Appendix B: Energy and Construction Cost Estimates[1]

This appendix describes the energy modeling used in the analysis presented in Section 2.2 of this document. The analysis showed that the combination of energy-savings features added to the prototype building had a savings-to-investment ratio of nearly 1.5 and an adjusted internal rate of return of almost 5%, which makes a compelling business case for sustainability.

Figure B-1 illustrates the main steps of the modeling process. As the figure shows, the modeling effort began with a characterization of a base-case building. This building, intended to represent a typical new Federal office building, was the basis against which the sustainable building was compared. The base-case building's energy use was then estimated using a building energy simulation model, DOE-2.1E. The base-case characterization and model assumptions are documented in Section B.1 of this appendix.

The sustainable building was defined in terms of a number of improvements made to the base-case building. A set of potential improvements was developed and simulated in another energy simulation model, ENERGY-10, which optimized for energy and lifecycle cost savings. This simulation provided information that allowed a final set of improvement options to be selected based on maximum energy and lifecycle cost savings. These options defined the sustainable building. This process is described in Section B.2 of this appendix.

The sustainable building was then simulated in DOE-2.1E to obtain energy-use estimates. These were compared with the energy-use estimates of the base-case building, and estimated energy savings and the associated incremental costs were calculated. The simulation of the sustainable building is described in Section B.3, and the results of the energy-savings and cost calculations are described in Section B.4. Section B.5 explains some of the differences between DOE-2.1E and ENERGY-10.

B.1 Base-Case Building Characterization

B.1.1 Energy Design Standard

The study used the American Society of Heating, Refrigerating, and Air Conditioning Engineering (ASHRAE) standard 90.1-1999 as the energy design standard or code for the base-case building and ASHRAE 90.1-1999, Table A-13, to implement the base-case building envelope parameters. The HVAC equipment in the base case was modeled at the minimum efficiency levels according to ASHRAE 90.1-1999, Tables 6.2.1B and 6.2.1E. The supply fan energy was modeled separately by breaking down the energy-efficiency ratio (EER) and coefficient of performance (COP) into its components. For some building characteristics not specified in ASHRAE 90.1, such as the building operation schedules and HVAC system types, assumptions were made based on data from several sources including the "Commercial Buildings Energy Consumption Survey" (Energy Information Administration 1995), the Proposed Appendix G to ASHRAE 90.1-2001, and general engineering practices.

B.1.2 Construction Cost Estimating for the Base-Case Building Design

The purpose of the construction cost estimate for the overall base-case building was to set a reasonable order-of-magnitude cost for use in the lifecycle cost calculations. The estimating method was parametric –

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[1] This appendix was written by D. Winiarski, S. Shankle, J. Hail, and B. Liu, Pacific Northwest National Laboratory, and A. Walker, National Renewable Energy Laboratory.

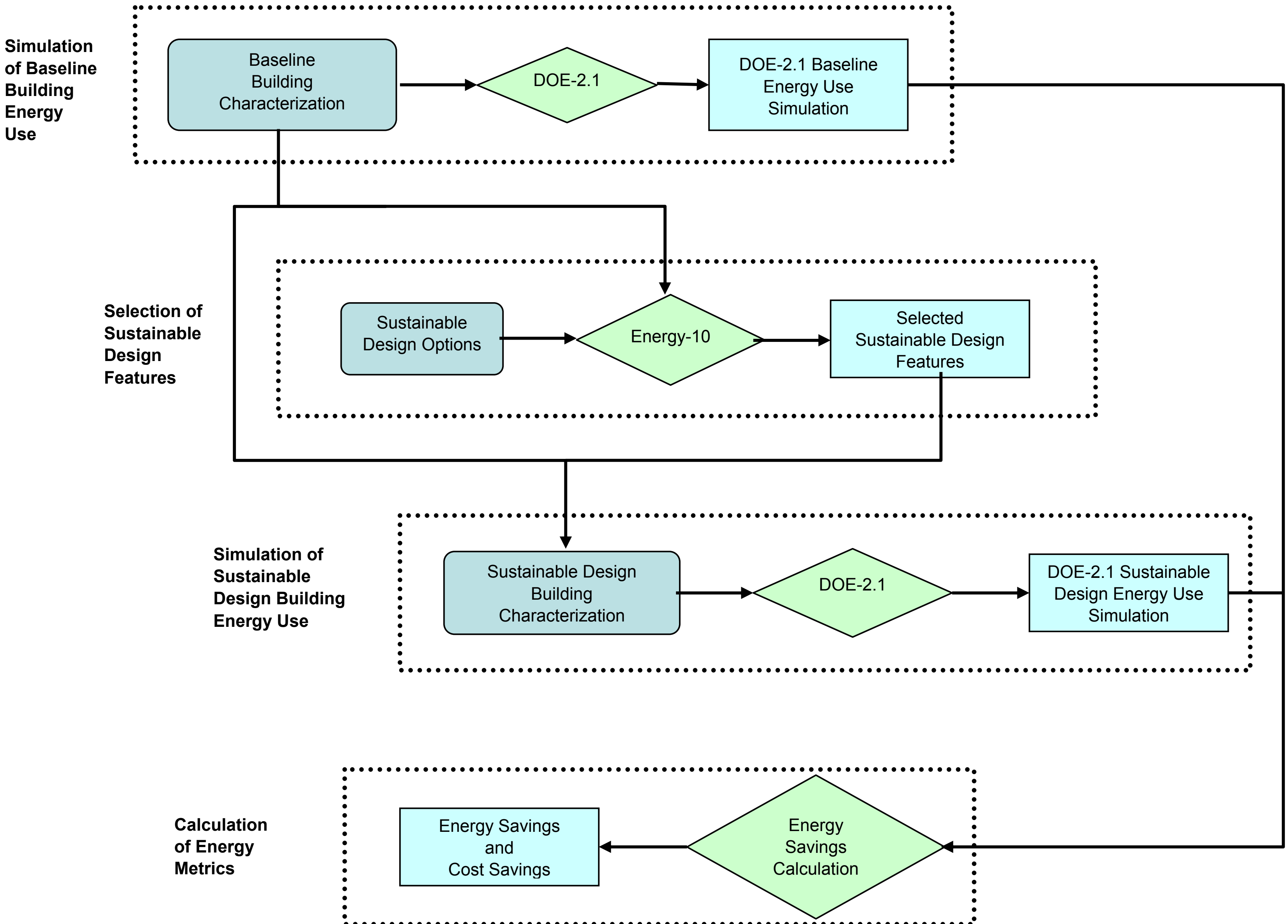

Figure B-1. Energy Simulation Flow Diagram

using simple inputs such as the square feet of the building and subareas and the generic type of structural system. The parametric tool was the Commercial Construction Knowledgebase module within "Timberline Precision Estimating – Extended Edition, Version 6.2."[2] Timberline uses RS Means cost data and adjusts costs to Baltimore, Maryland. The Timberline parametric modules allow some specific inputs for a building such as specifying gas or electric heat. This study specified some of those inputs to approximate the natural gas heating for the base-case building but otherwise relied on the modules' assumptions.

B.1.3 Building Occupancy Type and Size

The study focused on an office-building model. According to the U.S. General Services Administration (GSA), offices are the second largest square-footage category (after housing) and the largest building cost category. The study selected a building size of 20,000 ft^2 because the average size of the office buildings in GSA's inventory is 20,979 ft^2.

B.1.4 Building Location

The study selected Baltimore, Maryland, as the location for the DOE-2.1e and construction cost estimating because it represented a large city with a substantial Federal construction market and a moderate East Coast climate. Because one purpose of this study is to help guide new Federal construction projects, the study reviewed FY 2002 capital appropriations and found that roughly two-thirds of the appropriations were slated for states in the southern half of the continental United States. The appropriations for California appeared to be the highest of any individual state. However, when grouping states into informal regional climate zones, the states in the "moderate eastern climate" zone had significantly more appropriations than California. The selection of an appropriate average climate was also based on Pacific Northwest National Laboratory's (PNNL's) experience gained through developing ASHRAE 90.1-1999 and Federal Energy Code (10 CFR 434) standards.

