DESIGN AND ANALYSIS OF A NET-ZERO ENERGY COMMERCIAL OFFICE BUILDING IN A HOT AND HUMID CLIMATE

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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To my parents, whose guidance is invaluable

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The purpose of this study is to analyze the design and economic benefits of a net-zero small office building in the hot and humid climate of Florida. Hot and humid climates are cooling dominated and require constant cooling and dehumidification to achieve a comfortable indoor environment, but lead to higher cooling energy costs. Being the most prevalent type of commercial building in Florida, net-zero small office buildings have the greatest potential in energy savings in Florida next to residential homes.

Various building designs are examined to reduce energy consumption of the building by utilizing energy modeling software. The final package of energy efficiency measures achieves 59% in energy savings of an established energy model baseline. A photovoltaic (PV) system provides the annual energy needs of the small office building. A life cycle cost (LCC) analysis determines whether the additional first costs associated with the net-zero small office design will pay back in energy cost savings. The results proved that the measures used to achieve 59% energy savings were cost effective. In addition, the PV system selected to generate the necessary energy for the small office building was cost effective as long as it met certain efficiency and cost criteria.

CHAPTER 1
INTRODUCTION

Background and Motivation

As concerns over energy independence in the United States and global warming increase well into the 21st century, many are seeking ways to continually increase energy efficiency and reduce energy consumption. Commercial and residential buildings alone account for 40% of primary energy consumption in the United States and 70% of electricity usage (CBECS, 2003). The demand for energy by the commercial sector is projected to increase by 1.2% per year from 2006 to 2030, driven by trends in population and economic growth (EIA, 2009). In order to reduce the energy consumption of the commercial building sector, the Department of Energy (DOE) has established the Commercial Building Initiative, a goal to create technologies and design approaches that lead to marketable zero-energy commercial buildings (ZEB) by 2025. This goal is evident in Section 422 of the Energy Independence and Security Act of 2007, which calls for the increased production of clean renewable fuels and increased efficiency of products, buildings, and vehicles (EISA, 2007).

Today, more and more building owners are looking to have their existing or new building be “green”, a term ubiquitous with clean energy and environmental friendliness. Whether driven by financial or environmental reasons, the green movement is driving building designers and engineers to develop ever more inventive methods to conserve energy in buildings. New materials, techniques, technologies, and computer modeling programs have helped energy efficient buildings come to life. However, despite the gains in lower energy use and improved building quality, the question all building owners ask about new technologies is “What will it cost?”

Net-Zero Energy Buildings - Definitions

There are several definitions for a ZEB. Each definition differs depending on the boundary and metric used to define the building. A net ZEB is, ideally, a building that through high efficiency gains can meet the rest of its energy needs through renewable technologies. Zero is the point at which the building no longer consumes energy but rather produces it. At the zero point, the sum of the energy flows in equal the sum of the energy flows out. There are four definitions used for ZEB's: net-zero source energy building, net-zero site energy building, net-zero energy cost building, net-zero energy emissions buildings.

A source ZEB produces at least as much energy as it uses in a year, when compared to the energy produced at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. The boundary of the system encompasses the building, transmission system, power plant, and the energy required getting the fuel source to power the plant. To calculate a building's total source energy, both imported and exported energy is multiplied by an appropriate site-to-source energy factor. This definition is difficult to assess since it depends on the method the utility is buying and producing power (Torcellini et al, 2006).

A site ZEB produces at least as much energy as it uses in a year, when accounted for at the site. This definition tends to promote energy efficient designs and can be easily verified through metering (Torcellini et al, 2006). Photovoltaic systems, small scale wind power, or solar hot water collectors are options to generate on-site power. However, this definition does not distinguish between fuel types. One unit of electricity on site is considered equal to one unit of gas on site; however, electricity may be worth three times more at the source than gas. For buildings that use a significant amount of gas, a site ZEB will need to generate much more electricity on-site than a source ZEB.

In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for energy services and energy used over the year. However, since utility rates vary from year to year, a ZEB that has consistent energy performance can meet a cost ZEB goal one year and fail the next year. Also, if a significant number of buildings meet a cost ZEB goal fewer funds would be available to maintain the utility infrastructure (Torcellini et al, 2006). Thus, the utility would have to charger higher fixed and demand rates to customers.

An emissions ZEB produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources. Achieving a zero emissions goal depends widely on the method of source energy production, whether it be nuclear, hydro, coal, or wind. If a building consumes energy from an entirely wind generated source, then that building will not need to produce any on-site energy. However, if a building is a in a mixed field of energy generation sources, say coal and wind power, it is much more difficult to determine the amount of on-site energy needed to be produced (Torcellini et al, 2006).

Net-Zero Energy Buildings - Examples

The U.S. Department of Energy’s Building Technologies Program website maintains the Zero Energy Buildings database. Currently, eight ZEB’s located in the U.S. are listed along with their project information as well as energy performance characteristics, listed in Table 1-1.

These buildings had aggressive energy saving goals when being designed. Off the shelf energy saving technologies were used in conjunction with daylighting, radiant heating, natural ventilation, evaporative cooling, ground source heat pumps, photovoltaics, and passive solar strategies to reduce their energy use and minimize environmental impacts (DOE, 2008).

Table 1-1. Zero energy building list

Building Name	Building Type	Floor Area (ft^2)	Annual Energy Generated ($kBtu/ft^2$)	Annual Energy Purchased ($kBtu/ft^2$)	Total Project Cost
Aldo Leopold Legacy Center	Commercial Office; Interpretive Center	11,900	17.6	-2.02	$3,943,418
Audubon Center at Debs Park	Recreation; Interpretive Center; Park	5,020	17.1		$5,500,000
Challengers Tennis Club	Recreation	3,500	9.17	-0.0955	$1,800,000
Environmental Tech. Center, Sonoma State	Higher Education, Laboratory	2,200	3.79	-1.47	$1,116,000
Hawaii Gateway Energy Center	Commercial Office; Interpretive Center; Assembly; Other	3,600	31.1	-3.46	$3,400,000
IDeAs Z Squared Design Facility	Commercial Office	6,560		-0.00052	
Oberlin College Lewis Center	Higher Education; Library; Assembly; Campus	13,600	36.4	-4.23	$6,405,000
Science House	Interpretive Center	1,530	17.6	0	$650,000

Barriers to Net-Zero Energy Buildings

If the strategy and technologies exist to build more energy efficient buildings, then the question is how come all buildings in the country are not moving towards net-zero. The fault may be in the traditional way of designing buildings as well as perceived associated higher costs with green buildings.

Many building designers still design their respective systems individually without giving considerations on how much their system affects other building systems. In the traditional building design process, the architectural team works with the owner to create a building program that specifies the needs for the building. The architect designs the building to satisfy the program requirements, and then the project engineers design the electrical and mechanical systems and evaluate compliance with energy codes and acceptable levels of environmental comfort. However, because many important architectural decisions are set at this point, few changes can be made that would improve energy performance.

In contrast to the traditional building process, the whole-building design process requires the team, including the architect, engineers (lighting, electrical, and mechanical), energy and other consultants, and the building's owner and occupants, to work together to set and understand the energy performance goals. The full design team focuses from the outset on energy and energy cost savings. The process relies heavily on energy simulation. To be effective, the process must continue through design, construction, and commissioning (Torcellini et al, 2006a).

Despite the inherit benefits of reducing or eliminating energy costs, building owners ultimately ask how much of an investment must be made and what is the value of such an investment. The cost of such a project varies greatly depending on the strategy undertaken to reduce energy use and the climate in which the building is constructed.   Langdon (2007) showed that there was no significant difference in the cost of green buildings vs. non-green buildings. Green building construction projects around the country meeting LEED certification showed an average upfront cost of 2% of project cost with as high of an upfront cost of 6% of project cost (Kats, 2003). Fisk (2000) and Heerwagen (2001) showed other added financial benefits in improved indoor air quality and increased indoor daylighting, which lead to substantial savings in work productivity and moral.

The purpose of this study is to analyze the design and economic benefits of a net-zero small office building in the hot and humid climate of Florida. Hot and humid climates are cooling dominated and require constant cooling and dehumidification to achieve a comfortable indoor environment, but lead to higher cooling energy costs. Being the most prevalent type of commercial building in Florida, net-zero small offices will have the greatest potential in energy savings in Florida next to residential homes. Various building designs will be explored to reduce energy consumption of the building. The final design solution, however, is intended not to be the optimal solution, as there are many variations of design that could achieve the same effect. The economic analysis will only be limited to construction costs and energy costs. A Life Cycle Cost (LCC) analysis will help determine whether the first costs associated with the net-zero small office design will pay back in energy cost savings.

CHAPTER 2
LITERATURE REVIEW

Commercial Building Energy Consumption and Modeling

The Commercial Buildings Energy Consumption Survey (CBECS) is a national sample survey performed by the federal Energy Information Administration (EIA) every four years. The survey collects information on the U.S. stock of commercial buildings, their energy related building characteristics, and their energy consumption and expenditures. The CBECS provides valuable information regarding the energy performance characteristics of the current U.S. stock of commercial buildings.

Commercial Buildings Energy Consumption Survey

The CBECS defines commercial buildings as buildings in which at least half of its floor space is used for purposes other than residential, industrial, or agriculture. Therefore, this survey includes buildings that are not typically thought of as commercial buildings, such as schools, prisons, and buildings for religious worship. According to the 2003 CBECS, office buildings were the most numerous type of building and comprise of 19% of total commercial floor space and 17% of energy use, ranking highest above all other principal building activities (CBECS, 2003). The southern region, which includes hot and humid Florida, had the most office square footage of the entire country as well as the most energy consumption. The southern region also had lower energy use intensity (EUI) when compared to the Northeast and the Midwest, but a higher EUI when compared to the West.

Department of Energy Commercial Benchmark Energy Models

To determine the value of implementing a certain energy saving building technology, the DOE’s National Renewable Energy Laboratory (NREL) developed modeling methodologies to attempt to model the current building stock based on the 2003 CBECS. The study found energy models using EnergyPlus modeling software were roughly consistent with the 2003 CBECS survey. The modeling methods utilized were valid and could be used to model the building sector (Griffith et al, 2008).

The NREL developed commercial energy model benchmarks in order to establish a common comparison baseline so that researches studying building energy efficiency and net-zero buildings could compare their findings. Fifteen typical building types were developed based on information from the 2003 CBECS. The building prototypes were categorized into three vintages and 16 locations based on climate zone and modeled in EnergyPlus. An attempt was not made to match CBECS energy use data. The results showed a small 5,500 ft^2 office building in hot and humid Houston, TX had an annual energy consumption of 33.6 $kBtu/ft^2$ compared to the 2003 CBECS average of 79.9 $kBtu/ft^2$ (Torcellini et al, 2008).

Feasibility and Case Studies

Feasibility

The NREL also studied the technical feasibility of commercial ZEBs. The main question determined by the study was to what extent a photovoltaic system can provide for a building's energy needs. Based on EnergyPlus simulations of various buildings and existing and projected technologies to 2025, the study found that 62% of buildings could reach net zero (Griffith, 2007). Concurrently, 47% of building floor space could achieve net zero. The study also found, assuming exportation of excess electricity from PV systems, new buildings could, on average, consume only 12.2 $kBtu/ft^2$, which was an 86% reduction from current stock. Office buildings, when compared to ASHRAE Standard 90.1-2004, required 67% in energy savings to reach the ZEB goal.

A sector analysis showed that office buildings have a below average chance of achieving net zero, due largely in part to high plug and process loads and building height. Ranking individual technologies ability to reach the ZEB goal, the potential to reduce net-site EUI was highest for thermal insulation, followed by lighting, plug and process loads, HVAC, dynamic windows, daylighting, and passive solar. The assessment concluded that achieving a ZEB goal was more achievable than generally assumed.

Case Studies

The Buildings and Thermal System Center at the NREL studied six high performance buildings over a four year period to understand the issues in the design, construction, operation, and evaluation of low energy buildings in order to determine best practices that should be applied to future buildings to reach the ZEB goal (Torcellini et al, 2006a). The study found value was favored over cost and a whole-building design approach was a good way to lower energy and cost. However, the buildings used more energy than predicted in the design and simulation stage. The higher than predicted energy use resulted from higher than predicted plug loads, PV system degradation, and unpredictable occupancy behavior. Each of the buildings saved 25% to 70% in energy lower than code. Energy monitoring provided valuable feedback in maintaining efficient performance of building systems in order to reach design goals. A set of best practices were developed from the study to be applied to future designs of low energy buildings and ZEBs. Further details of the best practices can be found in the literature.

American Society of Heating, Refrigerating and Air-Conditioning Engineers Energy Efficiency Standards and Design Guides

ASHRAE Standard 90.1

Originating in 1975 in response to that decade’s energy crisis, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) developed ASHRAE Standard 90.1. Standard 90.1 provides minimum energy-efficient requirements for the design and construction of new buildings and their systems. Standard 90.1 has been widely adopted as building code throughout many regions in the U.S. and applies to all buildings except for low-rise residential buildings (three habitable floors or less). The standard specifies reasonable design practices and technologies that minimize energy consumption without sacrificing either the comfort or productivity of the occupants. Appropriate for a wide range of building types, climate zones, and site conditions, the provisions of this standard apply to envelopes of buildings, HVAC equipment, service water heating equipment, and power and lighting. Standard 90.1 is continually being revised and published every three years.

In addition to being used for code compliance, Standard 90.1 is often used as a baseline for energy efficient and green building programs, such as the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED). ASHRAE added Appendix G with the 2004 update to Standard 90.1 to outline a procedure to show that the building design is significantly better than code minimum. The Performance Rating Method procedures in Appendix G intend to provide more flexibility and to give credit for energy savings measures such as building orientation, natural ventilation, daylighting, and HVAC system design and selection. The method outlined in Appendix G establishes a baseline for the entire energy consumption of the building to be used to calculate percentage energy savings. However, it does not reward energy savings in plug and process loads as it considers these loads equal in both the baseline and proposed models. Plug and process loads include appliances, office equipment, computers, monitors, and other electrical and gas equipment.

ASHRAE Design Guides

ASHRAE has published several building type advanced energy design guidelines to achieve energy efficiency surpassing Standard 90.1. Currently, the guides provide methods to achieve 30% efficiency over 90.1-1999 for small warehouses, K-12 schools, highway lodgings, small office buildings, and small retail buildings. Eventually the ultimate goal of the advanced energy guides is to provide designers methods to achieve a net-zero energy building based on the type of building being designed. For this study, the Advanced Energy Design Guide for Small Office Buildings was used as a starting point for design in achieving net-zero. In addition, The ASHRAE Green Guide was utilized to identify methods in designing mechanical systems for sustainable buildings as well as identify possible energy saving building technologies. Also, the ASHRAE Design Guide for Hot and Humid Climates was utilized to identify key issues for designing buildings in hot and humid climates.

CHAPTER 3
METHODOLOGY

Evaluation Approach

The objective of this study was to assess and quantify the energy savings potential of a small commercial office building located in a hot and humid climate. The percent savings goal was based on the definition of net site energy use: the amount of energy used by a building minus any renewable energy generated within its footprint. The whole-building energy savings method was used to determine energy savings to achieve a net-zero energy building, in line with the Performance Rating Method detailed in Appendix G of Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004a).

Historically, energy savings have been expressed in two ways: for regulated loads only and for all loads (whole building). Regulated load metrics did not include plug and process loads that were not code regulated. Whole-building energy savings, on the other hand, included all loads (regulated and unregulated) in the calculations. In general, whole-building energy savings were more challenging than regulated load savings given the same numerical target, but more accurately represented the impact of the building on the national energy system.

In order to fulfill the objective, existing floor plans of a small commercial office building were utilized as a starting point to develop a prototype small commercial office building. Once a prototype building was established, a baseline model of the prototype building was created as dictated by the criteria of Appendix G of ASHRAE 90.1-2004 (ANSI/ASHRAE/IESNA 2004a). The baseline prototype building was then simulated using the Typical Meteorological Year 3 (TMY3) weather data for Gainesville, FL to establish a yearly baseline energy usage. Chapter 4 documents the baseline model inputs and assumptions.

Next, a proposed model based on recommended energy-efficient technologies in the current literature was developed and simulated. The proposed model was designed by applying perturbations, or energy efficiency measures (EEMs), in the baseline model. Various combinations of current commercially available technologies were analyzed to measure their ability to reduce energy usage over the baseline model. A target between 50% to 70% energy savings was set in order to achieve a potential net-zero energy building. Chapter 5 documents the advanced model inputs and assumptions. A second objective was to seek calculate the selected design’s cost effectiveness over a twenty-year analysis period. Thus, percent net site energy savings as well as a twenty-year total life cycle cost of the selected design were analyzed.

