg.Columns.Add("COL_2", "");
         dg.Columns.Add("COL_3", "");
         dg.Columns.Add("COL_4", "");
         dg.Columns.Add("COL_5", "");
         dg.Columns.Add("COL_6", "");
         dg.Columns.Add("COL_7", "");
         dg.Columns.Add("COL_8", "");
         dg.Columns.Add("COL_9", "");
```

```
dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[4].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[5].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[6].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[7].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[8].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

dg.ReadOnly = true;

// row Setting
dg.Rows.Clear();
dg.Rows.Add(12);

// Value
dg[0, 2].Value = "WID";
dg[0, 3].Value = "WEI";
dg[0, 4].Value = "Lakeshore";
dg[0, 5].Value = "Education";
dg[0, 6].Value = "School of Nursing";
dg[0, 7].Value = "Union South";
dg[0, 8].Value = "School of Nursing";
dg[0, 9].Value = "UW MFCB";
dg[0, 11].Value = "WIMR";

dg[1, 2].Value = "20 years";
dg[1, 3].Value = "20 years";
dg[1, 4].Value = "20 years";
dg[1, 5].Value = "20 years";
dg[1, 6].Value = "20 years";
dg[1, 7].Value = "20 years";
dg[1, 8].Value = "20 years";
dg[1, 9].Value = "20 years";
dg[1, 11].Value = "20 years";

double AN28 = double.Parse(dgUPV[24, 20].Value.ToString());

dg[2, 0].Value = "Net saving";
dg[2, 2].Value = "2368090.74191999";
dg[2, 3].Value = "3326655.2754528";
dg[2, 4].Value = "109336.459319213";
```

```
dg[2, 5].Value = "135774.008142572";
dg[2, 6].Value = "2052554.84925666";
dg[2, 7].Value = "1423575.57602063";
dg[2, 8].Value = "2033313.17845479";
dg[2, 9].Value = "1638904.94609571";
dg[2, 11].Value = AN28.ToString();

double AP28 = double.Parse(dgUPV[26, 20].Value.ToString());

dg[3, 0].Value = "Net saving";
dg[3, 2].Value = "7.22827325342245";
dg[3, 3].Value = "31.0850069656768";
dg[3, 4].Value = "1.70282140072596";
dg[3, 5].Value = "1.35307198308408";
dg[3, 6].Value = "12.3249918891811";
dg[3, 7].Value = "5.14550348444549";
dg[3, 8].Value = "10.0847283219414";
dg[3, 9].Value = "12.6069611238132";
dg[3, 11].Value = AP28.ToString();

double AR25 = double.Parse(dgUPV[27, 17].Value.ToString());
double AR28 = double.Parse(dgUPV[27, 20].Value.ToString());

dg[4, 0].Value = "SIR";
dg[4, 2].Value = "2.29987602354178";
dg[4, 3].Value = "3.96069554225663";
dg[4, 4].Value = "1.31221058568997";
dg[4, 5].Value = "1.09545260143339";
dg[4, 6].Value = "3.44604234281891";
dg[4, 7].Value = "1.49668668985948";
dg[4, 8].Value = "7.34029373038972";
dg[4, 9].Value = AR25.ToString();
dg[4, 11].Value = AP28.ToString();

double AT25 = double.Parse(dgUPV[28, 17].Value.ToString());
double AT28 = double.Parse(dgUPV[28, 20].Value.ToString());

dg[5, 0].Value = "AIRR";
dg[5, 2].Value = "0.118443615212402";
dg[5, 3].Value = "0.203975820426216";
dg[5, 4].Value = "0.0675788451630334";
dg[5, 5].Value = "0.0564158089738194";
dg[5, 6].Value = "0.177471180655174";
```

```
dg[5, 7].Value = "0.0770793645277634";
dg[5, 8].Value = "0.137949257161571";
dg[5, 9].Value = AT25.ToString();
dg[5, 11].Value = AT28.ToString();

double AV28 = double.Parse(dgUPV[29, 20].Value.ToString());

dg[6, 0].Value = "BPI";
dg[6, 2].Value = "1.47684310650289";
dg[6, 3].Value = "6.08027914105654";
dg[6, 4].Value = "0.903767940724576";
dg[6, 5].Value = "0.470357354966004";
dg[6, 6].Value = "3.84283833386566";
dg[6, 7].Value = "1.75357077292995";
dg[6, 8].Value = "4.29683688315511";
dg[6, 9].Value = "3.47195682976669";
dg[6, 11].Value = AV28.ToString();

double AX28 = double.Parse(dgUPV[30, 20].Value.ToString());

dg[7, 0].Value = "CEI";
dg[7, 2].Value = "20.8009038605429";
dg[7, 3].Value = "14.2447103138009";
dg[7, 4].Value = "6.36020463404396";
dg[7, 5].Value = "2.67";
dg[7, 6].Value = "9.48769633623001";
dg[7, 7].Value = "4.74157542022485";
dg[7, 8].Value = "21.0854470959893";
dg[7, 9].Value = "11.0526130566146";
dg[7, 11].Value = AX28.ToString();

double Invest_D20 = 0;
double Invest_F20 = 0;

try
{
   Invest_D20 = double.Parse(dgInvest[1, dgInvest.Rows.Count - 1].Value.ToString());
}
catch (Exception ex)
{
}

try
```

```
            {
                Invest_F20 = double.Parse(dgInvest[3, dgInvest.Rows.Count - 1].Value.ToString());
            }
            catch (Exception ex)
            {
            }

            dg[8, 0].Value = "Premium";
            dg[8, 2].Value = "1.26";
            dg[8, 3].Value = "2.62";
            dg[8, 4].Value = "3.49";
            dg[8, 5].Value = "6.5";
            dg[8, 6].Value = "2.14166455639375";
            dg[8, 7].Value = "4.64495736285991";
            dg[8, 8].Value = "0.913626035035878";
            dg[8, 9].Value = "1.62601626016261";
            dg[8, 11].Value = ((Invest_F20-Invest_D20)/Invest_D20*100).ToString();

            if (dg[8, 11].Value.ToString() == "NaN")
            {
                dg[8, 11].Value = "0";
            }
        }

        public static void Setting_DataGridView_Indexes2(DataGridView dg, DataGridView dgUPV,
DataGridView dgInvest, DataGridView dgEnergy, DataGridView dgWater, string sMain_I30,
string sMain_K30, DataGridView dgEmission_1, DataGridView dgEmission_2, DataGridView
dgOccup, string sDiscount)
        {
            // Invest
            double dInvest_D20 = 0;
            try
            {
                dInvest_D20 = double.Parse(dgInvest[1, dgInvest.Rows.Count - 1].Value.ToString());
            }
            catch (Exception ex)
            {
            }

            double dInvest_E20 = 0;
            try
            {
                dInvest_E20 = double.Parse(dgInvest[2, dgInvest.Rows.Count - 1].Value.ToString());
```

```
}
catch (Exception ex)
{
}

double dInvest_F20 = 0;
try
{
   dInvest_F20 = double.Parse(dgInvest[3, dgInvest.Rows.Count - 1].Value.ToString());
}
catch (Exception ex)
{
}

// Energy
double dEnergy_F22 = 0;
try
{
   dEnergy_F22 = double.Parse(dgEnergy[3, dgEnergy.Rows.Count - 1].Value.ToString());
}
catch (Exception ex)
{
}

double dEnergy_I22 = 0;
try
{
   dEnergy_I22 = double.Parse(dgEnergy[6, dgEnergy.Rows.Count - 1].Value.ToString());
}
catch (Exception ex)
{
}

// Water
double dWater_F15 = 0;
try
{
   dWater_F15 = double.Parse(dgWater[3, dgWater.Rows.Count - 1].Value.ToString());
}
catch (Exception ex)
{
}
```