B.1.5 Energy Rates

The study used energy cost rates for Baltimore, Maryland, as shown in Table B-1. The rates were developed from the local utility, Baltimore Gas and Electric Company (BGE). Baltimore is a deregulated utility market and BGE's rate structure has many options to select from despite a few frozen tariffs. Apparently, GSA has a contract with BGE with very different schedules – see http://hydra.gsa.gov/pbs/xu/areawides/word/bgemod.doc. For simplicity, this study developed an average or blended rate based on the information provided through BGE's website (the current link is http://www.bge.com/cmp/CDA/section/0,1668,603,00.html). This study used $0.077 per kilowatt-hour (kWh) and $0.692 per therm based on review of BGE rate schedules.

Table B-1. Energy Rates for the Base-Case Building

Energy Type	Rate
Natural gas ($/therm)	$0.692
Electricity ($/kWh)	$0.077

[2] http://www.timberline.com/products/estimating/commercial_construction_knowledgebase.htm.

Derivation of Blended Electricity Rate

Commercial buildings such as the one used in the study's base-case building are likely to be on a general service or a small general service rate schedule. Neither schedule is a typical demand schedule. The general service schedule has two complex options for the energy demand charge averaging summer and non-summer costs. The small general service schedule does not have a standard demand rate but uses peak and offpeak rates. The base simple general service schedule option would be as follows:

Base rate	$11.50/month
Energy charge	
October through May	$0.03749/kWh
June through Sept.	$0.05383/kWh
Transmission charge	$0.00298/kWh
Delivery service charge	$0.02250/kWh
Competitive transmission charge	$0.00576/kWh

The above rates can be simplified to the following schedule for the study's base-case building:

Base rate	$11.50/month
Energy charge	
October through May	$0.06873/kWh
June through Sept.	$0.08507/kWh

Derivation of Blended Gas Rate

The general service gas schedules are located at http://www.bge.com/CDA/Files/Bsch_c.doc; however, this schedule appears to cover delivery cost but not the energy cost:

Customer charge	$27.00 /month
Delivery price	
First 10,000 therms	$0.1724/therm
All remaining therms	$0.0936/therm

BGE also charges separately for automated/daily metering. A complete rate was obtained by BGE customer service, who reported that costs varied between the three major suppliers in the area and from year to year. However, the average costs based on the last two years available are shown in Table B-2.

Table B-2. Average BGE Rate (based on the last two years)

Month	$/Therm	Month	$/Therm
January	$0.570	July	$0.502
February	$0.597	August	$0.458
March	$0.504	September	$0.461
April	$0.517	October	$0.498
May	$0.495	November	$0.476
June	$0.500	December	$0.562

B.1.6 Base-Case Building Design Assumptions

Table B-3 summarizes the key input assumptions used for the base-case building design in the DOE-2.1E models.

Table B-3. Base-Case Assumptions Used in the DOE-2.1E Models

Characteristic	Base-Case Assumptions
General	
Building type	Office
Location	Baltimore, Maryland
Gross area	20,164 ft^2
Operating hours	8am - 5pm Monday-Friday
Utility rates	
Electric energy rate	Base rate: $11.50/month
	Energy charge: $0.077/kWh
Natural gas price ($/therm)	Base rate: $27.0/month
	Energy charge: $0.692/therm
Architectural features	
Configuration/shape	
Aspect ratio	2:1
Perimeter zone depth	15 ft
Number of floors	2
Window area	20% window-to-wall ratio
Floor-to-ceiling height	9 ft
Floor-to-floor height	13 ft
Exterior walls	
Wall type	4" Face brick façade on 16" on-center metal framing
Opaque wall U-value	0.124
Wall insulation	R-13 cavity insulation
Roof	
Roof type	Builtup roofing with concrete deck
Solar absorptance	0.7 (medium dark)
Roof U-value	0.063 Btu/hr-ft^2-°F
Roof insulation	R-15 continuous insulation
Floor structure	
Floor type	Concrete
Floor insulation	R-5.4 perimeter insulation*
Fenestration/windows	
Window type	Aluminum frames with thermal beaks and double panes
Total U-value	0.57 Btu/hr-ft^2-°F
Shading coefficient	0.45

Characteristic	Base-Case Assumptions
Visual transmittance	0.52
Window shading/overhangs	None
Building internal loads	
Occupancy	
Number of occupants	96
Occupancy schedule	8am - 5pm Monday-Friday
Lighting	
Fixture type	T-8 with electronic ballasts
Peak lighting power density	1.38 watts/ft² (net building wattage from ASHRAE's space by space analysis)
Lighting schedule	7am - 6pm Monday-Friday
Occupancy sensors	None
Daylighting	None
Office equipment	
Equipment schedule	7am - 6pm Monday-Friday
Peak load density	0.72 watts /ft²
HVAC system	
HVAC system type	Package rooftop unit; constant-air-volume with gas furnace
Number of HVAC units	Five units to serve five HVAC thermal zones
Space temperature setpoint	75°F coling/70°F heating
Space setback/setup	80°F cooling/65°F heating
Cooling equipment efficiency	10.1 EER
Outside air supply	20 cubic feet/minute (cfm) per person, 17% of supply air cfm
Heating furnace efficiency	80%
Ventilation control mode	Constant during occupied periods, cycle during unoccupied periods
Economizer	None
Design supply air	Minimum 0.5 cfm/ft²
Air-to-air energy recovery ventilation	None
Fan total static pressure	2.0 in. total, 1.0 in. related to ductwork system
Fan schedule	6am - 6pm Monday-Friday with night cycle on/off
Fan motor efficiency	85%
Fan efficiency	65%
Service/domestic/potable water heating	
Hot water fuel type	Natural gas
Thermal efficiency	80%
Supply temperature	120
Hot water consumption	0.9 gallons per day/person
* Exceeds ASHRAE 90.1-1999.	

B.2 Selection of Sustainable Design Features

The National Renewable Energy Laboratory (NREL) performed a screening analysis of potential sustainable design options using ENERGY-10, a PC-based software design tool developed by NREL. The rationale for using ENERGY-10 in this study is that with the new lifecycle costing capabilities of Version 1.6, it is quick and easy to search possible solutions and narrow the optimal combination of measures for further analysis with the more detailed DOE-2.1E model (see section B.5 for a brief discussion of the differences between ENERGY-10 and DOE 2.1E). ENERGY-10 was used to initially assess and optimize a number of design options:

- Changes in the installed lighting power density
- Addition of daylighting controls
- Changes in building aspect ratio
- Skylighting in the building core
- Changes in fenestration area by orientation for daylighting, passive solar heating, and cooling load avoidance
- Changes in building insulation levels.

The NREL screening analysis, documented in this section, was used to characterize a suite of measures that maximizes energy savings and reduces the lifecycle cost of the sustainable building. However, many of the details of the implementation of the sustainable design options differ between their characterization in the NREL screening analysis and the final DOE-2.1E simulation. This section documents the screening analysis, while Section B.4 documents the final sustainable building simulation.

B.2.1 Aspect Ratio

One feature varied in the analysis was the aspect ratio[3] of the building (see Figures B-2 and B-3). For a building of 20,000 ft^2 and two stories, an aspect ratio of less than 6 requires a core zone, whereas an aspect ratio from 6 to 12 could be a double-loaded corridor with no core zone. For the base case, a window-to-wall-area ratio of 0.20 was maintained for all four sides. For the energy-efficient case (designated the "EE" case in the figures), the south window-to-wall-area ratio was as follows: south, 0.38; east, 0.07; west, 0.05; and north, 0.11.

Energy use was minimized by an aspect ratio of 1.5 for both the base and sustainable cases.[4] However, for the sustainable design, the benefits of passive solar heating and daylighting compensated for the increased surface area, and energy use increased only slightly with increasing aspect ratio. However, increasing aspect ratio increased first costs substantially because of the additional materials to accommodate the increased surface area for both the base and sustainable design cases.

[3] The ratio of the longer side of the building to the shorter side.

[4] In DOE-2.1e aspect ratio was 2.0 in both the base and sustainable cases. This may have resulted in a slightly higher energy use and capital cost than the ENERGY-10 simulation, but differences were not deemed significant enough to warrant changing the model setup.