Simulation Tool Description

Designing, building, and renovating commercial buildings in order to achieve higher energy efficiency performance involve complex systems engineering. This complexity has led to a broader use of energy simulation software. eQuest, the Quick Energy Simulation Tool, is a free graphical user interface (GUI) that drives the DOE-2 simulation engine. DOE-2 is a well-established building energy modeling program that has been in existence for over two decades. This program simulates the energy performance of a building using hourly time steps for all 8760 hours in a year. Weather files representing typical years are utilized to simulate climatic conditions for hundreds of locations throughout North America and the world. For many years, this program was accessed via a text-based programming language, known as the Building Description Language (BDL). This required extensive knowledge not only of building science fundamentals but also of the intricacies of the DOE-2 programming methodology. The advent of GUIs such as eQuest allows the user to create building models in DOE-2 via easy-to use dialog boxes and graphical displays.

eQuest can be utilized in two different modes, known as the Wizard mode and the Detailed mode. The Wizard mode is intended as a guide through the creation of the building energy model. Building types, geometries, internal loads, schedules, zoning and water- and air-side systems can all be specified within the wizards. eQuest also utilizes a dynamic default process that continually populates certain inputs with pre-established default values based on the user-selected inputs within the wizard. This allows the user to choose the level of detail that suits their particular needs. Models can be built early on in the schematic design phase that utilize high-level project information and mostly rely on eQuest defaults. Then, as the project progresses, building-specific information can be entered by the user.

In general, eQuest modeling follows the order of operations originally established for creating the BDL input file in DOE-2. This order falls under the categories of LOADS, SYSTEM, PLANT, and ECONOMICS. It is important to note that these categories are not immediately apparent when using the eQuest GUI. However, they are still the foundation of the DOE-2 engine that eQuest is operating and thus are important to understand.

The LOADS category consists of the building geometry and the associated space and zone definitions. Within these spaces, internal loads and schedules are defined for people, lights, equipment and infiltration. Daily, weekly and annual schedules dictate when the loads are active within the spaces.

The SYSTEM category is where the secondary HVAC systems are defined and are sized to meet the loads defined in the LOADS section. Each space is assigned to an air-side HVAC system and the internal loads for that space are served by the system. The loads are served on an hourly basis.

The PLANT category consists of the primary HVAC components that provide the necessary heating and/or cooling energy to the secondary systems. Primary systems include chillers, boilers, cogeneration systems and numerous other types. The energy required to meet the loads and power the secondary systems are determined for each plant type and the cost of this energy use is then calculated in the ECONOMICS category.

The ECONOMICS category allows the user to define utility rates for various fuel sources, such as electricity or natural gas. Utility rates can be simple rate structures or complex block or ratchet charges. Consumption rates as well as demand charges are also specified. The monthly and annual cost for operating the building model is then computed and reported in the results output.

Development of the Small Office Building Prototype

The small office prototype used for this study was based on existing floor plans for a small office building in Gainesville, FL. Figure 3-1 shows the floor plan of the small office building prototype. The office space consisted of two separate suites that total 7,320 ft^2. The building was rectangular shaped and 161 ft by 45 ft with an aspect ratio of 3.6. A larger plot of the building floorplan can be found in Appendix A.

The floor plan for the office was divided into seven thermal zones, each zone being served by an air handling system. These thermal zones are shown in Figure 3-2. A summary of zone names and corresponding characteristics are shown in Table 3-1.

The AEDG contained a unique set of energy efficiency recommendations for each International Energy Conservation Code (IECC)/ASHRAE climate zone. The zones were categorized by heating degree days (HDDs) and cooling degree days (CDDs), and range from the very hot Zone 1 to the very cold Zone 8. Sub-zones indicated varying moisture conditions.

Humid sub-zones were designated by the letter A, dry sub-zones by B, and marine sub-zones by C.

To provide a basis for analysis, Gainesville, FL was chosen to depict typical climate conditions in Zone 2A, which represents the hot and humid climate of the Southeastern United States. The weather file for Gainesville was obtained from the Typical Meteorological Year, version 3 data set (TMY3), which was available for download via the World Wide Web at http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3.

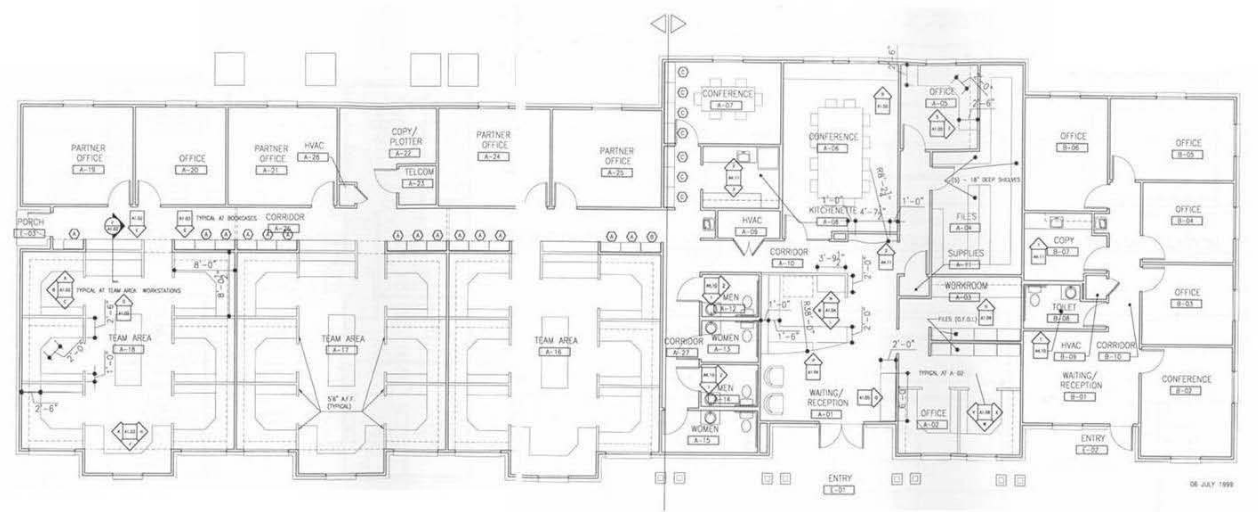


Figure 3-1. Small commercial office building prototype floor plan

Figure 3-2. Office floor plan thermal zoning

Table 3-1. Small office prototype thermal zone characteristics

Zone Name	*Area (ft^2)*	*Floor-to-Ceiling Height (ft)*	*Gross Wall Area (ft^2)*	*Window Glass Area (ft^2)*	*Window/Wall Ratio*
Team Area 1	754	10.00	598.3	44.0	7.4%
Team Area 2	754	10.00	343.3	44.0	12.8%
Team Area 3	754	10.00	341.7	44.0	12.9%
Private Offices	1,575	10.00	1,030.0	86.6	8.4%
Lobby Area	939	10.00	563.3	34.6	6.1%
Conference Area	1,289	10.00	583.3	69.3	11.9%
Suite B	1,257	10.00	1,093.3	138.6	12.7%

CHAPTER 4
BASELINE MODEL DEVELOPMENT

A number of reports and datasets were surveyed to develop typical commercial office building characteristics including the Commercial Building Energy Consumption Survey (CBECS 2003) and the DOE Commercial Building Research Benchmarks for Commercial Buildings (Deru, Griffith et al. 2008). The modeling methods outlined in Appendix G of Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004a) provided the majority of baseline modeling information. Some Assumptions used for analysis originated from the Advanced Energy Design Guide for Small Office Buildings (Jarnagin et al. 2006). Details on baseline model inputs can be found in Appendix B.

Building Operating Characteristics

The majority of commercial office floor space surveyed by CBECS operated between 40 and 60 hours a week. Typical occupancy, HVAC, lighting, miscellaneous equipment, and service hot water schedules were provided by 90.1-2004 User's Manual (ANSI/ASHRAE/IESNA 2004b). The building was assumed to follow typical office occupancy patterns with peak occupancy occurring during normal business hours from 8 AM to 5 PM Monday through Friday. Limited occupancy was assumed to begin at 6 AM and after business hours through midnight for janitorial functions. Saturday occupancy was assumed to be 30% of peak occupancy while Holiday and weekend occupancy were assumed to be approximately 5% of peak occupancy.

The HVAC system operating schedule started prior to the beginning of normal business hours to bring the space to the set point temperature. Lighting, miscellaneous equipment, and service hot water schedules were matched to occupancy schedules with limited usage during unoccupied times. Figure 4-1 illustrates the schedules for occupancy, lighting, miscellaneous equipment, HVAC system, and service hot water system for a typical weekday of the small office simulation. Further detailed building operation and load schedules can be found in Table B-1 of Appendix B.

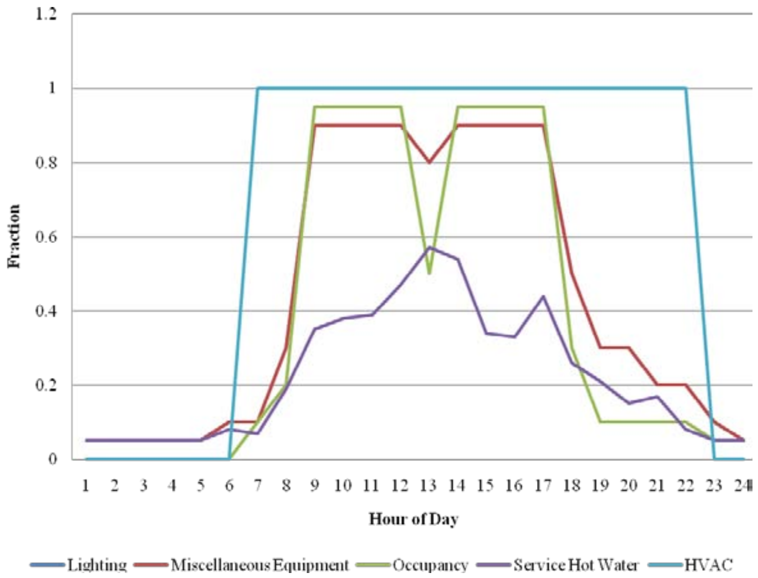


Figure 4-1. Weekday schedule for small office building prototype

Baseline Building Envelope Characteristics

CBECS data showed a majority of opaque constructions consisted of mass walls, built-up roofing with insulation above deck, and slab-on-grade floors. The small office building floor to ceiling height was assumed to be 10 ft with a 3 ft plenum space. Figure 4-2 shows an axonometric view of the building modeled in eQuest. Appendix G of Standard 90.1-2004 required that the baseline opaque assemblies match the appropriate maximum U-factors stated in Tables 5.5-1 through 5.5-8 of Standard 90.1-2004. Table 5.5-2 of Standard 90.1-2004 contained the appropriate U-factor information for climate zone 2A (ANSI/ASHRAE/IESNA, 2004a).

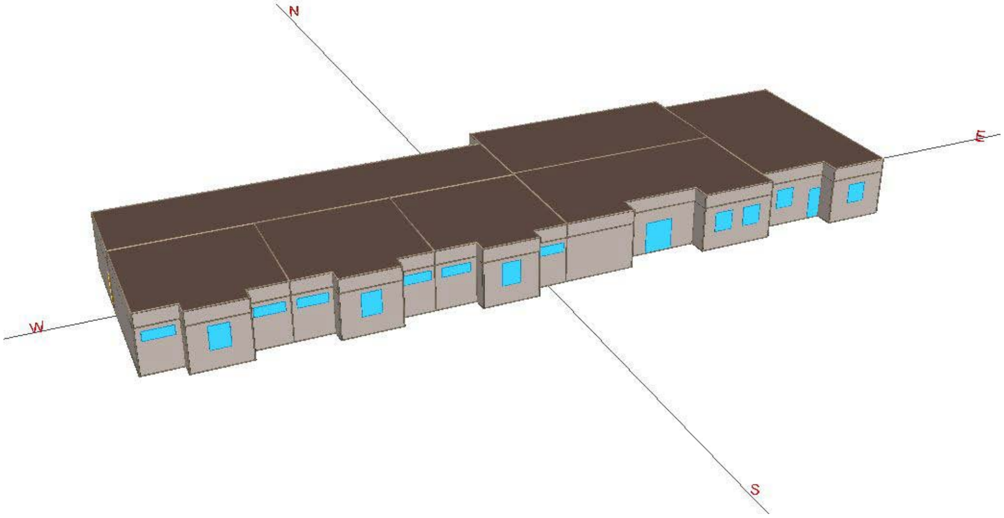


Figure 4-2. Axonometric view of the eQuest small office building model

Exterior Walls

Appendix G of Standard 90.1-2004 required that the baseline building model's exterior walls be steel-framed above-grade walls. Appendix A of Standard 90.1-2004 (ANSI/ASHRAE/IESNA, 2004a) provided further details of the specified wall assembly components including R-values. The exterior wall included the following layers:

- Exterior Air Film, R-0.17 h·ft^2·°F/Btu
- Stucco, R-0.08 h·ft^2·°F/Btu
- 0.625-in. gypsum board, R-0.56 h·ft^2·°F/Btu
- Steel framing at 16 in. OC with R-13 cavity insulation, R-6 h·ft^2·°F/Btu
- 0.625-in. gypsum board, R-0.56 h·ft^2·°F/Btu
- Interior Air Film, R-0.68 h·ft^2·°F/Btu

The overall U-value of the wall assembly was 0.124 Btu/hr·ft^2·°F, which met the building envelope requirements of Standard 90.1-2004 for climate zone 2A stated in Table 5.5-2 of Standard 90.1-2004.

Roof

The small office building baseline prototype consisted of a flat roof with insulation entirely above a metal deck as required by Appendix G. Roof insulation R-values were set to match the maximum roof U-value requirements in Table 5.5-2 of Standard 90.1-2004 (ANSI/ASHRAE/IESNA, 2004a). As defined in Appendix A of 90.1-2004, the roof construction consisted of the following layers:

- Exterior Air Film, R-0.17 h·ft^2·°F/Btu
- Continuous rigid insulation, R-15 h·ft^2·°F/Btu
- Metal deck, R-0
- Interior air film-heat flow up, R-0.61 h·ft^2·°F/Btu

The overall U-value of the roof assembly was 0.063 Btu/hr·ft^2·°F (0.358 W/K·m^2). Appendix G of Standard 90.1-2004 also specified that the roof surfaces be modeled with a reflectivity of 0.3.

Slab-On-Grade Floors

Appendix G of Standard 90.1-2004 required that the slab-on-grade floors match the F-factor for unheated slabs stated in the same table as above. eQuest did not have an explicit F-Factor input. Therefore, the slab-on-grade floor assembly for the small office prototype was assumed to be carpet over 6 in. concrete slab floor poured directly onto the earth. Modeled below the slab was 12 in. soil, with soil conductivity of 0.75 Btu/h·ft^2·°F.

Fenestration

Statistics on the amount and distribution of windows on office buildings was not provided in the 2003 CBECS data. Appendix G of Standard 90.1-2004 required that the vertical fenestration areas modeled in the baseline equal the vertical fenestration area of the proposed design or 40% of the gross above-grade wall area, whichever was smaller. For the baseline and proposed model, the amount and distribution of windows was taken off of the existing architectural drawings of the building. The fenestration area equaled 7.8% of the gross above – grade wall area.

The fenestration U-factor matched the appropriate requirements in Table 5.5-2 of Standard 90.1-2004 as well as solar heat gain coefficient (SHGC) for all orientations. The U-factor assembly maximum for climate zone 2A was 1.22 Btu/hr·ft^2·°F and the SHGC equaled 0.25. eQuest did not have an input for SHGC, but instead had an input for the shading coefficient (SC). Therefore, in order to input the appropriate SC, the SHGC was multiplied by a factor of 0.86 (ANSI/ASHRAE/IESNA, 2004b). The vertical glazing was modeled as fixed and flush with the exterior wall. No shading projections and no shading devices such as blinds or shades were modeled.

Air Infiltration

Standard 90.1 did not specify a requirement for maximum air infiltration rate. Chapter 16, *Ventilation and Infiltration*, of the 2009 Fundamentals Handbook discussed air infiltration in residential, commercial, and institutional buildings. Emmerich et al. (2005) studied the energy impact through improving building envelope air tightness in U.S. commercial buildings. For this analysis, the infiltration rate was derived from a starting point of 2.3 cfm/ft² of above-grade envelope surface area at 0.3 in. w.c. (Emmerich et al. 2005). This infiltration rate was based on testing buildings at greatly increased pressure difference than in normal operating conditions. An air infiltration schedule was applied to the model. The infiltration schedule assumed no infiltration occurred when the HVAC system was on, and infiltration occurred only when the HVAC system was off.

For input into eQuest, the infiltration rate at 0.3 in. w.c. was converted to a wind driven rate with an equation developed by Gowri et al. (2009). The infiltration rate can be calculated by equation 3-1,

$$I_{design} = (\alpha_{Bldg} + 1) I_{0.3w.c.} \left(\frac{0.5 C_s \rho U_H^2}{75} \right)^n \tag{3-1}$$

Where α_{Bldg} = terrain factor

$I_{0.3w.c.}$ = infiltration rate at 0.3. in. w.c.