```
double dWater_I15 = 0;
try
{
   dWater_I15 = double.Parse(dgWater[6, dgWater.Rows.Count - 1].Value.ToString());
}
catch (Exception ex)
{
}

// Main
double dMain_I30 = 0;
try
{
   dMain_I30 = double.Parse(sMain_I30);
}
catch (Exception ex)
{
}

double dMain_K30 = 0;
try
{
   dMain_K30 = double.Parse(sMain_K30);
}
catch (Exception ex)
{
}

// Emission
double dEmission_F14 = 0;
try
{
   dEmission_F14 = double.Parse(dgEmission_1[3, dgEmission_1.Rows.Count -
1].Value.ToString());
}
catch (Exception ex)
{
}

double dEmission_I14 = 0;
try
{
```

```
            dEmission_I14 = double.Parse(dgEmission_1[6, dgEmission_1.Rows.Count -
1].Value.ToString());
        }
        catch (Exception ex)
        {
        }

        // Emission
        double dEmission_F28 = 0;
        try
        {
            dEmission_F28 = double.Parse(dgEmission_2[3, dgEmission_2.Rows.Count -
1].Value.ToString());
        }
        catch (Exception ex)
        {
        }

        double dEmission_I28 = 0;
        try
        {
            dEmission_I28 = double.Parse(dgEmission_2[6, dgEmission_2.Rows.Count -
1].Value.ToString());
        }
        catch (Exception ex)
        {
        }

        // Occup
        double dOccup_F15 = 0;
        try
        {
            dOccup_F15 = double.Parse(dgOccup[3, dgOccup.Rows.Count - 1].Value.ToString());
        }
        catch (Exception ex)
        {
        }

        double dOccup_I15 = 0;
        try
        {
            dOccup_I15 = double.Parse(dgOccup[6, dgOccup.Rows.Count - 1].Value.ToString());
        }
```

```
catch (Exception ex)
{
}

// DataGridView Setting
dg.Columns.Clear();
dg.Rows.Clear();

dg.RowHeadersVisible = false;       // row
dg.ColumnHeadersVisible = false;    // col

for(int i = 0 ; i < 35 ; i++)
{
   dg.Columns.Add("COL_" + i.ToString(), "");
}

dg.Rows.Add(51);

// Row Indws
for (int i = 0; i <= 51; i++)
{
   dg[0, i].Value = i.ToString();
}

// UPV Copy
for (int i = 0; i <= 51; i++)
{
   dg[1, i].Value = dgUPV[1, i].Value;
   dg[2, i].Value = dgUPV[2, i].Value;
   dg[3, i].Value = dgUPV[3, i].Value;
}

// Baseline Copy
dg[5, 0].Value = "B.Invest";
dg[6, 0].Value = "B.Energy";
dg[7, 0].Value = "B.Water";
dg[8, 0].Value = "B.Main";
dg[9, 0].Value = "B.Emission.1";
dg[10, 0].Value = "B.Emission.2";
dg[11, 0].Value = "B.Occup";

for (int i = 1; i <= 51; i++)
{
```

```
    dg[5, i].Value = dInvest_D20;
    dg[6, i].Value = dEnergy_F22;
    dg[7, i].Value = dWater_F15;
    dg[8, i].Value = dMain_I30;
    dg[9, i].Value = dEmission_F14;
    dg[10, i].Value = dEmission_F28;
    dg[11, i].Value = dOccup_F15;
}

// Proposed
dg[13, 0].Value = "P.Invest";
dg[14, 0].Value = "P.Energy";
dg[15, 0].Value = "P.Water";
dg[16, 0].Value = "P.Main";
dg[17, 0].Value = "P.Emission.1";
dg[18, 0].Value = "P.Emission.2";
dg[19, 0].Value = "P.Occup";

for (int i = 1; i <= 51; i++)
{
    dg[13, i].Value = dInvest_F20;
    dg[14, i].Value = dEnergy_I22;
    dg[15, i].Value = dWater_I15;
    dg[16, i].Value = dMain_K30;
    dg[17, i].Value = dEmission_I14;
    dg[18, i].Value = dEmission_I28;
    dg[19, i].Value = dOccup_I15;
}

// Cal
dg[21, 0].Value = "L.Baseline";
dg[22, 0].Value = "L.Proposed";

for (int i = 1; i <= 51; i++)
{
    dg[21, i].Value = double.Parse(dg[5, i].Value.ToString())
        + (double.Parse(dg[6, i].Value.ToString()) * double.Parse(dg[1, i].Value.ToString()))
        + (double.Parse(dg[7, i].Value.ToString()) * double.Parse(dg[2, i].Value.ToString()))
        + (double.Parse(dg[8, i].Value.ToString()) * double.Parse(dg[3, i].Value.ToString()))
        + (double.Parse(dg[9, i].Value.ToString()) * double.Parse(dg[1, i].Value.ToString()))
        + (double.Parse(dg[10, i].Value.ToString()) * double.Parse(dg[2, i].Value.ToString()))
        + (double.Parse(dg[11, i].Value.ToString()) * double.Parse(dg[3, i].Value.ToString()));
```

```
        dg[22, i].Value = double.Parse(dg[13, i].Value.ToString())
          + (double.Parse(dg[14, i].Value.ToString()) * double.Parse(dg[1, i].Value.ToString()))
          + (double.Parse(dg[15, i].Value.ToString()) * double.Parse(dg[2, i].Value.ToString()))
          + (double.Parse(dg[16, i].Value.ToString()) * double.Parse(dg[3, i].Value.ToString()))
          + (double.Parse(dg[17, i].Value.ToString()) * double.Parse(dg[1, i].Value.ToString()))
          + (double.Parse(dg[18, i].Value.ToString()) * double.Parse(dg[2, i].Value.ToString()))
          + (double.Parse(dg[19, i].Value.ToString()) * double.Parse(dg[3, i].Value.ToString()));
      }

      // Graph Data
      dg[24, 0].Value = "G.Net Saving";
      dg[25, 0].Value = "G.S/F";
      dg[26, 0].Value = "G.Net Savings";
      dg[27, 0].Value = "G.SIR";
      dg[28, 0].Value = "G.AIRR";
      dg[29, 0].Value = "G.BPI";
      dg[30, 0].Value = "G.CEI";

      for (int i = 1; i <= 51; i++)
      {
        dg[24, i].Value = double.Parse(dg[21, i].Value.ToString()) - double.Parse(dg[22,
i].Value.ToString());
        dg[25, i].Value = dInvest_E20;
        dg[26, i].Value = double.Parse(dg[24, i].Value.ToString()) / double.Parse(dg[25,
i].Value.ToString());

        if (dg[26, i].Value.ToString() == "NaN")
        {
          dg[26, i].Value = "0";
        }
      }

      for (int i = 1; i <= 51; i++)
      {
        double C9 = double.Parse(sDiscount);
        double I9 = double.Parse(dg[1, i].Value.ToString());
        double J9 = double.Parse(dg[2, i].Value.ToString());
        double K9 = double.Parse(dg[3, i].Value.ToString());
        double N9 = double.Parse(dg[5, i].Value.ToString());
        double O9 = double.Parse(dg[6, i].Value.ToString());
        double P9 = double.Parse(dg[7, i].Value.ToString());
        double Q9 = double.Parse(dg[8, i].Value.ToString());
        double R9 = double.Parse(dg[9, i].Value.ToString());
```

```
double S9 = double.Parse(dg[10, i].Value.ToString());
double T9 = double.Parse(dg[11, i].Value.ToString());
double X9 = double.Parse(dg[13, i].Value.ToString());
double Y9 = double.Parse(dg[14, i].Value.ToString());
double Z9 = double.Parse(dg[15, i].Value.ToString());
double AA9 = double.Parse(dg[16, i].Value.ToString());
double AB9 = double.Parse(dg[17, i].Value.ToString());
double AC9 = double.Parse(dg[18, i].Value.ToString());
double AD9 = double.Parse(dg[19, i].Value.ToString());

