BUILDING DESIGN STRATEGIES AND THEIR CONTRIBUTION TO ENERGY PERFORMANCE FOR LEED CERTIFICATION

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INTRODUCTION

Leadership in Energy and Environmental Design (LEED) is a national set of standards put forth by the U. S. Green Building Council in 1994 that was intended to inspire building designers to plan greener, more sustainable buildings. LEED offers up to ten points for improved energy optimization performance. It should be noted that achieving these ten points is time consuming, complex, and expensive. This research is a case study that details the process of using a computer simulation study as a building energy optimizing tool in order to achieve these optional points. Determination is made as to how many LEED points can be obtained when basic strategies such as window performance and daylighting are integrated into one energy optimized building design. The results show that well-established energy conservation methods achieve as few as two or three LEED energy points, thereby possibly offering a disincentive for designers to attempt this difficult challenge. These fundamental efforts to achieve energy optimized building design are the first steps toward high performance building design and offer a fundamental solution to the substantial, negative environmental impacts caused by buildings today.

1. TOWARD ARCHITECTURAL DESIGN THAT REDUCES ENERGY CONSUMPTION

According to Edward Mazria, we have a glaring ". . . blind spot in America's energy consciousness."[1] Mazria, one of the pioneers of sustainable architecture since the 1970s, claimed in his 2003 article that "It's the Architecture, Stupid!" He attributes 48% of U.S. energy consumption and the resulting global warming, environmental pollution, and energy waste to buildings. And as Mazria says, "Buildings are among the most long-lived physical artifacts society produces. They are typically used for 50–100 years, so their inertia has a major impact on future energy use and emissions patterns. Today's architecture will be with us for a long time."[1] Most people, including the government and even architects, do not recognize the environmental impacts resulting from the energy consumption of buildings. More to the point, many architects do not recognize that they have the power to remedy these problems through their designs, and yet "The design of a building—its form, fenestration, construction materials, [lighting], and finishes—largely determines the building's lifetime energy consumption. . . ."[1]

In his article, Mazria outlines a blueprint for nothing less than a revolution in architectural design in order to fulfill the goal of achieving higher energy performance in buildings. His blueprint stresses "architecture [that is] intimately linked to the natural world,"[1] stronger standards, and whole building design using computer simulation. Mazria has long stressed how important it is for architects to integrate buildings into their natural settings in order to reduce energy dependence and environmental impacts. A designer should integrate the indoor space with the outdoors, for example, by maximizing the use of daylighting and thereby reducing electric lighting energy. Mazria also promotes stronger government standards based on a shift from current prescriptive code compliance to a performance-based standard that requires overall building energy reduction. (Mazria calls for a 50% reduction requirement.) A performance-based standard takes a whole building approach, relying on computerized energy simulations to predict the functionality of the building by determining how components and strategies interact. Ideally, this takes place during the design phase, thereby allowing for early

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changes. Further, Mazria calls for better and more accessible computer simulation programs. Finally, he believes that professional architectural schools must offer computer simulation training, as well as a deeper study of the relationship between building design and the natural environment.

This study echoes several aspects of Mazria's revolutionary blueprint for reducing building energy consumption and the corresponding environmental impacts caused by modern building design practices: integration of a building with its surroundings, use of a performance-based building standard, and whole building design using computer simulation. Specifically, interactions between the building's components and/or strategies and climate and/or surroundings were measured in order to optimize energy performance. The goal was to achieve the most energy performance points under Leadership in Energy and Environmental Design (LEED) 2.1, a green building rating system. These points fall under the Optimize Energy Performance certification credit, which is based on the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard, 90.1, designed for commercial buildings. This study used ASHRAE 90.1's performance path (an integrated, whole building approach that requires computer simulation) rather than prescriptive path (isolated building component approach). A computer simulation parametric analysis was performed that helped determine how to best reduce energy consumption that was related to building design as opposed to system efficiency. Additionally, a duplicatable process that included all of these concepts was designed to simplify the practice of energy analysis. This energy analysis was successful in that simulated energy costs were reduced and three LEED points were obtained. Overall, by drawing on Mazria's blueprint for success, this study contributes to the furthering of his vision of architecture as an integral part of our ecosystem.

2. METHODS

This research set out to establish a process for improving building energy performance, specifically to maximize the number of LEED points under the OEP credit. LEED 2.1 offers up to ten points for energy reduction depending on quantity reduced. This study focused on energy reduction through architectural design and the use of standard building Energy Conservation Measures (ECMs) related to building design and envelope as opposed to system efficiency, as per LEED's three-step approach.[11] (See Carol Marroitt's July ASHRAE Journal article, p. 44, for improving HVAC systems to gain OEP.) LEED 2.1 requires that ASHRAE 90.1's Energy Cost Budget Method be used to measure the energy cost improvement. The ECB method is based on computer simulation and is a process for comparing the proposed building to an ASHRAE 90.1 prescriptive path-compliant baseline building. The information garnered from the simulation output can help designers understand the interactions of ECM inputs in order to reduce energy costs in the proposed building.

The case study involved a simulation of a five-zone prototypical office building (see Figure 1).

Building type, construction, dimensions, and climate were all considered when determining the features for this case study's simulation model (Table 1).

This case study simulation used a Typical Recorded Year weather file for Detroit, Michigan latitude 42.42° and longitude 83°. Detroit is predominantly a cold climate with short, hot, humid summers; its latitude places it in the northern temperate zone and is defined by four distinct seasons. The average minimum daily temperatures reach below freezing for almost half of the year from April through mid-October. Average maximum daily temperatures are into the 80s for three months in the year, June, July and August, and often go higher. For

FIGURE 1. Case study Detroit office building as modeled in *eQUEST*, as well as a zoning diagram.

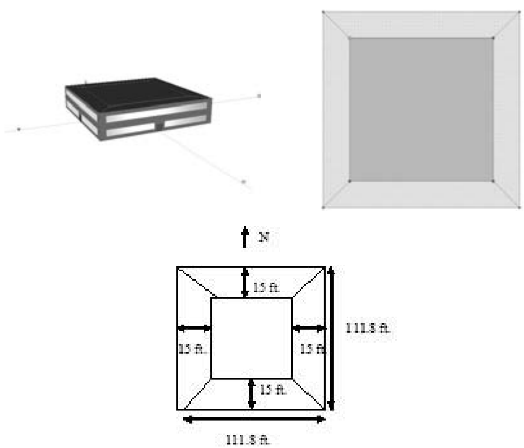


TABLE 1. Case study building model.

Building type	Office building, mid size
Location	Detroit, Michigan
Building area	25,000 sf
Number of floors	Two floors above grade
Zones	Five, four perimeter & one core
Footprint dimensions	111.8 by 111.8
Core zone	6,691 sf per floor; 53.5% of total space
Perimeter zone	15 ft. 5,808 sf per floor; 46.5% of total space
Floor height	12 ft. floor to floor height
Roof	Metal frame, > 24 in o.c., built-up
Wall	Metal frame, 2 by 6, 24 in. o.c. Wood/plywood
Schedule	8 a.m. to 6 p.m. Sat. and Sun., holidays closed
HVAC	Cooling source: Chilled water coils Heating source: Hot water coils
System types	Cooling: Standard VAV Chilled water coils with HW reheat Heating: Hot water coils
Lighting type	Suspended fluorescent
Light power density	1.0 (W/sf) for all areas
CFM	0.50 CFM/sf
Design temperature	Cooling design: 74 Heating design: 68
WWR	45%

these same summer months, humidity also peaks. Detroit's heating degree days number over 6,500 and cooling degree days just over 600. For this case study, it should be noted that, even though Detroit is mostly a heating climate, the internal heat gain in the office setting along with the intensely hot summer will cause a substantial cooling load.

The simulation tool that was chosen for the study was *eQUEST. eQUEST* was chosen because it had the following features:

- Hourly weather building energy analysis program.
- Ability to quantify energy consumption and relationships between separate zones.
- Graphical user interface for ease of use.
- Intelligent defaults.
- Ease of parametric runs
- Wide range of output reports that allow for in-depth analysis.
- Compliance with ASHRAE 90.1 ECB method computer simulation requirements as per Section 11.2.1.1 of the Standard.[2]

In the ECB method, annual energy cost in dollar amount is "the unit of measure" for energy performance.[11] Costs can be determined by the adopting authority or by using the local utility rate structure. In this study, costs were determined using the local utility rate structure of DTE for Ann Arbor, MI based on pricing in May of 2005.[3]

2.1 Procedures

The following procedure is intended to create an optimally designed "proposed" building that has the lowest possible annual energy costs so as to achieve the most LEED 2.1 Optimize Energy Performance (OEP) points. In order to achieve LEED OEP points, ASHRAE 90.1's Energy Cost Budget Method (ECB) must be followed. The ECB method requires that the proposed building be computer simulated and compared to an ASHRAE 90.1 compliant computer simulated baseline.[10] OEP points are determined by the annual energy cost reduction of the proposed building from the baseline. The purpose of this parametric study then is to determine optimal ECMs for the proposed building that will minimize energy costs as much as possible relative to the baseline so as to achieve as many OEP points as possible. See Table 2 for percent reduction and LEED point correlation.

