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General Merchandise 50% Energy Savings

Technical Support Document

Elaine Hale, Matthew Leach, Adam Hirsch, and Paul Torcellini

Technical Report
NREL/TP-550-46100
September 2009

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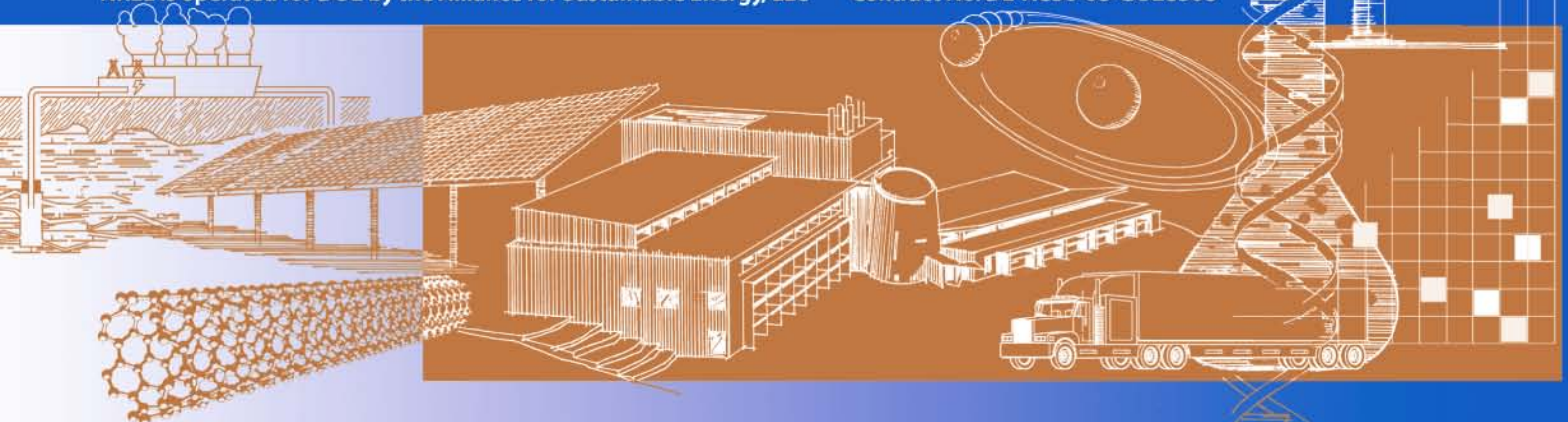

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National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
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We are indebted to a number of retailers and building industry professionals for taking the time to review our analysis assumptions and earlier versions of this report. Jim Kirk of A&P Grocery Stores, Kathy Loftus of Whole Foods, and Scott Williams of Target, all members of the Retailer Energy Alliance, commented on our prototype and energy design measure (EDM) model assumptions based on their companies' experiences and standard practices. Don Zerrip, Ben Butler, and H. J. Enck of CxGBS; Tim A. Speller of Speller Energy Consulting; and Thomas H. Phoenix of Moser Mayer Phoenix Associates reviewed an earlier draft of this report.

We extend our thanks to our colleagues Larry Brackney and Kristin Field for conducting formal internal reviews of this document, and to Stefanie Woodward for editing assistance.

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Tens of thousands of EnergyPlus simulations were run for this report. This would not have been possible without the support of the NREL High Performance Computing Center managed by Wesley Jones and Jim Albin.

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Executive Summary

This Technical Support Document (TSD) was developed by the Commercial Buildings Group at NREL, under the direction of the DOE Building Technologies Program. It documents technical analysis and design guidance for general merchandise stores to achieve whole-building energy savings of at least 50% over ASHRAE Standard 90.1-2004 and represents a step toward determining how to provide design guidance for aggressive energy savings targets.

This report:

- Documents the modeling and integrated analysis methods used to identify cost-effective sets of recommendations for different locations.
- Demonstrates sets of recommendations that meet or exceed the 50% goal. There are 16 sets of recommendations, one for each climate zone location.
- Establishes methodology for providing a family of solutions, as opposed to a single solution, that meet the 50% goal as a means of exploring the relative importance of specific design strategies.
- Demonstrates the energy efficiency, and, to a lesser extent, cost implications, of using ASHRAE Standard 90.1-2007 instead of Standard 90.1-2004.
- Explores the effect of floor area on energy use intensity in baseline and low-energy models.

This report, along with a sister document for grocery stores (Leach et al. 2009), also evaluates the possibility of compiling a 50% *Advanced Energy Design Guide* (AEDG) in the tradition of the 30% AEDGs available through the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and developed by an interorganizational committee structure.

Methodology

To account for energy interactions between building subsystems, we used EnergyPlus to model the predicted energy performance of baseline and low-energy buildings to verify that 50% energy savings can be achieved. EnergyPlus computes building energy use based on the interactions between climate, building form and fabric, internal gains, HVAC systems, and renewable energy systems. Percent energy savings are based on a minimally code-compliant building as described in Appendix G of ASHRAE 90.1-2004, and whole-building, net site energy use intensity (EUI): the amount of energy a building uses for regulated and unregulated loads, minus any renewable energy generated within its footprint, normalized by building area.

The following steps were used to determine 50% savings:

1. Define architectural-program characteristics (design features not addressed by ASHRAE 90.1-2004) for typical general merchandise stores, thereby defining a prototype model.
2. Create baseline energy models for each climate zone that are elaborations of the prototype models and are minimally compliant with ASHRAE 90.1-2004.
3. Create a list of energy design measures (EDMs) that can be applied to the baseline models to create candidate low-energy models.

4. Use industry feedback to strengthen inputs for baseline energy models and EDMs.
5. Simulate and select low-energy models for each climate zone that achieve 50% energy savings (or more). Give preference to those models that have low five-year total life cycle cost.

The simulations supporting this work were managed with the NREL commercial building energy analysis platform, Opt-E-Plus. Opt-E-Plus employs an iterative search technique to find EDM combinations that best balance percent energy savings with total life cycle cost for a given building in a given location. The primary advantages of the analysis platform are its abilities to: (1) transform high-level building parameters (building area, internal gains per zone, HVAC system configuration, etc.) into a fully parameterized input file for EnergyPlus; (2) conduct automated searches to optimize multiple criteria; and (3) manage distributed EnergyPlus simulations on the local CPU and a Linux cluster. In all, 118,231 EnergyPlus models were run. The economic criterion used to filter the recommendations is five-year total life cycle cost (using the January 2008 OMB real discount rate, 2.3%). The five-year analysis period was established in our statement of work and is assumed acceptable to a majority of developers and owners.

The bulk of this report (Section 3.0) documents prototype building characteristics, baseline building model inputs, and modeling inputs for each EDM. The prototypes are 40,500 ft^2 (3,760 m^2), one-story rectangular buildings with a 1.25 aspect ratio. We assume 1,000 ft^2 (93 m^2) of glazing on the façade, which gives a 22% window-to-wall ratio for that wall, and a 6% window-to-wall ratio for the whole building. The prototype buildings have masonry wall construction and a roof with all insulation above deck. HVAC equipment consists of 10-ton packaged rooftop units with natural gas furnaces for heating, and electric direct-expansion coils with air-cooled condensers for cooling. We examine two plug load levels, 0.29 W/ft^2 (3.1 W/m^2) and 1.32 W/ft^2 (14.2 W/m^2), the low and high plug load scenarios, respectively. The EDMs considered in this work fall into the following categories:

- **Lighting technologies**. Reduced lighting power density, occupancy controls, and daylighting controls.
- **Plug loads**. Reduced nighttime loads.
- **Fenestration**. Amounts and types of façade glazing and skylights; overhangs.
- **Envelope**. Opaque envelope insulation, air barriers, and vestibules.
- **HVAC equipment**. Higher efficiency equipment and fans, economizers, demand control ventilation (DCV), and energy recovery ventilators (ERVs).
- **Generation**. Photovoltaic (PV) electricity generation.

Findings

The results show that 50% net site energy savings can be achieved cost-effectively in general merchandise stores. On-site generation technology (in this case, PV) was not necessary to meet the energy goal in any climate zone. Specific recommendations for achieving the 50% goal are tabulated for all climate zones. The following EDMs are recommended in all locations:

- Reduce lighting power density by 47%, and install occupancy sensors in the active storage, mechanical room, restroom, and office zones.
- Add a vestibule to the front entrance to reduce infiltration.

- Equip rooftop HVAC units with high efficiency fans.
- Install daylighting sensors tuned to a 46.5 fc (500 lux) set point.
- Reduce south façade window-to-wall ratio by 50%.
- Replace baseline exterior walls with better insulated constructions.
- Reduce plug loads to 10% of peak during off hours in high plug load stores.

One EDM was not chosen for any location:

- Shaded overhangs above the windows on the south façade.

In general, EDM selection trends were as expected:

- Skylights were selected in warm and hot climates where there is ample sunlight for daylighting.
- High coefficient of performance (a 20% increase over baseline) HVAC rooftop units were selected in all but the cold and marine climates, which have low cooling loads.
- Infiltration reduction measures (front entrance vestibule and envelope air barrier) were selected often, especially in humid and cold climates.
- Economizers were generally forgone in favor of ERV because of the high availability of exhaust air.
- ERV played an important role in achieving the energy savings goal, especially in humid and cold climates.

A comparison of baseline models that satisfy ASHRAE 90.1-2004 and ASHRAE 90.1-2007 demonstrates that the newest standard does save energy, but at the expense of increased capital and lifetime costs (except in climate zone 8, where capital costs for the low-energy model are less than baseline).

Comparison of energy use intensities (EUIs) for the medium box (40,500 ft^2 [3,760 m^2]) low plug load prototype to those for a big box (100,000 ft^2 [9,290 m^2]) low plug load prototype indicates that EUIs decrease with the surface area to volume ratio of the building. As this ratio decreases, the energy use associated with building envelope constructions have a reduced impact on a per floor area basis. We also found it to be slightly easier to achieve 50% energy savings in the big box stores, as applying the same EDMs selected in the low-energy medium box models usually resulted in energy savings greater than 50%. The only exception to this was Los Angeles, California (climate zone 3B-CA), which achieved 44.4% energy savings. Of course, individual stores should look at total energy use, rather than EUI or energy savings, when comparing possible store sizes and configurations since total energy use is the true impact of any project.

A novel post-processing methodology designed to identify multiple designs that reach the energy savings goal while simultaneously answering questions like, "Is daylighting required to meet the goal?" was developed and applied to five climate zones and both plug load levels. It identified eight to ten additional designs per scenario, and demonstrated that ERV is required in Fairbanks, Alaska (climate zone 8), and HVAC improvements and ERV are required for the high plug load scenario in Miami, Florida (climate zone 1A), to reach the 50% energy savings goal (subject to the assumptions of this report). The successful designs are significantly different from each other in both composition and performance across several criteria of interest, including capital cost, lifetime cost, and maximum electricity demand. Perturbation information is also extracted and used to calculate the amount of PV required to replicate the energy savings associated with the EDMs used in the original low-energy model.

A number of modeling errors skewed the results of our original optimizations over the complete set of EDMs. The original results indicated that the low-energy models would require a larger initial capital investment than the corresponding baseline models and that in most of the climate zones they would not be able to save enough energy to offset those higher capital costs within the five-year analysis period. By correcting the modeling errors and performing abbreviated optimization runs to determine which of ERV, DCV, and PV should actually be included in each low-energy model, we were able to show that 50% energy savings can be achieved cost effectively. The corrected low-energy models all paid for themselves within the five-year analysis period, and only the climate zone 2A, high plug load scenario model showed increased capital costs over baseline.

Although this TSD is fairly comprehensive and describes design packages that achieve the 50% energy savings goal cost effectively, future analyses may benefit from adopting some of the recommendations outlined in Section 5.0. For instance, EDMs we feel are deserving of increased attention, but omitted because of modeling constraints, are:

- Alternative HVAC systems such as ground source heat pumps, packaged variable air volume systems and radiant heating and cooling
- Solar thermal technologies for service water heating and space conditioning
- Direct and indirect evaporative cooling
- Decreased pressure drop via improved duct design
- Advanced humidity control

Nomenclature

5-TLCC	five-year total life cycle cost
AEDG	Advanced Energy Design Guide
AIA	American Institute of Architects
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CBECS	Commercial Buildings Energy Consumption Survey
CDD	cooling degree day
c.i.	continuous insulation
CO_2	carbon dioxide
COP	coefficient of performance
DEA	Dedicated Exhaust Air
DOE	U.S. Department of Energy
DX	direct expansion
EA	Exfiltrated Air
EER	energy efficiency ratio
ERV	energy recovery ventilator
EUI	energy use intensity
HDD	heating degree day
HVAC	heating, ventilation, and air conditioning
IECC	International Energy Conservation Code
IESNA	Illuminating Engineering Society of North America
LEED	Leadership in Energy and Environmental Design
LPD	lighting power density
NREL	National Renewable Energy Laboratory
OA	outside air
O&M	operations and maintenance
RTU	rooftop unit
PSZ	A package single zone DX rooftop unit
SHGC	solar heat gain coefficient
5-TLCC	total life cycle cost
TSD	Technical Support Document
USGBC	U.S. Green Building Council
VAV	variable air volume
VLT	visible light transmittance
w.c.	water column
XML	extensible markup language

Contents

Figures and Tables

Figures

Tables

1.0 Introduction

This report is often referred to as a *Technical Support Document*, or TSD, because it is a detailed compilation of the modeling assumptions, analysis techniques, and results that provide the technical basis for recommending building design packages that achieve a desired level of net energy savings as compared to a baseline general merchandise store model. Historically, there have been a series of TSDs for different building types and different energy savings levels, some of which have led to the production of volumes in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Advanced Energy Design Guide (AEDG) series. The AEDGs are user-friendly books containing the design recommendations of the TSDs plus relevant case studies and best practice tips.

The TSDs and AEDGs are part of an inter-organizational effort to progressively facilitate the design, construction, and operation of more efficient buildings, with the eventual goal of achieving net zero energy buildings (Torcellini et al. 2006). The first phase concentrated on achieving 30% energy savings over ANSI/ASHRAE/IESNA Standard 90.1-2004 (ASHRAE). The study presented here is part of the second phase of this effort as it provides design guidance that architects, designers, contractors, developers, owners and lessees of general merchandise stores can use to achieve whole-building net site energy savings of at least 50% compared to the minimum requirements of Standard 90.1-2004. The recommendations are given by climate zone, and address building envelope (including infiltration through walls and doors), fenestration quantities and types, electrical lighting systems, daylighting, HVAC systems, outside air (OA) quantity and treatment, plug load schedules, and photovoltaic (PV) systems. In all cases, the recommendations are not part of a code or a standard, and should be used as starting points for project-specific analyses.

This TSD belongs to a first set of studies aimed at the 50% milestone on the path toward Zero Energy Buildings (ZEBs), which generate or purchase an amount of renewable energy equivalent to or greater than the fossil fuel-derived energy they purchase over the course of a year. A number of public, private, and nongovernmental organizations have adopted ZEB goals. Directly relevant to this report is this statement by the U.S. Department of Energy (DOE) Efficiency and Renewable Energy Building Technologies Program (DOE 2005):

> By 2025, the Building Technologies Program will create technologies and design approaches that enable the construction of net-zero energy buildings at low incremental cost. A net-zero energy building is a residential or commercial building with greatly reduced needs for energy through efficiency gains, with the balance of energy needs supplied by renewable technologies.

The interorganizational AEDG effort is one pathway being pursued to help reach these goals. We hope that this TSD will result in the production of a General Merchandise 50% AEDG, in support of the ASHRAE Vision 2020 Committee and AEDG Scoping Committee goals to enable interested parties to achieve 50% energy savings by 2010 (Jarnagin et al. 2007; Mitchell et al. 2006). This work will also reach its intended audience of architects, designers, contractors, developers, owners, and lessees of general merchandise stores through the DOE-sponsored Retailer Energy Alliance (REA) (DOE 2008a).

This TSD was developed by the Commercial Buildings Section at the National Renewable Energy Laboratory (NREL), under the direction of the DOE Building Technologies Program, and in parallel with a sister TSD for grocery stores (Leach et al. 2009). It builds on previous work (Hale et al. 2008a; Hale et al. 2008b) that established a basic methodology for finding building designs that achieve 50% energy savings over ASHRAE 90.1-2004. These analyses improve on the earlier work in that (1) the analysis assumptions were reviewed by external experts; (2) an extended methodology for determining alternative 50% designs was developed; and (3) the extended methodology was applied to select climate zones.

1.1 Objectives

The modeling and analysis described in this report are intended to:

- **Develop recommendations that meet a numeric goal**. The energy savings goal is a hard value, not an approximate target. All recommendation sets have been verified to give at least 50% net site energy savings compared with Standard 90.1-2004. The savings are calculated on a whole-building energy consumption basis, which includes non-regulated loads.

- **Develop recommendations that can assist a range of interested parties**. Multiple designs that meet the 50% goal are provided in select climate zones (1A, 3B-NV, 4C, 5A, and 8). The method for producing those design packages also provides guidance as to whether particular strategies (types of design measures) or combinations of strategies are necessary to reach the target.

- **Investigate and communicate the benefits of integrated design.** An EnergyPlus-based building optimization tool, Opt-E-Plus, is used to find complementary combinations of efficiency measures that economically achieve the desired level of energy savings. The resulting recommendations demonstrate and quantify the benefits of considering the energy and economic implications of every design decision on a whole-building basis.

- **Incorporate review of modeling assumptions by industry representatives.** A condensed compilation of baseline and energy design measure (EDM) cost and performance assumptions was circulated to the REA to assess their validity. Several collaborating engineering firms reviewed an earlier draft of this document. Many of their comments were incorporated into this study or taken into consideration for future study.

- **Compare ASHRAE 90.1-2004 to ASHRAE 90.1-2007 as they apply to general merchandise stores.** We report the energy use and approximate cost difference between baseline general merchandise stores that prescriptively satisfy ASHRAE 90.1-2004 and ASHRAE 90.1-2007 so interested parties can evaluate the progression of Standard 90.1.

- **Investigate sensitivity to store size.** We report the energy use intensities (EUIs) of the baseline and low-energy selected models for a 100,000 ft^2 (9,290 m^2) prototype store and compare them with those of the standard 40,500 ft^2 (3,763 m^2) prototype store in order to bracket the general merchandise subsector (medium box to big box).

1.2 Scope

This document provides recommendations and design assistance to designers, developers, and owners of general merchandise stores that will encourage steady progress toward net zero energy buildings. To ease the burden of designing and constructing energy-efficient general merchandise stores, we describe a set of designs that reach the 50% energy savings target for each climate zone. The recommendations and discussion apply to general merchandise stores of

20,000 to 140,000 ft^2 (1,860 m^2 to 13,000 m^2), with plug loads and accent lighting loads up to 1.32 W/ft^2 (14.2 W/m^2).

The TSD is not intended to substitute for rating systems or other references that address the full range of sustainable issues, such as acoustics, productivity, indoor environmental quality, water efficiency, landscaping, and transportation, except as they relate to operational energy consumption. It is also not a design text—we leave detailed design to the experts working on particular projects. Our results are intended to demonstrate the advantages of integrated whole-building design, and to suggest sets of design features that seem to work well together in each climate zone.

1.3 Report Organization

This report is organized into four sections. The introduction, **Section 1.0**, gives background, overview and scope information. **Section 2.0** introduces our modeling methodology including definitions, analysis framework, post-processing of results, and industrial review. **Section 3.0** describes all our modeling assumptions, starting with a single prototype model, and followed by detailed cost and performance data first for climate-specific baseline buildings, and then for EDMs, which may provide energy savings in one or more climates. **Section 4.0** contains the results of the modeling study, including cost and energy use intensity (EUI) of baseline and low-energy models, the EDMs chosen in different climate zones to reach the energy savings goal, and the post-processing results showing alternative paths to 50% energy savings. We also show how the baseline energy use changes when using ASHRAE 90.1-2007/62.1-2004 instead of 90.1-2004/62.1-1999, how baseline and low-energy use changes when the prototype model is expanded from 40,500 ft^2 (3,763 m^2) to 100,000 ft^2 (9,290 m^2), and compare baseline results with the 2003 Commercial Buildings Energy Consumption Survey (CBECS) dataset.

2.0 Methodology

This chapter describes the methodology and assumptions used to develop early stage building designs that achieve 50% energy savings. We begin with an overall approach of the study to modeling energy savings in general merchandise stores, including the energy and economic metrics used and the scope of EDMs that are considered in the analysis. We describe how we found models that meet the 50% energy savings goal, and conclude with a summary of our solicitations for retailer and engineering review and the results of that activity.

2.1 Guiding Principles

Our objective is to find general merchandise store designs that achieve 50% energy savings over ASHRAE 90.1-2004. We also seek designs that are cost effective over a five-year analysis period. These objectives lead us to examine the *Percent Net Site Energy Savings* and the *Five-Year Total Life Cycle Cost* (5-TLCC) of candidate buildings. Of course, other objectives could be used; this choice best fits the mandate for this project.

Achieving 50% savings cost effectively requires integrated building design—a design approach that analyzes buildings as holistic systems, rather than as disconnected collections of individually engineered subsystems. Indeed, accounting for and taking advantage of interactions between subsystems is a paramount concern. As an example, a reduction in installed lighting power density (LPD) can often be accompanied by a smaller HVAC system, but only if an integrated design process allows for it. (In one instance, we found that the capacity of the HVAC system could be reduced by 0.7 tons cooling for every kilowatt reduction in installed lighting power.)

Candidate designs are chosen by applying one or more perturbations to a baseline building. The perturbations are called *Energy Design Measures* (EDMs) to reflect that they are meant to have an impact on energy use. We use the following guiding principles to develop a list of prospective EDMs:

- We recommend off-the-shelf technologies that are available from multiple sources, as opposed to technologies or techniques that are available only in limited quantities or from one manufacturer.
- The EDMs are limited to technologies that can be modeled with EnergyPlus and the NREL Opt-E-Plus platform.

The methodology for developing candidate integrated designs is discussed in Sections 2.4 and 2.5. That the recommended low-energy designs achieve 50% energy savings is verified during the process of model development and simulation. The recommended designs are also expected to be reasonably cost effective, but not necessarily the most cost effective, given the difficulty of obtaining accurate and timely cost data on all the technologies required to reach 50% savings in all climate zones.

2.2 Definitions

This section specifies how we calculate building energy use and percent energy savings relative to ASHRAE 90.1-2004. This description includes the site boundary used to calculate net site energy use, how we deal with energy demands not treated by the ASHRAE Standards, and how Appendix G of ASHRAE 90.1 is applied.

2.2.1 Energy Use

Building energy use can be calculated a number of ways based on where the energy is assumed to originate, and on which loads are included in the calculation. The assumptions used in this TSD follow.

2.2.1.1 Net Site Energy Use

The percent energy savings goal is based on net site energy use: the amount of energy delivered to a building by the utility (typically in the form of electricity or natural gas) minus any renewable energy generated within its footprint. Other metrics, such as energy cost savings, source energy savings, and carbon savings, could be used (Torcellini et al. 2006). Each metric has advantages and disadvantages in calculation and interpretation, and each favors different technologies and fuel types. This TSD uses net site energy savings to retain consistency with the previous AEDGs, and to serve as a milestone on the path to the DOE goal of zero net site energy.

2.2.1.2 Whole Building Energy Use

Historically, energy savings have been expressed in two ways: for regulated loads only and for all loads (the whole building). Regulated loads metrics do not include plug and process loads that are not code regulated. Whole-building energy savings calculations, on the other hand, include all loads, whether regulated or not. In general, whole-building savings are more challenging than regulated loads savings given the same numerical target, but more accurately represent a building's impact on the national energy system.

We use the whole-building energy savings method to determine 50% energy savings, in line with the current ASHRAE and Leadership in Energy and Environmental Design (LEED) practices specified in Appendix G of ASHRAE 90.1-2004 and in LEED 2.2. However, we do not limit our recommendations to the regulated loads, as was done in the 30% AEDGs, and we study multiple plug load levels to reflect the variations in the general merchandise store subsector.

2.2.2 Percent Energy Savings

Percent energy savings are based on the notion of a minimally code-compliant building as described in Appendix G of ASHRAE 90.1-2004 (ASHRAE 2004a). The following steps were used to determine 50% savings:

1. Define architectural program characteristics (design aspects not addressed by ASHRAE 90.1-2004) for typical general merchandise stores, thereby defining prototype models.
2. Create baseline energy models for each climate zone that are elaborations of the prototype models and are minimally compliant with ASHRAE 90.1-2004.
3. Create a list of EDMs that can be applied to the baseline models to create candidate low-energy models.
4. Select low-energy models for each climate zone that achieve 50% energy savings as compared to the baseline models, giving preference to those models that have low 5-TLCC.

2.2.3 ASHRAE 90.1-2004 Baseline

The 50% level of savings achieved by each low-energy building model is demonstrated in comparison with a baseline model that minimally satisfies the requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004 (ASHRAE 2004a). The baseline models are constructed in a manner similar to what was used in the previous TSDs (Hale et al. 2008a; Hale et al. 2008b; Jarnagin et al. 2006; Liu et al. 2006; Pless et al. 2007), and in compliance with

Appendix G of Standard 90.1-2004 when appropriate. Notable deviations from Standard 90.1-2004 Appendix G include:

- Glazing amounts (window area and skylight area) are allowed to vary between the baseline and low-energy models. We thereby demonstrate the effects of optimizing window and skylight areas for daylighting and thermal considerations.
- Fan efficiencies are set slightly higher than code minimum[1] to represent a more realistic split of energy efficiency ratio (EER) between the supply fan and the compressor/condenser system in a packaged rooftop direct expansion HVAC unit.
- Net site energy use, rather than energy cost, is used to calculate energy savings.
- Mass walls are modeled in the baseline and low-energy models to ensure that our baseline accurately reflects typical design practice.

2.3 Building Energy Modeling Methodology

2.3.1 EnergyPlus

EnergyPlus Version 3.1 (DOE 2009), a publicly available building simulation engine, is used for all energy analyses. The simulations are managed with the NREL analysis platform, Opt-E-Plus, which transforms user-specified, high-level building parameters (building area, internal gains per zone, HVAC system configuration, etc.) stored in XML files into an input file for EnergyPlus. Opt-E-Plus can automatically generate the XML files, or it can manage XML files that have been assembled or modified elsewhere. Working with the XML files is much faster than modifying EnergyPlus input files directly, because a single XML parameter usually maps to multiple EnergyPlus inputs.

We selected EnergyPlus because it is a detailed DOE simulation tool that computes building energy use based on the interactions between climate, building form and fabric, internal gains, HVAC systems, and renewable energy systems. The simulations were run with EnergyPlus Version 3.1 compiled on local personal computers (PCs), and a 64-bit cluster computer at NREL. EnergyPlus is a heavily tested program with formal BESTEST validation efforts repeated for every release (Judkoff and Neymark 1995).

2.3.2 Climate Zones

The AEDGs contain a unique set of energy efficiency recommendations for each International Energy Conservation Code (IECC)/ASHRAE climate zone. The eight zones and 15 subzones in the United States are depicted in Figure 2-1. The zones are 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. Subzones indicate varying moisture conditions. Humid sub-zones are designated by the letter A, dry subzones by B, and marine subzones by C. This document may also be beneficial for international users, provided the location of interest can be mapped to a climate zone (ASHRAE 2006).

[1] We use the code-minimum EER value with a typical value for the compressor/condenser coefficient of performance (COP) and the total static pressure to calculate fan power. The resulting horsepower per 1000 cfm is lower than code-maximum.

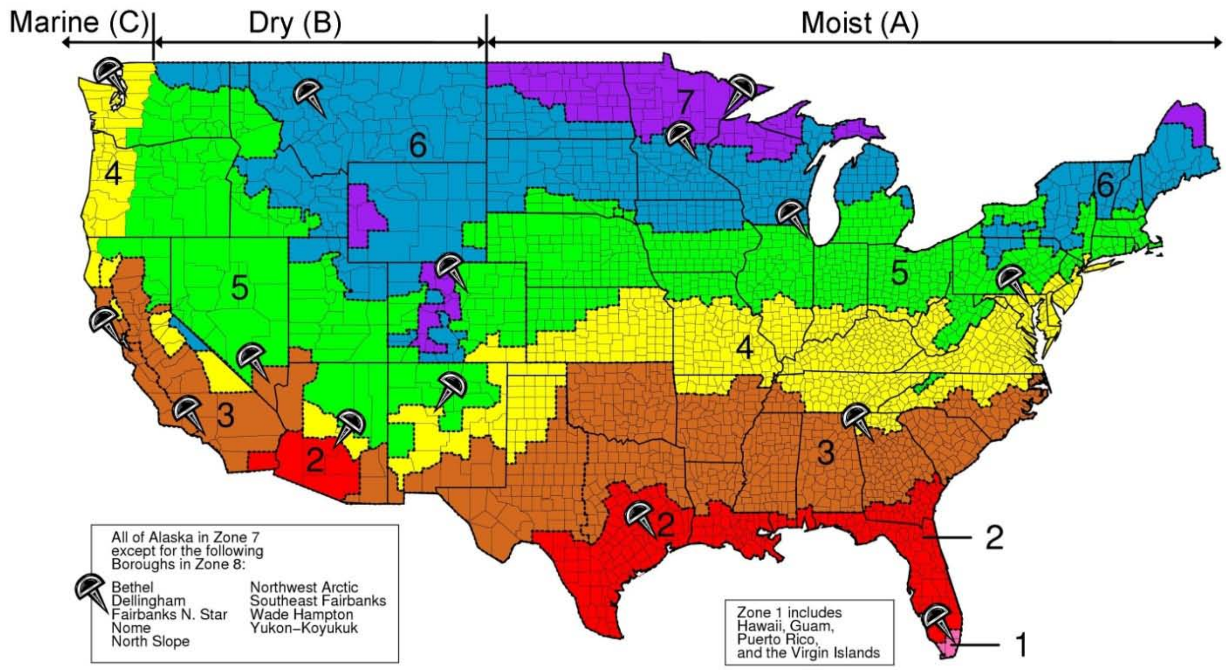

Figure 2-1 DOE climate zones and representative cities

To provide a concrete basis for analysis, the 16 specific locations (cities) used in the Benchmark Project (Deru et al. 2008) are designated as representatives of their climate zones. The cities are marked in Figure 2-1 and listed below. Larger cities were chosen, as their weather and utility data directly apply to a large fraction of building floor area. Two cities are provided for Zone 3B to account for the microclimate effects in California. Climate zone-specific recommendations were validated by running baseline and low-energy model simulations with the same weather file (one set of simulations for each city).

Zone 1A: Miami, Florida (hot, humid)

Zone 2A: Houston, Texas (hot, humid)

Zone 2B: Phoenix, Arizona (hot, dry)

Zone 3A: Atlanta, Georgia (hot, humid)

Zone 3B: Las Vegas, Nevada (hot, dry) and Los Angeles, California (warm, dry)

Zone 3C: San Francisco, California (marine)

Zone 4A: Baltimore, Maryland (mild, humid)

Zone 4B: Albuquerque, New Mexico (mild, dry)

Zone 4C: Seattle, Washington (marine)

Zone 5A: Chicago, Illinois (cold, humid)

Zone 5B: Denver, Colorado (cold, dry)

Zone 6A: Minneapolis, Minnesota (cold, humid)

Zone 6B: Helena, Montana (cold, dry)

Zone 7: Duluth, Minnesota (very cold)

Zone 8: Fairbanks, Alaska (extremely cold)

2.4 Integrated Design Methodology

We used Opt-E-Plus, an internal NREL building energy and cost optimization research tool, to determine combinations of EDMs that best balance two objective functions: net site energy savings and Five-Year Total Life Cycle Cost (5-TLCC, see Section 3.1.2.6). After the user specifies these functions, a baseline building, and a list of EDMs, Opt-E-Plus generates new building models, manages EnergyPlus simulations, and algorithmically determines optimal combinations of EDMs. The building models are first specified in high-level eXtensible Markup Language (XML) files. The NREL preprocessor then translates them into EnergyPlus input files. The output of the optimization is a 5-TLCC versus Percent Energy Savings graph (see Figure 2-2) that includes one point for each building, and a curve that connects the minimum cost buildings starting at 0% savings (the baseline building) and proceeding to the building with maximum percent savings.

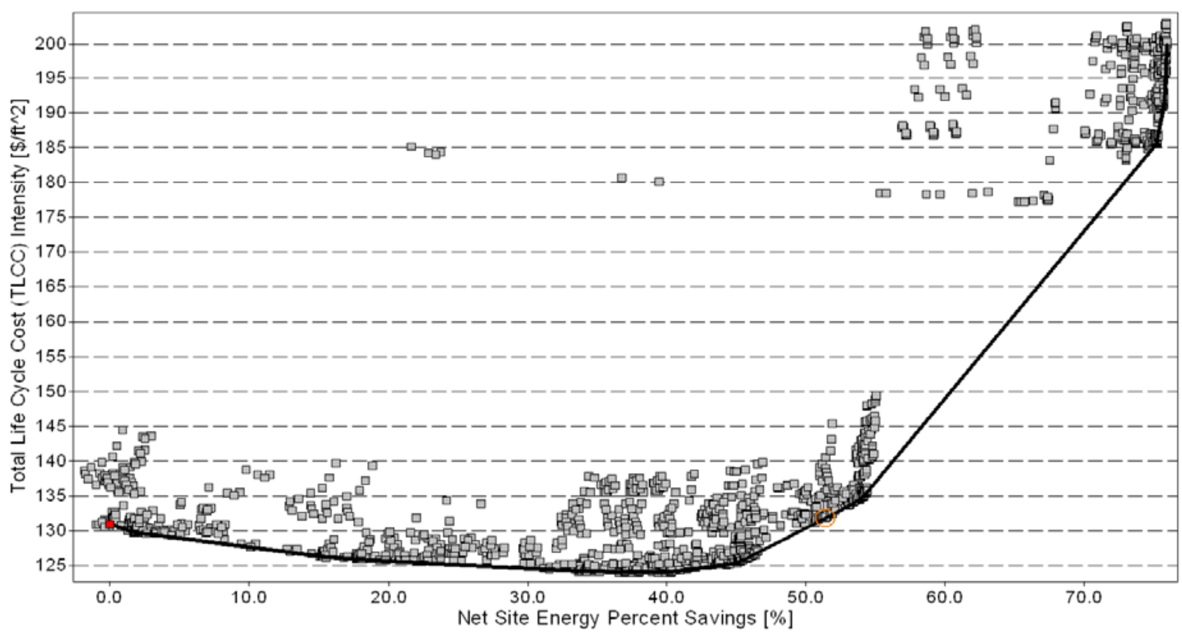

Figure 2-2 Example Opt-E-Plus output: climate zone 1A (Miami, Florida), high plug load scenario

The buildings along the portion of this curve, which starts at the minimum cost building (5-TLCC intensity of ~125 $\$/ft^2$ and percent energy savings of ~40%) and continues toward higher percent energy savings, are called *Pareto Points*. For such buildings, if one objective is improved, the other must deteriorate. For instance, for a given Pareto point, moving to a less expensive building necessitates that it will have a lower level of energy savings, and moving to a more energy-efficient building necessitates higher total life cycle costs. The set of Pareto points determines a Pareto front, which in general is a curve that represents the most cost-effective pathway to achieving low-energy buildings (given the limitations of our input data and search algorithm). This is the portion of the black curve in Figure 2-2 from about 40% savings to 75% savings.

2.4.1 Initialization

To set up the analysis, we apply methods to a custom defined high-level building model to create a code-compliant building for each desired location. These location-sensitive methods apply code minimum building constructions and other values specified by ASHRAE 90.1-2004 and

ASHRAE 62-1999 (ASHRAE 1999; ASHRAE 2004a). Economizers are manually added to the baseline buildings in climate zones 3B, 3C, 4B, 4C, 5B, and 6B (see Section 2.3.2 for climate zone definitions). All the EDMs described in Section 3.4 are available in all climate zones. Although climate considerations could have allowed us, for instance, to eliminate the highest levels of insulation in Miami, all measures were retained to simplify the initialization procedures, and to ensure that a potentially useful measure was not unintentionally excluded.

2.4.2 Execution

Opt-E-Plus searches for lowest cost designs starting from the baseline model at 0% energy savings, and proceeds to designs with higher and higher predicted energy savings. An iterative search algorithm is used to avoid an exhaustive search of all possible EDM combinations. Each iteration starts at the most recently found Pareto point, and then creates, simulates and analyzes all the models that are single-EDM perturbations of that point. The algorithm stops when it cannot find additional Pareto points. Cost is measured in terms of 5-TLCC, which is described in Section 3.1.2.6, and is calculated using the economic data in Sections 0, 3.3, and 3.4.

Even with the sequential search algorithm, an Opt-E-Plus search often requires numerous simulations. For this study, each optimization required 1,290 to 3,020 simulations, each of which took 5 to 19 minutes of computer time to complete. Such computational effort requires distributed computing. Opt-E-Plus manages two pools of simulations: local simulations (if the PC contains multiple cores) and those sent to a Linux cluster. The Linux cluster can, on average, run 64 simulations simultaneously. When the simulations are complete, the Opt-E-Plus database run manager specifies the next batch of simulations and distributes them based on the available resources.

2.5 Post-Processing Methodology

2.5.1 Basic

Once the search for the lowest cost designs is complete, we select a point along the Pareto front that satisfies our percent energy savings goal. All the EDMs besides photovoltaic (PV) panels are treated as discrete design choices that are either applied or not. The number of roof-mounted PV panels, on the other hand, is automatically selected to just reach the 50% energy savings goal, subject to a cap on the allowable amount of roof coverage (see Section 3.4.3.6).

Figure 2-2 shows an example Opt-E-Plus search with the selected building identified by an orange circle. In this case, PV was not needed to reach the target and the selected point was simulated during the normal course of running the search algorithm. The percent savings goal is exceeded by about 1%.

When PV is required to reach the 50% energy savings goal, the first Pareto front point beyond 50% is used to determine exactly how much PV is needed to just reach the goal. The resulting model with reduced PV is run, and shows up on the Opt-E-Plus plot as a ‘+’ (see Figure 2-3). The selected point (again, identified by an orange circle), is identical to the first Pareto point after the long straight segment associated with adding PV at maximum roof coverage (near 88% energy savings in the figure), except that the PV coverage has been scaled back to achieve 50% net savings.

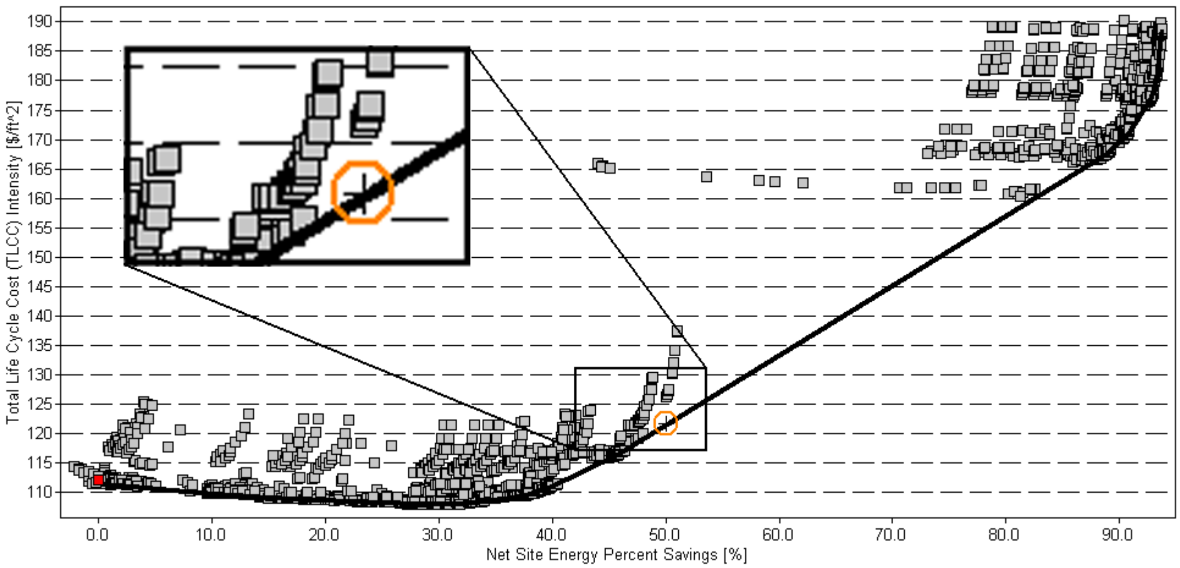

Figure 2-3 Example Opt-E-Plus output with PV post-processing: climate zone 3B (Las Vegas, Nevada), high plug load scenario

2.5.2 Finding Families of Solutions

For most climate zones, this TSD presents a single low-energy model for each plug load scenario. However, we appreciate that one size does not fit all. Design teams are subject to constraints imposed by the owner and other stakeholders, and may be interested in alternative designs that also reach 50% energy savings.

Although the standard Opt-E-Plus output appears to produce a number of models near the 50% target, those models are closely related to the Pareto front models and are thus not able to fully answer questions such as, "Is daylighting required to reach my target?"

To address this issue, we created a new post-processing routine for Opt-E-Plus that creates new searches based on turning sets of EDMs off and on. For instance, to determine whether daylighting is required to reach the target, we remove daylighting controls and skylights from the selected point and from the search options. The resulting search will then either reach the energy target or not, and the best building design (determined in the same way as described in Section 2.5.1) from that search is identified.

Starting with the selected low-energy model, one new search is created for each strategy (each group of EDMs the user clusters together) used in that model. Then, if at least one of the new searches is able to reach the target, more searches can be created to see if the goal can be reached without combinations of two strategies. This process may be repeated as often as the user wishes, as long as new searches that reach the goal remain unexplored.

This analysis is computationally intensive, so it was not completed for all climate zones, and we conducted only the first iteration of searches. Section 4.4 describes the results of this analysis for a subset of climate zones that we feel represents the categories of climates in the full set: 1A, hot and humid; 3B, hot and arid; 4C, marine; 5A, cold and humid; and 8, very cold.

2.6 External Review Process and Results

Our assumptions were reviewed by several members of the REA (DOE 2008a) and by several engineering firms. All retailers in the REA were invited to submit comments on a document that summarized our prototype model assumptions and our list of EDMs. NREL has contractual relationships with several engineering firms that were asked to review an earlier draft of this document that contained our assumptions (Section 3.0) and preliminary results (parts of Section 4.0).

Everyone in the REA was invited to comment. Our request form was quite brief, but the e-mail request for review (see Appendix E) produced only a few responses. We were also able to obtain helpful information from NREL's National Account partners. Both sources provided information about occupancy and HVAC schedules, LPDs, HVAC equipment, and plug loads.

An early draft of this report was reviewed by CxGBS, Speller Energy Consulting, and Moser Mayer Phoenix Associates. The comments we received led us to:

- Update the baseline exterior wall construction prices using recent data from the ASHRAE 90.1 Envelope Subcommittee.
- Correct the EDM window costs to reflect the inflation of the original data to 2008 dollars.
- Investigate adding a tankless water heater EDM. In the end, we did not add one because its implementation would require a significant programming effort and hot water accounts for only about 0.5% of baseline energy use.
- Modify the inputs for and the implementation of our ERV EDM.

3.0 Model Development and Assumptions

This section documents the development of model inputs. **Section 3.1** describes assumptions that apply to the entire study, including our economic assumptions and methodology. **Section 3.2** describes the programmatic characteristics of a typical general merchandise store, and uses them to develop a high-level, prototype model. **Section 3.3** elaborates on Section 3.2 to define the EnergyPlus baseline models that provide a reference for determining percent savings and are minimally compliant with Standard 90.1-2004. **Section 3.4** describes the list of EDMs used to create low-energy models.

3.1 Analysis Assumptions

Most of Section 3.0 concerns the assembly of valid and useful building energy and cost models, component by component. Here we touch on two types of assumptions that color our entire analysis: the often implicit assumptions required to conduct building energy simulation studies, and our economic model.

3.1.1 Integrity of Simulation Models

We made the following assumptions in this study:

1. The models developed in this work represent typical general merchandise stores well enough to provide climate-specific guidance as to the kinds of design changes that should be considered first when plans for a high-performance general merchandise store are developed.
2. These virtual buildings are well maintained and operated.

In reality, the anticipated energy savings are often not achieved or erode over time because they are not properly commissioned, operated, or maintained. For example, economizer dampers are notorious for failing, and rooftop HVAC equipment must be shielded from adverse weather conditions such as hail to maintain performance. Periodic recommissioning finds and resolves some of these problems.

3.1.2 Economics

One outcome of this project is a list of cost-effective design recommendations. The objective function of interest is 5-TLCC, which is further described in Section 3.1.2.6.

3.1.2.1 Building Economic Parameters

Our statement of work mandates that the design recommendations be analyzed for cost effectiveness based on a five-year analysis period, which is assumed acceptable to a majority of developers and owners. The other basic economic parameters required for the 5-TLCC calculation were taken from RSMeans and the Office of Management and Budget (Balboni 2008b; OMB 2008).

This analysis uses the real discount rate, which accounts for the projected rate of general inflation found in the Report of the President's Economic Advisors, Analytical Perspectives, and is equal to 2.3% for a five-year analysis period (OMB 2008). By using this rate, we do not have to explicitly account for energy and product inflation rates.

Regional capital cost modifiers are used to convert national averages to regional values. These are available from the RSMeans data sets and are applied before any of the additional fees listed in Table 3-1, three of which are also provided by RSMeans (Balboni 2008b).

Table 3-1 Economic Parameter Values

Economic Parameter	Value	Data Source
Analysis period	5 years	DOE
Discount rate	2.3%	OMB
O&M cost inflation	0%	OMB
Gas cost inflation	0%	OMB
Electricity cost inflation	0%	OMB
Bond fee	10%	RSMeans
Contractor fee	10%	RSMeans
Contingency fee	12%	RSMeans
Commissioning fee	0.5%	Assumption

3.1.2.2 Energy Design Measure Cost Parameters

Each EDM has its own cost data. The cost categories for each are the same, but the units vary:

- **Units** define how the EDM is costed (e.g. $/m^2, $/kW cooling, $/each).
- **Expected life** is the time (in years) that the EDM is expected to last. Once that period has expired, the EDM is replaced; that is, the full materials and installation costs are added to that year's cash flows.
- **Capital cost** is the per-unit cost of all materials and installation required for the EDM.
- **Fixed operations & maintenance (O&M)** is a per-unit, per-year cost.
- **Variable O&M** is a per-unit, per-year cost.

We report fixed and variable O&M costs together as a single maintenance cost.