// SIR
dg[27, i].Value = ((((O9 * I9) - (Y9 * I9)) + ((P9 * J9) - (Z9 * J9)) + ((Q9 * K9) - (AA9 * K9))
+ ((R9 * I9) - (AB9 * I9)) + ((S9 * J9) - (AC9 * J9)) + ((T9 * K9) - (AD9 * K9))) / (X9 -
N9)).ToString("N3");

if (dg[27, i].Value.ToString() == "NaN")
{
   dg[27, i].Value = "0";
}

// AIRR
double AM9 = double.Parse(dg[0, i].Value.ToString());
double AR9 = double.Parse(dg[27, i].Value.ToString());

dg[28, i].Value = (1 + C9) * Math.Pow(AR9, (1 / AM9)) - 1;

if (dg[28, i].Value.ToString() == "NaN")
{
   dg[28, i].Value = "0";
}

// BPI
double AH9 = double.Parse(dg[21, i].Value.ToString());
double AJ9 = double.Parse(dg[22, i].Value.ToString());

dg[29, i].Value = (AH9-AJ9)/AH9*100;

if (dg[29, i].Value.ToString() == "NaN")
{
   dg[29, i].Value = "0";
}

// CEI
```

```
            dg[30, i].Value = (((1-
((Y9*I9)+(Z9*J9)+(AA9*K9)+(AB9*I9)+(AC9*J9)+(AD9*K9))/((O9*I9)+(P9*J9)+(Q9*K9)+(R9*I9)+(
S9*J9)+(T9*K9)))))/((X9/N9)-1);

            if (dg[30, i].Value.ToString() == "NaN")
            {
               dg[30, i].Value = "0";
            }

         }
      }

      public static void Setting_DataGridView_Indexes1_1(DataGridView dg, DataGridView
dgInvest, string sLEED)
      {
         double dInvest_F20 = 0;
         double dInvest_D20 = 0;

         try
         {
            if (double.Parse(dgInvest[1, dgInvest.Rows.Count - 1].Value.ToString()) == 0)
            {
            }
            else
            {
               dInvest_F20 = double.Parse(dgInvest[3, dgInvest.Rows.Count - 1].Value.ToString());
               dInvest_D20 = double.Parse(dgInvest[1, dgInvest.Rows.Count - 1].Value.ToString());
            }
         }
         catch (Exception ex)
         {
         }

         double dResult = (dInvest_F20 - dInvest_D20) / dInvest_D20;

         dg[3, 1].Value = dResult.ToString() + "(" + sLEED + ")";
      }

      public static void Setting_DataGridView_Indexes1_2(DataGridView dg, DataGridView
dgLCCA1, Chart chart_Indexes1_1, Chart chart_Indexes1_2)
      {
         // Economy
         dg[1, 1].Value = "0";
```

```
        try
        {
           dg[1, 1].Value = (double.Parse(dgLCCA1[1, 2].Value.ToString()) +
double.Parse(dgLCCA1[1, 3].Value.ToString()) + double.Parse(dgLCCA1[1, 4].Value.ToString()) +
double.Parse(dgLCCA1[1, 6].Value.ToString())).ToString();
        }
        catch (Exception ex)
        {
        }

        dg[2, 1].Value = "0";

        try
        {
           dg[2, 1].Value = (double.Parse(dgLCCA1[5, 2].Value.ToString()) +
double.Parse(dgLCCA1[5, 3].Value.ToString()) + double.Parse(dgLCCA1[5, 4].Value.ToString()) +
double.Parse(dgLCCA1[5, 6].Value.ToString())).ToString();
        }
        catch (Exception ex)
        {
        }

        // Environment
        dg[1, 2].Value = "0";

        try
        {
           dg[1, 2].Value = (double.Parse(dgLCCA1[1, 8].Value.ToString()) +
double.Parse(dgLCCA1[1, 10].Value.ToString())).ToString();
        }
        catch(Exception ex)
        {
        }

        dg[2, 2].Value = "0";

        try
        {
           dg[2, 2].Value = (double.Parse(dgLCCA1[5, 8].Value.ToString()) +
double.Parse(dgLCCA1[5, 10].Value.ToString())).ToString();
        }
        catch(Exception ex)
```

```
        {
        }

        // Human
        dg[1, 3].Value = "0";

        try
        {
          dg[1, 3].Value = double.Parse(dgLCCA1[1, 11].Value.ToString()).ToString();
        }
        catch (Exception ex)
        {
        }

        dg[2, 3].Value = "0";

        try
        {
          dg[2, 3].Value = double.Parse(dgLCCA1[5, 11].Value.ToString()).ToString();
        }
        catch (Exception ex)
        {
        }

        // Chart 1
        double[] yValues_1 = { double.Parse(dg[1, 1].Value.ToString()), double.Parse(dg[1,
2].Value.ToString()), double.Parse(dg[1, 3].Value.ToString()) };
        string[] xValues_1 = { "Economy", "Environment", "Human" };
        chart_Indexes1_1.Series[0].Points.DataBindXY(xValues_1, yValues_1);

        // Chart 2
        double[] yValues_2 = { double.Parse(dg[2, 1].Value.ToString()), double.Parse(dg[2,
2].Value.ToString()), double.Parse(dg[2, 3].Value.ToString()) };
        string[] xValues_2 = { "Economy", "Environment", "Human" };
        chart_Indexes1_2.Series[0].Points.DataBindXY(xValues_2, yValues_2);
      }

      public static void Setting_DataGridView_LCCA1(DataGridView dg, DataGridView dgInvest,
string sMain_I30, DataGridView dgUPV, string sMain_K30, DataGridView dgEnergy,
DataGridView dgWater, DataGridView dgEmission_1, DataGridView dgEmission_2,
DataGridView dgOccup, Chart chart_LCCA1_1, Chart chart_LCCA1_2, CheckBox chkOccup)
      {
        // Construction cost - Baseline building
```

```
double dInvest_D20 = 0;
try
{
   dInvest_D20 = double.Parse(dgInvest[1, dgInvest.Rows.Count - 1].Value.ToString());
}
catch (Exception ex)
{

}

dg[1, 2].Value = dInvest_D20.ToString("N3");
dg[2, 2].Value = dInvest_D20.ToString("N3");
dg[3, 2].Value = dInvest_D20.ToString("N3");
dg[4, 2].Value = dInvest_D20.ToString("N3");

// Construction cost - Proposed building
double dInvest_F20 = 0;
try
{
   dInvest_F20 = double.Parse(dgInvest[3, dgInvest.Rows.Count - 1].Value.ToString());
}
catch (Exception ex)
{

}

dg[5, 2].Value = dInvest_F20.ToString("N3");
dg[6, 2].Value = dInvest_F20.ToString("N3");
dg[7, 2].Value = dInvest_F20.ToString("N3");
dg[8, 2].Value = dInvest_F20.ToString("N3");

// Maintenance cost - Baseline building
double dMain_I30 = 0;
try
{
   dMain_I30 = double.Parse(sMain_I30);
}
catch (Exception ex)
{

}
```

```
        dg[1, 3].Value = (dMain_I30 * double.Parse(dgUPV[3, 20 +
1].Value.ToString())).ToString("N3");
        dg[2, 3].Value = (dMain_I30 * double.Parse(dgUPV[3, 25 +
1].Value.ToString())).ToString("N3");
        dg[3, 3].Value = (dMain_I30 * double.Parse(dgUPV[3, 30 +
1].Value.ToString())).ToString("N3");
        dg[4, 3].Value = (dMain_I30 * double.Parse(dgUPV[3, 50 +
1].Value.ToString())).ToString("N3");

