# AUTOMATED DECISION SUPPORT SYSTEM FOR OPTIMIZING THE SELECTION OF GREEN BUILDING MEASURES

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## ABSTRACT

Buildings in the United States account for 72% of electricity consumption, 40% of energy consumption, 13% of water consumption, 39% of carbon footprint, and 30% of waste output. In order to minimize these negative environmental impacts, many public and private owners are requesting that their buildings be more sustainable and certified under the widely known programs such as leadership in energy and environmental design for existing buildings (LEED-EB). To accomplish this, buildings are increasingly integrating green building measures including energy efficient lighting, motion sensors, thermal pane glass, geothermal heat pumps, EnergyStar rated HVAC systems, photovoltaic systems, and wind turbines. This research paper presents the development of an automated decision support system (DSS) that is designed to optimize the selection of green building measures which can be used to upgrade existing buildings. The developed DSS incorporates two optimization models that are capable of (i) minimizing the total upgrade costs required to accomplish a specified LEED-EB certification level such as silver or gold; and (ii) maximizing the number of accredited LEED-EB points within a specified budget of upgrade costs. The DSS is designed to identify a set of optimal upgrade decisions that accomplishes these two optimization objectives. An application example is used to illustrate the capabilities of the DSS and to validate its result.

## KEYWORDS

Optimizing sustainability decisions, LEED-EB certification, maximizing building sustainability

## INTRODUCTION

U.S. Green Building Council reported that buildings consume 72% of the electricity, 40% of energy, and 13% of water in the United States. Furthermore, these buildings account for 39% of USA's carbon footprint, and 30% of waste output in the United States (USGBC (a), 2012). These high energy and water consumption and negative environmental impacts motivated many owners in the private and public sectors to demand that their building implement green measures and sustainable technologies. These measures and technologies can be implemented in buildings to reduce energy and water consumption, increase life expectancy, reduce greenhouse gas (GHG) emissions, increase material recycling, reduce waste, and improve indoor environmental quality. Several studies have been conducted to analyze and evaluate the performance of green measures and sustainable technologies in buildings, including energy efficient lighting (CREE Corporation, 2009; Nadarajah and Yimin, 2005; Robert, 2009); motion sensors (Bill et al., 2001); photovoltaic systems (Karen et al., 2007; Scott et. al., 2004); double pane glass (Allen, 2007; Scofield, 2009); energy-efficient HVAC systems (Karen et al., 2007; GHC, 2006); and water-saving fixtures (GAO, 2000). A number of guidelines and certification programs have also been developed to promote the implementation of these green measures in buildings such as Leadership in Energy and Environmental Design (LEED), EnergyStar, and Cleaner & Greener programs. Many building owners are requiring that their buildings be certified under these green certification programs. This research paper presents the development of an automated Decision Support System (DSS) which can aid decision makers in optimizing the selection of LEED upgrade decisions for existing buildings in order to achieve a specified certification level with the minimum upgrade cost. In addition, the automated DSS enables decision makers to achieve the highest LEED points within a specified budget. The following sections provide a concise description of the automated DSS and an application example to illustrate its use and capabilities.

## AUOTOMATED DECISION SUPPORT SYSTEM (DSS)

The automated DSS is designed to identify optimal building upgrade decisions and credit points from the available alternatives in the LEED rating system for Existing Buildings (LEED-EB). This rating system provides several green upgrade measures which are classified into seven main divisions including: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Material and Resources (MR), Indoor Environmental Quality (IEQ), Innovation in Operation (IO), and Regional Priority (RP).

Each of these divisions includes performance requirements that specify the required measures to achieve LEED points. All these upgrade and green friendly measures improve the performance of existing buildings and reduce their environmental impacts; however, they vary in initial cost, annual operating costs, environmental effect, and potential LEED credits. A LEED certified project should fulfill all the prerequisites in each division and earn a sufficient number of points to achieve the desired certification level (i.e., certified, silver, gold, or platinum). The automated DSS is designed to provide decision makers with the ability to: (1) minimize the required upgrade cost to achieve a specified LEED certification level (e.g. Gold); and (2) maximize the number of earned LEED points within a specified budget for upgrades. To accomplish these optimization objectives, the DSS is designed to model all available LEED credits in the aforementioned seven divisions in the LEED-EB. The following section presents an example of modeling the water efficiency division in the LEED-EB.