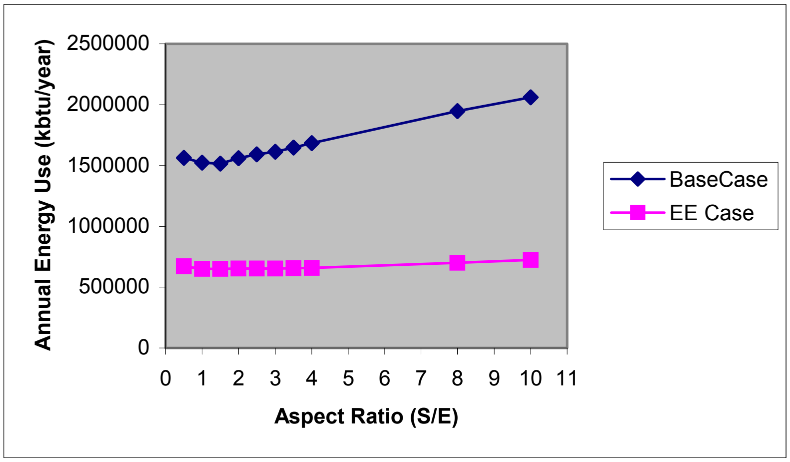

Figure B-2. Annual Energy Use (kBtu/yr) versus Aspect Ratio (south/east)

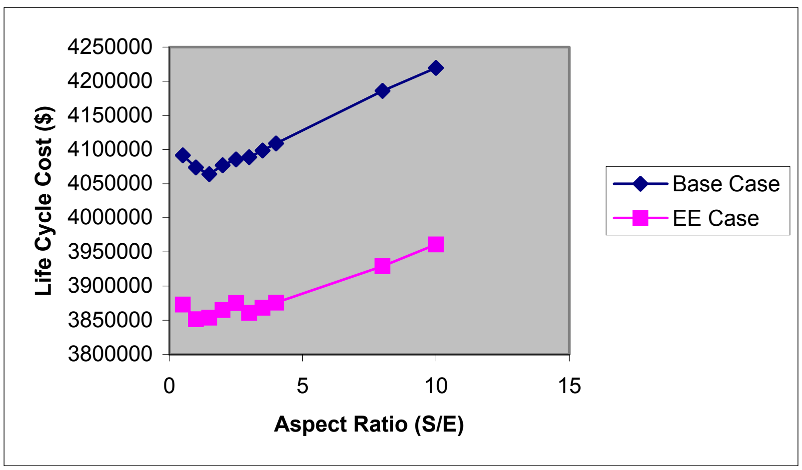

Figure B-3. Lifecycle Cost ($) versus Aspect Ratio (south/east)

B.2.2 Energy Conservation Measures

Eight energy conservation measures (ECMs) were selected to define the sustainable building: daylighting, improved windows, improved lighting efficiency, window shading, improved insulation, passive solar heating, economizer cycle, and high-efficiency equipment. Each measure and its cost are briefly described below.

ECM 1 – Daylighting

Ten lighting zones were set up, one facing each direction (i.e., east , south, west, and north) on each floor, a core zone on the top floor with 12 skylights, and a 4592 ft^2 core zone on the first floor with no daylighting. Continuous dimming controls maintain a 50-foot-candle lighting level. The cost of this measure was $188/ lighting zone for dimming sensor and controls and $0.75/ ft^2 of floor space to cover the cost of upgrading to dimming ballasts. Therefore, the total cost of daylighting controls was $13,371.

Window dimensions were optimized and costed in the passive solar heating ECM (described below), including the effects of daylight savings. The 4592-ft^2 core zone on the second floor is daylit only by skylights. The ratio of skylight area to zone roof area was varied from 0.02 to 0.08, and annual energy use was minimized by an area ratio of 0.06. The cost of skylights was estimated at $90/$ft^2$, which is significantly more expensive than wall windows. Figures B-4 and B-5 show the annual energy use and lifecycle costs, respectively, as functions of skylight to zone roof area.

ECM 2 – Improved Windows

Double-pane windows with U=0.67 Btu/hr-ft^2-°F were replaced with low-emissivity windows with U=0.31 Btu/hr-ft^2-°F; the solar heat gain coefficient remains at 0.39 for both, but the premium

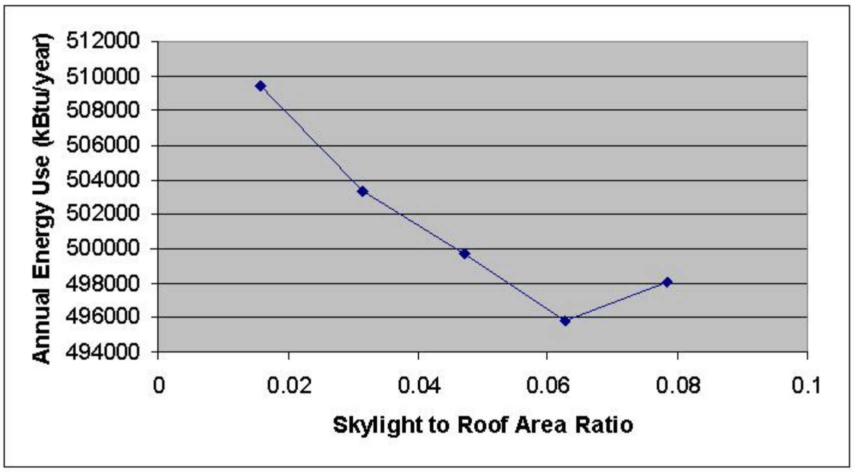

Figure B-4. Annual Energy Use (kBtu/yr) as a Function of Skylight to Zone Roof Area Ratio

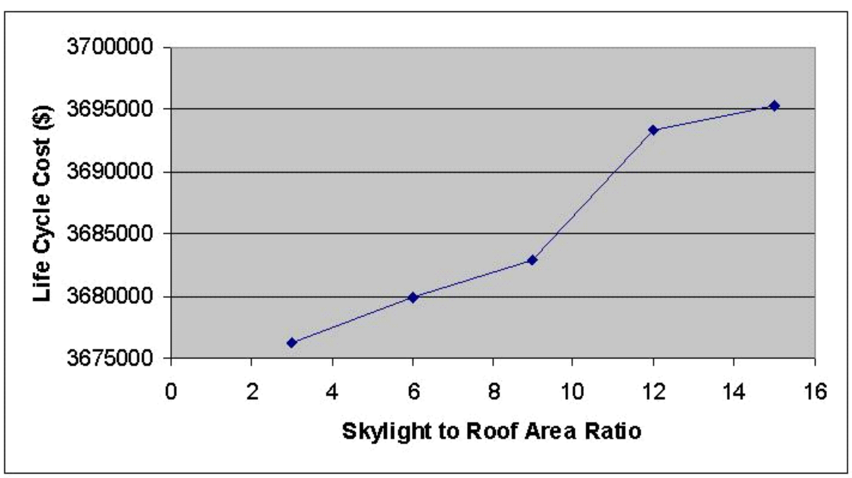

Figure B-5. Lifecycle Cost ($) as a Function of Skylight-to-Zone-Roof-Area Ratio

glazing uses a selective surface with visible transmittance of 0.7. The cost of the premium glazing was $25 ($22 to $28/ft^2) for item 08810 3004000 in RS Means (2002) (super-efficient glazing, triple-glazed with low-e glass, argon filled U=0.26). The cost of standard glass was $22.50 for item 4600400 in RS Means (2002) (3/16 float, 5/8 thick unit, U=0.56) for a $2.50/ft^2 difference or $1.22/ft^2/R-value. Table B-4 lists the results of the glazing improvement.

Table B-4. Results of Glazing Improvement

	Base Case	Premium Glazing
Window construction	Buscase, U=0.67	4060 low-e al/b, U=0.31,etc.
Window total gross area (ft^2)	2,208	2,208
Windows (north/east/south/west:roof)	23/23/23/23:0	23/23/23/23:0
Glazing name	Buscase, U=0.56	Double low-e selective, U=0.26
Energy use (kBtu)	904,917	820,385
Energy cost ($)	16,058	15,633
Construction costs	3,146,828	3,149,669
Lifecycle cost	3,815,530	3,805,379

ECM 3 – Improved Lighting Efficiency

The lighting power density was reduced from 1.38 to 1.0 W/ft^2 by architectural design of the lighting system and premium efficiency equipment. The cost was estimated at $0.36/ft^2 or $7259.