        // Maintenance cost - Proposed building
        double dMain_K30 = 0;
        try
        {
          dMain_K30 = double.Parse(sMain_K30);
        }
        catch (Exception ex)
        {

        }

        dg[5, 3].Value = (dMain_K30 * double.Parse(dgUPV[3, 20 +
1].Value.ToString())).ToString("N3");
        dg[6, 3].Value = (dMain_K30 * double.Parse(dgUPV[3, 25 +
1].Value.ToString())).ToString("N3");
        dg[7, 3].Value = (dMain_K30 * double.Parse(dgUPV[3, 30 +
1].Value.ToString())).ToString("N3");
        dg[8, 3].Value = (dMain_K30 * double.Parse(dgUPV[3, 50 +
1].Value.ToString())).ToString("N3");

        // Energy costs - Baseline building
        double dEnergy_F22 = 0;
        try
        {
          dEnergy_F22 = double.Parse(dgEnergy[3, dgEnergy.Rows.Count - 1].Value.ToString());
        }
        catch (Exception ex)
        {

        }

        dg[1, 4].Value = (dEnergy_F22 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
```

```
        dg[2, 4].Value = (dEnergy_F22 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[3, 4].Value = (dEnergy_F22 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[4, 4].Value = (dEnergy_F22 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");

        // Energy costs - Proposed building
        double dEnergy_I22 = 0;
        try
        {
          dEnergy_I22 = double.Parse(dgEnergy[6, dgEnergy.Rows.Count - 1].Value.ToString());
        }
        catch (Exception ex)
        {

        }

        dg[5, 4].Value = (dEnergy_I22 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[6, 4].Value = (dEnergy_I22 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[7, 4].Value = (dEnergy_I22 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[8, 4].Value = (dEnergy_I22 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");

        // Water costs - Baseline building
        double dWater_F15 = 0;

        try
        {
          dWater_F15 = double.Parse(dgWater[4, dgWater.Rows.Count - 1].Value.ToString());
        }
        catch (Exception ex)
        {

        }

        dg[1, 6].Value = (dWater_F15 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[2, 6].Value = (dWater_F15 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
```

```
        dg[3, 6].Value = (dWater_F15 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[4, 6].Value = (dWater_F15 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");

        // Water costs - Proposed building
        double dWater_I15 = 0;
        try
        {
          dWater_I15 = double.Parse(dgWater[6, dgWater.Rows.Count - 1].Value.ToString());
        }
        catch (Exception ex)
        {

        }

        dg[5, 6].Value = (dWater_I15 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[6, 6].Value = (dWater_I15 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[7, 6].Value = (dWater_I15 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[8, 6].Value = (dWater_I15 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");

        // CO2 costs - Baseline building
        double dEmission_F14 = 0;
        try
        {
          dEmission_F14 = double.Parse(dgEmission_1[3, dgEmission_1.Rows.Count -
1].Value.ToString());
        }
        catch (Exception ex)
        {

        }

        dg[1, 8].Value = (dEmission_F14 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[2, 8].Value = (dEmission_F14 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[3, 8].Value = (dEmission_F14 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
```

```
        dg[4, 8].Value = (dEmission_F14 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");

        // CO2 costs - Proposed building
        double dEmission_I14 = 0;
        try
        {
          dEmission_I14 = double.Parse(dgEmission_1[6, dgEmission_1.Rows.Count -
1].Value.ToString());
        }
        catch (Exception ex)
        {

        }

        dg[5, 8].Value = (dEmission_I14 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[6, 8].Value = (dEmission_I14 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[7, 8].Value = (dEmission_I14 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");
        dg[8, 8].Value = (dEmission_I14 * double.Parse(dgUPV[1, 20 +
1].Value.ToString())).ToString("N3");

        // Water disposal costsA - Baseline building
        double dEmission_F28 = 0;
        try
        {
          dEmission_F28 = double.Parse(dgEmission_2[3, dgEmission_2.Rows.Count -
1].Value.ToString());
        }
        catch (Exception ex)
        {

        }

        dg[1, 10].Value = (dEmission_F28 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[2, 10].Value = (dEmission_F28 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[3, 10].Value = (dEmission_F28 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
```

```
        dg[4, 10].Value = (dEmission_F28 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");

        // Water disposal costsA - Proposed building
        double dEmission_I28 = 0;
        try
        {
           dEmission_I28 = double.Parse(dgEmission_2[6, dgEmission_2.Rows.Count -
1].Value.ToString());
        }
        catch (Exception ex)
        {

        }

        dg[5, 10].Value = (dEmission_I28 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[6, 10].Value = (dEmission_I28 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[7, 10].Value = (dEmission_I28 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");
        dg[8, 10].Value = (dEmission_I28 * double.Parse(dgUPV[2, 20 +
1].Value.ToString())).ToString("N3");

        // Occupant satisfaction - Baseline building
        double dOccup_F15 = 0;
        try
        {
           if (chkOccup.Checked == true)
           {
              dOccup_F15 = double.Parse(dgOccup[3, dgOccup.Rows.Count - 1].Value.ToString());
           }
        }
        catch (Exception ex)
        {

        }

        dg[1, 11].Value = (dOccup_F15 * double.Parse(dgUPV[3, 20 +
1].Value.ToString())).ToString("N3");
        dg[2, 11].Value = (dOccup_F15 * double.Parse(dgUPV[3, 25 +
1].Value.ToString())).ToString("N3");
```

```
        dg[3, 11].Value = (dOccup_F15 * double.Parse(dgUPV[3, 30 +
1].Value.ToString())).ToString("N3");
        dg[4, 11].Value = (dOccup_F15 * double.Parse(dgUPV[3, 50 +
1].Value.ToString())).ToString("N3");

        // Occupant satisfaction - Proposed building
        double dOccup_I15 = 0;
        try
        {
          if (chkOccup.Checked == true)
          {
            dOccup_I15 = double.Parse(dgOccup[6, dgOccup.Rows.Count - 1].Value.ToString());
          }
        }
        catch (Exception ex)
        {

        }

        dg[5, 11].Value = (dOccup_I15 * double.Parse(dgUPV[3, 20 +
1].Value.ToString())).ToString("N3");
        dg[6, 11].Value = (dOccup_I15 * double.Parse(dgUPV[3, 25 +
1].Value.ToString())).ToString("N3");
        dg[7, 11].Value = (dOccup_I15 * double.Parse(dgUPV[3, 30 +
1].Value.ToString())).ToString("N3");
        dg[8, 11].Value = (dOccup_I15 * double.Parse(dgUPV[3, 50 +
1].Value.ToString())).ToString("N3");


        // SUM
        for (int i = 1; i <= 8; i++)
        {
          double sSum = 0;

          for (int j = 2; j <= 11; j++)
          {
            try
            {
              sSum = sSum + double.Parse(dg[i, j].Value.ToString());
            }
            catch(Exception ex)
            {
            }
```