The Water Efficiency (WE) division includes one required credit (prerequisite) and four optional credits with a total of 14 LEED-EB points, as shown in Table 1. The automated DSS was designed to achieve this prerequisite by reducing (if needed) the water consumption to meet the threshold requirements of the LEED-EB rating system. If the current water consumption of the building does not meet the LEED-EB threshold, the developed DSS uses the water reduction measures that are defined in the second credit of this division (i.e., additional indoor plumbing fixture and fitting efficiency) to reduce the building water consumption. It should be noted that the DSS will provide an infeasible solution if the water reduction measures cannot meet the threshold of this prerequisite and will accordingly display a warning message. The first possible credit in this division (i.e., water performance measurements) is modeled by three alternatives that account for installing (a) a meter system for the whole building that can measure the total water consumption; (b) a sub-meter system for the building in addition to the whole building meter unit to measure the water consumption for individual categories of water consumption such as toilets, or urinals; (c) no metering systems which recommends none of the alternatives in this credit. The input data for the first two alternatives include their initial cost and associated LEED-EB points according to the LEED-EB rating system; however, the third alternative has no upgrade cost and no accredited points. These three alternatives are mutually exclusive to enable the DSS to identify an optimal selection from these feasible alternatives based on their cost and accredited LEED-EB points in order to achieve a specified LEED-EB certification or maximize the number of accredited LEED-EB points.

Table 1. Water Efficiency division in the LEED rating system for existing buildings (USGBC, 2012)

| # | Credit | Possible points |
|---|---|---|
| --- | Minimum indoor plumbing fixture and fitting efficiency | Required |
| 1.0 | Water performance measurement | 1-2 |
| 2.0 | Additional indoor plumbing fixture and fitting efficiency | 1-5 |
| 3.0 | Water efficient landscaping | 1-5 |
| 4.0 | Cooling tower water management | 1-2 |

The second credit in this division (i.e., additional indoor plumbing fixtures and fitting efficiency) is modeled by defining multiple alternatives for three main categories of plumbing fixtures that can reduce indoor water consumption. These categories include the installation of (1) low flow faucets, and/or aerator upgrade for existing manual faucets; (2) water efficient urinals; and (3) water efficient toilets. Each of these categories can consider multiple feasible alternatives for improving water efficiency. The input data of each of these feasible alternatives include the initial cost and amount of water savings, as shown in Figure 1. These feasible alternatives in each category are mutually exclusive to enable the DSS to identify an optimal selection from these alternatives based on their cost and water-saving performance. The DSS calculates automatically the number of accredited LEED-EB points based on the current performance of the building and the selected indoor water performance measures. To enable the use of linear programming in the DSS, an approximate method, that has an accuracy of more than 94%, was used to calculate the accredited LEED-EB points of this credit by converting the non-linear relationship between the percentage of water reduction and accredited points to a linear relationship. The third and fourth credits in this division (i.e., water efficient landscaping and cooling tower water management) are modeled in a similar manner to the aforementioned first two credits in this division.

| C 2.0 | Additional Indoor Plumbing Fixture and Fitting Efficiency (1-5 points) | Initial Cost ($) | Accredited points (points) |
|---|---|---|---|
| | Performance of indoor water consumption | 3774 | 5 |

**Indoor water efficiency measures**

| Low flow faucets, and/or aerator upgrade for manual faucets | Initial Cost ($) | Annual expected water savings (gallons) |
|---|---|---|
| Alternative 1: Faucets replacement | 4080 | 400339 |
| Alternative 2: Aerator upgrade | 60 | 341466 |
| Alternative 3: None | 0 | 0 |

| Water saving urinals | Initial Cost ($) | Annual expected water savings (gallons) |
|---|---|---|
| Alternative 1: Urinals replacement | 5504 | 659382 |
| Alternative 2: None | 0 | 0 |

| Water saving toilets | Initial Cost ($) | Annual expected water savings (gallons) |
|---|---|---|
| Alternative 1: Toilets replacement for women's bathroom | 3714 | 1318764 |
| Alternative 2: Toilets replacement for men's bathroom | 2476 | 263752 |
| Alternative 3: Toilets replacement for men's and women's bathroor | 6190 | 1582516 |
| Alternative 4: None | 0 | 0 |