ECM 4 – Window Shading

Overhangs provide shade over the south-facing windows. The cost was estimated at $12.37/ft of overhang projection per linear foot of shaded window. Only windows facing east, south, and west were supplied with overhangs for a linear window length of 360 ft. Overhang projection was varied in the model from 0 to 4 ft, with a 3-ft projection minimizing annual energy use. The cost of the 3-ft projection was $13,359. Figures B-6 and B-7 show the annual energy use and lifecycle costs, respectively, as a function of overhang projection.

ECM 5 – Improved Insulation

Six wall cross-sections were considered to achieve different R-values: R-9, R-18, R-22, R-36, and R-50 and R-1000 (R-1000 was also considered just to provide a limiting case of the importance of insulation). While R-36 provides the lowest lifecycle cost, it is only slightly lower than R-18, so R-18 was adopted. Figure B-8 shows the net present value as a function of wall U-value (the inverse of the R-value).

The overall loss coefficient of the envelope was reduced from 3276 to 1556 Btu/hr-°F at a total cost of $18,868. (Upgrading to 6-in. steel frame walls with polyisocyanurate insulation added $0.05/unit R-value/ft^2 of wall area or $3943 for wall insulation; adding foam insulation to reduce the slab perimeter F-value from 0.35 to 0.20 Btu/hrft^2-°F cost $5/ft of perimeter or $8283 for foundation insulation; improving roof insulation added $0.03/unit R-value/ft^2 of roof area totaling $6505 for roof insulation; and adding premium doors cost $137.)

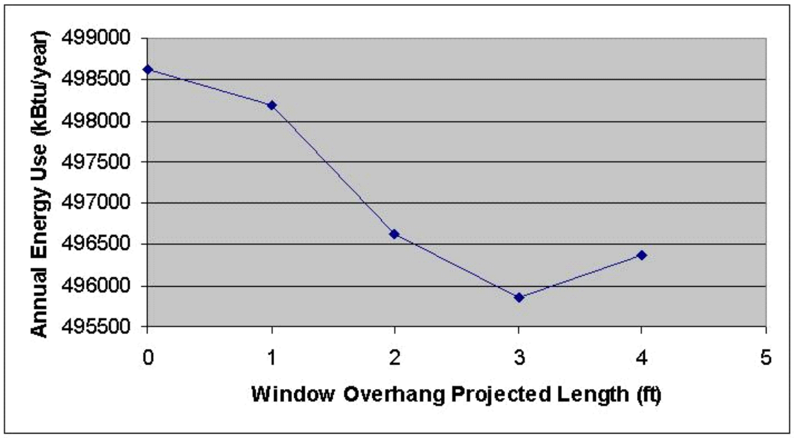

Figure B-6. Annual Energy Use (kBtu/yr) as a Function of Overhang Projection (ft)

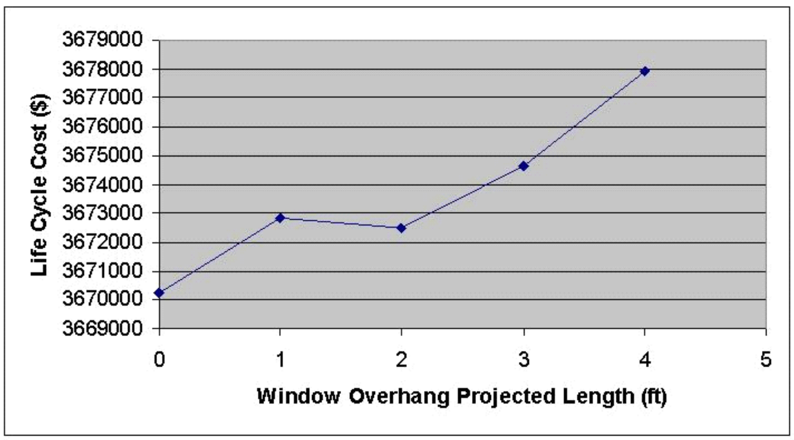

Figure B-7. Lifecycle Cost ($) as a Function of Overhang Projection (ft)

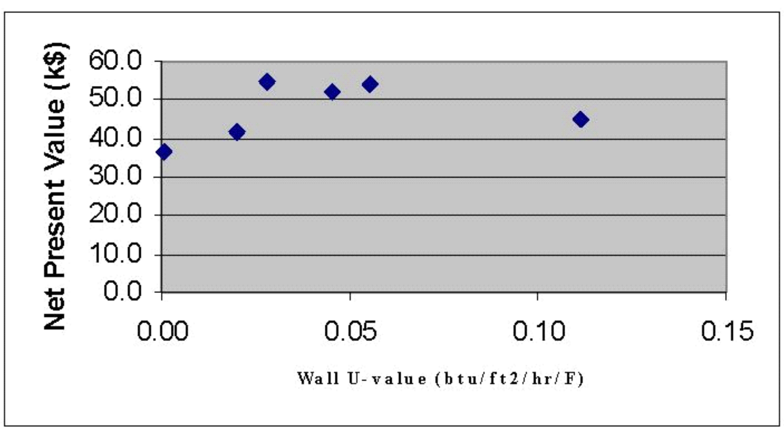

Figure B-8. Net Present Value (k$) as a Function of Wall U-Value

ECM 6 – Passive Solar Heating

The amount of glazing on the east, west, north, and south walls was varied to minimize annual energy use. The passive solar heating measure was implemented by changing from an even distribution of windows on all sides (20% window-to-wall-area ratio) to the following distribution:

- 0.15 on the north
- 0.10 on the east
- 0.10 on the west
- 0.30 on the south.

The total window area in the walls decreased from 2208 ft^2 to 2064 ft^2 (not including the 12 skylights in the daylighting measure). The cost was $25/$ft^2$ of window area for a total cost savings of $3600 over the base case. Figures B-9 through B-16 show the annual energy use and lifecycle costs as a function of the window-to-wall-area ratios for east, west, south, and north windows, respectively.

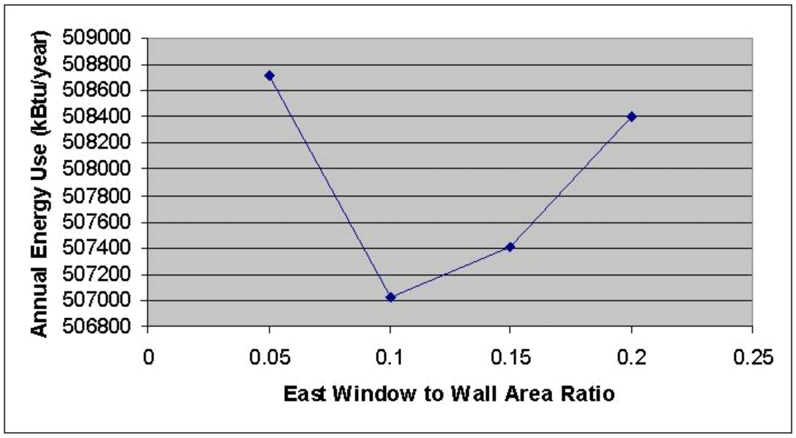

Figure B-9. Annual Energy Use (kBtu) as a Function of East Window-to-Wall-Area Ratio