TABLE 2. Percent energy cost reduction required to gain LEED OEP points.

Percent cost reduction	LEED Optimize Energy Performance
12.5%–17.5%	1 point
17.51%–22.5%	2 points
22.51%–27.5%	3 points
27.51%–31.5%	4 points
32.51%–37.5%	5 points
37.51%–42.5%	6 points
42.51%–47.5%	7 points
47.51%–52.5%	8 points
52.51%–57.5%	9 points
57.51 and up	10 points

FIGURE 2. Overview of three phases.

PHASE ONE
Run and Analyze Baseline
PHASE TWO
Perform Parametric Analysis
PHASE THREE
Run Proposed Building

To undertake this comparison test the study is structured into three action phases that will be presented, for reference, by a flow chart similar to Figure 2. Each action phase is further broken down into steps. Figure 2 presents an overview of the three phases.

Phase One of this section focuses on the baseline simulation. Phase Two focuses on the energy reduction parametric study as a part of designing the proposed building. Phase Three runs the proposed building simulation.

2.1.1 Phase One: Run and Analyze Baseline. Phase One of the study focused on set-up and simulation of the baseline. Figure 3 below provides an overview of Phase One divided into three steps. Then Figure 4 will provide greater detail of the steps in Phase One.

2.1.1.1 Step 1: Prepare ASHRAE 90.1 Compliant Baseline. Before the baseline could be run, it had to be set up according to the requirements of the ECB method. First, the baseline window properties, such as its U-factor and SHGC, and wall and roof R-values must meet ASHRAE 90.1 Prescriptive Path basic efficiency requirements. Table 3 shows these criteria as they apply to the Detroit climate.[10] In addition, the ECB method requires that the baseline must have certain consistencies with the proposed building. These include: e.g., building type, shape, opaque assemblies with the same heat capacities, conditioned floor area, exterior dimensions and orientations, all building systems and equipment, design space temperature and HVAC system operating setpoints, schedules, and zones. The HVAC system must be compared to a "like" system. Orientation and thermal mass could not be altered. Certain components that can enhance energy performance could be altered exclusively in the proposed building for the purpose of increasing energy efficiency. For example, walls could have a higher insulation value. Window type could be altered. Window size could be larger than the baseline, but not smaller. Strategies such as

FIGURE 3. Phase One, Level 1.

PHASE ONE
Run & Analyze Baseline
Step 1: Prepare ASHRAE 90.1 compliant baseline
Step 2: Run baseline
Step 3: Analyze baseline output

FIGURE 4. Phase One, Level 2.

PHASE ONE

Step 1: Prepare ASHRAE 90.1 compliant baseline

- Select WWR
- Select Windows
  - U-factor
  - SHGC
- Select Roof and Walls
  - R-value
- Select Strategies
  - Daylighting
  - Shading

Step 2: Run baseline

Step 3: Analyze baseline output

- Analyze Total Energy Consumption
  - Convert Consumption to appropriate indicator (e.g. cost)
  - Rank end uses
    - Lighting
    - Cooling
    - Heating
  - Rank end uses by energy types
    - Electricity
      - Lighting
      - Cooling
    - Natural gas
      - Heating
- Analyze sources of building loads
  - Electric
    - Lighting
  - Thermal
    - Windows
    - Walls and roof
    - Electric lights

TABLE 3. Inputs of components and strategies in compliance with ASHRAE 90.1 Prescriptive Path for the baseline simulation for Detroit, Michigan.

		ASHRAE requirements	Baseline building
Window	Glass Code		2447*
	Glass type		Double glazing Ref-C Clear-H, 1/4 inch pane
	Frame		Alum. with break, operable
	Gap		1/2 inch, air
	For WWR	40.1-50%	45%
	U-factor	0.47	0.47
	SHGC (all)	0.26	0.26
	VT		0.2
	LSG		0.77
Opaque	Roof insulation	R-15	R-15
	Above grade wall insulation	R-13	R-13
	Floor	R-20	R-20
Strategy	Daylighting	No	No
	Shading	No	No

**DOE-2* Glass Library.

daylighting and shading could be implemented. HVAC efficiencies could be enhanced.

Therefore, the following components and strategies were specifically addressed in the baseline simulation in Step 1: Window U-factor and SHGC, and roof and wall R-values. In the Prescriptive Path window characteristics such as U-factor and SHGC are based on climate and WWR, which in this case is 45%, and were selected from the *DOE-2* Glass Library. Table 3 details the simulation input selections for the baseline.

The first column presents ASHRAE 90.1, 2004 maximum requirements for applicable WWR.[10] (Note 2004 code was used, not 1999 code, which is what LEED 2.1 requires.) The second column presents the properties chosen for the baseline as a part of Step 1. ASHRAE 90.1 requires a maximum U-factor of 0.47 and SGHC of 0.26 for a Detroit WWR of 45%. Glass Type 2447 was chosen from the *EQUEST-DOE-2* Glass Library as it satisfied these requirements. Figure 5 shows this window in detail.

In addition to windows, wall and roof insulation was also selected. The insulation for the roof was R-15, the walls R-13, as minimally required. Details of the baseline roof and wall are shown in Figures 6 and 7.

As stated earlier, daylighting and shading were not allowed to be implemented in the baseline. Additionally, except for the components and strategies specifi-

FIGURE 5. *DOE-2* Glass Library Code 2447 glass chosen for baseline.

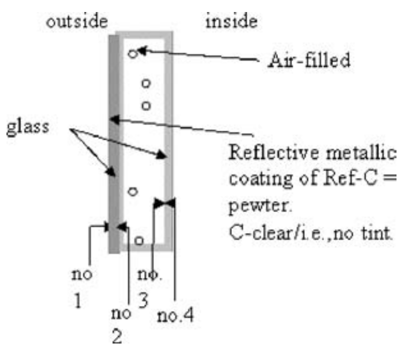


FIGURE 6. Baseline roof structure, including insulation.

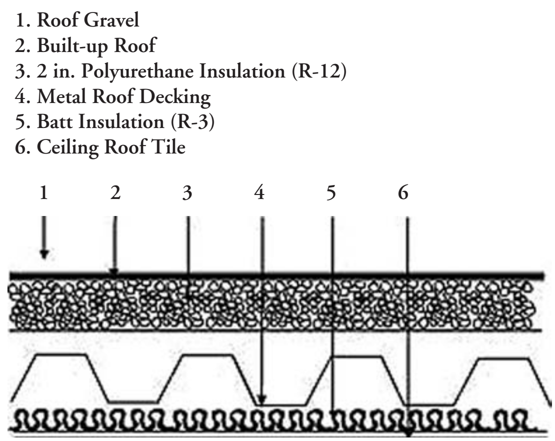
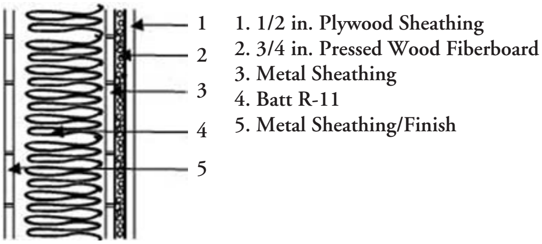


FIGURE 7. Baseline wall structure, including insulation.