Figure 1 – Example of modeling the second credit in the "water efficiency division"

The automated DSS is designed to consider and evaluate the implementation of all feasible green building alternatives in the LEED-EB credits and energy and water saving measures. Accordingly, each of these alternatives in the automated DSS is represented by a binary decision variable to represent whether the alternative is selected for implementation or not. For example, the implementation of the alternative "faucets replacement" in the "additional indoor plumbing fixture and fitting efficiency" credit is represented by a binary decision variable. The automated DSS is designed to examine the implementation of all the alternatives in the seven divisions in order to achieve a specified LEED-EB certification or maximize LEED-EB points.

The automated DSS is designed to incorporate the two aforementioned optimization objective by developing two optimization models that are designed to (i) minimize upgrade costs for achieving LEED-EB certification levels; and (ii) maximize number of LEED-EB points within a specified upgrade budget. The objective function of the first optimization model is formulated to minimize the total upgrade costs that are calculated by summing up all the multiplications of the upgrade cost of each alternative and its binary decision variable. On the other hand, the objective function of the second optimization model is formulated to maximize the total number of earned LEED points that are calculated by summing up the multiplication of the potential LEED point of each alternative and its binary decision variable.

The automated DSS is designed to comply with all related constraints in the aforementioned two optimization models. The main constraints in the first optimization model is formulated to comply with the required minimum number of LEED-EB points to achieve a specified LEED-EB certification level as follows: (1) certified level which requires 40 – 49 points; (2) silver level which requires 50 – 59 points; (3)

gold level which requires 60 – 79 points; and (4) platinum level which requires 80 points or more. Similarly, the main constraints in the second optimization model is formulated to ensure that all upgrade costs are less than or equal the specified available budget. In addition to these two unique constraints, the two models are formulated to comply with another set of common constraints to satisfy the minimum building performance requirements and the scoring criteria of the LEED-EB rating system.

The automated DSS utilizes linear programming to perform the optimization computations because of (1) its guarantee to generate a global optimal solution for building upgrade decisions; (2) its reasonable computational time and effort compared to other optimization techniques; and (3) its practical implementation using commercially available software systems such as Solver add-in in Microsoft Excel spreadsheets. The developed spreadsheet in Microsoft Excel provides friendly graphical user interface (GUI) and facilitates the use of the DSS by decision makers. In addition, the DSS in its current spreadsheet format can be easily expanded to adapt to new versions of the LEED-EB rating systems. Microsoft Excel Solver add-in was used to carry out the calculations of optimizing the upgrade decisions of LEED-EB rating system using linear programming. Upon the completion of these computations, the DSS presents the optimization results using friendly graphical user interfaces (GUI) including tables and figures that summarize the optimal green alternatives selected by the model and their associated LEED-EB points, the optimal total upgrade cost, and the optimal total number of accredited LEED-EB points.

## APPLICATION EXAMPLE

An application example of a real public building was analyzed to (1) illustrate the use of the developed DSS; (2) demonstrate its newly developed and unique optimization capabilities; and (3) evaluate its performance. This section provides a brief description of the public building, specifies the input data that is required by the DSS, and summarizes the findings of the analysis. The total area of the public building is 9,072 square foot and it was built in 1971 and renovated in 1989. The public building includes a lobby, women's bathroom, men's bathroom, mechanical room, water treatment room, storage room, and a technician office.

In order to optimize the upgrade decisions of this public building, the DSS requires decision makers to provide a set of input data, including: (1) building data such as total area, energy and water consumption and billing rates, baselines for energy and water consumption rates of similar buildings, and building zip code, as shown in Table 2; and (2) upgrade costs of feasible green building alternatives, as shown in the example in Table 3. Based on the provided input data, the DSS was used to identify an optimal set of upgrade measures for this building.  Two types of optimization analyses were conducted to illustrate the capabilities of the DSS in optimizing the aforementioned two practical objectives.