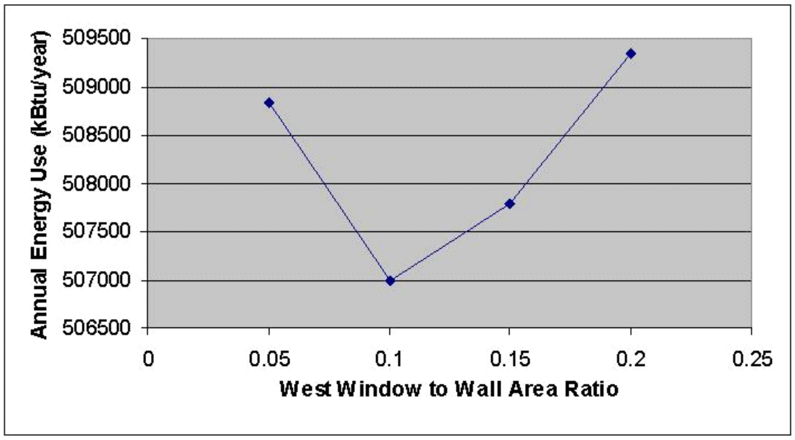

Figure B-10. Annual Energy Use (kBtu) as a Function of West Window-to-Wall-Area Ratio

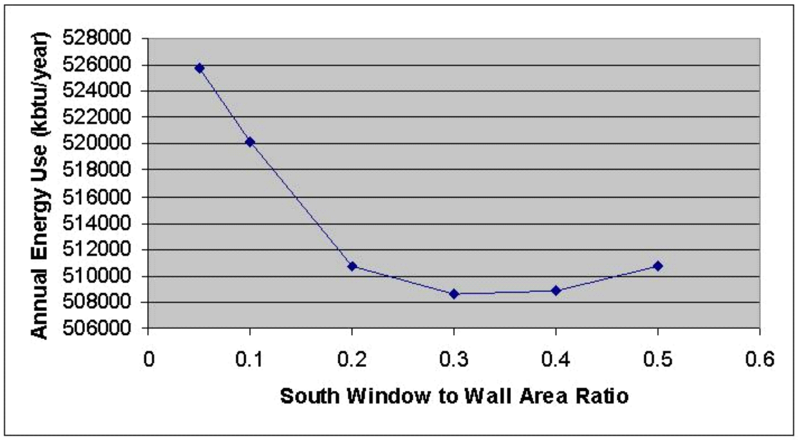

Figure B-11. Annual Energy Use (kBtu) as a Function of South Window-to-Wall-Area Ratio

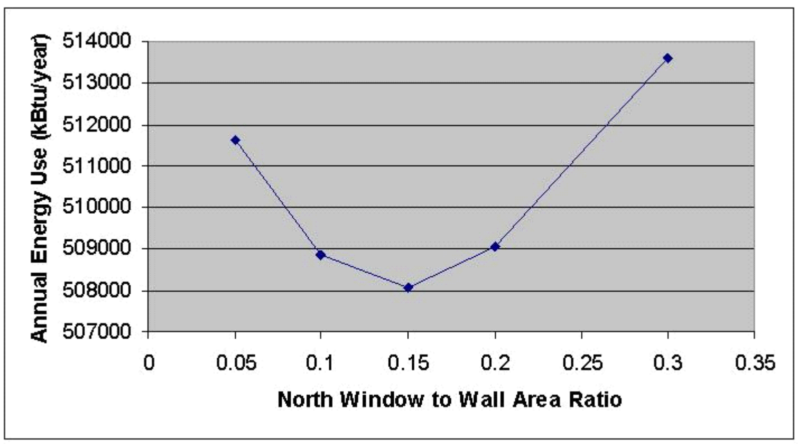

Figure B-12. Annual Energy Use (kBtu) as a Function of North Window-to-Wall-Area Ratio

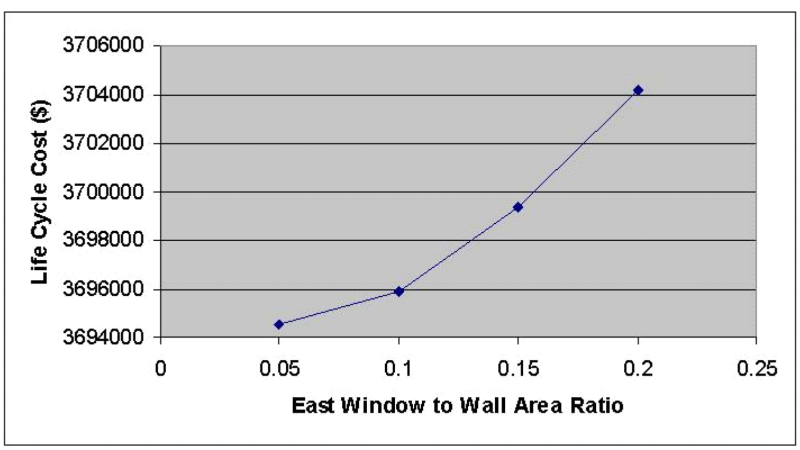

Figure B-13. Lifecycle Cost ($) as a Function of East Window-to-Wall-Area Ratio

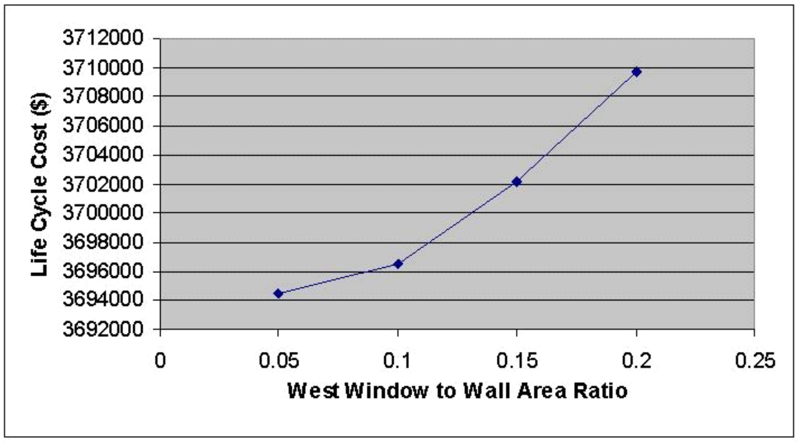

Figure B-14. Lifecycle Cost ($) as a Function of West Window-to-Wall-Area Ratio

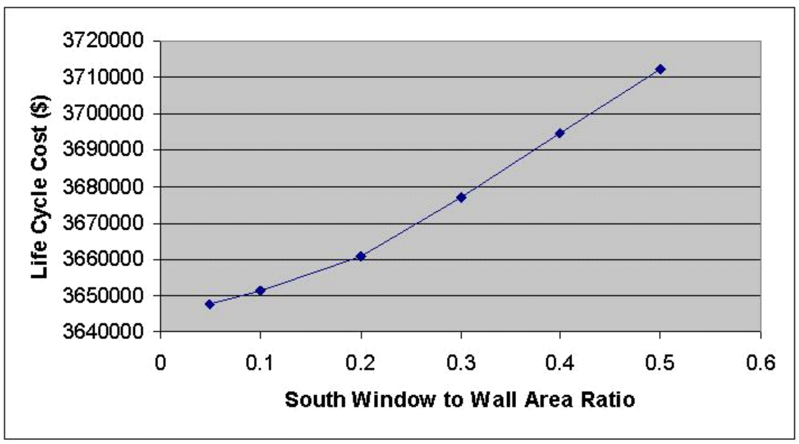

Figure B-15. Lifecycle Cost ($) as a Function of South Window-to-Wall-Area Ratio

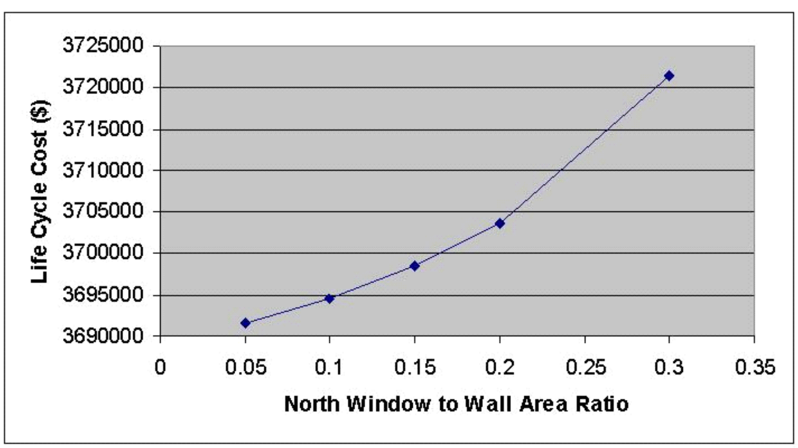

Figure B-16. Lifecycle Cost ($) as a Function of North Window-to-Wall-Area Ratio

ECM 7 – Economizer Cycle

An economizer was added with a fixed dry bulb temperature of 60°F. The cost was $0.25/ft^2 of floor area for a total cost of $5041.