```
      }

      dg[i, dg.Rows.Count - 1].Value = sSum.ToString("N3");
    }

    // Chart 1
    double dCOL_1_ROW_2 = 0;
    double dCOL_1_ROW_3 = 0;
    double dCOL_1_ROW_4 = 0;
    double dCOL_1_ROW_6 = 0;
    double dCOL_1_ROW_8 = 0;
    double dCOL_1_ROW_10 = 0;
    double dCOL_1_ROW_11 = 0;

    if (double.Parse(dg[1, dg.Rows.Count - 1].Value.ToString()) == 0)
    {
      Console.WriteLine("NULL");
    }
    else
    {
      dCOL_1_ROW_2 = double.Parse((double.Parse(dg[1, 2].Value.ToString()) /
double.Parse(dg[1, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
      dCOL_1_ROW_3 = double.Parse((double.Parse(dg[1, 3].Value.ToString()) /
double.Parse(dg[1, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
      dCOL_1_ROW_4 = double.Parse((double.Parse(dg[1, 4].Value.ToString()) /
double.Parse(dg[1, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
      dCOL_1_ROW_6 = double.Parse((double.Parse(dg[1, 6].Value.ToString()) /
double.Parse(dg[1, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
      dCOL_1_ROW_8 = double.Parse((double.Parse(dg[1, 8].Value.ToString()) /
double.Parse(dg[1, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
      dCOL_1_ROW_10 = double.Parse((double.Parse(dg[1, 10].Value.ToString()) /
double.Parse(dg[1, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
      dCOL_1_ROW_11 = double.Parse((double.Parse(dg[1, 11].Value.ToString()) /
double.Parse(dg[1, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
    }

    double[] yValues_1 = { dCOL_1_ROW_2, dCOL_1_ROW_3, dCOL_1_ROW_4,
dCOL_1_ROW_6, dCOL_1_ROW_8, dCOL_1_ROW_10, dCOL_1_ROW_11 };
    string[] xValues_1 = { "Construction cost", "Maintenance cost", "Energy costs", "Water
costs", "CO2 costs", "Water disposal costsA", "Occupant satisfaction" };
    chart_LCCA1_1.Series[0].Points.DataBindXY(xValues_1, yValues_1);

    // Chart 2
```

```
            double dCOL_5_ROW_2 = 0;
            double dCOL_5_ROW_3 = 0;
            double dCOL_5_ROW_4 = 0;
            double dCOL_5_ROW_6 = 0;
            double dCOL_5_ROW_8 = 0;
            double dCOL_5_ROW_10 = 0;
            double dCOL_5_ROW_11 = 0;

            if (double.Parse(dg[5, dg.Rows.Count - 1].Value.ToString()) == 0)
            {
                Console.WriteLine("NULL");
            }
            else
            {
                dCOL_5_ROW_2 = double.Parse((double.Parse(dg[5, 2].Value.ToString()) /
double.Parse(dg[5, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
                dCOL_5_ROW_3 = double.Parse((double.Parse(dg[5, 3].Value.ToString()) /
double.Parse(dg[5, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
                dCOL_5_ROW_4 = double.Parse((double.Parse(dg[5, 4].Value.ToString()) /
double.Parse(dg[5, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
                dCOL_5_ROW_6 = double.Parse((double.Parse(dg[5, 6].Value.ToString()) /
double.Parse(dg[5, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
                dCOL_5_ROW_8 = double.Parse((double.Parse(dg[5, 8].Value.ToString()) /
double.Parse(dg[5, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
                dCOL_5_ROW_10 = double.Parse((double.Parse(dg[5, 10].Value.ToString()) /
double.Parse(dg[5, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
                dCOL_5_ROW_11 = double.Parse((double.Parse(dg[5, 11].Value.ToString()) /
double.Parse(dg[5, dg.Rows.Count - 1].Value.ToString()) * 100).ToString("N3"));
            }

            double[] yValues_2 = { dCOL_5_ROW_2, dCOL_5_ROW_3, dCOL_5_ROW_4,
dCOL_5_ROW_6, dCOL_5_ROW_8, dCOL_5_ROW_10, dCOL_5_ROW_11 };
            string[] xValues_2 = { "Construction cost", "Maintenance cost", "Energy costs", "Water
costs", "CO2 costs", "Water disposal costsA", "Occupant satisfaction" };
            chart_LCCA1_2.Series[0].Points.DataBindXY(xValues_2, yValues_2);
        }

        public static void Setting_DataGridView_UPV(DataGridView dg, string sDiscount, string
sEnergy, string sWater, string sMain)
        {
            double dDiscount = double.Parse(sDiscount) * 0.01;
            double dEnergy = double.Parse(sEnergy) * 0.01;
            double dWater = double.Parse(sWater) * 0.01;
```

```
        double dMain = double.Parse(sMain) * 0.01;

        const int CON_ROW_HEADER = 1;
        const int CON_ROW_COUNT = 50;
        const int CON_ROW_SUM = 0;

        // 해¨ª더¥o Hidden
        dg.RowHeadersVisible = false;       // row
        dg.ColumnHeadersVisible = false;    // col

        // 길¾©¡이I 설ù©ø정¢´
        dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
        dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

        // col Setting
        dg.Columns.Clear();
        dg.Columns.Add("COL_1", "");
        dg.Columns.Add("COL_2", "");
        dg.Columns.Add("COL_3", "");
        dg.Columns.Add("COL_4", "");

        dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
        dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
        dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
        dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

        // row Setting
        dg.Rows.Clear();
        dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

        dg.ReadOnly = true;

        dg[0, 0].Value = "Year";
        dg[1, 0].Value = "Energy";
        dg[2, 0].Value = "Water";
        dg[3, 0].Value = "Main";

        for (int i = 1; i < dg.Rows.Count; i++)
        {
          dg[0, i].Value = i.ToString();
          dg[1, i].Value = (((1 + dEnergy) / (dDiscount - dEnergy)) * (((1 - Math.Pow(((1 + dEnergy)
/ (1 + dDiscount)), i))))).ToString("N3");
```

```
            dg[2, i].Value = (((1 + dWater) / (dDiscount - dWater)) * (((1 - Math.Pow(((1 + dWater)
/ (1 + dDiscount)), i))))).ToString("N3");
            dg[3, i].Value = (((1 + dMain) / (dDiscount - dMain)) * ((1 - (Math.Pow(((1 + dMain) / (1
+ dDiscount)), i))))).ToString("N3");
         }
      }

      public static void Setting_DataGridView_Invest(DataGridView dg)
      {
         const int CON_ROW_HEADER = 1;
         const int CON_ROW_COUNT = 15;
         const int CON_ROW_SUM = 1;

         // 해¨ª더¥o Hidden
         dg.RowHeadersVisible = false;      // row
         dg.ColumnHeadersVisible = false;   // col

         // 길¾©¡이I 설ù©ø정¢´
         dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
         dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

         // col Setting
         dg.Columns.Clear();
         dg.Columns.Add("NAME", "");
         dg.Columns.Add("BD", "Beseline Design");
         dg.Columns.Add("SS", "System SF");
         dg.Columns.Add("PD", "Proposed Design");

         dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
         dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
         dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
         dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

         // row Setting
         dg.Rows.Clear();
         dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

         dg.Rows[0].ReadOnly = true;
         dg.Rows[dg.Rows.Count - 1].ReadOnly = true;

         dg[0, 0].Value = "";
         dg[1, 0].Value = "Baseline Design";
```

```
    dg[2, 0].Value = "System SF";
    dg[3, 0].Value = "Proposed Design";

    dg[0, dg.Rows.Count - 1].Value = "Subtotal Construction cost";

    // BackGround Color
    int nRow = 0;

    nRow = 0;
    dg[0, nRow].Style.BackColor = System.Drawing.Color.LightGray;
    dg[1, nRow].Style.BackColor = System.Drawing.Color.LightGray;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.LightGray;
    dg[3, nRow].Style.BackColor = System.Drawing.Color.LightGray;

    nRow = dg.Rows.Count - 1;
    dg[0, nRow].Style.BackColor = System.Drawing.Color.LightGray;
    dg[1, nRow].Style.BackColor = System.Drawing.Color.LightGray;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.LightGray;
    dg[3, nRow].Style.BackColor = System.Drawing.Color.LightGray;
}

public static void Setting_DataGridView_Occup(DataGridView dg)
{
    const int CON_ROW_HEADER = 2;
    const int CON_ROW_COUNT = 4;
    const int CON_ROW_SUM = 1;

    // 해¨ª더¥o Hidden
    dg.RowHeadersVisible = false;      // row
    dg.ColumnHeadersVisible = false;   // col

    // 길¾©¡이I 설ù©ø정¢´
    dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
    dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