C_s = surface pressure coefficient

ρ = air density

U_H = wind speed at building height

n = flow exponent

The resulting infiltration rate input into eQuest was calculated to be 0.2579 cfm/ft^2.

Internal and External Loads

Internal loads included heat generated from occupants, lights, miscellaneous equipment (plug loads). Plug loads included equipment such as computers, printers, copy machines, refrigerators, coffee makers, etc. Modeling the energy impacts of the building internal loads using the eQuest simulation program required assumptions about the building internal load intensity and operation schedules.

People

The 2003 CBECS data provided little information in regards to building occupancy in office buildings. ASHRAE Standard 62.1-2004 provided peak occupant density of 5 people per 1,000 ft^2 (ANSI/ASHRAE, 2004). Occupant density was derived from existing building furniture plans and from Standard 62.1-2004 for areas without a specified furniture plan. The peak occupancy of the small office prototype was calculated to be 67 people. It was assumed that the occupant activity level was 450 Btu/hr per person, including 250 Btu/hr sensible heat gain and 200 Btu/hr latent heat gain. These values represented the degree of activity in offices, moderate active office work and were derived from Table 1 of Chapter 18 in the ASHRAE 2009 Fundamentals Handbook (ASHRAE, 2009).

Lighting

Baseline lighting levels were determined by the Space-by-Space method and the corresponding lighting power densities in Table 9.6.1 of ASHRAE 90.1-2004 (ANSI/ASHRAE/IESNA, 2004a). Each space was assigned a light power density based on its use. Then the overall HVAC zone lighting power density was calculated by adding the power densities of the spaces in the corresponding zone and dividing by the HVAC zone area. Table 4-1 shows the power light densities of each HVAC zone. Table B-2 of Appendix B details lighting power density calculations.

Miscellaneous Equipment (Plug Loads)

Office buildings generally have plug loads pertaining to office equipment (computers, monitors, copiers, fax machines, printers, coffee makers, and beverage vending machines etc.). Plugs loads not only increase electrical usage, but also impact the sizing of the HVAC system.

To determine plug load density, a break-down plug load calculation was developed in accordance with ASHRAE's recommended heat gains from various office equipment and appliances (ASHRAE, 2009). The amount and type of equipment was assumed based on existing architectural drawings. Table 4-1 shows the plug load density summary for each HVAC zone. Table B-3 of Appendix B details the plug load density calculations.

Table 4-1. Lighting power density and plug load density by HVAC zone

Zone Name	Lights (kW)	Electric Plug and Process Loads (kW)
Team Area 1	0.83	0.71
Team Area 2	0.83	0.71
Team Area 3	0.83	0.71
Private Offices	1.51	1.71
Lobby Area	1.05	0.46
Conference Area	1.38	1.45
Suite B	1.44	1.76

Baseline Building Heating, Ventilation and Air-Conditioning Systems

Building HVAC Operating Schedule

The HVAC system operating schedule was based on building occupancy. The system was scheduled “on” two hours prior to occupancy to pre-condition the space. Then the system was scheduled “off” at 10 pm. When the system was “on”, the fan ran continuously to supply the required ventilation air, while the compressor cycled on and off to meet the building’s cooling and heating loads. During off hours, the system shut off and only cycled “on” when the setback thermostat control called for heating or cooling to maintain the setback temperature. A single HVAC system schedule was used for all the packaged units in the building. A detailed HVAC schedule can be found in Table B-1 in Appendix B.

HVAC Zoning and Heating and Cooling Thermostat Setpoint

The small office building was divided into seven thermal zones as described in Chapter 3. The HVAC systems maintained a 70°F (21°C) heating setpoint and 75°F (24°C) cooling setpoint during occupied hours. During off hours, thermostat setback control strategy was applied in the baseline prototype, assuming a 5°F temperature setback to 65°F for heating and 80°F for cooling.

HVAC Equipment Sizing

Section G3.1.2.2 of ASHRAE 90.1-2004 required that sizing runs for the HVAC system were to be oversized by 15% for cooling and 25% for heating. eQuest had two methods to size to size the HVAC equipment, annual-run method and design-day method. In the annual-run method, the program determined the corresponding design peak heating or cooling loads using weather file data. When using the design-day method, two separate design days were input, one for heating and one for cooling. The program determined the design peak loads by simulating the building for a 24-hour period on each of the design days. The design peak loads were used by the subprogram for sizing HVAC equipment. This study used the design-day method since it was general practice for HVAC system designers to size HVAC equipment.

The design day data for the climate location of Gainesville, FL was developed based on the weather data contained in the ASHRAE 2009 Handbook of Fundamentals (ASHRAE, 2009). In this data set, heating design day condition was based on the 99.6 annual percentile frequency of occurrence. The 99.6 annual percentile meant that the dry-bulb temperature equaled or was below the heating design conditions for 35 hours per year in cold conditions. Similarly, annual cooling design condition was based on dry-bulb temperature corresponding to 1% annual cumulative frequency of occurrence in warm conditions. A 1% value of occurrence meant that the dry-bulb temperature equaled or exceeded the cooling design conditions for 88 hours per year. Additionally, the range of the dry-bulb temperature for summer was in compliance with ASHRAE Standard 90.1-2004. In eQuest, design day schedules were also specified. To be consistent with general design practice for HVAC equipment sizing, the internal loads (occupancy, lights, and plug loads) were scheduled as zero on the heating design day, and as maximum level on the cooling design day.

HVAC Equipment Efficiency

Table G3.1.1A of ASHRAE 90.1-2004 Appendix G specified the required baseline HVAC system type for different building types. For this study, the small office building prototype baseline classified as a non-residential building under 75,000 ft^2. Accordingly, Appendix G specified for an electric heat source the baseline model be a PSZ-HP (Packaged Single Zone Heat Pump). Table G3.1.1B further specified the PSZ-HP to be a packaged rooftop heat pump, with constant volume fan control, direct expansion (DX) cooling, and electric heat pump heating.

Appendix G also required that the fan energy be modeled separately from the cooling energy. eQuest called for the cooling energy to be input as the energy input ratio (EIR) and a kW/cfm value for the fan energy for simulation. EIR was defined simply as the inverse of the coefficient of performance (COP) (Equation 4-2). To satisfy the requirements of the modeling method and determine the EIR and kW/cfm, an iterative spreadsheet calculation was developed.

$$EIR = 1/COP \tag{4-2}$$

To perform the iterative calculation, eQuest was run initially with default EIR values to size the HVAC system. From the system sizing reports, the gross cooling capacity, heating capacity, and supply air volume requirements for the HVAC zones were input into the spreadsheet. The spreadsheet then determined the kW/cfm value as the baseline fan power as required by Appendix G divided by the supply air volume determined by eQuest for each thermal zone. From the gross cooling and heating capacities and supply air volume, the spreadsheet subtracted the fan power from the cooling power calculated from the minimum cooling and heating efficiencies required by Section 6.4 of Standard 90.1-2004.

The kW/cfm values calculated were then entered into eQuest and the simulation reran to calculate the gross cooling and heating capacities again. The new cooling and heating capacities replaced the old values and the spreadsheet again calculated the EIR. The process was repeated until the gross cooling and heat capacities matched the calculated EIR.

Standard 90.1-2004 specified HVAC equipment efficiency based on heating and cooling capacities. For packaged single zone equipment with cooling capacities less than 65,000 Btu/h, cooling efficiency was rated by the seasonal efficiency ratio (SEER). The SEER represented the average efficiency of the system throughout the year. Cooling equipment with capacities greater than 65,000 Btu/h was rated by the energy efficiency ratio (EER). The EER represented the efficiency at a particular design condition. Similarly, for cooling capacities less than 65,000 Btu/h, the heating efficiency was rated by the heating seasonal performance factor (HSPF). The term HSPF is similar to SEER except it is used to signify the seasonal heating efficiency of heat pumps. For cooling capacities greater than 65,000 Btu/h, heating efficiency was rated by the COP.

In order for the spreadsheet to determine the proper cooling EIR to be input into eQuest, the minimum efficiencies from Standard 90.1-2004 were converted into COP (Equation 4-3). The EIR was then determined from the COP from equation 4-2 above. For equipment cooling efficiency rated by SEER, a conversion from SEER to EER was determined (Wassmer and Brandemuehl, 2006). Equation 4-4 converts the SEER rating into EER.

$$COP = \frac{EER}{3.413} \tag{4-3}$$

$$EER = -0.0182 \times SEER^2 + 1.1008 \times SEER \tag{4-4}$$

Similarly, for equipment heating efficiencies rated by HSPF, a conversion from HSPF to COP was calculated by equation 4-5 (Wassmer and Brandemuehl, 2006).

$$COP = -0.0255 \times HSPF^2 + 0.6239 \times HSPF \tag{4-5}$$

HVAC System Fan Power

System fan electrical power for supply, return, exhaust, and relief fans were calculated from equation 4-6 (ANSI/ASHRAE/IESNA, 2004a),

$$P_{fan} = \frac{746}{\left(1 - e^{-0.2437839 \times \ln(bhp) - 1.685541}\right) \times bhp} \tag{4-6}$$

Where P_{fan} = electric power to fan motor (Watts)

bhp = brake horsepower of baseline fan motor

The baseline fan brake horsepower equation is taken from Table G3.1.2.9 based on the supply air volume cfm and the system type. For a constant volume PSZ-HP with a supply air volume less than 20,000 cfm, the baseline fan motor brake horsepower was calculated from equation 4-7 (ANSI/ASHRAE/IESNA, 2004a),

$$17.25 + (cfm - 20{,}000) \times 0.0008625 \tag{4-7}$$

Table 4-2 summarizes the fan energy and cooling and heating EIRs input into eQuest for the baseline model. Detailed fan power calculations as well as the EIR for cooling and heating systems from the iterative calculation method can be found in Table B-4 in Appendix B.

Table 4-2. Fan energy, cooling EIR, and heating EIR baseline model summary

System	Supply Fan (kW/cfm)	Cooling EIR	Heating EIR
Office 1	0.000806	0.240	0.239
Office 2	0.000811	0.242	0.240
Office 3	0.000811	0.241	0.240
Private Offices	0.000780	0.268	0.395
Conference Area	0.000778	0.271	0.397
Lobby	0.000797	0.246	0.244
Suite B	0.000776	0.266	0.205

Outdoor Air Ventilation and Exhaust Rates

Outdoor minimum ventilation air requirements were determined as required by ASHRAE Ventilation Standard 62.1-2004 (ANSI/ASHRAE 2004). The Ventilation Rate Procedure prescribes ventilation rates for typical occupancy categories. The prescribed ventilation rates for the small office prototype was calculated as the sum of an occupant related component, expressed as volumetric airflow per person (cfm/person), and a building related component, expressed as a volumetric airflow per unit floor area (cfm/ft^2). The efficiency of the air distribution system in delivering outdoor air to the breathing zone of the space was explicitly included in the rate calculation method. The people outdoor air rate R_p, area outdoor air rate R_a can be found in Table 6-1 of ASHRAE Standard 62.1-2004 (ANSI/ASHRAE 2004). The air distribution effectiveness E_z can be found in Table 6-2 of the same standard. Equation 4-8

(ANSI/ASHRAE 2004) calculates the required airflow in cfm for a space corrected by the zone air distribution effectiveness.

$$V_{oz} = \frac{P_z R_p + A_z R_a}{E_z} \tag{4-8}$$

Where P_z = Room population (# of persons)

R_p = People outdoor air rate (cfm/person)

A_z = Room floor area (ft^2)

R_a = Area outdoor air rate (cfm/ft^2)

E_z = Air distribution effectiveness

Required minimum exhaust rates were taken from Table 6-4 of ASHRAE Standard 90.1-2004 and applied to the appropriate spaces. Table 4-3 summarizes the minimum ventilation required for each zone. Detailed ventilation and exhaust calculations are found in Table B-5 in Appendix B.

Table 4-2. Ventilation and exhaust rates by HVAC zone

Zone Name	Required Ventilation (cfm)	Exhaust (cfm)
Team Area 1	81.00	-
Team Area 2	81.00	-
Team Area 3	81.00	-
Private Offices	107.00	87.00
Lobby Area	77.00	100.00
Conference Area	181.00	26.00
Suite B	150.00	76.00

Economizer Use

Appendix G of Standard 90.1 specified economizer use based on system type and climate location. For climate location zone 2A, an economizer was not required to be modeled in the energy simulation.

Service Hot Water System

The baseline service hot water system for the small office building was assumed as an electric storage water heater. The equipment met the minimum efficiency requirements under ASHRAE Standard 90.1-2004. The hot water supply temperature was assumed to be 120°F.

In order to estimate the energy performance of a service hot water heater with a storage tank, eQuest required the user to define the following key input variables as operating parameters:

- Rated storage tank volume
- Peak hot water flow rate
- Hot water use schedule
- Maximum heater capacity
- Standby heat loss coefficient (UA)
- Heater thermal efficiency

Hot Water Usage

The typical hot water use for office buildings was assumed to be 1 gallon per person per day, derived from Chapter 49, *Service Water Heating*, in ASHRAE Applications Handbook (ASHRAE, 2007). Based on the maximum occupancy schedule, this resulted in a daily maximum hot water consumption of 67 gallons per day for the small office building prototype. To determine the peak water flow rate in gpm, the daily hot water consumption was divided by the operating hours for the day, which was 8 full load hours. Thus, the peak hot water flow rate was calculated as 0.447 gpm.

Storage Tank Size

The water heat storage tank volume was sized based on the methodology described in the 2007 ASHRAE Applications Handbook (ASHRAE, 2007). For a usable storage capacity of 0.6 gallons per person for 67 people, the total usable storage capacity was 40 gallons. The actually storage tank size was increased by 25% to compensate for unusable hot water, which was calculated to be a total storage capacity of 50 gallons.

Input Power and Standby Heat Loss Coefficient

For electric water heaters, the minimum efficiency required by ASHRAE Standard 90.1-2004 was expressed as the Energy Factor (EF). Equation 4-9 calculates the EF for an electric water heater as

$$EF = 0.93 - 0.00132 \times V \tag{4-9}$$

Where V = Tank storage volume

Water heater characteristics were obtained from Energy Efficiency Standards for Consumer Products: Residential Water Heaters (DOE, 2000). The document modeled and analyzed energy efficiency features in electric and gas water heaters. For a 50 gallon electric water heater, the baseline model had an energy recovery factor of 0.86, which met the minimum energy factor in Standard 90.1-2004. The baseline model also had a recovery efficiency of 98% and a heat loss coefficient UA of 3.64 Btu/hr·°F. Two heating elements were modeled with a power consumption of 4.50 kW each and 100% efficiency.

CHAPTER 5
PROPOSED MODEL DEVELOPMENT

The proposed office building model was developed by modifying the baseline model with energy efficiency measures (EEMs). The measures aimed to reduce the internal heat loads and energy usage of the baseline model and then meet the heating and cooling requirements of the reduced loads model through more efficient HVAC strategies. Two rules were developed to guide the identification of energy efficiency measures. First, the EEMs had to be based on technologies that were commercially available. Also, eQuest had to have been capable of modeling the EEMs directly or via an equivalent approach. Together, the EEMs identified had to have been able to achieve a whole building energy savings ranging from 50% to 70%. After such savings were achieved, an on-site photovoltaic system was sized to meet the reduced loads model's annual energy needs.

The EEM concepts were developed from the sources discussed in Chapter 2. All EEMs were grouped into the following five categories:

- Building envelope measures
- Lighting measures
- Plug load measures
- HVAC measures
- Service water heating measures

Although any combination of EEMs could achieve the same goal, it was not the intent of this study to find the optimum combination. This section describes the EEMs that were implemented in the proposed model that demonstrated and met the criteria for energy savings in eQuest.

Building Envelope Energy Efficiency Measures

Enhanced Wall Assembly

Improving the thermal performance of the wall assembly was explored to reduce heating and cooling loads. A high performing wall assembly kept heat inside the building during the heating season and kept heat outside of the building during the cooling season. In order to determine the optimal amount of additional insulation to add to the wall assembly, the U-value of the wall assembly was increased incrementally based on the effective assembly U-values found in Appendix A of 90.1-2004. The energy savings gained by the added insulation was correlated to its U-value. Figure 5-1 shows energy savings correlated with increasing R-value.

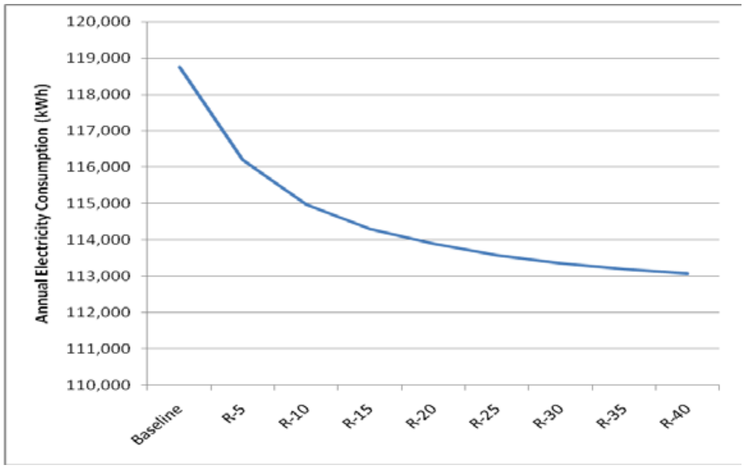


Figure 5-1. Correlation between annual building energy consumption and added wall insulation.