3.1.2.3 Costing Methodology

Unless otherwise stated, all costs are in 2008 dollars. Costs originally from another year are adjusted according to the Consumer Price Index inflation calculator (Labor 2009).

The cost data used for the EDMs and the baseline walls, roofs, windows, lighting systems, and HVAC equipment are adapted from multiple sources and adjusted to 2008 dollars. The envelope costs were acquired from personal communications with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007a; ASHRAE 2008). The ABO Group developed a cost database for energy efficient overhang designs (Priebe 2006). The HVAC cost data were generated by the RMH Group (2006), a mechanical design contractor who received price quotes on a range of HVAC system types and sizes. All other cost data, including maintenance costs, come from the RSMeans data set (Balboni 2008a; Balboni 2008b; Greene 2008; Mossman 2005; Plotner 2009; Waier 2008; Waier 2005), the PNNL *AEDG TSD*s (Liu et al. 2006; Liu et al. 2007), and other sources (Emmerich et al. 2005; Roth et al. 2005). The cost data sources and values are listed explicitly throughout Section 3.3 and Section 3.4.

3.1.2.4 Baseline Capital Costs

Cost estimates at early planning stages are not very accurate. This report includes data on technologies that are not fully mature, so the reported costs may be even less accurate than usual.

Nevertheless, we wanted to start with reasonable baseline costs, so we adjusted our baseline cost per unit area to match that found for one-story department stores in the *2008 RSMeans Square Foot Costs* book (Balboni 2008b). The adjustment is made before regional adjustments, contractor fees, and architecture fees are applied, and results in an approximate baseline cost of $\$81.60/ft^2$ ($\$878.34/m^2$) in 2008 dollars. This cost assumes stucco on concrete block, bearing exterior walls; a floor area of 40,500 ft^2 (3,673 m^2); a perimeter of 810 ft (75.3 m^2); and a height of 20 ft (6.1 m). The cost is implemented in Opt-E-Plus, under a category that is not affected by any EDMs. The baseline capital cost is therefore fixed, thus enabling realistic estimates of the percent change in 5-TLCC when the low-energy models are compared to the baselines.

3.1.2.5 Utility Tariffs

One set of utility tariffs is used for all locations to make the results from each climate zone easier to compare. We chose Florida Power & Light's 2008 General Service Demand (GSD-1) electricity tariff because of data availability, the closeness of Florida's average commercial electricity rates to the national average, and the electricity demand of our models (generally within the required range of 20–500 kW) (EIA 2009b; Florida Power & Light 2008). The tariff is summarized in Table 3-2. The tax rate is a population-weighted average of state plus average county and city sales taxes from Sales Tax Clearinghouse (Sales Tax Clearinghouse 2009; U.S. Census Bureau 2009).

Table 3-2 Electricity Tariff

Tariff Name	General Service Demand
Monthly charge	\$33.10
Base demand charge	\$5.10/kW
Demand capacity charge	\$1.63/kW
Nonfuel energy charge	\$0.01392/kWh
Fuel energy charge	\$0.05564/kWh
Conservation energy charge	\$0.00133/kWh
Environmental energy charge	\$0.00038/kWh
Taxes	7.1%

A national average gas tariff was calculated by averaging the Energy Information Administration compilation of national average monthly prices for April 2006 through March 2009 (EIA 2007; EIA 2009a). Multiple years were averaged together, rather than simply taking the last year's worth of data, because recent prices are highly volatile. The resulting tariff and source data is reproduced in Table 3-3. While using a national-average tariff might lead to some design solutions that are suboptimal because of regional tariff variability, it allows us to isolate climate variability as a driving factor in designing buildings to save energy. For specific case studies, it is recommended that both regional tariff structures and incentives be considered in the economic side of the analysis.

Table 3-3 National Average Natural Gas Tariff and Source Data in $/MCF

	Year				
Month	**2006**	**2007**	**2008**	**2009**	**Tariff**
January	–	11.15	11.01	11.04	11.07
February	–	11.21	11.32	10.68	11.07
March	–	11.79	11.81	10.1	11.23
April	11.57	11.49	12.44	–	11.83
May	11.61	11.48	13.24	–	12.11
June	11.09	11.86	14.39	–	12.45
July	10.98	11.61	15.45	–	12.68
August	11.2	11.16	14.04	–	12.13
September	11.16	10.9	13.02	–	11.69
October	10.05	10.9	11.83	–	10.93
November	11.05	11.19	11.45	–	11.23
December	11.61	11.02	11.32	–	11.32

3.1.2.6 Total Life Cycle Cost

Our objective is to simultaneously achieve 50% net site energy savings and minimize 5-TLCC. The 5-TLCC is the total expected cost of the whole building (capital and energy costs) over the five-year analysis period. The 5-TLCC uses the real discount rate to account for inflation of energy and O&M costs, instead of using the nominal discount rate paired with explicit estimates of energy and O&M inflation.

The annual cash flow is summed over the analysis period to calculate the 5-TLCC. The annual energy use is assumed constant over the whole analysis period. Equation 3-1 defines the annual cash flows.

$$C_n = \left(\sum_{j=0}^{J} CC_n + FOM_n + VOM_n \right) + C_g + C_e \qquad (3\text{-}1)$$

Where:

C_n	=	cost in year n
J	=	total number of unique energy efficiency measures
CC_n	=	capital cost
FOM_n	=	fixed O&M costs
VOM_n	=	variable O&M costs
C_g	=	annual cost of gas consumption
C_e	=	annual cost of electricity consumption

The 5-TLCC is determined in Equation 3-2.

$$5 - TLCC = \sum_{n=0}^{5} \frac{C_n}{(1+d)^n} \qquad (3\text{-}2)$$

Where:

5-TLCC = present value of the five-year 5-TLCC

C_n = cost in year n

d = annual discount rate

3.2 Prototype Model

We surveyed a number of reports and datasets to develop typical general merchandise store characteristics and obtain energy performance estimates. These include:

- *2003 Commercial Buildings Energy Consumption Survey* (*CBECS*) (EIA 2005)
- *DOE Commercial Building Research Benchmarks for Commercial Buildings* (Deru et al. 2008)
- *Methodology for Modeling Building Energy Performance Across the Commercial Sector* (Griffith et al. 2008)

Each data source is described briefly; then the reasoning behind the prototype model assumptions is described in several functional groupings. The general merchandise store prototype models are summarized in Section 3.2.5.

3.2.1 Program

This section addresses programmatic considerations that are not affected by Standard 90.1-2004: building size, space types, and internal loads.

3.2.1.1 Building Size

This TSD assumes that general merchandise stores have 20,000 to 140,000 ft^2 (1,860 m^2 to 13,000 m^2) of floor area. The lower bound originates from the inclusion of stores up to 20,000 ft^2 (1,860 m^2) in the *Advanced Energy Design Guide for Small Retail Buildings* (ASHRAE et al. 2006). The upper bound encompasses so-called medium box and some big box stores according to the definitions in Hale et al. (2008b).

Our main prototype store has a floor area of 40,500 ft^2, and is thus a medium box store. Some of its characteristics are developed by examining the 33 *2003 CBECS* non-mall retail buildings that are in the medium box range of 20,000 ft^2 to 100,000 ft^2 (1,860 m^2 to 9,290 m^2) and were built since 1970 and renovated since 1980.

To better bracket general merchandise stores, we also examine a big box store with a floor area of 100,000 ft^2 (9,290 m^2). (This floor area actually represents the boundary between medium box and big box defined in Hale et al. (2008b).) The big box store model development and results are discussed in Section 4.3.

3.2.1.2 Space Types

85% of the gross floor area is allocated to sales display in the 40,500 ft^2 (3,763m^2) prototype model. The remaining 15% is subdivided to reflect the typical layout of a medium box general merchandise store: 8% for active storage, 1% for a meeting room, 1% for a dining room, 2% for restrooms, and roughly 3% total for several other spaces such as an enclosed office, a mechanical room, a corridor, and a vestibule. Table 3-4 provides a detailed space breakdown.

Table 3-4 Medium Box Space Types and Sizes

Space Type	Floor Area (ft^2)	Floor Area (m^2)	Percent of Total
Main Sales	31,500	2,926	77.8
Perimeter Sales	3,076	286	7.6
Enclosed Office	300	28	0.7
Meeting Room	500	47	1.2
Dining Room	500	47	1.2
Restroom	625	58	1.5
Mechanical Room	200	19	0.5
Corridor	450	42	1.1
Vestibule	300	28	0.7
Active Storage	3,050	283	7.5
Total	40,500	3,763	100.0

3.2.1.3 Internal Load Densities

Internal loads include the heat generated by occupants, lights, and appliances (plug and process loads). This section addresses the aspects of these loads not addressed in Standard 90.1, including peak occupant and plug load densities.

3.2.1.3.1 Occupancy Density

Occupancy density values by space type are defined according to ASHRAE Standard 62.1-2004 (ASHRAE 2004b). The mapping between each space type and the standard and the resulting occupancy density value are presented in Table 3-5. Values for space types without direct mapping to the standard were estimated. Restrooms were assumed to be a continuation of the sales areas, and thus assigned the corresponding occupancy density value. Mechanical rooms were assumed empty most of the time, and thus were assigned an occupancy density value of zero. The occupancy density value for the active storage zone was taken from the benchmark report (Deru et al. 2008).

Table 3-5 Occupancy Density Mapping and Peak Values

Space Type	Mapping to 62.1-2004	Occupancy Density	
		(#/1000 ft^2)	(#/100 m^2)
Main Sales	Retail::Sales	15	16.15
Perimeter Sales	Retail::Sales	15	16.15
Enclosed Office	Offices::Office space	5	5.38
Meeting Room	Offices::Conference/meeting	50	53.82
Dining Room	Food & Beverage::Restaurant dining rooms	70	75.35
Restroom	Retail::Sales	15	16.15
Mechanical Room	CUSTOM VALUE	0	0.00
Corridor	Retail::Sales	15	16.15
Vestibule	Retail::Sales	15	16.15
Active Storage	CUSTOM VALUE	3.33	3.59

3.2.1.3.2 Plug and Process Loads

Plug and process loads are notoriously difficult to estimate. Griffith et al. (2008) tried to reconcile the *2003 CBECS* and Commercial End Use Survey (CEUS) data on such loads, settling on an area-weighted average peak plug load of 0.346 W/ft^2 (3.73 W/m^2) in the *2003 CBECS* medium-sized, post-1970 general merchandise building models (with little variation—the loads ranged from 0.345 to 0.353 W/ft^2 [3.71 to 3.80 W/m^2]). Liu et al. (2006) cites a 2004 study that gives plug load density ranges of 0.20 to 0.60 W/ft^2 (2.2 to 6.5 W/m^2) during peak hours, and 0 to 0.20 W/ft^2 (0 to 2.2 W/m^2) during off hours (PNNL 2004). That document also specifies varying levels of accent lighting, which can reasonably be modeled as a plug load, in its prototype stores. Those accent lighting levels varied from zero to 3.9 W/ft^2 (42 W/m^2) in the merchandising area.

The Standard 90.1-2004 space-by-space method allows accent lighting on a display area basis (horizontal or vertical). Most merchandise may be lit at 1.6 W/ft^2 (17.2 W/m^2); high-value items such as jewelry, china, silver, and art are allowed 3.9 W/ft^2 (42 W/m^2).

For this work, there are two prototype models based on whole-building plug load densities of approximately 0.29 W/ft^2 (low plug load store), and 1.32 W/ft^2 (high plug load store) (3.12 W/m^2 and 14.21 W/m^2, respectively). We use the benchmark study plug loads for all low plug load zones except the sales zones (Deru et al. 2008). Peak plug loads for the low plug load sales zones are estimated based on the above plug load survey. Plug loads for the high plug load prototype are based on industry feedback. The low plug load level is meant to model stores such as bookstores, which have little to no accent lighting or plug-in merchandise. A typical high plug load store would be an electronics store, which has a much larger amount of plug-in merchandise and accent lighting. The peak plug loads for both the low and high plug load prototypes are listed by space type in Table 3-6.

Table 3-6 Peak Plug Loads

Space Type	Low Plug Load Store			High Plug Load Store		
	Electric (W/ft^2)	Accent Lighting (W/ft^2)	Total (W/ft^2)	Electric (W/ft^2)	Accent Lighting (W/ft^2)	Total (W/ft^2)
Main Sales	0.2	0	0.2	0.7	0.8	1.5
Perimeter Sales	0.4	0	0.4	0.6	0	0.6
Enclosed Office	0.75	0	0.75	1.1	0	1.1
Meeting Room	0.75	0	0.75	1.1	0	1.1
Dining Room	2.6	0	2.6	2.6	0	2.6
Restrooms	0.1	0	0.1	0.1	0	0.1
Mechanical Room	0	0	0	0	0	0
Corridor	0	0	0	0	0	0
Vestibule	0	0	0	0	0	0
Active Storage	0.75	0	0.75	0.75	0	0.75
Average			0.29			1.32

The sector-wide methodology study determined that general merchandise stores are subject to small gas appliance process loads; however, the peak densities were only 0.009 W/ft^2 to 0.028 W/ft^2 (0.097 W/m^2 to 0.301 W/m^2). Thus, most stores likely have no such loads, and this small amount probably results from a few stores having significantly larger loads. We assume the prototypical medium box general merchandise store has no gas process loads.

3.2.1.4 Schedules

3.2.1.4.1 Operating Hours

The operating hours are defined according to ASHRAE 90.1-1989 (ASHRAE 1989): Monday through Friday, 7:00 a.m. to 9:00 p.m.; Saturday, 7:00 a.m. to 10:00 p.m.; and Sunday and Holidays, 9:00 a.m. to 7:00 p.m.

3.2.1.4.2 Occupancy Schedule

The occupancy schedule for the prototypes is defined according to ASHRAE 90.1-1989 (ASHRAE 1989) (see Table 3-7).

Table 3-7 Occupancy Schedule, in Fraction of Peak Occupancy

Hour	Weekdays	Saturdays	Sundays, Holidays, Other
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0.10	0.10	0
9	0.20	0.20	0
10	0.50	0.50	0.10
11	0.50	0.60	0.20
12	0.70	0.80	0.20
13	0.70	0.80	0.40
14	0.70	0.80	0.40
15	0.70	0.80	0.40
16	0.80	0.80	0.40
17	0.70	0.80	0.40
18	0.50	0.60	0.20
19	0.50	0.20	0.10
20	0.30	0.20	0
21	0.30	0.20	0
22	0	0.10	0
23	0	0	0
24	0	0	0

3.2.1.4.3 Lighting Schedule

The *2003 CBECS* data indicate that almost no medium box, post-1970 general merchandise buildings have independent lighting controls or sensors. However, 71% of floor area is subject to an energy management control system that controls lighting, and 80% of floor area is lighted with electronic ballast fixtures. Figure 3-1 and Figure 3-2 show the distribution of lighting percentage when the store is open and closed, respectively. These figures and the abundance of energy management control systems support a lighting schedule with significant reductions during unoccupied hours. The lighting schedule for this TSD is defined according to ASHRAE 90.1-1989 and is listed in Table 3-8.

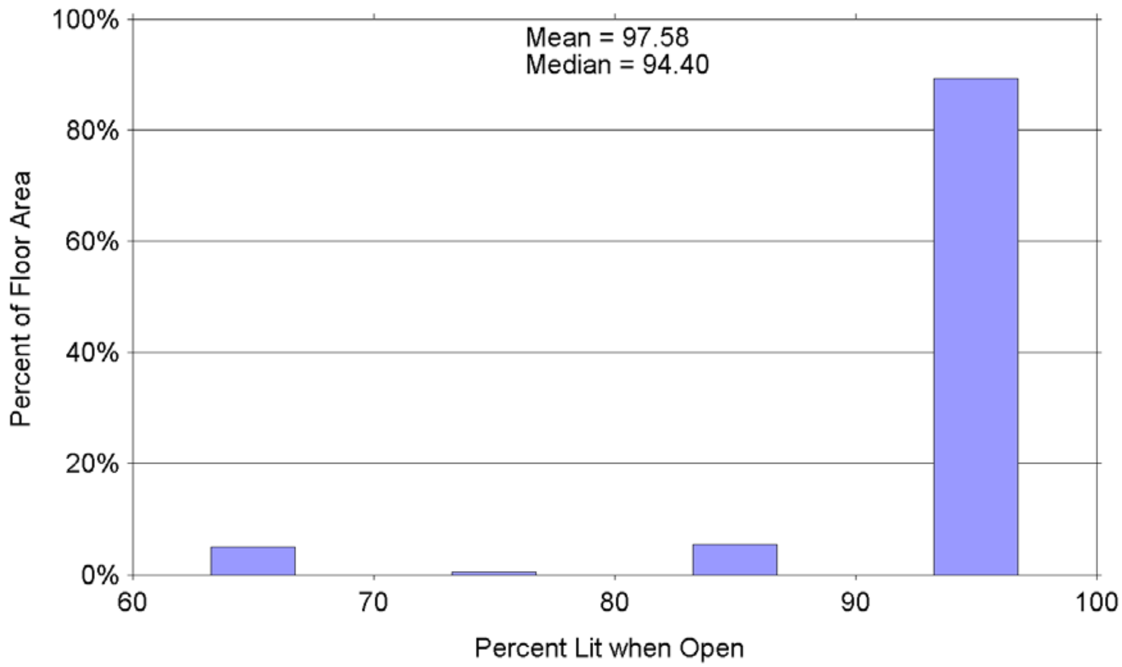

Figure 3-1 Area-weighted histogram of post-1970 medium box store open hours lighting percentage

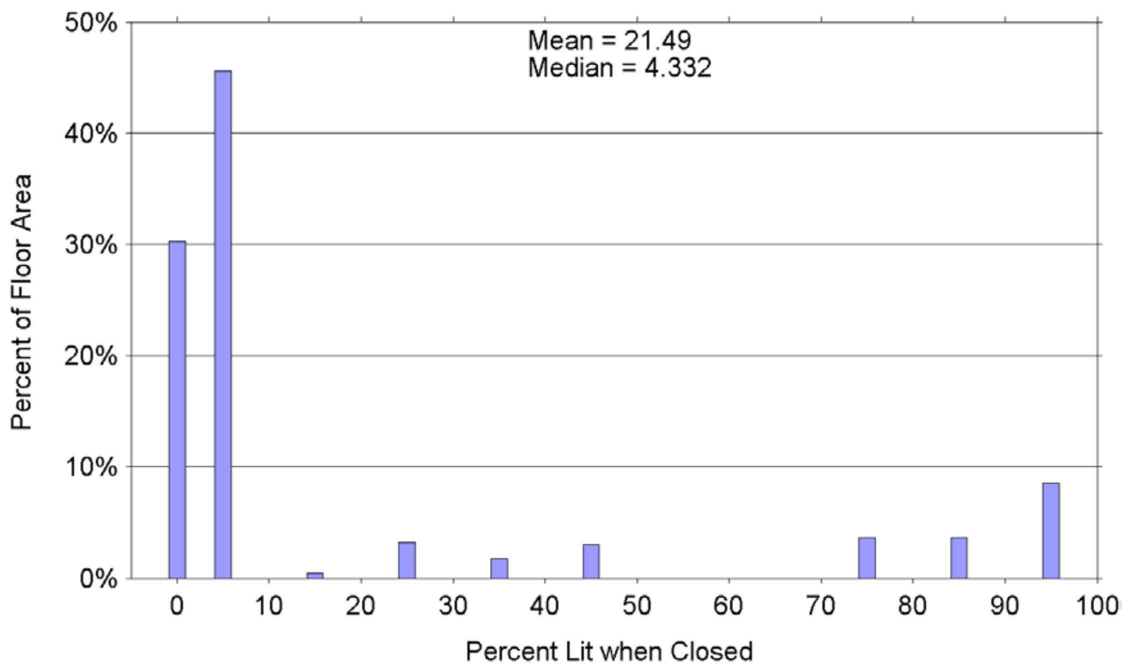

Figure 3-2 Area-weighted histogram of post-1970 medium box store closed hours lighting percentage

Table 3-8 Lighting Schedule, in Fraction of Peak Lighting Density

Hour	Weekdays	Saturdays	Sundays, Holidays, Other
1	0.05	0.05	0.05
2	0.05	0.05	0.05
3	0.05	0.05	0.05
4	0.05	0.05	0.05
5	0.05	0.05	0.05
6	0.05	0.05	0.05
7	0.05	0.05	0.05
8	0.20	0.10	0.05
9	0.50	0.30	0.05
10	0.90	0.60	0.10
11	0.90	0.90	0.40
12	0.90	0.90	0.40
13	0.90	0.90	0.60
14	0.90	0.90	0.60
15	0.90	0.90	0.60
16	0.90	0.90	0.60
17	0.90	0.90	0.60
18	0.90	0.90	0.40
19	0.60	0.50	0.20
20	0.60	0.30	0.05
21	0.20	0.30	0.05
22	0.20	0.10	0.05
23	0.05	0.05	0.05
24	0.05	0.05	0.05
Total Hours/Day	10.85	9.85	5.20

3.2.1.4.4 Plug Load Schedule

The sector-wide methodology study set the plug load schedule to 95% on during operating hours, and to a value between 10% and 95% on during closed hours. The off-hours percentage was derived directly from the *2003 CBECS* variable RDOFEQ8, which specifies whether equipment is turned off during off hours. The Small Retail TSD plug load schedule was simply 0.4 W/ft^2 (4.3 W/m^2) peak density, 5% of peak during off hours, 90% of peak during operating hours, and an hour-long transition at 50% of peak (Liu et al. 2006). The benchmark plug load schedule increases the percentage on during off-hours to account for more computing equipment (15% to 20% on), and is quite complex, with long ramp-up and ramp-down periods (Deru et al. 2008).

We used a modified version of the plug load schedule (see Table 3-9) from the benchmark study (Deru et al. 2008), increasing the percentage on during off hours based on industry feedback.

Table 3-9 Prototype Plug Equipment Schedule, in Fraction of Peak Load

Hour	Weekdays	Saturdays	Sundays, Holidays, Other
1	0.33	0.30	0.30
2	0.33	0.30	0.30
3	0.33	0.30	0.30
4	0.33	0.30	0.30
5	0.33	0.30	0.30
6	0.33	0.30	0.30
7	0.33	0.30	0.30
8	0.4	0.30	0.30
9	0.7	0.50	0.30
10	0.9	0.80	0.30
11	0.9	0.90	0.60
12	0.9	0.90	0.60
13	0.9	0.90	0.80
14	0.9	0.90	0.80
15	0.9	0.90	0.80
16	0.9	0.90	0.80
17	0.9	0.90	0.80
18	0.9	0.90	0.60
19	0.8	0.70	0.40
20	0.8	0.50	0.30
21	0.70	0.50	0.30
22	0.40	0.30	0.30
23	0.33	0.30	0.30
24	0.33	0.30	0.30
Total Hours/Day	14.87	13.50	10.70

3.2.2 Form

This section completes the characterization of the prototype model’s shape and size by specifying aspect ratio, floor-to-floor and ceiling height, and fenestration amount and placement.

3.2.2.1 Building Shape

Based on *2003 CBECS* statistics (see Figure 3-3), the 40,500 ft^2 (3,760 m^2) prototype stores are one-story rectangular buildings with a 1.25 aspect ratio, resulting in a footprint of 225 ft × 180 ft (68.6 m × 54.9 m).

The Small Retail TSD assumed an 11-ft (3.4 m) ceiling and a 14-ft (4.3 m) floor-to-floor height for the strip mall prototype, and a 12-ft (3.7 m) ceiling and a 16-ft (4.9 m) floor-to-floor height for the standalone prototype. Larger stores tend to have a more open feel, so we assume a ceiling height of 20 ft (6.1 m)—there is no drop ceiling or plenum.

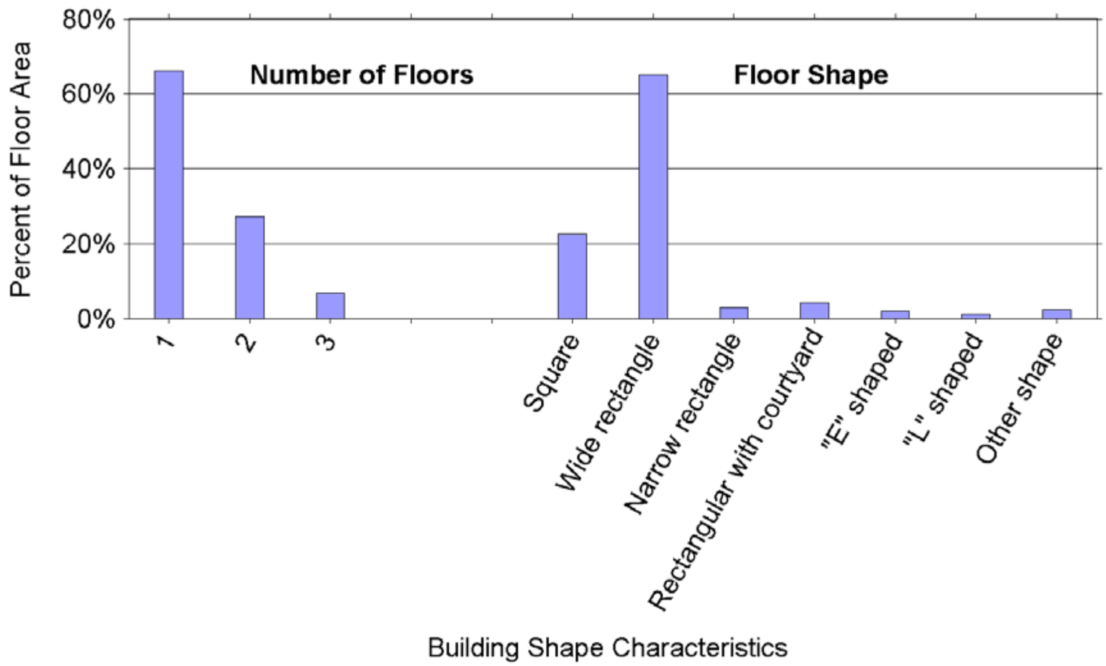

Figure 3-3 Area-weighted histograms of post-1970 medium box store shape characteristics

3.2.2.2 Fenestration

The *2003 CBECS* reports on several aspects of fenestration form. Figure 3-4 shows statistics on the amount and distribution of windows. Figure 3-5 gives statistics on window shading (with awnings or overhangs), skylights, and percentage of floor area that is daylit. These data indicate that our prototype store should have 10% or less of its wall area glazed, and that the glazing should be unevenly distributed. We adopt the typical glazing distribution for medium box general merchandise stores, which is to install all of the glazing in the main entrance wall, the south façade in this case. Although the *2003 CBECS* supports overhangs, they are not included in the prototype stores because of the procedures in Appendix G of Standard 90.1-2004. The baseline stores do not include skylights or daylighting controls.

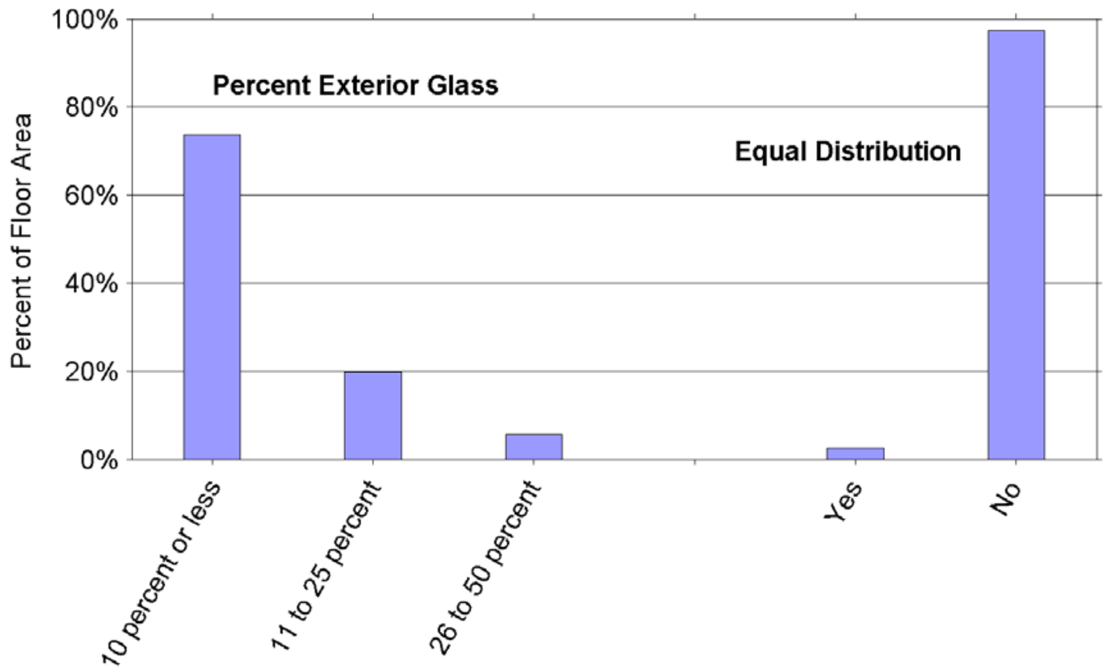

Figure 3-4 Area-weighted histograms of post-1970 medium box store fenestration amounts

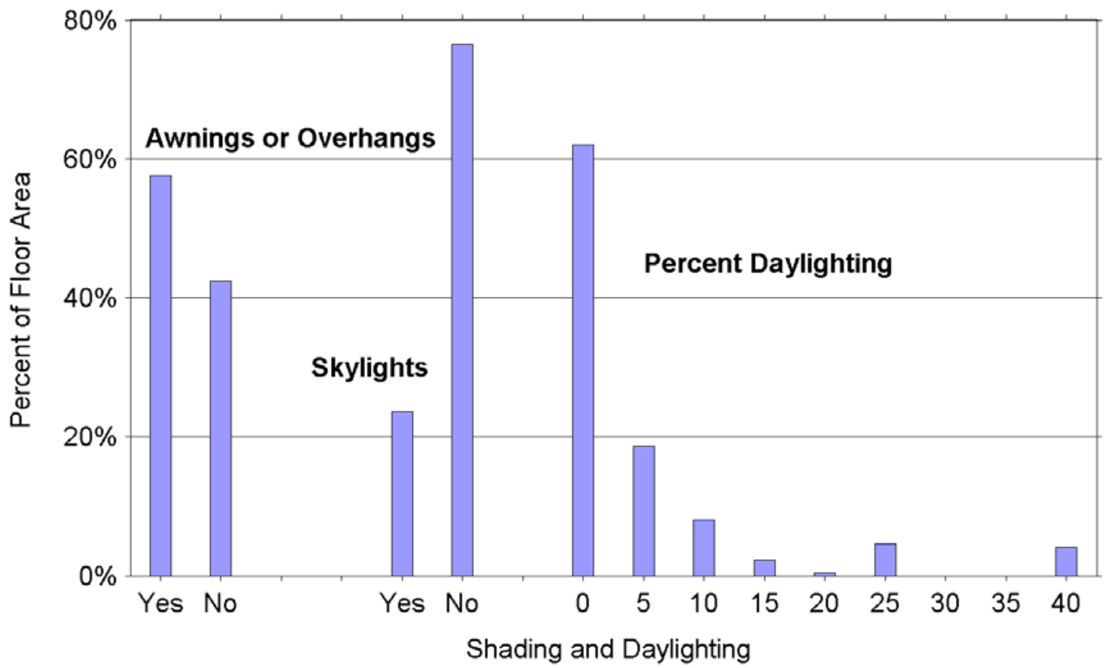

Figure 3-5 Area-weighted histograms of post-1970 medium box store sunlight management

The Small Retail TSD had all glazing on the front façade—in particular, 70% of the front wall was glazed in both prototypes. This results in overall window-to-wall ratios (WWRs) of 20% and 17% for the strip mall and the standalone store, respectively. According to building dimensions, those WWRs amount to 980 ft^2 (91.0 m^2) of glazing for the strip mall and 1,344 ft^2 (124.9 m^2) of glazing for the standalone building. We assume that the amount of glazing on a general merchandise store is fairly independent of store size and that a reasonable range for glazing area is 200 ft^2 to 1,400 ft^2 (18.6 m^2 to 130.1 m^2). For our prototype, we select a glazing area of 1,000 ft^2 (92.9 m^2), which corresponds to a 22% WWR for the south façade, and a 6.2% WWR for the entire building.

3.2.3 Fabric

This section specifies the types of envelope and interior constructions used in the prototype and baseline models. Specific fenestration constructions and insulation levels are listed in Section 3.3.3, as Standard 90.1-2004 specifies the minimum performance of these components.

3.2.3.1 Construction Types

The *2003 CBECS* data for wall and roof construction types are shown in Figure 3-6. The prototype building has masonry wall construction (which includes the brick, stucco, and concrete construction categories) and a roof with all insulation above deck (which includes the built-up and plastic/rubber/synthetic sheeting construction categories). The masonry wall assumption ignores the 34% of medium box general merchandise buildings that have metal walls.

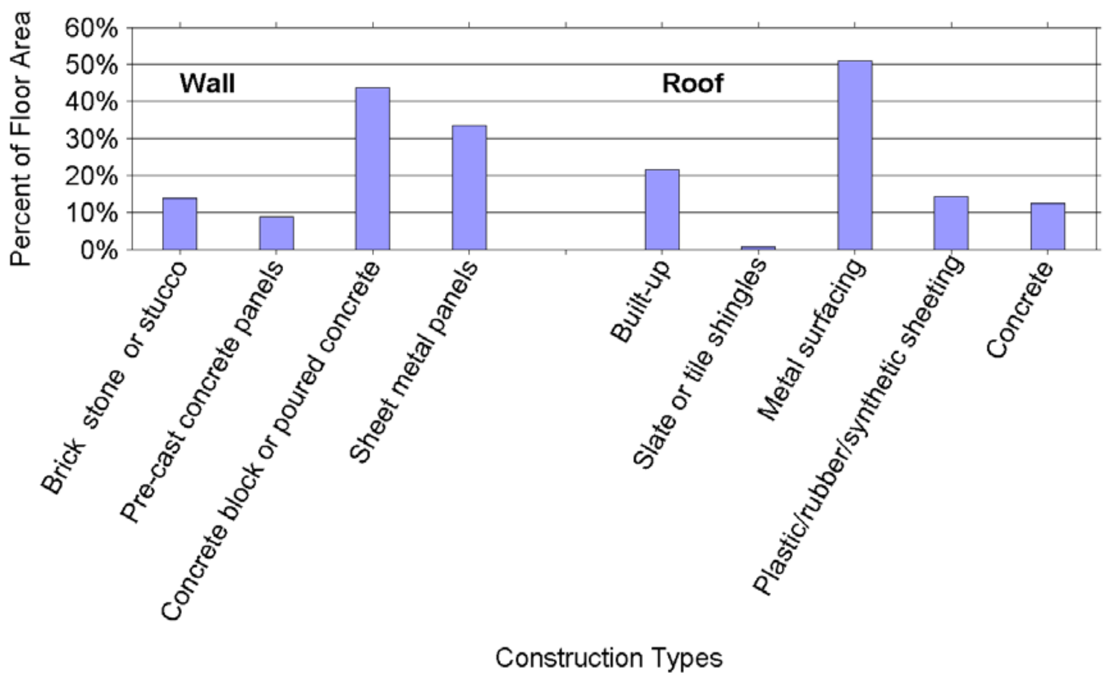

Figure 3-6 Area-weighted histograms of post-1970 medium box store construction types

3.2.3.2 Interior Partitions and Mass

We assume that the interior partitions that separate zones are composed of 4-in. (0.1-m) thick steel-frame walls covered with gypsum board. Internal mass is modeled as 81,000 ft^2 (7,525 m^2) of 6-in. (0.15-m) thick wood.

3.2.4 Equipment

This section specifies the types of HVAC and service water heating equipment used in the prototype and baseline models. Performance and cost data are discussed in Sections 3.3.4.2 and 3.3.4.3.

3.2.4.1 Heating, Ventilating, and Air-Conditioning

According to the *2003 CBECS*, all medium box general merchandise stores have some heating and cooling. More than 70% of floor area is in stores that are 100% heated; about 55% is in stores that are 100% cooled. We therefore assume that the prototypes are fully heated and cooled.

Figure 3-7 summarizes the *2003 CBECS* statistics on the types of heating and cooling equipment used in medium box general merchandise stores. All cooling is electric; the types of fuel used for heating are shown in Figure 3-8. Most stores (about 75% of the floor area) do not have secondary heating sources.

Based on these findings, the prototype HVAC equipment consists of packaged rooftop units (RTUs) with natural gas furnaces for heating, and electric direct expansion (DX) coils with air-cooled condensers for cooling. Primarily for humid climates, we control relative humidity to a set point of 60%, which, according to our thermostat set points (see Appendix B.5), corresponds to a dew point of approximately 14°F (57°F). The standard dehumidification strategy is subcooling and superheat, where a reheat coil uses DX condenser waste heat (superheat) to reheat the subcooled, dehumidified air stream at zero additional energy cost (notwithstanding the pressure drop that occurs across the reheat coil). Accordingly, each RTU is equipped with a superheat coil and each thermal zone is equipped with a humidistat to monitor humidity. The units do not have variable air volume (VAV) systems, because the *2003 CBECS* reports that just 27% of medium box general merchandise floor area uses them. Economizers are applied as per Standard 90.1-2004.

According to the *2003 CBECS*, most stores reduce heating and cooling during unoccupied hours. About 60% use a thermostat schedule; 30% use an energy management control system; the rest rely on manual reset. Our prototype store captures such behavior with a thermostat schedule (see Table B-6 and Table B-7).

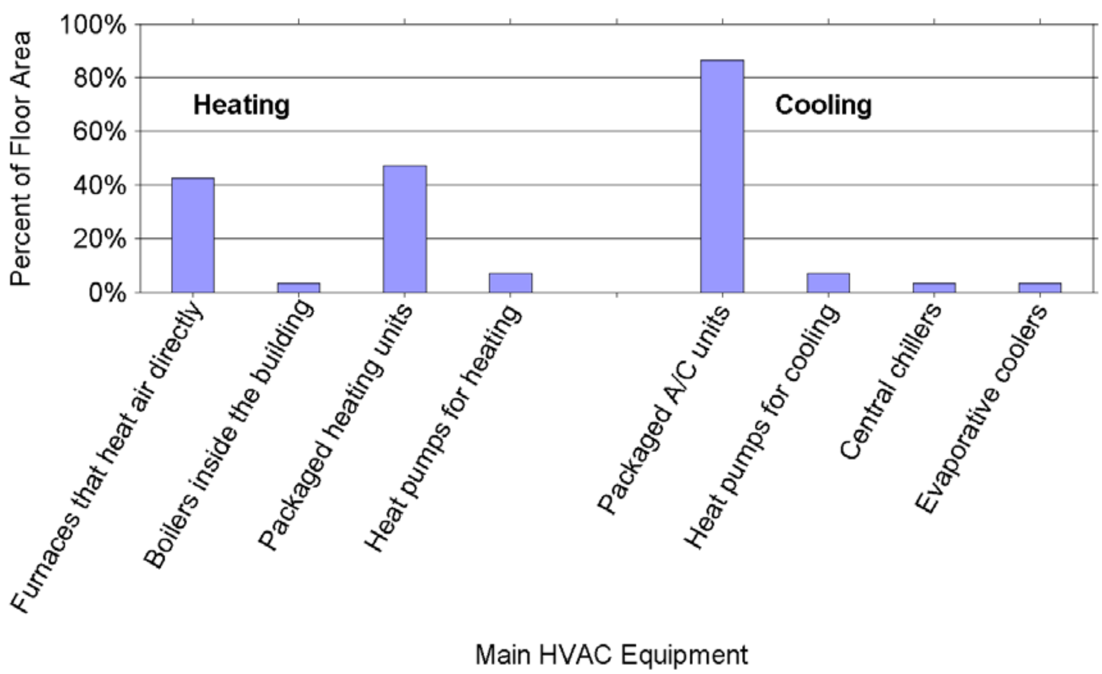

Figure 3-7 Area-weighted histograms of post-1970 medium box store heating and cooling equipment

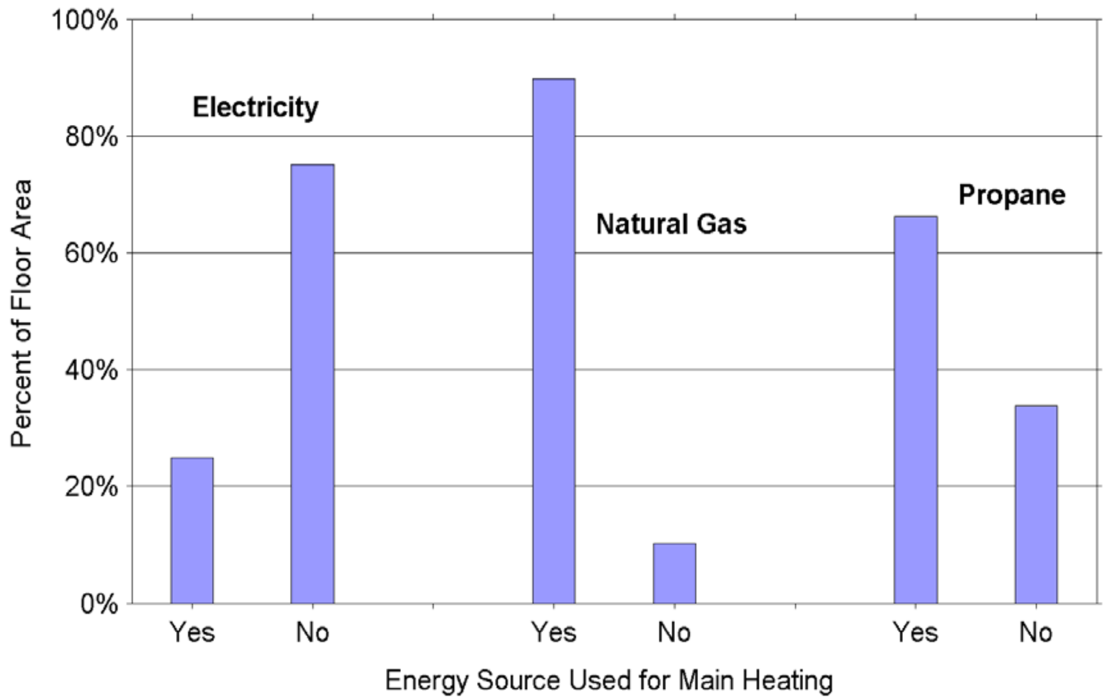

Figure 3-8 Area-weighted histograms of post-1970 medium box store main heating source

3.2.4.2 Service Water Heating

Figure 3-9 shows *2003 CBECS* data that indicate that most medium box general merchandise stores have centralized, tank storage hot water heaters that run on electricity or natural gas, and serve moderate hot water loads. Other CBECS variables suggest that instant hot water heaters and alternative fuel types are not widely used. The prototype store has an electric water heater, since that is the type used to service a majority of the *2003 CBECS* floor area, sized according to the ASHRAE (ASHRAE 2003) (see Section 3.3.4.3).

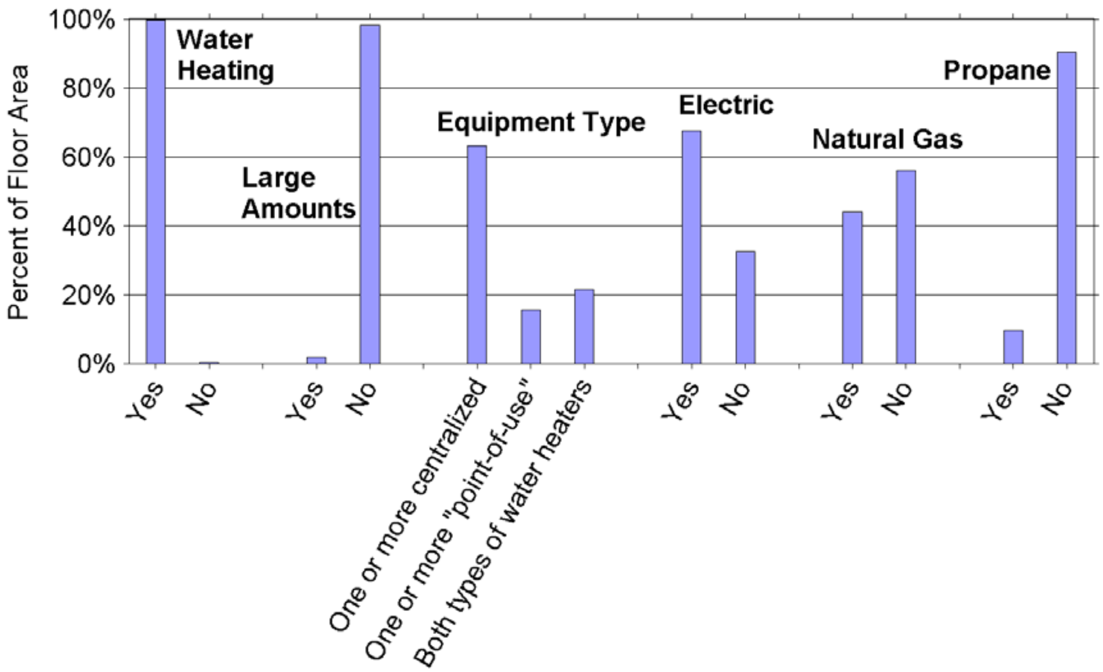

Figure 3-9 Area-weighted histograms of post-1970 medium box store service water heating characteristics

3.2.5 Prototype Model Summary

This section summarizes the building characteristics that define the medium box general merchandise prototype models. In particular, they must specify characteristics that are not found in ASHRAE 90.1-2004 or ASHRAE 62-1999 (ASHRAE 1999; ASHRAE 2004a), but are needed to develop baseline and low-energy models. Many characteristics are summarized in Table 3-10, the space type sizes and plug load levels are in Table 3-11, and the floor plan is shown in Figure 3-10. The two levels of plug loads developed in Section 3.2.1.3.2 and shown in Table 3-11 define two distinct prototype models that will be carried forward through the remainder of this work. They will be referred to as the low and high plug load models or scenarios.