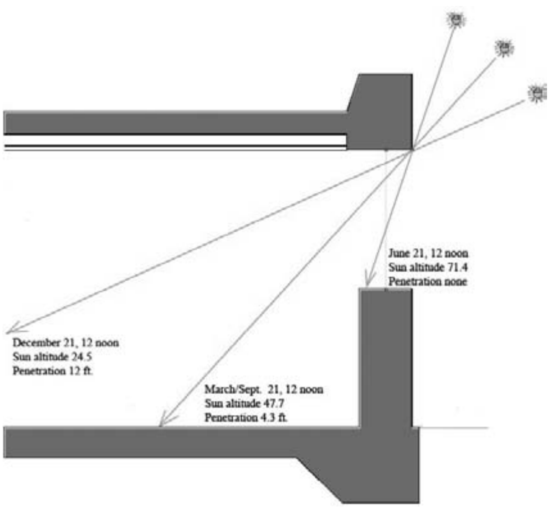


cally detailed above, all of the rest of the inputs for the baseline were a part of the case study model or used *eQUEST*'s default and were identical to the proposed building. This completed Step 1 of preparing the baseline. Figure 8 below shows the baseline (i.e., with no shading) window and indoor space penetration to the sun noontime at the spring and fall equinox and at the summer and winter solstices.

2.1.1.2 Step 2: Run Baseline

2.1.1.3 Step 3: Analyze Baseline Output. Once the baseline was run it had to be analyzed in order to see where energy was being used (end uses) and what was causing the end uses (loads). This analysis occurred in Step 3 and is presented in two sections: one, total energy consumption and end uses, and

FIGURE 8. Baseline window and indoor space sun exposure at two solar equinoxes and solstices.[5]



two, sources of building loads. Total energy consumption will be addressed first.

2.1.1.3.1 Analyze Total Energy Consumption. Table 4 was assembled in order to analyze the energy data of the baseline. It is based on the BEPS (Building Energy Performance) report, the most critical output provided by *eQUEST* for this study. The BEPS Report provides the total annual energy consumption of the simulated building and is broken down by energy end uses, e.g., lighting, heating, cooling, equipment, and types, such as, electric and natural gas. The BEPS Report is presented in a common MBtu energy unit for ease of comparison across utilities and is derived from the BEPU Report, which details the energy type and end use in "utility units" such as kWh and therms.

The first three lines of Table 4 indicates original output from the *eQUEST* BEPS (Building Energy Performance) report. In order to assemble the table, calculations were performed in MS Excel to determine percentages and ranking of the baseline's energy end uses. For this case study the cost is the indicator. Therefore, this output was then converted from energy (MBtu) to costs. Costs were based on DTE energy prices[3] as of May 2005 when electricity sold for 0.09526 per kWh ($27.93 per MBtu) and natural gas sold for 0.799 per CCM ($7.99 per MBtu).

Although there are many data on this table that will be expanded upon with graphs to further emphasize important relationships, the most significant number for this study is the total annual energy cost of $25,283. This number is most important because this is the number that must be reduced in the proposed building to achieve OEP credits.

2.1.1.3.2 Rank End Uses. In addition to providing data for end uses and energy types, Table 4 ranks end uses by energy consumption and cost from most usage to least. This ranking becomes a useful indicator for determining priorities for any energy analysis. Figure 9 highlights this ranking. The highest cost end use, electric lighting, was ranked number one at $6,991 or 28%, and heating was ranked number two at $6,551 or 26%. Miscellaneous equipment was ranked number three at $4,636 or 18%, but it will not be addressed because it is not directly related to choices in building

TABLE 4. Baseline total energy consumption by end use and energy type with additional calculations, including total costs and ranking.

Building Energy End Uses	Lighting	Misc equipment	Heating	Cooling	Pump & Aux.	Vent Fans	Hot Water	Total
				(Mbtu)				
Electric	250	166	0	111	44	90	0	661
Natural gas	0	0	820	0	0	0	36	856
Total	250	166	820	111	44	90	36	1,516
% of Total Energy	17%	11%	54%	7%	3%	6%	2%	
Energy Usage Rank (1 = high)	2	3	1	4	6	5	7	
Building Cost End Uses	**Lighting**	**Misc equipment**	**Heating**	**Cooling**	**Pump & Aux.**	**Vent Fans**	**Hot Water**	**Total**
				($)				
Electric Cost	6,991	4,636	0	3,092	1,215	2,514	0	18,448
% of Electric Cost	38%	25%	0%	17%	7%	14%	0%	
Natural Gas Cost	0	0	6,551	0	0	0	284	6,835
% of Natural Gas Cost	0%	0%	96%	0%	0%	0%	4%	
Total Annual Cost	6,991	4,636	6,551	3,092	1,215	2,514	284	25,283
% of Total Annual Cost	28%	18%	26%	12%	5%	10%	1%	
Energy Cost Rank (1 = high)	1	3	2	4	6	5	7	

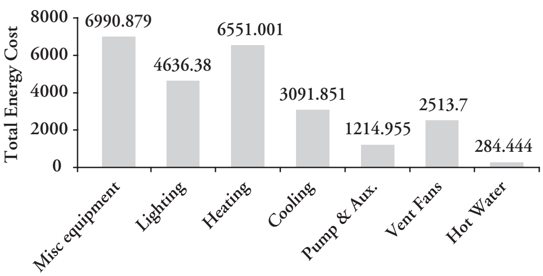
design and the building envelope. Cooling ranked number four at $3,092, or 12%.

Of the twelve end uses, this study focused on electric lighting, heating, and cooling not only because they were the only end uses related to building design but also because they were ranked one, two, and four of the end uses. Electric lighting, heating, and cooling combined to equal about $17,000, or 66%, of the over $25,000 total annual energy cost of the baseline. The following section presents the primary energy types and how they were spent by end use.

2.1.1.3.3 Rank End Uses by Energy Type. This next section breaks down energy type by end use. As was shown in Table 4, electricity used $18,500 or 73% of total energy cost and natural gas used almost $7,000 or the other 27%. That 73% of energy costs came from electricity magnified the importance of reducing the building's electrical energy use in a cost based study.

Of total electric cost, electric lighting used 37% and cooling 17%. This reveals the significance of lighting and cooling in the baseline and their potential for improvement in the proposed building. Although electricity is significant, natural gas also offers opportunities for cost reduction.

FIGURE 9. Total energy cost by end-use.



2.1.1.3.4 Analyze Sources of Building Loads. It was seen that electric lighting, heating, and cooling comprised 66% of total energy cost. In order to improve the proposed building's energy costs, the building loads that caused this consumption were analyzed next. The building loads were divided by electric and thermal loads that were impacted by building design.

In this study electric load will refer to the quantity of energy (kWh or MBtu) that is required by a device to perform the electrical work and (as is often the case) thermal loads will generically refer to the undesired loss (or gain) of heat (resulting from building design) which causes an energy demand on an HVAC system. A thermal load can be attributed to building design factors and components and is determined through a load computation.

In this case, electricity was broken down by end use which also shows the load on electricity by end use. The most significant electric load impacted by design was the load from electric lighting. This load (the same as the end use energy consumption by electric lighting) was 250 MBtu for the year. Next was miscellaneous equipment, not included in this analysis, and then cooling at 111 MBtu. It should be noted here that the 111 MBtu energy that the HVAC cooling system used is the result of the thermal cooling load that is discussed next.

Thermal load caused by building components was determined next. Figures 10 and 11 identify building components that caused the heating and cooling loads and were obtained from *eQUEST*'s LS-F Building Monthly Load Component report. (Negative values refer to heat lost in the winter that must be mechanically resupplied; positive values refer to heat gain that must be mechanically removed in the summer.)

Figures 10 and 11 show that window conductance caused the greatest heating load, followed by roof and wall conduction and infiltration (infiltration not being a function of building design was not specifically addressed). Electric lighting (electricity converted to heat) and solar heat gain through windows contributed most to the cooling load (equipment and occupants also were not addressed).

FIGURE 10. Cumulative monthly heating loads by building component (derived from LS-F report).

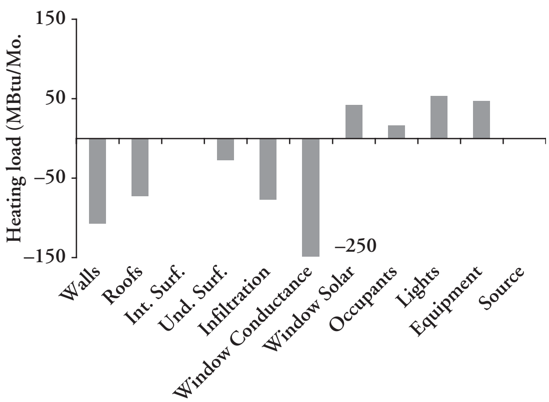
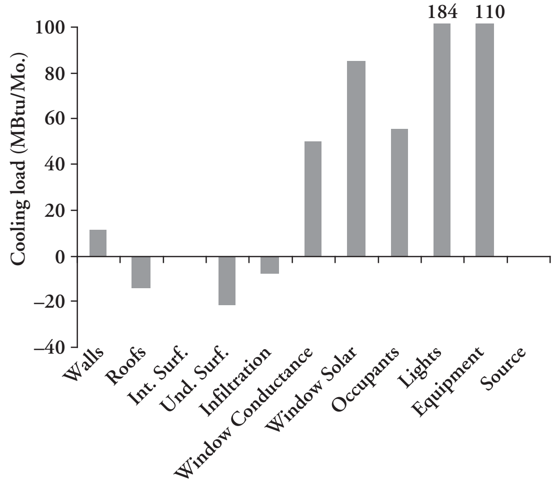


FIGURE 11. Cumulative cooling loads by building component (derived from LS-F report).