For the proposed mode, R-20 insulation was added as additional insulation to the baseline model wall assembly. Further measures were taken to improve the performance of the wall assembly by reducing infiltration. An air barrier was added to the wall assembly to reduce infiltration of the baseline model. Emmerich et al. (2004) determined an infiltration rate of 0.24 cfm/ft^2 at 0.3 in. w.c. was a level of airtightness achievable through good construction practice. Thus, 0.24 cfm/ft^2 was selected as the infiltration rate for the proposed model. For input into eQuest, the infiltration rate was converted, as discussed in Chapter 4, to 0.0269 cfm/ft^2.

Cool Roof

To reduce the cooling load in a hot and humid climate, a cool roof was added to the building roof assembly. By reflecting solar energy, a cool roof reduced the require size of the HVAC system. The modeled cool roof for the advanced design was a light colored reflective roof membrane with a solar reflectance of 0.7. Conversely, the modeled roof for the baseline model had a solar reflectance of 0.3. Furthermore, additional insulation was explored for added energy savings. However, adding additional roof insulation resulted in minimal energy savings. The roof assembly insulation remained the same as the baseline model.

High Performance Windows and Shading Devices

The advanced model maintained the same window area as the baseline mode, but window constructions were improved in terms of U-factor and SHGC value. Double-pane low emissivity glass was modeled in the advanced along with permanent shading devices. The argon filled double-pane windows had a center of glass U-factor of 0.24 Btu/hr·ft^{2}·°F, a SHGC of 0.43 and a visual transmittance of 0.7.

Window overhangs were implemented as a passive solar design strategy for south-oriented facades. Overhangs limited the solar gain during the summer months while allowing solar gain during the winter months. The overhangs were designed to completely shade the south-oriented fenestrations during the summer solstice, where the sun was at its highest during the year.

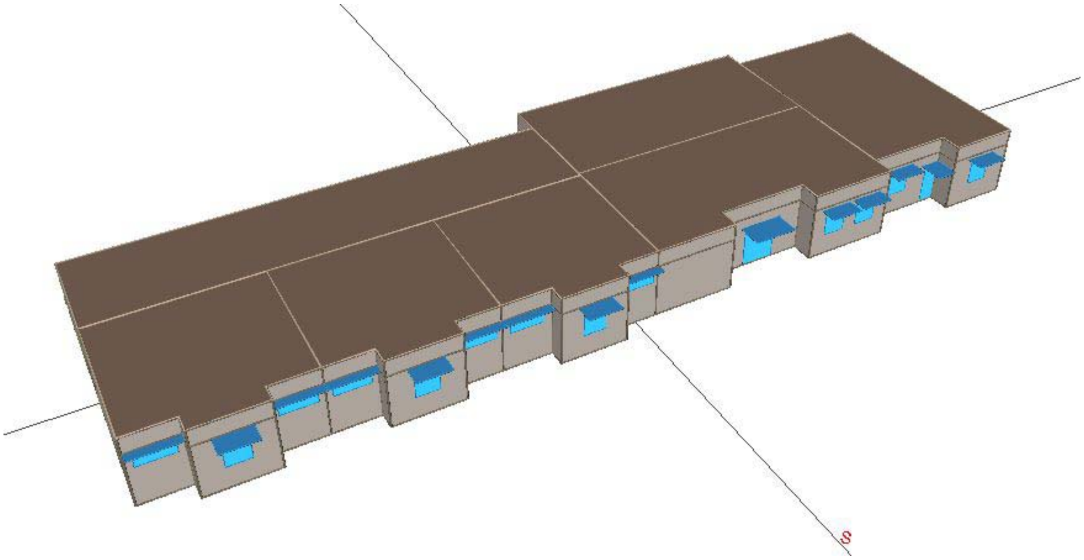


Figure 5-2. Proposed model with the addition of window overhangs on the south façade.

Lighting Energy Conservation Measures

Reduced Interior Lighting Power

After a review of the literature, it was determined that T8 lamps were the more dominate fluorescent fixture type than T5 lamps. Although solid state lighting provided far better energy savings compared to fluorescent lamps, the technology was not yet marketable or cost effective (Kendall, 2001).

To model the lighting power required by T8 lamps, the number of lamp fixtures per room were estimated based on existing architectural drawings. The T8 lamps were assumed to consume 32 watts per lamp. Then the total lamp wattage was calculated per zone.

Occupancy Sensor Control

Appendix G of ASHRAE Standard 90.1-2004 allowed for a 10% power adjustment for occupancy sensor control for the small office building proposed model. Occupancy sensors were modeled in all occupied spaces. To model occupancy sensor control, the lighting power for each area with occupancy sensor control was reduced by 10%. Table 5-1 compares the lighting power of the proposed model with occupancy control and T8 lamps versus the lighting power of the baseline model.

Table 5-1. Lighting power of baseline model and proposed model

HVAC Zones	Baseline Model Total Watts (kW)	Proposed Model Total Watts (kW)
Team Area 1	0.8290	0.5184
Team Area 2	0.8290	0.5184
Team Area 3	0.8290	0.5184
Private Office Area	1.5134	1.5840
Lobby Area	1.0546	0.7488
Conference Area	1.3840	1.2096
Suite B	1.4425	1.1520
Total	7.8815	6.2496

Daylight Harvesting

Daylight sensors were modeled in perimeter spaces with automatic dimming controls to take advantage of available daylight to reduce electrical energy consumption while maintaining desired levels of illumination. Interior shading devices were also modeled for the advanced model. The baseline model did not include interior shading devices as dictated by Appendix G of Standard 90.1-2004. Interior shading devices were closed when the glare index was above the setpoint of 22, typical for offices. The glare index was the ratio of window luminance to the average surrounding surface luminance within the view field.

Daylight sensors were placed two-thirds the depth of the perimeter spaces and half the length inward at a height of 2.5 ft. All of the ambient lighting in the spaces zone was dimmed in response to daylight. The dimming control system had an illuminance setpoint of 50 footcandles, typical for desk work. Dimming controls were continuous, which could dim down to 10% of maximum light output with a corresponding 10% of maximum power input. Table C-1 of Appendix C shows further details in the proposed lighting model calculations.

Miscellaneous Equipment (Plug Loads) Measures

According to the CBECS survey, plug loads in office buildings accounted for 25% of total onsite energy consumption. In the baseline model, plug loads accounted for 24% of total building energy use. However, as other building systems became more efficient, that percentage became even higher. Plug loads affected the cooling loads and heating loads of the building due to internal heat gains.

In order to reduce the plug load energy usage, Energy Star rated equipment were implemented in the advanced model. A savings calculator provided by the Energy Star website for each equipment category (computers, monitors, copy machines, fax machines, water coolers, and refrigerators) was used to calculate the energy savings compared with non-compliant Energy Star equipment (EPA, 2009). The percentage savings was used as a savings factor to calculate the new plug load.

To further reduce plug load energy usage, a strategy of shifting from using energy intensive desktop computers to energy efficient laptop computers was implemented. All desktops in the baseline case were changed to laptop computers. Table 5-2 compares the baseline plug loads to the new calculated advanced model plug loads. Table 5-3 shows the percent reduction in equipment power to Energy Star labeled rated equipment. Detailed plug load calculations can be found in Table C-2 of Appendix C.

Table 5-2. Plug load of baseline model and proposed model

HVAC Zone	Baseline Model Plug Load (kW)	Proposed Model Plug Load (kW)
Team Area 1	0.707	0.384
Team Area 2	0.707	0.384
Team Area 3	0.707	0.384
Private Office Area	1.706	1.369
Lobby Area	0.458	0.242
Conference Area	1.452	1.049
Suite B	1.76	1.375
Total	7.497	5.187

Table 5-3. Percent reduction of Energy Star equipment

Office Equipment Inventory	Peak Power (W)	Energy Reduction	Energy Star Peak Power
Computers - servers	65	33%	43.55
Computers - desktop	65	33%	43.55
Computers - laptop	40	33%	26.8
Monitors - LCD	36	22%	28.08
Laser printer - desktop	110	33%	73.37
Copy machine (large)	1100	7%	1023
Multifunction	135	50%	67.5
Fax machine	20	50%	10
Water cooler	350	45%	192.5
Refrigerator	76	20%	60.8
Vending machine - snack	275	53%	129.25

HVAC System Measures

There were numerous types of HVAC systems and strategies to reduce energy consumption in the advanced model. For this study, a geothermal ground source heat pump system serving each zone was modeled. In addition to the geothermal heat pump system, a dedicated outdoor air system (DOAS) with energy recovery ventilation (ERV) was modeled to provide ventilation air to the building.

Geothermal Heat Pump System

A geothermal ground source heat pump system was used in each thermal zone to satisfy the heating and cooling loads. Geothermal heat pumps (GHPs) have been proven a capable technology to reduce energy usage and peak demand in buildings (ASHRAE, 2006). Hundreds of millions of dollars were spent annually on more expensive renewable energy technologies than GHPs, such as power generation from solar, wind, geothermal, and biomass resources, as well as on strategies to reduce our dependence on foreign oil (Hughes, 2008). Aggressive installation of GHP's could avoid the need to build 91 to 105 GW of electricity generation capacity, or 42 to 48 percent of the 218 GW of net new capacity additions projected to be needed nationwide by 2030 (Hughes 2008). $33 to 38 billion annually in reduced utility bills at 2006 rates could be achieved through aggressive GHP installation (Hughes, 2008). Over the last several decades GHP systems have gradually improved and been incorporated into the systems for heating, cooling, and water heating equipment for U.S. buildings.

The GHP system for this study utilized the natural properties of the earth to provide heating and cooling to the advanced model building. The system design was a vertical closed loop system, having a dedicated fluid loop that was circulated through the ground in order to exchange heat. Earth temperature had a significant effect on the performance of the GHP system. The suitability of the earth as a heat source or sink for a GCHP system was greatly influenced by the soil thermal characteristics. For this study, several assumptions about the soil thermal properties were made. The ground soil's thermal diffusivity was assumed to be 0.030 ft^2/hr and thermal conductivity to be 1.270 Btu/h·ft·°F. The earth's undisturbed temperature was estimated using a groundwater temperature profile map of the United States. For Gainesville, FL, the undisturbed ground temperature was assumed to be 72°F.

The most important factor to the design and operation of the GHP system was the rate of heat transfer between the working fluid in the GHP and the surrounding soil. Heat transfer between the GHP and its surrounding soil was rather complicated and difficult to model for the purpose of sizing GHP's or for energy analysis of the system. Structural and geometrical configuration of the system, ground temperature distribution, soil moisture content and its thermal properties, groundwater movement, and possible freezing and thawing in soil were among the many factors that influenced performance. Models of varying complexity have been presented for practical applications in design and performance prediction of GHP's. Most of the design and simulation programs require monthly building loads and provided monthly average ground loop entering and exiting temperatures of the heat transfer fluid.

A good number of the analytical design approaches were based on Kelvin's line source theory or its derivations by Ingersoll et al. (Bose et al., 1985). The line source approach approximated the ground loop borehole as an infinitely long line with radial heat flow in a uniform, continuous infinite media. The expression is:

$$T - T_o = \frac{Q'}{2\pi k_s} \int_{\frac{r}{2\sqrt{\alpha t}}}^{\infty} \frac{e^{-\beta^2}}{\beta} d\beta = \frac{Q'}{2\pi k_s} I(x) \qquad (5\text{-}1)$$

Where Q' = Heat input, to line source, Btu/h· ft (W/m)
T = Temperature at distance r, F (°C)
T_o = Undisturbed earth temperature, F (°C)
r = Radial distance to line source, ft (m)
t = Time, hours
β = Variable of integration
$I(x)$ = Values of the integral

To estimate the length of tube required for the ground heat exchanger, the required ground heat exchanger length calculated based on heating requirements L_H is:

$$L_H = q_{d,heat} \left[\frac{\frac{COP_h - 1}{COP_h}\left(R_p + R_s F_h\right)}{T_{g,\min} - T_{ewt,\min}} \right] \qquad (5\text{-}2)$$

Where $q_{d,heat}$ = Design heating load
COP_h = Design heating coefficient of performance of the heat pump
R_p = Pipe thermal resistance
R_s = Soil/field thermal resistance
F_h = GHX part load factor for heating
$T_{g,\min}$ = Minimum undisturbed ground temperature
$T_{ewt,\min}$ = Minimum design entering water temperature at the heat pump

A similar equation estimated the required length L_C based on cooling requirements:

$$L_C = q_{d,cool}\left[\frac{\frac{COP_c - 1}{COP_c}\left(R_p + R_s F_c\right)}{T_{ewt,\max} - T_{g,\max}}\right] \tag{5-3}$$

Where $q_{d,cool}$ = Design cooling load

COP_c = Design cooling coefficient of performance of the heat pump

F_c = GHX part load factor for cooling

$T_{g,\max}$ = Maximum undisturbed ground temperature

$T_{ewt,\max}$` = Maximum design entering water temperature at the heat pump

The load factor was defined as the ratio of the heat pump run hours divided by the time period. A run fraction of 50% would represent a heat pump run time of 360 hours in a 720 hour month. The subscript C or H specified cooling or heating.

Equations 5-2 and 5-6 were simplifications and do not take into consideration long-term thermal balances that could alter the soil temperature field over a period of many years. To accurately account of long-term thermal soil temperature balance, GS2000 v3, a ground heat exchanger sizing software developed by Caneta Research, Inc., was utilized to calculate the heat exchanger size required for the advanced model.

The ground heat exchanger system design was composed of 20 boreholes in a 4 x 5 borehole field configuration spaced 20 ft apart. Each borehole contained high density polyethylene (HDPE) single U-tubes. Boreholes were 6 in. in diameter with U-tubes sized at ¾ in. nominal diameter. Each borehole depth was 212 ft. The holes were backfilled with grouting have a thermal conductivity of 0.85 Btu/h·ft·°F. Grouting was required to prevent contamination of the ground water and give better thermal contact between the pipe and the ground. The land area required by the heat exchanger field was 4,800 sq. ft.

Heat pump efficiencies of the geothermal system were based on geothermal heat pumps manufactured by ClimateMaster Inc. Table 5-4 lists the characteristics of the selected geothermal heat pumps.

Table 5-4. Performance characteristics of geothermal heat pumps

System	Nominal Cap (Tons)	Cooling Capacity (Btu/hr)	Heating Capacity (Btu/hr)	Cooling Effiency (EER)	Heating Efficiency (COP)
Office 1	1	12,300	9,500	18.1	5.3
Office 2	1	12,300	9,500	18.1	5.3
Office 3	1	12,300	9,500	18.1	5.3
Private Offices	2	26,000	19,400	20.0	5.0
Conference Area	3	34,600	25,800	20.2	5.9
Lobby	1	12,300	9,500	18.1	5.3
Suite B	3	34,600	25,800	20.2	5.9

Dedicated Outdoor Air System

A dedicated outdoor air system (DOAS) was used to condition and deliver the required minimum outdoor ventilation air to each individual zone. Outdoor ventilation airflow for the proposed model was equivalent to the baseline model. The DOAS setup consisted of an enthalpy wheel, a cooling coil, a heating coil and a supply fan.

The DOAS allowed for a centralized location of outdoor air intake and the use of a single ERV to pretreat incoming outdoor air. For the advanced model, the DOAS fans were run continuously to meet outdoor air requirements while the zone heat pump fans were cycled on and off to meet the loads of its dedicated zone. Contrarily, the baseline model had to have all its fans run continuously to meet outside air requirements.

The DOAS supply air temperature was maintained at 55°F (12.8°C). The system provided the minimum outdoor ventilation air required when the building was occupied. The ERV reclaimed energy from exhaust airflows to precondition the outdoor ventilation air. Both heat and moisture were able to be transferred between exhaust air and outdoor air streams. The sensible and latent effectiveness of the energy recovery was 76 and 74, respectively. The cooling efficiency of the DOAS was assumed to be 14.0 SEER.

Service Water Heating Measures

Service water heating in office buildings used little energy in the overall total energy usage. In order to heat service hot water in the advanced model, the task was transferred from a traditional electric water heater to the geothermal heat pump system. This was done with the addition of a desuperheater to the geothermal heat pump system. eQuest did not have the capability to explicitly model a desuperheater. Instead, the hot water demand was modeled as a process load on the circulation loop of the geothermal heat pump system and was to be able to meet the annual hot water demands of the building.