Table 3-10 General Merchandise Prototype Model Characteristics and Data Sources

Retail Store Characteristic	Medium Box General Merchandise TSD Prototype	Source
Program		
Size	40,500 ft^2 (3,763 m^2)	*2003 CBECS*
Space types	See Table 3-11	Assumption
Operating hours	Monday through Friday, 7:00:00 a.m. to 9:00:00 p.m.; Saturday, 7:00:00 a.m. to 10:00:00 p.m.; and Sunday and Holidays, 9:00:00 a.m. to 7:00:00 p.m.	ASHRAE 90.1-1989
Occupancy	See Table 3-5 for density; see Table 3-7 for schedule	ASHRAE 62.1-2004; DOE Benchmark Retail; Assumption; ASHRAE 90.1-1989
Lighting	See Table 3-8 for schedule	ASHRAE 90.1-1989
Plug and process	See Table 3-6 for density; see Table 3-9 for schedule	DOE Benchmark Retail; Industry Feedback
Form		
Number of floors	1	*2003 CBECS*
Aspect ratio	1.25	*2003 CBECS*; Assumption
Floor-to-floor height	20 ft (6.10 m)	Assumption
Window area	1,000 ft^2 (93 m^2, 0.062 WWR)	*2003 CBECS*; Assumption
Floor plan	See Figure 3-10	Assumption
Fabric		
Wall type	Mass (brick, stone, stucco or concrete)	*2003 CBECS*
Roof type	All insulation above deck	*2003 CBECS*
Interior partitions	2 x 4 steel-frame with gypsum boards	Assumption
Internal mass	81,000 ft^2 (7,525 m^2) of 6” wood	Assumption
Equipment		
HVAC system type	Unitary rooftop units with DX coils, natural gas heating, and constant volume fans; Economizer as per ASHRAE 90.1-2004	*2003 CBECS*
HVAC unit size	10 tons (35 kW) cooling	Assumption
HVAC controls	Setback during unoccupied hours	*2003 CBECS*
Service water heating	Electric resistance heating with storage tank	*2003 CBECS*

Table 3-11 Space Type Floor Areas and Peak Plug Loads in the Medium Box General Merchandise Store Prototype Models

Space Type Name	Floor Area (ft^2)	Percent of Total	Peak Plug Load (W/ft^2)	
			Low Plug	High Plug
Main Sales	31,500	77.8	0.2	1.5
Perimeter Sales	3,076	7.6	0.4	0.6
Enclosed Office	300	0.7	0.75	1.1
Meeting Room	500	1.2	0.75	1.1
Dining Room	500	1.2	2.6	2.6
Restroom	625	1.5	0.1	0.1
Mechanical Room	200	0.5	0	0
Corridor	450	1.1	0	0
Vestibule	300	0.7	0	0
Active Storage	3,050	7.5	0.75	0.75

Figure 3-10 General merchandise store prototype model floor plan

3.3 Baseline Model

This section contains a topic-by-topic description of the baseline building models' EnergyPlus inputs, including the building form and floor plate; envelope characteristics; internal loads; HVAC equipment efficiency, operation, control, and sizing; service water heating; and schedules. We also list the costs that were used by Opt-E-Plus to compute 5-TLCC. The baseline models for medium box general merchandise stores were developed by applying the criteria in ASHRAE Standard 90.1-2004 and ASHRAE Standard 62-1999 (ASHRAE 1999; ASHRAE 2004a) to the prototype characteristics. (ASHRAE Standard 90.1-2004 explicitly references, and thereby includes, Standard 62.1-1999.)

3.3.1 Program

3.3.1.1 Occupancy

The internal load derived from the occupants is calculated assuming 120 W (409 Btu/h) of heat per person, which falls between the values listed for "seated, very light work" and "standing, light work; walking" in Chapter 30 of (ASHRAE 2005). Occupant comfort is calculated assuming clothing levels of 1.0 clo October through April, and 0.5 clo May through September; and an in-building air velocity of 0.66 ft/s (0.2 m/s).

3.3.2 Form

The prototype characteristics, together with a few modeling assumptions, are used to generate the baseline models' forms and floor plates. Per Appendix G of ASHRAE 90.1-2004, overhangs are not included in the baseline models.

Form and floor plate parameters are listed in Table 3-12. A rendering of the general merchandise baseline model is shown in Figure 3-11, which shows an isometric view of the baseline model from the southwest. All parameters except glazing sill height are specified in the prototype model.

Table 3-12 Selected Baseline Modeling Assumptions

Model Parameters	Value
Floor area	40,500 ft^2 (3,763 m^2)
Aspect ratio	1.25
Ceiling height	20 ft (6.096 m)
Fraction of fenestration to gross wall area	5.6%
Glazing sill height	3.609 ft (1.1 m)

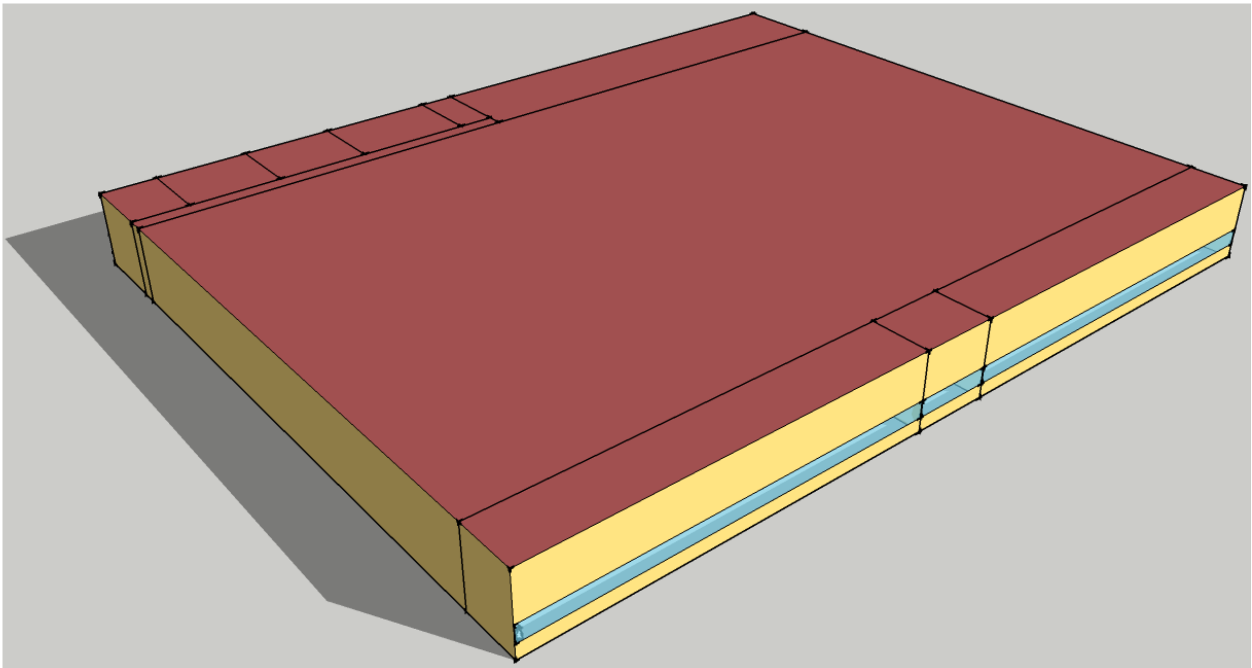

Figure 3-11 General merchandise store baseline model rendering: View from southwest

3.3.3 Fabric

Based on the *2003 CBECS* and engineering experience, we assume that general merchandise stores are typically constructed with mass exterior walls, built-up roofs, and slab-on-grade floors. These choices are further developed to meet the prescriptive design option requirements of ASHRAE 90.1-2004 Section 5.5. Layer-by-layer descriptions of the exterior surface constructions were used to model the building thermal envelope in EnergyPlus.

3.3.3.1 Exterior Walls

The baselines are modeled with mass wall constructions. The layers consist of stucco, concrete block, rigid isocyanurate insulation, and gypsum board. The assembly U-factors vary based on the climate zone and are adjusted to account for standard film coefficients. R-values for most of the layers are derived from Appendix A of ASHRAE 90.1-2004. Continuous insulation (c.i.) R-values are selected to meet the minimum R-values required in Section 5 of ASHRAE 90.1-2004. The baseline exterior walls' performance metrics, including costs, are listed in Table 3-13 (see Table C-1 for metric units). The mass wall includes the following layers:

- Exterior air film (calculated by EnergyPlus)
- 1-in (2.5-cm) exterior stucco, 116 lb/ft^3 (1858 kg/m^3)
- 8-in. (20.3-cm) heavyweight concrete block with solid grouted cores, 140 lb/ft^3 (2243 kg/m^3)
- 1-in. (2.5-cm) metal clips with rigid insulation (R-value varies by climate)
- 0.5-in. (1.3-cm) thick gypsum board, 49 lb/ft^3 (785 kg/m^3)
- Interior air film (calculated by EnergyPlus).

The materials and installation costs are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2008). The thermal performance of the interior and exterior air films are calculated with the EnergyPlus "detailed" algorithm for surface heat transfer film coefficients, which is based on linearized radiation coefficients separate from the convection coefficients determined by surface roughness, wind speed, and terrain.

Table 3-13 Baseline Exterior Wall Constructions

Properties	Climate Zones 1–2	Climate Zones 3–4	Climate Zone 5	Climate Zone 6	Climate Zone 7	Climate Zone 8
Key	Baseline Wall Construction, No c.i.	Baseline Wall Construction, R-5.7 c.i.	Baseline Wall Construction, R-7.6 c.i.	Baseline Wall Construction, R-9.5 c.i.	Baseline Wall Construction, R-11.4 c.i.	Baseline Wall Construction, R-13.3 c.i.
U-factor (Btu/ h·ft^2·°F)	0.754	0.173	0.137	0.114	0.0975	0.0859
Capital cost ($/ft^2)	$20.37	$21.06	$21.42	$21.68	$21.80	$21.86

3.3.3.2 Roofs

The baseline model roofs are built-up, with rigid insulation above a structural metal deck. The layers consist of roof membrane, insulation, and metal decking. The assembly U-factors vary by climate zone and are adjusted to account for the standard film coefficients. R-values for most of the layers are derived from Appendix A of ASHRAE 90.1-2004. Insulation R-values for continuous insulations are selected to meet the minimum R-values required in ASHRAE 90.1-2004, which vary by climate zone. The thermal performance metrics and construction costs are listed by climate zone in Table 3-14 (see Table C-2 for metric units). The costs are estimated based on (Balboni 2008a) and assume:

- A 60-mil (0.15-cm) thick, mechanically-fastened ethylene propylene diene monomer single-ply membrane
- Polyisocyanurate insulation, including a tapered drainage piece finished with 7/16-in. (1.11-cm) strand board
- 0.05-in. (0.13-cm) base flashing and edging around the perimeter of the roof.

Table 3-14 Baseline Roof Constructions

Properties	Climate Zones 1–7	Climate Zone 8
Key	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-20 c.i.
U-Factor (Btu/h·ft^2·°F)	0.0675	0.0506
Capital Cost ($/ft^2)	$8.69	$9.11

The prescriptive portion of Standard 90.1-2004 does not specify performance characteristics such as roof reflectance or absorption. Appendix G states that the reflectivity of reference buildings should be 0.3. We assume the baseline roof ethylene propylene diene monomer membrane has a solar reflectance of 0.3, a thermal absorption of 0.9, and a visible absorption of 0.7.

3.3.3.3 Slab-on-Grade Floors

The baseline buildings are modeled with slab-on-grade floors, made up of carpet pad over 8 in. (0.2 m) thick heavyweight concrete. A separate program, *slab.exe*, was used to model the ground coupling (DOE 2008b). It determines the temperature of the ground under the slab based on the area of the slab, the location of the building. It also reports the type of insulation under or around the slab and reports the perimeter ground monthly temperatures, the core ground monthly temperatures, and average monthly temperatures. For this analysis, the core average monthly temperatures are passed to EnergyPlus to specify the ground temperatures under the slab.

3.3.3.4 Fenestration

The baseline general merchandise stores' fenestration systems are modeled as three windows on the façade totaling 1,000 ft^2 (92.9 m^2) of glazing area. Windows are collected into a single object per zone; frames are not explicitly modeled to reduce complexity in EnergyPlus and make the simulations run faster. However, the U-factors and solar heat gain coefficients (SHGCs) are whole-assembly values that include frames. Those performance criteria are set to match the requirements of Appendix B of ASHRAE 90.1-2004. If a particular climate zone has no ASHRAE 90.1-2004 SHGC recommendation, its SHGC value is set to that of the previous (next warmest) climate zone.

The multipliers from the visible light transmittance (VLT) table, Table C3.5 in ASHRAE 90.1-2004 Appendix C (ASHRAE 2004a), are used to calculate VLT values for the baseline windows. An iterative process is used to refine the material properties in the layer-by-layer descriptions to just match the required assembly performance level. The baseline window constructions and costs are summarized in Table 3-15 (see Table C-3 for metric units). The costs are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007a).

Table 3-15 Baseline Window Constructions

Properties	**Climate Zones 1– 2**	**Climate Zone 3**	**Climate Zones 4–6**	**Climate Zone 7**	**Climate Zone 8**
Key	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction
SHGC	0.250	0.390	0.490	0.490	0.490
VLT	0.250	0.495	0.622	0.490	0.490
U-Factor (Btu/h·ft^2·°F)	1.21	0.570	0.570	0.570	0.460
Capital Cost ($/ft^2)	$44.00	$47.23	$46.65	$47.23	$49.97
Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22	$0.22	$0.22

Some of the recommended designs for 50% energy savings include skylight-facilitated daylighting. Four of the skylight construction choices match the fenestration performance criteria outlined in Appendix B of ASHRAE 90.1-2004. These baseline skylight constructions are summarized in Table 3-16 (see Table C-4 for metric units). Costs based on personal communication with the ASHRAE 90.1 Envelope Subcommittee are also listed (ASHRAE 2007a).

Table 3-16 Baseline Skylight Constructions

EDM Instance	Climate Zones 1–3	Climate Zones 4–6	Climate Zone 7	Climate Zone 8
Key	**Baseline Skylight Construction**	**Baseline Skylight Construction**	**Baseline Skylight Construction**	**Baseline Skylight Construction**
SHGC	0.36	0.490	0.490	0.490
VLT	0.457	0.622	0.490	0.490
U-factor (Btu/h·ft^2·°F)	1.22	0.690	0.690	0.580
Capital cost ($/ft^2)	$46.28	$47.23	$47.22	$51.04
Fixed O&M cost ($/ft^2)	$0.22	$0.22	$0.22	$0.22

3.3.3.5 Infiltration

Building air infiltration is addressed indirectly in ASHRAE 90.1-2004 through requirements for building envelope sealing, fenestration, door air leakage, etc. The air infiltration rate is not specified. This analysis assumes that the peak infiltration rate is 0.291 air changes per hour (ACH) during operating hours, when the HVAC system is on and customers are entering and leaving the store. At night, when the HVAC system is off and the doors are closed, we assume that the infiltration rate reduces to 0.081 ACH (see Appendix B.4 for the hourly infiltration schedule). Infiltration through a surface is dependent on the pressure gradient acting on the surface. We calculated pressure gradients for each of the four walls according to the following assumptions:

- A constant 8 mph (3.6 m/s) wind blows directly into the front (south facade) of the store.
- The wind creates a constant, uniform, positive pressure (0.023 in. w.c. [5.8 Pa]) on the front wall and a constant, uniform, negative pressure of equal magnitude (0.023 in. w.c. [5.8 Pa]) on the back wall.
- The wind exerts no external pressure on the side walls.
- When the HVAC system is on, the building is pressurized to 0.016 in. w.c. (4 Pa) above the ambient air pressure.
- When the HVAC system is off, the building is not pressurized with respect to the outside air.

The resulting pressures (magnitudes and directions) acting on each exterior wall during operating and non-operating hours are listed in Table 3-17 and Table 3-18, respectively (see Table C-5 and Table C-6 for metric units), and presented graphically in Figure 3-12.

Table 3-17 Pressures Acting on Exterior Walls During Operating Hours

Exterior Wall	Resultant Pressure Gradient	
	Magnitude (Pa)	Direction
Front	1.8	Infiltration
Back	9.8	Exfiltration
Side	4.0	Exfiltration

Table 3-18 Pressures Acting on Exterior Walls During Non-operating Hours

Exterior Wall	Resultant Pressure Gradient	
	Magnitude (Pa)	Direction
Front	5.8	Infiltration
Back	5.8	Exfiltration
Side	0	NA

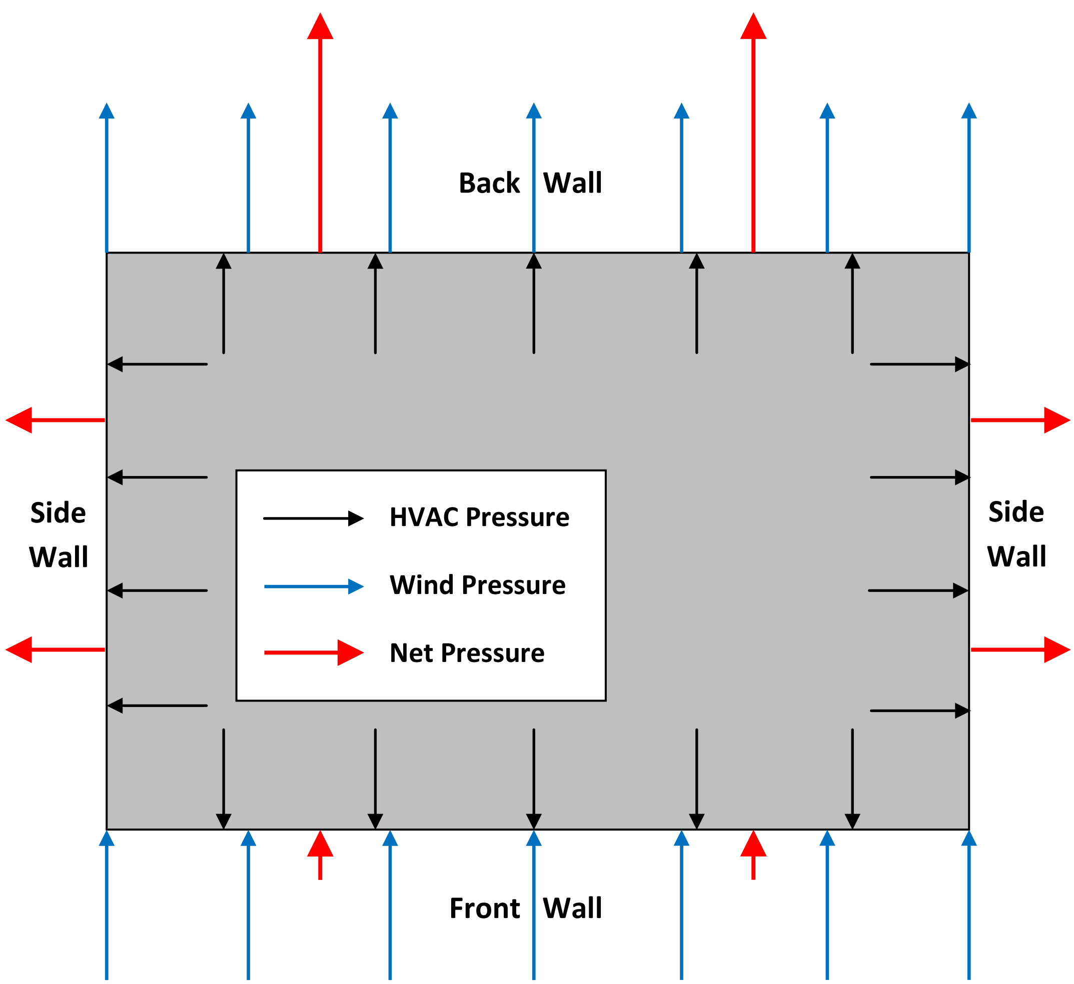

Figure 3-12 Building flow balance diagram

Pressure gradients driving infiltration are used to calculate infiltration rates for the building. The envelope infiltration rate is derived from CIBSE-T23 building tightness specifications for good construction practice (CIBSE 2000). The infiltration through the sliding doors is modeled using the door opening event modeling of Yuill et al. (2000). Pressure gradients driving exfiltration are used to calculate exfiltration rates, which have implications in regards to the flow of air available for ERV. See Section 3.4.3.5.2 for more detail.

3.3.4 Equipment

This section describes the performance and cost of our baseline buildings' lighting, HVAC and service water heating equipment.

3.3.4.1 Lighting

3.3.4.1.1 Interior

The baseline interior LPD for each space type is derived using the space-by-space method described in ASHRAE 90.1-2004 (ASHRAE 2004a). The mapping between each space type and the standard, and the resulting baseline LPDs are presented in Table 3-19. For the location of each space type, see Figure 3-10.

Table 3-19 Baseline Lighting and Occupancy Loads by Space Type

Space Type	Mapping to ASHRAE 90.1-2004	LPD (W/ft^2)	LPD (W/m^2)
Main Sales	Sales area	1.7	18.3
Perimeter Sales	Sales area	1.7	18.3
Enclosed Office	Office-enclosed	1.1	11.8
Meeting Room	Conference/meeting/multipurpose	1.3	14.0
Dining Room	Dining area	0.9	9.7
Restrooms	Restrooms	0.9	9.7
Mechanical Room	Electrical/mechanical	1.5	16.1
Corridor	Corridor/transition	0.5	5.4
Vestibule	Corridor/transition	0.5	5.4
Active Storage	Active storage	0.8	8.6
Whole Building		1.6	17.0

The baseline cost of the lighting system is modeled as $7.42/ft^2 ($24.35/m^2, $4,706/kW) for capital costs, and $0.12/ft^2·yr ($0.40/m^2·yr, $77.24/kW·yr) for maintenance, where kW refers to the total installed lighting power. The material and installation costs are estimated based on (Balboni 2008b); the maintenance costs are estimated using (Plotner 2009). Thus, the baseline capital costs are approximately $300,500, and the baseline maintenance costs are about $4,930/yr.

3.3.4.1.2 Exterior

The baseline general merchandise stores have 1 W/ft (3.28 W/m) of exterior façade lighting, per ASHRAE 90.1-2004, Table 9.4.5 (ASHRAE 2004a). The model does not include a parking lot or parking lot lighting.

3.3.4.2 HVAC Systems and Components

3.3.4.2.1 System Type and Sizing

This TSD assumes packaged single-zone (PSZ) unitary heating and cooling equipment, based on the *2003 CBECS*. These systems are modeled by placing an autosized PSZ system with a constant volume fan, DX cooling, and gas-fired furnace in each thermal zone (the disjoint rectangles in Figure 3-10). To apply ASHRAE 90.1-2004, we develop performance data consistent with 10-ton, 4,000 cfm (1.88 m^3/s) RTUs, under the assumption that the larger zones would be served by multiple such units.

We use the design-day method to autosize the cooling capacity of the DX cooling coil and the heating capacity of the furnace in the packaged RTUs. The design-day data for all 16 climate locations are developed from (ASHRAE 2005). In those data sets, we base the heating design condition on 99.6% annual percentiles, and the cooling design condition on 0.4% annual percentiles. The internal loads (occupancy, lights, and plug loads) were scheduled as zero on the heating design day, and at their peak on the cooling design day. A 1.2 sizing factor was applied to all autosized heating and cooling capacities and air flow rates. Because EnergyPlus autosizes HVAC equipment according to sensible load, additional sizing factors needed to be applied in humid climates to zones with large outdoor air requirements to handle the large latent loads.

3.3.4.2.2 Outside Air

Ventilation rates by zone are defined according to ASHRAE Standard 62-1999 (ASHRAE 1999). The mapping between each space type and the standard and the resulting ventilation rate are presented in Table 3-20. Rates for spaces without direct mapping to the standard were estimated. ASHRAE 62-1999 requires 50 cfm (24 L/s) of OA per toilet for restrooms, and we assume an area of roughly 48 ft^2 (4.5 m) per toilet. Mechanical rooms were assigned a ventilation rate of zero, based on the assumption that they are unoccupied most of the time.

Table 3-20 Baseline Minimum Ventilation Rates

Space Type	Mapping to ASHRAE 62-1999	Ventilation per Person		Ventilation per Area	
		cfm/person	L/s·person	cfm/ft^2	L/ s·m^2
Main Sales	Retail::Basement and street	–	–	0.30	0.15
Perimeter Sales	Retail::Basement and street	–	–	0.30	0.15
Enclosed Office	Offices::Office space	20.0	10.0	–	–
Meeting Room	Offices::Conference rooms	20.0	10.0	–	–
Dining Room	Food & Beverage::Dining rooms	20.0	10.0	–	–
Restrooms	CUSTOM VALUE	–	–	1.04	0.52
Mechanical Room	CUSTOM VALUE	–	–	0.00	0.00
Corridor	Public Spaces::Corridors & utilities	–	–	0.05	0.03
Vestibule	Public Spaces::Corridors & utilities	–	–	0.05	0.03
Active Storage	Retail::Shipping and receiving	–	–	0.15	0.08

OA intake follows the same schedule as the HVAC system, which turns on an hour before the store is occupied in the morning and turns off when the store closes in the evening. The HVAC system also runs intermittently during off hours to adhere to the off hours temperature requirements.

3.3.4.2.3 Economizers

In accordance with ASHRAE 90.1-2004, Section 6.5.1, an economizer is required in climate zones 3B, 3C, 4B, 4C, 5B, 5C, and 6B for systems between 65,000 Btu/h (19 kW) and 135,000 Btu/h (40 kW) cooling capacity. Therefore, the 10-ton (120,000 Btu/h, 35.16 kW) baseline RTUs include economizers in these climate zones only.

3.3.4.2.4 Minimum Efficiency

The code-minimum efficiency for cooling equipment is determined based on cooling system type and size. To apply ASHRAE 90.1-2004, we assume baseline RTUs with 10 tons cooling and 4,000 cfm (1.88 m^3/s) air flow. ASHRAE 90.1-2004 requires single packaged unitary air conditioners of this size (between 65,000 Btu/h [19 kW] and 135,000 Btu/h [40 kW]) and with nonelectric heating units to have a minimum EER of 10.1. The gas-fired furnace efficiency levels were set to 80% to match the efficiency requirements for gas heating.

The ASHRAE 90.1-2004 minimum EER values include fan, compressor, and condenser power. EnergyPlus, however, models compressor and condenser power separately from fan power. We assume EER and compressor/condenser coefficient of performance (COP) values, and then use them to calculate fan efficiency. As stated above, the EER is 10.1. We assume a compressor/condenser COP of 3.69, based on publically available industrial spec sheets for EER 10.1 units.

3.3.4.2.5 Fan Power Assumptions

We assume that the package RTU contains only a supply fan, and no return or central exhaust fans. The constant volume supply fan energy use is determined from three primary input parameters: system-wide EER, compressor/condenser COP, and total static pressure drop. ASHRAE 90.1-2004 specifies maximum fan motor power, which, together with static pressure drop, can be used to determine fan efficiency and compressor/condenser COP for a given EER. We choose to deviate from this practice to obtain a more realistic split between fan and compressor/condenser power; we recognize, however, that our fan efficiencies are better than code minimum.

The total supply fan static pressure drops are based on the 10-ton units modeled in Liu et al. (2007) plus 50% more supply and return ductwork. Table 3-21 (see Table C-7 for metric units) summarizes the breakdown of the fan total static pressure for the baseline RTU. The 10-ton unit without an economizer has a total fan static pressure of 1.53 in. (w.c.) (381 Pa); those with economizers have a total static pressure of 1.62 in. w.c. (404 Pa).

Table 3-21 Baseline Fan System Total Pressure Drops

Component	Package Rooftop, Constant Volume, 10-ton, 4000 cfm, no Economizer (in. w.c.)	Package Rooftop, Constant Volume, 10-ton, 4000 cfm, with Economizer (in. w.c.)
Internal Static Pressure Drop	0.67	0.76
External Static Pressure Drop	0.86	0.86
Total Static Pressure Drop	1.53	1.62

* Used friction rate of 0.1 in. w.c./100 ft (25 Pa/30 m) for the baseline duct pressure drop.

We back out the baseline total fan efficiency from the 10.1 EER requirement, the static pressures, and a combined compressor and condenser COP of 3.69. This calculation proceeds in three steps:

1. Determine the portion of the EER dedicated to the supply fan by subtracting out the compressor/condenser contribution:

   After converting EER and COP to units of tons of cooling per kilowatt of electricity, one finds that the supply fan uses 0.235 kW (801.9 Btu/h) of electricity for every ton of cooling.

$$\frac{kW\ fan\ power}{ton\ cooling} = \frac{12}{EER} - \frac{3.516}{COP}$$

2. Determine the nameplate motor power per supply air volume:

Assuming 400 cfm per ton of cooling (0.054 (m^3/s)/kW), the fan power per volumetric unit of air is 0.788 hp/1000 cfm (1,245 W/(m^3/s)). This is well within the Standard 90.1-2004 requirement that units with less than 20,000 cfm (9.44 m^3/s) have fans with nameplate motor power less than 1.2 hp/1000 cfm (1896 W/(m^3/s)).

$$\frac{motor\ hp}{1000\, cfm} = \frac{kW\ fan\ power}{ton\ cooling} \cdot \frac{1 ton\ cooling}{400\, cfm} \cdot 1341$$

3. Calculate fan efficiency:

The fan efficiency is equal to the total static pressure (using the external static pressure value specified by the ARI standard) divided by the nameplate motor power per supply air volume, in compatible units. Thus the RTUs without economizers have a fan efficiency of 30.6%; those with economizers have an efficiency of 32.4%.

3.3.4.2.6 Summary and Costs

This report uses HVAC system cost data prepared for NREL by the RMH Group (2006). The 10-ton RTUs described in that report have EER values of 9.0, 10.4, and 11.0. The baseline unit costs are assumed to be the same as the lowest efficiency unit's even though the EER of our baseline unit is higher (10.1 instead of 9.0). This cost is \$8,478 plus \$1.89/cfm (\$4,005/(m^3/s)) for ductwork materials and installation. Assuming 400 cfm per ton of cooling (0.054 (m^3/s)/kW), the cost of ductwork for a 10-ton unit is \$7,560, and the total system capital cost is \$1603.75/ton of cooling (\$456.13/kW). The cost of an economizer, including controls and an additional relief hood, is given as \$1,002 for a 10-ton unit, that is, an extra \$100.20/ton of cooling (\$28.48/kW). Maintenance costs for the 10-ton unit are \$160/year for fixed O&M plus \$1,240/yr for repair and replacement costs: \$140/ton·yr (\$39.87/kW·yr) total. Table 3-22 (see

Table C-8 for metric units) summarizes the primary HVAC performance characteristics and cost data for the baseline general merchandise stores.

Table 3-22 Baseline HVAC Models Summary

HVAC Input	ASHRAE 90.1-2004 Baseline PSZ DX, Gas Furnace, No Economizer	ASHRAE 90.1-2004 Baseline PSZ DX, Gas Furnace, with Economizer
System EER	10.1	10.1
COP of compressor/condenser	3.69	3.69
Heating efficiency	80%	80%
Fan power	0.788 hp/1000 cfm	0.788 hp/1000 cfm
Fan static pressure	1.53 in. w.c.	1.62 in. w.c.
Fan efficiency	30.6%	32.4%
Economizers	None	Included
Capital cost ($/ton cooling)	$1,604	$1,704
O&M cost ($/ton cooling·yr)	$140	$140

3.3.4.3 Service Water Heating

The baseline service water heating system is an electric storage water heater that meets the ASHRAE 90.1-2004 requirements. We assume a thermal efficiency of 86.4% to meet the energy factor requirement for units with rated input power less than 12 kW (40.95 kBtu/h).

The consumption rates of hot water are determined using (ASHRAE 2003), specifically Chapter 49, Table 8. That table does not have an entry for retail, so we assume that the hot water use in general merchandise buildings is similar to that in office buildings. The baseline general merchandise stores' peak hot water consumption rate is modeled as 18 gph (1.9E-5 m^3/s), based on 40 gph (4.2E-5 m^3/s) for sinks and 20 gph (2.1E-5 m^3/s) for public lavatories, multiplied by a demand factor of 0.3. The storage tank has a volume of 50 gallons (0.19 m^3) based on a storage capacity factor of 2.0 and 71.4% usable volume percentage. The consumption schedule as a fraction of peak load is shown in Table B-8. The hot water outlet temperature is assumed to be 104ºF (40ºC). The water heater set point is 140ºF (60ºC).

3.4 Energy Design Measures

The optimization algorithm described in Section 2.4 determines which EDMs are applied to the baseline models to create low-energy models that meet the 50% energy savings target. This section contains a topic-by-topic description of the EDMs under consideration. They fall into the following categories:

- Reduced LPD and occupancy controls
- Reduced plug and process load densities
- PV electricity generation
- Varying levels of façade glazing and skylights
- Overhangs to shade the façade glazing
- Daylighting controls

- Enhanced opaque envelope insulation
- Window and skylight glazing constructions
- Reduced infiltration via an air barrier or vestibule
- Higher efficiency HVAC equipment
- Higher efficiency fans
- Demand controlled ventilation (DCV)
- ERVs
- Economizers

The low-energy building models are built by perturbing the baseline models with the efficiency measures described below. Any aspect of the building previously discussed but not mentioned below is constant across all models.

We were not able to include all efficiency measures of interest in this analysis. For a discussion of items that could be included in a subsequent study, see Section 5.0.

3.4.1 Form

3.4.1.1 Fenestration

These EDMs change the amount of horizontal and vertical glazing. None has an inherent cost; instead, each determines the amount of glazing. Window and skylight costs are calculated by multiplying the glazing areas (as determined by the baseline glazing amount and these EDMs) by the cost per unit area of the selected glazing types (see Section 3.4.2.3).

3.4.1.1.1 Front Façade Windows

One EDM reduces the amount of façade fenestration by 50%. This results in a reduction in the south façade WWR from 22.2% to 11.1%. The sill height for this EDM is consistent with that of the baseline building.

3.4.1.1.2 Skylights

Another set of EDMs adds skylights to the baseline building. Skylights can be added to all zones except the perimeter sales and vestibule zones (see Figure 3-13). The skylight EDMs result in 2%, 3%, or 4% coverage of the roof area in the applicable zones.

3.4.1.2 Overhangs

Roof-framed overhangs were added assuming a 0.82 ft (0.25 m) offset from the top of each window, and a projection factor of 0.5 to 1.1, in steps of 0.2. This yields four EDMs, which were all priced at \$10.09/ft^2 (\$108.63/m^2) of overhang in 2008 dollars (ABO Group 2006). The size of each overhang was determined using the height of the window, the offset, and the projection factor. For instance, a 3-ft (0.91-m) wide, 2-ft (0.61-m) tall window, a 0.25-ft (0.076-m) offset, and a projection factor of 1.1 yield a 2.475-ft (0.75-m) deep by 3-ft (0.91-m) wide overhang.

3.4.2 Fabric

3.4.2.1 Exterior Walls

The mass wall EDMs are shown in Table 3-23 (see Table C-9 for metric units), along with capital costs that are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2008). Construction method, insulation material and insulation thickness are listed independently for each exterior wall construction to provide sufficient means for comparison.

The interior insulation construction is the baseline construction (see Section 3.3.3.1). Its layers are:

- Exterior air film (calculated by EnergyPlus)
- 1-in (2.5-cm) exterior stucco, 116 lb/ft^3 (1,858 kg/m^3)
- 8-in. (20.3-cm) heavyweight concrete block with solid grouted cores, 140 lb/ft^3 (2,243 kg/m^3)
- 1-in. (2.5-cm) metal clips with rigid insulation (R-value varies by climate)
- 0.5-in. (1.3-cm) thick gypsum board, 49 lb/ft^3 (785 kg/m^3)
- Interior air film (calculated by EnergyPlus).

The exterior insulation construction has a different insulation location and slightly different layer materials and thicknesses from those reported above. The latter differences stem from the fact that the exterior insulation construction is representative of the most recent ASHRAE 90.1 Envelope Subcommittee data, whereas the interior insulation construction was developed from an earlier data set. The layers of the exterior insulation construction are:

- Exterior air film (calculated by EnergyPlus)
- 0.75-in (1.9-cm) exterior stucco, 120 lb/ft^3 (1,920 kg/m^3)
- Rigid insulation (R-value varies by climate)
- 7.625-in. (20.1-cm) lightweight concrete block with partially grouted cores, 38 lb/ft^3 (609 kg/m^3)
- 1-in. (2.5-cm) metal clips with air
- 0.5-in. (1.3-cm) thick gypsum board, 49 lb/ft^3 (785 kg/m^3)
- Interior air film (calculated by EnergyPlus).

The brick cavity construction consists of two “skin” layers, in this case an exterior brick layer and an interior concrete block layer, separated by a hollow space (cavity) that can be filled with insulation. Cavity walls are more expensive to build, but provide better sound and heat insulation and have a higher resistance to rain penetration. The layers of the brick cavity construction are identical to those of the exterior insulation construction, except that the stucco layer is replaced with brick:

- Exterior air film (calculated by EnergyPlus)
- 3.625-in (9.2-cm) medium-weight brick, 110 lb/ft^3 (1,760 kg/m^3)
- Rigid insulation (R-value varies by climate)
- 7.625-in. (20.1-cm) lightweight concrete block with partially grouted cores, 38 lb/ft^3 (609 kg/m^3)
- 1-in. (2.5-cm) metal clips with air
- 0.5-in. (1.3-cm) thick gypsum board, 49 lb/ft^3 (785 kg/m^3)
- Interior air film (calculated by EnergyPlus).

Table 3-23 Exterior Wall EDMs

Insulation R-value, Nominal	Assembly U-Factor (Btu/h·ft^2·°F)	Construction Method	Insulation Material	Insulation Thickness (in)	Capital Cost ($/ft^2)
R-5.7 c.i.	0.1754	Interior insulation	Isocyanurate	1.3	$21.06
R-9.5 c.i.	0.1053	Interior insulation	Isocyanurate	2.2	$21.68
R-13.3 c.i.	0.0752	Interior insulation	Isocyanurate	3.1	$21.86
R-15.0 c.i.	0.0532	Exterior insulation	Polystyrene extruded	3	$22.42
R-19.5 c.i.	0.0430	Exterior insulation	Polyisocyanurate	3	$22.75
R-22.5 c.i.	0.0372	Brick cavity	Polyurethane foam	3.75	$28.35
R-28.5 c.i.	0.0303	Brick cavity	Polyurethane foam	4.75	$28.83

3.4.2.2 Roofs

The insulation above deck roof EDMs are shown in Table 3-24 (see Table C-10 for metric units), along with capital costs that are estimated based on (Balboni 2008a). The construction of the EDM roofs in the EnergyPlus models is identical to that of the baseline roofs, except for the amount of c.i. and the possible addition of high albedo (cool) roof membranes. Thus, the roofs are described by the R-value of the c.i. and the presence or absence of a cool roof.

The high albedo/cool roofs have a Solar Reflective Index of 78 and an outer layer with a thermal absorption of 0.9, a solar reflectivity of 0.7, and a visible absorption of 0.3.

Table 3-24 Roof EDMs

EDM Key	U-Factor (Btu/h·ft^2·°F)	Capital Cost ($/ft^2)
R-20 c.i.	0.0507	$5.43
R-20 c.i. with cool roof	0.0507	$5.43
R-25 c.i.	0.0405	$5.82
R-25 c.i. with cool roof	0.0405	$5.82
R-30 c.i.	0.0332	$6.25
R-30 c.i. with cool roof	0.0332	$6.25
R-35 c.i.	0.0289	$6.64
R-35 c.i. with cool roof	0.0289	$6.64
R-40 c.i.	0.0229	$7.20
R-50 c.i.	0.0201	$7.60
R-60 c.i.	0.0161	$8.43
R-75 c.i.	0.0134	$9.29
R-95 c.i.	0.0109	$10.13

3.4.2.3 Fenestration

3.4.2.3.1 Front Façade Windows

Table 3-25 (see Table C-11 for metric units) lists the seven window EDMs, including a short description, performance data, and cost data. The set is selected from a list of glazing systems compiled by the ABO Group to provide a good mix of available performances (Priebe 2006).

Table 3-25 South Fenestration Construction EDMs

EDM Key	SHGC	VLT	U-Factor (Btu/h·ft^2·°F)	Capital Cost ($/ft^2)	Fixed O&M Cost ($/ft^2·yr)
Single pane with clear glass	0.810	0.881	1.08	$37.40	$0.21
Single pane with pyrolytic low-e	0.710	0.811	0.745	$40.70	$0.21
Double pane with low-e and argon	0.564	0.745	0.264	$44.00	$0.21
Double pane with low-e2 and argon	0.416	0.750	0.235	$50.60	$0.21
Double pane with low-e2 and tinted glass	0.282	0.550	0.288	$50.60	$0.21
Triple layer with low-e polyester film	0.355	0.535	0.215	$59.75	$0.21
Quadruple layer with low-e polyester films and krypton	0.461	0.624	0.136	$62.59	$0.21

3.4.2.3.2 Skylights

Several skylight EDMs are similarly chosen from a list of constructions provided by the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007a) in an attempt to select high/low U-factors and high/low SHGCs, see Table 3-26 (Table C-12 for metric units).

Table 3-26 Skylight Fenestration Construction EDMs

EDM Key	SHGC	VLT	U-Factor (Btu/h·ft^2·°F)	Capital Cost ($/ft^2)	Fixed O&M Cost ($/ft^2·yr)
Single pane with high solar gain	0.610	0.672	1.22	$47.22	$0.24
Single pane with medium solar gain	0.250	0.245	1.22	$51.22	$0.24
Single pane with low solar gain	0.190	0.174	1.22	$51.22	$0.24
Double pane with high solar gain	0.490	0.622	0.580	$45.68	$0.24
Double pane with low-e and high solar gain	0.460	0.584	0.451	$45.78	$0.24
Double pane with medium solar gain	0.390	0.495	0.580	$57.70	$0.24
Double pane with low-e and medium solar gain	0.320	0.406	0.451	$63.17	$0.24
Double pane with low solar gain	0.190	0.241	0.580	$58.83	$0.24
Double pane with low-e and low solar gain	0.190	0.240	0.451	$63.54	$0.24

3.4.2.4 Infiltration

The infiltration EDMs reduce the baseline infiltration rate by applying an envelope air barrier or a front entrance vestibule. The air barrier is assumed to reduce the envelope infiltration from 0.038 to 0.015 ACH, based on CIBSE-T23 building tightness specifications for good and best construction practice, respectively (CIBSE 2000). The cost of the air barrier is estimated at \$1.40/ft^2 (\$15.07/m^2) of exterior wall area (Emmerich et al. 2005). A vestibule is assumed to reduce the front door infiltration from 0.253 to 0.158 ACH, based on the door opening event modeling of Yuill et al. (2000). The cost of this EDM is assumed to be that of replacing two, 8-ft (2.44-m) tall sliding doors with a total surface area of 120 ft^2 (11.15 m^2) with four, 7-ft (2.13-m) tall sliding doors (adding the vestibule requires a second set of doors) with a total surface area of 210 ft^2 (19.51 m^2) and adding 30 linear feet (9.14 m) of interior walls (based on a 15-ft. [4.6 m] deep vestibule), corresponding to an additional interior wall area of 600 ft^2 (55.74 m^2). According to that assumption, the cost associated with adding a vestibule is \$5,853 (Waier 2008).

3.4.3 Equipment

3.4.3.1 Daylighting Controls

The daylighting EDM adds light sensors and dimming controls to zones with windows or skylights. Skylights or windows (depending on the source of daylighting for the zone) are not added by this EDM, rather, the EDM impact and cost are dependent on how many skylights or windows are installed.

Each zone has access to, at most, one daylighting source. As depicted in Figure 3-13, most of the store only receives daylight from skylights, which may or may not be included in a given model. The front zones containing windows are limited to a depth of 15 ft. to ensure good sidelighting of those zones.

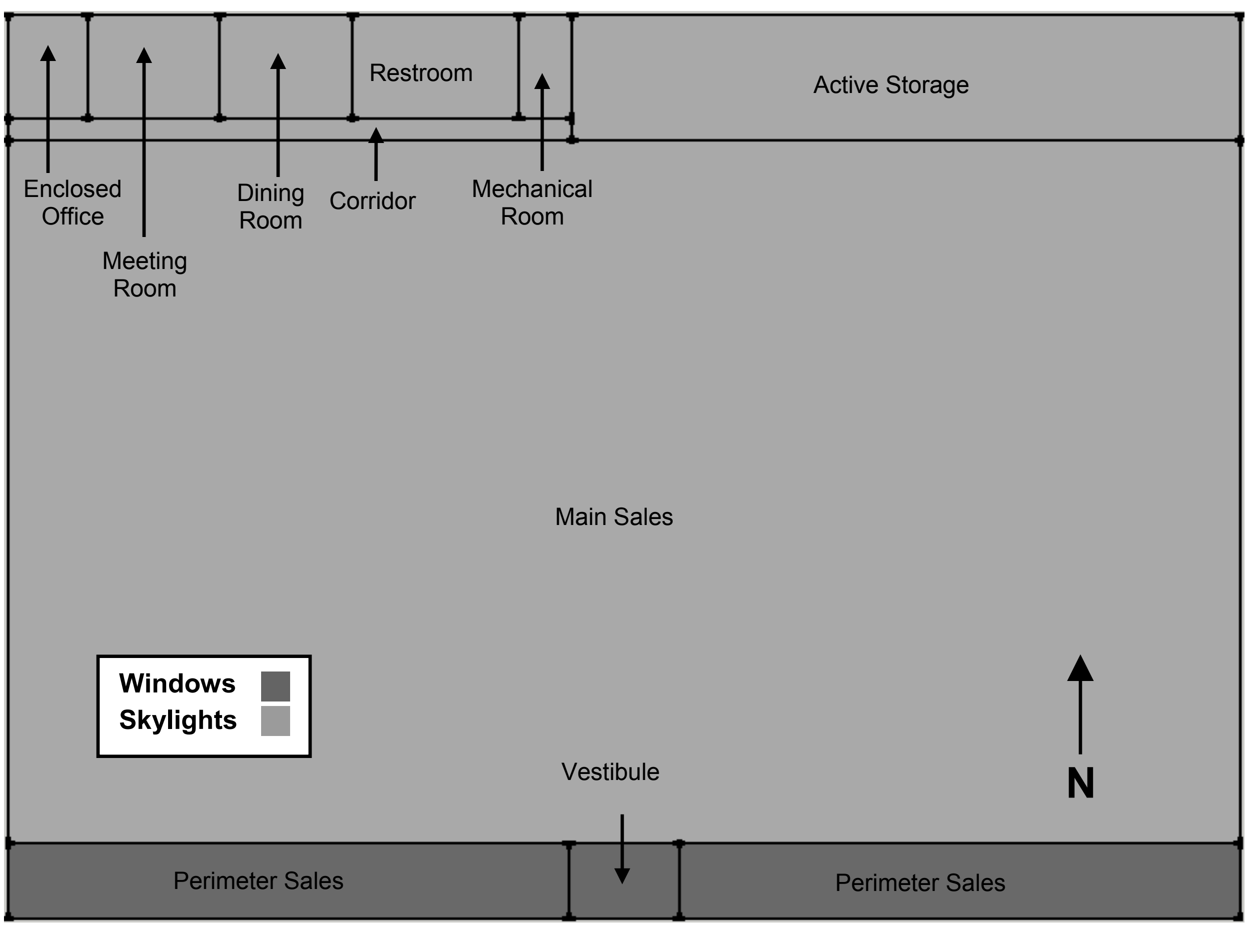

Figure 3-13 Potential daylight sources for each zone

There is one light sensor per zone, placed in the center at a height of 2.95 ft (0.90 m) from the floor. For zones daylit by skylights, the sensor is placed between two skylights (if a skylight is directly above the center). The dimming controls are continuous; they start dimming when the lighting set point is exceeded, linearly decreasing until the lighting set point is met or the input power decreases to 30% of its maximum (where the light output is 20% of its maximum), whichever comes first.