Table 2.  Example building data

| Data | Value |
|---|---|
| Annual interest rate | 2% |
| Building square footage | 4539 SF |
| Annual electricity consumption | 605,492 KWH |
| Annual indoor water consumption | 4,662,771 Gallons |
| Annual outdoor water consumption | 0 Gallons |
| Average electricity rate | 0.093 $/KWH |
| Average water rate | 0 $/Gallon* |
| Annual indoor baseline consumption based on LEED-EB and Uniform Plumbing Code (UPC) | 4,287,866 Gallons |
| National average source energy use | 612 KBTU/sf |
| Building zip code | 60449 |

* Groundwater is used to supply the demand of the public building

Table 3 – Example upgrade costs of feasible alternatives in Energy and Atmosphere division

| Credit | Cost ($) | Points/savings |
|---|---|---|
| **Optimize Energy Efficiency Performance** | | |
| Additional energy savings - Motion Activated Lighting (MAL) Systems | | |
| Alternative 1: Installing motion activated lighting for bathrooms. | $1,137 | 5,800 KWH |
| Additional energy savings – More efficient HVAC system | | |
| Alternative 1: Installing more efficient HVAC system. | $19,870 | 59,400 KWH |
| Additional energy savings - Hand Dryers | | |
| Alternative 1: Installing air blade hand dryers for women's and men's bathrooms. | $10,440 | 17,100 KWH |
| Alternative 2: Installing blast hand dryers for women's and men's bathrooms. | $6,048 | 17,700 KWH |
| Additional energy savings - thermal pane glass | | |
| Alternative 1: Installing double pane glass for building entrance. | $60,900 | 17,700 KWH |
| **Existing Building Commissioning-Investigation and Analysis** | | |
| Alternative 1: an energy audit report was developed after the site visit to the public building which showed the distribution of energy consumption, major contributors of energy consumption, and measures that can provide annual savings, and improve comfort. No additional cost needed to achieve this credit. | $0 | 2 points |
| **Existing Building Commissioning-Implementation** | | |
| Alternative 1: Assuming that the building owner will implement the no or low-cost operational improvements based on the conducted survey. These no or low cost operation improvements will end up with low upgrade cost which can be paid back within 1~2 years. The major retrofits or upgrades for energy performance are considered in the first credit of this division. | $0 | 2 points |
| **Performance Measurement-System Level Metering** | | |
| Alternative 1: Installing electricity metering system to measure energy consumption for HVAC system. This new meter is data logger which can provide more analysis for energy consumption of the HVAC system. | $680 | 1 point |
| Alternative 2: In addition to installing meter for HVAC system, another three meters will be installed to measure energy consumption of exterior lighting, water heaters, and hand dryers. | $1,760 | 2 points |
| **On-site and Off-site Renewable Energy** | | |
| Geothermal HVAC systems | | |
| Alternative 1: Installing geothermal heat pump with horizontal loop. | $49,730 | 62,625 KWH |
| Alternative 2: Installing geothermal heat pump with vertical loop. | $55,760 | 62,625 KWH |
| Photovoltaic Systems | | |
| Alternative 1: Install grid connected photovoltaic system to offset 5% of the building energy consumption. | $54,000 | 15,275 KWH |
| Solar water heaters | | |
| Alternative 1: Installing roof mount solar water heater. | $5,480 | 12,700 KWH |
| Alternative 2: Installing ground mount solar water heater. | $5,810 | 12,700 KWH |
| **Emissions Reduction Reporting** | | |
| Alternative 1: The LEED APs of the building owner will identify and quantify the reduction in energy consumption and emissions based on the | 0 | 1 Point |

results of this DSS.