On-Site Energy Generation

In order to meet the on-site energy needs of the advanced mode, a rooftop photovoltaic system was modeled to provide the yearly electrical energy needs of the office building. PV Watts v2.0, a web based calculator provided by the National Renewable Energy Laboratory, calculated the yearly electrical energy production of a photovoltaic system in Gainesville, FL.

A holistic approach was used to size the photovoltaic system. An initial system size was input into the calculator. Then the system size was increased incrementally until the electrical energy production for the year satisfied the office building’s energy needs. The photovoltaic system size for the office building was initially chosen to be 40 kW. Facing due south and tilted to the building’s latitude, the system produced 52,184 kWh of electrical energy per year, with a DC to AC de-rate factor of 0.77. The results of the photovoltaic system simulation are found in Table 5-5.

PV Watts had a built in PV system efficiency of approximately 10%. Higher PV system efficiencies for several sized PV systems were calculated ranging from 10% to 25% in 5% increments. The results of the PV system efficiency calculations are shown in Figure 5-3.

Table 5-5. PV Watts v2.0 PV simulation results

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
1	4.33	3892
2	4.76	3856
3	5.6	4954
4	6.14	5179
5	5.79	4879
6	5.43	4391
7	5.43	4560
8	5.28	4408
9	5.23	4282
10	5.13	4426
11	4.4	3752
12	4.03	3605
Year	5.13	52184

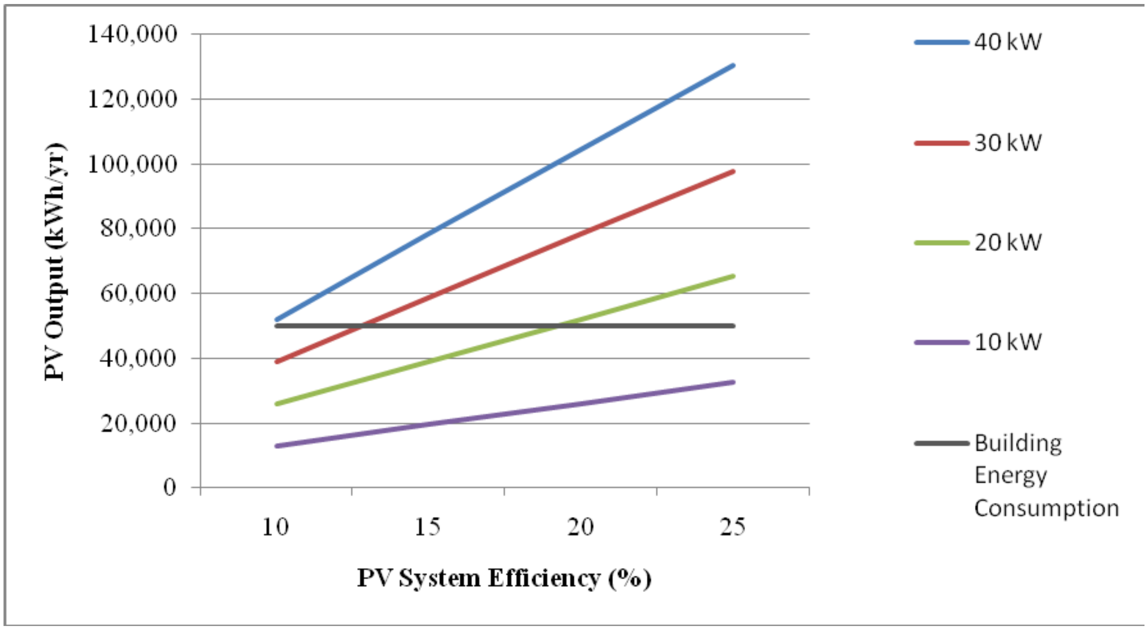


Figure 5-3. PV system efficiency range and output

CHAPTER 6
SIMULATION RESULTS

Baseline Model Energy Simulation Results

The baseline model of a small office building located in Gainesville, FL was modeled to meet the requirements of the ASHRAE 90.1-2004 Appendix G Performance Rating Method. The baseline building contained many of the same features as the proposed model, with the exception that building envelope, HVAC system parameters, and other components that were targeted for energy saving measures. This allowed for a reliable comparison of the energy use between the two models and provided a way to accurately credit energy-saving features in the proposed building. It was important to remember that some of the energy uses and building features in computer energy models will not exactly mirror real-life conditions. However, the purpose of the ASHRAE Performance Rating Method was to evaluate the impact of building and system design choices on energy consumption.

Table 6-1 shows the annual energy end-use breakdown for the small office baseline model. Appendix G of Standard 90.1-2004 required the building be simulated in its original orientation and then rotated 90, 180, and 270 degrees. The results of the simulations were then averaged. The building had an energy use intensity (EUI) of 56.3 kBtu/ft^2. Note that this figure represented site energy use and does not account for losses due to transmission and production at the source. According to the 2003 CBECS survey, the average EUI for small office buildings, defined as having floor areas of approximately 5,500 ft^2, was 79.9 kBtu/ft^2.

Figure 6-1 shows a graphical view of the energy end-uses for the small office baseline model. Fan energy use accounted for 28% of the total electricity consumption. The next largest consumers of electricity were miscellaneous equipment (plug loads), cooling systems, and lighting which accounted for 24%, 20% and 18% of total electricity consumption, respectively.

Heating systems made up the next largest portion of electricity use at 6%. The rest of the small office energy consumption profile was made up of heating hot water and supplemental heat pump energy, which accounted for a small fraction of total electrical energy consumption.

Table 6-1. Annual energy end-use breakdown of the baseline model

Components	Electricity (kWh)	Total (kBtu)
Space Cool	23,543	80,351
Space Heat	6,745	23,021
HP Supp.	315	1,075
Hot Water	5,720	19,522
Vent. Fans	33,495	114,318
Pumps & Aux.	200	683
Misc. Equip.	28,550	97,441
Area Lights	22,280	76,042
Total	120,848	412,453

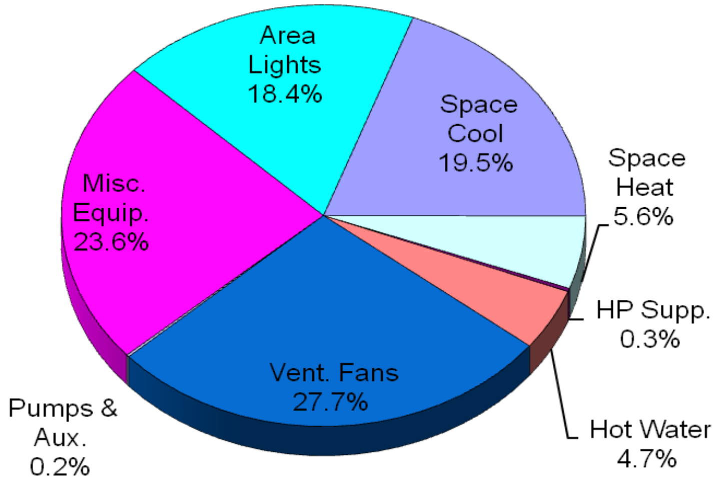


Figure 6-1. Annual energy end-use percentage of baseline model

The annual utility cost for the small office baseline model was $8,459. Electricity costs made up 100% of the baseline model’s utility costs. The electricity rate was based on the local utility provider’s rate of $0.07/kWh. No demand charges or time of day charges were applied to the baseline model. Appendix D details the energy use calculations of the small office baseline model.

Advanced Model Energy Simulation Results

The small office building proposed model represented the energy conservation measures outlined in Chapter 5. Table 6-2 shows the annual energy usage by end-use for the proposed model. The proposed building had an annual energy use intensity (EUI) of 23.4 kBtu/ft^2. Without on-site energy generation, this represented a 59% reduction in energy use from the baseline building. Annual utility costs for the proposed model without the photovoltaic system were $3,506.

With the addition of a 40 kW photovoltaic system, the percentage improvement in energy use was 102%, meaning the proposed model produced more energy than was necessary and eliminated all annual utility costs. The total carbon dioxide emissions due to the small office building were reduced by 102% from the baseline to the proposed design. This represented an avoidance of approximately 165,000 lbs of CO2 emissions and was an important metric in the growing movement to reduce the carbon footprint of buildings and institutions worldwide. Higher efficiency PV systems could allow for a smaller PV system, reducing the footprint of the system on the roof of the building. From the on-site energy generation analysis performed, a 30 kW PV system with a 15% efficiency or a 20 kW PV system with a 20% efficiency could also generate enough electricity to satisfy the proposed small office building’s energy needs.

Figure 6-2 shows the breakdown of total energy consumption in the proposed model. Space cooling experienced a 72% improvement in energy use, primarily due to the reduction internal loads, improved envelope characteristics, and use of more efficient HVAC system. Along with space cooling, the space heating energy was reduced by 84%. With lower cooling and heating loads, fan energy improved by 81%. Interior lighting improved by 50% and miscellaneous equipment (plug loads) improved by 23%. With increased energy conservation measures in building systems, total energy consumption for the proposed model was now dominated by miscellaneous (plug loads) equipment and interior lighting energy, constituting 44% and 22%, respectively, of total energy consumption. Space cooling, space heating, fan energy, and pump energy comprised 13%, 2%, 13%, and 6% of total building energy consumption, respectively.

Table 6-2. Annual energy end-use breakdown of the proposed model

Components	Electricity (kWh)	Electricity (kBtu)
Space Cool	6,600	22,526
Space Heat	1,050	3,584
HP Supp.	0	0
Hot Water	0	0
Vent. Fans	6,430	21,946
Pumps & Aux.	2,910	9,932
Misc. Equip.	22,010	75,120
Area Lights	11,080	37,816
Total	50,080	170,923

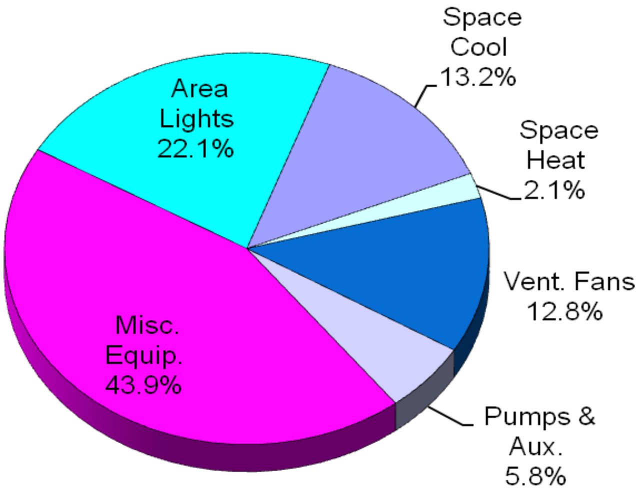


Figure 6-2. Annual end-use percentage of proposed model

CHAPTER 7
COST ANALYSIS

A life cycle cost (LCC) analysis was performed to determine the economics of additional costs incurred by the proposed package of energy efficiency measures versus the baseline. The Building Life Cycle Cost program developed and provided by the National Institute of Standards and Technology (NIST) was utilized to calculate life cycle cost. LCC estimates were calculated in present-value dollars, where all futures costs were discounted to a present value as of the base date and summed to arrive at the total life-cycle cost of the proposed package. The analysis assumed a project life of 20 years and a 3.0% real discount rate. Operations and maintenance costs were not included into the LCC estimates. Energy escalation rates were based on energy price projections provided by DOE's Energy Information Administration (EIA).

Cost estimates were based on several sources. One of the most widely accepted sources of construction cost information was the RS Means Guide (2009), which was utilized for much of the cost estimating. Other sources utilized for cost information were from published reports and online information. Unfortunately, conflicting sources of information yielded dramatic differences in cost. The total building cost was estimated using data from the 2009 RS Means Building Construction Guide. For the small office building in this study, the total construction cost estimate was calculated to be \$118.80/ft^2, for a total building construction cost of \$869,616. The general approach was to take a conservative estimate when confronted with various or vague cost estimates. Details in the cost estimate calculations are found in Appendix F.

Two main cost scenarios were explored for this study. The first cost scenario explored costs of only the proposed package of EEMs that were analyzed in this study, while the second cost scenario determined the costs of a solar PV system. A baseline LCC established the LCC of the baseline case, where no upfront costs were incurred. The calculated LCC of the baseline scenario was $138,713. For the case of scenarios with a PV system, it was assumed the selected PV system generated all the building's annual energy requirements. No federal or state tax credits were added to the cost calculations.

The first cost scenario calculated the LCC of the proposed energy savings package without the addition of the PV system. Before the addition of a PV system, the additional cost of the proposed EEM package was 5.3% of the total building cost, with a LCC of $103,172. Compared to the baseline, the proposed package saved $35,541 over the twenty year study period. The second cost scenario added the cost of a PV system that generated all the proposed small office building's needed energy for the year. The cost of PV installation was assumed over a range of costs, ranging from $10/W to $2/W in $2/W increments. The PV systems that were discussed earlier were selected for cost analysis. Table 7-1 and Table 7-2 summarize the cost calculations.

Table 7-1. Summary of proposed package LCC analysis

Package	Additional Cost	% of Building Cost	Annual Energy Savings	LCC	Simple Payback
Baseline	$ -		$ -	$ 138,713	-
Package w/o PV	$ 45,690	5.3%	$ 4,953	$ 103,172	9.22

Table 7-2. Summary of PV system LCC analysis (including proposed package costs)

Package	Additional Cost	% of Building Cost	Annual Energy Savings	LCC	Simple Payback
Baseline	$ -		$ -	$ 138,713	-
40 kW (10% efficient)					
($10/W)	$ 444,842	54%	$ 8,206	$ 444,842	54.21
($8/W)	$ 364,842	42%	$ 8,206	$ 364,842	44.46
($6/W)	$ 284,842	33%	$ 8,206	$ 284,842	34.71
($4/W)	$ 204,842	24%	$ 8,206	$ 204,842	24.96
($2/W)*	$ 124,842	14%	$ 8,206	$ 124,842	15.21
30 kW (15% efficient)					
($10/W)	$ 344,842	40%	$ 8,206	$ 344,842	42.02
($8/W)	$ 284,842	33%	$ 8,206	$ 284,842	34.71
($6/W)	$ 224,842	26%	$ 8,206	$ 224,842	27.40
($4/W)	$ 164,842	19%	$ 8,206	$ 164,842	20.09
($2/W)	$ 104,842	12%	$ 8,206	$ 104,842	12.78
20 kW (20% efficient)					
($10/W)	$ 244,842	28%	$ 8,206	$ 244,842	29.84
($8/W)	$ 204,842	24%	$ 8,206	$ 204,842	24.96
($6/W)	$ 120,000	14%	$ 8,206	$ 120,000	14.62
($4/W)	$ 80,000	9%	$ 8,206	$ 80,000	9.75
($2/W)	$ 40,000	5%	$ 8,206	$ 40,000	4.87

CHAPTER 8
CONCLUSIONS

Design and Energy Analysis

The design and energy use analysis of a small office building located in the hot and humid climate of Gainesville, Florida was performed for this study. A baseline of building energy performance was established based on the Performance Rating Method established by Appendix G in ASHRAE Standard 90.1. To reduce energy consumption of the baseline office building, energy efficiency measures (EEMs) were applied to the baseline design and the resulting energy savings were determined from energy modeling analysis with eQuest utilizing the DOE-2 engine. With an energy savings target between 50% and 75% over the baseline, energy savings gained by the proposed package of EEMs were 59% over the baseline small office building. The remaining annual energy needs of the proposed office building were met by the addition of a 40 kW rooftop PV system.

Determining which EEMs were implemented was based on published design guides as well as research papers on building energy saving methods. EEMs, however, were limited to currently market available products as well as building form. No attempt was made to redesign the architecture of the building envelope. Although some measures may have been a better choice from an energy savings standpoint, many of these measures were still in the research stage and not as yet widely accepted by industry. Modeling EEMs was a simple matter of implementing the EEM into the model and analyzing its energy savings. Although each individual EEM had varying degrees of energy savings, any combination of EEMs may have saved an equal amount of energy.

Analysis of EEMs was also limited by the energy modeling program itself. Available energy modeling programs were limited by their ability to model building technologies. Usually, the latest technologies would not be available in modeling software. Though, from experience, it seemed eQuest was gaining popularity over established proprietary software, such as Trane Trace or Carrier HAP, within the growing field of energy modeling due to its easy to use graphical interface and cost free availability to the public.

Life Cycle Cost Analysis

After a proposed package of EEMs was established, an economic analysis was performed to determine additional costs required by the chosen energy efficiency measures and life cycle cost (LCC). Two scenarios explored cost implications with and without a PV system. The proposed EEM package with a GSHP system had a LCC than the baseline and was considered cost effective. Addition of a PV system cost increased LCC dramatically. A few PV systems had an attractive LCC, but only when the cost of PV was at $2/W. However, with a high efficiency PV system, such as the 20 kW, 20% efficient PV system, PV system costs of $6/W and $4/W were cost effective. The addition of federal and state tax credits given to solar PV systems as well as GSHP systems made the LCC of the analyzed systems even more attractive. Excess electricity generated from the PV system was not considered, however, could be more favorable if the right economics were in place to sell excess electricity where the building was located. If energy reduction goals were met above and beyond the achieved 59% energy savings, the size of and, consequently, cost of the PV system would be reduced even further, making the path to net-zero more cost effective.