Based on feedback from retailers, we chose a daylighting set point of 46.5 fc (500 lux). The cost of this set point system is $0.38/ft^2 ($4.10/m^2) of daylit area (Liu et al. 2007).

3.4.3.2 Interior Lighting

Two whole-building LPD reductions are considered: 30% and 47%. For the sales areas, this corresponds to LPDs of 1.20 W/ft^2 (12.9 W/m^2) and 0.90 W/ft^2 (9.7 W/m^2), respectively.

The baseline system is modeled as T12 lamps with electronic ballasts in a basic luminaire with 40.3 ft^2 (3.74 m^2) per fixture. The ballast factor is 0.85, and the luminaire efficiency is 0.90.

The first EDM (30% reduction) corresponds to super T8s, ballast factors of 0.88, and a luminaire efficiency of 0.93. This system covers 44.6 ft^2 (4.15 m^2) with a single fixture, and has an incremental capital cost of $82/kW of lighting power reduction. The total incremental cost is thus $1,879, because the EDM reduces the lighting power installed in the store from 63.9 kW to 44.7 kW.

The second EDM system can be realized with some combination of luminaires that do not direct any light upward, and modest reductions in lighting levels. For instance, with super T8s and ballast factors of 0.88, a basic luminaire (with 17% of the light directed upward) results in an LPD of 1.19 W/ft^2 (12.8 W/m^2) at 49 fc (527 lux), and 0.72 W/ft^2 (7.8 W/m^2) at 30 fc (323 lux). On the other hand, a more directed luminaire requires just 1.06 W/ft^2 (11.4 W/m^2) to achieve 49 fc (527 lux), and 0.64 W/ft^2 (6.9 W/m^2) for 29 fc (312 lux). We model the 47% reduction (0.90 W/ft^2 [9.69 W/m^2]) as costing an additional $225/kW of lighting power reduction over the EDM 1 level. Thus, the total incremental cost of EDM 2 over baseline is $4,321.

The first EDM maintenance costs are the same as the baseline case: $4,932/yr. The second EDM includes an increase in the cost of changing out a lamp, but a decrease in the number of lamps and in the frequency of lamp change-outs (from 5 years in the baseline and first EDM scenarios to 5.5 years) resulting in maintenance costs of $2,981/yr.

Each LPD EDM includes a 1% LPD reduction based on the inclusion of occupancy sensors in all of the back-of-store zones (storage, restrooms, office, etc.). The whole-building LPD reduction of 1% is calculated by assuming that the sensors achieve 10% savings in the areas where they are installed. Because those areas comprise just 14% (5,625 ft^2 [58 m^2]) of the building and have lower LPDs than the sales floor, one arrives at a conservative whole-building LPD reduction of approximately 1%.

The cost of one occupancy sensor is $150.00, including materials and labor (Greene 2008). The cost of a power pack, which powers the occupancy sensors and activates the lighting control relay, is $63.50. Two sensors and one power pack are required for every 1000 ft^2 (93 m^2) (Roth et al. 2005), such that the approximate cost of this EDM is $0.36/ft^2 ($3.88/m^2).

In Opt-E-Plus, the lighting costs are expressed in dollars per installed kilowatt. Each EDM results in fewer installed kilowatts, so the baseline and marginal costs are summed on a whole-building basis, and then divided by the actual installed kilowatts to arrive at the EDM cost. The resulting EDM LPDs and costs are shown in Table 3-27 (see Table C-13 for metric units).

Table 3-27 Lighting Power Density EDMs

EDM Key	LPD (W/ft^2)	Capital Cost ($/kW)	Capital Cost ($\$/ft^2$)	Fixed O&M Cost ($/kW·yr)	Fixed O&M Cost ($\$/ft^2\cdot yr$)
Baseline	1.58	$4,706	$7.42	$77.24	$0.12
30% LPD reduction	1.10	$6,909	$7.63	$110.34	$0.12
47% LPD reduction	0.84	$9,242	$7.72	$128.73	$0.07

3.4.3.3 Plug Loads

The plug load EDM reduces plug load densities to 10% of their peak values at night, see Table 3-28. The baseline plug load schedule (Table 3-9) reduces plug load densities to no less than 30% of their peak values at night, depending on the day, such that this EDM saves more than two thirds of the energy plug equipment consumes during off hours. This amounts to an overall plug load reduction of 15%.

A minimum amount of equipment must presumably remain on at all times. For the high plug load store, we estimate this minimum to be roughly 10% of peak value. For the low plug load store, which has considerably lower peak plug load densities, we feel that the baseline schedule provides appropriate off-hour densities. Accordingly, this EDM is applied only to the high plug load store.

We assume that this EDM can be realized by installing contactors in the electrical subpanels that serve the sales floor plug load equipment. This would allow the store's energy management system (EMS) to fully turn off plug loads that might otherwise be left on during nighttime hours. An electrical engineering firm estimates that a high plug load, general merchandise store of this size would require seven contactors (for seven subpanels), at a cost of $4,500 for materials and $7,500 for labor. This is because plug equipment is often distributed onto a number of subpanels, without much concern given to organization or consolidation. We assume that in new construction, the electrical subpanels could be organized to place all of the sales floor plug load equipment on two subpanels, such that the total capital cost of this EDM is $3,425 ($1,285 for materials and $2,140 for labor).

Table 3-28 EDM Plug Equipment Schedule

Hour	Weekdays	Saturdays	Sundays, Holidays, Other
1	0.10	0.10	0.10
2	0.10	0.10	0.10
3	0.10	0.10	0.10
4	0.10	0.10	0.10
5	0.10	0.10	0.10
6	0.10	0.10	0.10
7	0.10	0.10	0.10
8	0.4	0.30	0.10
9	0.7	0.50	0.30
10	0.9	0.80	0.30
11	0.9	0.90	0.60
12	0.9	0.90	0.60
13	0.9	0.90	0.80
14	0.9	0.90	0.80
15	0.9	0.90	0.80
16	0.9	0.90	0.80
17	0.9	0.90	0.80
18	0.9	0.90	0.60
19	0.8	0.70	0.40
20	0.8	0.50	0.10
21	0.70	0.50	0.10
22	0.40	0.30	0.10
23	0.10	0.10	0.10
24	0.10	0.10	0.10
Total Hours/Day	12.80	11.70	8.10

3.4.3.4 HVAC Systems and Components

3.4.3.4.1 Direct Expansion Coil Efficiency

Possible DX coil efficiency improvements are developed from publically available industry spec sheets for 10-ton unitary DX units with constant volume supply fans over an EER range of 10.1 to 12.3. These data suggest that the COP of the 10-ton RTUs, which includes compressor and condenser, but not supply fan, power, can be improved as much as 20% over the baseline of 3.69. Thus, we have two EDMs that improve DX coil efficiency: a 10% increase in COP that increases capital cost by $61.43/ton cooling ($17.47/kW); and a 20% increase in COP that increases capital cost by $123.94/ton cooling ($35.25/kW). The incremental cost for these improvements is taken as the cost to upgrade from the baseline model to each of the two higher efficiency units mentioned in Section 3.3.4.2.6: from 9.0 to 10.4 EER and from 9.0 to 11.0 EER, respectively (RMH Group 2006).

3.4.3.4.2 Higher Efficiency Fans

The baseline HVAC unit has an EER of 10.1, a COP of 3.69, and a total static pressure drop of 1.53 in. w.c. (381.1 Pa) (without an economizer). We use those specifications to calculate a baseline fan efficiency of 30.6%. We set our EDM fan efficiency to 63%, which, according to industry data, is near the upper bound for RTU fan efficiency. The cost of the EDM for increased fan efficiency is assumed to be 10% of the baseline HVAC system capital cost, that is, an additional $160.38/ton cooling ($45.61/kW). This cost premium is roughly based on the incremental cost of upgrading from a constant volume supply fan to a VAV supply fan (Mossman 2005).

3.4.3.4.3 Economizers

In this analysis, economizers can be combined with any available HVAC system. They are controlled with a mix of dry bulb temperature (OA of 36ºF to 66ºF [2ºC to 19ºC]) and enthalpy limits (OA less than 14 Btu/lb [32,000 J/kg]). An economizer increases system cost by $100.20/ton cooling ($28.48/kW), adds 0.09 in. w.c. (22.4 Pa) of static pressure, and replaces gravity dampers with motorized dampers.

The DX coil efficiency, fan efficiency, and economizer EDMs are implemented together as HVAC system EDMs. A summary of the available systems is presented in Table 3-29 (see Table C-14 for metric units).

3.4.3.5 Outside Air

This report considers two options beyond code-minimum for reducing OA loads: carbon dioxide (CO_2) DCV, and energy recovery from exhaust air.

3.4.3.5.1 Demand-Controlled Ventilation

The CO_2 DCV EDM is modeled by matching the outdoor air schedules (by person and by area) to the occupancy schedules using the Ventilation:Mechanical object in EnergyPlus. A motorized OA damper is applied with DCV to prevent unwanted OA from entering. The cost of installing DCV is equal to that of installing one CO_2 sensor per RTU, since the RTUs should be able to implement DCV without major modification. The cost of one sensor is $185.50, such that DCV has a capital cost of $18.55/ton cooling ($5.28/kW) (Greene 2008).

3.4.3.5.2 Energy Recovery Ventilators

ERVs with sensible effectiveness of 60% or 80%, and latent effectiveness 10 percentage points lower are available as EDMs. For each ERV unit, Table 3-30 (see Table C-15 for metric units) lists the associated pressure drop and implementation cost, which vary with effectiveness.

Table 3-29 HVAC System EDMs

EDM Key	Cooling COP (Ratio)	Heating Efficiency (%)	Economizer	Motorized Damper	Fan Efficiency (%)	Fan Static Pressure (in. w.c.)	Capital Cost ($/ton)	Fixed O&M Cost ($/ton·yr)
Baseline without economizer	3.69	80.0	No	No	30.6	1.53	$1,603.75	$140.18
10% increased COP	4.06	80.0	No	No	30.6	1.53	$1,665.18	$140.18
Baseline with economizer	3.69	80.0	Yes	Yes	32.4	1.62	$1,703.89	$140.18
20% increased COP	4.43	80.0	No	No	30.6	1.53	$1,727.69	$140.18
Baseline COP with efficient fan	3.69	80.0	No	No	63.0	1.53	$1,747.31	$140.18
10% increased COP with economizer	4.06	80.0	Yes	Yes	32.4	1.62	$1,765.31	$140.18
10% increased COP with efficient fan	4.06	80.0	No	No	63.0	1.53	$1,808.74	$140.18
20% increased COP with economizer	4.43	80.0	Yes	Yes	32.4	1.62	$1,827.83	$140.18
Baseline COP with economizer and efficient fan	3.69	80.0	Yes	Yes	64.8	1.62	$1,847.48	$140.18
20% increased COP with efficient fan	4.43	80.0	No	No	63.0	1.53	$1,871.25	$140.18
10% increased COP with economizer and efficient fan	4.06	80.0	Yes	Yes	64.8	1.62	$1,908.91	$140.18
20% increased COP with economizer and efficient fan	4.43	80.0	Yes	Yes	64.8	1.62	$1,973.46	$140.18

Table 3-30 Energy Recovery EDMs

EDM Key	Sensible Effectiveness (%)	Latent Effectiveness (%)	Pressure Drop (in. w.c.)	Capital Cost ($/unit)	Capital Cost ($)
Low effectiveness	60.0	50.0	0.42	$9,243	$18,486
High effectiveness	80.0	70.0	0.60	$13,368	$26,736

In general, more effective ERVs have higher pressure drops. The pressure drops listed in Table 3-30 (see Table C-15 for metric units) are based on internal data, which predict the pressure drop through one side of the high effectiveness energy recovery wheel at 1 in. w.c. (249 Pa). Based on the fact that air passes through the wheel twice (once when it enters the store as unconditioned OA and once when it leaves the store as conditioned return air), and on the assumption of roughly 30% OA, an overall pressure drop of 0.6 in. w.c. (150 Pa) is applied to the implementation of high effectiveness ERV. The pressure drop for the low effectiveness ERV unit (0.42 in. w.c. [105 Pa]) is scaled according to our internal ERV data.

The modeling of ERV in EnergyPlus assumes that the exhaust air stream, which powers the ERVs, is equal in magnitude to the OA intake. For this assumption to be valid, the building must be airtight and all the exhaust air must be usable. Neither is generally the case for a general merchandise store, so we performed an air flow balance calculation to determine the fraction of OA that would be available for energy recovery. The air flow balance can be defined as follows.

$$F_{ERV} = \frac{OA - DEA - EA}{OA} \tag{3-3}$$

where,

F_{ERV} = the fraction of OA available for energy recovery

DEA = the amount of dedicated exhaust air from which energy cannot be recovered

EA = the amount of air that leaves the building through exfiltration, which is driven by HVAC and wind pressurization.

Infiltrated air is intentionally omitted from this equation because unconditioned air cannot be used for energy recovery. All air quantities are measured in units of flow (cfm or m^3/s).

For a general merchandise store, DEA comprises restroom exhaust. Per Table 3-20, restroom DEA was given a value of 1.04 cfm/ft^2 (0.005 ($m^3/s)/m^2$), which amounts to a total flow rate of approximately 650 cfm (0.31 m^3/s).

EA is calculated according to the pressurization analysis described in Section 3.3.3.5. From the exfiltration pressure gradients in Table 3-17, we estimated a peak exfiltration rate of 0.215 ACH (2,900 cfm [1.4 m^3/s]) during operating hours, when the HVAC system is on (ERV units operate only when the HVAC system is on). ASHRAE 62-1999 requires 12,750 cfm (6.0 m^3/s) of OA intake, such that F_{ERV} for the baseline general merchandise store is 0.72. With the application of infiltration reduction EDMs (addition of envelope air barrier and vestibule), F_{ERV} increases to

0.86. The appropriate value for F_{ERV} is achieved by adding (in EnergyPlus) idealized, energy free exhaust fans to each zone to exhaust the fraction of OA not available for ERV ($1 - F_{ERV}$).

The cost of implementing the least-effective ERV unit is adapted from the cost of 6000 cfm (2.8 m^3/s) ERVs given by (Greene 2008). We assume two units could serve the entire building (up to 10,965 cfm [5.2 m^3/s] of air is available for energy recovery).

3.4.3.6 Photovoltaic Panels

Ignoring any electricity tariff changes associated with varying amounts of PV, 5-TLCC and the amount of electricity generated by the PV panels vary linearly with panel area. We thus include a single PV EDM, and then use a post-processing step to determine the PV panel area needed to reach 50% energy savings.

We assume the following in all cases:

- The panels are 10% efficient,
- The DC to AC inverters are 90% efficient.
- The panels are installed flat on the roof.
- The PV efficiency does not degrade with increasing temperature
- The panels do not shade the roof.
- The cost is \$6.65 for materials and \$1.16 for installation per installed Watt based on the price of a 10-kW, grid-connected system (Greene 2008) minus the 30% Federal Tax Credit that is available through 2016 (DSIRE 2009).
- The EDM used by Opt-E-Plus covers 60% of the net roof area (total area minus skylight area) with PV panels and is sized assuming 1000 W/m^2 incident solar radiation.

4.0 Results

This section describes simulation results for a number of building models. **Section 4.1** describes the baseline models, both the ASHRAE 90.1-2004 (ASHRAE 2004a) baselines that serve as the standard for our percent energy savings calculations, and ASHRAE 90.1-2007 (ASHRAE 2007b) baselines that are provided for reference purposes (for individuals wishing to compare the two and to see what 50% energy savings versus 90.1-2004 means when it is replaced by 90.1-2007). **Section 4.2** describes the selected low-energy models for each climate zone, and compares their energy and economic performance to the baseline. The low-energy models are described by enumerating which EDM perturbations were applied to the baseline model to arrive at the low-energy model. **Section 4.3** explores the effect of floor area on energy use intensity (using a 100,000 ft^2 [9,290 m^2] prototype store) for both the baseline and low-energy models. Finally, **Section 4.4** briefly describes some alternative low-energy models for selected climate zones. These models are not described in full, but we report whether we were able to achieve the 50% energy savings goal without certain strategies.

In this section, we report performance using the following metrics:

- **Net site EUI.** This is reported in $MJ/m^2 \cdot yr$ or $kBtu/ft^2 \cdot yr$. It is the whole-building net site yearly energy use (Section 2.2.1) divided by the building floor area.
- **5-TLCC intensity.** This is reported in $\$/m^2$ or $\$/ft^2$. It is the 5-TLCC divided by the building floor area. It represents the total cost of the building for a five-year analysis period (see Section 3.1.2.6).
- **Electricity intensity.** This is reported in $kWh/m^2 \cdot yr$ or $kWh/ft^2 \cdot yr$ and is the yearly electrical consumption divided by the building floor area.
- **Natural gas intensity.** This is reported in $kWh/m^2 \cdot yr$ or $therms/ft^2 \cdot yr$ and is the yearly natural gas consumption divided by the building floor area.
- **PV power intensity.** This is reported in $kWh/m^2 \cdot yr$ or $kWh/ft^2 \cdot yr$ and is the yearly electricity production of the PV panels divided by the building floor area.
- **Capital cost.** This is reported in $\$/m^2$ or $\$/ft^2$ and is the total cost for materials, installation, fees and commissioning divided by the building floor area.
- **Min/max monthly electricity demand.** This is reported in kW and is the net electrical demand, taking credit for electricity produced by PV, computed for each month of the annual simulation.
- **Min/max monthly load factor.** This is the average net monthly electricity demand (net kilowatt-hours divided by the number of hours in the month), divided by the overall net electricity demand.

4.1 Baseline Models

This section summarizes the energy and economic performance of the baseline models described in Section 3.3.

4.1.1 ASHRAE 90.1-2004 Baseline Models: Performance

The energy and cost intensities of the ASHRAE 90.1-2004 baseline models are shown in Table 4-1 to Table 4-3. The EUIs vary substantially across the climate zones, such that the difficulty in achieving 50% energy savings and the amount of energy saved in doing so vary by climate zone. Costs vary in response to climate-specific constructions, equipment, and thermal loads.

Table 4-1 ASHRAE 90.1-2004 Baseline Model Performance: Humid Climates

Building Type	Units	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug General Merchandise	SI	EUI (MJ/m^2·yr)	1,250	1,190	914	1,020	1,050	1,220
		5-TLCC intensity ($/m^2)	1,350	1,340	1,260	1,260	1,200	1,210
		Electricity intensity (kWh/m^{2}yr)	346	313	213	201	146	144
		Natural gas intensity (kWh/m^{2}yr)	0.444	17.8	40.9	83.1	145	195
		Capital cost ($/m^2)	1,190	1,180	1,150	1,140	1,090	1,100
	IP	EUI (kBtu/ft^{2}yr)	110	105	80.5	89.9	92.1	107
		5-TLCC intensity ($/ft^2)	126	124	117	117	111	112
		Electricity intensity (kWh/ft^{2}yr)	32.1	29.1	19.8	18.6	13.5	13.3
		Natural gas intensity (Therms/ft^{2}yr)	0.00141	0.0563	0.130	0.263	0.460	0.617
		Capital cost ($/ft^2)	110	110	106	106	102	102
	N/A	Max. elec. demand (kW)	387	408	326	326	211	211
		Min. load factor	0.332	0.286	0.282	0.274	0.301	0.288
High Plug General Merchandise	SI	EUI (MJ/m^2·yr)	1,590	1,500	1,160	1,210	1,180	1,340
		5-TLCC intensity ($/m^2)	1,410	1,390	1,300	1,300	1,230	1,230
		Electricity intensity (kWh/m^{2}yr)	442	406	296	280	216	214
		Natural gas intensity (kWh/m^{2}yr)	0.188	11.0	25.4	56.7	111	157
		Capital cost ($/m^2)	1,200	1,190	1,150	1,150	1,100	1,100
	IP	EUI (kBtu/ft^{2}yr)	140	132	102	107	104	118
		5-TLCC intensity ($/ft^2)	131	129	121	121	114	114
		Electricity intensity (kWh/ft^{2}yr)	41.1	37.7	27.5	26.1	20.1	19.9
		Natural gas intensity (therms/ft^{2}yr)	0.000594	0.0348	0.0805	0.180	0.352	0.498
		Capital cost ($/ft^2)	112	111	107	107	102	102
	N/A	Max. elec. demand (kW)	473	483	369	388	270	262
		Min. load factor	0.370	0.336	0.371	0.308	0.366	0.360

Table 4-2 ASHRAE 90.1-2004 Baseline Model Performance: Arid Climates

Building Type	Units	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug General Merchandise	SI	EUI ($MJ/m^2 \cdot yr$)	747	541	689	747	842	1,040
		5-TLCC intensity ($\$/m^2$)	1,180	1,150	1,170	1,160	1,160	1,170
		Electricity intensity (kWh/m^2yr)	189	137	161	142	131	125
		Natural gas intensity (kWh/m^2yr)	18.8	13.4	30.7	65.4	102	163
		Capital cost ($\$/m^2$)	1,080	1,080	1,080	1,080	1,080	1,070
	IP	EUI ($kBtu/ft^2yr$)	65.8	47.6	60.7	65.8	74.1	91.4
		5-TLCC intensity ($\$/ft^2$)	109	107	108	108	108	109
		Electricity intensity (kWh/ft^2yr)	17.5	12.7	14.9	13.2	12.2	11.6
		Natural gas intensity ($therms/ft^2yr$)	0.0597	0.0423	0.0972	0.207	0.324	0.517
		Capital cost ($\$/ft^2$)	100	100	100	100	99.9	99.8
	N/A	Max. elec. demand (kW)	227	170	200	180	168	161
		Min. load factor	0.393	0.336	0.383	0.384	0.377	0.361
High Plug General Merchandise	SI	EUI ($MJ/m^2 \cdot yr$)	989	758	910	931	996	1,150
		5-TLCC intensity ($\$/m^2$)	1,220	1,190	1,210	1,200	1,200	1,210
		Electricity intensity (kWh/m^2yr)	262	204	234	214	204	195
		Natural gas intensity (kWh/m^2yr)	12.7	6.36	19.1	44.6	73.2	125
		Capital cost ($\$/m^2$)	1,090	1,080	1,090	1,090	1,090	1,090
	IP	EUI ($kBtu/ft^2yr$)	87.1	66.7	80.1	82.0	87.7	101
		5-TLCC intensity ($\$/ft^2$)	113	110	112	112	112	112
		Electricity intensity (kWh/ft^2yr)	24.3	19.0	21.7	19.9	18.9	18.1
		Natural gas intensity ($therms/ft^2yr$)	0.0403	0.0202	0.0605	0.141	0.232	0.395
		Capital cost ($\$/ft^2$)	101	101	101	101	101	101
	N/A	Max. elec. demand (kW)	284	219	260	238	227	221
		Min. load factor	0.426	0.401	0.428	0.425	0.424	0.409

Table 4-3 ASHRAE 90.1-2004 Baseline Model Performance: Marine and Cold Climates

Building Type	Units	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug General Merchandise	SI	EUI (MJ/m²·yr)	586	787	1,350	1,940
		5-TLCC intensity ($/m²)	1,130	1,150	1,190	1,270
		Electricity intensity (kWh/m²yr)	115	118	122	121
		Natural gas intensity (kWh/m²yr)	48.1	101	251	416
		Capital cost ($/m²)	1,060	1,070	1,080	1,130
	IP	EUI (kBtu/ft²yr)	51.6	69.3	118	170
		5-TLCC intensity ($/ft²)	105	107	111	118
		Electricity intensity (kWh/ft²yr)	10.6	10.9	11.4	11.3
		Natural gas intensity (therms/ft²yr)	0.152	0.320	0.797	1.32
		Capital cost ($/ft²)	98.8	99.6	100	105
	N/A	Max. elec. demand (kW)	149	161	171	139
		Min. load factor	0.350	0.327	0.323	0.391
High Plug General Merchandise	SI	EUI (MJ/m²·yr)	752	908	1,420	1,960
		5-TLCC intensity ($/m²)	1,170	1,180	1,220	1,300
		Electricity intensity (kWh/m²yr)	183	185	191	185
		Natural gas gntensity (kWh/m²yr)	25.9	67.4	203	360
		Capital cost ($/m²)	1,080	1,080	1,090	1,140
	IP	EUI (kBtu/ft²yr)	66.2	80.0	125	173
		5-TLCC intensity ($/ft²)	109	110	113	120
		Electricity intensity (kWh/ft²yr)	17.0	17.2	17.7	17.2
		Natural gas intensity (Therms/ft²yr)	0.0822	0.214	0.645	1.14
		Capital cost ($/ft²)	99.9	100	101	106
	N/A	Max. elec. demand (kW)	207	217	225	188
		Min. load factor	0.400	0.378	0.380	0.445

4.1.2 ASHRAE 90.1-2007 Baseline Models: Performance

For comparison, we also constructed baseline models that satisfy ASHRAE 90.1-2007 and ASHRAE 62.1-2004 (ASHRAE Standard 90.1-2007 explicitly references, and thereby includes, Standard 62.1-2004). The differences between the ASHRAE 90.1-2004 and ASHRAE 90.1-2007 baselines are the window, wall, and roof performance requirements, and the OA requirements. The OA requirements differ in structure and amount: starting in 2004, ASHRAE 62.1 started specifying OA requirements per area and per person in many space types. ASHRAE 62-1999 (the ventilation standard corresponding to ASHRAE 90.1-2004), on the other hand, specifies OA requirements as either per area or per person. For instance, in applying ASHRAE 62.1-2004 instead of ASHRAE 62-1999 for a retail sales zone, the ventilation prescription changes from a flat per area requirement of 0.30 cfm/ft^2 (0.0015 (m^3/s)/m^2) to a combined per area and per person requirement of 0.12 cfm/ft^2 (0.0006 (m^3/s)/m^2) and 7.5 cfm/person (0.0038 (m^3/s)/person), where the number of people is taken as the peak occupancy of that zone.

For completeness, the 90.1-2007 baseline windows, walls, and roofs are summarized in Table 4-4 to Table 4-7. The OA requirements are summarized in Table 4-8. To compare to the 90.1-2004 values, see Table 3-13 to Table 3-16, and Table 3-20.

Table 4-4 ASHRAE 90.1-2007 Baseline Exterior Wall Constructions

Properties	Climate Zone 1	Climate Zone 2	Climate Zone 3	Climate Zone 4	Climate Zone 5	Climate Zone 6	Climate Zones 7–8
Key	Baseline Wall Construction, No c.i.	Baseline Wall Construction, R-5.7 c.i.	Baseline Wall Construction, R-7.6 c.i.	Baseline Wall Construction, R-9.5 c.i.	Baseline Wall Construction, R-11.4 c.i.	Baseline Wall Construction, R-13.3 c.i.	Baseline Wall Construction, R-15.2 c.i.
U-factor (Btu/h·ft^2·°F)	0.754	0.173	0.137	0.114	0.0975	0.0859	0.0756
Capital cost ($/ft^2)	$20.37	$21.06	$21.42	$21.68	$21.80	$21.86	$21.97

Table 4-5 ASHRAE 90.1-2007 Baseline Roof Constructions

Properties	Climate Zone 1	Climate Zones 2–8
Key	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-20 c.i.
U-factor (Btu/h·ft^2·°F)	0.0675	0.0506
Capital cost ($/ft^2)	$8.69	$9.11

Table 4-6 ASHRAE 90.1-2007 Baseline Window Constructions

Properties	Climate Zones 1–3	Climate Zones 4–6	Climate Zones 7–8
Key	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction
SHGC	0.390	0.400	0.450
VLT	0.495	0.508	0.450
U-factor (Btu/h·ft^2·°F)	0.570	0.550	0.450
Capital cost ($/ft^2)	$47.23	$47.57	$47.23
Fixed O&M cost ($/ft^2)	$0.22	$0.22	$0.22

Table 4-7 ASHRAE 90.1-2007 Baseline Skylight Constructions

Properties	Climate Zones 1–2	Climate Zone 3	Climate Zones 4–6	Climate Zone 7	Climate Zone 8
Key	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction
SHGC	0.360	0.390	0.490	0.680	0.710
VLT	0.457	0.490	0.622	0.680	0.710
U-factor (Btu/h·ft^2·°F)	1.22	0.690	0.690	0.690	0.580
Capital cost ($/ft^2)	$46.28	$48.91	$47.24	$45.90	$50.46
Fixed O&M cost ($/ft^2)	$0.22	$0.22	$0.22	$0.22	$0.22

Table 4-8 ASHRAE 90.1-2007 Baseline Minimum Ventilation Rates

Space Type	Mapping to ASHRAE 62.1-2004	Ventilation per Person		Ventilation per Area	
		cfm/person	L/s·person	cfm/ft^2	L/s·m^2
Main Sales	Retail::Sales	7.5	3.8	0.12	0.60
Perimeter Sales	Retail::Sales	7.5	3.8	0.12	0.60
Enclosed Office	Office Buildings::Office space	5.0	2.5	0.06	0.30
Meeting Room	Offices::Conference/meeting	5.0	2.5	0.06	0.30
Dining Room	Food & Beverage::Restaurant dining rooms	7.5	3.8	0.18	0.90
Restrooms	CUSTOM VALUE	7.5	3.8	0.06	0.30
Mechanical Room	CUSTOM VALUE	–	–	0.00	0.00
Corridor	General::Corridors	–	–	0.06	0.30
Vestibule	General::Corridors	–	–	0.06	0.30
Active Storage	General::Storage rooms	–	–	0.12	0.60

The performance of the ASHRAE 90.1-2007 baseline models is summarized in Table 4-9 to Table 4-11.

Table 4-9 ASHRAE 90.1-2007 Baseline Model Performance: Humid Climates

Building Type	Units	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug General Merchandise	SI	EUI ($MJ/m^2 \cdot yr$)	1,180	1,080	832	889	883	1,010
		5-TLCC intensity ($\$/m^2$)	1,400	1,390	1,310	1,310	1,250	1,250
		Electricity intensity (kWh/m^2yr)	327	292	207	195	145	143
		Natural gas intensity (kWh/m^2yr)	0.271	6.84	24.2	52.1	101	139
		Capital cost ($\$/m^2$)	1,240	1,240	1,200	1,210	1,150	1,150
	IP	EUI ($kBtu/ft^2yr$)	104	94.8	73.2	78.3	77.7	89.4
		5-TLCC intensity ($\$/ft^2$)	130	129	122	122	116	116
		Electricity intensity (kWh/ft^2yr)	30.3	27.1	19.2	18.1	13.4	13.3
		Natural gas intensity ($therms/ft^2yr$)	0.000859	0.0217	0.0769	0.165	0.319	0.440
		Capital cost ($\$/ft^2$)	115	115	112	112	107	107
	N/A	Max. elec. demand (kW)	373	374	307	309	211	206
		Min. load factor	0.338	0.286	0.293	0.284	0.338	0.304
High Plug General Merchandise	SI	EUI ($MJ/m^2 \cdot yr$)	1,520	1,410	1,100	1,110	1,030	1,150
		5-TLCC intensity ($\$/m^2$)	1,450	1,440	1,360	1,350	1,280	1,280
		Electricity intensity (kWh/m^2yr)	423	388	293	278	215	213
		Natural gas intensity (kWh/m^2yr)	0.0635	2.60	11.9	29.0	70.6	106
		Capital cost ($\$/m^2$)	1,250	1,250	1,210	1,210	1,160	1,160
	IP	EUI ($kBtu/ft^2yr$)	134	124	96.7	97.3	90.6	101
		5-TLCC intensity ($\$/ft^2$)	135	134	126	126	119	119
		Electricity Intensity (kWh/ft^2yr)	39.3	36.0	27.2	25.8	20.0	19.8
		Natural gas intensity ($therms/ft^2yr$)	0.000201	0.00823	0.0376	0.0921	0.224	0.336
		Capital cost ($\$/ft^2$)	116	116	113	113	108	107
	N/A	Max. elec. demand (kW)	456	450	373	380	262	257
		Min. load factor	0.381	0.337	0.397	0.351	0.361	0.369

Table 4-10 ASHRAE 90.1-2007 Baseline Model Performance: Arid Climates

Building Type	Units	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug General Merchandise	SI	EUI ($MJ/m^2 \cdot yr$)	656	513	633	658	722	863
		5-TLCC intensity ($\$/m^2$)	1,230	1,210	1,220	1,220	1,220	1,220
		Electricity intensity (kWh/m^2yr)	173	136	157	141	131	125
		Natural gas intensity (kWh/m^2yr)	9.79	6.71	19.2	42.1	69.1	114
		Capital cost ($\$/m^2$)	1,140	1,140	1,140	1,140	1,140	1,140
	IP	EUI ($kBtu/ft^2yr$)	57.8	45.1	55.7	58.0	63.6	76.0
		5-TLCC intensity ($\$/ft^2$)	114	113	114	113	113	114
		Electricity intensity (kWh/ft^2yr)	16.0	12.6	14.5	13.1	12.2	11.6
		Natural gas intensity ($therms/ft^2yr$)	0.031	0.0213	0.0608	0.133	0.219	0.363
		Capital cost ($\$/ft^2$)	106	106	106	106	106	106
	N/A	Max. elec. demand (kW)	208	172	194	169	160	154
		Min. load factor	0.411	0.341	0.397	0.398	0.391	0.377
High Plug General Merchandise	SI	EUI ($MJ/m^2 \cdot yr$)	918	740	866	856	892	990
		5-TLCC intensity ($\$/m^2$)	1,270	1,250	1,270	1,260	1,260	1,260
		Electricity intensity (kWh/m^2yr)	251	204	231	214	204	196
		Natural gas intensity (kWh/m^2yr)	4.61	1.96	9.72	24.1	43.5	79.5
		Capital cost ($\$/m^2$)	1,150	1,150	1,150	1,150	1,150	1,150
	IP	EUI ($kBtu/ft^2yr$)	80.9	65.1	76.2	75.3	78.5	87.2
		5-TLCC intensity ($\$/ft^2$)	118	116	118	117	117	117
		Electricity Intensity (kWh/ft^2yr)	23.3	18.9	21.4	19.8	19.0	18.2
		Natural gas intensity ($therms/ft^2yr$)	0.0146	0.00621	0.0308	0.0763	0.138	0.252
		Capital cost ($\$/ft^2$)	107	106	107	107	107	107
	N/A	Max. elec. demand (kW)	266	219	256	229	220	214
		Min. load factor	0.455	0.397	0.440	0.436	0.437	0.423

Table 4-11 ASHRAE 90.1-2007 Baseline Model Performance: Marine and Cold Climates

Building Type	Units	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug General Merchandise	SI	EUI (MJ/m^2·yr)	512	660	1,090	1,630
		5-TLCC intensity ($/m^2)	1,200	1,210	1,240	1,260
		Electricity intensity (kWh/m^{2}yr)	114	118	123	120
		Natural gas intensity (kWh/m^{2}yr)	28.0	65.3	180	331
		Capital cost ($/m^2)	1,130	1,140	1,140	1,130
	IP	EUI (kBtu/ft^{2}yr)	45.1	58.1	95.8	143
		5-TLCC intensity ($/ft^2)	111	113	115	117
		Electricity intensity (kWh/ft^{2}yr)	10.6	11.0	11.4	11.2
		Natural gas intensity (therms/ft^{2}yr)	0.0888	0.207	0.570	1.05
		Capital cost ($/ft^2)	105	106	106	105
	N/A	Max. elec. demand (kW)	142	156	177	137
		Min. load factor	0.364	0.339	0.316	0.394
High Plug General Merchandise	SI	EUI (MJ/m^2·yr)	696	795	1,180	1,670
		5-TLCC intensity ($/m^2)	1,230	1,240	1,270	1,280
		Electricity intensity (kWh/m^{2}yr)	182	185	191	185
		Natural gas intensity (kWh/m^{2}yr)	11.3	35.4	138	278
		Capital cost ($/m^2)	1,140	1,140	1,150	1,140
	IP	EUI (kBtu/ft^{2}yr)	61.3	70.0	104	147
		5-TLCC intensity ($/ft^2)	114	115	118	119
		Electricity Intensity (kWh/ft^{2}yr)	16.9	17.2	17.8	17.2
		Natural gas intensity (therms/ft^{2}yr)	0.0358	0.112	0.436	0.882
		Capital cost ($/ft^2)	106	106	107	106
	N/A	Max. elec. demand (kW)	198	211	227	186
		Min. load factor	0.403	0.391	0.383	0.453

4.1.3 Comparison to CBECS

To compare the EUIs of the ASHRAE 90.1-2004 and ASHRAE 90.1-2007 baseline models to the *2003 CBECS* data, we use climate zone weighting factors from (Deru et al. 2008) to calculate average baseline EUIs, electricity intensities, and natural gas intensities for each numerical climate zone. The weightings are shown in Table 4-12; the resulting EUIs, electricity intensities, and natural gas intensities are depicted graphically in Figure 4-1 to Figure 4-3, where they are compared against the corresponding values from the *2003 CBECS* survey. Only retail stores built since 1980, or built since 1970 and renovated since 1980, which were occupied for the full survey year, with floor areas between 20,000 ft^2 and 70,000 ft^2 (1,858 m^2 to 6,503 m^2) are used: 26 CBECS buildings match that description. The climate zone for each is determined by following the procedure described in (Griffith et al. 2008). No CBECS buildings are located in climate zones 1 and 8; and only one building each is located in climate zones 2 and 7.

Table 4-12 Retail Building Climate Zone Weighting Factors

ASHRAE Climate Zone	Weighting Factor
1A	80.57
2A	570.62
2B	125.71
3A	648.97
3B-CA	607.32
3B-NV	97.03
3C	27.85
4A	1,137.03
4B	35.98
4C	129.68
5A	1,144.83
5B	288.69
6A	321.90
6B	4.94
7	45.22
8	2.93

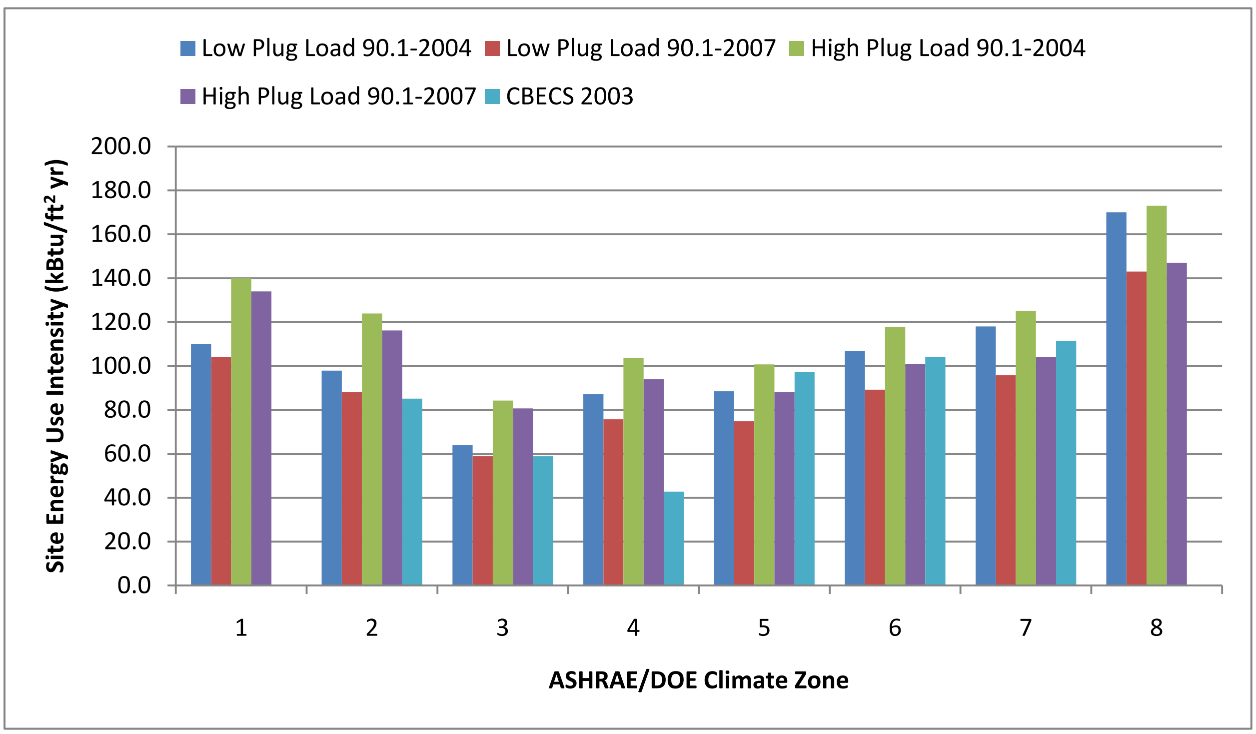

Figure 4-1 EUI comparison for baseline and CBECS survey buildings

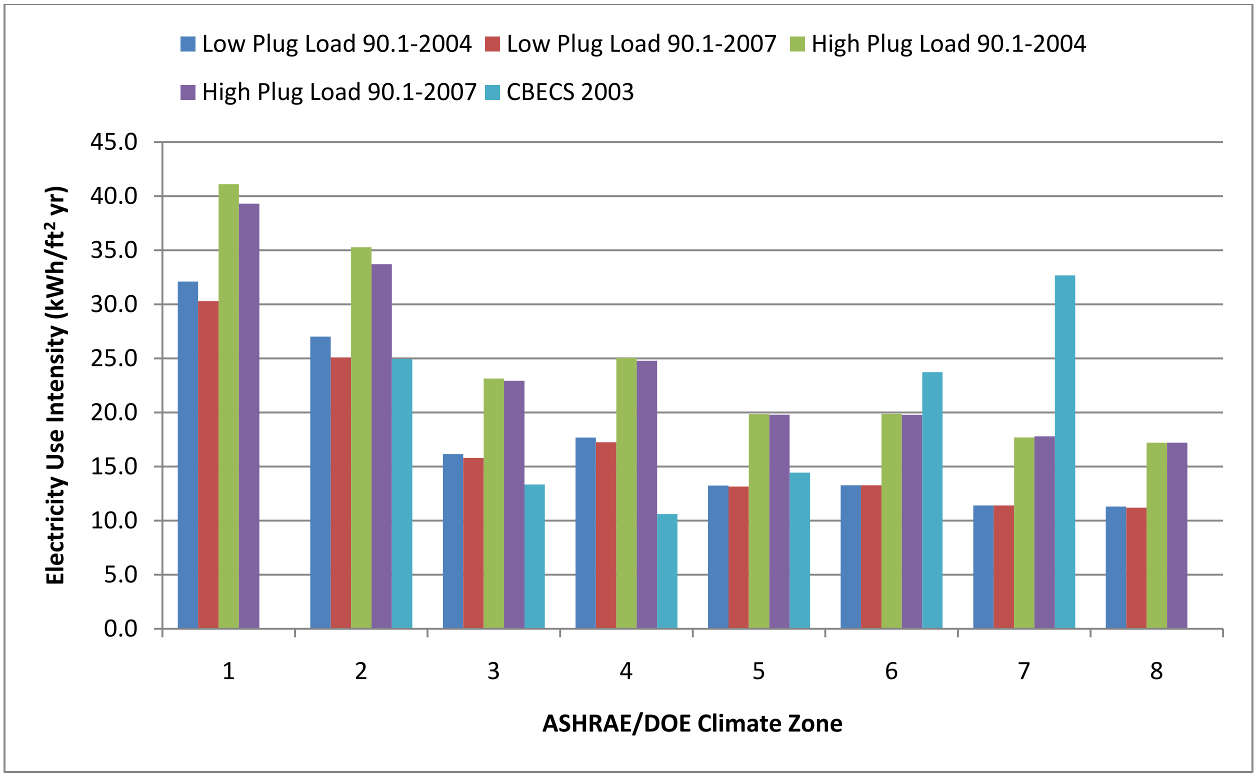

Figure 4-2 Electricity use intensity comparison for baseline and CBECS survey buildings

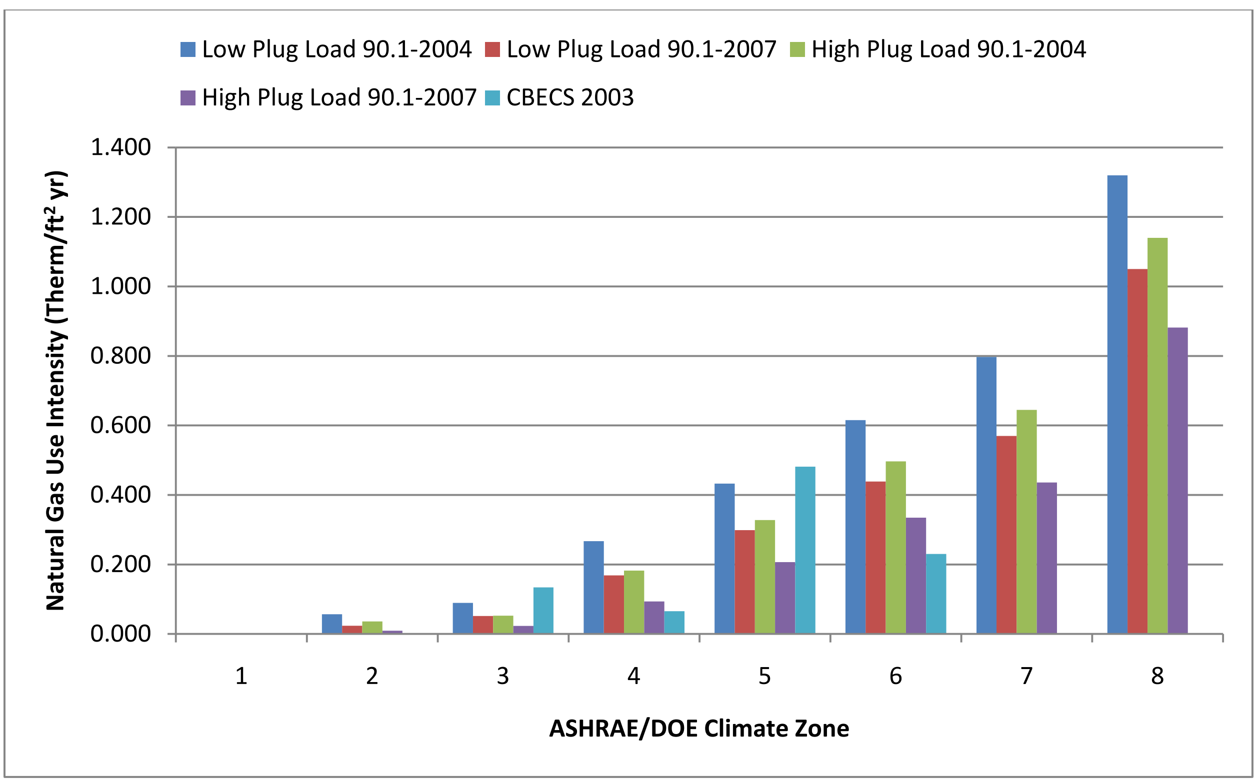

Figure 4-3 Natural gas intensity comparison for baseline and CBECS survey buildings

4.1.4 Discussion

There is reasonable agreement between our data and the *2003 CBECS* data, considering the small CBECS sample sizes. The overall EUIs are most out of agreement in climate zone four. The CBECS buildings in climate zones 6 and 7 on average use less natural gas and more electricity than our models, which follows from the fact that one of the four climate zone 6 buildings, and the single climate zone 7 building, use electricity rather than natural gas for heating. (Overall, seven of the *2003 CBECS* buildings are heated with electricity, and 18 use natural gas.)