Phase One thus served to identify the most significant ways energy was used in the baseline revealing opportunities for reduction to take place in Phase Two. In summary, electric lighting and cooling were identifiable contributors to electric load, and windows, roof and walls were identifiable contributors to thermal load of the baseline based on building design and would be the most important changes that would be addressed in the proposed building. The parametric study that follows in Phase Two will assist in figuring what changes should be made.

2.1.2 Phase Two: Perform Parametric Analysis. In Phase Two a parametric analysis was conducted to identify the optimal energy reduction inputs for the proposed building simulation. Figure 12 offers an overview of Phase Two.

FIGURE 12. Phase Two: Level 1.

PHASE TWO

Perform Parametric Analysis

Step 1: Identify optimal building envelope strategies using parametric study.

Step 2: Evaluate identified building envelope strategies.

Step 3: Select final proposed building properties.

TABLE 5. Strategies and components to reduce end use consumption by rank (based on Table 4).

Ranking	End Use Consumption	Strategies and Components to Reduce End Use Consumption
1	Electric lighting	Strategy: Daylighting Windows: VT
2	Heating	Windows: U-factor, SHGC Roof and walls: U-values
3	Cooling	Strategy: Shading Windows: SHGC

Phase Two involved using three steps: (1) to identify optimal building values and strategies for this location using a parametric study, (2) to evaluate individual building envelope components and strategies using the identified values from Step 1, and (3) select final characteristics for the proposed building simulation with the purpose of reducing the end uses and loads identified in Phase One. Before beginning Step 1, Table 4 was reviewed. Table 5 provides a summary of Table 4 that ranked energy end uses identified in the Phase One baseline analysis. Table 5 reviews the ECM strategies and components that can be used to address the end uses.

Table 5 identifies design strategies and components that combat energy end uses relating to building design in the baseline. The sequence for the following parametric study was based on this ranking. Figure 13, Phase Two: Level 2, presents Phase Two in detail and includes the questions that will be first asked and then answered in the parametric study in Step 2.

Step 1 involved running a series of computer simulations that would address the questions presented in Figure 13 to determine the optimal building envelope values and strategies. The question order reflects the ranking of Table 4 and 5.

2.1.2.1 Step 1: Identify Optimal Building Envelope Strategies Using Parametric Analysis

2.1.2.1.1 Daylighting. Daylighting is an energy strategy that optimizes natural lighting through windows and supplements it with electric lighting minimally in order to satisfy design light levels. In daylighting photosensors measure light levels and adjust and dim electric lighting as determined by the sensors thereby requiring less electrical energy consumption. The first parametric run was to determine if implementing daylighting controls reduced the load on electric lighting, and if so, by how much. Therefore, daylighting controls were turned “On” during this simulation and default settings used. The *eQUEST* default for daylighting is set at 100% of lighting at perimeter zones at 50 footcandles, with photosensors 2.5 feet above the floor at 50% of zone depth and adjusted on a continuum. Except for adding daylighting there were no other alterations of any other aspect of the building design.

The output of this daylighting simulation showed that with the use of daylighting controls electric lighting energy for the year decreased from baseline 73,000 kWh to 52,000 kWh or around a 20,000 kWh reduction. The loss of heat gain from electric

FIGURE 13. Phase Two, Level 2.

PHASE TWO

Design Proposed Building

Step 1: Identify optimal building envelope properties using parametric study.

Daylighting

- Q1: Did implementing daylighting reduce the total energy costs in the building?

Window characteristics

U-factor

- Q2: What is the optimal U-factor?

SHGC

- Q3: What is the optimal SHGC without shading?

Shading

- Q4: What is the optimal SHGC with shading?

VT

- Q5: What is the optimal VT with daylighting?

Walls

- Q6: What is the optimal R-value for the walls?

Roof

- Q7: What is the optimal R-value for the roof?

Step 2: Evaluate identified building envelope strategies.

Step 3: Select final proposed building properties.

lighting increased heating energy only slightly and cooling energy decreased by just less than 2,000 kWh. The total cost decreased from $25,200 to $23,400. By installing daylight controls alone, with no other changes, total energy costs were reduced by almost $2,000 or a 7% decrease.

Q1: Did implementing daylighting reduce the total energy costs in the building?

A1: Yes.

2.1.2.1.2 Window Characteristics. The next parametric runs focused on window selection by determining optimal window characteristics such as the window's U-factor, SHGC, and VT. Additionally, exterior shading as a window strategy was included in the study of SHGC to see whether shading altered the optimal SHGC for the window.

2.1.2.1.2.1 U-Factor. The U-factor is the measure of non-solar heat conductance through the window over a period of time and is measured as the Btu/ft^{2}hr°F. The U-factor parametric was run in the following increments: 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2 (Btu/h ft^2 F). The other window characteristics were held relatively constant with the baseline: SHGC of 0.3 (vs. baseline of 0.26), VT of 0.2, and WWR of 45%.

Figure 14 shows that cost was directly proportional with U-factor. The following equation shows the relationship of U-factor with cost:

$$y = 1742.2x + 21004 \qquad (R^2 = 0.99)$$

As the U-factor increased by 0.2, the cost increased by $1742. Clearly, the graph shows that the window's U-factor should be as low as is possible in Detroit. ASHRAE 90.1's U-factor maximum of 0.46 for a 45% WWR is fairly stringent and towards the low end of the U-factor scale.

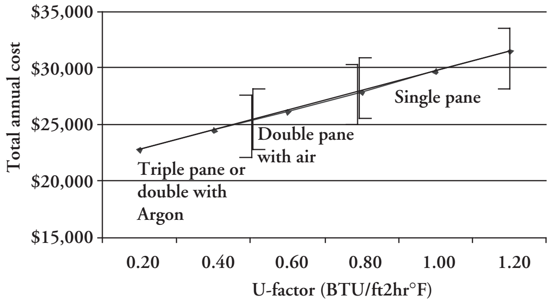
The *DOE-2* Glass Library shows that U-factors over 0.80 tend to be single pane glass. U-factors from 0.50, to 0.80 tend to be double pane with air, U-factors below 0.50 are double pane with argon fill or triple pane.

Q2: What is the optimal window U-factor?

A2: The lowest feasible value, likely a triple pane or double pane with argon.

2.1.2.1.2.2 SHGC. A window's solar heat gain coefficient (SHGC) is the ratio of solar radiation that penetrates through the window compared to the solar radiation of a standardized clear, single pane of glass (which is rated at one). SHGC is the most challenging window characteristic to optimize because the same window should allow solar heat to enter the space in the winter and prevent it from entering in the summer. In a temperate climate with cold and hot seasons, a very low SHGC and a high SHGC both result in high energy costs because a SHGC that is too low excludes desired heat gain during the winter thereby increasing heating costs, and a SHGC that is too high admits too much heat gain during the summer thereby increasing cooling costs. Thus the next two tests were designed to determine the optimal SHGC that lies in between these extremes, one without shade, and the other with shade.

FIGURE 14. Total cost as a function of U-factor.



The SHGC parametric was run in the following increments: 0.1, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5, 0.6, and 0.7. The U-factor, VT, and WWR were the same as the baseline: 0.46, 0.2, and 45% respectively. Neither shading nor daylighting were implemented. The output from these parametric runs resulted in Figure 15.

The relationship between SHGC without shade and cost can be described by the following parabolic function:

$$y = 8502.6x^2 - 4225.3x + 25499 \quad (R^2 \text{ of } 0.94)$$

$$y_{min},\ x = 0.25$$

The SHGC was optimized at a very low SHGC of 0.25—comparable with ASHRAE 90.1 maximum prescriptive value of 0.26. In terms of cost, the study confirmed that cooling had to be highly controlled, even in a cold climate like Detroit.