ECM 8 – High-Efficiency Equipment

HVAC efficiency was improved by using larger ducts and more efficient equipment. Heating efficiency was raised from 80% to 90% at a cost of $1.00/unit of heating capacity in kBtu/hr per unit increase in efficiency. Cooling efficiency was raised from an EER of 10.1 to 13.0 at a cost of $5.00/unit of cooling capacity in kBtu/hr per unit of improvement in EER. The total cost of the mechanical equipment upgrades was therefore estimated to be $7006.

B.3 Simulation of the Energy Use of the Sustainable Building

The sustainable building was characterized by incorporating the information developed in the NREL screening analysis with the base-case building characterization. Figure B-17 lists the features incorporated in the sustainable building, and Table B-5 shows the sustainable building characterization.

The study developed construction and replacement cost estimates for the evaluated building energy features from several sources, including vendors and facility engineering staff (through personal communication), vendor websites, RS Means construction cost estimating books, and case studies and reports. Table B-6 summarizes the estimates and sources. The estimates are shown as the net incremental cost change (increase or decrease) to the base-case construction cost.

B.4 Results of the Energy Simulations

B.4.1 Energy Use and Energy Cost Estimates

Tables B-7 and B-8 show the energy use and energy cost by end use for both the base-case and the sustainable buildings. The tables show energy use and cost with and without plug loads. Although the model estimated energy consumption for plug loads and other miscellaneous office equipment, these were not included in the analysis of the percent energy reductions that could be achieved using various energy efficiency technologies. This is consistent with the practice within the Leadership in Energy and Environmental Design (LEED™) Rating System.

B.4.2 Lifecycle Cost Calculations

This study estimated the lifecycle cost or present value of the initial construction costs, the outyear replacement costs, and the annual energy costs over 25 years. Most replacement costs were based on the service life values in Table 27.3 in Marshall and Petersen (1995). This study did not evaluate the costs of annual recurring maintenance, the cost of nonrecurring or irregular repairs and maintenance, or the cost impacts on the environment and occupants' productivity.

The lifecycle cost tool was an Excel spreadsheet workbook titled, "User-Friendly Building Life-Cycle Cost Analysis" (M.S. Addison and Associates 2002). The developers say the workbook is compliant with National Institute of Standards and Technology Handbook lifecycle costing procedures and offer the workbook free of charge at http://www.doe2.com/. The study used the following key inputs for the lifecycle cost workbook:

• DOE/FEMP fiscal year	2002
• Real discount rate for this analysis	3.2%
• Number of analysis years	25
• DOE fuel price escalation region	3 (south)
• Analysis sector	2 (commercial).

Table B-9 shows the lifecycle cost calculations for the base-case and the sustainable buildings.

Lighting Measures

- **Increased daylighting.** Skylights were added, increasing daylight to the top floor.
- **Reduced lighting intensity.** Lighting power densities recommended by the Illuminating Engineering Society of North America and ASHRAE, as a proposed addenda to the 90.1 standard, were adopted. The lighting level was reduced from 40 to 35 footcandles in the office area, with some increase in task lighting.
- **Perimeter daylighting controls with dimmers.** Daylight sensors (six per floor) control stepped ballast controls so that electric lighting is dimmed when sufficient daylight exists. In the base case, no dimming of electric lighting occurs.

Envelope Measures

- **Window distribution.** The square footage of the windows was redistributed to optimize solar gain with heating and cooling costs. The optimized window-to-wall ratio is 15% window for the north wall, 10% window for the east and west walls, and 30% window for the south wall. The base-case ratio is 20% for all walls.
- **Additional wall insulation.** On the outside face of the exterior wall framing, R-10 rigid insulation was added compared with only R-13 batt insulation in the base-case walls. The resulting insulation in the sustainable building was R-23.
- **Additional roof insulation.** The R-15 rigid insulation was increased to R-20.
- **White roof.** A white roof finish material with low solar radiation absorptance of 0.30 was used compared with the base case's absorptance of 0.70.
- **Highly energy-efficient windows.** The sustainable option balances window performance with the low lighting levels and the use of daylighting controls. The result is a cost-optimized window with a U-factor of 0.31 and a shading coefficient of 0.39.

Mechanical Systems

- **High-efficiency air conditioner.** The air conditioning unit has an energy-efficiency ratio of 13 compared with 10 for the base case.
- **High-efficiency water heater.** A 90% thermal efficiency condensing water heater was used compared with a commercial gas water heater with 80% thermal efficiency for the base case.
- **Low-pressure ducts.** The fan external static pressure was reduced from 1.0 inch water column to 0.5 inch water column by enlarging the duct sizes.
- **Economizers.** An integrated economizer, including an outside air enthalpy sensor with a high-limit enthalpy setpoint, was used; the setpoint was set at 25 Btu/lb in conjunction with a dry bulb temperature high limit of 74°F.

Figure B-17. Features Included in the Sustainable Building

Table B-5. Characterization of Sustainable Building (includes base-case building comparison)

Characteristic	ASHRAE 90.1-1999 Base Case	Sustainable Building
General		
Building type	Office	Same as in base case
Location	Baltimore, Maryland	Same as in base case
Gross area	20,164 Ft^2	Same as in base case
Operation hours	8am - 5pm Monday-Friday	Same as in base case
Utility Rates		
Electric energy rate	Base rate: $11.50/month	Same as in base case
	Energy charge: $0.077/kWh	Same as in base case
Natural gas price ($/therm)	Base rate: $27.0/month	Same as in base case
	Energy charge: $0.692/therm	Same as in base case
Architectural features		
Configuration/shape		
Aspect ratio	2:1	Same as in base case
Perimeter zone depth	15 ft	Same as in base case
Number of floors	2	Same as in base case
Window area	20% window-to-wall ratio	Redistribute windows to optimize solar gain: north 15%, south 30%, and east and west 10%. Net overall: 18%.
Floor-to-ceiling height	9 ft	Same as in base case
Floor-to-floor height	13 ft	Same as in base case
Exterior walls		
Wall type	4-in. face brick façade on 16-in. on-center metal framing	See next item
Opaque wall U-value	0.124	0.055
Wall insulation	R-13 cavity insulation	Add R-10 rigid foam insulation under brick façade
Roof		
Roof type	Builtup roofing with concrete deck	See next item
Solar absorptance	0.7 (medium dark)	0.3 (white roof)

Characteristic	ASHRAE 90.1-1999 Base Case	Sustainable Building
Roof U-value	0.063	0.048
Roof insulation	R-15 continuous insulation	R-20 continuous insulation
Floor structure		
Floor type	Concrete	Same as in base case
Floor insulation	R-5.4 perimeter insulation*	Same as in base case
Fenestration/windows		
Window type	Aluminum frames with thermal breaks and double panes	See next item
Total U-value	0.57	0.31
Shading coefficient	0.45	0.39
Visual transmittance	0.52	0.70
Window shading/overhangs	None	*Overhang was considered but not included because overhangs made little impact on energy efficiency and the construction cost was substantial.
Building internal loads		
Occupancy		
Number of occupancy	96	Same as in base case
Occupancy schedule	8am - 5pm Monday-Friday	Same as in base case
Lighting		
Fixture type	T-8 with electronic ballasts	Same as in base case
Peak lighting power density	1.38 watts/ft^2 (net building wattage from ASHRAE's space by space analysis)	1.0 watts/ft^2. The density was recommended by the Illuminating Engineering Society of North America and ASHRAE as a proposed addenda to ASHRAE's 90.1 standard. For this building, the level was reduced from 40 to 35 foot candles in the office area.
Lighting schedule	7am – 6pm Monday-Friday	Same as in base case
Occupancy sensors	None	Same as in base case
Daylighting	None	Light sensors and dimmable fixtures the perimeter zones (15 feet in from the window walls). Skylights in second floor core with light sensors and dimmable fixtures.
Office equipment		