The ASHRAE 90.1-2007 baseline models use less energy than the ASHRAE 90.1-2004 baseline models for the low and high plug load cases in each climate zone. This result is to be expected since ASHRAE 90.1-2007 has more stringent requirements for energy efficiency than ASHRAE 90.1-2004.

The improved energy performance of the ASHRAE 90.1-2007 baselines comes at the expense of an increase in capital cost (in all climate zones except zone 8, in which capital costs held steady). This is because ASHRAE 90.1-2007 requires better insulated, and thus costlier, opaque envelope and fenestration constructions than those required by ASHRAE 90.1-2004 (again, except in climate zone 8). Although ASHRAE 90.1-2007 requires a lower ventilation rate in sales areas than does ASHRAE 90.1-2004, the resulting reduction in overall HVAC system size in the 90.1-2007 baseline models did not lower capital costs enough to offset the increase in costs of the opaque envelope and fenestration constructions.

The energy savings provided by the updates required to satisfy ASHRAE 90.1-2007 were not enough to offset the associated increase in capital cost, resulting in larger 5-TLCC values for the ASHRAE 90.1-2007 baseline models than for the ASHRAE 90.1-2004 baseline models (except in climate zone 8).

As ASHRAE 90.1 evolves to require more and more energy efficiency, it will become increasingly difficult to achieve the same percent energy savings targets. This point is discussed further in Section 5.1.1, which contains a general discussion of alternative metrics that might be of interest for future AEDG work.

4.2 Selected Low-Energy Models

The models described in this section meet the goal of 50% energy savings over ASHRAE 90.1-2004 as defined in Section 2.2. The models are assembled by applying a number of the Energy Design Measures described in Section 3.4 to the baseline models described in Section 3.3. The models are chosen according to the procedures outlined in Sections 2.4 and 2.5.1.

4.2.1 Description

The selected low-energy models are described in terms of which EDMs were chosen to achieve 50% energy savings. These choices are summarized for each climate zone in Table 4-13 to Table 4-18. The data reveal several options in all climate zones:

- South façade WWR ratio is reduced by 50%, likely because opaque constructions are less expensive than fenestration constructions and have better insulation properties.
- Vestibules are added to the front entrance. In the baseline models, 87% of infiltrated air enters the store through the front entrance. Adding a vestibule is a relatively inexpensive way to significantly reduce infiltration through the front entrance.
- HVAC RTUs are equipped with efficient fans.

- LPD is reduced by 47%, and occupancy sensors are installed in the active storage, mechanical room, restroom, and office zones.
- Daylighting sensors (with 46.5 fc [500 lux] set points) are installed. Note that skylights are not included in every climate zone. In the absence of skylights, daylighting controls are installed only in the zones adjacent to the south façade fenestration (within 15 ft [4.6 m] of the view glass.
- Exterior walls with improved insulation properties over baseline (either the R-18.1 or R-22.6 construction in each case) are selected (See Table 4-18).
- Plug loads are reduced to 10% of peak during off hours in all high plug load stores.

One EDM was not chosen for any location:

- Shaded overhangs above the windows on the south façade.

Some general trends noted are:

- Skylights are chosen in warm climates only (zones 1 through 5 in low plug load stores, and 1 through 6 in high plug loads), likely because colder climates receive too little sun for the energy saved by daylighting to compensate for the increase in capital costs and reduction in insulation associated with skylights. In all cases where skylights are installed, high solar gain constructions are selected. This is likely because high solar gain skylights also have the highest VLT values, which maximize daylighting performance.
- Fenestration constructions with poor insulation properties are selected in the hottest, most humid climates. The sensible heat being added by the poorly insulated glazing may be replacing some portion of the reheat needed to meet the high latent load and still maintain the temperature requirements. In that case, less expensive windows with poorer insulation properties can be selected without adding to overall energy use. All selected skylights have double-pane constructions (most also have low-e and argon) except the skylights selected in the 1A and 2A low plug load stores and in the 1A high plug load store, which have single-pane constructions. All selected windows are double pane with low-e and argon, except those selected in the 1A, 2A, and 3A low plug load stores and in the 1A high plug load stores, which have single pane constructions. The fact that this phenomenon occurs in less high plug load stores than in low plug load stores can likely be attributed to the higher plug loads, which add to the overall sensible load. Thus, high plug load stores can allow less solar gain into the space before incurring an energy penalty.
- In general, baseline roof constructions are selected. The exception occurs in climate zone 8, the coldest climate, where a roof construction with improved insulation (R-25, as opposed to R-20) seems reasonable.
- Infiltration reduction EDMs are selected quite often. Vestibules are chosen in all climates. Envelope air barriers (which reduce infiltration by eliminating cracks in the envelope) are selected in all low plug load stores in humid (except 4A) and cold (5 through 8) climates; and in all high plug load stores except those in hot dry climates (2B and 3B-NV).

- Twenty percent increased COP is selected for RTUs in low plug load stores in all except very cold (6, 7, and 8) climates and those classified as marine; and in high plug load stores in all but the coldest climates (7 and 8). This is likely because not enough cooling is needed in cold or mild climates to justify the cost associated with upgrading RTU COPs. That increased COP is selected in more climates for high plug load stores than for low plug load stores reflects the larger cooling loads experienced by high plug load stores (because of the sensible heat that plug loads add to the space).
- Economizers are not selected in any climate except 3B-CA, in the high plug load case. This appears to go hand in hand with the fact that ERV is selected so often.
- Because of a modeling artifact (see Section 5.1.3), DCV and ERV could be selected individually, but not in combination. ERV is selected in all climates except the hottest arid climates (2B, and 3B-CA), where DCV is selected instead. ERV is likely selected so often because of the large fraction of the OA intake available for energy recovery, especially where infiltration reduction measures were also selected. The current trend shows that ERV should be effective in all but the mildest climates, especially in humid and cold climates, so we expect that DCV and ERV would work well in combination in many cases, such that DCV and ERV would have been selected in more climates were it not for the modeling artifact.

Table 4-13 Selected Low-Energy Models, Low Plug: Humid Climates

Category	Subcategory	EDM Type	Humid					
			1A	2A	3A	4A	5A	6A
Form	Fenestration	Skylight Fraction	4% roof area in non-sidelit zones	3% roof area in non-sidelit zones	2% roof area in non-sidelit zones	2% roof area in non-sidelit zones	None	None
		South Window Fraction	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing
	Shading	Shading Depth	None	None	None	None	None	None
Fabric	Fenestration	Skylights	Baseline Skylight Construction	Baseline Skylight Construction	Double pane with high solar gain	Double pane with low-e and high solar gain	Baseline Skylight Construction	Baseline Skylight Construction
		South Windows	Baseline Window Construction	Single pane with clear glass	Single pane with pyrolytic low-e	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon
	Infiltration	Infiltration	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Front door vestibule	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.
	Opaque Constructions	Walls	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6
		Roof	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.
Equipment	Energy Generation	PV	None	None	None	None	None	None
	HVAC System	System	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan
	Lighting	Daylighting Controls	500 lux set point	500 lux set point	500 lux set point	500 lux set point	500 lux set point	500 lux set point
		LPD	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors
	Outdoor Air	DCV	None	None	None	None	None	None
		ERV	70% effective	70% effective	50% effective	70% effective	70% effective	70% effective

Table 4-14 Selected Low-Energy Models, Low Plug: Arid Climates

Category	Subcategory	EDM Type	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Form	Fenestration	Skylight Fraction	3% roof area in non-sidelit zones	4% roof area in non-sidelit zones	3% roof area in non-sidelit zones	3% roof area in non-sidelit zones	2% roof area in non-sidelit zones	None
		South Window Fraction	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing
	Shading	Shading Depth	None	None	None	None	None	None
Fabric	Fenestration	Skylights	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Baseline Skylight Construction
		South Windows	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon
	Infiltration	Infiltration	Front door vestibule	Front door vestibule	Front door vestibule	Front door vestibule	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.
	Opaque Constructions	Walls	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6
		Roof	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.
Equipment	Energy Generation	PV	None	1.1% of net roof area	None	None	None	None
	HVAC System	System	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	Baseline COP with efficient fan
	Lighting	Daylighting Controls	500 lux set point	500 lux set point	500 lux set point	500 lux set point	500 lux set point	500 lux set point
		LPD	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors
	Outdoor Air	DCV	Installed	Installed	None	None	None	None
		ERV	None	None	50% effective	50% effective	50% effective	70% effective

Table 4-15 Selected Low-Energy Models, Low Plug: Marine and Cold Climates

Category	Subcategory	EDM Type	Marine		Cold	
			3C	4C	7	8
Form	Fenestration	Skylight Fraction	3% roof area in non-sidelit zones	None	None	None
		South Window Fraction	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing
	Shading	Shading Depth	None	None	None	None
Fabric	Fenestration	Skylights	Double pane with low-e and high solar gain	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction
		South Windows	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon
	Infiltration	Infiltration	Front door vestibule	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.
	Opaque Constructions	Walls	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6
		Roof	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	R-25 c.i.
Equipment	Energy Generation	PV	None	None	None	None
	HVAC System	System	Baseline COP with efficient fan	Baseline COP with efficient fan	Baseline COP with efficient fan	Baseline COP with efficient fan
	Lighting	Daylighting Controls	500 lux set point	500 lux set point	500 lux set point	500 lux set point
		LPD	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors
	Outdoor Air	DCV	None	None	None	None
		ERV	50% effective	70% effective	70% effective	50% effective

Table 4-16 Selected Low-Energy Models, High Plug: Humid Climates

Category	Subcategory	EDM Type	Humid					
			1A	2A	3A	4A	5A	6A
Program	Plug Loads	Schedule	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night
Form	Fenestration	Skylight Fraction	2% roof area in non-sidelit zones	3% roof area in non-sidelit zones	3% roof area in non-sidelit zones	3% roof area in non-sidelit zones	2% roof area in non-sidelit zones	None
		South Window Fraction	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing
	Shading	Shading Depth	None	None	None	None	None	None
Fabric	Fenestration	Skylights	Single pane with high solar gain	Double pane with high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Baseline Skylight Construction
		South Windows	Single pane with clear glass	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon
	Infiltration	Infiltration	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.
	Opaque Constructions	Walls	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6
		Roof	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.
Equipment	Energy Generation	PV	None	None	None	None	None	None
	HVAC System	System	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan
	Lighting	Daylighting Controls	500 lux set point	500 lux set point	500 lux set point	500 lux set point	500 lux set point	500 lux set point
		LPD	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors
	Outdoor Air	DCV	None	None	None	None	None	None
		ERV	50% effective	50% effective	70% effective	70% effective	70% effective	70% effective

Table 4-17 Selected Low-Energy Models, High Plug: Arid Climates

Category	Subcategory	EDM Type	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Program	Plug Loads	Schedule	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night
Form	Fenestration	Skylight Fraction	4% roof area in non-sidelit zones	4% roof area in non-sidelit zones	4% roof area in non-sidelit zones	3% roof area in non-sidelit zones	3% roof area in non-sidelit zones	2% roof area in non-sidelit zones
		South Window Fraction	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing
	Shading	Shading Depth	None	None	None	None	None	None
Fabric	Fenestration	Skylights	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
		South Windows	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon
	Infiltration	Infiltration	Front door vestibule	Tighter envelope and front door vestibule.	Front door vestibule	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.
	Opaque Constructions	Walls	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-18.1	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6
		Roof	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.
Equipment	Energy Generation	PV	7.6% of net roof area	9.2% of net roof area	5.8% of net roof area	0.94% of net roof area	None	None
	HVAC System	System	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan
	Lighting	Daylighting Controls	500 lux set point	500 lux set point	500 lux set point	500 lux set point	500 lux set point	500 lux set point
		LPD	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors
	Outdoor Air	DCV	Installed	Installed	None	None	None	None
		ERV	None	None	50% effective	70% effective	70% effective	70% effective

Table 4-18 Selected Low-Energy Models, High Plug: Marine and Cold Climates

Category	Subcategory	EDM Type	Marine		Cold	
			3C	4C	7	8
Program	Plug Loads	Schedule	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night	Plug loads reduced to 10% at night
Form	Fenestration	Skylight Fraction	4% roof area in non-sidelit zones	3% roof area in non-sidelit zones	None	None
		South Window Fraction	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing	50% of baseline glazing
	Shading	Shading Depth	None	None	None	None
Fabric	Fenestration	Skylights	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Baseline Skylight Construction	Baseline Skylight Construction
		South Windows	Double pane with low-e2 and argon	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon
	Infiltration	Infiltration	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.	Tighter envelope and front door vestibule.
	Opaque Constructions	Walls	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6	Mass_ASHRAE 90.1 2008_pg c.i. mtl frame ext ins R-22.6
		Roof	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-15 c.i.	R-25 c.i.
Equipment	Energy Generation	PV	5.8% of net roof area	None	None	None
	HVAC System	System	20% increased COP with efficient fan	20% increased COP with efficient fan	Baseline COP with efficient fan	Baseline COP with efficient fan
	Lighting	Daylighting Controls	500 lux set point	500 lux set point	500 lux set point	500 lux set point
		LPD	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors	47% LPD reduction and occupancy sensors
	Outdoor Air	DCV	None	None	None	None
		ERV	50% effective	70% effective	70% effective	70% effective

4.2.2 Performance

The energy performance of the selected low-energy models is summarized in Table 4-19 to Table 4-21, and depicted graphically in Figure 4-4 to Figure 4-6. The tables report several whole-building metrics; the figure depicts site energy use broken out into end uses. The data shown in the figure are also listed in table form in Appendix D.

Table 4-19 Selected Low-Energy Model Energy Performance: Humid Climates

Building Type	Building Name	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug General Merchandise	Low-Energy	Percent Energy Savings	58.3%	59.4%	53.1%	55.9%	55.0%	55.2%
	Baseline (SI)	EUI (MJ/m²·yr)	1,250	1,190	914	1,020	1,050	1,220
	Low-Energy (SI)	EUI (MJ/m²·yr)	520	484	429	450	471	546
	Baseline (SI)	Electricity Intensity (kWh/m²yr)	346	313	213	201	146	144
	Low-Energy (SI)	Electricity Intensity (kWh/m²yr)	144	128	94.5	88.4	77.1	76.0
	Baseline (SI)	Natural Gas Intensity (kWh/m²yr)	0.444	17.8	40.9	83.1	145	195
	Low-Energy (SI)	Natural Gas Intensity (kWh/m²yr)	0.708	6.88	24.7	36.7	53.8	75.5
	Low-Energy (SI)	PV Power Intensity (kWh/m²yr)	0.000	0.000	0.000	0.000	0.000	0.000
	Baseline (IP)	EUI (kBtu/ft²yr)	110	105	80.5	89.9	92.1	107
	Low-Energy (IP)	EUI (kBtu/ft²yr)	45.8	42.6	37.8	39.6	41.5	48.0
	Baseline (IP)	Electricity Intensity (kWh/ft²yr)	32.1	29.1	19.8	18.6	13.5	13.3
	Low-Energy (IP)	Electricity Intensity (kWh/ft²yr)	13.3	11.8	8.78	8.21	7.16	7.07
	Baseline (IP)	Natural Gas Intensity (Therms/ft²yr)	0.00141	0.0563	0.130	0.263	0.460	0.617
	Low-Energy (IP)	Natural Gas Intensity (Therms/ft²yr)	0.00224	0.0218	0.0784	0.116	0.170	0.239
	Low-Energy (IP)	PV Power Intensity (kWh/ft²yr)	0.000	0.000	0.000	0.000	0.000	0.000
High Plug General Merchandise	Low-Energy	Percent Energy Savings	51.4%	52.5%	51.5%	52.0%	52.2%	50.6%
	Baseline (SI)	EUI (MJ/m²·yr)	1,590	1,500	1,160	1,210	1,180	1,340
	Low-Energy (SI)	EUI (MJ/m²·yr)	773	713	561	583	564	660
	Baseline (SI)	Electricity Intensity (kWh/m²yr)	442	406	296	280	216	214
	Low-Energy (SI)	Electricity Intensity (kWh/m²yr)	214	193	148	143	120	130
	Baseline (SI)	Natural Gas Intensity (kWh/m²yr)	0.188	11.0	25.4	56.7	111	157
	Low-Energy (SI)	Natural Gas Intensity (kWh/m²yr)	0.351	4.54	7.60	18.8	36.5	53.8
	Low-Energy (SI)	PV Power Intensity (kWh/m²yr)	0.000	0.000	0.000	0.000	0.000	0.000
	Baseline (IP)	EUI (kBtu/ft²yr)	140	132	102	107	104	118
	Low-Energy (IP)	EUI (kBtu/ft²yr)	68.0	62.8	49.4	51.3	49.6	58.1
	Baseline (IP)	Electricity Intensity (kWh/ft²yr)	41.1	37.7	27.5	26.1	20.1	19.9
	Low-Energy (IP)	Electricity Intensity (kWh/ft²yr)	19.9	18.0	13.8	13.3	11.1	12.0
	Baseline (IP)	Natural Gas Intensity (Therms/ft²yr)	0.000594	0.0348	0.0805	0.180	0.352	0.498
	Low-Energy (IP)	Natural Gas Intensity (Therms/ft²yr)	0.00111	0.0144	0.0241	0.0596	0.116	0.171
	Low-Energy (IP)	PV Power Intensity (kWh/ft²yr)	0.000	0.000	0.000	0.000	0.000	0.000

Table 4-20 Selected Low-Energy Model Energy Performance: Arid Climates

Building Type	Building Name	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug General Merchandise	Low-Energy	Percent Energy Savings	50.8%	50.0%	54.2%	52.3%	51.1%	54.7%
	Baseline (SI)	EUI (MJ/m²·yr)	747	541	689	747	842	1,040
	Low-Energy (SI)	EUI (MJ/m²·yr)	367	270	316	356	411	470
	Baseline (SI)	Electricity Intensity (kWh/m²yr)	189	137	161	142	131	125
	Low-Energy (SI)	Electricity Intensity (kWh/m²yr)	80.8	58.6	68.5	58.4	57.3	66.4
	Baseline (SI)	Natural Gas Intensity (kWh/m²yr)	18.8	13.4	30.7	65.4	102	163
	Low-Energy (SI)	Natural Gas Intensity (kWh/m²yr)	21.2	18.1	19.2	40.6	57.0	64.2
	Low-Energy (SI)	PV Power Intensity (kWh/m²yr)	0.000	1.67	0.000	0.000	0.000	0.000
	Baseline (IP)	EUI (kBtu/ft²yr)	65.8	47.6	60.7	65.8	74.1	91.4
	Low-Energy (IP)	EUI (kBtu/ft²yr)	32.4	23.8	27.8	31.4	36.2	41.4
	Baseline (IP)	Electricity Intensity (kWh/ft²yr)	17.5	12.7	14.9	13.2	12.2	11.6
	Low-Energy (IP)	Electricity Intensity (kWh/ft²yr)	7.51	5.45	6.36	5.42	5.32	6.17
	Baseline (IP)	Natural Gas Intensity (Therms/ft²yr)	0.0597	0.0423	0.0972	0.207	0.324	0.517
	Low-Energy (IP)	Natural Gas Intensity (Therms/ft²yr)	0.0673	0.0575	0.061	0.129	0.181	0.203
	Low-Energy (IP)	PV Power Intensity (kWh/ft²yr)	0.000	0.155	0.000	0.000	0.000	0.000
High Plug General Merchandise	Low-Energy	Percent Energy Savings	50.0%	50.0%	50.0%	50.0%	50.4%	51.4%
	Baseline (SI)	EUI (MJ/m²·yr)	989	758	910	931	996	1,150
	Low-Energy (SI)	EUI (MJ/m²·yr)	495	379	455	465	494	559
	Baseline (SI)	Electricity Intensity (kWh/m²yr)	262	204	234	214	204	195
	Low-Energy (SI)	Electricity Intensity (kWh/m²yr)	138	111	126	117	112	111
	Baseline (SI)	Natural Gas Intensity (kWh/m²yr)	12.7	6.36	19.1	44.6	73.2	125
	Low-Energy (SI)	Natural Gas Intensity (kWh/m²yr)	13.6	8.60	11.0	14.1	25.1	44.8
	Low-Energy (SI)	PV Power Intensity (kWh/m²yr)	13.9	14.4	10.4	1.68	0.000	0.000
	Baseline (IP)	EUI (kBtu/ft²yr)	87.1	66.7	80.1	82.0	87.7	101
	Low-Energy (IP)	EUI (kBtu/ft²yr)	43.6	33.4	40.1	41.0	43.5	49.2
	Baseline (IP)	Electricity Intensity (kWh/ft²yr)	24.3	19.0	21.7	19.9	18.9	18.1
	Low-Energy (IP)	Electricity Intensity (kWh/ft²yr)	12.8	10.3	11.7	10.9	10.4	10.3
	Baseline (IP)	Natural Gas Intensity (Therms/ft²yr)	0.0403	0.0202	0.0605	0.141	0.232	0.395
	Low-Energy (IP)	Natural Gas Intensity (Therms/ft²yr)	0.0431	0.0273	0.0347	0.0446	0.0796	0.142
	Low-Energy (IP)	PV Power Intensity (kWh/ft²yr)	1.29	1.33	0.970	0.156	0.000	0.000

Table 4-21 Selected Low-Energy Model Energy Performance: Marine and Cold Climates

Building Type	Building Name	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug General Merchandise	Low-Energy	Percent Energy Savings	54.6%	55.8%	55.9%	50.2%
	Baseline (SI)	EUI (MJ/m²·yr)	586	787	1,350	1,940
	Low-Energy (SI)	EUI (MJ/m²·yr)	266	348	593	965
	Baseline (SI)	Electricity Intensity (kWh/m²yr)	115	118	122	121
	Low-Energy (SI)	Electricity Intensity (kWh/m²yr)	47.6	64.5	66.6	62.6
	Baseline (SI)	Natural Gas Intensity (kWh/m²yr)	48.1	101	251	416
	Low-Energy (SI)	Natural Gas Intensity (kWh/m²yr)	26.3	32.2	98.1	205
	Low-Energy (SI)	PV Power Intensity (kWh/m²yr)	0.000	0.000	0.000	0.000
	Baseline (IP)	EUI (kBtu/ft²yr)	51.6	69.3	118	170
	Low-Energy (IP)	EUI (kBtu/ft²yr)	23.4	30.6	52.2	84.9
	Baseline (IP)	Electricity Intensity (kWh/ft²yr)	10.6	10.9	11.4	11.3
	Low-Energy (IP)	Electricity Intensity (kWh/ft²yr)	4.43	5.99	6.19	5.81
	Baseline (IP)	Natural Gas Intensity (Therms/ft²yr)	0.152	0.320	0.797	1.32
	Low-Energy (IP)	Natural Gas Intensity (Therms/ft²yr)	0.0832	0.102	0.311	0.651
	Low-Energy (IP)	PV Power Intensity (kWh/ft²yr)	0.000	0.000	0.000	0.000
High Plug General Merchandise	Low-Energy	Percent Energy Savings	50.0%	51.1%	51.6%	56.1%
	Baseline (SI)	EUI (MJ/m²·yr)	752	908	1,420	1,960
	Low-Energy (SI)	EUI (MJ/m²·yr)	376	444	687	861
	Baseline (SI)	Electricity Intensity (kWh/m²yr)	183	185	191	185
	Low-Energy (SI)	Electricity Intensity (kWh/m²yr)	103	106	120	116
	Baseline (SI)	Natural Gas Intensity (kWh/m²yr)	25.9	67.4	203	360
	Low-Energy (SI)	Natural Gas Intensity (kWh/m²yr)	10.1	17.2	70.9	123
	Low-Energy (SI)	PV Power Intensity (kWh/m²yr)	8.69	0.000	0.000	0.000
	Baseline (IP)	EUI (kBtu/ft²yr)	66.2	80.0	125	173
	Low-Energy (IP)	EUI (kBtu/ft²yr)	33.1	39.1	60.5	75.8
	Baseline (IP)	Electricity Intensity (kWh/ft²yr)	17.0	17.2	17.7	17.2
	Low-Energy (IP)	Electricity Intensity (kWh/ft²yr)	9.57	9.87	11.2	10.8
	Baseline (IP)	Natural Gas Intensity (Therms/ft²yr)	0.0822	0.214	0.645	1.14
	Low-Energy (IP)	Natural Gas Intensity (Therms/ft²yr)	0.0321	0.0545	0.225	0.391
	Low-Energy (IP)	PV Power Intensity (kWh/ft²yr)	0.807	0.000	0.000	0.000

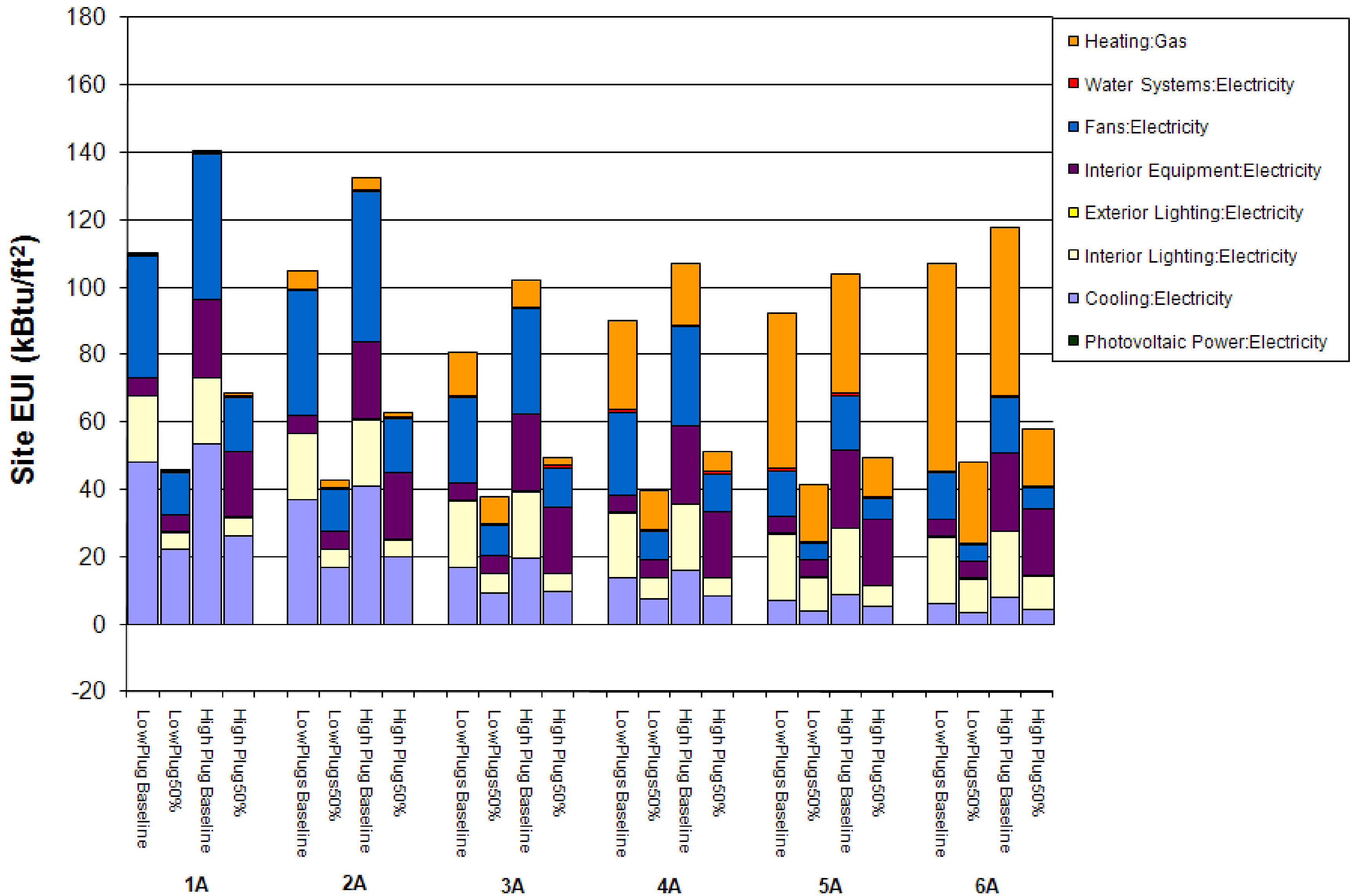

Figure 4-4 Energy intensity by end use for baseline and selected low-energy models in humid climates

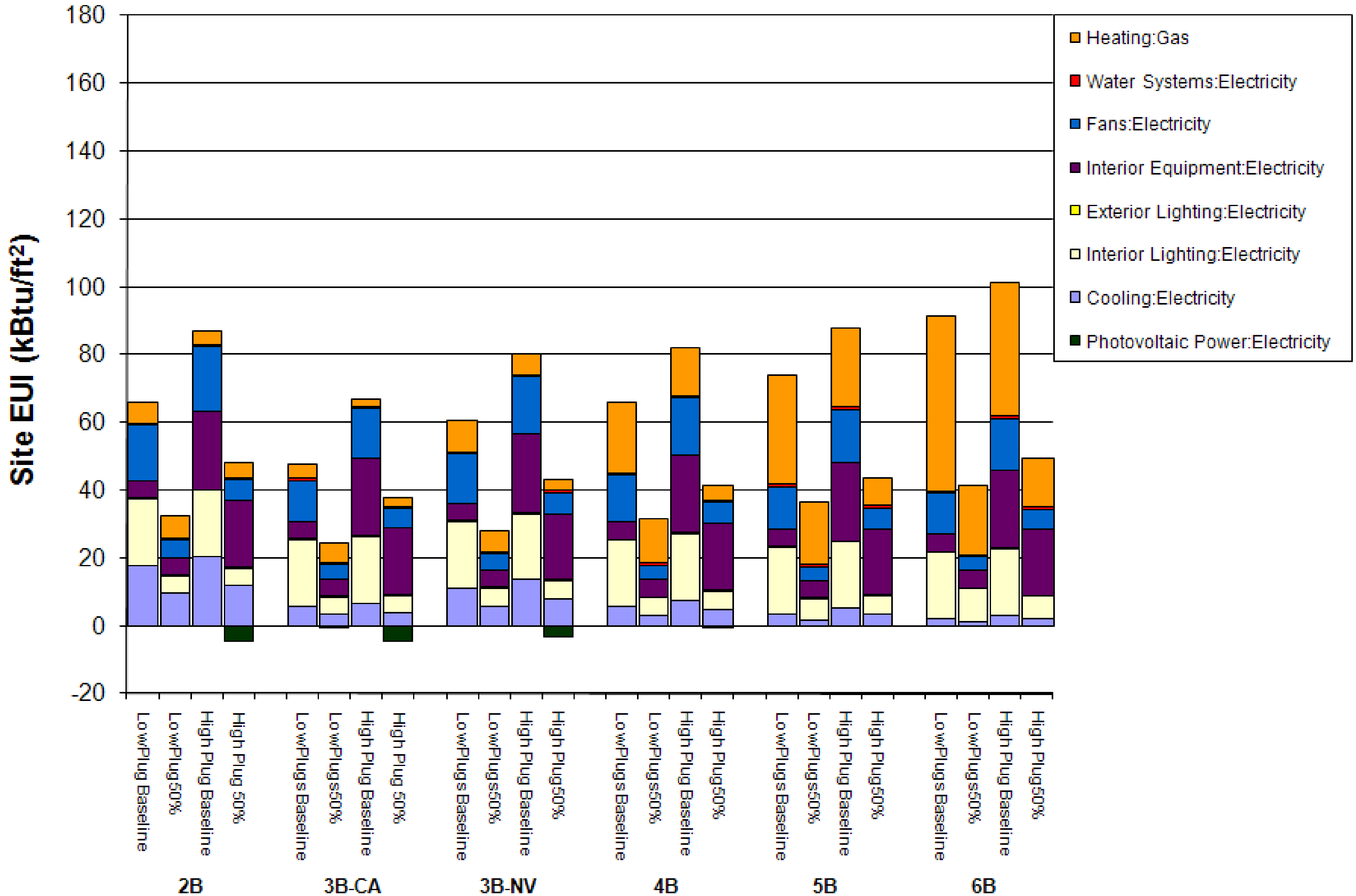

Figure 4-5 Energy intensity by end use for baseline and selected low-energy models in arid climates

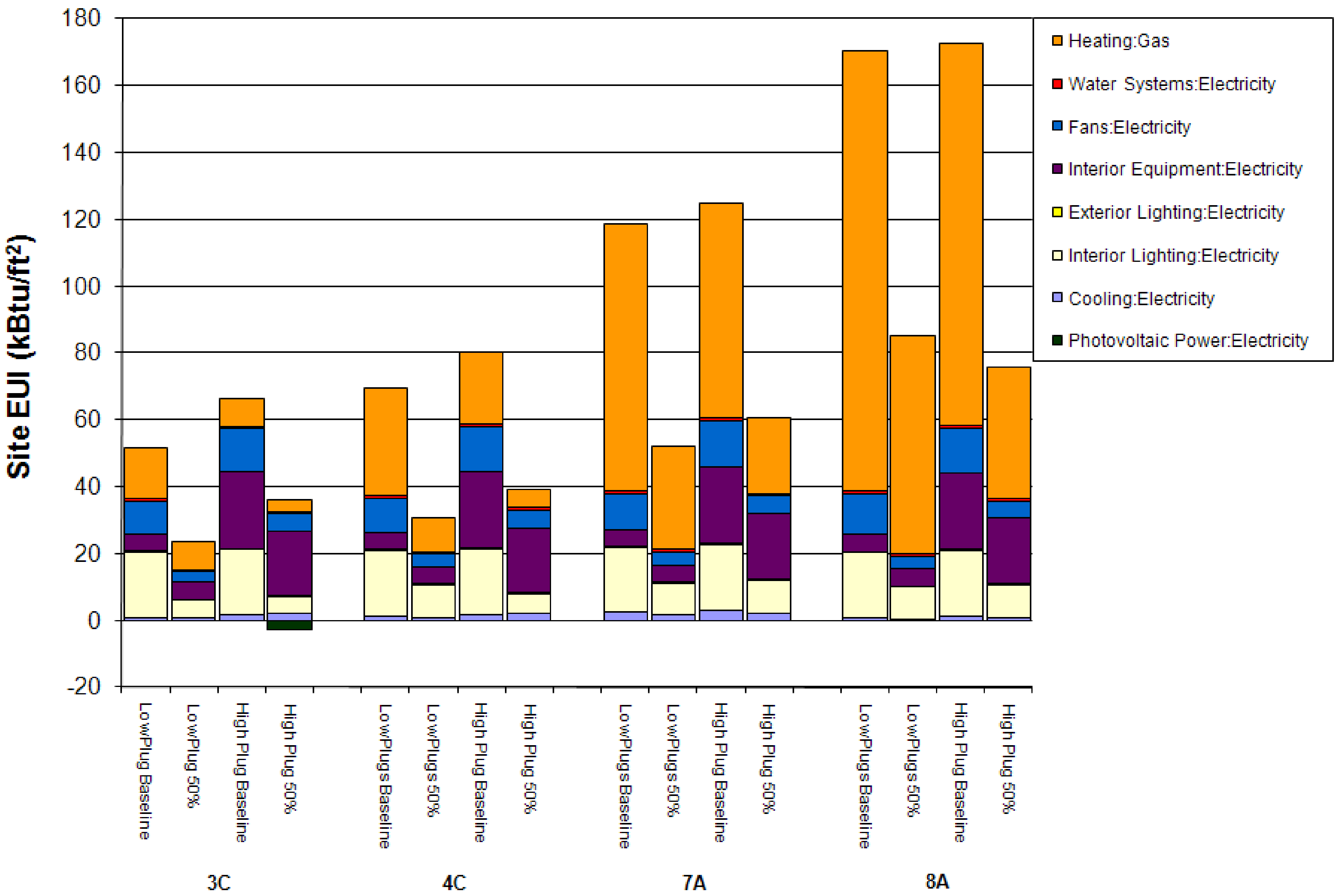

Figure 4-6 Energy intensity by end use for baseline and selected low-energy models in marine and cold climates

The economic performance of the selected low-energy models is summarized in Table 4-22 to Table 4-24.

Table 4-22 Selected Low-Energy Model Costs: Humid Climates

Building Type	Building Name	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug General Merchandise	Baseline (SI)	5-TLCC Intensity ($/m^2)	1,350	1,340	1,260	1,260	1,200	1,210
	Low-Energy (SI)	5-TLCC Intensity ($/m^2)	1,390	1,380	1,300	1,320	1,250	1,260
	Baseline (SI)	Capital Cost ($/m^2)	1,190	1,180	1,150	1,140	1,090	1,100
	Low-Energy (SI)	Capital Cost ($/m^2)	1,320	1,310	1,240	1,260	1,200	1,200
	Baseline (IP)	5-TLCC Intensity ($/ft^2)	126	124	117	117	111	112
	Low-Energy (IP)	5-TLCC Intensity ($/ft^2)	129	128	120	122	116	117
	Baseline (IP)	Capital Cost ($/ft^2)	110	110	106	106	102	102
	Low-Energy (IP)	Capital Cost ($/ft^2)	122	122	115	117	112	112
High Plug General Merchandise	Baseline (SI)	5-TLCC Intensity ($/m^2)	1,410	1,390	1,300	1,300	1,230	1,230
	Low-Energy (SI)	5-TLCC Intensity ($/m^2)	1,420	1,410	1,380	1,380	1,310	1,290
	Baseline (SI)	Capital Cost ($/m^2)	1,200	1,190	1,150	1,150	1,100	1,100
	Low-Energy (SI)	Capital Cost ($/m^2)	1,310	1,310	1,300	1,300	1,240	1,220
	Baseline (IP)	5-TLCC Intensity ($/ft^2)	131	129	121	121	114	114
	Low-Energy (IP)	5-TLCC Intensity ($/ft^2)	132	131	128	128	121	120
	Baseline (IP)	Capital Cost ($/ft^2)	112	111	107	107	102	102
	Low-Energy (IP)	Capital Cost ($/ft^2)	122	122	121	121	115	113

Table 4-23 Selected Low-Energy Model Costs: Arid Climates

Building Type	Building Name	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug General Merchandise	Baseline (SI)	5-TLCC Intensity ($/m^2)	1,180	1,150	1,170	1,160	1,160	1,170
	Low-Energy (SI)	5-TLCC Intensity ($/m^2)	1,170	1,160	1,220	1,210	1,210	1,230
	Baseline (SI)	Capital Cost ($/m^2)	1,080	1,080	1,080	1,080	1,080	1,070
	Low-Energy (SI)	Capital Cost ($/m^2)	1,120	1,120	1,180	1,170	1,170	1,180
	Baseline (IP)	5-TLCC Intensity ($/ft^2)	109	107	108	108	108	109
	Low-Energy (IP)	5-TLCC Intensity ($/ft^2)	109	108	113	112	113	114
	Baseline (IP)	Capital Cost ($/ft^2)	100	100	100	100	99.9	99.8
	Low-Energy (IP)	Capital Cost ($/ft^2)	104	104	110	109	109	110
High Plug General Merchandise	Baseline (SI)	5-TLCC Intensity ($/m^2)	1,220	1,190	1,210	1,200	1,200	1,210
	Low-Energy (SI)	5-TLCC Intensity ($/m^2)	1,270	1,280	1,310	1,290	1,290	1,280
	Baseline (SI)	Capital Cost ($/m^2)	1,090	1,080	1,090	1,090	1,090	1,090
	Low-Energy (SI)	Capital Cost ($/m^2)	1,210	1,220	1,250	1,230	1,220	1,220
	Baseline (IP)	5-TLCC Intensity ($/ft^2)	113	110	112	112	112	112
	Low-Energy (IP)	5-TLCC Intensity ($/ft^2)	118	119	122	120	119	119
	Baseline (IP)	Capital Cost ($/ft^2)	101	101	101	101	101	101
	Low-Energy (IP)	Capital Cost ($/ft^2)	112	113	116	115	114	113

Table 4-24 Selected Low-Energy Model Costs: Marine and Cold Climates

Building Type	Building Name	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug General Merchandise	Baseline (SI)	5-TLCC Intensity ($/m^2)	1,130	1,150	1,190	1,270
	Low-Energy (SI)	5-TLCC Intensity ($/m^2)	1,190	1,220	1,240	1,280
	Baseline (SI)	Capital Cost ($/m^2)	1,060	1,070	1,080	1,130
	Low-Energy (SI)	Capital Cost ($/m^2)	1,160	1,180	1,190	1,210
	Baseline (IP)	5-TLCC Intensity ($/ft^2)	105	107	111	118
	Low-Energy (IP)	5-TLCC Intensity ($/ft^2)	111	114	115	119
	Baseline (IP)	Capital Cost ($/ft^2)	98.8	99.6	100	105
	Low-Energy (IP)	Capital Cost ($/ft^2)	108	110	110	113
High Plug General Merchandise	Baseline (SI)	5-TLCC Intensity ($/m^2)	1,170	1,180	1,220	1,300
	Low-Energy (SI)	5-TLCC Intensity ($/m^2)	1,300	1,280	1,280	1,340
	Baseline (SI)	Capital Cost ($/m^2)	1,080	1,080	1,090	1,140
	Low-Energy (SI)	Capital Cost ($/m^2)	1,250	1,230	1,210	1,260
	Baseline (IP)	5-TLCC Intensity ($/ft^2)	109	110	113	120
	Low-Energy (IP)	5-TLCC Intensity ($/ft^2)	121	119	119	124
	Baseline (IP)	Capital Cost ($/ft^2)	99.9	100	101	106
	Low-Energy (IP)	Capital Cost ($/ft^2)	116	114	112	117

The electricity demand performance of the selected low-energy models is summarized in Table 4-25 to Table 4-27.

Table 4-25 Selected Low-Energy Model Electricity Demand: Humid Climates

Building Type	Building Name	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug General Merchandise	Baseline	Monthly Max Electric Demand [min-max] (kW)	344–387	323–408	156–326	126–326	101–211	102–211
	Low-Energy	Monthly Max Electric Demand [min-max] (kW)	186–218	149–214	71.8–169	62.4–173	53.9–122	53.9–122
	Baseline	Monthly Electrical Load Factor [min-max]	0.332–0.490	0.286–0.494	0.282–0.448	0.274–0.540	0.301–0.525	0.288–0.536
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.243–0.371	0.225–0.357	0.201–0.414	0.213–0.485	0.277–0.517	0.272–0.527
High Plug General Merchandise	Baseline	Monthly Max Electric Demand [min-max] (kW)	391–473	376–483	214–369	185–388	145–270	147–262
	Low-Energy	Monthly Max Electric Demand [min-max] (kW)	234–278	192–273	122–238	107–239	94.9–169	95.0–182
	Baseline	Monthly Electrical Load Factor [min-max]	0.370–0.512	0.336–0.511	0.371–0.473	0.308–0.535	0.366–0.557	0.360–0.563
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.288–0.405	0.284–0.396	0.299–0.455	0.271–0.485	0.308–0.493	0.346–0.521

Table 4-26 Selected Low-Energy Model Electricity Demand: Arid Climates

Building Type	Building Name	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug General Merchandise	Baseline	Monthly Max Electric Demand [min-max] (kW)	135–227	125–170	106–200	102–180	98.7–168	97.4–161
	Low-Energy	Monthly Max Electric Demand [min-max] (kW)	59.3–117	54.4–85.8	54.5–93.6	53.0–74.1	52.5–75.3	52.3–85.6
	Baseline	Monthly Electrical Load Factor [min-max]	0.393–0.488	0.336–0.451	0.383–0.510	0.384–0.520	0.377–0.524	0.361–0.526
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.336–0.455	0.241–0.418	0.346–0.440	0.342–0.433	0.353–0.463	0.362–0.515
High Plug General Merchandise	Baseline	Monthly Max Electric Demand [min-max] (kW)	189–284	178–219	153–260	146–238	144–227	142–221
	Low-Energy	Monthly Max Electric Demand [min-max] (kW)	108–156	102–140	101–138	100–123	96.8–123	92.7–123
	Baseline	Monthly Electrical Load Factor [min-max]	0.426–0.511	0.401–0.487	0.428–0.534	0.425–0.554	0.424–0.556	0.409–0.558
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.362–0.464	0.294–0.403	0.378–0.450	0.416–0.470	0.416–0.466	0.417–0.498

Table 4-27 Selected Low-Energy Model Electricity Demand: Marine and Cold Climates

Building Type	Building Name	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug General Merchandise	Baseline	Monthly Max Electric Demand [min-max] (kW)	94.9–149	94.5–161	95.4–171	97.1–139
	Low-Energy	Monthly Max Electric Demand [min-max] (kW)	45.3–74.8	51.8–86.5	51.2–106	50.8–82.0
	Baseline	Monthly Electrical Load Factor [min-max]	0.350–0.517	0.327–0.516	0.323–0.528	0.391–0.550
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.286–0.419	0.321–0.512	0.291–0.525	0.342–0.525
High Plug General Merchandise	Baseline	Monthly Max Electric Demand [min-max] (kW)	139–207	139–217	140–225	139–188
	Low-Energy	Monthly Max Electric Demand [min-max] (kW)	85.8–127	91.1–121	93.2–174	92.8–122
	Baseline	Monthly Electrical Load Factor [min-max]	0.400–0.557	0.378–0.555	0.380–0.563	0.445–0.575
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.326–0.456	0.389–0.491	0.313–0.531	0.436–0.531

4.2.3 Discussion

The economic performance data indicate that achieving the 50% energy savings goal in medium box general merchandise stores almost always occurs at the cost of an increase in 5-TLCC. Due to the upgraded and additional constructions and equipment associated with the implementation of the EDM selections, the low-energy buildings have higher capital costs than their corresponding baseline buildings. Although those costs are partially paid back through energy savings throughout the life of the building, the increase in capital costs required to reach the 50% energy goal cannot be recouped within 5 years (except in the low plug load store in climate zone 2B) . A costing bug in Opt-E-Plus for Energy Recovery Ventilation (ERV), which played an important role in reaching 50% energy savings in many cases, is at least partially to blame for the lack of cost-effective low-energy models.