    // col Setting
    dg.Columns.Clear();

    dg.Columns.Add("COL_1", "");
    dg.Columns.Add("COL_2", "");
    dg.Columns.Add("COL_3", "");
    dg.Columns.Add("COL_4", "");
```

```
dg.Columns.Add("COL_5", "");
dg.Columns.Add("COL_6", "");
dg.Columns.Add("COL_7", "");

dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[4].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[5].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[6].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

// row Setting
dg.Rows.Clear();
dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

dg.Rows[0].ReadOnly = true;
dg.Rows[1].ReadOnly = true;
dg.Rows[2].ReadOnly = true;
dg.Rows[5].ReadOnly = true;
dg.Rows[dg.Rows.Count - 1].ReadOnly = true;

dg.Columns[0].ReadOnly = true;
dg.Columns[3].ReadOnly = true;
dg.Columns[6].ReadOnly = true;

dg[1, 0].Value = "Baseline building";
dg[4, 0].Value = "Proposed building";

dg[1, 1].Value = "Full time equivalent";
dg[2, 1].Value = "Unit cost";
dg[3, 1].Value = "Total costs";
dg[4, 1].Value = "Full time equivalent";
dg[5, 1].Value = "Unit cost";
dg[6, 1].Value = "Total costs";

dg[0, 3].Value = "Male";
dg[0, 4].Value = "Female";

dg[2, 3].Value = "745";
dg[2, 4].Value = "745";

dg[5, 3].Value = "650";
```

```
    dg[5, 4].Value = "650";

    dg[0, dg.Rows.Count - 1].Value = "Total";

    // BackGround Color
    for (int i = 0; i < dg.Rows.Count; i++)
    {
        for (int j = 0; j < dg.Columns.Count; j++)
        {
            dg[j, i].Style.BackColor = System.Drawing.Color.LightGray;
        }
    }

    int nRow = 0;

    nRow = 3;

    dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[4, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[5, nRow].Style.BackColor = System.Drawing.Color.White;

    nRow = 4;

    dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[4, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[5, nRow].Style.BackColor = System.Drawing.Color.White;
}

public static void Setting_DataGridView_Emission_1(DataGridView dg)
{
    const int CON_ROW_HEADER = 2;
    const int CON_ROW_COUNT = 15;
    const int CON_ROW_SUM = 1;

    // 해¨ª더¥o Hidden
    dg.RowHeadersVisible = false;       // row
    dg.ColumnHeadersVisible = false;    // col

    // 길¾©¡이ı 설ù©ø정¢´
    dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
```

```
    dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

    // col Setting
    dg.Columns.Clear();

    dg.Columns.Add("COL_1", "");
    dg.Columns.Add("COL_2", "");
    dg.Columns.Add("COL_3", "");
    dg.Columns.Add("COL_4", "");
    dg.Columns.Add("COL_5", "");
    dg.Columns.Add("COL_6", "");
    dg.Columns.Add("COL_7", "");

    dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
    dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
    dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
    dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
    dg.Columns[4].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
    dg.Columns[5].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
    dg.Columns[6].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

    // row Setting
    dg.Rows.Clear();
    dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

    dg.Rows[0].ReadOnly = true;
    dg.Rows[1].ReadOnly = true;
    dg.Rows[dg.Rows.Count - 1].ReadOnly = true;

    dg[1, 0].Value = "Baseline building";
    dg[4, 0].Value = "Proposed building";

    dg[0, 1].Value = "Emission type";
    dg[1, 1].Value = "Energy use";
    dg[2, 1].Value = "Unit cost";
    dg[3, 1].Value = "Total costs";
    dg[4, 1].Value = "Energy use";
    dg[5, 1].Value = "Unit cost";
    dg[6, 1].Value = "Total costs";

    dg[0, dg.Rows.Count - 1].Value = "Total";
}
```

```
    public static void Setting_DataGridView_Emission_1(DataGridView dg, DataGridView
dg_Energy)
    {
      const int CON_ROW_HEADER = 2;
      const int CON_ROW_COUNT = 3;
      const int CON_ROW_SUM = 1;

      // 해¨ª더¥o Hidden
      dg.RowHeadersVisible = false;      // row
      dg.ColumnHeadersVisible = false;   // col

      // 길¾©¡이 설ù©ø정¢´
      dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
      dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

      // col Setting
      dg.Columns.Clear();

      dg.Columns.Add("COL_1", "");
      dg.Columns.Add("COL_2", "");
      dg.Columns.Add("COL_3", "");
      dg.Columns.Add("COL_4", "");
      dg.Columns.Add("COL_5", "");
      dg.Columns.Add("COL_6", "");
      dg.Columns.Add("COL_7", "");

      dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
      dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
      dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
      dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
      dg.Columns[4].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
      dg.Columns[5].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
      dg.Columns[6].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

      // row Setting
      dg.Rows.Clear();
      dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

      dg.Rows[0].ReadOnly = true;
      dg.Rows[1].ReadOnly = true;
      dg.Rows[dg.Rows.Count - 1].ReadOnly = true;
```

```
    dg.Columns[0].ReadOnly = true;
    dg.Columns[1].ReadOnly = true;
    dg.Columns[3].ReadOnly = true;
    dg.Columns[4].ReadOnly = true;
    dg.Columns[5].ReadOnly = true;
    dg.Columns[6].ReadOnly = true;

    dg[1, 0].Value = "Baseline building";
    dg[4, 0].Value = "Proposed building";

    dg[0, 1].Value = "Emission type";
    dg[1, 1].Value = "Energy use";
    dg[2, 1].Value = "Unit cost";
    dg[3, 1].Value = "Total costs";
    dg[4, 1].Value = "Energy use";
    dg[5, 1].Value = "Unit cost";
    dg[6, 1].Value = "Total costs";

    dg[0, 3].Value = "Carbon Dioxide";

    dg[1, 3].Value = dg_Energy[1, dg_Energy.Rows.Count - 1].Value;
    dg[4, 3].Value = dg_Energy[4, dg_Energy.Rows.Count - 1].Value;

    dg[0, dg.Rows.Count - 1].Value = "Total";

    // BackGround Color
    for (int nCol = 0; nCol < dg.Columns.Count; nCol++)
    {
        for (int nRow = 0; nRow < dg.Rows.Count; nRow++)
        {
            dg[nCol, nRow].Style.BackColor = System.Drawing.Color.LightGray;
        }
    }

    int nRow2 = 0;

    nRow2 = 3;

    dg[2, nRow2].Style.BackColor = System.Drawing.Color.White;
}

public static void Setting_DataGridView_Emission_2(DataGridView dg)
{
```

```
const int CON_ROW_HEADER = 2;
const int CON_ROW_COUNT = 15;
const int CON_ROW_SUM = 1;

// 해¨ª더¥o Hidden
dg.RowHeadersVisible = false;      // row
dg.ColumnHeadersVisible = false;   // col

// 길¾©¡이I 설ù©ø정¢´
dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

// col Setting
dg.Columns.Clear();

dg.Columns.Add("COL_1", "");
dg.Columns.Add("COL_2", "");
dg.Columns.Add("COL_3", "");
dg.Columns.Add("COL_4", "");
dg.Columns.Add("COL_5", "");
dg.Columns.Add("COL_6", "");
dg.Columns.Add("COL_7", "");

dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[4].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[5].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[6].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

// row Setting
dg.Rows.Clear();
dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

dg.Rows[0].ReadOnly = true;
dg.Rows[1].ReadOnly = true;
dg.Rows[dg.Rows.Count - 1].ReadOnly = true;

dg[1, 0].Value = "Baseline building";
dg[4, 0].Value = "Proposed building";
```

```
        dg[0, 1].Value = "Water resource";
        dg[1, 1].Value = "Water usages";
        dg[2, 1].Value = "Unit costs";
        dg[3, 1].Value = "Total costs";
        dg[4, 1].Value = "Water usages";
        dg[5, 1].Value = "Unit costs";
        dg[6, 1].Value = "Total costs";

        dg[0, dg.Rows.Count - 1].Value = "Total";
    }

    public static void Setting_DataGridView_Emission_2(DataGridView dg, DataGridView
dg_Water)
    {
        const int CON_ROW_HEADER = 2;
        const int CON_ROW_COUNT = 5;
        const int CON_ROW_SUM = 1;