The *DOE-2* Glass Library shows that windows that have high SHGC above 0.65 are either clear or iron tint. SHGC between 0.47 and 0.65 are tinted

FIGURE 15. Total cost as a function of SHGC without shade.

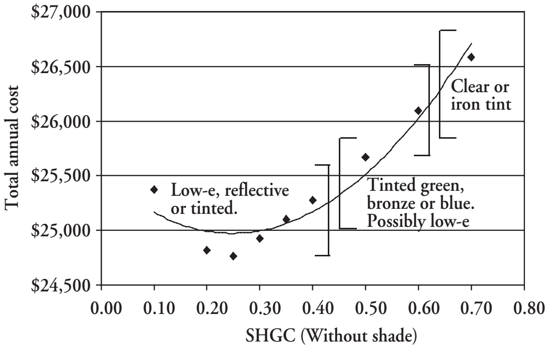
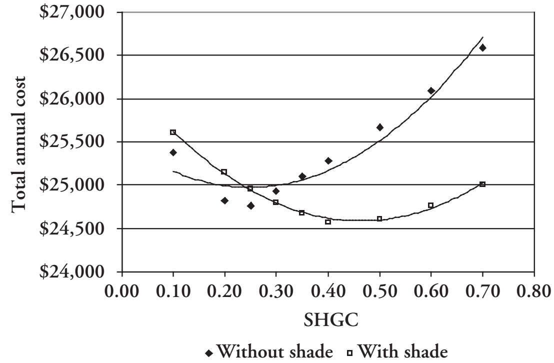


FIGURE 16. Total cost as a function of SHGC with and without shade.



green, bronze, or blue. Also, some Low-e windows fall in the midrange. Windows with very low SHGC below 0.47 tend to be low-e, reflective or tinted.

Q3: What is the optimal SHGC without shading?

A3: 0.25, likely a low-e, reflective or tinted window.

2.1.2.1.2.3 SHGC with Shading. The next parametric was designed to determine whether the introduction of exterior shading altered the optimal SHGC. The SHGC with shading parametric was based on the same increments of SHGC as the above set of SHGC without shade parametric: 0.1, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5, 0.6, and 0.7. Similarly, the U-factor, VT, and WWR were in line with the baseline of 0.46, 0.2 and 45% respectively. Shading was implemented on the south, east, and west with an overhang depth of 4.2 feet and fins at 3 feet as recommended for a cold climate by Carmody, Selkowitz, Lee, Arasteh, and Willmert in *Window Systems for High Performance Buildings*.[4] The output from the parametric run resulted in Figure 16 (shown with and without shade for comparative purposes) which shows the SHGC with shade and its relationship with costs.

The relationship between SHGC, with shade, and cost can be described by the following parabolic function:

$$y = 7806.7x^2 - 7237.5x + 26264 \quad (R^2 \text{ of } 0.99)$$

y_{min}, x = 0.46

The SHGC with shade came to be optimized at a much higher SHGC of 0.46, which is almost twice as high as without shade SHGC (0.25); these are compared to the ASHRAE 90.1 maximum of SHGC 0.26 (ASHRAE 90.1 assumes no shading).

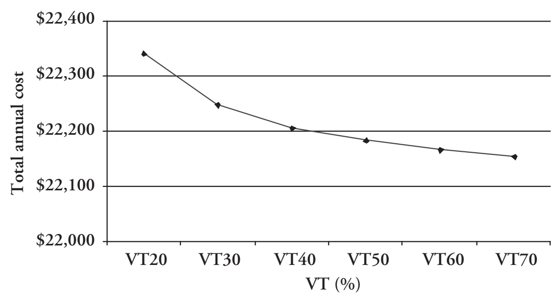
Q4: What is the optimal window SHGC with shading?

A4: 0.46.

2.1.2.1.2.4 VT. The visible light transmission (VT) of the window is the fraction of visible radiation from outdoor light that is transmitted through the glass. A VT parametric was run next to determine whether there was a relationship between optimal VT and costs. The VT parametric was run in the following increments: 0.2, 0.3, 0.4, 0.5, and 0.6. The U-factor of 0.43, SHGC of 0.26 and WWR of 45% were held constant with the baseline. In this case, daylighting was implemented.

It can be determined from the output that cost decreased as VT increased, though not substantially. A *DOE-2* Glass Library graph shows that low-e windows tend to have the highest VT relative to Shading

FIGURE 17. Total cost as a function of VT.



Coefficient (SHGC), i.e., that low-e windows with low SHGC have the highest VT windows.

Q5: What is the optimal VT with daylighting?

A5: As high as is feasible, accounting for glare and visual comfort. Likely using a low-e window.

2.1.2.1.3 Walls and Roof R-value. Insulating materials slow down the transfer of heat in and out of the space and are measured by R-value, the material's resistance to heat transfer. R-value is the number of hours required for one Btu to penetrate 1 square foot of the material for each degree Fahrenheit of temperature difference from each side of the wall. Parametrics for walls and the roof insulation were performed with R-values increasing from R-5 to R-40 for walls and R-50 for the roof. Figure 18 shows the relationships between R-value and total cost for the roof and walls.

This graph shows a diminishing return of benefit as R-value increases at around R-25 for both walls and the roof. Three inches of polyurethane and R-7 batt provides R-25 insulation.

Q6: What is the optimal R-value for the walls?

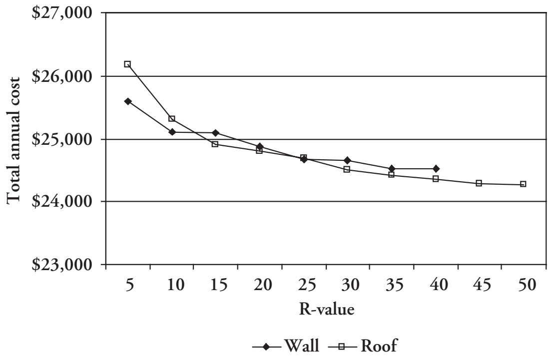
A6: R-25.

Q7: What is the optimal R-value for the roof?

A7: R-25.

The outcome of the parametric study of Step 1 of Phase Two provided optimal window and wall characteristics and determined strategic options for the building. This outcome is listed in Table 6.

FIGURE 18. Total cost as a function of roof and wall insulation.



It is important to note in the results of this parametric study that daylighting is helpful, SHGC can be higher with shading, and wall and roof insulation reaches a diminishing return at R-25. In Step 2 of Phase Two, all of this information was assembled to determine a specific window, wall and roof insulation as well as daylighting and shading strategies.

2.1.2.2 Step 2: Evaluate Identified Building Envelope Strategies. In Step 2 building components and strategies were evaluated based on the optimal building envelope values and strategies identified in Step 1. This included narrowing down the selection of the specific window type and opaque surface insulation.

TABLE 6. Outcomes from Phase Two parametric study: Q & A.

Building Characteristics and Strategies	Questions for Proposed Building	Answers
Daylighting	*Q: Did implementing daylighting reduce the total energy costs in the building?*	*A: Yes.*
U-factor	*Q: What is the optimal window U-factor?*	*A: The lowest feasible value likely a triple pane or double pane with argon.*
SHGC without shading	*Q: What is the optimal window SHGC without shading?*	*A: 0.25; likely a low-e, reflective or tinted window.*
SHGC with shading	*Q: What is the optimal window SHGC with shading?*	*A: 0.46.*
VT	*Q: What is the optimal window VT with daylighting?*	*A: As high as is feasible, likely using a low-e window, accounting for glare and visual comfort.*
Wall Insulation	*Q: What is the optimal R-value for the walls?*	*A: R-25.*
Roof Insulation	*Q: What is the optimal R-value for the roof?*	*A: R-25.*

TABLE 7. Window type (with characteristics) selected as inputs for proposed simulations (with baseline window for comparison).

	DOE-2 Window Library name	*DOE-2* Glass type code	# Panes	Gap thickness (in)	Gap gas fill	U-factor	SHGC	VT
Baseline	Double Ref-C Clear-H	2447	2	0.50	Air	0.47	0.26	0.2
Alternative 1	Triple Low-E Film (66) Tint	3664	3	0.50	Air	0.28	0.25	0.32
Alternative 2	Triple Low-E (e2=e5=.1) Clear	3623	3	0.50	Argon	0.18	0.47	0.66

This also included making a decision whether or not to use daylighting and shading. Since the analysis was clear that daylighting was beneficial in reducing the total energy costs, and roof and wall R-values were optimized at R-25, there was no need to address these further. The window analysis, however, revealed two optimized alternatives and therefore needed more consideration.