In fact, several modeling errors were uncovered near the end of the month-long super-computer simulation runs. These errors affect both the baseline and low-energy model results and to varying degrees, but were discovered too late in the process to be remedied. Whereas we feel that these errors have not fundamentally changed the results of the overall analysis, we include them here for completeness:

- A costing bug in Opt-E-Plus resulted in an underestimation of HVAC capital costs. The size of the HVAC system in the largest zone (main sales) was taken as the total cost of the HVAC system for the whole building.
- Costs for infiltration reduction measures, which were calculated per zone based on the total number of zones, were not updated when the number of zones was reduced from 15 to 11.
- A costing bug in Opt-E-Plus resulted in an overestimation of the cost of ERV by an order of magnitude. Each of the 11 zones was assigned an ERV cost equivalent to what the cost of ERV for the entire building should have been. As a result, in all cases in which ERV was selected, the low-energy model building costs are significantly overestimated. The fact that ERV was still deemed a sufficiently cost-effective EDM to be selected in those cases is a testament to the significant energy savings that ERV can provide in certain climate zones.
- The cost of shaded overhangs was not updated for the inflation that occurred between 2006 and 2008. Shaded overhangs were not selected in any climate zone, however, so this error had no effect on the overall analysis.
- High effectiveness ERV was assigned the same pressure drop (0.42 in. w.c. [105 Pa]) as low effectiveness ERV. High effectiveness ERV should have been assigned a pressure drop of 0.7 in. w.c. (150 Pa), according to the assumption that higher effectiveness ERV would result in a larger pressure drop.
- The cost of the R-15 roof construction was not updated according to the new roof construction calculations.
- An EnergyPlus requirement associated with the allowable ratio between OA intake and exhaust fan flow rate for ERV operation prevented DCV and ERV from being selected in combination as EDMs. With DCV installed, OA intake in one or more zones reduces to the point that the ratio of OA intake to exhaust fan flow rate reaches a threshold value for ERV control in EnergyPlus that results in a fatal error.
- Finally, the original configuration of the HVAC RTUs with the desuperheat option for reheat did not properly control nighttime relative humidity. At night, the RTUs were only cycled to meet the dry bulb temperature set point; the humidistat set point (60%) was ignored.

4.3 Big Box Stores

We also want to comment on general merchandise stores larger than our primary prototype. For this reason, we developed prototype and baseline models for a big box 100,000 ft^2 (9,290 m^2) store with low plug load levels and the same space types as the medium box 40,500 ft^2 store. We then constructed "selected low-energy" models by applying the EDM sets selected for the medium box low plug load scenario to the corresponding big box baselines. The results of this exercise follow.

We did not redevelop our cost data for the big box stores, and so we refrain from reporting capital cost and 5-TLCC in this section. Larger stores typically cost less to construct per unit area (Balboni 2008b).

4.3.1 Baseline Model Performance

4.3.1.1 ASHRAE 90.1-2004 Baselines

The big box baseline models are developed using the same process and input data as that described in Sections 3.2 and 3.3 for the low plug load scenario. The only deviations are in the store floor plan. Although the organization of space types in the big box prototype is identical to that shown in Figure 3-10, the aspect ratio is 1.0 rather than 1.25. Within that framework, the dimensions of each space type are adjusted to fill the floor area. The vestibule is expanded to reflect the likelihood of greater foot traffic in the larger store; the auxiliary zones in the back of the store are also enlarged to accommodate more sales staff and shoppers. The size of each space type within the big box prototype is listed in Table 4-28.

Table 4-28 Big Box Space Types and Sizes

Space Type Name	Floor Area (ft^2)	Floor Area (m^2)	Percent of Total
Main Sales	78,750	7,316	79.4
Perimeter Sales	4,050	376	4.1
Enclosed Office	664	62	0.7
Meeting Room	1,106	103	1.1
Dining Room	1,106	103	1.1
Restroom	1,382	128	1.4
Mechanical Room	442	41	0.4
Corridor	450	42	0.5
Vestibule	675	63	0.7
Active Storage	10,600	985	10.7
Total	99,225	9,218	100.0

The performance data for the big box baseline models is listed in Table 4-29 to Table 4-31 alongside the corresponding low-energy model data.

4.3.1.2 Comparison to Medium Box Stores and CBECS

The site EUIs for the low plug load medium and big box stores (40,500 ft^2 [3,760 m^2] and 100,000 ft^2 [9,290 m^2], respectively) are shown in Figure 4-7 along with CBECS averages for stores in the same size ranges. The calculations follow the method outlined in Section 4.1.3. CBECS 40k includes retail stores of 20,000 ft^2 to 70,000 ft^2 (1,860 m^2 to 6,500 m^2) and includes 31 survey buildings. CBECS 100k covers stores of 70,000 ft^2 to 140,000 ft^2 (6,500 m^2 to 13,000 m^2) and includes 28 buildings.

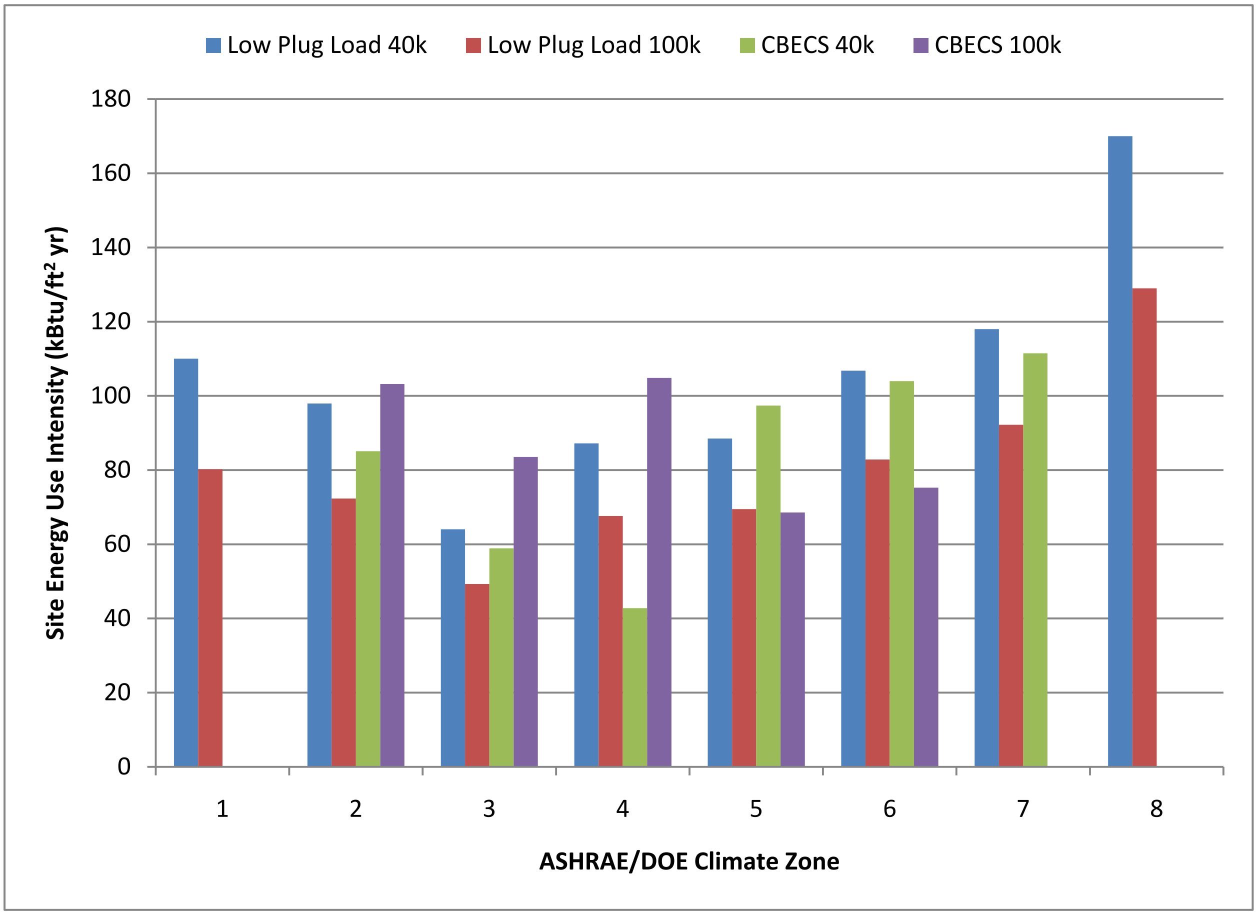

Figure 4-7 EUI comparison of the low plug load medium and big box baseline models, and CBECS survey results.

According to our models, the larger stores have consistently lower EUIs than the smaller stores. The CBECS findings are mixed on this account.

4.3.2 Selected Low-Energy Models

Big box low-energy models are constructed using the EDMs chosen for the low plug load stores as listed in Section 4.2.1. Thus, we will not repeat the descriptions of these buildings. Furthermore, 50% energy savings is not reached in all of the results that follow, but this does not mean that it is not possible to reach 50% energy savings in those cases. EDMs selected specifically for big box stores would result in 50% energy savings more cost effectively, but those searches were not run to keep the project at a manageable scale.

4.3.2.1 Performance

The energy performance of the selected low-energy models is summarized in Table 4-29 to Table 4-31. The tables report several whole-building metrics.

Table 4-29 Large Store Selected Low-Energy Model Performance: Humid Climates

Building Name	Metric	Humid					
		1A	2A	3A	4A	5A	6A
Low-Energy	Percent Energy Savings	57.8%	61.4%	55.6%	60.2%	59.0%	58.6%
Baseline (SI)	EUI ($MJ/m^2 \cdot yr$)	910	878	697	788	818	942
Low-Energy (SI)	EUI ($MJ/m^2 \cdot yr$)	384	339	309	314	336	390
Baseline (SI)	Electricity Intensity (kWh/m^2yr)	253	228	158	148	111	109
Low-Energy (SI)	Electricity Intensity (kWh/m^2yr)	107	88.0	60.5	56.6	53.3	53.7
Baseline (SI)	Natural Gas Intensity (kWh/m^2yr)	0.267	15.6	35.4	70.6	117	153
Low-Energy (SI)	Natural Gas Intensity (kWh/m^2yr)	0.0805	6.12	25.4	30.5	40.0	54.7
Low-Energy (SI)	PV Power Intensity (kWh/m^2yr)	0.000	0.000	0.000	0.000	0.000	0.000
Baseline (IP)	EUI ($kBtu/ft^2yr$)	80.2	77.4	61.4	69.4	72.0	83.0
Low-Energy (IP)	EUI ($kBtu/ft^2yr$)	33.8	29.8	27.2	27.6	29.6	34.4
Baseline (IP)	Electricity Intensity (kWh/ft^2yr)	23.5	21.2	14.7	13.8	10.3	10.1
Low-Energy (IP)	Electricity Intensity (kWh/ft^2yr)	9.90	8.17	5.62	5.26	4.95	4.99
Baseline (IP)	Natural Gas Intensity ($Therms/ft^2yr$)	0.000845	0.0494	0.112	0.224	0.369	0.484
Low-Energy (IP)	Natural Gas Intensity ($Therms/ft^2yr$)	0.000255	0.0194	0.0804	0.0968	0.127	0.173
Low-Energy (IP)	PV Power Intensity (kWh/ft^2yr)	0.000	0.000	0.000	0.000	0.000	0.000

Table 4-30 Large Store Selected Low-Energy Model Performance: Arid Climates

Building Name	Metric	Arid					
		2B	3B-CA	3B-NV	4B	5B	6B
Low-Energy	Percent Energy Savings	50.8%	44.4%	56.9%	53.8%	51.2%	57.7%
Baseline (SI)	EUI ($MJ/m^2 \cdot yr$)	559	420	536	596	674	827
Low-Energy (SI)	EUI ($MJ/m^2 \cdot yr$)	275	234	231	275	329	350
Baseline (SI)	Electricity Intensity (kWh/m^2yr)	138	105	120	109	102	97.5
Low-Energy (SI)	Electricity Intensity (kWh/m^2yr)	50.2	37.5	42.0	36.8	37.3	47.7
Baseline (SI)	Natural Gas Intensity (kWh/m^2yr)	17.3	11.7	28.3	57.0	85.4	132
Low-Energy (SI)	Natural Gas Intensity (kWh/m^2yr)	26.2	27.4	22.2	39.6	54.1	49.5
Low-Energy (SI)	PV Power Intensity (kWh/m^2yr)	0.000	0.000	0.000	0.000	0.000	0.000
Baseline (IP)	EUI ($kBtu/ft^2yr$)	49.3	37.0	47.2	52.5	59.4	72.8
Low-Energy (IP)	EUI ($kBtu/ft^2yr$)	24.2	20.6	20.3	24.2	29.0	30.8
Baseline (IP)	Electricity Intensity (kWh/ft^2yr)	12.8	9.77	11.2	10.1	9.46	9.06
Low-Energy (IP)	Electricity Intensity (kWh/ft^2yr)	4.67	3.48	3.90	3.42	3.47	4.43
Baseline (IP)	Natural Gas Intensity ($Therms/ft^2yr$)	0.0549	0.037	0.0898	0.181	0.271	0.419
Low-Energy (IP)	Natural Gas Intensity ($Therms/ft^2yr$)	0.0829	0.087	0.0703	0.126	0.172	0.157
Low-Energy (IP)	PV Power Intensity (kWh/ft^2yr)	0.000	0.000	0.000	0.000	0.000	0.000

Table 4-31 Large Store Selected Low-Energy Model Performance: Marine and Cold Climates

Building Name	Metric	Marine		Cold	
		3C	4C	7	8
Low-Energy	Percent Energy Savings	53.0%	59.3%	59.3%	51.0%
Baseline (SI)	EUI (MJ/m^2·yr)	477	640	1,050	1,470
Low-Energy (SI)	EUI (MJ/m^2·yr)	224	260	426	720
Baseline (SI)	Electricity Intensity (kWh/m^{2}yr)	89.1	91.9	95.1	90.8
Low-Energy (SI)	Electricity Intensity (kWh/m^{2}yr)	31.2	46.4	48.1	46.0
Baseline (SI)	Natural Gas Intensity (kWh/m^{2}yr)	43.3	85.9	196	317
Low-Energy (SI)	Natural Gas Intensity (kWh/m^{2}yr)	31.1	25.8	70.4	154
Low-Energy (SI)	PV Power Intensity (kWh/m^{2}yr)	0.000	0.000	0.000	0.000
Baseline (IP)	EUI (kBtu/ft^{2}yr)	42.0	56.3	92.2	129
Low-Energy (IP)	EUI (kBtu/ft^{2}yr)	19.7	22.9	37.6	63.4
Baseline (IP)	Electricity Intensity (kWh/ft^{2}yr)	8.28	8.54	8.83	8.44
Low-Energy (IP)	Electricity Intensity (kWh/ft^{2}yr)	2.90	4.31	4.47	4.27
Baseline (IP)	Natural Gas Intensity (Therms/ft^{2}yr)	0.137	0.272	0.621	1.01
Low-Energy (IP)	Natural Gas Intensity (Therms/ft^{2}yr)	0.0985	0.0818	0.223	0.489
Low-Energy (IP)	PV Power Intensity (kWh/ft^{2}yr)	0.000	0.000	0.000	0.000

4.3.2.2 Discussion

Compared to the 40,500-ft^2 (3,760-m^2) stores, the 100,000-ft^2 (9,290-m^2) stores have lower EUIs. This is true for the baseline and low-energy models.

For a given building height and aspect ratio, increasing floor area reduces the ratio of exterior wall area to interior volume. Both sensible and latent loads are introduced to the interior of the building through constructions associated with its exterior walls (conduction and infiltration through the walls, windows, and doors). By reducing the exterior wall area to volume ratio, the heating and cooling loads associated with those constructions make up a smaller percentage of the overall heating and cooling load on the building. This results in a reduction in overall EUI.

The exterior wall area to volume ratio for the 100,000-ft^2 (9,290-m^2) store is 37% less than that of the 40,500-ft^2 (3,760-m^2) store.

Adding to the reduced impact of infiltration on EUI in the big box store as compared to the medium box store is the fact that the exterior door area is the same for both. Thus, although the infiltration through the exterior door is the same for both stores, the resultant ACH is 59% less in the larger store.

We do not present cost results for the big box store, but generally expect cost intensities to follow a trend similar to EUI, that is, lower cost intensities for similar, but larger, stores. There will be less cost per unit area for constructions related to the exterior walls, and reduced EUI should correlate with less HVAC capacity per unit area.

4.4 Alternative Low-Energy Models

The methodology described in Section 2.5.2 is used to find alternative designs that also reach 50% energy savings for a subset of the climate zones. Each design is found with a new search designed to determine whether a specific high-performance strategy is required to meet the energy savings goal.

For this algorithm, a *strategy* is an EDM category or set of categories that can be turned off or on. To turn a strategy off means to set each EDM category to its baseline value. To turn a strategy on means to fix each EDM category to the value taken in a selected low-energy model. The strategy definitions used in this work are summarized in Table 4-32. Each strategy is a set of one or more EDM types.

Table 4-32 High Performance Building Strategies as used in the Algorithm for Identifying Alternative Low-Energy Models.

Strategy Name	EDM Type	See Section
Plug loads	Schedule	3.4.3.3
Infiltration	Infiltration	3.4.2.4
Electric lighting	LPD	3.4.3.2
Daylighting	Daylighting controls	3.4.3.1
	Skylight fraction	3.4.1.1.2
Window area & shading	South window fraction	3.4.1.1.1
	Shading depth	3.4.1.2
Envelope insulation	Walls	3.4.2.1
	Roof	3.4.2.2
Fenestration types	South windows	3.4.2.3.1
	Skylights	3.4.2.3.2
HVAC	System	3.4.3.4
DCV	DCV	3.4.3.5.1
ERV	ERV	3.4.3.5.2
PV	PV	3.4.3.6

In what follows, the PV strategy was treated differently from the others. In particular, the PV EDM defines an upper limit on the amount of PV. Then for any selected points that achieve the 50% energy savings target with PV, we calculated the actual amount of PV required to reach the target and reran the selected model after making just that change. Models that included PV and still did not reach the target were marked as unsuccessful.

The algorithm used to find alternative models that meet the target is computationally intensive, requiring 187% to 305% of the effort of the original search. For this reason, we only ran it in five climate zones: 1A (Miami, Florida), 3B-NV (Las Vegas, Nevada), 4C (Seattle, Washington), 5A (Chicago, Illinois), and 8 (Fairbanks, Alaska). We also only ran one iteration of the algorithm, which means that each new search was generated directly from the selected low energy models described in Section 4.2 by removing a single strategy.

4.4.1 Results

The bulk of the results are listed in Appendix E. Here we walk through the results for one plug load scenario in one climate zone, and summarize the overall results in a few tables.

4.4.1.1 Example Results for One Building

By starting with the selected low-energy model, removing a strategy from both the model and the search, and then restarting the search, one ends up with two new models of interest: the new start point, and the new selected point. The results reported in Appendix E summarize both for every strategy used in the original selected models.

After a brief summary of the computational effort required for the searches, the next two items in each subsection of Appendix E, a figure and an accompanying table, provide information on the new selected points. For convenience, here we reproduce those items for the high plug load scenario in climate zone 1A (Miami, Florida), see Figure 4-8 and Table 4-33.

The figure represents each low-energy model as a node. Circular nodes meet the 50% energy savings goal; octagonal nodes do not. Nodes outlined in gold contain PV; black nodes do not. The root node (the top circle labeled 00) represents the selected low-energy model described in Section 4.2. Each child node represents a model chosen in the same way as the root node, but from a new search that excluded the indicated strategy from the search options, and that started from the model defined by removing that strategy from the root node.

The accompanying table further summarizes the low-energy models represented in the figure. The two are linked by the node labels 00, 01, 02, etc. The first row repeats a subset of the performance data listed above for the original selected low-energy model, and adds to that an explicit listing of which strategies were used in that model. For example, the original low-energy model chosen for the high plug load Miami store applies the plug load schedule EDM, at least one infiltration EDM, and some aspect of daylighting (controls, skylights, or both).

The subsequent rows summarize the new low-energy models. Each one excludes one of the strategies used by the original selected model. In some cases, the new low-energy models use strategies that were not used in the original model. This is to be expected since different actions must be taken to reach the 50% goal in the absence of the excluded strategy. Sometimes those actions are more extreme measures taken within the confines of one of the strategies used in the original model, but at other times entirely new strategies are introduced.

The performance data allows interested parties to screen all of the models that reach the 50% goal against several criteria, including some that are not used directly in the search. Recall that the search simultaneously minimizes net site energy and lifetime cost. To these, the table adds PV energy, capital cost, and peak demand.

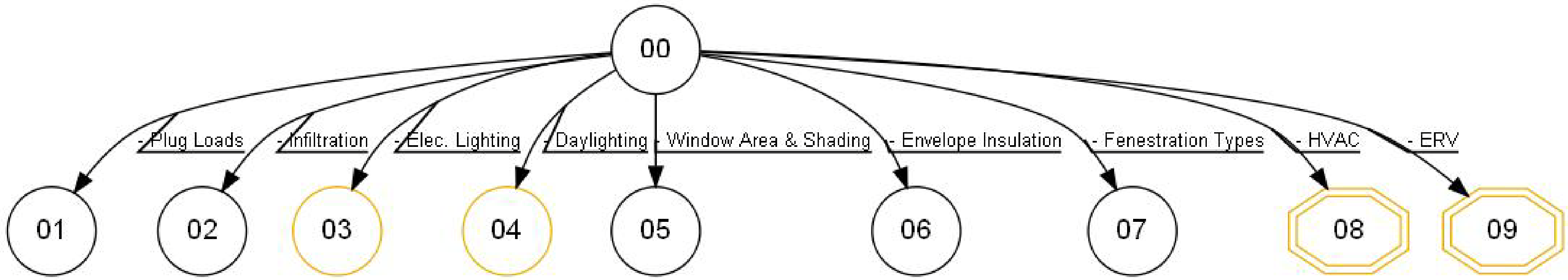

Figure 4-8 Visualization of original and alternative low-energy models for the high plug load Miami, Florida store.

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table 4-33 Summary of Low Energy Models for the High Plug Load Miami, Florida Store.

Node numbers correspond to Figure 4-8. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Plug Loads	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
											MJ/m^2yr	$kBtu/ft^2yr$	MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$		
0	X	X	X	X	X	X	X	X		X	773	68.0	0	0	1420	131.90	1314	122.08	278	51.4
1		X	X	X	X	X	X	X		X	774	68.1	0	0	1451	134.76	1346	125.05	279	51.4
2	X		X	X	X	X	X	X		X	781	68.7	0	0	1453	134.99	1345	124.92	293	50.9
3	X	X		X	X	X	X	X		X	796	70.0	206	18.1	1835	170.44	1723	160.05	299	50.0
4	X	X	X		X	X	X	X		X	796	70.1	176	15.5	1755	163.01	1646	152.96	273	50.0
5	X	X	X	X		X	X	X		X	777	68.4	0	0	1423	132.16	1317	122.31	277	51.2
6	X	X	X	X	X		X	X		X	770	67.8	0	0	1436	133.45	1331	123.70	285	51.6
7	X	X	X	X	X	X		X		X	766	67.4	0	0	1427	132.54	1321	122.72	278	51.9
8	X	X	X	X	X	X	X			X	978	86.0	338	29.7	2252	209.23	2118	196.79	341	38.6
9	X	X	X	X	X	X	X	X			1184	104.2	59	5.2	1497	139.08	1350	125.43	281	25.6

The results in Appendix E also summarize the new start points as they relate to the original low-energy model. Those two points only differ by one strategy (any PV effects are removed) such that the difference in their performance data can be interpreted as sensitivity data and answers the question, "How much impact does the given strategy have on the EUI of the selected low-energy model?" The table that summarizes this data for the high plug load Miami store is reproduced in Table 4-34. Except for Equivalent PV, each reported quantity is the result of taking the value of the listed performance metric for the original low-energy model and subtracting that for the new start point (original model minus the indicated strategy). Thus, in most cases we expect EUI Savings to be a positive number.

Equivalent PV is provided as an alternative valuation for the given strategy. For each location, we use EnergyPlus to calculate the annual amount of energy produced per unit area of PV assuming horizontal orientation, 10% cell efficiency, 90% inverter efficiency, and the insolation data provided in the appropriate TMY2 weather file. It is then possible to convert the EUI savings provided by a strategy to an equivalent area of PV panels. Although equivalent to EUI savings, equivalent PV gives readers a more tangible way to think about a given level of energy savings and provides an alternative cost metric (a maximum allowable capital cost) once a realistic PV cost is chosen. With incentives and more PV production capacity coming online, we have heard of costs as low as \$2.50-\$5 per Watt of PV capacity; installed capacity is about 100 W/m^2.

Table 4-34 Sensitivity Analysis for the Strategies used in the Selected Low-Energy Model for the High Plug Load Miami, Florida Store.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		$MJ/m^2·yr$	$kBtu/ft^2·yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$	m^2	ft^2
Plug Loads	1	39.1	3.44	4.05	0.38	0.00	0.00	246.2	2650
Infiltration	2	46.2	4.06	4.75	0.44	–1.37	–0.13	291.0	3132
Elec. Lighting	3	95.6	8.41	18.67	1.73	4.26	0.40	602.3	6483
Daylighting	4	279.0	24.56	10.60	0.98	–18.50	–1.72	1758.7	18930
Window Area & Shading	5	4.5	0.39	2.80	0.26	2.51	0.23	28.2	304
Envelope Insulation	6	34.1	3.00	–9.68	–0.90	–14.55	–1.35	215.2	2316
Fenestration Types	7	224.8	19.78	24.80	2.30	1.62	0.15	1416.7	15249
HVAC	8	286.5	25.21	11.93	1.11	–23.90	–2.22	1805.4	19433
ERV	9	87.9	7.74	–62.21	–5.78	–71.61	–6.65	554.3	5966

4.4.1.2 Summary Tables

Table 4-35 and Table 4-36 list the number of low-energy models found for each climate zones to which the analysis was applied for the low plug load and high plug load scenarios, respectively. Since some models did not reach 50% savings, the number of models that did is also listed. The rest of the data indicates the range of performances seen in those models that did reach the energy savings goal. These data are provided to give the reader an idea of the amount of diversity present in the sets of alternative designs.

Table 4-35 Low Plug Load Families of Low-Energy Models Summary

Climate Zone	No. of 50% Models/ Total No. of Models	PV Energy Intensity Range (50% Models)		5-TLCC Intensity Range (50% Models)		Capital Cost Intensity Range (50% Models)		Maximum Electricity Demand Range (50% Models)
		MJ/ m^2·yr	kBtu/ ft^2·yr	$/$m^2$	$/$ft^2$	$/$m^2$	$/$ft^2$	kW
1A	8/8	0–104	0–9.2	1320–1573	122.63–146.10	1228–1481	114.07–137.59	202–281
3B-NV	9/9	0–95	0–8.3	1215–1374	112.92–127.68	1172–1331	108.90–123.70	94–116
4C	9/9	0–144	0–12.7	1218–1660	113.17–154.22	1175–1624	109.17–150.84	69–103
5A	9/9	0–206	0–18.1	1252–1790	116.31–166.29	1198–1743	111.28–161.91	106–144
8	8/9	0	0	1284–1322	119.30–122.81	1210–1249	112.44–116.06	79–113

Table 4-36 High Plug Load Families of Low-Energy Models Summary

Climate Zone	No. of 50% Models/Total No. of Models	PV Energy Intensity Range (50% Models)		5-TLCC Intensity Range (50% Models)		Capital Cost Intensity Range (50% Models)		Maximum Electricity Demand Range (50% Models)
		MJ/m^2·yr	kBtu/ft^2·yr	$/$m^2$	$/$ft^2$	$/$m^2$	$/$ft^2$	kW
1A	8/10	0–206	0–18.1	1420–1835	131.90–170.44	1314–1723	122.08–160.05	273–299
3B-NV	10/10	38–170	3.3–14.9	1310–1511	121.67–140.39	1249–1450	116.03–134.68	138–168
4C	10/10	0–178	0–15.7	1282–1779	119.14–165.28	1226–1727	113.87–160.41	112–140
5A	10/10	0–184	0–16.1	1305–1690	121.28–156.97	1237–1626	114.95–151.11	161–201
8	9/10	0	0	1331–1372	123.70–127.51	1247–1288	115.83–119.64	120–156

Table 4-37 and Table 4-38 attempt to summarize the value of the high performance design strategies across climate zones. Each cell is shaded to indicate whether the given metric always improves (green), sometimes improves (grey), or always degrades (orange) in response to the addition of the indicated strategy.

Table 4-37 Low Plug Load Sensitivity Analysis Summary by Strategy

Green (orange) indicates that the strategy always improves (degrades) the performance metric.

Strategy	No. of Data Points	EUI Savings Range		5-TLCC Savings Range		Capital Cost Savings Range		Equivalent PV Range	
		MJ/ m^2·yr	kBtu/ ft^2·yr	$/$m^2$	$/$ft^2$	$/$m^2$	$/$ft^2$	m^2	ft^2
Infiltration	5	20 to 219	1.7 to 19.3	–10.09 to 12.71	–0.94 to 1.18	–12.30 to 0.20	–1.14 to 0.02	106 to 2,756	1,140 to 26,660
Elec. Lighting	5	40 to 81	3.5 to 7.1	15.52 to 36.03	1.44 to 3.35	3.04 to 23.95	0.28 to 2.22	343 to 750	3,690 to 8,080
Daylighting	5	3 to 64	0.2 to 5.6	–16.08 to 0.40	–1.49 to 0.04	–21.81 to –0.38	–2.03 to –0.04	31 to 401	340 to 4,310
Window Area & Shading	5	–0.7 to 2.6	–0.1 to 0.2	3.70 to 4.32	0.34 to 0.40	3.49 to 3.70	0.32 to 0.34	–5.5 to 21.4	–60 to 230
Envelope Insulation	5	24 to 96	2.1 to 8.5	–4.73 to 19.25	–0.44 to 1.79	–9.80 to 14.69	–0.91 to 1.36	130 to 1,213	1,400 to 13,050
Fenestration Types	4	3.5 to 12.1	0.3 to 1.1	0.66 to 1.40	0.06 to 0.13	0.12 to 0.99	0.01 to 0.09	32 to 103	350 to 1,110
HVAC	5	3 to 354	0.3 to 31.1	1.59 to 20.80	0.15 to 1.93	–18.44 to –0.56	–1.71 to –0.05	36 to 2,790	380 to 30,030
ERV	5	84 to 548	7.4 to 48.3	–93.30 to –42.18	–8.67 to –3.92	–103.57 to –71.61	–9.62 to –6.65	458 to 6,902	4,930 to 74,290

Table 4-38 High Plug Load Sensitivity Analysis Summary by Strategy

Green (orange) indicates that the strategy always improves (degrades) the performance metric.

Strategy	No. of Data Points	EUI Savings Range		5-TLCC Savings Range		Capital Cost Savings Range		Equivalent PV Range	
		MJ/ m^2·yr	kBtu/ ft^2·yr	$/$m^2$	$/$ft^2$	$/$m^2$	$/$ft^2$	m^2	ft^2
Plug Loads	5	11 to 39	0.9 to 3.4	2.44 to 4.05	0.23 to 0.38	0	0	134 to 247	1,440 to 2,660
Infiltration	5	15 to 189	1.3 to 16.6	–11.45 to 4.75	–1.06 to 0.44	–13.01 to –1.37	–1.20 to –0.13	79 to 2,374	845 to 25,560
Elec. Lighting	5	53 to 96	4.7 to 8.4	5.74 to 18.67	0.53 to 1.73	–5.53 to 4.26	–0.51 to 0.40	331 to 753	3,570 to 8,100
Daylighting	5	3 to 279	0.3 to 24.6	–20.82 to 10.60	–1.93 to 0.98	–26.62 to –0.45	–2.47 to –0.04	42 to 1,759	450 to 18,930
Window Area & Shading	5	0.0 to 4.5	0.0 to 0.4	2.80 to 4.44	0.26 to 0.41	2.51 to 3.62	0.23 to 0.34	0 to 49	0 to 530
Envelope Insulation	5	22 to 84	1.9 to 7.4	–9.68 to –5.31	–0.90 to –0.49	–14.55 to –7.49	–1.35 to –0.70	118 to 1,054	1,270 to 11,350
Fenestration Types	5	6 to 225	0.6 to 19.8	0.55 to 24.80	0.05 to 2.30	0.36 to 1.62	0.03 to 0.15	38 to 1,417	410 to 15,250
HVAC	5	21 to 287	1.9 to 25.2	1.60 to 13.03	0.15 to 1.21	–23.90 to –2.77	–2.22 to –0.26	269 to 2,146	2,900 to 23,100
ERV	5	64 to 684	5.6 to 60.2	–92.65 to –62.21	–8.61 to –5.78	–103.57 to–71.61	–9.62 to –6.65	344 to 8,604	3,710 to 92,610

4.4.2 Discussion

The algorithm described here and in Section 2.5.2 allowed us to identify 8 to 10 low-energy models for each of the ten climate zones/plug load combinations analyzed in this manner. Each model meets the 50% energy savings goal in a significantly different way, concretely demonstrating that there are multiple ways to meet most energy efficiency goals. Furthermore, because different EDMs provide different performance in terms of 5-TLCC, capital cost, and electricity demand changes per unit of energy savings, the performance of the models are significantly different when compared using those criteria (and likely any others of interest that are not reported here).

We found that we could not reach the 50% savings goal in Fairbanks, Alaska (climate zone 8) without ERV. Similarly, HVAC improvements and ERV are required to reach 50% energy savings in Miami, Florida when there are high plug load levels. For the most part, high plug load levels increase the cost of individual strategies over the low plug load scenarios. Similarly, whole building cost (capital and 5-TLCC) is higher for the high plug load low-energy buildings, and PV is required more often (for instance, in all of the low-energy models for the high plug load scenario in Las Vegas, Nevada).

The sensitivity analysis results highlight which strategies are most valuable from an energy savings perspective, and which have first cost and lifetime cost issues. (The reported results for ERV are off by an order of magnitude in this regard, see Section 4.2.3.)

For the sake of brevity, we are not providing detailed descriptions of each low-energy model found in this study or poring through our data to answer admittedly interesting questions such as "What is the relationship between the high performance strategies and maximum electricity demand?" The main contribution of this work is to demonstrate a new methodology that enables users to generate a number of significantly different designs that meet a common energy efficiency goal.

4.5 Addressing Known Issues

Due to the large number of simulation runs required for this analysis, time constraints did not allow us to rerun full optimizations after discovering the modeling errors listed in Section 4.2.3. Those errors have since been addressed however, and we feel that it is worth presenting a set of modified results to illustrate their effects on the analysis. Most of the modeling errors affected costs and EDM selection order rather than the final list of chosen EDMs. The exceptions to this rule are related to the ERV EDMs: the ERV costing bug, which overpriced ERV by an order of magnitude; and the ERV-DCV interaction bug, which prevented ERV and DCV from being selected simultaneously. In some cases, it appeared that PV was erroneously selected instead of ERV. In others, it seemed as though the selection of either ERV or DCV was prevented by the presence of the other. In an attempt to predict what the results of the optimizations would have been in the absence of these modeling errors, we took the following steps:

1. Removed any ERV, DCV, or PV EDMs from the selected low-energy model.
2. Fixed the remaining EDM selections.
3. Performed an abbreviated optimization over the ERV, DCV, and PV EDMs to determine corrected low-energy models.

In all cases in which PV was previously selected, it was removed. In the low plug scenarios for climate zones 1A, 2A, and 3B-NV, ERV was removed in favor of DCV. In all cases in which 70% effective ERV was previously selected, it was replaced with 50% effective ERV.

Addressing the modeling errors resulted in baseline models with higher EUIs (due to the energy cost of controlling humidity at night), capital costs, and TLCCs (due to the previous underestimation of HVAC and roofing costs). It also resulted in low-energy models with lower TLCCs than their corresponding baselines (8.5% lower on average, as opposed to 4.7% higher for the original optimizations). Detailed energy and economic performance data for the models selected from the abbreviated optimizations are presented in Appendix F.

5.0 Suggestions for Future Work

In this section we outline several types of improvements recommended for future *AEDG* work.

5.1.1 Problem Formulation

The current problem formulation could be adapted to make future 50% TSDs and AEDGs more useful. Energy savings is currently defined against a baseline (ASHRAE Standard 90.1) that is changing steadily over time (see Section 4.1.4). Unless the 90.1-2004/62-1999 baseline is used in perpetuity, it may be advantageous to use a different energy metric. One possible approach would be to use targets based on EUI levels rather than percent savings. Eventually, a net EUI of zero will be the goal. Some work would be required to determine how or if the EUI goals should vary across climate zones on the way to net zero energy use. A consideration of the Pareto front as a whole would give a sense of the effort required to achieve different EUIs on the way to net zero. Several key features for guiding the choice of absolute EUI goals are illustrated in Figure 5-1, which shows results for Atlanta (Climate Zone 3A), low plug load scenario. Notice that the graph uses EUI on the *x*-axis rather than percent energy savings. “BL” designates the baseline point as defined in this study. The other points labeled on the Pareto Front are:

1) The minimum 5-TLCC design
2) The “knee” of the Pareto front, before the cost escalates dramatically due to inclusion of PV in the design
3) A design equal in 5-TLCC cost to the baseline building
4) The 50% energy savings building identified as the low-energy model in this study
5) A design meeting an arbitrary net 10 kBtu/ft^2 target (could be any target down to, or even past net zero EUI)

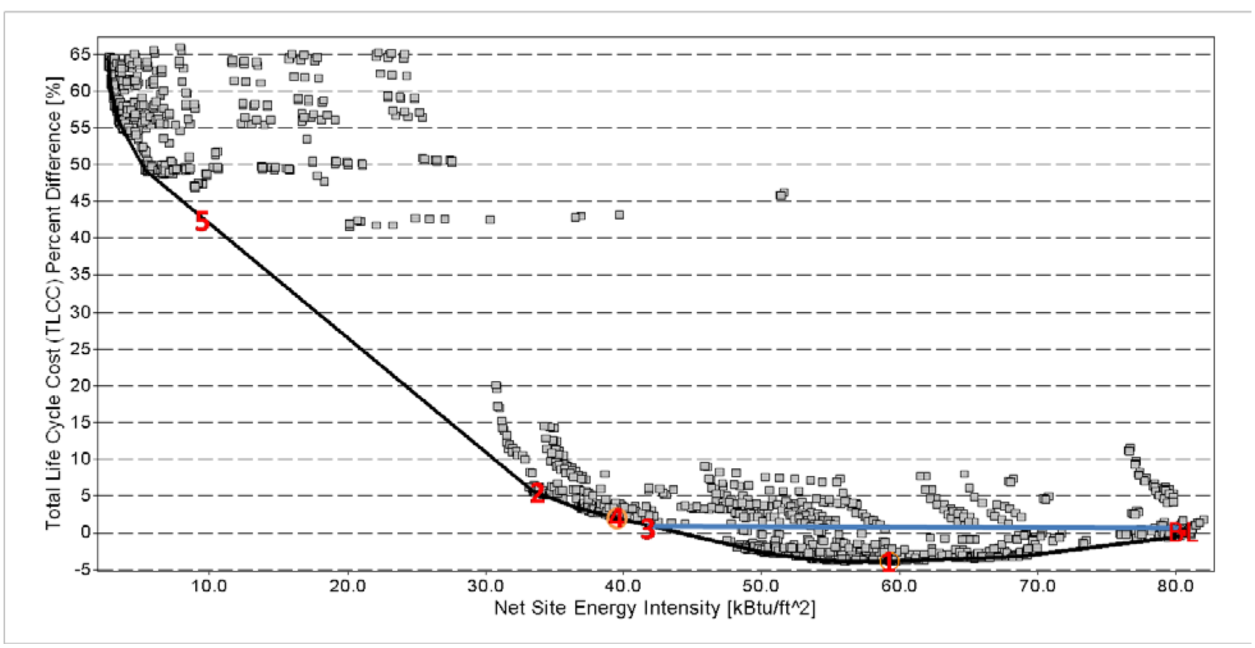

Figure 5-1 Key Pareto curve features to provide absolute EUI targets

An additional consideration is that there are often a number of building design options that are clustered around 50% energy savings; choosing a single "solution" is somewhat arbitrary, given uncertainties in modeling assumptions and inputs. The "family enumeration" analysis used in this study is an effort to start down the road of identifying multiple solution sets for providing more general design guidance.

5.1.2 Economic Data

It is important to weigh capital and maintenance costs versus future energy costs, both for the whole building and for individual EDMs. However, doing so is difficult. Today's costs for basic building materials, new technologies, and energy are constantly moving targets; future energy costs cannot be predicted with reasonable accuracy; economic parameters such as discount rates and acceptable payback periods vary by building owner; and one of the goals of the Energy Alliances is to provide enough buying power to drive the underlying economics, thereby rendering the current costs moot.

Several approaches that address one or more of these problems are:

- Ignore economics in all general analyses. Instead, work with a specified set of EDMs that are deemed reasonably mature and cost effective. Only recommend EDMs that have an appreciable impact on energy use.
- Integrate algorithms and methodologies that can deal with data uncertainties into Opt-E-Plus, and exercise them by providing ranges or probability distributions, rather than single values, for highly uncertain economic and performance parameters.
- Develop automatic or industry-assisted methods for obtaining up-to-date cost data on well-established items such as basic construction materials, common HVAC technologies, and utility tariffs. For more uncertain costs, that is, new technology and future energy costs, develop methods for handling uncertainty information, exercising different scenarios and/or calculating what the cost would have to be for the item to be cost effective.

5.1.3 Energy Modeling

A number of EDMs were not included in this report due to limitations in EnergyPlus or Opt-E-Plus, lack of reliable input data, or the added simulation time that would have been required. Measures we feel deserve increased attention are:

- **Alternative HVAC systems**. For simplicity, we assumed that all HVAC needs were supplied with 10-ton DX RTUs. DX RTUs are by far the most common HVAC systems used in medium box general merchandise stores, but they are not necessarily the best choice. Future studies could consider centralized systems, radiant heating and cooling, thermal storage systems, ground-source heat pumps, and other technologies. In addition, to obtain true comparisons with a baseline building that uses RTUs, the dynamics of each system should be modeled more accurately, especially at part load conditions. This would require developing much more accurate input data for models of HVAC systems and their controls. Adding such capability would require a large effort, both from the Opt-E-Plus team, and in acquiring accurate measured data.
- **Air flow models.** Right now, our EnergyPlus models assume that air masses in different thermal zones are isolated from one another. Modeling air transfers between zones

would increase the accuracy of our models and allow us to better study design features such as vestibules. For instance, infiltration through the front entrance is currently divided on an area-weighted basis between the vestibule and the main sales area, based on the assumption that the air would pass through the vestibule and into the main sales area. According to that division, most air infiltrating through the front entrance is applied directly to the main sales area. In reality, vestibules are equipped with dedicated HVAC units that precondition the air before it passes through to the rest of the store. A more accurate model (EnergyPlus's AirFlowNetwork) would allow us to capture the significance of using the vestibule to precondition infiltrated air.

- **Reduced static pressure drops via better RTU and ductwork design.** We did not undertake a detailed study of the range of possible internal and external static pressures, so we did not attempt to define an EDM along these lines. Industry feedback suggested that we may be able to reduce our total static pressure by 50%, but we have yet to verify that suggestion by matching it to available equipment. Reliable information about standard and best practice static pressures would be a welcome addition to the next study.
- **Direct and indirect evaporative cooling.** We attempted to model indirect evaporative cooling in the RTUs, but were unsatisfied with the modeling results. We could not dynamically model the effects of bypassing the indirect evaporative cooler when it was not needed, so we are uncertain of our previous finding (Hale et al. 2008b) that evaporative cooling should not be used in any climate zone. The EnergyPlus modeling methods and the input data need to be refined.
- **Alternative service water heating systems.** We did not model solar or instantaneous hot water systems. Including these technologies would require modifications to the Opt-E-Plus platform to handle sizing and design issues, and would only affect about 0.5% of baseline energy use.
- **More effective plug and process load EDMs.** A detailed study of plug and process loads and their reduction measures in general merchandise stores should be undertaken to answer questions about realistic performance metrics and costs for possible EDMs.
- **Desiccant-based humidity control.** Unlike earlier work (Hale et al. 2008b), this TSD enforces a humidity set point using humidistats and reheat coils fed by DX condenser waste heat (superheat). The next step is to explore advanced dehumidification strategies such as desiccant-based humidity control.
- **Alternative business models.** The more retail business moves online, and the more stores can be designed to reduce the amount of on-floor merchandise, the more warehouse and storage space can be substituted for high energy intensity retail floor area. Such a design measure is well beyond the scope of this study, but could have a large impact on sector energy efficiency, assuming that associated transportation energy use does not increase significantly.

We also recommend that some model inputs be re-evaluated or validated:

- **Whole-building pressurization analysis.** The model inputs for infiltration and ERV are based on a whole-building pressurization analysis (described in Section 3.3.3.5), which depends heavily on a number of simple assumptions. The EnergyPlus AirFlowNetwork should be used to determine the validity of those assumptions.

- **Infiltration.** The whole-building pressurization analysis through which infiltration inputs were developed was based on driving pressures associated with HVAC pressurization and wind speed. To strengthen the analysis, stack effect should be factored in as well. Stack effect was omitted from the current analysis because of its strong dependence on ambient temperature, which varies by season and location. Updates will likely need to be made to EnergyPlus to accommodate stack effect analysis.