Recommendations for Future Research

The goal to achieve cost effective net-zero energy buildings is hindered by cost itself. However, finding the optimal cost effective energy saving strategy for a particular location can be a daunting task. Research into automated optimal designs through energy modeling simulations can provide a deeper understanding of the trade-offs between EEMs. Automated optimization tools can evaluate individual energy measures and determine the marginal benefit and cost of each measure in various combinations of measures for any particular location. Automated optimization would require increased computing power, but would likely be a welcome design tool for the energy modeler.

Other potential EEMs are worth considering and some already evaluated could be further refined. The new and refined measures have the potential to achieve the goal of net-zero in a more cost-effective manner or to achieve even more onsite energy savings. Research into potential EEMs could include:

- Building form and orientation - Determine the range of savings for different configurations including options for more constrained sites.
- Daylight harvesting - Investigate most cost-effective ways to provide toplighting and sidelighting.
- Window shading - Consider advanced window shading measures for better control of cooling loads while supporting daylighting.
- Window area - Investigate optimal window areas for the combined impact on heating, cooling and daylighting.
- HVAC controls – HVAC control strategies that control heating and cooling setpoints based on occupancy
- Alternative radiant/convective systems - Systems for office buildings include chilled ceiling panels, chilled beam, and radiant floors. Determine if reasonable opportunities exist for smaller buildings to incorporate chillers and boilers.

APPENDIX A
SMALL OFFICE FLOORPLAN AND ROOM DESCRIPTIONS

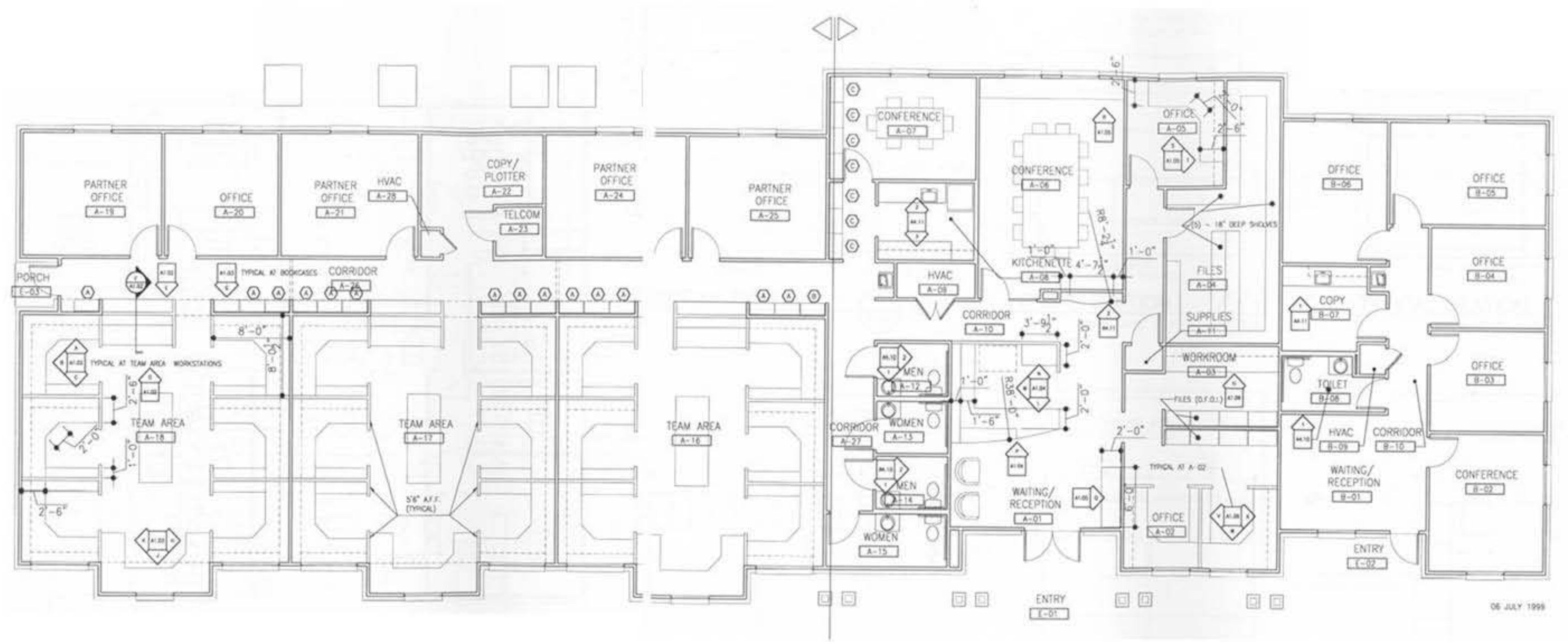


Table A-1. Small office building room descriptions

Room Name	**Room Area (ft^2)**	**Room Number**	**HVAC Zone Group**
Waiting/Reception	352	A-01	Lobby Area
Office	282	A-02	Lobby Area
Workroom	103	A-03	Lobby Area
File Room	255	A-04	Conference Area
Office	113	A-05	Conference Area
Conference	354	A-06	Conference Area
Conference	166	A-07	Conference Area
Kitchenette	84	A-08	Conference Area
HVAC	35	A-09	Conference Area
Corridor	118	A-10	Conference Area
Supplies	13	A-11	Lobby Area
Men's Room	43	A-12	Lobby Area
Women's Room	42	A-13	Lobby Area
Men's Room	41	A-14	Lobby Area
Women's Room	64	A-15	Lobby Area
Team Area	754	A-16	Team Area 1
Team Area	754	A-17	Team Area 2
Team Area	754	A-18	Team Area 3
Partner Office	188	A-19	Private Offices
Office	158	A-20	Private Offices
Partner Office	185	A-21	Private Offices
Copy/Plotter	172	A-22	Private Offices
Telecom	31	A-23	Private Offices
Partner Office	185	A-24	Private Offices
Partner Office	188	A-25	Private Offices
Corridor	453	A-26	Private Offices
Corridor	163	A-27	Conference Area
HVAC	14	A-28	Private Offices
Waiting/Reception	182	B-01	Suite B
Conference	177	B-02	Suite B
Office	131	B-03	Suite B
Office	131	B-04	Suite B
Office	179	B-05	Suite B
Office	165	B-06	Suite B
Copy Room	102	B-07	Suite B
Toilet	102	B-08	Suite B
HVAC	10	B-09	Suite B
Corridor	78	B-10	Suite B
Total	**7,320**	**SF**	

APPENDIX B
BASELINE MODE INPUTS

Table B-1. Building load schedules

Schedule	Type	Day of Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lighting	Fraction	WD	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.9	0.9	0.9	0.9	0.8	0.9	0.9
		Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.3	0.3	0.3	0.15	0.15	0.15
		Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		CDD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equipment	Fraction	WD	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.9	0.9	0.9	0.9	0.8	0.9	0.9
		Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.3	0.3	0.3	0.15	0.15	0.15
		Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		CDD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Occupancy	Fraction	WD	0	0	0	0	0	0	0.1	0.2	0.95	0.95	0.95	0.95	0.5	0.95	0.95
		Sat	0	0	0	0	0	0	0.1	0.1	0.3	0.3	0.3	0.3	0.1	0.1	0.1
		Sun	0	0	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		CDD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration	Fraction	WD	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
		Sat	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
		Sun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		CDD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		HDD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table B-1. Continued

Schedule	**Type**	**Day of Week**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Lighting	Fraction	WD	0.9	0.9	0.5	0.3	0.3	0.2	0.2	0.1	0.05
		Sat	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		CDD	1	1	1	1	1	1	1	1	1
		HDD	0	0	0	0	0	0	0	0	0
Equipment	Fraction	WD	0.9	0.9	0.5	0.3	0.3	0.2	0.2	0.1	0.05
		Sat	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		CDD	1	1	1	1	1	1	1	1	1
		HDD	0	0	0	0	0	0	0	0	0
Occupancy	Fraction	WD	0.95	0.95	0.3	0.1	0.1	0.1	0.1	0.05	0.05
		Sat	0.1	0.1	0.05	0.05	0	0	0	0	0
		Sun	0.05	0.05	0.05	0.05	0	0	0	0	0
		CDD	1	1	1	1	1	1	1	1	1
		HDD	0	0	0	0	0	0	0	0	0
Infiltration	Fraction	WD	0	0	0	0	0	0	0	1	1
		Sat	0	0	0	1	1	1	1	1	1
		Sun	1	1	1	1	1	1	1	1	1
		CDD	1	1	1	1	1	1	1	1	1
		HDD	1	1	1	1	1	1	1	1	1

Table B-1. Continued

Schedule	Type	Day of Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DHW	Fraction	WD	0.05	0.05	0.05	0.05	0.05	0.08	0.07	0.19	0.35	0.38	0.39	0.47	0.57	0.54	0.34
		Sat	0.05	0.05	0.05	0.05	0.05	0.08	0.07	0.11	0.15	0.21	0.19	0.23	0.2	0.19	0.15
		Sun	0.04	0.04	0.04	0.04	0.04	0.07	0.04	0.04	0.04	0.04	0.04	0.06	0.06	0.09	0.06
		CDD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		HDD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HVAC	On/Off	WD	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
		Sat	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
		Sun	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heating	Temp	WD	60	60	60	60	60	60	70	70	70	70	70	70	70	70	70
		Sat	60	60	60	60	60	60	70	70	70	70	70	70	70	70	70
		Sun	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
		CDD	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
		HDD	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Cooling	Temp	WD	86	86	86	86	86	86	75	75	75	75	75	75	75	75	75
		Sat	86	86	86	86	86	86	75	75	75	75	75	75	75	75	75
		Sun	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86
		CDD	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
		HDD	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86

Table B-1. Continued

Schedule	**Type**	**Day of Week**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
DHW	Fraction	WD	0.33	0.44	0.26	0.21	0.15	0.17	0.08	0.05	0.05
		Sat	0.12	0.14	0.07	0.07	0.07	0.07	0.09	0.05	0.05
		Sun	0.04	0.04	0.04	0.04	0.04	0.04	0.07	0.04	0.04
		CDD	1	1	1	1	1	1	1	1	1
		HDD	0	0	0	0	0	0	0	0	0
HVAC	On/Off	WD	1	1	1	1	1	1	1	0	0
		Sat	1	1	1	0	0	0	0	0	0
		Sun	0	0	0	0	0	0	0	0	0
Heating	Temp	WD	70	70	70	70	70	70	70	60	60
		Sat	70	70	70	60	60	60	60	60	60
		Sun	60	60	60	60	60	60	60	60	60
		CDD	60	60	60	60	60	60	60	60	60
		HDD	70	70	70	70	70	70	70	70	70
Cooling	Temp	WD	75	75	86	86	86	86	86	86	86
		Sat	75	75	75	86	86	86	86	86	86
		Sun	86	86	86	86	86	86	86	86	86
		CDD	75	75	75	75	75	75	75	75	75
		HDD	86	86	86	86	86	86	86	86	86

Table B-2. Baseline model lighting power calculations

Room Name	Room Number	Room Use	HVAC Zone	Lighting Density (W/ft^2)	Lighting Total Watts
Waiting/Reception	A-01	Reception	Lobby Area	1.3	457.1
Office	A-02	Office (Open Plan)	Lobby Area	1.1	310.1
Workroom	A-03	Office (Private)	Lobby Area	1.1	113.0
File Room	A-04	Office (Private)	Conference Area	1.1	280.7
Office	A-05	Office (Private)	Conference Area	1.1	124.7
Conference	A-06	Conference	Conference Area	1.3	459.9
Conference	A-07	Conference	Conference Area	1.3	215.3
Kitchenette	A-08	Breakroom	Conference Area	1.3	109.6
HVAC	A-09	Mech/Elec Room	Conference Area	1.5	53.0
Corridor	A-10	Office (Open Plan)	Conference Area	0.5	59.2
Supplies	A-11	Reception	Lobby Area	0.3	3.9
Men's Room	A-12	Restroom	Lobby Area	0.9	38.7
Women's Room	A-13	Restroom	Lobby Area	0.9	37.6
Men's Room	A-14	Restroom	Lobby Area	0.9	36.9
Women's Room	A-15	Restroom	Lobby Area	0.9	57.3
Team Area	A-16	Office (Open Plan)	Team Area 1	1.1	829.0
Team Area	A-17	Office (Open Plan)	Team Area 2	1.1	829.0
Team Area	A-18	Office (Open Plan)	Team Area 3	1.1	829.0
Partner Office	A-19	Office (Private)	Private Office Area	1.1	207.2
Office	A-20	Office (Private)	Private Office Area	1.1	174.2
Partner Office	A-21	Office (Private)	Private Office Area	1.1	203.2
Copy/Plotter	A-22	Copy Room	Private Office Area	1.3	223.7
Telecom	A-23	Mech/Elec Room	Private Office Area	1.5	46.8
Partner Office	A-24	Office (Private)	Private Office Area	1.1	203.2
Partner Office	A-25	Office (Private)	Private Office Area	1.1	207.2
Corridor	A-26	Office (Open Plan)	Private Office Area	0.5	226.5
Corridor	A-27	Office (Open Plan)	Conference Area	0.5	81.7
HVAC	A-28	Mech/Elec Room	Private Office Area	1.5	21.3
Waiting/Reception	B-01	Reception	Suite B	1.3	236.7
Conference	B-02	Conference	Suite B	1.3	230.6
Office	B-03	Office (Private)	Suite B	1.1	144.0
Office	B-04	Office (Private)	Suite B	1.1	144.0
Office	B-05	Office (Private)	Suite B	1.1	196.6
Office	B-06	Office (Private)	Suite B	1.1	181.0
Copy Room	B-07	Copy Room	Suite B	1.3	132.2
Toilet	B-08	Restroom	Suite B	0.9	91.5
HVAC	B-09	Mech/Elec Room	Suite B	1.5	15.4
Corridor	B-10	Office (Open Plan)	Suite B	0.9	70.6

Table B-3. Baseline model plug load calculations

Room Name	Room Number	HVAC Zone Group	Office Equipment	Qty.	Total W
Waiting/Reception	A-01	Lobby Area	Computers - desktop	1	65
		Lobby Area	Monitors - LCD	1	36
		Lobby Area	Multifunction	1	135
		Lobby Area	Fax machine	1	20
Office	A-02	Lobby Area	Computers - desktop	2	130
		Lobby Area	Monitors - LCD	2	72
Workroom	A-03	Lobby Area	None		0
File Room	A-04	Conference Area	None		0
Office	A-05	Conference Area	Computers - desktop	1	65
		Conference Area	Monitors - LCD	1	36
Conference	A-06	Conference Area	Computers - desktop	1	65
		Conference Area	None		0
		Conference Area	Projector	1	185
Conference	A-07	Conference Area	None		0
Kitchenette	A-08	Conference Area	Water cooler	1	350
		Conference Area	Refrigerator	1	76
		Conference Area	Vending machine - snack	1	275
		Conference Area	Microwave	1	400
		Conference Area	Coffee maker	0	0
HVAC	A-09	Conference Area	None		0
Corridor	A-10	Conference Area	None		0
Supplies	A-11	Lobby Area	None		0
Men's Room	A-12	Lobby Area	None		0
Women's Room	A-13	Lobby Area	None		0
Men's Room	A-14	Lobby Area	None		0
Women's Room	A-15	Lobby Area	None		0
Team Area	A-16	Team Area 1	Computers - desktop	7	455
		Team Area 1	Monitors - LCD	7	252
Team Area	A-17	Team Area 2	Computers - desktop	7	455
		Team Area 2	Monitors - LCD	7	252
Team Area	A-18	Team Area 3	Computers - desktop	7	455
		Team Area 3	Monitors - LCD	7	252
Partner Office	A-19	Private Office Area	Computers - desktop	1	65
		Private Office Area	Monitors - LCD	1	36
Office	A-20	Private Office Area	Computers - desktop	1	65
		Private Office Area	Monitors - LCD	1	36
Partner Office	A-21	Private Office Area	Computers - desktop	1	65
		Private Office Area	Monitors - LCD	1	36
Copy/Plotter	A-22	Private Office Area	Copy machine (large)	1	1,100
Telecom	A-23	Private Office Area	Computers - servers	1	65
		Private Office Area	Monitors - LCD	1	36
Partner Office	A-24	Private Office Area	Computers - desktop	1	65
		Private Office Area	Monitors - LCD	1	36