Characteristic	ASHRAE 90.1-1999 Base Case	Sustainable Building
Equipment schedule	7am – 6pm Monday-Friday	Same as in base case
Peak load density	0.72 watts/ft^2	Same as in base case
HVAC system		
HVAC system type	Package rooftop constant air volume with gas furnace	Same as in base case
Number of HVAC units	Five units to serve five HVAC thermal zones	Same as in base case
Space temperature setpoint	75°F cooling/70°F heating	Same as in base case
Space setback/setup	80°F cooling/65°F heating	Same as in base case
Cooling equipment efficiency	10.1 EER	13.0 EER
Outside air supply	20 cfm/person, 17% of supply air cfm	Same as in base case
Heating furnace efficiency	80%	Same as in base case
Ventilation control mode	Constant during occupied periods, cycle during unoccupied periods	See next item
Economizer	None	Economizer in each rooftop unit with outside air enthalpy-based controls
Design supply air	Minimum 0.5 cfm/ft^2	Same as in base case
Air-to-air energy recovery ventilation	None	Same as in base case
Fan total static pressure	2.0 in. total, 1.0 in. related to ductwork system	Increase duct size to reduced static pressure to 1.5 inches total (0.5 inches related to ductwork system).
Fan schedule	6am - 6pm Monday-Friday with night cycle on/off	Same as in base case
Fan motor efficiency	85%	Same as in base case
Fan efficiency	65%	Same as in base case
Service/domestic/potable water heating		
Hot water fuel type	Natural gas	Same as in base case
Thermal efficiency	80%	90%
Supply temperature	120	Same as in base case
Hot water consumption	0.9 gallons per minute/person	Same as in base case
* Exceeds ASHRAE 90.1-1999.		

Table B-6. Costs of Technology Options and Data Sources

Alternate Feature or Technology Option	Construction Cost Impact on Base Case	Basis and Source of Cost	Service Life of Alternate
Lighting			
Reduce lighting power density – Level 1: Reduce from 1.38 watts/ft^2 to 1.0 watts/ft^2 (from 40 to 35 foot candles)	-$16,970	Based on the watts/ft^2 (1.0 watt) and the cost/ft^2 ($2.32) needed to meet the current Illuminating Engineering Society of North America handbooks lighting levels for the space types in the office building design (office, lobby, corridor/support areas, and kitchen) with T-8 fixtures, electronic ballasts, and compact fluorescent lamps). The fixture choices remain the same as in ASHRAE's 90.1-1999 baseline.	25 yr; assumes light replacement costs are the same even though lower light levels reduce the number of fixtures and lamps that need to be replaced – and therefore reduces costs – over the life of the building.
Add perimeter daylighting with dimming control	$11,246	Based on $0.88/ft^2 for daylighting controls and fully dimming ballasts for all office space in a 15-ft depth from the building perimeter on both floors of the building. The range of cost per ft^2 was $0.23/ft^2 to $1.88/ft^2. One daylight sensor/controller was assumed per 600 ft^2 of perimeter floor space. Cost data for fully dimming ballasts were based on available costs in the Industrial Supply Lighting Catalog (W.W. Grainger 2000). Controller cost data with installation based on 2001 Means Electrical Cost Data.	15 yr
Add skylights and daylighting controls to center core of building	$18,219	18 skylights, fixed double-glazed, 44 in. x 46 in., $550 each (RS Means BCCD 08600-100-0130), effectively $39.13/ft^2. Eighteen light wells built up from suspended ceiling t-bar components. Dimmable controls and fixtures at $1.15/ft^2 of skylit core floor space; $/ft^2 rate developed from manufacturers' data indicating a range of $0.75 to $0.88/ft^2; plus 40% for labor.	Controls: 15 yr Skylights: 25 yr
Mechanical			
Add high-efficiency air conditioning (increase EER from 10 to 13)	$5,686	Base-case costs developed from distributors' purchase cost data collected during analysis of unitary air conditioning equipment for DOE's EPAct standards program, 2000-2002. Baseline system cost would then be $475/ton of cooling and the alternate would be $510/ton for an incremental cost of $40/EER/ton. A 25% distributor-to-contractor cost markup was assumed. The sustainable design option (EER 13) was taken from DOE's Unitary Air Conditioner Technology Procurement website at http://www.pnl.gov/uac/products.stm.	25 yr for both the base case and sustainable building

Alternate Feature or Technology Option	Construction Cost Impact on Base Case	Basis and Source of Cost	Service Life of Alternate
Add economizer with enthalpy-based controls	$2,700	Based on $540/rooftop air-handling units (5 units total) based on materials from multiple manufacturers.	15 yr; assumes controls are the weak point
Enlarge duct sizes to reduce static air pressure at fans and therefore reduce fan and motor sizes	$7,000	Based on ductwork at $1200/ton for baseline pressure duct design (0.1 in. H_2O/100-ft-length pressure drop) and $1400/ton for a low-pressure design (0.05 in./100-ft pressure drop). Assumes 120 lb of sheet metal per ton of air conditioning and $6.40/lb for the duct plus insulation cost. Cost data from RS Means Building Construction Cost Data.	25 yr [Note: although the expected lifetime is 30 years, the analysis has a 25-year time-frame, so lifetimes past 25 years are not considered.]
Envelope			
Add 1-in. (R-10) rigid foam board insulation behind brick façade	$2,946	Isocyanurate, 4 x 8 sheets, foil-faced, both sides. 1.5-in.-thick, R-10.8. RS Means 072-100-116-1650: $0.88.	25 yr for both the base case and sustainable building
Decrease total U-value from 0.57 to 0.31; decrease shading coefficient from 0.45 to 0.39; and increase visual transmittance from 0.52 to 0.70	$5,538	Cost of premium glazing is $25 ($22 to $28/ft^2) for item 08810 3004000 in RS Means (super-efficient glazing, triple-glazed with low-e glass, argon filled U=.26). Standard glass cost is $22.50 for item 4600400 in RS Means (3/16 float, 5/8 thick unit, U=.56) for a $2.50/ft^2 difference.	25 yr for both the base case and sustainable building
Reallocate window distribution to optimize solar gains	-$3,457	Based on $37.24/ft^2 for windows and $18.52 for wall. Baseline window-to-wall ratio was 20% and the sustainable design case nets 18%. Window cost decreased $6875. Wall cost increased $3418.	25 yr
Increase roof insulation from R-10 to R-20	$1,916	Based on difference in Means construction costs between baseline of 3-in. expanded polystyrene (R-11.49, $0.82/ft^2) and 3-in. polyisocyanurate (R-21.74, $1.01/ft^2).	25 yr for both the base case and sustainable building
Replace roofing with a white roof system	$1,553	Based on a 10% extra cost ($0.15/ft^2) for white over baseline roofing at $1.54/ft^2. Unit costs derived from RS Means Building Construction Cost Data (1999), line numbers 075-302. Manufacturers' information indicates the additional cost may be higher, possibly a multiple of 2.	25 yr for both the base case and sustainable building
Other			
Replace gas-fired service hot water heater (80% efficiency) with higher-efficiency unit (90% efficiency)	$1,200	Based on review of cost information from multiple manufacturers/ vendors and web-based reports.	25 yr for both the base case and sustainable building

Table B-7. Simulated Energy Use by End Use for the Base-Case and Sustainable Buildings

End Use	Fuel	Units	Base-Case Building	Sustainable Building	% Change
Lighting	Electricity	kWh	79,314	41,518	-47.7%
Space cooling	Electricity	kWh	23,440	17,082	-27.1%
Space heat	Natural gas	Therms	2,606	1,854	-28.9%
Other	All	Million Btu	118	92	-22.4%
Fans	Electricity	kWh	15,207	10,401	-31.6%
Pumps and misc.	Electricity	kWh	674	879	30.4%
Hot water	Natural gas	Therms	642	534	-16.8%
Total	All	Million Btu	730	477	-34.6%

Table B-8. Simulated Annual Energy Costs by End Use for the Base-Case and Sustainable Buildings