The parametric study showed that SHGC was the most critical consideration when choosing a window especially as it was related to shading. The windows without shading optimized at a lower SHGC than windows with shading. Therefore, out of hundreds in the *DOE-2* Glass Library database, two different windows were evaluated. Table 7 shows the characteristics of these two windows, 3664 and 3623, along with the baseline window 2447 for comparison.

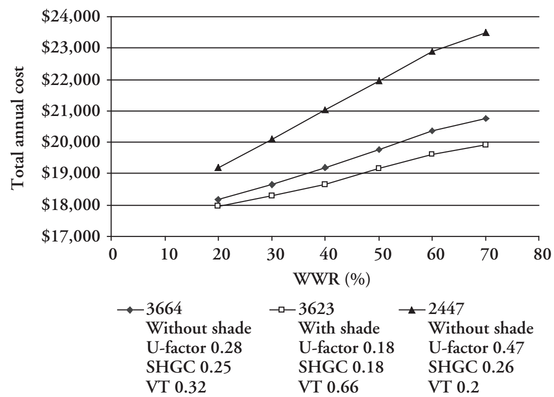
Triple Low-e Film with tint (Glass type code 3664) and Triple Low-e clear (Glass type code 3623) were assessed based on their SHGC, (as well as their U-factor and VT.) The window chosen for its low SHGC, at 0.25, had a lower VT and the one with high SHGC, at 0.47, had a higher VT. They both had a relatively low U-factor (0.28 and 0.18, respectively) as compared with the baseline of 0.47. The windows shown in this table were then tested in the next WWR simulations to help determine the preferred window.

2.1.2.2.1 Compare Window Scenarios. The next part of Step 2 was to further establish the building envelope design using the two window scenarios, with shading and without. (It should be noted that in an actual building study each façade should be tested separately.)

Figure 19 shows the results of a simulation study that looked at the relationship between WWR and cost for two windows (along with the baseline window for comparison).

The study measured total cost of energy as a function of WWR as it rose in increments of 0.1 up to 0.7. Daylight was implemented and wall and roof had R-values of 25, as per Step 2. This was measured using 3664 without shade and 3623 with shade. This comparison was originally intended to elucidate the optimal WWR for each of the windows. However, as the figure shows, cost rose proportionally with WWR for all three windows and provided little new insight from what would be expected when using increasingly large windows. For example, the benefit of daylighting did not outweigh the energy cost of the large windows. The more relevant outcome of this data, however, was the relationship *between* the three

FIGURE 19. Total cost as a function of WWR for three window scenarios.



windows. The following equations show these three relationships:

$$Y_{2447} = 88x + 17489 \quad (R^2 \text{ of } 0.99)$$

$$Y_{3664} = 53x + 17096 \quad (R^2 \text{ of } 0.99)$$

$$Y_{3623} = 40x + 17104 \quad (R^2 \text{ of } 0.99)$$

The baseline window (2447, without shade) increased with a steeper slope (m = 88) than 3664 (without shade) which increased faster (m = 53) than 3623 (with shade) (m = 40). Window 3623 with shade was lower for every WWR. This information was then used to complete the next step, the final selection of proposed building components and strategies.

2.1.2.3 Step 3: Select Final Proposed Building Properties. In Step 3, each of the optimized values and strategies discovered from Step 2 were incorporated into one optimized proposed design. This included daylighting, roof and walls, windows, and shading. As was previously determined in Step 1, daylighting would be implemented and roof and walls would have insulation with R-25. For WWR, the ECB method requires that the baseline WWR be the same as the proposed building unless the proposed building is greater than the 50% allowed maximum. The WWR parametric shows no cost advantage for increasing the WWR above 50%. Therefore, the WWR for the proposed building was chosen to be the same as the baseline, 45%. At WWR 45% (and every WWR, for that matter) the cost is less for window 3623 with shade than for windows 2447 and 3664 both without shade. Thus, window 3623, with shading, was selected for the proposed building. Now that everything was decided for the proposed building, in the next Phase, Phase Three, all the information from Phase Two was collected into the proposed building simulation, and the optimized proposed building was finally simulated.

2.1.3 Phase Three: Prepare and Run Proposed Building. Phase Three was the final stage of the study. This phase focused on the proposed building

FIGURE 20. Phase Three.

PHASE THREE

Run Proposed Building

Step 1: Prepare proposed building:

- Windows
- Roof and Walls
- WWR
- Daylighting
- Shading

Step 2: Run proposed building and analyze.

TABLE 8. Inputs of components and strategies for the proposed simulation.

Component		Identified Optimal Values and Strategies	Proposed Building
Windows	Glass Code		3623*
	Glass type		Triple Low-e (e2=e5=.1), Clear, 3 Panes
	Frame		Alum. with break, operable
	Gap		1/2 inch, Argon
	WWR	45% (same as baseline)	45%
	U-factor (operable, NFRC**)	As low as possible	0.18
	SHGC (all)	0.46	0.47
	VT	As high as possible	0.66
	LSG		0.71
Opaque	Roof insulation	R-25	R-25
	Above grade wall insulation	R-25	R-25
Strategies	Daylighting	Yes	Yes
	Shading	Yes	Yes

**DOE*-2 Glass Library.

**National Fenestration Rating Council.

simulation. Figure 20 shows the flow chart for the third phase.

Step 1 of this chart lists the components and strategies that were optimized in the proposed building. Table 8 shows the components with their properties, and strategies that were used in the simulation run. Except for the components and strategies specifically detailed in the table, all of the rest of the inputs for the proposed building were a part of the case study model or used *eQUEST's* default and were identical to the baseline building.

The proposed building energy components and strategies are summarized in Table 8. In the proposed building simulation, WWR was set at 45%. Window code 3623, with a high SHGC of 0.47 and a low U-factor of 0.18, was the selected window, and shading was used. Figure 21 shows window design.

Roof and wall insulation was set at R-25. In addition, daylighting was implemented. Figures 23 and 24 show the roof and wall for the proposed building in detail.

Based on these decisions, the proposed building was prepared and, finally, run.

3. RESULTS

3.1 Summary of Results

The proposed building simulation produced the results shown in Table 9. The box in the bottom right hand corner shows the percent reduction of the proposed building from the baseline ("budget"). Total energy costs were reduced from $25,283 for the baseline to $19,054 for the proposed building for a total energy cost reduction of 24.64%. Since 24.64% is

FIGURE 21. *DOE-2* Glass Library Code 3623 glass chosen for proposed building.

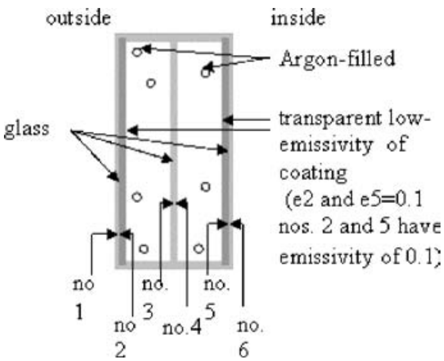


FIGURE 22. Proposed building (with shade) window and indoor space sun exposure at two solar equinoxes and at two solstices.[5]

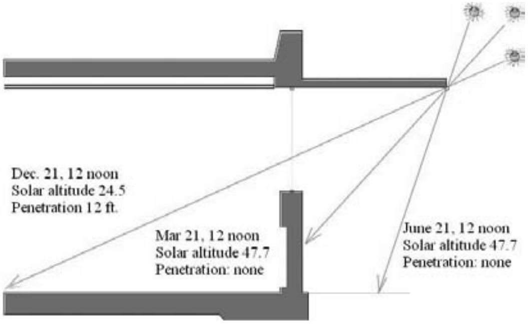


FIGURE 23. Proposed roof: R-19 batt insulation covered by R-6 rigid foam board.

1. Roof Gravel
2. Built-up Roof
3. 3 in. Polyurethane Insulation (R-18)
4. Metal Roof Decking
5. Batt Insulation (R-7)
6. Ceiling Roof Tile

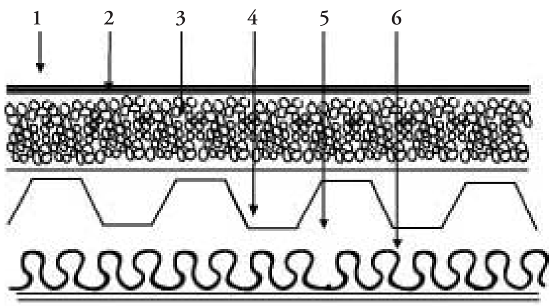
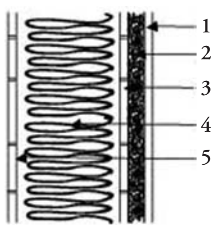


FIGURE 24. Proposed wall: R-13 batt insulation covered by R-12 rigid foam board.