5.1.4 Search Algorithms

Opt-E-Plus currently uses a sequential search routine to approximate the Pareto front associated with two design objectives. The sequential search has advantages of efficiency and dual-criteria optimization, but has several drawbacks in the context of this study:

- The search routine is heuristic, and therefore not guaranteed to find the true Pareto curve.
- We were not interested in the Pareto curve per se, but in designs that achieve 50% energy savings cost effectively. Our computation time would have been better used fleshing out multiple designs that meet this criterion, rather than tracing out the entire Pareto front.
- The EDMs are all discrete choices, even though continuous methods could be used to expedite the determination of design features by initially using continuous variables such as R-values, and only later determining the actual construction or product.
- There is no way to express or use uncertainty information such as cost or performance variable ranges.

The next generation of Opt-E-Plus should be equipped with better search routines that address varying numbers of objective functions (0, 1, 2, etc.), use continuous variables in early iterations, and propagate uncertainty information.

5.1.5 Advanced Energy Design Guide Format

The current AEDGs are meant to provide easily accessible design recommendations that can be incorporated into real-world projects. However, these guides do not respond to the needs of specific projects, and thus cannot provide truly integrated designs. If technologies such as Opt-E-Plus are used to automate the development of low-energy design recommendations, direct Web-based or software-based assistance could be offered to individual building projects. One possible path would be to use the TSD process to develop a list of acceptable EDMs for a given building type. The AEDGs would then be a portal through which designers could select EDMs that are acceptable to their specific projects, enter basic geometric information, and obtain a customized set of recommendations.

6.0 Conclusions

This report finds that achieving 50% energy savings is possible for general merchandise stores in each U.S. climate zone. Reaching 50% is cost-effective in all climate zones, both in terms of capital costs and 5-TLCC (except in the high plug load case in climate zone 2A, for which capital costs were slightly higher than baseline).

As ASHRAE Standard 90.1 evolves, baseline buildings become increasingly energy efficient, such that achieving the 50% energy savings target becomes increasingly difficult in terms of the overall net EUI value that must be achieved. We also found that the 90.1-2007 baseline buildings are generally more expensive than the 90.1-2004 baseline buildings in terms of both capital cost and 5-TLCC. Some of the extra expense might be mitigated by choosing different envelope components that satisfy the standard, but overall this finding points towards using more detailed and robust analysis methods in standards design.

Most of the analysis was conducted with 40,500 ft^2 (3,762 m^2) models. To explore the differences between medium and big box stores, we also constructed 100,000 ft^2 baseline and low-energy models. As the building surface area to volume ratio decreases, EUIs typically decrease, presumably because heat transfer through the envelope of a building becomes less significant as the interior spaces are increasingly isolated from ambient conditions. We also found it to be slightly easier to achieve 50% energy savings in the big box stores, as applying the same EDMs selected in the low-energy medium box models usually resulted in energy savings greater than 50%. The only exception to this was Los Angeles, California (climate zone 3B-CA), which achieved 44.4% energy savings. Of course, individual stores should look at total energy use, rather than EUI or energy savings, when comparing possible store sizes and configurations since total energy use is the true impact of any project.

A methodology for identifying a diverse set of low-energy designs is introduced and applied in five climate zones for two different levels of plug loads. Eight to ten models, each differing by the presence or absence of at least one type of EDM (for instance, increased envelope insulation) were automatically identified for each scenario. The algorithm also yields perturbation information on the cost and energy savings provided by EDM categories used in the original low-energy design. An equivalent PV metric is calculated based on these results; our intention is for this to be used as an alternative valuation of energy efficient design changes.

A number of modeling errors skewed the results of our original optimizations over the complete set of EDMs. The original results indicated that the low-energy models would require a larger initial capital investment than the corresponding baseline models and that in most of the climate zones they would not be able to save enough energy to offset those higher capital costs within the five-year analysis period. By correcting the modeling errors and performing abbreviated optimization runs to determine which of ERV, DCV, and PV should actually be included in each low-energy model, we were able to show that 50% energy savings can be achieved cost effectively. The corrected low-energy models all paid for themselves within the five-year analysis period, and only the climate zone 2A, high plug load scenario model showed increased capital costs over baseline.

The 50% recommendations presented in this TSD are intended to serve as starting points for project-specific analyses. The recommendations are not meant for specific design guidance for an actual project because of project-specific variations in economic criteria and EDMs. Project-specific analyses are also recommended because they can account for site-specific rebate programs that may improve the cost-effectiveness of certain efficiency measures.

For both sector-wide studies and individual projects, the approach used in this study has several advantages: it allows for the exploration of thousands of different building design options in an efficient manner, and economic considerations are explicitly considered so that the most cost-efficient solutions can be identified. The design features explored by the analysis can be tailored to match the energy savings target and climate zone, and a new methodology for identifying multiple designs that meet a common target provides additional flexibility.

7.0 References

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Appendix A. Space Types and ASHRAE Standards

The mapping between our space types and ASHRAE Standards 62-1999 and 62.1-2004 is listed in Table A-1. The mapping between our spaces types and ASHRAE Standards 90.1-2004 and 90.1-2007 is listed in Table A-2.

Table A-1 Mapping between Analysis Space Types and ASHRAE Standard 62.1

Space Type	Mapping to ASHRAE 62-1999	Mapping to ASHRAE 62.1-2004
Main Sales	Retail::Basement and street	Retail::Sales
Perimeter Sales	Retail::Basement and street	Retail::Sales
Enclosed Office	Offices::Office space	Office Buildings::Office space
Meeting Room	Offices::Conference rooms	Offices::Conference/meeting
Dining Room	Food & Beverage::Dining rooms	Food & Beverage::Restaurant dining rooms
Restrooms	CUSTOM VALUE	CUSTOM VALUE
Mechanical Room	CUSTOM VALUE	CUSTOM VALUE
Corridor	Public Spaces::Corridors & utilities	General::Corridors
Vestibule	Public Spaces::Corridors & utilities	General::Corridors
Active Storage	Retail::Shipping and receiving	General::Storage rooms

Table A-2 Mapping between Analysis Space Types and ASHRAE Standard 90.1

Space Type	Mapping to ASHRAE 90.1-2004	Mapping to ASHRAE 90.1-2007
Main Sales	Sales area	Sales area
Perimeter Sales	Sales area	Sales area
Enclosed Office	Office-enclosed	Office-enclosed
Meeting Room	Conference/meeting/multi-purpose	Conference/meeting/multi-purpose
Dining Room	Dining area	Dining area
Restrooms	Restrooms	Restrooms
Mechanical Room	Electrical/mechanical	Electrical/mechanical
Corridor	Corridor/transition	Corridor/transition
Vestibule	Corridor/transition	Corridor/transition
Active Storage	Active Storage	Active Storage

Appendix B. Baseline Schedules

The following schedules are a combination of prototype characteristics, assumptions, and the retail building schedule sets available in ASHRAE 90.1-1989 (ASHRAE 1989). Schedules are presented as fractions of peak, unless otherwise noted. The entries for total hours/day, etc. are the equivalent number of peak hours during the given time period. For instance, the total lighting load for the year can be calculated by multiplying the peak load density by the value given for total hours/year.

B.1 Occupancy

The occupancy schedule for all zones, as described in Section 3.2.1.4.2, is shown in Table B-1.

Table B-1 Occupancy Schedule

Hour	Weekdays	Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0	0	1	0	0
2	0	0	1	0	0
3	0	0	1	0	0
4	0	0	1	0	0
5	0	0	1	0	0
6	0	0	1	0	0
7	0	0	1	0	0
8	0.10	0.10	1	0	0
9	0.20	0.20	1	0	0
10	0.50	0.50	1	0	0.10
11	0.50	0.60	1	0	0.20
12	0.70	0.80	1	0	0.20
13	0.70	0.80	1	0	0.40
14	0.70	0.80	1	0	0.40
15	0.70	0.80	1	0	0.40
16	0.80	0.80	1	0	0.40
17	0.70	0.80	1	0	0.40
18	0.50	0.60	1	0	0.20
19	0.50	0.20	1	0	0.10
20	0.30	0.20	1	0	0
21	0.30	0.20	1	0	0
22	0	0.10	1	0	0
23	0	0	1	0	0
24	0	0	1	0	0
Total Hours/Day	7.20	7.50	24.00	0.00	2.80
Total Hours/Week	46.30				

B.2 Lighting

Each zone in the baseline models uses the lighting schedule developed in Section 3.2.1.4.3 and shown in Table B-2.

Table B-2 Lighting Schedule

Hour	Weekdays	Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0.05	0.05	1	0	0.05
2	0.05	0.05	1	0	0.05
3	0.05	0.05	1	0	0.05
4	0.05	0.05	1	0	0.05
5	0.05	0.05	1	0	0.05
6	0.05	0.05	1	0	0.05
7	0.05	0.05	1	0	0.05
8	0.20	0.10	1	0	0.05
9	0.50	0.30	1	0	0.05
10	0.90	0.60	1	0	0.10
11	0.90	0.90	1	0	0.40
12	0.90	0.90	1	0	0.40
13	0.90	0.90	1	0	0.60
14	0.90	0.90	1	0	0.60
15	0.90	0.90	1	0	0.60
16	0.90	0.90	1	0	0.60
17	0.90	0.90	1	0	0.60
18	0.90	0.90	1	0	0.40
19	0.60	0.50	1	0	0.20
20	0.60	0.30	1	0	0.05
21	0.20	0.30	1	0	0.05
22	0.20	0.10	1	0	0.05
23	0.05	0.05	1	0	0.05
24	0.05	0.05	1	0	0.05
Total Hours/Day	10.85	9.85	24.00	0.00	5.20
Total Hours/Week	69.30				

B.3 Plug and Process Loads

Each zone in the baseline models uses the equipment schedules shown in Table B-3 which were developed in Section 3.2.1.4.4.

Table B-3 Plug and Process Load Schedule

Hour	Weekdays	Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0.33	0.30	1	0	0.30
2	0.33	0.30	1	0	0.30
3	0.33	0.30	1	0	0.30
4	0.33	0.30	1	0	0.30
5	0.33	0.30	1	0	0.30
6	0.33	0.30	1	0	0.30
7	0.33	0.30	1	0	0.30
8	0.4	0.30	1	0	0.30
9	0.7	0.50	1	0	0.30
10	0.9	0.80	1	0	0.30
11	0.9	0.90	1	0	0.60
12	0.9	0.90	1	0	0.60
13	0.9	0.90	1	0	0.80
14	0.9	0.90	1	0	0.80
15	0.9	0.90	1	0	0.80
16	0.9	0.90	1	0	0.80
17	0.9	0.90	1	0	0.80
18	0.9	0.90	1	0	0.60
19	0.8	0.70	1	0	0.40
20	0.8	0.50	1	0	0.30
21	0.70	0.50	1	0	0.30
22	0.40	0.30	1	0	0.30
23	0.33	0.30	1	0	0.30
24	0.33	0.30	1	0	0.30
Total Hours/Day	14.87	13.50	24.00	0.00	10.70
Total Hours/Week	98.55				

B.4 Infiltration and HVAC

The infiltration schedule is tied to the HVAC schedule in that it is on at peak value when the HVAC system is running. When the HVAC system is off, infiltration reduces to a fraction of peak value based on changes in building pressurization and front entrance door opening frequency. The HVAC schedule is set to turn on one hour before occupancy each day to allow the system to bring the space conditions back within operating limits during occupancy. The baseline model HVAC and infiltration schedules are listed in Table B-4 and Table B-5 respectively.

Table B-4 HVAC Schedule

Hour	Weekdays	Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	1	1	1	1	0
8	1	1	1	1	0
9	1	1	1	1	1
10	1	1	1	1	1
11	1	1	1	1	1
12	1	1	1	1	1
13	1	1	1	1	1
14	1	1	1	1	1
15	1	1	1	1	1
16	1	1	1	1	1
17	1	1	1	1	1
18	1	1	1	1	1
19	1	1	1	1	1
20	1	1	1	1	0
21	1	1	1	1	0
22	0	1	0	1	0
23	0	0	0	0	0
24	0	0	0	0	0
Total Hours/Day	15.00	16.00	15.00	16.00	11.00
Total Hours/Week	102.00				

Table B-5 Infiltration Schedule

Hour	Weekdays	Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0.28	0.28	0.28	1	0.28
2	0.28	0.28	0.28	1	0.28
3	0.28	0.28	0.28	1	0.28
4	0.28	0.28	0.28	1	0.28
5	0.28	0.28	0.28	1	0.28
6	1.00	1.00	1.00	1	0.28
7	1.00	1.00	1.00	1	0.28
8	1.00	1.00	1.00	1	1.00
9	1.00	1.00	1.00	1	1.00
10	1.00	1.00	1.00	1	1.00
11	1.00	1.00	1.00	1	1.00
12	1.00	1.00	1.00	1	1.00
13	1.00	1.00	1.00	1	1.00
14	1.00	1.00	1.00	1	1.00
15	1.00	1.00	1.00	1	1.00
16	1.00	1.00	1.00	1	1.00
17	1.00	1.00	1.00	1	1.00
18	1.00	1.00	1.00	1	1.00
19	1.00	1.00	1.00	1	1.00
20	1.00	1.00	1.00	1	0.28
21	1.00	1.00	1.00	1	0.28
22	0.28	1.00	0.28	1	0.28
23	0.28	0.28	0.28	1	0.28
24	0.28	0.28	0.28	1	0.28
Total Hours/Day	18.24	18.96	18.24	24.00	15.36
Total Hours/Week	125.52				

B.5 Thermostat Set Points

Each zone in the baseline models uses the heating and cooling schedules shown in Table B-6 and Table B-7, respectively, which list temperatures in ºC. The HVAC systems have dual thermostatic control based on dry bulb temperature in the zones. The thermostat set points are 70ºF (21ºC) for heating and 75ºF (24ºC) for cooling. Thermostat setup to 86ºF (30ºC) and setback to 60.1ºF (15.6ºC) is included in the models.

Table B-6 Heating Set Point Schedule (ºC)

Hour	Weekdays	Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	15.6	15.6	15.6	21.0	15.6
2	15.6	15.6	15.6	21.0	15.6
3	15.6	15.6	15.6	21.0	15.6
4	15.6	15.6	15.6	21.0	15.6
5	15.6	15.6	15.6	21.0	15.6
6	15.6	15.6	15.6	21.0	15.6
7	21.0	21.0	15.6	21.0	15.6
8	21.0	21.0	15.6	21.0	15.6
9	21.0	21.0	15.6	21.0	21.0
10	21.0	21.0	15.6	21.0	21.0
11	21.0	21.0	15.6	21.0	21.0
12	21.0	21.0	15.6	21.0	21.0
13	21.0	21.0	15.6	21.0	21.0
14	21.0	21.0	15.6	21.0	21.0
15	21.0	21.0	15.6	21.0	21.0
16	21.0	21.0	15.6	21.0	21.0
17	21.0	21.0	15.6	21.0	21.0
18	21.0	21.0	15.6	21.0	21.0
19	21.0	21.0	15.6	21.0	21.0
20	21.0	21.0	15.6	21.0	15.6
21	21.0	21.0	15.6	21.0	15.6
22	15.6	21.0	15.6	21.0	15.6
23	15.6	15.6	15.6	21.0	15.6
24	15.6	15.6	15.6	21.0	15.6

Table B-7 Cooling Set Point Schedule (ºC)

Hour	Weekdays	Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	30.0	30.0	30.0	30.0	30.0
2	30.0	30.0	30.0	30.0	30.0
3	30.0	30.0	30.0	30.0	30.0
4	30.0	30.0	30.0	30.0	30.0
5	30.0	30.0	30.0	30.0	30.0
6	30.0	30.0	30.0	30.0	30.0
7	24.0	24.0	24.0	30.0	30.0
8	24.0	24.0	24.0	30.0	30.0
9	24.0	24.0	24.0	30.0	24.0
10	24.0	24.0	24.0	30.0	24.0
11	24.0	24.0	24.0	30.0	24.0
12	24.0	24.0	24.0	30.0	24.0
13	24.0	24.0	24.0	30.0	24.0
14	24.0	24.0	24.0	30.0	24.0
15	24.0	24.0	24.0	30.0	24.0
16	24.0	24.0	24.0	30.0	24.0
17	24.0	24.0	24.0	30.0	24.0
18	24.0	24.0	24.0	30.0	24.0
19	24.0	24.0	24.0	30.0	24.0
20	24.0	24.0	24.0	30.0	30.0
21	24.0	24.0	24.0	30.0	30.0
22	30.0	24.0	30.0	30.0	30.0
23	30.0	30.0	30.0	30.0	30.0
24	30.0	30.0	30.0	30.0	30.0

B.6 Service Water Heating

The service water heating schedules are adopted from ASHRAE 90.1-1989, and are shown in Table B-8.

Table B-8 Service Water Heating Schedule

Hour	Weekdays	Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0.04	0.11	0.04	0.11	0.07
2	0.05	0.10	0.05	0.10	0.07
3	0.05	0.08	0.05	0.08	0.07
4	0.04	0.06	0.04	0.06	0.06
5	0.04	0.06	0.04	0.06	0.06
6	0.04	0.06	0.04	0.06	0.06
7	0.04	0.07	0.04	0.07	0.07
8	0.15	0.20	0.15	0.20	0.10
9	0.23	0.24	0.23	0.24	0.12
10	0.32	0.27	0.32	0.27	0.14
11	0.41	0.42	0.41	0.42	0.29
12	0.57	0.54	0.57	0.54	0.31
13	0.62	0.59	0.62	0.59	0.36
14	0.61	0.60	0.61	0.60	0.36
15	0.50	0.49	0.50	0.49	0.34
16	0.45	0.48	0.45	0.48	0.35
17	0.46	0.47	0.46	0.47	0.37
18	0.47	0.46	0.47	0.46	0.34
19	0.42	0.44	0.42	0.44	0.25
20	0.34	0.36	0.34	0.36	0.27
21	0.33	0.29	0.33	0.29	0.21
22	0.23	0.22	0.23	0.22	0.16
23	0.13	0.16	0.13	0.16	0.10
24	0.08	0.13	0.08	0.13	0.06
Total Hours/Day	6.62	6.90	6.62	6.90	4.59
Total Hours/Week	44.59				

Appendix C. Metric Unit Tables

Table C-1 Baseline Exterior Wall Constructions (SI Units)

Properties	Climate Zones 1–2	Climate Zones 3–4	Climate Zone 5	Climate Zone 6	Climate Zone 7	Climate Zone 8
Key	Baseline Wall Construction, No c.i.	Baseline Wall Construction, R-5.7 c.i.	Baseline Wall Construction, R-7.6 c.i.	Baseline Wall Construction, R-9.5 c.i.	Baseline Wall Construction, R-11.4 c.i.	Baseline Wall Construction, R-13.3 c.i.
U-factor ($W/m^2{\cdot}K$)	4.28	0.98	0.78	0.65	0.55	0.49
Capital cost ($\$/m^2$)	$219.26	$226.69	$230.56	$233.36	$234.65	$235.30

Table C-2 Baseline Roof Constructions (SI Units)

Properties	Climate Zones 1–7	Climate Zone 8
Key	Baseline Roof Construction, R-15 c.i.	Baseline Roof Construction, R-20 c.i.
U-factor ($W/m^2{\cdot}K$)	0.38	0.29
Capital cost ($\$/m^2$)	$93.54	$98.06

Table C-3 Baseline Window Constructions (SI Units)

Properties	Climate Zones 1–2	Climate Zone 3	Climate Zones 4–6	Climate Zone 7	Climate Zone 8
Key	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction
SHGC	0.250	0.390	0.490	0.490	0.490
VLT	0.250	0.495	0.622	0.490	0.490
U-factor ($W/m^2{\cdot}K$)	6.87	3.24	3.24	3.24	2.61
Capital cost ($\$/m^2$)	$473.61	$508.38	$502.14	$508.38	$537.87
Fixed O&M cost ($\$/m^2$)	$2.37	$2.37	$2.37	$2.37	$2.37

Table C-4 Baseline Skylight Constructions (SI Units)

Properties	Climate Zones 1–3	Climate Zones 4–6	Climate Zone 7	Climate Zone 8
Key	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction
SHGC	0.36	0.490	0.490	0.490
VLT	0.457	0.622	0.490	0.490
U-factor (Btu/h·ft^2·°F)	6.93	3.92	3.92	3.29
Capital cost ($/ft^2)	$498.15	$508.38	$508.27	$549.39
Fixed O&M cost ($/ft^2)	$2.37	$2.37	$2.37	$2.37

Table C-5 Pressures Acting on Exterior Walls During Operating Hours (SI Units)

Exterior Wall	Resultant Pressure Gradient	
	Magnitude (Pa)	Direction
Front	1.8	Infiltration
Back	9.8	Exfiltration
Side	4.0	Exfiltration

Table C-6 Pressures Acting on Exterior Walls During Non-Operating Hours (SI Units)

Exterior Wall	Resultant Pressure Gradient	
	Magnitude (Pa)	Direction
Front	5.8	Infiltration
Back	5.8	Exfiltration
Side	0	NA

Table C-7 Baseline Fan System Total Pressure Drops (SI Units)

Component	Package Rooftop, Constant Volume, 10-ton, 4000 cfm, no Economizer (Pa)	Package Rooftop, Constant Volume, 10-ton, 4000 cfm, with Economizer (Pa)
Internal static pressure drop	167	189
External static pressure drop	214	214
Total static pressure drop	381	404

*Used friction rate of 25 Pa/30 m for the baseline duct pressure drop.

Table C-8 Baseline HVAC Models Summary (SI Units)

HVAC Input	ASHRAE 90.1-2004 Baseline PSZ DX, Furnace, No Economizer	ASHRAE 90.1-2004 Baseline PSZ DX, Furnace, With Economizer
System EER	10.1	10.1
COP of compressor/condenser	3.69	3.69
Heating efficiency	80%	80%
Fan power	1,245 W/(m^3/s)	1,245 W/(m^3/s)
Fan static pressure	381.1 Pa	403.5 Pa
Fan efficiency	30.6%	32.4%
Economizers	None	Included
Capital cost ($/kW cooling)	$456.20	$484.64
O&M cost ($/kW cooling·yr)	$39.82	$39.82

Table C-9 Exterior Wall EDMs (SI Units)

Insulation R-value, Nominal	Assembly U-Factor (W/m·K)	Construction Method	Insulation Material	Insulation Thickness (cm)	Capital Cost ($/m^2)
R-5.7 c.i.	0.996	Interior insulation	Isocyanurate	3.3	$226.69
R-9.5 c.i.	0.598	Interior insulation	Isocyanurate	5.6	$233.36
R-13.3 c.i.	0.427	Interior insulation	Isocyanurate	7.9	$235.30
R-15.0 c.i.	0.302	Exterior insulation	Polystyrene extruded	7.6	$241.33
R-19.5 c.i.	0.244	Exterior insulation	Polyisocyanurate	7.6	$244.88
R-22.5 c.i.	0.211	Brick cavity	Polyurethane foam	9.5	$305.16
R-28.5 c.i.	0.172	Brick cavity	Polyurethane foam	12.1	$310.32

Table C-10 Roof EDMs (SI Units)

EDM Key	U-Factor (W/m·K)	Capital Cost ($/m²)
R-20 c.i.	0.288	$58.45
R-20 c.i. with cool roof	0.288	$58.45
R-25 c.i.	0.230	$62.65
R-25 c.i. with cool roof	0.230	$62.65
R-30 c.i.	0.189	$67.27
R-30 c.i. with cool roof	0.189	$67.27
R-35 c.i.	0.164	$71.47
R-35 c.i. with cool roof	0.164	$71.47
R-40 c.i.	0.130	$77.50
R-50 c.i.	0.114	$81.81
R-60 c.i.	0.091	$90.74
R-75 c.i.	0.076	$100.00
R-95 c.i.	0.062	$109.04

Table C-11 South Fenestration Construction EDMs (SI Units)

EDM Key	SHGC	VLT	U-Factor (W/m·K)	Capital Cost ($/m²)	Fixed O&M Cost ($/m²·yr)
Single pane with clear glass	0.810	0.881	6.13	$402.57	$2.26
Single pane with pyrolytic low-e	0.710	0.811	4.23	$438.09	$2.26
Double pane with low-e and argon	0.564	0.745	1.50	$473.61	$2.26
Double pane with low-e2 and argon	0.416	0.750	1.33	$544.65	$2.26
Double pane with low-e2 and tinted glass	0.282	0.550	1.64	$544.65	$2.26
Triple layer with low-e polyester film	0.355	0.535	1.22	$643.14	$2.26
Quadruple layer with low-e polyester films and krypton	0.461	0.624	0.77	$673.71	$2.26

Table C-12 Skylight Fenestration Construction EDMs (SI Units)

EDM Key	SHGC	VLT	U-Factor (W/m·K)	Capital Cost ($/m²)	Fixed O&M Cost ($/m²·yr)
Single pane with high solar gain	0.610	0.672	6.93	$508.27	$2.58
Single pane with medium solar gain	0.250	0.245	6.93	$551.33	$2.58
Single pane with low solar gain	0.190	0.174	6.93	$551.33	$2.58
Double pane with high solar gain	0.490	0.622	3.29	$491.70	$2.58
Double pane with low-e and high solar gain	0.460	0.584	2.56	$492.77	$2.58
Double pane with medium solar gain	0.390	0.495	3.29	$621.08	$2.58
Double pane with low-e and medium solar gain	0.320	0.406	2.56	$679.96	$2.58
Double pane with low solar gain	0.190	0.241	3.29	$633.24	$2.58
Double pane with low-e and low solar gain	0.190	0.240	2.56	$683.94	$2.58

Table C-13 Lighting Power Density EDMs (SI Units)

EDM Key	LPD (W/m²)	Capital Cost ($/kW)	Capital Cost ($/m²)	Fixed O&M Cost ($/kW·yr)	Fixed O&M Cost ($/m²·yr)
Baseline	17.0	$4,706	$79.87	$77.24	$1.31
30% LPD reduction	11.9	$6,909	$82.13	$110.34	$1.31
47% LPD reduction	9.0	$9,242	$83.10	$128.73	$0.80

Table C-14 HVAC System EDMs (SI Units)

EDM Key	Cooling COP (Ratio)	Heating Efficiency (%)	Economizer	Motorized Damper	Fan Efficiency (%)	Fan Static Pressure (Pa)	Capital Cost ($/kW)	Fixed O&M Cost ($/kW·yr)
Baseline without economizer	3.69	80.0	No	No	30.6	381.1	$456.13	$39.87
10% increased COP	4.06	80.0	No	No	30.6	381.1	$473.60	$39.87
Baseline with economizer	3.69	80.0	Yes	Yes	32.4	403.5	$484.61	$39.87
20% increased COP	4.43	80.0	No	No	30.6	381.1	$491.38	$39.87
Baseline COP with efficient fan	3.69	80.0	No	No	63.0	381.1	$496.96	$39.87
10% increased COP with economizer	4.06	80.0	Yes	Yes	32.4	403.5	$502.08	$39.87
10% increased COP with efficient fan	4.06	80.0	No	No	63.0	381.1	$514.43	$39.87
20% increased COP with economizer	4.43	80.0	Yes	Yes	32.4	403.5	$519.86	$39.87
Baseline COP with economizer and efficient fan	3.69	80.0	Yes	Yes	64.8	403.5	$525.45	$39.87
20% increased COP with efficient fan	4.43	80.0	No	No	63.0	381.1	$532.21	$39.87
10% increased COP with economizer and efficient fan	4.06	80.0	Yes	Yes	64.8	403.5	$542.92	$39.87
20% increased COP with economizer and efficient fan	4.43	80.0	Yes	Yes	64.8	403.5	$561.28	$39.87

Table C-15 Energy Recovery EDMs (SI Units)

EDM Key	Sensible Effectiveness (%)	Latent Effectiveness (%)	Pressure Drop (Pa)	Capital Cost ($/unit)	Capital Cost ($)
Low effectiveness	60.0	50.0	105	$9,243	$18,486
High effectiveness	80.0	70.0	150	$13,368	$26,736

Appendix D. Energy Use Data by End Use

The following tables present energy use data by end use. Table D-1, Table D-2, and Table D-3 present energy use intensities (in kBtu/ft^2) by end use. Table D-4, Table D-5, and Table D-6 present percentages of site EUI (excluding any reduction in overall EUI provided by PV) by end use.

Table D-1 Energy Use Intensity (kBtu/ft^2) Decomposed by End Use for Humid Climates

		End Use	1A		2A		3A		4A		5A		6A	
			Base	50%	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%
Low Plug Load	Electricity	PV power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	48.0	22.4	36.8	16.8	16.8	9.3	13.5	7.4	7.2	4.0	6.2	3.6
		Interior lighting	19.6	4.9	19.6	5.3	19.6	5.6	19.6	6.2	19.6	9.7	19.6	9.7
		Exterior lighting	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		Interior equipment	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
		Fans	36.2	12.5	37.1	12.5	25.3	9.1	24.5	8.5	13.4	4.7	13.6	4.7
		Water systems	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
	Gas	Heating	0.1	0.2	5.6	2.2	13.0	7.8	26.3	11.6	46.0	17.0	61.7	23.9
High Plug Load	Electricity	PV Power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	53.3	26.3	41.1	20.0	19.6	9.8	15.8	8.3	8.7	5.1	7.7	4.6
		Interior lighting	19.6	5.3	19.6	5.0	19.6	5.0	19.6	5.3	19.6	6.2	19.6	9.7
		Exterior lighting	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		Interior equipment	23.0	19.5	23.0	19.5	23.0	19.5	23.0	19.5	23.0	19.5	23.0	19.5
		Fans	43.5	16.1	44.3	16.1	30.9	11.8	29.6	11.3	16.3	6.2	16.5	6.2
		Water systems	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
	Gas	Heating	0.1	0.1	3.5	1.4	8.1	2.4	18.0	6.0	35.2	11.6	49.8	17.1

Table D-2 Energy Use Intensity (kBtu/ft²) Decomposed by End Use for Arid Climates

		End Use	2B		3B-CA		3B-NV		4B		5B		6B	
			Base	50%	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%
Low Plug Load	Electricity	PV power	0.0	0.0	0.0	–0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	17.8	9.7	5.7	3.5	11.0	5.7	5.6	3.0	3.7	1.8	2.1	1.3
		Interior lighting	19.6	5.1	19.6	5.0	19.6	5.4	19.6	5.3	19.6	6.3	19.6	9.7
		Exterior lighting	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		Interior equipment	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
		Fans	16.6	5.1	12.2	4.2	14.6	4.7	13.9	4.3	12.5	4.1	12.0	4.0
		Water systems	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.7
	Gas	Heating	6.0	6.7	4.2	5.8	9.7	6.1	20.7	12.9	32.4	18.1	51.7	20.3
High Plug Load	Electricity	PV power	0.0	–4.4	0.0	–4.6	0.0	–3.3	0.0	–0.5	0.0	0.0	0.0	0.0
		Cooling	20.3	12.1	6.7	3.9	13.5	8.1	7.5	5.0	5.1	3.4	3.0	2.2
		Interior lighting	19.6	4.8	19.6	5.0	19.6	5.1	19.6	5.3	19.6	5.4	19.6	6.4
		Exterior lighting	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		Interior equipment	23.0	19.5	23.0	19.5	23.0	19.5	23.0	19.5	23.0	19.5	23.0	19.5
		Fans	19.4	6.4	14.6	5.9	17.2	6.4	16.8	6.3	15.8	6.2	15.2	5.9
		Water systems	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.7
	Gas	Heating	4.0	4.3	2.0	2.7	6.1	3.5	14.1	4.5	23.2	8.0	39.5	14.2

Table D-3 Energy Use Intensity (kBtu/ft^2) Decomposed by End Use for Marine and Cold Climates

		End Use	3C		4C		7		8	
			Base	50%	Base	50%	Base	50%	Base	50%
Low Plug Load	Electricity	PV power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	0.9	0.7	1.2	1.0	2.4	1.5	0.7	0.2
		Interior lighting	19.6	5.3	19.6	9.7	19.6	9.7	19.6	9.8
		Exterior lighting	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		Interior equipment	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
		Fans	9.9	3.2	10.5	3.8	10.7	3.7	12.0	3.6
		Water systems	0.6	0.6	0.6	0.6	0.8	0.8	0.9	0.9
	Gas	Heating	15.2	8.3	32.0	10.2	79.7	31.1	132.0	65.1
High Plug Load	Electricity	PV power	0.0	–2.8	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	1.5	2.0	1.8	2.0	3.1	2.3	1.2	0.9
		Interior lighting	19.6	5.0	19.6	5.8	19.6	9.7	19.6	9.8
		Exterior lighting	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
		Interior equipment	23.0	19.5	23.0	19.5	23.0	19.5	23.0	19.5
		Fans	13.0	5.2	13.3	5.3	13.7	5.4	13.6	5.3
		Water systems	0.6	0.6	0.6	0.6	0.8	0.8	0.9	0.9
	Gas	Heating	8.2	3.2	21.4	5.5	64.5	22.5	114.0	39.1

Table D-4 Percent of Site EUI (excluding PV) Devoted to Each End Use for Humid Climates

		End Use	1A		2A		3A		4A		5A		6A	
			Base	50%	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%
Low Plug Load	Electricity	PV power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	43.8	48.9	35.1	39.5	20.8	24.6	15.0	18.8	7.8	9.6	7.7	9.4
		Interior lighting	17.9	10.7	18.7	12.3	24.3	14.9	21.8	15.5	21.3	23.5	16.8	18.6
		Exterior lighting	0.3	0.7	0.3	0.7	0.4	0.8	0.3	0.8	0.3	0.7	0.3	0.6
		Interior equipment	4.6	11.1	4.8	11.9	6.3	13.4	5.6	12.8	5.5	12.2	4.3	9.7
		Fans	33.0	27.3	35.3	29.4	31.4	24.1	27.3	21.3	14.5	11.4	28.3	22.0
		Water systems	0.4	0.9	0.5	1.1	0.7	1.5	0.7	1.6	0.7	1.6	0.6	1.4
	Gas	Heating	0.1	0.5	5.4	5.1	16.1	20.7	29.3	29.3	49.9	41.0	42.0	38.3
High Plug Load	Electricity	PV power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	38.0	38.7	31.1	31.8	19.2	19.8	14.8	16.1	8.4	10.4	6.6	7.8
		Interior lighting	14.0	7.8	14.8	7.9	19.2	10.2	18.3	10.4	18.9	12.5	16.7	16.7
		Exterior lighting	0.2	0.4	0.2	0.5	0.3	0.6	0.3	0.6	0.3	0.6	0.3	0.5
		Interior equipment	16.4	28.7	17.4	31.0	22.5	39.5	21.5	38.0	22.2	39.3	19.5	33.6
		Fans	31.0	23.7	33.5	25.6	30.3	23.9	27.7	22.0	15.7	12.5	14.0	10.7
		Water systems	0.3	0.6	0.4	0.8	0.5	1.1	0.6	1.2	0.6	1.3	0.6	1.2
	Gas	Heating	0.0	0.2	2.6	2.3	7.9	4.9	16.8	11.6	33.9	23.4	42.3	29.4

Table D-5 Percent of Site EUI (excluding PV) Devoted to Each End Use for Arid Climates

		End Use	1A		2A		3A		4A		5A		6A	
			Base	50%	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%
Low Plug Load	Electricity	PV power	0.0	0.0	0.0	–2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	27.1	30.0	12.0	14.5	18.1	20.6	8.6	9.6	4.9	5.0	2.2	3.0
		Interior lighting	29.8	15.7	41.1	20.3	32.3	19.4	29.8	16.7	26.4	17.3	21.4	23.5
		Exterior lighting	0.5	0.9	0.6	1.2	0.5	1.1	0.5	0.9	0.4	0.8	0.3	0.7
		Interior equipment	7.7	15.6	10.6	20.8	8.3	18.2	7.7	16.1	6.8	14.0	5.5	12.2
		Fans	25.2	15.6	25.6	17.3	24.0	17.0	21.1	13.6	16.9	11.2	13.1	9.7
		Water systems	0.7	1.4	1.1	2.2	0.8	1.8	0.9	1.9	0.9	1.8	0.8	1.7
	Gas	Heating	9.1	20.8	8.9	23.6	16.0	21.9	31.5	41.1	43.7	49.9	56.5	49.1
High Plug Load	Electricity	PV power	0.0	–9.2	0.0	–12.0	0.0	–7.6	0.0	–1.3	0.0	0.0	0.0	0.0
		Cooling	23.3	25.3	10.0	10.4	16.8	18.6	9.2	12.0	5.8	7.9	2.9	4.5
		Interior lighting	22.5	10.1	29.4	13.1	24.5	11.8	23.9	12.7	22.4	12.5	19.4	13.0
		Exterior lighting	0.3	0.6	0.4	0.8	0.4	0.7	0.4	0.7	0.3	0.7	0.3	0.6
		Interior equipment	26.4	40.7	34.5	51.5	28.7	45.0	28.1	47.0	26.2	44.9	22.7	39.6
		Fans	22.3	13.4	21.9	15.7	21.5	14.7	20.5	15.3	18.0	14.2	15.0	11.9
		Water systems	0.5	0.9	0.8	1.4	0.6	1.1	0.7	1.5	0.8	1.5	0.7	1.5
	Gas	Heating	4.6	9.0	3.0	7.2	7.5	8.0	17.2	10.8	26.5	18.3	39.0	28.9

Table D-6 Percent of Site EUI (excluding PV) Devoted to Each End Use for Marine and Cold Climates

		End Use	3C		4C		7		8	
			Base	50%	Base	50%	Base	50%	Base	50%
Low Plug Load	Electricity	PV power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	1.7	3.0	1.8	3.1	2.0	2.9	0.4	0.3
		Interior lighting	38.0	22.5	28.3	31.8	16.5	18.6	11.5	11.5
		Exterior lighting	0.6	1.3	0.4	1.0	0.3	0.6	0.2	0.3
		Interior equipment	9.8	21.6	7.3	16.5	4.3	9.7	3.0	6.0
		Fans	19.3	13.4	15.1	12.2	9.0	7.2	7.0	4.2
		Water systems	1.2	2.6	0.9	2.1	0.7	1.5	0.5	1.0
	Gas	Heating	29.5	35.5	46.2	33.3	67.3	59.5	77.4	76.6
High Plug Load	Electricity	PV power	0.0	–7.7	0.0	0.0	0.0	0.0	0.0	0.0
		Cooling	2.2	5.5	2.2	5.2	2.5	3.8	0.7	1.2
		Interior lighting	29.6	14.0	24.5	14.9	15.7	16.1	11.4	12.9
		Exterior lighting	0.5	0.8	0.4	0.8	0.2	0.5	0.2	0.4
		Interior equipment	34.7	54.4	28.7	49.9	18.4	32.2	13.3	25.7
		Fans	19.6	14.6	16.6	13.6	11.0	8.9	7.9	7.0
		Water systems	0.9	1.7	0.8	1.7	0.6	1.3	0.5	1.2
	Gas	Heating	12.4	9.0	26.7	13.9	51.6	37.2	66.1	51.6

Appendix E. Alternative Low-Energy Model and Sensitivity Analysis Results

Please see Section 4.4.1.1 for an explanation of the figures and tables that follow.

E.1 Climate Zone 1A (Miami, Florida)

E.1.1 Low Plug Load

Computational Effort. Original search: 1,521 EnergyPlus simulations, 13 days of CPU time. Enumeration of additional models: 7 new searches; 2,770 new simulations; 420 total and 407 new simulations per search on average.

Alternative Low-Energy Models

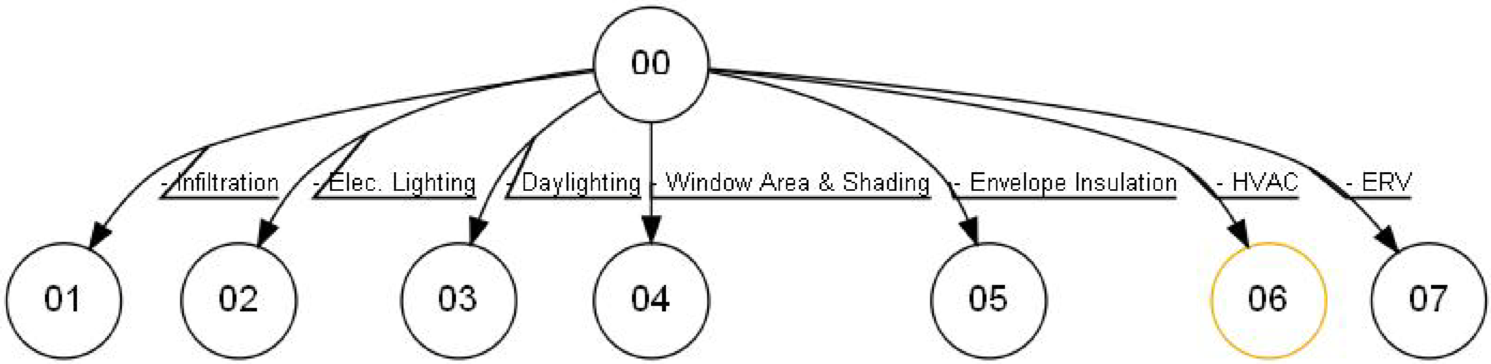

Figure E-1 Visualization of original and alternative low-energy models for the low plug load Miami, Florida store.

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-1 Summary of Low Energy Models for the Low Plug Load Miami, Florida Store

Node numbers correspond to Figure E-1. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
										MJ/m^2yr	$kBtu/ft^2yr$	MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$		
0	X	X	X	X	X		X		X	520	45.7	0	0	1392	129.36	1317	122.36	218	58.3
1		X	X	X	X		X		X	578	50.8	0	0	1391	129.23	1309	121.57	219	53.6
2	X		X	X	X		X		X	591	52.0	0	0	1428	132.71	1341	124.59	251	52.6
3	X	X		X	X		X		X	583	51.3	0	0	1378	128.03	1295	120.34	236	53.2
4	X	X	X		X		X		X	520	45.8	0	0	1396	129.71	1321	122.69	214	58.3
5	X	X	X	X			X		X	548	48.2	0	0	1412	131.15	1332	123.73	240	56.0
6	X	X	X	X	X				X	623	54.8	104	9.2	1573	146.10	1481	137.59	281	50.0
7	X	X	X	X	X	X	X	X		614	54.0	0	0	1320	122.63	1228	114.07	202	50.8

Sensitivity Analysis by Strategy

Table E-2 Sensitivity Analysis for the Strategies Used in the Selected Low-Energy Model for the Low Plug Load Miami, Florida Store

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$	m^2	ft^2
Infiltration	1	57.9	5.09	–1.38	–0.13	–8.57	–0.80	364.6	3925
Elec. Lighting	2	71.0	6.25	36.03	3.35	23.95	2.22	447.8	4820
Daylighting	3	63.6	5.59	–14.37	–1.34	–21.81	–2.03	400.6	4312
Window Area & Shading	4	0.4	0.03	3.70	0.34	3.49	0.32	2.3	25
Envelope Insulation	5	28.3	2.49	19.25	1.79	14.69	1.36	178.4	1920
HVAC	6	209.0	18.39	9.34	0.87	–18.44	–1.71	1317.1	14177
ERV	7	108.3	9.53	–93.30	–8.67	–103.57	–9.62	682.3	7344

E.1.2 High Plug Load

Computational Effort. Original search: 1,950 EnergyPlus simulations, 22 days of CPU time. Enumeration of additional models: 9 new searches; 3,762 new simulations; 461 total and 418 new simulations per search on average.

Alternative Low-Energy Models

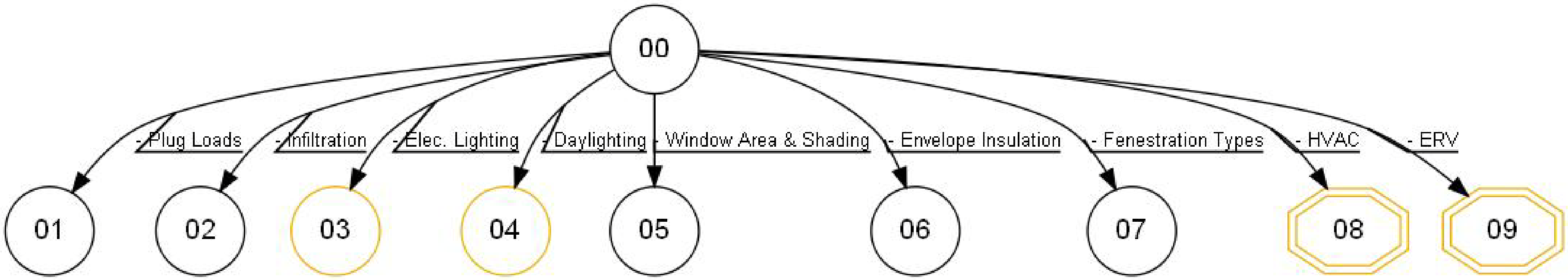

Figure E-2 Visualization of original and alternative low-energy models for the high plug load Miami, Florida store.

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-3 Summary of Low Energy Models for the High Plug Load Miami, Florida Store.

Node numbers correspond to Figure E-2. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Plug Loads	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
											MJ/m^2yr	$kBtu/ft^2yr$	MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$		
0	X	X	X	X	X	X	X	X		X	773	68.0	0	0	1420	131.90	1314	122.08	278	51.4
1		X	X	X	X	X	X	X		X	774	68.1	0	0	1451	134.76	1346	125.05	279	51.4
2	X		X	X	X	X	X	X		X	781	68.7	0	0	1453	134.99	1345	124.92	293	50.9
3	X	X		X	X	X	X	X		X	796	70.0	206	18.1	1835	170.44	1723	160.05	299	50.0
4	X	X	X		X	X	X	X		X	796	70.1	176	15.5	1755	163.01	1646	152.96	273	50.0
5	X	X	X	X		X	X	X		X	777	68.4	0	0	1423	132.16	1317	122.31	277	51.2
6	X	X	X	X	X		X	X		X	770	67.8	0	0	1436	133.45	1331	123.70	285	51.6
7	X	X	X	X	X	X		X		X	766	67.4	0	0	1427	132.54	1321	122.72	278	51.9
8	X	X	X	X	X	X	X			X	978	86.0	338	29.7	2252	209.23	2118	196.79	341	38.6
9	X	X	X	X	X	X	X	X			1184	104.2	59	5.2	1497	139.08	1350	125.43	281	25.6

Sensitivity Analysis by Strategy

Table E-4 Sensitivity Analysis for the Strategies used in the Selected Low-Energy Model for the High Plug Load Miami, Florida Store

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m²yr	kBtu/ft²yr	\$/m²	\$/ft²	\$/m²	\$/ft²	m²	ft²
Plug Loads	1	39.1	3.44	4.05	0.38	0.00	0.00	246.2	2650
Infiltration	2	46.2	4.06	4.75	0.44	–1.37	–0.13	291.0	3132
Elec. Lighting	3	95.6	8.41	18.67	1.73	4.26	0.40	602.3	6483
Daylighting	4	279.0	24.56	10.60	0.98	–18.50	–1.72	1758.7	18930
Window Area & Shading	5	4.5	0.39	2.80	0.26	2.51	0.23	28.2	304
Envelope Insulation	6	34.1	3.00	–9.68	–0.90	–14.55	–1.35	215.2	2316
Fenestration Types	7	224.8	19.78	24.80	2.30	1.62	0.15	1416.7	15249
HVAC	8	286.5	25.21	11.93	1.11	–23.90	–2.22	1805.4	19433
ERV	9	87.9	7.74	–62.21	–5.78	–71.61	–6.65	554.3	5966

E.2 Climate Zone 3B-NV (Las Vegas, Nevada)

E.1.3 Low Plug Load

Computational Effort. Original search: 1,460 EnergyPlus simulations, 15 days of CPU time. Enumeration of additional models: 8 new searches; 4,485 new simulations; 591 total and 561 new simulations per search on average.