        // 해¨ª더¥o Hidden
        dg.RowHeadersVisible = false;      // row
        dg.ColumnHeadersVisible = false;   // col

        // 길¾©¡이I 설ù©ø정¢´
        dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
        dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

        // col Setting
        dg.Columns.Clear();

        dg.Columns.Add("COL_1", "");
        dg.Columns.Add("COL_2", "");
        dg.Columns.Add("COL_3", "");
        dg.Columns.Add("COL_4", "");
        dg.Columns.Add("COL_5", "");
        dg.Columns.Add("COL_6", "");
        dg.Columns.Add("COL_7", "");

        dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
        dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
        dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
        dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
        dg.Columns[4].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
```

```
dg.Columns[5].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[6].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

// row Setting
dg.Rows.Clear();
dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

dg.Rows[0].ReadOnly = true;
dg.Rows[1].ReadOnly = true;
dg.Rows[dg.Rows.Count - 1].ReadOnly = true;

dg.Columns[0].ReadOnly = true;
dg.Columns[1].ReadOnly = true;
dg.Columns[3].ReadOnly = true;
dg.Columns[4].ReadOnly = true;
dg.Columns[5].ReadOnly = true;
dg.Columns[6].ReadOnly = true;

dg[1, 0].Value = "Baseline building";
dg[4, 0].Value = "Proposed building";

dg[0, 1].Value = "Water resource";
dg[1, 1].Value = "Water usages";
dg[2, 1].Value = "Unit costs";
dg[3, 1].Value = "Total costs";
dg[4, 1].Value = "Water usages";
dg[5, 1].Value = "Unit costs";
dg[6, 1].Value = "Total costs";

dg[0, dg.Rows.Count - 1].Value = "Total";

for (int i = 2; i < dg_Water.Rows.Count - 1; i++)
{
  dg[0, i].Value = dg_Water[0, i].Value;
  dg[1, i].Value = dg_Water[2, i].Value;
  dg[4, i].Value = dg_Water[6, i].Value;
}

// BackGround Color
for (int nCol = 0; nCol < dg.Columns.Count; nCol++)
{
  for (int nRow = 0; nRow < dg.Rows.Count; nRow++)
  {
```

```
        dg[nCol, nRow].Style.BackColor = System.Drawing.Color.LightGray;
      }
    }

    for (int nRow = 2; nRow < dg.Rows.Count - 1; nRow++)
    {
      dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    }
}

public static void Setting_DataGridView_Water(DataGridView dg)
{
    const int CON_ROW_HEADER = 2;
    const int CON_ROW_COUNT = 5;
    const int CON_ROW_SUM = 1;

    // 해¨ª더¥o Hidden
    dg.RowHeadersVisible = false;      // row
    dg.ColumnHeadersVisible = false;   // col

    // 길¾©¡이I 설ù©ø정¢´
    dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
    dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

    // col Setting
    dg.Columns.Clear();
    dg.Columns.Add("COL_1", "");
    dg.Columns.Add("COL_2", "");
    dg.Columns.Add("COL_3", "");
    dg.Columns.Add("COL_4", "");
    dg.Columns.Add("COL_5", "");
    dg.Columns.Add("COL_6", "");
    dg.Columns.Add("COL_7", "");
    dg.Columns.Add("COL_8", "");
    dg.Columns.Add("COL_9", "");

    dg.Columns[2].ReadOnly = true;
    dg.Columns[4].ReadOnly = true;
    dg.Columns[6].ReadOnly = true;
    dg.Columns[7].ReadOnly = true;
    dg.Columns[8].ReadOnly = true;
```

```
dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[4].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[5].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[6].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[7].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[8].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

// row Setting
dg.Rows.Clear();
dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

dg.Rows[0].ReadOnly = true;
dg.Rows[1].ReadOnly = true;
dg.Rows[dg.Rows.Count - 1].ReadOnly = true;

dg[1, 0].Value = "Baseline building";
dg[5, 0].Value = "Proposed building";

dg[0, 1].Value = "Water resource";
dg[1, 1].Value = "Water consumption\r\n - Input";
dg[2, 1].Value = "Water consumption\r\n - /748";
dg[3, 1].Value = "Unit costs";
dg[4, 1].Value = "Total costs";
dg[5, 1].Value = "Water consumption\r\n - Input";
dg[6, 1].Value = "Water consumption\r\n - /748";
dg[7, 1].Value = "Unit costs";
dg[8, 1].Value = "Total costs";

dg[0, dg.Rows.Count - 1].Value = "Total";

// Sample Data
dg[0, 2].Value = "Landscaping";
dg[0, 3].Value = "Annual water";
dg[0, 4].Value = "Non-potable";

dg[3, 2].Value = "1.37";
dg[3, 3].Value = "1.37";
dg[3, 4].Value = "1.37";

dg[7, 2].Value = "1.37";
```

```
dg[7, 3].Value = "1.37";
dg[7, 4].Value = "1.37";

// BackGround Color
int nRow = 0;

nRow = 0;

for (int nCol = 0; nCol < dg.Columns.Count; nCol++)
{
   dg[nCol, nRow].Style.BackColor = System.Drawing.Color.LightGray;
}

nRow = 1;

for (int nCol = 0; nCol < dg.Columns.Count; nCol++)
{
   dg[nCol, nRow].Style.BackColor = System.Drawing.Color.LightGray;
}

nRow = dg.Rows.Count - 1;

for (int nCol = 0; nCol < dg.Columns.Count; nCol++)
{
   dg[nCol, nRow].Style.BackColor = System.Drawing.Color.LightGray;
}

int nCol2 = 0;

nCol2 = 2;

for (int nRow2 = 0; nRow2 < dg.Rows.Count; nRow2++)
{
   dg[nCol2, nRow2].Style.BackColor = System.Drawing.Color.LightGray;
}

nCol2 = 4;

for (int nRow2 = 0; nRow2 < dg.Rows.Count; nRow2++)
{
   dg[nCol2, nRow2].Style.BackColor = System.Drawing.Color.LightGray;
}
```

```
  nCol2 = 6;

  for (int nRow2 = 0; nRow2 < dg.Rows.Count; nRow2++)
  {
    dg[nCol2, nRow2].Style.BackColor = System.Drawing.Color.LightGray;
  }

  nCol2 = 7;

  for (int nRow2 = 0; nRow2 < dg.Rows.Count; nRow2++)
  {
    dg[nCol2, nRow2].Style.BackColor = System.Drawing.Color.LightGray;
  }

  nCol2 = 8;

  for (int nRow2 = 0; nRow2 < dg.Rows.Count; nRow2++)
  {
    dg[nCol2, nRow2].Style.BackColor = System.Drawing.Color.LightGray;
  }
}

public static void Setting_DataGridView_Energy(DataGridView dg)
{
  const int CON_ROW_HEADER = 2;
  const int CON_ROW_COUNT = 11;
  const int CON_ROW_SUM = 1;

  // 해¨ª더¥o Hidden
  dg.RowHeadersVisible = false;      // row
  dg.ColumnHeadersVisible = false;   // col

  // 길¾©¡이ı 설ù©ø정¢´
  dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
  dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

  // col Setting
  dg.Columns.Clear();
  dg.Columns.Add("COL_1", "");
  dg.Columns.Add("COL_2", "");
  dg.Columns.Add("COL_3", "");
  dg.Columns.Add("COL_4", "");
```