Table B-3. Continued

Room Name	Room Number	HVAC Zone Group	Office Equipment	Qty.	Total W
Partner Office	A-25	Private Office Area	Computers - desktop	1	65
		Private Office Area	Monitors - LCD	1	36
Corridor	A-26	Private Office Area	None		0
Corridor	A-27	Conference Area	None		0
HVAC	A-28	Private Office Area	None		0
Waiting/Reception	B-01	Suite B	Computers - desktop	1	65
		Suite B	Monitors - LCD	1	36
		Suite B	Multifunction	1	135
		Suite B	Fax machine	1	20
Conference	B-02	Suite B	None		0
Office	B-03	Suite B	Computers - desktop	1	65
		Suite B	Monitors - LCD	1	36
Office	B-04	Suite B	Computers - desktop	1	65
		Suite B	Monitors - LCD	1	36
Office	B-05	Suite B	Computers - desktop	1	65
		Suite B	Monitors - LCD	1	36
Office	B-06	Suite B	Computers - desktop	1	65
		Suite B	Monitors - LCD	1	36
Copy Room	B-07	Suite B	Copy machine (large)	1	1,100
Toilet	B-08	Suite B	None		0
HVAC	B-09	Suite B	None		0
Corridor	B-10	Suite B	None		0

TableB-4. Baseline office equipment power usage

Office Equipment Inventory	Peak Power (W)
Computers - servers	65
Computers - desktop	65
Computers - laptop	40
Monitors - LCD	36
Laser printer - desktop	110
Copy machine (large)	1100
Multifunction	135
Fax machine	20
Water cooler	350
Refrigerator	76
Vending machine - snack	275
Coffee maker	1500
Microwave	400
Projector	185

Table B-4. EIR calculations for heating and cooling

	Data from eQuest			Supply Air Volume and Fan Efficiency		
System	**Gross Cooling Capacity**	**Heating Capacity**	**Supply Air Volume**	**Baseline Fan Motor Brake Horsepower**	**Baseline Supply Fan Power**	**Supply Fan kW/CFM**
	Btu/hr	Btu/hr	CFM	hp	kW	kW/CFM
Office 1	37,921	41,391	824	0.71	0.66	0.000806
Office 2	35,114	38,486	745	0.64	0.60	0.000811
Office 3	34,820	38,165	743	0.64	0.60	0.000811
Private Offices	68,083	95,351	1,469	1.27	1.15	0.000780
Conference Area	74,424	102,923	1,539	1.33	1.20	0.000778
Lobby	48,802	53,481	992	0.86	0.79	0.000797
Suite B	73,568	53,987	1,634	1.41	1.27	0.000776

Table B-4. Continued

	Supply Fan Power and Cooling EIR							
System	**Net Cooling Capacity**	**Gross Cooling Capacity**	**Total EER**	**Total Input Power**	**Cooling Power**	**Cooling COP**	**Cooling EIR**	**Total EIR**
	Btu/hr	Btu/hr	Btu/hr/W	kW	kW	-	-	-
Office 1	35,655	37,921	10.70	3.3	2.7	4.16	0.240	0.319
Office 2	33,052	35,114	10.70	3.1	2.5	4.14	0.242	0.319
Office 3	32,764	34,820	10.70	3.1	2.5	4.15	0.241	0.319
Private Offices	64,173	68,083	9.90	6.5	5.3	3.74	0.268	0.345
Conference Area	70,337	74,424	9.90	7.1	5.9	3.69	0.271	0.345
Lobby	46,104	48,802	10.70	4.3	3.5	4.06	0.246	0.319
Suite B	69,242	73,568	9.90	7.0	5.7	3.76	0.266	0.345

Table B-4. Continued

	Supply Fan Power and Heating EIR							
System	**Net Heating Capacity**	**Heating Capacity**	**Total EER**	**Total Input Power**	**Heating Power**	**Heating COP**	**Heating EIR**	**Total EIR**
	Btu/hr	Btu/hr	Btu/hr/W	kW	kW	-	-	-
Office 1	39,125	41,391	11.00	3.6	2.9	4.19	0.239	0.310
Office 2	36,424	38,486	11.00	3.3	2.7	4.17	0.240	0.310
Office 3	36,109	38,165	11.00	3.3	2.7	4.17	0.240	0.310
Private Offices	91,441	95,351	7.50	12.2	11.0	2.53	0.395	0.455
Conference Area	98,836	102,923	7.50	13.2	12.0	2.52	0.397	0.455
Lobby	50,783	53,481	11.00	4.6	3.8	4.10	0.244	0.310
Suite B	49,661	53,987	11.00	4.5	3.2	4.87	0.205	0.310

Table B-5. Minimum outdoor air calculations

Room Name	Room Area A_z (ft^2)	Room Number	Space Type	Room Pop. P_z (per)	People Outdoor Air Rate R_p (cfm/per)	Area Outdoor Air Rate R_a (cfm/ft^2)	P_z*R_p (cfm)	A_z*R_a (cfm)	Zone Air Distribution Effectiveness E_z	Outdoor airflow to the space corrected for zone air distribution effectiveness V_{oz} (P_z*R_p + A_z*R_a)/E_z, cfm
Waiting/ Reception	352	A-01	Reception areas	3	5.0	0.06	15.0	21.10	1	36.10
Office	282	A-02	Office space	2	5.0	0.06	10.0	16.91	1	26.91
Workroom	103	A-03	Storage rooms	0	0.0	0.12	0.0	12.33	1	12.33
File Room	255	A-04	Storage rooms	0	0.0	0.12	0.0	30.62	1	30.62
Office	113	A-05	Office space	1	5.0	0.06	5.0	6.80	1	11.80
Conference	354	A-06	Conference / meeting	12	5.0	0.06	60.0	21.23	1	81.23
Conference	166	A-07	Conference / meeting	6	5.0	0.06	30.0	9.94	1	39.94
Kitchenette	84	A-08	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
HVAC	35	A-09	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
Corridor	118	A-10	Corridors	0	0.0	0.06	0.0	7.10	1	7.10
Supplies	13	A-11	Storage rooms	0	0.0	0.12	0.0	1.55	1	1.55
Men's Room	43	A-12	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
Women's Room	42	A-13	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
Men's Room	41	A-14	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00

Table B-5. Continued

Room Name	**Room Area A_z (ft^2)**	**Room Number**	**Space Type**	**Room Pop. P_z (per)**	**People Outdoor Air Rate R_p (cfm/per)**	**Area Outdoor Air Rate R_a (cfm/ft^2)**	**P_z*R_p (cfm)**	**A_z*R_a (cfm)**	**Zone Air Distribution Effectiveness E_z**	**Outdoor airflow to the space corrected for zone air distribution effectiveness V_{oz} (P_z*R_p + A_z*R_a)/E_z, cfm**
Women's Room	64	A-15	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
Team Area	754	A-16	Office space	7	5.0	0.06	35.0	45.22	1	80.22
Team Area	754	A-17	Office space	7	5.0	0.06	35.0	45.22	1	80.22
Team Area	754	A-18	Office space	7	5.0	0.06	35.0	45.22	1	80.22
Partner Office	188	A-19	Office space	1	5.0	0.06	5.0	11.30	1	16.30
Office	158	A-20	Office space	1	5.0	0.06	5.0	9.50	1	14.50
Partner Office	185	A-21	Office space	1	5.0	0.06	5.0	11.09	1	16.09
Copy/ Plotter	172	A-22	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
Telecom	31	A-23	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
Partner Office	185	A-24	Office space	1	5.0	0.06	5.0	11.09	1	16.09
Partner Office	188	A-25	Office space	1	5.0	0.06	5.0	11.30	1	16.30
Corridor	453	A-26	Corridors	0	0.0	0.06	0.0	27.18	1	27.18
Corridor	163	A-27	Corridors	0	0.0	0.06	0.0	9.80	1	9.80
HVAC	14	A-28	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00

Table B-5. Continued

Room Name	**Room Area A_z (ft^2)**	**Room Number**	**Space Type**	**Room Pop. P_z (per)**	**People Outdoor Air Rate R_p (cfm/per)**	**Area Outdoor Air Rate R_a (cfm/ft^2)**	**P_z*R_p (cfm)**	**A_z*R_a (cfm)**	**Zone Air Distribution Effectiveness E_z**	**Outdoor airflow to the space corrected for zone air distribution effectiveness V_{oz} (P_z*R_p + A_z*R_a)/E_z, cfm**
Waiting/ Reception	182	B-01	Reception areas	5	5.0	0.06	27.3	10.92	1	38.23
Conference	177	B-02	Conference / meeting	9	5.0	0.06	44.3	10.64	1	54.99
Office	131	B-03	Office space	1	5.0	0.06	3.3	7.85	1	11.12
Office	131	B-04	Office space	1	5.0	0.06	3.3	7.85	1	11.12
Office	179	B-05	Office space	1	5.0	0.06	4.5	10.72	1	15.19
Office	165	B-06	Office space	1	5.0	0.06	4.1	9.87	1	13.99
Copy Room	102	B-07	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
Toilet	102	B-08	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
HVAC	10	B-09	Does not apply	0	0.0	0.00	0.0	0.00	1	0.00
Corridor	78	B-10	Corridors	0	0.0	0.06	0.0	4.70	1	4.70

APPENDIX C
PROPOSED MODEL INPUTS

Table C-1. Proposed model lighting calculations

Room Name	**Room Number**	**Lighting Fixture**	**W/Fixture**	**# of Fixtures**	**Total Watts**	**Total Watts w/ Occupancy Sensor**
Waiting/ Reception	A-01	(2) 48 in. T8 lamp, Electronic	64	5	320	288
Office	A-02	(2) 48 in. T8 lamp, Electronic	64	4	256	230
Workroom	A-03	(2) 48 in. T8 lamp, Electronic	64	2	128	115
File Room	A-04	(2) 48 in. T8 lamp, Electronic	64	5	320	288
Office	A-05	(2) 48 in. T8 lamp, Electronic	64	2	128	115
Conference	A-06	(2) 48 in. T8 lamp, Electronic	64	6	384	346
Conference	A-07	(2) 48 in. T8 lamp, Electronic	64	2	128	115
Kitchenette	A-08	(2) 48 in. T8 lamp, Electronic	64	2	128	115
HVAC	A-09	None	0	0	0	0
Corridor	A-10	(2) 48 in. T8 lamp, Electronic	64	1	64	58
Supplies	A-11	(1) 48 in. T8 lamp, Electronic	32	0	0	0
Men's Room	A-12	(1) 48 in. T8 lamp, Electronic	32	1	32	29
Women's Room	A-13	(1) 48 in. T8 lamp, Electronic	32	1	32	29
Men's Room	A-14	(1) 48 in. T8 lamp, Electronic	32	1	32	29
Women's Room	A-15	(1) 48 in. T8 lamp, Electronic	32	1	32	29
Team Area	A-16	(2) 48 in. T8 lamp, Electronic	64	9	576	518
Team Area	A-17	(2) 48 in. T8 lamp, Electronic	64	9	576	518
Team Area	A-18	(2) 48 in. T8 lamp, Electronic	64	9	576	518
Partner Office	A-19	(2) 48 in. T8 lamp, Electronic	64	4	256	230
Office	A-20	(2) 48 in. T8 lamp, Electronic	64	4	256	230

Table C-1. Continued

Room Name	**Room Number**	**Lighting Fixture**	**W/Fixture**	**# of Fixtures**	**Total Watts**	**Total Watts w/ Occupancy Sensor**
Partner Office	A-21	(2) 48 in. T8 lamp, Electronic	64	4	256	230
Copy/Plotter	A-22	(2) 48 in. T8 lamp, Electronic	64	2	128	115
Telecom	A-23	(1) 48 in. T8 lamp, Electronic	32	1	32	29
Partner Office	A-24	(2) 48 in. T8 lamp, Electronic	64	4	256	230
Partner Office	A-25	(2) 48 in. T8 lamp, Electronic	64	4	256	230
Corridor	A-26	(2) 48 in. T8 lamp, Electronic	64	5	320	288
Corridor	A-27	(2) 48 in. T8 lamp, Electronic	64	3	192	173
HVAC	A-28	None	0	0	0	0
Waiting/ Reception	B-01	(2) 48 in. T8 lamp, Electronic	64	3	192	173
Conference	B-02	(2) 48 in. T8 lamp, Electronic	64	4	256	230
Office	B-03	(2) 48 in. T8 lamp, Electronic	64	2	128	115
Office	B-04	(2) 48 in. T8 lamp, Electronic	64	2	128	115
Office	B-05	(2) 48 in. T8 lamp, Electronic	64	3	192	173
Office	B-06	(2) 48 in. T8 lamp, Electronic	64	2	128	115
Copy Room	B-07	(2) 48 in. T8 lamp, Electronic	64	2	128	115
Toilet	B-08	(2) 48 in. T8 lamp, Electronic	64	1	64	58
HVAC	B-09	None	0	0	0	0
Corridor	B-10	(2) 48 in. T8 lamp, Electronic	64	1	64	58

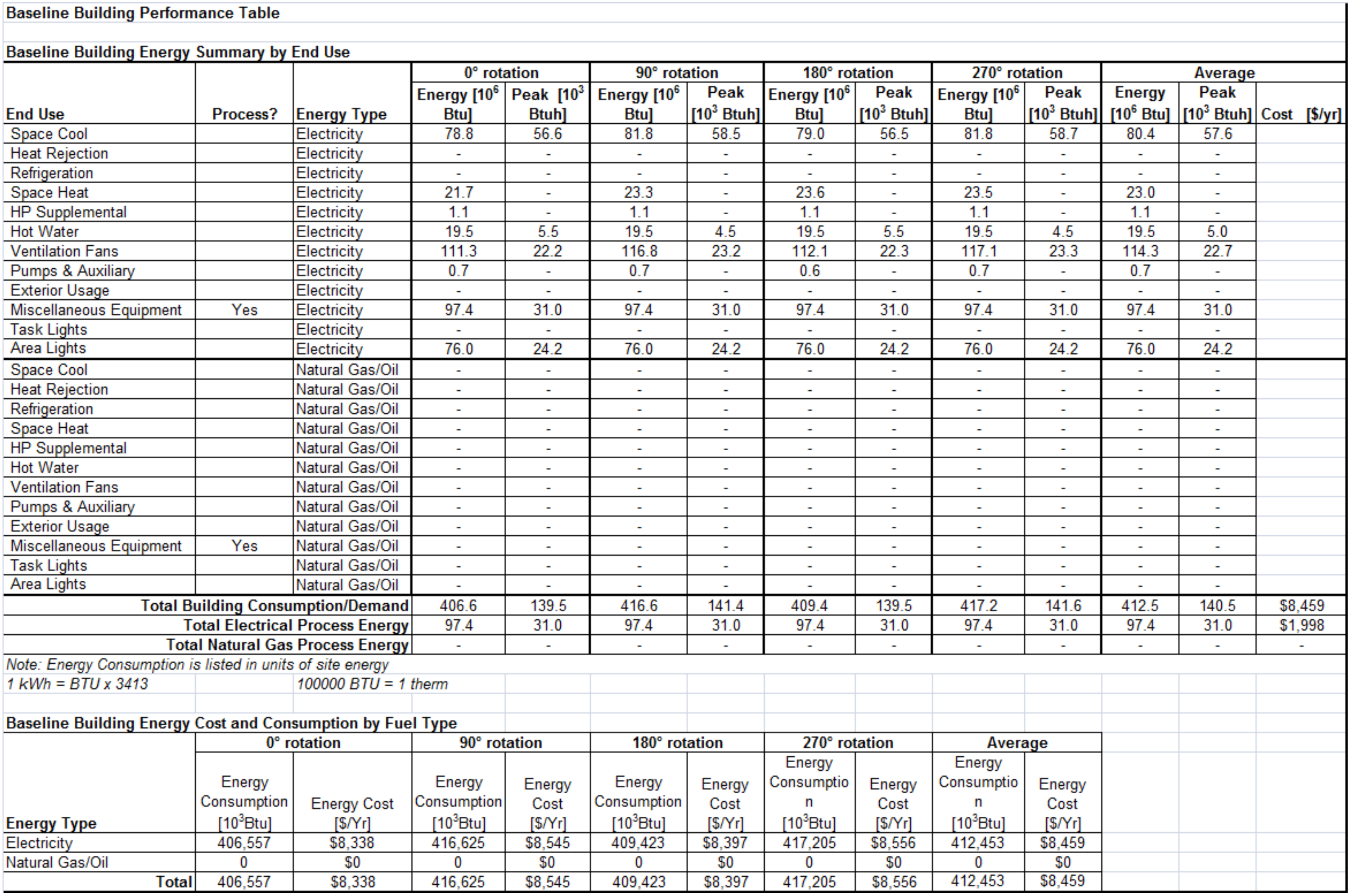
Table C-2. Proposed model plug load calculations