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The first optimization analysis focused on minimizing the upgrade costs that are required to achieve “certified” and “silver” LEED-EB levels. The results of this analysis indicate that the minimum upgrade costs to achieve 40 points (i.e., certified LEED-EB level), and 50 points (i.e. Silver LEED-EB level) were estimated by the DSS to be $68,709 and $136,669, respectively. The developed DSS also provides a detailed description of the optimal solution that produced these optimal results, including the identified optimal upgrade measures, as well as their upgrade costs and accredited points. The DSS was not able to provide feasible solutions for the “gold” and “platinum” LEED-EB levels since the maximum number of LEED-EB credits that can be earned by this building example is 56 points due to the inapplicability of some credit points for the public building and its high energy consumption compared to similar buildings. The second optimization analysis focused on maximizing the number of accredited LEED-EB points that can be earned under a specified limited budget for upgrade costs. This analysis used varying scenarios of budget limits that ranged from $25,000 to $425,000 with increments of $25,000 and the DSS was able to identify the maximum number of LEED-EB points that can be achieved under each of these upgrade budget limits as, shown in Figure 2. For example, specifying that the upgrade budget was $100,000 led the model to identify an optimal solution that achieves a maximum of 49 LEED-EB points.”

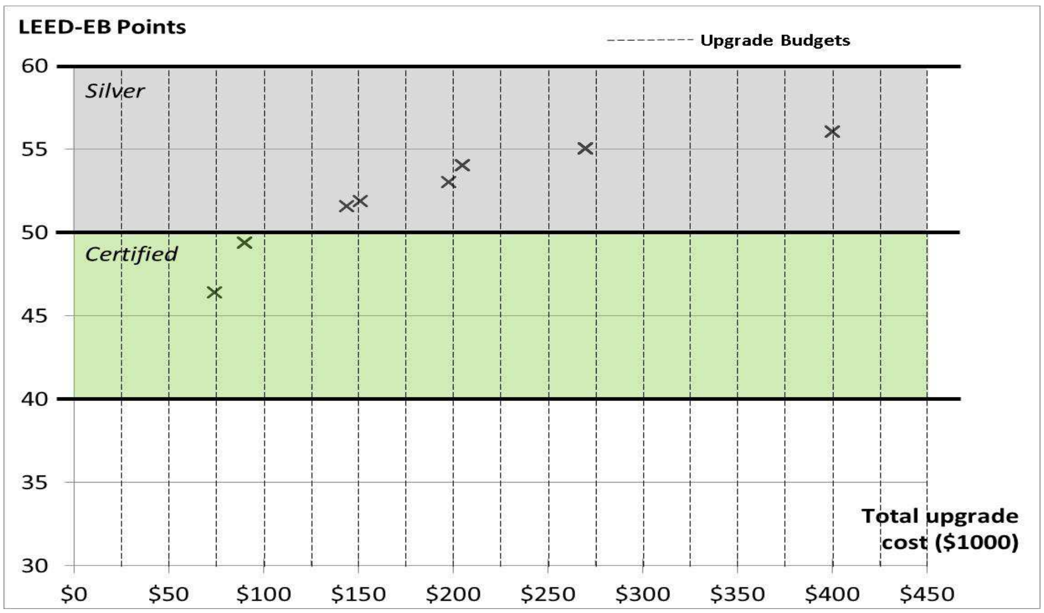


Figure 2 – Maximum number of LEED-EB points for varying upgrade budgets

## SUMMARY AND CONCLUSION

This paper presented the development of an automated Decision Support System (DSS) for optimizing the selection of LEED upgrade decisions in Existing Buildings (LEED-EB). The DSS provides decision makers with the flexibility to minimize the required total upgrade costs to achieve a specified LEED-EB certification level such as gold or silver; or maximize the number of LEED-EB points that can be achieved within a specified limited budget. The developed DSS utilized linear programming to perform the optimization computations because of its guarantee to generate a global optimal solution and its reasonable computational time and effort compared to other optimization techniques. An application example was analyzed to illustrate the use of the developed DSS and evaluate its performance. The developed DSS was able to identify the optimal upgrade decisions for minimizing total upgrade costs for achieving Certified and Silver LEED-EB levels. Furthermore, the DSS was able to identify the optimal upgrade decisions for maximizing the number of LEED-EB points within a range of specified upgrade budgets. The DSS offers unique and important capabilities to aid decision makers in achieving the highest benefits for upgrading their buildings within the specified budgets. It provides a practical tool to evaluate and optimize various green upgrade options effectively and efficiently.

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