```
dg.Columns.Add("COL_5", "");
dg.Columns.Add("COL_6", "");
dg.Columns.Add("COL_7", "");

dg.Columns[0].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[1].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[2].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[3].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[4].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[5].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
dg.Columns[6].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;

dg.Columns[5].ReadOnly = true;

// row Setting
dg.Rows.Clear();
dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

dg.Rows[0].ReadOnly = true;
dg.Rows[1].ReadOnly = true;
dg.Rows[2].ReadOnly = true;
dg.Rows[7].ReadOnly = true;
dg.Rows[8].ReadOnly = true;
dg.Rows[12].ReadOnly = true;
dg.Rows[dg.Rows.Count - 1].ReadOnly = true;

dg.Columns[0].ReadOnly = true;
dg.Columns[3].ReadOnly = true;
dg.Columns[6].ReadOnly = true;

// Row Value
dg[1, 0].Value = "Baseline building";
dg[4, 0].Value = "Proposed building";

dg[0, 1].Value = "Emission type";
dg[1, 1].Value = "Energy use";
dg[2, 1].Value = "Unit cost";
dg[3, 1].Value = "Total costs";
dg[4, 1].Value = "Energy use";
dg[5, 1].Value = "Unit cost";
dg[6, 1].Value = "Total costs";

// Column Value
```

```
dg[0, 3].Value = "Electricity";
dg[0, 4].Value = "Purchased water";
dg[0, 5].Value = "Purchased steam";
dg[0, 6].Value = "Natural gas";
dg[0, 7].Value = "Sub total";

dg[0, 9].Value = "Solar hot water";
dg[0, 10].Value = "Geothermal heat";
dg[0, 11].Value = "etc";

dg[0, dg.Rows.Count - 1].Value = "Total";

// Sample Data
dg[2, 3].Value = "0.077";
dg[5, 3].Value = "0.077";

dg[2, 4].Value = "0.0869";
dg[5, 4].Value = "0.0869";

dg[2, 5].Value = "9.375";
dg[5, 5].Value = "9.375";

dg[2, 6].Value = "0";
dg[5, 6].Value = "0";

dg[5, 11].Value = "0.077";

// BackGround Color
for (int i = 0; i < dg.Rows.Count; i++)
{
   for (int j = 0; j < dg.Columns.Count; j++)
   {
      dg[j, i].Style.BackColor = System.Drawing.Color.LightGray;
   }
}

int nRow = 0;

nRow = 3;
dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
dg[4, nRow].Style.BackColor = System.Drawing.Color.White;
```

```
    nRow = 4;
    dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[4, nRow].Style.BackColor = System.Drawing.Color.White;

    nRow = 5;
    dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[4, nRow].Style.BackColor = System.Drawing.Color.White;

    nRow = 6;
    dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[4, nRow].Style.BackColor = System.Drawing.Color.White;

    nRow = 9;
    dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[4, nRow].Style.BackColor = System.Drawing.Color.White;

    nRow = 10;
    dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[4, nRow].Style.BackColor = System.Drawing.Color.White;

    nRow = 11;
    dg[1, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[2, nRow].Style.BackColor = System.Drawing.Color.White;
    dg[4, nRow].Style.BackColor = System.Drawing.Color.White;
}

public static void Setting_DataGridView_LCCA1(DataGridView dg)
{
    const int CON_ROW_HEADER = 2;
    const int CON_ROW_COUNT = 9;
    const int CON_ROW_SUM = 1;

    // 해¨ª더¥o Hidden
    dg.RowHeadersVisible = false;       // row
    dg.ColumnHeadersVisible = false;    // col

    // 길¾©¡이ı 설ù©ø정¢´
```

```
dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

// col Setting
dg.Columns.Add("COL_1", "");
dg.Columns.Add("COL_2", "");
dg.Columns.Add("COL_3", "");
dg.Columns.Add("COL_4", "");
dg.Columns.Add("COL_5", "");
dg.Columns.Add("COL_6", "");
dg.Columns.Add("COL_7", "");
dg.Columns.Add("COL_8", "");
dg.Columns.Add("COL_9", "");

for (int i = 0; i < dg.Columns.Count; i++)
{
   dg.Columns[i].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
}

// row Setting
dg.Rows.Clear();
dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

dg.ReadOnly = true;

dg[1, 0].Value = "Baseline building";
dg[5, 0].Value = "Proposed building";

dg[0, 1].Value = "Categories";
dg[1, 1].Value = "20years";
dg[2, 1].Value = "25years";
dg[3, 1].Value = "30years";
dg[4, 1].Value = "50years";
dg[5, 1].Value = "20years";
dg[6, 1].Value = "25years";
dg[7, 1].Value = "30years";
dg[8, 1].Value = "50years";

dg[0, 2].Value = "Construction cost";
dg[0, 3].Value = "Maintenance cost";
dg[0, 4].Value = "Energy costs";
dg[0, 6].Value = "Water costs";
dg[0, 8].Value = "CO2 costs";
```

```
    dg[0, 10].Value = "Water disposal costsA";
    dg[0, 11].Value = "Occupant satisfaction";
    dg[0, 12].Value = "Total costs";
}

public static void Setting_DataGridView_Indexes1_1(DataGridView dg)
{
    const int CON_ROW_HEADER = 1;
    const int CON_ROW_COUNT = 4;
    const int CON_ROW_SUM = 0;

    // 해¨ª더¥o Hidden
    dg.RowHeadersVisible = false;       // row
    dg.ColumnHeadersVisible = false;    // col

    // 길¾©¡이ı 설ù©ø정¢´
    dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
    dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

    // col Setting
    dg.Columns.Add("COL_1", "");
    dg.Columns.Add("COL_2", "");
    dg.Columns.Add("COL_3", "");
    dg.Columns.Add("COL_4", "");

    for (int i = 0; i < dg.Columns.Count; i++)
    {
        dg.Columns[i].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
    }

    // row Setting
    dg.Rows.Clear();
    dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

    dg.ReadOnly = true;

    dg[0, 0].Value = "LEED";

    dg[1, 0].Value = "Preminum range";
    dg[2, 0].Value = "Proposed building";

    dg[0, 1].Value = "Certified";
```

```
    dg[1, 1].Value = "0 ~ 2.5%";

    dg[0, 2].Value = "Silver";
    dg[1, 2].Value = "0 ~ 3.3%";

    dg[0, 3].Value = "Gold";
    dg[1, 3].Value = "0.3 ~ 5.0%";

    dg[0, 4].Value = "Platinum";
    dg[1, 4].Value = "4.5 ~ 8.5%";
}

public static void Setting_DataGridView_Indexes1_2(DataGridView dg)
{
    const int CON_ROW_HEADER = 1;
    const int CON_ROW_COUNT = 3;
    const int CON_ROW_SUM = 0;

    // 해¨ª더¥o Hidden
    dg.RowHeadersVisible = false;      // row
    dg.ColumnHeadersVisible = false;   // col

    // 길¾©¡이I 설ù©ø정¢´
    dg.AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells;
    dg.AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells;

    // col Setting
    dg.Columns.Add("COL_1", "");
    dg.Columns.Add("COL_2", "");
    dg.Columns.Add("COL_3", "");

    for (int i = 0; i < dg.Columns.Count; i++)
    {
        dg.Columns[i].AutoSizeMode = DataGridViewAutoSizeColumnMode.Fill;
    }

    // row Setting
    dg.Rows.Clear();
    dg.Rows.Add(CON_ROW_HEADER + CON_ROW_COUNT + CON_ROW_SUM);

    dg.ReadOnly = true;
```

```
            dg[1, 0].Value = "Baseline building";
            dg[2, 0].Value = "Proposed building";

            dg[0, 1].Value = "Economy";

            dg[0, 2].Value = "Environment";

            dg[0, 3].Value = "Human";
        }
    }
}
```