1. 1/2 in. Plywood Sheathing
2. 2 in. Polyurethane Board (R-12)
3. Metal Sheathing
4. Batt R-13
5. Metal Sheathing/Finish

TABLE 9. Energy summary by energy type: LEED table.

	Proposed Building		Budget Building		Proposed/Budget	
	Energy (Mbtu/yr)	Cost ($/yr)	Energy (Mbtu/yr)	Cost ($/yr)	Energy (%)	Cost (%)
Electricity	542.1	15,141	660.5	18,448	17.93	17.93
Natural gas	489.8	3,914	855.5	6,835	42.75	42.75
Other fossil fuel	NA	NA	NA	NA	NA	NA
District steam	NA	NA	NA	NA	NA	NA
Total nonsolar	NA	NA	NA	NA	NA	NA
Solar or site recovered	NA	NA	NA	NA	NA	NA
Total including solar	1031.90	19,054	1516.00	25,283	31.93	24.64

between 22.51% and 27.5%, this case study design received three out of 10 Optimize Energy Performance points.

Electricity cost was reduced from $18,448 to $15,141 for a 17% cost reduction. Natural gas cost was reduced from $6,835 to $3,914 for a 43% cost reduction.

Before the results are presented in detail, a "check calculation" or hand calculation and an Energy Use Intensity comparison with other analyses or buildings offers a brief check to assure the analyst that the results are "on track." Table 10 is such a check calculation.

Table 10 shows that the simulation agrees with the hand calculation in some cases, as in total annual lighting, and disagrees in savings due to daylighting, for example. Table 11 shows various building EUIs for comparison with the baseline and the proposed. This provides another reference to determine accuracy of the simulation.

Table 11 shows that the studies simulations are low compared to all other estimates and compared to Pennsylvania's Department of Environmental Protection, Cambria office (DEP)[6], an actual building energy measurement. The DEP electrical consumption is low compared to the national average for office buildings, and high compared to those compliant with the Seattle Energy Code.

3.1.2 Baseline and Proposed Building Comparison. Table 12 provides a comparison of the simulation inputs for the two simulations. The proposed

TABLE 10. Check calculation of results.

	Hand Calculation		Simulation	
	No Daylight	Daylight	Baseline (no daylight)	Proposed (with daylight)
Total annual lighting energy (kWh)	69,996	56,986	73,343	49,366
Annual lighting energy EUI (kWh/sf)	2.80	1.68	2.93	1.97
Annual lighting energy EUI (kBtu/sf)	9.55	5.73	10.00	6.73
Total perimeter lighting energy (kWh)	32,525	13,010	34,080	10,103
Total perimeter lighting energy (kWh/sf)	2.80	1.68	2.93	0.87
Perimeter light energy savings due to daylighting (kWh)		13,010		23,977
Perimeter light energy savings due to daylighting (%)		40%		70.35%
Lighting power total area (kBtu/h)	85.32	69.46	89.40	60.17
Lighting power total area—EUI (Btu/h/sf)	3.41	2.78	3.58	2.41
Portion of cooling load due to lighting (%)	9.95%	5.97%	20.07%	14.80%
Reduction of perimeter cooling due to daylighting (kWh)		13,010		3,107
Cooling reduction due to daylighting (%)		40%		20.62%

TABLE 11. Energy use intensity comparisons.[6,7,8,9]

	Total Energy EUI (site) (kbtu/sf)	Electricity EUI (kBtu/sf)	Electricity EUI (kWh/sf)	Cost EUI ($/sf)
Baseline simulation	60.6	26.4	7.7	1.01
Proposed simulation	41.3	21.7	6.4	0.76
D.E.P, Cambria Office[6]	NA	42.0	12.3	0.82
DOE Determination Notice for 1999 ASHRAE 90.1 office buildings	50.9	44.6	13.0	1.09
Seattle Energy Code	35.6	30.3	8.8	
National average for office bldgs. between 25,001 and 50,000 sf	77.6		12.2	1.20
National average for all office bldgs.	92.9		17.3	1.71

building ECMs included triple pane, low-e, with Argon gas fill windows verses double pane air fill for the baseline. All of this contributed to the proposed building's low U-factor of 0.18. The proposed building had a higher SHGC and shading. The proposed building had more insulation in the roof and walls, and daylighting was implemented. Electric costs were reduced by 18%. Heating costs were reduced by 43%. The EUI (Energy Use Intensity) cost of the Proposed building was $0.8 $/sf as compared to the Baseline of $1.0/sf. The electricity EUI of the Proposed building was 6.4kWh/sf while for the baseline it was 7.7 kWh/sf. Total energy EUI of the Proposed building was 41.3 kBtu/sf while for the baseline it was 60.6 kBtu/sf.

TABLE 12. Inputs of components and strategies for the baseline and the proposed building simulation with EUI comparison.

	Baseline Building	Proposed Building
Window		
Glass Code	2447	3623
Glass type	Double pane Ref-C Clear-H, 1/4 inch pane	Triple Low-e (e2=e5=.1), Clear
Frame	Alum.	Alum.
Gap	1/2 inch, air	1/2 inch, Argon
WWR	45%	45%
U-factor (operable, NFRC*)	0.47	0.18
SHGC (all)	0.26	0.47
VT	0.2	0.66
Opaque		
Roof insulation	R-15	R-25
Above grade wall insulation	R-13	R-25
Strategies		
Daylighting	No	Yes
Shading	No	Yes
Electricity EUI (kWh/sf)	7.7	6.4
Cost EUI ($/sf)	1.0	0.8

*National Fenestration Rating Council.

3.1.3 Analysis of Results

3.1.3.1 End Uses. The original purpose of the study was to reduce the total energy cost of the proposed building from the baseline. The total cost is made up of individual end uses which are caused by loads. It is interesting, therefore, to look at a comparison of the baseline and the proposed building end uses and loads to see if they were reduced and, if so, by how much. Table 14, a variation of a LEED 2.1 table, compares annual end uses of the baseline and the proposed building, as well as the percent change.

Tables 13 and 14 show that energy costs were reduced from the baseline for all end uses. The last two columns of Table 14 display the end use comparison, first in energy, then in energy cost. Reductions by cost of end use is displayed in Figure 25.

Lighting was reduced from almost $7,000 to $4,000, a 33% reduction; heating was reduced from $6,500 to $3,600, a 45% reduction; and cooling was reduced from $3,000 to $2,800, a 10% reduction. Figure 26 displays the percentage reductions.

TABLE 13. Percentage reduction between baseline and proposed building by end use, energy type, energy, and cost.

	Lighting	Task lights	Misc equip	Heating	Cooling	Heat Rejection	Pump & Aux	Vent Fans	Refrige	Heat Pump	Hot Water	External	Total
Baseline													
							(Mbtu)						
Electric	250.3	0	166	0	110.7	0	43.5	90	0	0	0	0	660.5
Natural gas	0	0	0	819.9	0	0	0	0	0	0	35.6	0	855.5
Total	250.3	0	166	819.9	110.7	0	43.5	90	0	0	35.6	0	1516
							($)						
Electric cost	6,991	0	4,636	0	3,092	0	1,215	2,514	0	0	0	0	18,448
Natural gas cost	0	0	0	6,551	0	0	0	0	0	0	284	0	6,835
Annual energy cost	6,991	0	4,636	6,551	3,092	0	1,215	2,514	0	0	284	0	25,283
Proposed building													
							(Mbtu)						
Electric	168.5	0	166	0	100.1	0	40.9	66.7	0	0	0	0	542.1
Natural gas	0	0	0	454.2	0	0	0	0	0	0	35.6	0	489.8
Total	168.5	0	166	454.2	100.1	0	40.9	66.7	0	0	35.6	0	1031.9
							($)						
Electric cost	4,706	0	4,636	0	2,796	0	1,142	1,863	0	0	0	0	15,141
Natural gas cost	0	0	0	3,629	0	0	0	0	0	0	284	0	3,914
Annual energy cost	4,706	0	4,636	3,629	2,796	0	1,142	1,863	0	0	284	0	19,054
Baseline-proposed comparison													
Percent reduction, electric	–33%	NA	0%	NA	–10%	NA	–6%	–26%	NA	NA	NA	NA	–18%
Percent reduction, natural gas	NA	NA	NA	–45%	NA	NA	NA	NA	NA	NA	0%	NA	–43%
Percent reduction, total	–33%	NA	0%	–45%	–10%	NA	–6%	–26%	NA	NA	0%	NA	–24.64%

TABLE 14. Annual end use comparison between the baseline and the proposed building using ASHRAE 90.1 table.