End Use	Fuel	Units	Base-Case Building	Sustainable Building	% Change
Lighting	Electricity	$/Yr	6,099	3,193	-47.7
Space cooling	Electricity	$/Yr	1,803	1,314	-27.1
Space heat	Natural gas	$/Yr	1,804	1,284	-28.9
Other	All	$/Yr	2,128	1,699	-20.1
Fans	Electricity	$/Yr	1,169	800	-31.6
Pumps and misc.	Electricity	$/Yr	52	68	30.4
Hot water	Natural gas	$/Yr	445	370	-16.8
Base energy charges	All	$/Yr	462	462	0.0
Total	All	$/Yr	11,834	7,489	-36.7

Table B-9. Lifecycle Cost Calculations for the Base-Case and Sustainable Buildings

Cost Element	Units	Base-Case Building	Sustainable Building	Difference (Sustainable - Base)	% Difference	Comments
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%	Present value investment cost differs from first cost in the sustainable building because of replacement costs for lighting controls and economizers, which are assumed to have a 15-year life.
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%	Represents fixed energy connection charges.
Total annual energy cost	$/Yr	$11,834	$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 in the lifecycle cost	Not included in the lifecycle cost	Not applicable	Not applicable	Fixed charges not included in the lifecycle cost calculation. Because they are not impacted by the sustainable design options, they have no impact on the cost-effectiveness calculations.
Present value (total energy cost)	$	$191,007	$118,214	($72,793)	-38.1%	
Lifecycle cost	$	$2,591,007	$2,567,780	($23,228)	-0.9%	

B.5 ENERGY-10 and DOE-2.1E

While ENERGY-10 was designed for use with small buildings (i.e., 10,000 ft^2 or less in floor area), its ability to quickly assess the energy-use and lifecycle cost impact of design changes was used even with this study's larger, 20,000-ft^2 building. The same features that make ENERGY-10 quick and easy to use also limit its flexibility, and the base-case building in DOE-2.1E and ENERGY-10 exhibited some differences in cooling load and fan power.

The two models handle fundamental building characteristics in significantly different ways, including the limited equipment choices in ENERGY-10 and the fact that ENERGY-10 only models one or two zones. While a single zone may be appropriate for small buildings such as houses and small retail buildings, larger buildings may have substantial variation in thermal loads across the building, requiring some way to provide for individually served thermal zones. In addition, ENERGY-10's feature to automatically set up daylighting zones places the daylight sensor in the center of the zone, which in this case is close to a window, and therefore overestimates daylighting savings.

ENERGY-10 provides for a very simplified user entry using its "autobuild" procedure to create a very basic "shoe box" building model; however, the desire to match the prototype building led the team to specify a building description that closely matched the characteristics of the ASHRAE 90.1-1999 compliant base-case building modeled in DOE-2.1E.

In developing the specific features of the base-case building in ENERGY-10, careful attention was paid to the fundamental building characteristics so that they would be the same in the base-case ENERGY-10 and DOE-2.1E models. Less attention was focused on the final building energy use or EUI (kBtu/ft^2/yr). However, there were limits to how well the fundamental descriptions for infiltration, cooling equipment efficiency, and the presence of a building return air plenum could be matched between the ENERGY-10 and the DOE-2.1E base-case buildings. In the end, the base-case building simulations in the DOE-2.1E and ENERGY-10 models resulted in the buildings having very similar overall site energy consumption (within 1% of each other) and very similar scheduled energy use (lighting and plug and hot water loads total within 2% of each other). However, the ENERGY-10 base-case simulations showed higher cooling and fan energy consumption and lower heating energy use consumption than in the DOE-2.1E simulations. This may be explained by the known differences in implementation discussed above; the remaining difference may be attributable to the different underlying simulation engines. Note that ENERGY-10 calculates very different estimates of cost effectiveness measures for the energy-efficiency options, with an overall return on investment of 11%. The differences remain an area of study.

Table B-10 shows the ENERGY-10 description of the base-case building and of a low-energy version (i.e., sustainable design) of that base-case building. The low-energy building was developed by selecting from among the potential sustainable design options.

Table B-11 shows the results of the ENERGY-10 simulations of the base-case and sustainable buildings. Table B-12 shows the estimated cost impacts of the sustainable design options from ENERGY-10. These cost estimates were used to generate the lifecycle cost analysis used in the screening effort, but these are not the costs used in the final simulation of the sustainable building in DOE-2.1E. See Section B.4 for documentation of the final simulation of the sustainable building.

Table B-10. Summary of Base-Case and Sustainable Buildings

Description	Base-Case Building	Sustainable building
Building characteristics		
Weather file	Baltimore	Baltimore
Floor area (ft^2)	20,164	20,164
Surface area (ft^2)	31,240	31,240
Volume (ft^3)	262,132	262,132
Total conduction loss coefficient (Btu/hr-°F)	3,276	1,556
Average U-value (Btu/hr-ft^2-°F)	0.105	0.050
Wall construction	Buscase 6, R=8.9	Steelstud 6 poly, R=18.1
Roof construction	Buscase, R=15.9	Flat, R=38.0
Floor type, insulation	Slab on grade, R_{eff}=67.6	Slab on grade, R_{eff}=118.3
Window construction	Buscase, U=0.67 Btu/hr-ft^2-°F	4,060 low-E aluminum/thermobreak, U=0.31 Btu/hr-ft^2-°F
Window shading	None	3 ft overhangs on east, south, and west windows
Wall total gross area (ft^2)	11,076	11,076
Roof total gross area (ft^2)	10,082	10,082
Ground total gross area (ft^2)	10,082	10,082
Window total gross area (ft^2)	2,208	2,280
Windows (north/east/south/west:roof)	23/23/23/23:0	23/7/46/7:12
Glazing name	Buscase, U=0.56	Double low-E, U=0.26
Operating parameters		
HVAC System	Direct expansion cooling with gas furnace	Direct expansion cooling with gas furnace
Rated output (heat/sensible cool/total cool) (kBtu/h)	288/315/420	206/256/341
Rated air flow/minimum outside air (cfm)	12,597/1,585	9,527/1,585
Heating thermostat	70.0°F, set back to 65.0°F	70.0°F, set back to 65.0°F
Cooling thermostat	75.0°F, set up to 80.0°F	75.0°F, set up to 80.0°F
Heat/cool performance	Efficiency=80, EER=10.1	Efficiency=90, EER=13.0
Economizer?/type	No/not applicable	Yes/fixed dry bulb, 60.0°F
Duct leaks/conduction losses (total %)	2/0	2/0
Peak gains; internal lights, external lights, hot water, other; watt/ft^2	1.38/0.00/0.20/0.72	1.03/0.00/0.20/0.72
Added mass?	None	None
Daylighting?	No	Yes, continuous dimming
Infiltration (in^2)	Air changes per hour (ACH)=0.1	ACH=0.1

Table B-11. Annual Energy Use, Cost, and Emissions from ENERGY-10

	Base-Case Building	Sustainable Building
Simulation dates	Jan. 1 to Dec. 31	Jan. 1 to Dec. 31
Energy use (kBtu)	904,917	495,861
Energy cost ($)	16,058	9,208
Saved by daylighting (kWh)	–	25,011
Total electric (kWh)	183,542	108,238
Internal lights (kWh)	78,793	33,793
Cooling/fan (kWh)	35,242/17,106	19,066/2,977
Other (kWh)	52,402	52,402
Peak electric (kW)	83.8	50.6
Fuel (hot water/heat/total) (kBtu)	62,791/215,826/278,617	62,791/63,730/126,520
Emissions (CO_2/SO_2/NO_x) (lb)	279,585/1,481/789	160,414/869/460
Construction costs	3,146,828	3,195,257
Lifecycle cost	3,815,530	3,668,552

Table B-12. Cost of Modeled Energy Conservation Measures From ENERGY-10

Daylighting	Cost
Daylighting	13,371
Glazing (windows)	4,980
Shading	13,359
Energy-efficient lights	7,259
Insulation	18,868
Passive solar heating	-5,400
Economizer	5,041
High-efficiency HVAC	7,006
Total	**66,500**
Total after HVAC downsizing	**59,494**