Room Name	**Room Number**	**HVAC Zone Group**	**Office Equipment**	**Qty.**	**Energy Star Total W**
Waiting/ Reception	A-01	Lobby Area	Computers - laptop	1	27
		Lobby Area	Monitors - LCD	1	28
		Lobby Area	Multifunction	1	68
		Lobby Area	Fax machine	1	10
Office	A-02	Lobby Area	Computers - laptop	2	54
		Lobby Area	Monitors - LCD	2	56
Office	A-05	Conference Area	Computers - laptop	1	27
		Conference Area	Monitors - LCD	1	28
Conference	A-06	Conference Area	Computers - laptop	1	27
		Conference Area	Projector	1	185
Kitchenette	A-08	Conference Area	Water cooler	1	193
		Conference Area	Refrigerator	1	61
		Conference Area	Vending machine - snack	1	129
		Conference Area	Microwave	1	400
Team Area	A-16	Team Area 1	Computers - laptop	7	188
		Team Area 1	Monitors - LCD	7	197
Team Area	A-17	Team Area 2	Computers - laptop	7	188
		Team Area 2	Monitors - LCD	7	197
Team Area	A-18	Team Area 3	Computers - laptop	7	188
		Team Area 3	Monitors - LCD	7	197
Partner Office	A-19	Private Office Area	Computers - laptop	1	27
		Private Office Area	Monitors - LCD	1	28
Office	A-20	Private Office Area	Computers - laptop	1	27
		Private Office Area	Monitors - LCD	1	28
Partner Office	A-21	Private Office Area	Computers - laptop	1	27
		Private Office Area	Monitors - LCD	1	28
Copy/ Plotter	A-22	Private Office Area	Copy machine (large)	1	1,023
Telecom	A-23	Private Office Area	Computers - servers	1	44
		Private Office Area	Monitors - LCD	1	28
Partner Office	A-24	Private Office Area	Computers - laptop	1	27
		Private Office Area	Monitors - LCD	1	28
Partner Office	A-25	Private Office Area	Computers - laptop	1	27
		Private Office Area	Monitors - LCD	1	28
Waiting/ Reception	B-01	Suite B	Computers - laptop	1	27
		Suite B	Monitors - LCD	1	28
		Suite B	Multifunction	1	68
		Suite B	Fax machine	1	10
Office	B-03	Suite B	Computers - laptop	1	27
		Suite B	Monitors - LCD	1	28
Office	B-04	Suite B	Computers - laptop	1	27
		Suite B	Monitors - LCD	1	28

Table C-2. Continued

Room Name	**Room Number**	**HVAC Zone Group**	**Office Equipment**	**Qty.**	**Energy Star Total W**
Office	B-05	Suite B	Computers - laptop	1	27
		Suite B	Monitors - LCD	1	28
Office	B-06	Suite B	Computers - laptop	1	27
		Suite B	Monitors - LCD	1	28
Copy Room	B-07	Suite B	Copy machine (large)	1	1,023

APPENDIX D
BASELINE ENERGY SIMULATION OUTPUT



Baseline Building Performance Table

Baseline Building Energy Summary by End Use

			0° rotation		90° rotation		180° rotation		270° rotation		Average		
End Use	**Process?**	**Energy Type**	**Energy [10^6 Btu]**	**Peak [10^3 Btuh]**	**Energy [10^6 Btu]**	**Peak [10^3 Btuh]**	**Energy [10^6 Btu]**	**Peak [10^3 Btuh]**	**Energy [10^6 Btu]**	**Peak [10^3 Btuh]**	**Energy [10^6 Btu]**	**Peak [10^3 Btuh]**	**Cost [$/yr]**
Space Cool		Electricity	78.8	56.6	81.8	58.5	79.0	56.5	81.8	58.7	80.4	57.6	
Heat Rejection		Electricity	-	-	-	-	-	-	-	-	-	-	
Refrigeration		Electricity	-	-	-	-	-	-	-	-	-	-	
Space Heat		Electricity	21.7	-	23.3	-	23.6	-	23.5	-	23.0	-	
HP Supplemental		Electricity	1.1	-	1.1	-	1.1	-	1.1	-	1.1	-	
Hot Water		Electricity	19.5	5.5	19.5	4.5	19.5	5.5	19.5	4.5	19.5	5.0	
Ventilation Fans		Electricity	111.3	22.2	116.8	23.2	112.1	22.3	117.1	23.3	114.3	22.7	
Pumps & Auxiliary		Electricity	0.7	-	0.7	-	0.6	-	0.7	-	0.7	-	
Exterior Usage		Electricity	-	-	-	-	-	-	-	-	-	-	
Miscellaneous Equipment	Yes	Electricity	97.4	31.0	97.4	31.0	97.4	31.0	97.4	31.0	97.4	31.0	
Task Lights		Electricity	-	-	-	-	-	-	-	-	-	-	
Area Lights		Electricity	76.0	24.2	76.0	24.2	76.0	24.2	76.0	24.2	76.0	24.2	
Space Cool		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Heat Rejection		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Refrigeration		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Space Heat		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
HP Supplemental		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Hot Water		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Ventilation Fans		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Pumps & Auxiliary		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Exterior Usage		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Miscellaneous Equipment	Yes	Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Task Lights		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Area Lights		Natural Gas/Oil	-	-	-	-	-	-	-	-	-	-	
Total Building Consumption/Demand			406.6	139.5	416.6	141.4	409.4	139.5	417.2	141.6	412.5	140.5	$8,459
Total Electrical Process Energy			97.4	31.0	97.4	31.0	97.4	31.0	97.4	31.0	97.4	31.0	$1,998
Total Natural Gas Process Energy			-	-	-	-	-	-	-	-	-	-	-

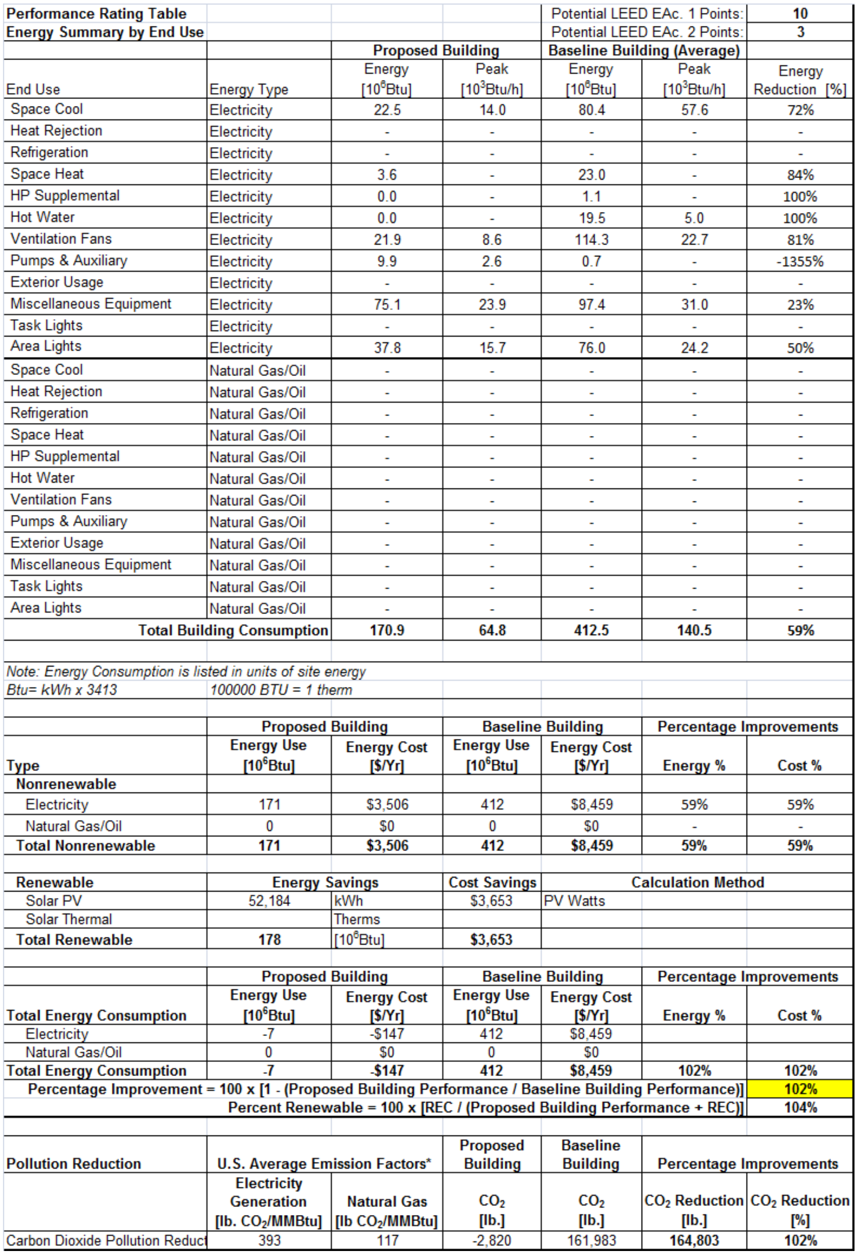
Note: Energy Consumption is listed in units of site energy

1 kWh = BTU x 3413 *100000 BTU = 1 therm*

Baseline Building Energy Cost and Consumption by Fuel Type

	0° rotation		90° rotation		180° rotation		270° rotation		Average	
Energy Type	Energy Consumption [10^3Btu]	Energy Cost [$/Yr]	Energy Consumption [10^3Btu]	Energy Cost [$/Yr]	Energy Consumption [10^3Btu]	Energy Cost [$/Yr]	Energy Consumptio n [10^3Btu]	Energy Cost [$/Yr]	Energy Consumptio n [10^3Btu]	Energy Cost [$/Yr]
Electricity	406,557	$8,338	416,625	$8,545	409,423	$8,397	417,205	$8,556	412,453	$8,459
Natural Gas/Oil	0	$0	0	$0	0	$0	0	$0	0	$0
Total	406,557	$8,338	416,625	$8,545	409,423	$8,397	417,205	$8,556	412,453	$8,459

APPENDIX E
PROPOSED ENERGY SIMULATION OUTPUT



Performance Rating Table				Potential LEED EAc. 1 Points:		**10**
Energy Summary by End Use				Potential LEED EAc. 2 Points:		**3**
		Proposed Building		**Baseline Building (Average)**		
End Use	Energy Type	Energy [10^6Btu]	Peak [10^3Btu/h]	Energy [10^6Btu]	Peak [10^3Btu/h]	Energy Reduction [%]
Space Cool	Electricity	22.5	14.0	80.4	57.6	72%
Heat Rejection	Electricity	-	-	-	-	-
Refrigeration	Electricity	-	-	-	-	-
Space Heat	Electricity	3.6	-	23.0	-	84%
HP Supplemental	Electricity	0.0	-	1.1	-	100%
Hot Water	Electricity	0.0	-	19.5	5.0	100%
Ventilation Fans	Electricity	21.9	8.6	114.3	22.7	81%
Pumps & Auxiliary	Electricity	9.9	2.6	0.7	-	-1355%
Exterior Usage	Electricity	-	-	-	-	-
Miscellaneous Equipment	Electricity	75.1	23.9	97.4	31.0	23%
Task Lights	Electricity	-	-	-	-	-
Area Lights	Electricity	37.8	15.7	76.0	24.2	50%
Space Cool	Natural Gas/Oil	-	-	-	-	-
Heat Rejection	Natural Gas/Oil	-	-	-	-	-
Refrigeration	Natural Gas/Oil	-	-	-	-	-
Space Heat	Natural Gas/Oil	-	-	-	-	-
HP Supplemental	Natural Gas/Oil	-	-	-	-	-
Hot Water	Natural Gas/Oil	-	-	-	-	-
Ventilation Fans	Natural Gas/Oil	-	-	-	-	-
Pumps & Auxiliary	Natural Gas/Oil	-	-	-	-	-
Exterior Usage	Natural Gas/Oil	-	-	-	-	-
Miscellaneous Equipment	Natural Gas/Oil	-	-	-	-	-
Task Lights	Natural Gas/Oil	-	-	-	-	-
Area Lights	Natural Gas/Oil	-	-	-	-	-
Total Building Consumption		**170.9**	**64.8**	**412.5**	**140.5**	**59%**

Note: Energy Consumption is listed in units of site energy

Btu= kWh x 3413 *100000 BTU = 1 therm*

	Proposed Building		**Baseline Building**		**Percentage Improvements**	
Type	**Energy Use [10^6Btu]**	**Energy Cost [$/Yr]**	**Energy Use [10^6Btu]**	**Energy Cost [$/Yr]**	**Energy %**	**Cost %**
Nonrenewable						
Electricity	171	$3,506	412	$8,459	59%	59%
Natural Gas/Oil	0	$0	0	$0	-	-
Total Nonrenewable	**171**	**$3,506**	**412**	**$8,459**	**59%**	**59%**

Renewable	**Energy Savings**		**Cost Savings**	**Calculation Method**		
Solar PV	52,184	kWh	$3,653	PV Watts		
Solar Thermal		Therms				
Total Renewable	**178**	[10^6Btu]	**$3,653**			

	Proposed Building		**Baseline Building**		**Percentage Improvements**	
Total Energy Consumption	**Energy Use [10^6Btu]**	**Energy Cost [$/Yr]**	**Energy Use [10^6Btu]**	**Energy Cost [$/Yr]**	**Energy %**	**Cost %**
Electricity	-7	-$147	412	$8,459		
Natural Gas/Oil	0	$0	0	$0		
Total Energy Consumption	**-7**	**-$147**	**412**	**$8,459**	**102%**	**102%**
Percentage Improvement = 100 x [1 - (Proposed Building Performance / Baseline Building Performance)]						**102%**
Percent Renewable = 100 x [REC / (Proposed Building Performance + REC)]						**104%**

Pollution Reduction	**U.S. Average Emission Factors***		**Proposed Building**	**Baseline Building**	**Percentage Improvements**	
	Electricity Generation [lb. CO_2/MMBtu]	**Natural Gas [lb CO_2/MMBtu]**	**CO_2 [lb.]**	**CO_2 [lb.]**	**CO_2 Reduction [lb.]**	**CO_2 Reduction [%]**
Carbon Dioxide Pollution Reduct	393	117	-2,820	161,983	**164,803**	**102%**

APPENDIX F
LIFE CYCLE COST CALCULATIONS

Baseline Package		**Proposed Package**		
Baseline Item	**Baseline Cost**	**Proposed Item**	**Proposed Cost**	**Cost Difference**
T12 Lamps	$ 268	T8 Lamps	$ 427	$ 159
		Daylighting Control	$ 848	$ 848
		Occupancy Sensors	$ 5,508	$ 5,508
	$ 268		**$ 6,783**	$ 6,515
Standard wall, R-13		Add R-20 insulation	$ 4,883	$ 4,883
		Reduce Infiltration w Air Barrier	$ 4,676	$ 4,676
Standard roofing, R-15		Add white roofing	$ 2,621	$ 2,621
			$ 12,180	$ 12,180
Equipment		Energy Star Equipment		$ -
Hot water heater	$ 300	Desuperheater	$ 550	$ 250
Windows	$ 3,066	Double Low E	$ 15,213	$ 12,147
		Overhangs	$ 1,626	$ 1,626
		DOAS	$ 5,275	$ 5,275
HVAC, PSZ-HP	$ 38,790	HVAC, GSHP	$ 46,488	$ 7,698
Total	**$ 42,424**	Total	**$ 88,114**	**$ 45,690**
		Photovoltaic System	**$ 424,400**	**$ 424,400**
		Proposed Package w/ PV	**$ 512,514**	**$ 470,090**
		Credits and Rebates		
		Federal Tax Credit: GSHP 30% gross cost	$ 13,946	
		GSHP w/ credits	**$ 32,542**	**$ (6,248)**
		Florida Rebate: $4/watt DC, up to $100,000	$ 100,000	
		Federal Tax Credit: 30% gross cost	$ 127,320	
		PV system w/ credits	**$ 197,080**	**$ 197,080**
		Proposed Package w/ GSHP Credit	**$ 74,168**	**$ 31,744**
		Proposed Package w/ PV + Credits	**$ 271,248**	**$ 228,824**
		Energy Savings		
		Annual savings w/o solar panel	$ 4,953	
		Annual savings w/ solar panel	$ 8,205.88	
		Estimated Total Building Cost	**$ 869,616**	
		Percent of Total Building Cost		
		Package w/o PV	5.3%	
		Package w/ PV	54.1%	
		Package w/o PV + GSHP Credits	3.7%	
		Package/ PV + All Credits	26.3%	

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BIOGRAPHICAL SKETCH

Thomas Vu was born and raised in Melbourne, Florida. He graduated from Melbourne Central Catholic High School in 2003 and began his college career at the University of Florida. In 2008, Thomas received his Bachelor of Science degree in mechanical engineering and decided to continue his education at UF and pursue Master of Science degrees in mechanical engineering and management.

Thomas has worked as an engineering intern with Reynolds, Smith, and Hills, Inc. and Affiliated Engineers, Inc, working on Heating, Ventilating, and Air-Conditioning design projects, building energy audits, and building energy modeling. He plans to obtain his Professional Engineering License as well as Leadership in Energy and Environmental Design Accredited Professional certification. After graduate school, Thomas wants to work in the HVAC industry to design sustainable high performance buildings.