		Proposed Building		Budget Building			
End Use	Energy Type	Energy (Mbtu/yr)	Energy ($)	Energy (Mbtu/yr)	Energy ($)	Proposed/ Budget Energy (%)	Proposed/ Budget Cost (%)
Lighting	electric	169	4,706	250	6,991	32.40	32.68
Space cooling	electric	100	2,796	111	3,092	9.91	9.57
Space heating	natural gas	254	3,629	820	6,551	69.02	44.60
Pumps	electric	41	1,142	44	1,215	6.82	5.98
Fans	electric	67	1,863	90	2,514	25.56	25.89
Hot water	electric	36	284	36	284	0.00	0.00
Equipment	electric	166	4,636	166	4,636	0.00	0.00

FIGURE 25. Total energy cost by end use.

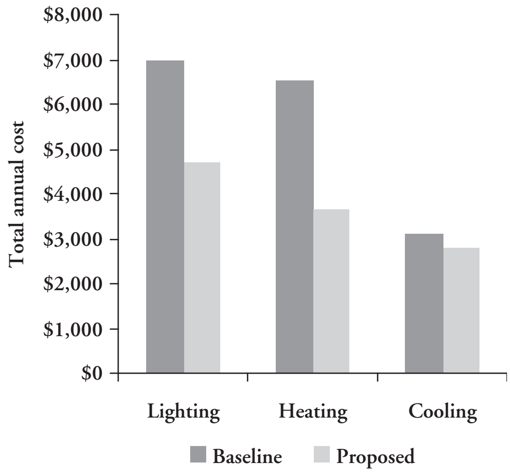
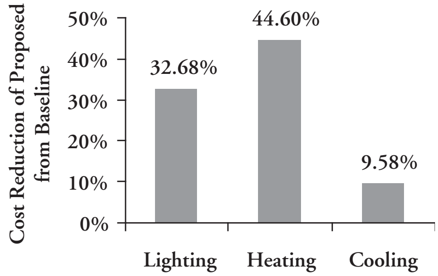


FIGURE 26. Percent cost reduction by end use.



When viewed by percent cost reduction, all three end uses were reduced: heating reduction was reduced by the most, then lighting, and finally cooling.

3.1.3.2 Loads. Various components contributed to the reduction of heating and cooling loads. Figure 27 shows a comparison of the heating loads between the baseline and the proposed building.

Figure 27 shows that window conductance was reduced from 293 MBtu/year to 109, over one-half. This can most likely be attributed to the proposed building window's low U-factor of 0.18 compared to the baseline's U-factor of 0.47. The winter solar heat gain of the proposed building stayed the same, which was against the prediction that the desired heat gain would be higher in the proposed building. The heat that was gained from the proposed building's electric lighting was less than half of the baseline's electric lighting, from 53 to 22 MBtu/year. This can be attributed to the implementation of daylighting in the proposed building. Heat loss through both the roof and walls was reduced by about one-third. This can be attributed to higher insulation levels by the proposed building. Figure 28 shows a comparison of the cooling loads.

The cooling load from window solar gain increased from 85 to 123 MBtu/year. This might have been expected from the higher SHGC; however, it was expected that the shading would have reduced

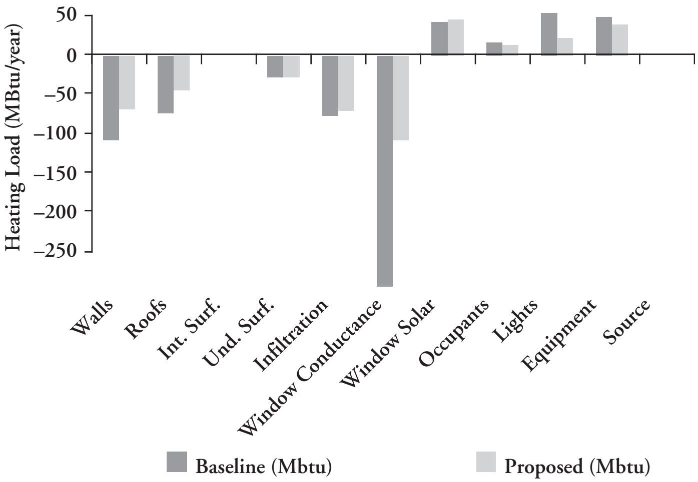
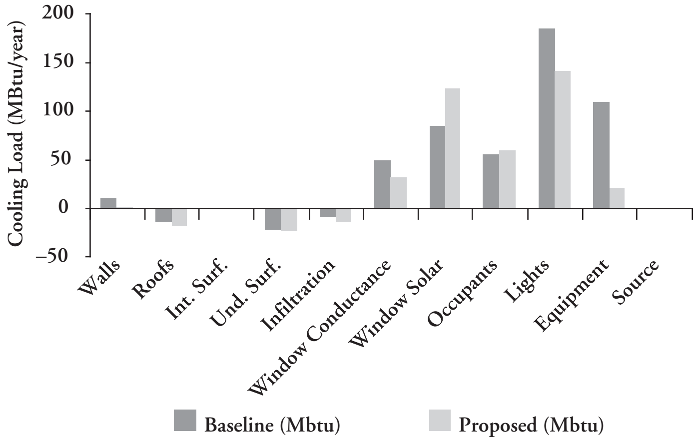


FIGURE 27. Heating load comparison between baseline and proposed building.

FIGURE 28. Cooling load comparison between baseline and proposed building.



this impact. The cooling load from lighting decreased by around one-fifth, from 184 to 142 MBtu/year. This can be attributed to daylight implementation in the proposed building.

3.1.3.3 Isolated Strategies. Additionally, it is interesting to determine how much energy reduction can be attributed to each strategy, when that was the only change and everything else was held constant. This was accomplished through separate simulations not described above. Table 15 shows each of the ECMs isolated; that is, using this strategy by itself with no other changes from the baseline.

It can be seen that only adding high performance windows with shading achieves one point, and that implementing daylighting, or adding insulation, or increasing the U-factor of the window, each achieves zero points when altered in isolation.

TABLE 15. The percent reduction and number of LEED points using this strategy.

	Percent Reduction	LEED OEP Points
Daylight	7.26%	0 Points
U-factor = 0.2	9.70%	0 Points
Window 3664	9.29%	0 Points
Window 3623 w/shade	13.47%	1 Point
Roof R = 25	2.26%	0 Points
Wall R = 25	2.37%	0 Points

4. DISCUSSION

4.1 The Value of This Study

The procedure and its outcome of how to gain LEED OEP credit by increasing energy efficiency in building design, especially through computer simulation, has not been well studied or documented. Therefore, the value of this research is two-fold: it offers designers a process that they can follow when designing their own high performance building; also it gives them an idea as to how many LEED OEP 2.1 points may be attained when using basic ECMs in this process. The importance of demonstrating this process is that it will encourage designers who may not have known how to approach an energy study to do so. Such energy planning will improve building designs which will conserve energy, protect our environment and resources for future generations.

The value of this research will remain regardless of when or how LEED requirements may change. For example, LEED 2.1 uses the ECB method for acquiring points, but the ECB method will become obsolete as LEED moves to 2.2 and ASHRAE 90.1's new Performance Rating Method. Although the criteria and requirements will change, the process will remain essentially the same.

This energy reduction process will also hold for any different certification, standard, or unit of measure, as needed. For example, if the energy company or tax credits provide incentives for energy reduction, in say, kWh or Btu, the process will remain the same. The parametric study would simply focus on kWh or Btu instead of cost.

4.2 Future Research

Since this research focused primarily on the process, the results of this study leave a number of questions unaddressed. It is suggested, therefore, that future research include, for example, a more comprehensive energy analysis that should differentiate energy impact by each façade and how each facade can be optimized. It should also include a more extensive load study, such as one that reviews monthly loads and peak demands. Each of these steps would be important in a complete simulation study.

5. NOTES

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4. Selkowitz et al. (2004)
5. Ecotect (2006)
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9. U.S. Department of Energy (2003)
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11. LEED (2003)

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