Alternative Low-Energy Models

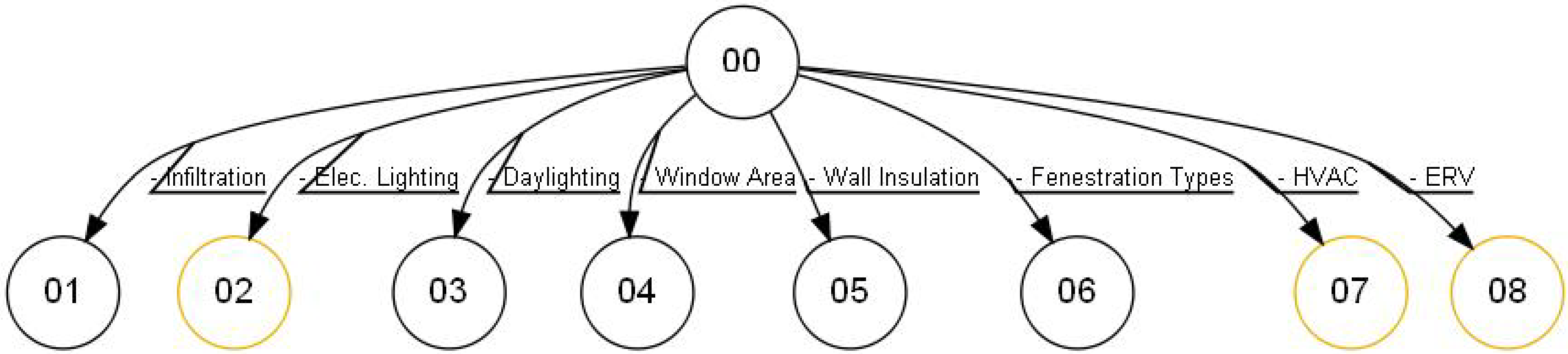

Figure E-3 Visualization of original and alternative low-energy models for the low plug load Las Vegas, Nevada store.

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-5 Summary of Low Energy Models for the Low Plug Load Las Vegas, Nevada Store.

Node numbers correspond to Figure E-3. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
										MJ/m^2yr	$kBtu/ft^2yr$	MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$		
0	X	X	X	X	X	X	X		X	316	27.8	0	0.0	1220	113.35	1180	109.60	94	54.2
1		X	X	X	X	X	X		X	335	29.5	0	0.0	1218	113.15	1176	109.28	96	51.3
2	X		X	X	X	X	X		X	344	30.3	31	2.7	1282	119.11	1233	114.52	116	50.0
3	X	X		X	X	X	X		X	340	29.9	0	0.0	1234	114.67	1190	110.54	107	50.7
4	X	X	X		X	X	X		X	318	28.0	0	0.0	1224	113.74	1183	109.94	95	53.8
5	X	X	X	X		X	X		X	340	29.9	0	0.0	1215	112.92	1172	108.90	101	50.7
6	X	X	X	X	X		X		X	328	28.8	0	0.0	1221	113.42	1180	109.61	95	52.4
7	X	X	X	X	X	X			X	344	30.3	95	8.3	1374	127.68	1331	123.70	115	50.0
8	X	X	X	X	X	X	X	X		344	30.3	43	3.8	1224	113.75	1181	109.76	102	50.0

Sensitivity Analysis by Strategy

Table E-6 Sensitivity Analysis for the Strategies used in the Selected Low-Energy Model for the Low Plug Load Las Vegas, Nevada Store.

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m²yr	kBtu/ft²yr	\$/m²	\$/ft²	\$/m²	\$/ft²	m²	ft²
Infiltration	1	19.5	1.72	–2.17	–0.20	–3.45	–0.32	105.8	1139
Elec. Lighting	2	63.2	5.56	15.52	1.44	3.04	0.28	342.7	3689
Daylighting	3	48.3	4.25	–16.08	–1.49	–21.81	–2.03	262.3	2823
Window Area & Shading	4	2.6	0.23	4.19	0.39	3.64	0.34	14.4	155
Envelope Insulation	5	23.9	2.11	–4.71	–0.44	–7.47	–0.69	129.9	1398
Fenestration Types	6	12.1	1.06	0.70	0.06	0.12	0.01	65.4	704
HVAC	7	131.2	11.54	9.29	0.86	–3.19	–0.30	711.6	7660
ERV	8	84.3	7.42	–66.16	–6.15	–71.61	–6.65	457.6	4925

E.1.4 High Plug Load

Computational Effort. Original search: 2,280 EnergyPlus simulations, 53 days of CPU time. Enumeration of additional models: 9 new searches; 6,345 new simulations; 739 total and 705 new simulations per search on average.

Alternative Low-Energy Models

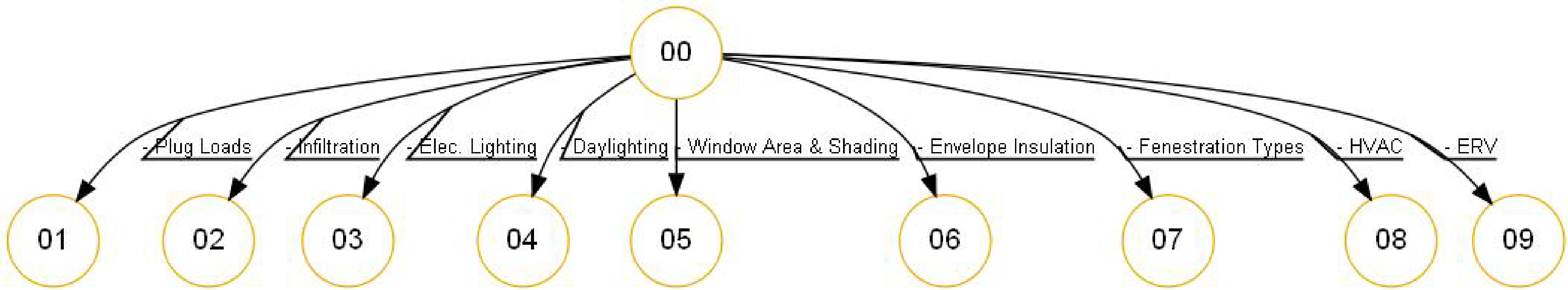

Figure E-4 Visualization of original and alternative low-energy models for the high plug load Las Vegas, Nevada store

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-7 Summary of Low Energy Models for the High Plug Load Las Vegas, Nevada Store

Node numbers correspond to Figure E-4. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Plug Loads	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
											MJ/m²yr	kBtu/ft²yr	MJ/m²yr	kBtu/ft²yr	$/m²	$/ft²	$/m²	$/ft²		
0	X	X	X	X	X	X	X	X		X	455	40.0	38	3.3	1310	121.67	1249	116.03	138	50.0
1		X	X	X	X	X	X	X		X	455	40.0	72	6.4	1362	126.51	1301	120.84	138	50.0
2	X		X	X	X	X	X	X		X	455	40.0	52	4.6	1329	123.48	1269	117.89	141	50.0
3	X	X		X	X	X	X	X		X	455	40.0	93	8.2	1401	130.18	1335	124.01	159	50.0
4	X	X	X		X	X	X	X		X	455	40.0	87	7.7	1362	126.54	1301	120.88	148	50.0
5	X	X	X	X		X	X	X		X	455	40.0	39	3.4	1317	122.37	1256	116.72	138	50.0
6	X	X	X	X	X		X	X		X	455	40.0	54	4.8	1333	123.82	1272	118.15	144	50.0
7	X	X	X	X	X	X		X		X	455	40.0	45	3.9	1320	122.67	1260	117.09	140	50.0
8	X	X	X	X	X	X	X			X	455	40.0	170	14.9	1511	140.39	1450	134.68	168	50.0
9	X	X	X	X	X	X	X	X	X		455	40.0	85	7.5	1323	122.95	1262	117.2	150	50.0

Sensitivity Analysis by Strategy

Table E-8 Sensitivity Analysis for the Strategies used in the Selected Low-Energy Model for the High Plug Load Las Vegas, Nevada Store

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$	m^2	ft^2
Plug Loads	1	34.6	3.05	3.83	0.36	0.00	0.00	187.9	2023
Infiltration	2	14.5	1.27	–0.68	–0.06	–1.64	–0.15	78.5	845
Elec. Lighting	3	61.1	5.37	11.75	1.09	0.30	0.03	331.2	3565
Daylighting	4	49.5	4.35	–20.82	–1.93	–26.62	–2.47	268.3	2888
Window Area & Shading	5	3.1	0.28	4.14	0.38	3.58	0.33	17.0	183
Envelope Insulation	6	21.7	1.91	–5.31	–0.49	–7.67	–0.71	117.9	1269
Fenestration Types	7	6.9	0.61	1.05	0.10	1.01	0.09	37.6	405
HVAC	8	138.1	12.15	10.63	0.99	–3.94	–0.37	749.0	8062
ERV	9	63.5	5.59	–67.59	–6.28	–71.61	–6.65	344.4	3707

E.3 Climate Zone 4C (Seattle, Washington)

E.1.5 Low Plug Load

Computational Effort. Original search: 2,033 EnergyPlus simulations, 16 days of CPU time. Enumeration of additional models: 8 new searches; 6,020 new simulations; 786 total and 753 new simulations per search on average.

Alternative Low-Energy Models

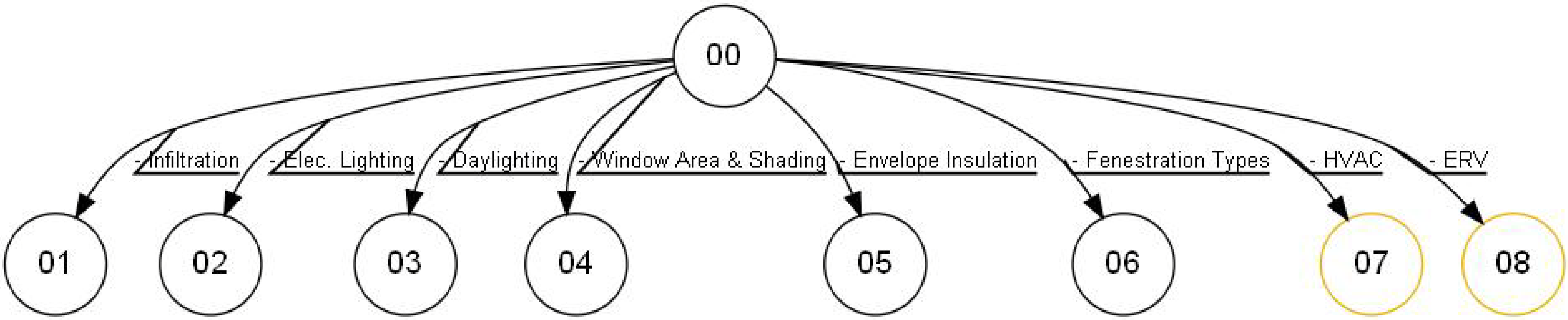

Figure E-5 Visualization of original and alternative low-energy models for the low plug load Seattle, Washington store

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-9 Summary of Low Energy Models for the Low Plug Load Seattle, Washington Store

Node numbers correspond to Figure E-5. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
										MJ/m^2yr	$kBtu/ft^2yr$	MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$		
0	X	X	X	X	X	X	X		X	348	30.6	0	0.0	1223	113.61	1182	109.82	86	55.8
1		X	X	X	X	X	X		X	376	33.1	0	0.0	1231	114.40	1192	110.76	69	52.2
2	X		X	X	X	X	X		X	373	32.9	0	0.0	1252	116.28	1204	111.82	103	52.6
3	X	X		X	X	X	X		X	352	31.0	0	0.0	1223	113.64	1182	109.78	89	55.2
4	X	X	X		X	X	X		X	350	30.8	0	0.0	1227	114.01	1186	110.16	90	55.5
5	X	X	X	X		X	X		X	383	33.7	0	0.0	1218	113.17	1175	109.17	91	51.3
6	X	X	X	X	X		X		X	352	30.9	0	0.0	1224	113.68	1183	109.87	86	55.3
7	X	X	X	X	X	X			X	394	34.6	144	12.7	1660	154.22	1624	150.84	81	50.0
8	X	X	X	X	X	X	X	X		394	34.6	107	9.4	1499	139.30	1463	135.93	69	50.0

Sensitivity Analysis by Strategy

Table E-10 Sensitivity Analysis for the Strategies used in the Selected Low-Energy Model for the Low Plug Load Seattle, Washington Store

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m²yr	kBtu/ft²yr	$/m²	$/ft²	$/m²	$/ft²	m²	ft²
Infiltration	1	53.9	4.74	–10.09	–0.94	–12.30	–1.14	498.1	5362
Elec. Lighting	2	81.2	7.14	24.94	2.32	9.20	0.85	750.2	8075
Daylighting	3	4.3	0.38	0.37	0.03	–0.39	–0.04	39.9	429
Window Area & Shading	4	2.2	0.19	4.32	0.40	3.66	0.34	20.4	219
Envelope Insulation	5	35.3	3.11	–4.73	–0.44	–6.97	–0.65	326.7	3516
Fenestration Types	6	3.5	0.31	0.75	0.07	0.49	0.05	32.4	349
HVAC	7	266.6	23.46	16.46	1.53	–0.56	–0.05	2463.9	26521
ERV	8	256.8	22.60	–90.07	–8.37	–103.57	–9.62	2373.3	25546

E.1.6 High Plug Load

Computational Effort. Original search: 2,402 EnergyPlus simulations, 37 days of CPU time. Enumeration of additional models: 9 new searches; 5,360 new simulations; 615 total and 596 new simulations per search on average.

Alternative Low-Energy Models

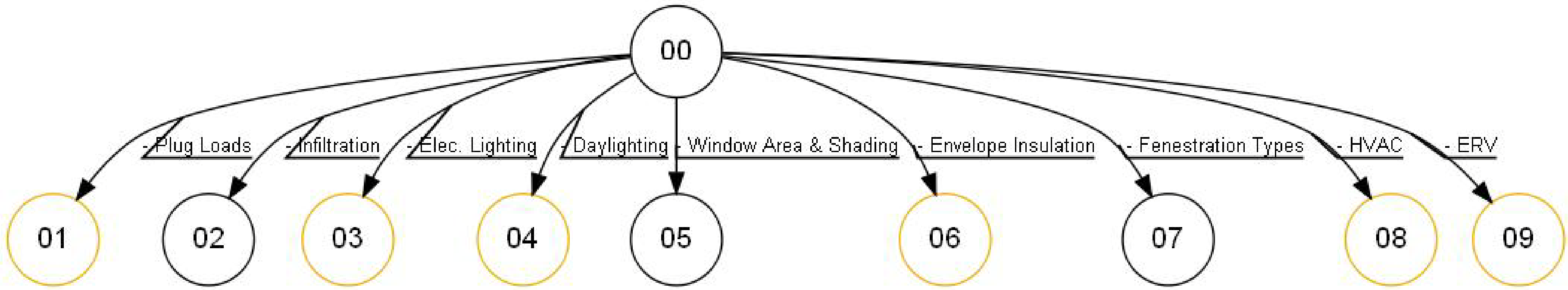

Figure E-6 Visualization of original and alternative low-energy models for the high plug load Seattle, Washington store

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-11 Summary of Low Energy Models for the High Plug Load Seattle, Washington Store

Node numbers correspond to Figure E-6. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Plug Loads	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
											MJ/m²yr	kBtu/ft²yr	MJ/m²yr	kBtu/ft²yr	$/m²	$/ft²	$/m²	$/ft²		
0	X	X	X	X	X	X	X	X		X	444	39.1	0	0.0	1282	119.14	1226	113.87	121	51.1
1		X	X	X	X	X	X	X		X	454	40.0	16	1.4	1328	123.39	1270	118.00	118	50.0
2	X		X	X	X	X	X	X		X	447	39.3	0	0.0	1350	125.45	1294	120.22	118	50.8
3	X	X		X	X	X	X	X		X	454	40.0	40	3.5	1389	129.02	1326	123.17	136	50.0
4	X	X	X		X	X	X	X		X	454	40.0	31	2.7	1344	124.83	1285	119.42	127	50.0
5	X	X	X	X		X	X	X		X	447	39.4	0	0.0	1287	119.53	1229	114.20	124	50.7
6	X	X	X	X	X		X	X		X	454	40.0	19	1.7	1324	122.97	1267	117.75	118	50.0
7	X	X	X	X	X	X		X		X	451	39.6	0	0.0	1283	119.19	1226	113.90	121	50.4
8	X	X	X	X	X	X	X			X	454	40.0	178	15.7	1779	165.28	1727	160.41	140	50.0
9	X	X	X	X	X	X	X	X	X		454	40.0	128	11.3	1589	147.59	1536	142.71	112	50.0

Sensitivity Analysis by Strategy

Table E-12 Sensitivity Analysis for the Strategies used in the Selected Low-Energy Model for the High Plug Load Seattle, Washington Store.

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m²yr	kBtu/ft²yr	$/m²	$/ft²	$/m²	$/ft²	m²	ft²
Plug Loads	1	26.7	2.35	3.35	0.31	0.00	0.00	247.1	2660
Infiltration	2	37.2	3.28	–11.45	–1.06	–13.01	–1.21	344.4	3707
Elec. Lighting	3	54.8	4.82	5.74	0.53	–5.53	–0.51	507.3	5461
Daylighting	4	41.4	3.64	–17.28	–1.61	–22.62	–2.10	382.8	4120
Window Area & Shading	5	3.1	0.27	4.20	0.39	3.58	0.33	28.7	309
Envelope Insulation	6	30.1	2.65	–8.74	–0.81	–10.64	–0.99	278.8	3001
Fenestration Types	7	6.3	0.55	0.55	0.05	0.36	0.03	58.1	626
HVAC	8	231.9	20.41	13.03	1.21	–3.90	–0.36	2146.1	23100
ERV	9	207.5	18.26	–92.65	–8.61	–103.57	–9.62	1920.1	20668

E.4 Climate Zone 5A (Chicago, Illinois)

E.1.7 Low Plug Load

Computational Effort. Original search: 2,322 EnergyPlus simulations, 12 days of CPU time. Enumeration of additional models: 8 new searches; 5,383 new simulations; 744 total and 673 new simulations per search on average.

Alternative Low-Energy Models

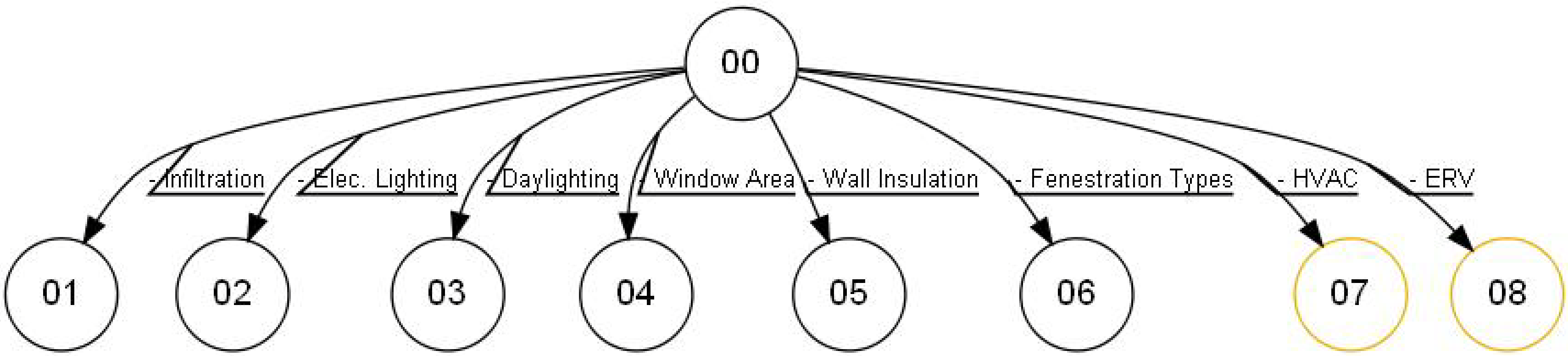

Figure E-7 Visualization of original and alternative low-energy models for the low plug load Chicago, Illinois store

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-13 Summary of Low Energy Models for the Low Plug Load Chicago, Illinois Store

Node numbers correspond to Figure E-7. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Wall Insulation	Roof Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
											MJ/m^{2}yr	kBtu/ft^{2}yr	MJ/m^{2}yr	kBtu/ft^{2}yr	\$/m^2	\$/ft^2	\$/m^2	\$/ft^2		
0	X	X	X	X	X		X	X		X	471	41.5	0	0.0	1254	116.49	1202	111.70	122	55.0
1		X	X	X	X		X	X		X	521	45.9	0	0.0	1260	117.07	1208	112.27	106	50.2
2	X		X	X	X		X	X		X	517	45.5	0	0.0	1280	118.93	1220	113.31	144	50.6
3	X	X		X	X		X	X		X	475	41.8	0	0.0	1254	116.53	1202	111.66	125	54.6
4	X	X	X		X		X	X		X	470	41.4	0	0.0	1258	116.87	1206	112.04	122	55.0
5	X	X	X	X			X	X		X	505	44.4	0	0.0	1252	116.31	1198	111.28	128	51.8
6	X	X	X	X	X			X		X	475	41.8	0	0.0	1255	116.55	1203	111.74	123	54.6
7	X	X	X	X	X	X	X			X	523	46.0	206	18.1	1790	166.29	1743	161.91	134	50.0
8	X	X	X	X	X	X	X	X	X		523	46.0	145	12.8	1594	148.11	1547	143.74	107	50.0

Sensitivity Analysis by Strategy

Table E-14 Sensitivity Analysis for the Strategies used in the Selected Low-Energy Model for the Low Plug Load Chicago, Illinois Store

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$	m^2	ft^2
Infiltration	1	78.6	6.92	-6.19	-0.57	-10.26	-0.95	619.8	6671
Elec. Lighting	2	78.9	6.94	26.01	2.42	10.03	0.93	621.8	6693
Daylighting	3	4.1	0.36	0.40	0.04	-0.38	-0.04	32.6	351
Window Area & Shading	4	-0.7	-0.06	4.05	0.38	3.63	0.34	-5.5	-59
Wall Insulation	5	33.6	2.96	-1.96	-0.18	-4.51	-0.42	264.9	2851
Fenestration Types	6	4.1	0.36	0.66	0.06	0.43	0.04	32.2	347
HVAC	7	353.9	31.14	20.80	1.93	-3.75	-0.35	2790.1	30032
ERV	8	325.4	28.63	-85.87	-7.98	-103.57	-9.62	2565.4	27613

E.1.8 High Plug Load

Computational Effort. Original search: 2,051 EnergyPlus simulations, 13 days of CPU time. Enumeration of additional models: 9 new searches; 4,118 new simulations; 476 total and 458 new simulations per search on average.

Alternative Low-Energy Models

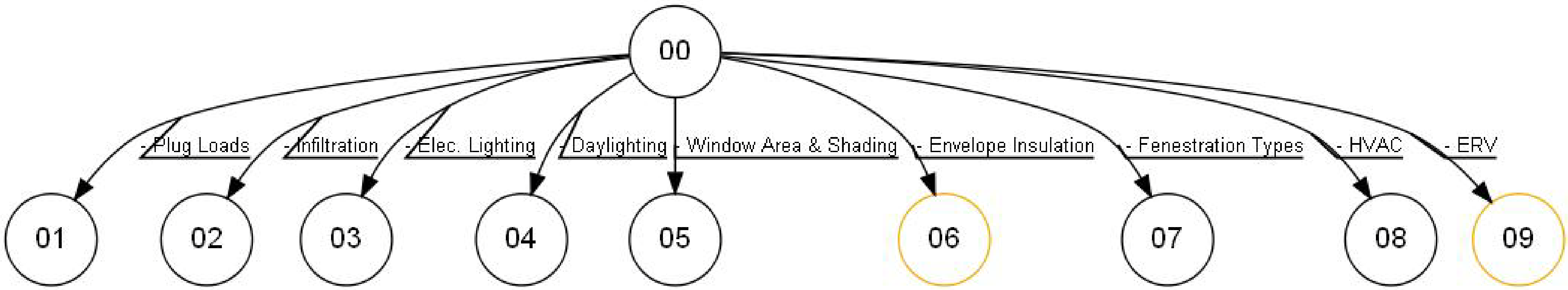

Figure E-8 Visualization of original and alternative low-energy models for the high plug load Chicago, Illinois store

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-15 Summary of Low Energy Models for the High Plug Load Chicago, Illinois Store

Node numbers correspond to Figure E-8. An ‘X’ under a strategy name indicates that the strategy is used in the model.

Node	Plug Loads	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
											MJ/m^2yr	$kBtu/ft^2yr$	MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$		
0	X	X	X	X	X	X	X	X		X	563	49.6	0	0	1305	121.28	1237	114.95	169	52.2
1		X	X	X	X	X	X	X		X	587	51.7	0	0	1309	121.58	1237	114.95	169	50.2
2	X		X	X	X	X	X	X		X	579	51	0	0	1383	128.53	1315	122.15	169	50.9
3	X	X		X	X	X	X	X		X	560	49.3	0	0	1399	130.02	1324	123.03	189	52.5
4	X	X	X		X	X	X	X		X	552	48.6	0	0	1372	127.5	1302	120.98	190	53.2
5	X	X	X	X		X	X	X		X	564	49.6	0	0	1309	121.64	1241	115.28	169	52.2
6	X	X	X	X	X		X	X		X	590	51.9	1	0.1	1310	121.7	1241	115.25	164	50.0
7	X	X	X	X	X	X		X		X	571	50.2	0	0	1306	121.37	1238	115.01	169	51.6
8	X	X	X	X	X	X	X			X	582	51.2	0	0	1389	129.05	1313	122.02	201	50.6
9	X	X	X	X	X	X	X	X	X		590	51.9	184	16.1	1690	156.97	1626	151.11	161	50.0

Sensitivity Analysis by Strategy

Table E-16 Sensitivity Analysis for the Strategies used in the Selected Low-Energy Model for the High Plug Load Chicago, Illinois Store.

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m²yr	kBtu/ft²yr	\$/m²	\$/ft²	\$/m²	\$/ft²	m²	ft²
Plug Loads	1	23.8	2.10	3.29	0.31	0.00	0.00	180.0	1938
Infiltration	2	71.8	6.32	–4.13	–0.38	–7.82	–0.73	542.6	5840
Elec. Lighting	3	52.9	4.66	8.57	0.80	–2.40	–0.22	399.6	4301
Daylighting	4	35.5	3.12	–12.30	–1.14	–17.30	–1.61	268.0	2885
Window Area & Shading	5	0.0	0.00	3.87	0.36	3.61	0.34	0.3	3
Envelope Insulation	6	32.1	2.82	–5.41	–0.50	–7.49	–0.70	242.1	2606
Fenestration Types	7	7.2	0.63	0.99	0.09	0.73	0.07	54.4	585
HVAC	8	63.4	5.58	1.60	0.15	–8.48	–0.79	478.8	5153
ERV	9	298.8	26.29	–87.37	–8.12	–103.57	–9.62	2256.6	24290

E.5 Climate Zone 8 (Fairbanks, Alaska)

E.1.9 Low Plug Load

Computational Effort. Original search: 2,287 EnergyPlus simulations, 9 days of CPU time. Enumeration of additional models: 8 new searches; 4,117 new simulations; 570 total and 515 new simulations per search on average.

Alternative Low-Energy Models

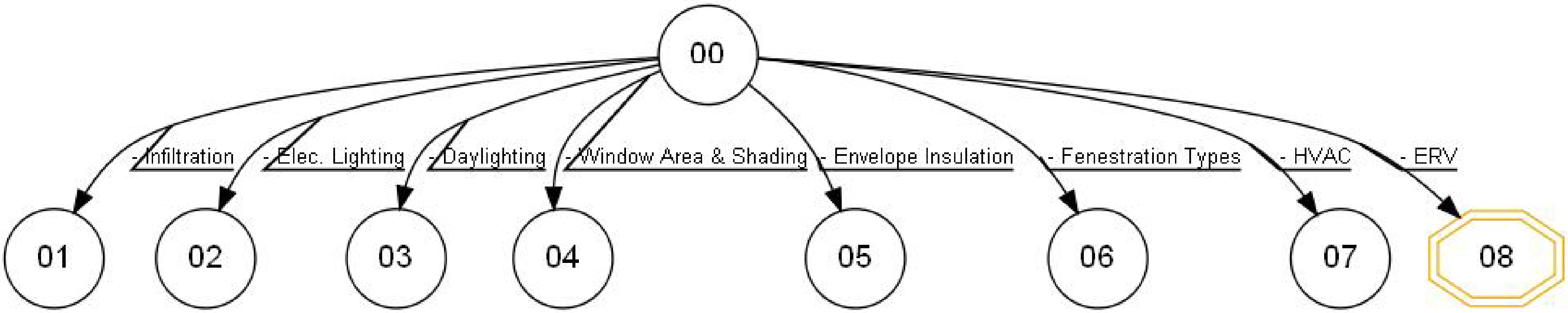

Figure E-9 Visualization of original and alternative low-energy models for the low plug load Fairbanks, Alaska store

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-17 Summary of Low Energy Models for the Low Plug Load Fairbanks, Alaska Store

Node numbers correspond to Figure E-9. An ‘X’ under a strategy name indicates that the strategy is used in the model.

Node	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy		PV Energy		Lifetime Cost		Capital Cost		Peak Demand (kW)	Energy Savings (%)
										MJ/m^{2}yr	kBtu/ft^{2}yr	MJ/m^{2}yr	kBtu/ft^{2}yr	\$/m^2	\$/ft^2	\$/m^2	\$/ft^2		
0	X	X	X	X	X	X	X		X	965	84.9	0	0.0	1284	119.29	1212	112.60	82	50.2
1		X	X	X	X	X	X		X	962	84.7	0	0.0	1322	122.81	1249	116.06	92	50.3
2	X		X	X	X	X	X		X	879	77.3	0	0.0	1320	122.66	1242	115.38	113	54.6
3	X	X		X	X	X	X		X	967	85.1	0	0.0	1284	119.30	1212	112.56	81	50.0
4	X	X	X		X	X	X		X	966	85.0	0	0.0	1288	119.69	1216	112.94	80	50.1
5	X	X	X	X		X	X		X	873	76.9	0	0.0	1302	120.93	1234	114.66	81	54.9
6	X	X	X	X	X		X		X	793	69.8	0	0.0	1308	121.50	1245	115.66	79	59.0
7	X	X	X	X	X	X			X	968	85.1	0	0.0	1286	119.44	1210	112.44	89	50.0
8	X	X	X	X	X	X	X	X		1121	98.7	179	15.8	1959	182.01	1882	174.89	60	42.1

Sensitivity Analysis by Strategy

Table E-18 Sensitivity Analysis for the Strategies Used in the Selected Low-Energy Model for the Low Plug Load Fairbanks, Alaska Store

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m^2yr	$kBtu/ft^2yr$	$\$/m^2$	$\$/ft^2$	$\$/m^2$	$\$/ft^2$	m^2	ft^2
Infiltration	1	218.9	19.27	12.71	1.18	0.20	0.02	2755.7	29662
Elec. Lighting	2	39.7	3.49	20.64	1.92	7.20	0.67	499.1	5373
Daylighting	3	2.5	0.22	0.11	0.01	–0.38	–0.04	31.3	337
Window Area & Shading	4	1.7	0.15	4.30	0.40	3.70	0.34	21.4	230
Envelope Insulation	5	96.3	8.48	–4.43	–0.41	–9.80	–0.91	1212.6	13052
Fenestration Types	6	8.2	0.72	1.40	0.13	0.99	0.09	103.3	1112
HVAC	7	2.8	0.25	1.59	0.15	–1.66	–0.15	35.7	384
ERV	8	548.3	48.25	–42.18	–3.92	–71.61	–6.65	6902.0	74292

E.1.10 High Plug Load

Computational Effort. Original search: 2,239 EnergyPlus simulations, 11 days of CPU time. Enumeration of additional models: 9 new searches; 4,536 new simulations; 535 total and 504 new simulations per search on average.

Alternative Low-Energy Models

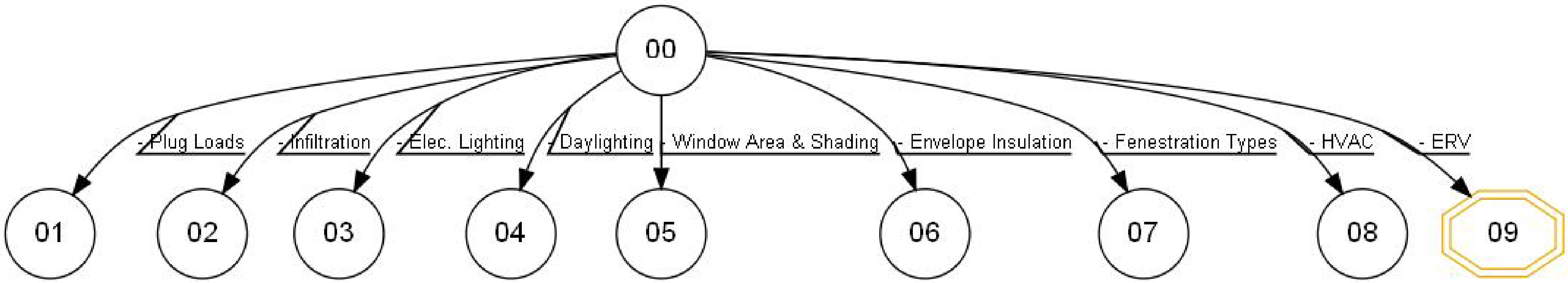

Figure E-10 Visualization of original and alternative low-energy models for the high plug load Fairbanks, Alaska store

Node 00 represents the original low-energy model. The other nodes represent the result of searches formed by taking Node 00 and removing the indicated strategy. Models that include PV are in gold. Any models that do not reach the 50% energy savings goal are indicated by octagons.

Table E-19 Summary of Low Energy Models for the High Plug Load Fairbanks, Alaska Store

Node numbers correspond to Figure E-10. An 'X' under a strategy name indicates that the strategy is used in the model.

Node	Plug Loads	Infiltration	Elec. Lighting	Daylighting	Window Area & Shading	Envelope Insulation	Fenestration Types	HVAC	DCV	ERV	Net Site Energy MJ/m²yr	Net Site Energy kBtu/ft²yr	PV Energy MJ/m²yr	PV Energy kBtu/ft²yr	Lifetime Cost $/m²	Lifetime Cost $/ft²	Capital Cost $/m²	Capital Cost $/ft²	Peak Demand (kW)	Energy Savings (%)
0	X	X	X	X	X	X	X	X		X	861	75.8	0	0.0	1338	124.29	1258	116.86	122	56.1
1		X	X	X	X	X	X	X		X	872	76.7	0	0.0	1340	124.52	1258	116.86	123	55.5
2	X		X	X	X	X	X	X		X	958	84.3	0	0.0	1372	127.51	1288	119.64	120	51.1
3	X	X		X	X	X	X	X		X	921	81.0	0	0.0	1354	125.75	1259	116.99	156	53.0
4	X	X	X		X	X	X	X		X	864	76.1	0	0.0	1338	124.31	1257	116.82	125	55.9
5	X	X	X	X		X	X	X		X	865	76.1	0	0.0	1342	124.71	1262	117.20	125	55.9
6	X	X	X	X	X		X	X		X	945	83.1	0	0.0	1331	123.70	1247	115.83	125	51.8
7	X	X	X	X	X	X		X		X	868	76.4	0	0.0	1339	124.42	1259	116.96	122	55.7
8	X	X	X	X	X	X	X			X	882	77.6	0	0.0	1341	124.59	1255	116.60	138	55.0
9	X	X	X	X	X	X	X	X	X		1173	103.2	179	15.8	1991	184.96	1902	176.73	94	40.1

Sensitivity Analysis by Strategy

Table E-20 Sensitivity Analysis for the Strategies Used in the Selected Low-Energy Model for the High Plug Load Fairbanks, Alaska Store

Savings numbers are calculated between the selected low-energy model (with PV removed as necessary), and the model created by removing the indicated strategy. Equivalent PV areas are calculated assuming a 0.1 cell efficiency and a 0.9 inverter efficiency, and the EnergyPlus algorithm for determining the annual amount of electricity produced given building geometry and local weather conditions.

Strategy	Search No.	EUI Savings		Lifetime Cost Savings		Capital Cost Savings		Equivalent PV	
		MJ/m²yr	kBtu/ft²yr	$/m²	$/ft²	$/m²	$/ft²	m²	ft²
Plug Loads	1	10.6	0.94	2.44	0.23	0.00	0.00	133.9	1441
Infiltration	2	188.6	16.60	–0.95	–0.09	–10.68	–0.99	2374.1	25555
Elec. Lighting	3	59.8	5.26	15.63	1.45	1.35	0.13	752.5	8099
Daylighting	4	3.3	0.29	0.14	0.01	–0.45	–0.04	41.9	451
Window Area & Shading	5	3.9	0.34	4.44	0.41	3.62	0.34	48.9	527
Envelope Insulation	6	83.8	7.37	–6.42	–0.60	–11.13	–1.03	1054.2	11348
Fenestration Types	7	7.0	0.62	1.38	0.13	1.01	0.09	88.1	948
HVAC	8	21.4	1.88	3.14	0.29	–2.77	–0.26	269.0	2896
ERV	9	683.5	60.15	–67.25	–6.25	–103.57	–9.62	8603.7	92610

Appendix F. Corrected Results from Abbreviated Optimization

The corrected energy performance of the selected low-energy models from the abbreviated optimizations described in Section 4.5 is summarized in Table F-1 to Table F-3.

Table F-1 Selected Low-Energy Model Corrected Energy Performance: Humid Climates

Building Type	Building Name	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug General Merchandise	Low-Energy	Percent Energy Savings	60.5%	56.4%	63.5%	59.3%	57.6%	55.2%
	Baseline (SI units)	EUI (MJ/m²·yr)	1,790	1,680	1,210	1,340	1,330	1,540
	Low-Energy (SI units)	EUI (MJ/m²·yr)	705	734	443	547	563	689
	Baseline (SI units)	Electricity Intensity (kWh/m²yr)	492	444	285	268	181	178
	Low-Energy (SI units)	Electricity Intensity (kWh/m²yr)	182	154	86.7	81.9	61.4	65.4
	Baseline (SI units)	Natural Gas Intensity (kWh/m²yr)	3.58	23.1	52.1	105	188	250
	Low-Energy (SI units)	Natural Gas Intensity (kWh/m²yr)	13.9	49.9	36.3	70.0	95.0	126
	Low-Energy (SI units)	PV Power Intensity (kWh/m²yr)	0.000	0.000	0.000	0.000	0.000	0.000
	Baseline (IP units)	EUI (kBtu/ft²yr)	157	148	107	118	117	136
	Low-Energy (IP units)	EUI (kBtu/ft²yr)	62.1	64.6	39.0	48.1	49.6	60.7
	Baseline (IP units)	Electricity Intensity (kWh/ft²yr)	45.7	41.2	26.4	24.9	16.8	16.5
	Low-Energy (IP units)	Electricity Intensity (kWh/ft²yr)	16.9	14.3	8.05	7.61	5.71	6.08
	Baseline (IP units)	Natural Gas Intensity (Therms/ft²yr)	0.0113	0.0733	0.165	0.333	0.597	0.792
	Low-Energy (IP units)	Natural Gas Intensity (Therms/ft²yr)	0.0441	0.158	0.115	0.222	0.301	0.399
	Low-Energy (IP units)	PV Power Intensity (kWh/ft²yr)	0.000	0.000	0.000	0.000	0.000	0.000
High Plug General Merchandise	Low-Energy	Percent Energy Savings	65.4%	65.4%	61.0%	59.0%	55.5%	54.0%
	Baseline (SI units)	EUI (MJ/m²·yr)	2,200	2,050	1,480	1,560	1,460	1,660
	Low-Energy (SI units)	EUI (MJ/m²·yr)	760	708	577	637	648	764
	Baseline (SI units)	Electricity Intensity (kWh/m²yr)	607	554	377	358	256	253
	Low-Energy (SI units)	Electricity Intensity (kWh/m²yr)	208	186	140	135	109	114
	Baseline (SI units)	Natural Gas Intensity (kWh/m²yr)	3.12	15.2	33.6	74.0	149	208
	Low-Energy (SI units)	Natural Gas Intensity (kWh/m²yr)	3.59	10.2	20.2	42.5	70.6	98.4
	Low-Energy (SI units)	PV Power Intensity (kWh/m²yr)	0.000	0.000	0.000	0.000	0.000	0.000
	Baseline (IP units)	EUI (kBtu/ft²yr)	193	180	130	137	128	146
	Low-Energy (IP units)	EUI (kBtu/ft²yr)	66.9	62.3	50.8	56.1	57.1	67.3
	Baseline (IP units)	Electricity Intensity (kWh/ft²yr)	56.4	51.4	35.0	33.3	23.8	23.5
	Low-Energy (IP units)	Electricity Intensity (kWh/ft²yr)	19.3	17.3	13.0	12.5	10.2	10.6
	Baseline (IP units)	Natural Gas Intensity (Therms/ft²yr)	0.0099	0.0481	0.106	0.235	0.473	0.661
	Low-Energy (IP units)	Natural Gas Intensity (Therms/ft²yr)	0.0114	0.0324	0.0641	0.135	0.224	0.312
	Low-Energy (IP units)	PV Power Intensity (kWh/ft²yr)	0.000	0.000	0.000	0.000	0.000	0.000

Table F-2 Selected Low-Energy Model Corrected Energy Performance: Arid Climates

Building Type	Building Name	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug General Merchandise	Low-Energy	Percent Energy Savings	61.3%	57.9%	52.6%	62.2%	60.6%	56.4%
	Baseline (SI units)	EUI ($MJ/m^2 \cdot yr$)	898	754	846	942	1,070	1,300
	Low-Energy (SI units)	EUI ($MJ/m^2 \cdot yr$)	347	318	401	356	422	568
	Baseline (SI units)	Electricity Intensity (kWh/m^2yr)	226	182	192	171	157	149
	Low-Energy (SI units)	Electricity Intensity (kWh/m^2yr)	64.8	54.7	56.3	48.0	44.6	48.5
	Baseline (SI units)	Natural Gas Intensity (kWh/m^2yr)	23.2	27.5	43.5	90.5	141	213
	Low-Energy (SI units)	Natural Gas Intensity (kWh/m^2yr)	31.6	33.5	55.2	50.8	72.7	109
	Low-Energy (SI units)	PV Power Intensity (kWh/m^2yr)	0.000	0.000	0.000	0.000	0.000	0.000
	Baseline (IP units)	EUI ($kBtu/ft^2yr$)	79.1	66.4	74.5	82.9	94.5	115
	Low-Energy (IP units)	EUI ($kBtu/ft^2yr$)	30.6	28.0	35.3	31.3	37.2	50.0
	Baseline (IP units)	Electricity Intensity (kWh/ft^2yr)	21.0	16.9	17.8	15.9	14.6	13.8
	Low-Energy (IP units)	Electricity Intensity (kWh/ft^2yr)	6.02	5.08	5.23	4.46	4.15	4.51
	Baseline (IP units)	Natural Gas Intensity ($Therms/ft^2yr$)	0.0735	0.0872	0.138	0.287	0.446	0.675
	Low-Energy (IP units)	Natural Gas Intensity ($Therms/ft^2yr$)	0.100	0.106	0.175	0.161	0.230	0.346
	Low-Energy (IP units)	PV Power Intensity (kWh/ft^2yr)	0.000	0.000	0.000	0.000	0.000	0.000
High Plug General Merchandise	Low-Energy	Percent Energy Savings	55.5%	50.8%	57.5%	57.2%	56.1%	54.5%
	Baseline (SI units)	EUI ($MJ/m^2 \cdot yr$)	1,170	963	1,080	1,130	1,230	1,420
	Low-Energy (SI units)	EUI ($MJ/m^2 \cdot yr$)	519	474	459	483	540	647
	Baseline (SI units)	Electricity Intensity (kWh/m^2yr)	308	250	270	248	236	225
	Low-Energy (SI units)	Electricity Intensity (kWh/m^2yr)	122	111	112	104	100	98.1
	Baseline (SI units)	Natural Gas Intensity (kWh/m^2yr)	15.5	17.3	29.9	65.6	106	170
	Low-Energy (SI units)	Natural Gas Intensity (kWh/m^2yr)	21.9	21.1	15.6	30.0	49.6	81.5
	Low-Energy (SI units)	PV Power Intensity (kWh/m^2yr)	0.000	0.000	0.000	0.000	0.000	0.000
	Baseline (IP units)	EUI ($kBtu/ft^2yr$)	103	84.8	95.0	99.5	108	125
	Low-Energy (IP units)	EUI ($kBtu/ft^2yr$)	45.7	41.7	40.4	42.6	47.6	57.0
	Baseline (IP units)	Electricity Intensity (kWh/ft^2yr)	28.6	23.2	25.1	23.1	21.9	20.9
	Low-Energy (IP units)	Electricity Intensity (kWh/ft^2yr)	11.4	10.3	10.4	9.69	9.33	9.12
	Baseline (IP units)	Natural Gas Intensity ($Therms/ft^2yr$)	0.0493	0.055	0.0949	0.208	0.336	0.539
	Low-Energy (IP units)	Natural Gas Intensity ($Therms/ft^2yr$)	0.0693	0.0668	0.0496	0.095	0.157	0.258
	Low-Energy (IP units)	PV Power Intensity (kWh/ft^2yr)	0.000	0.000	0.000	0.000	0.000	0.000

Table F-3 Selected Low-Energy Model Corrected Energy Performance: Marine and Cold Climates

Building Type	Building Name	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug General Merchandise	Low-Energy	Percent Energy Savings	62.6%	59.0%	54.7%	55.7%
	Baseline (SI units)	EUI (MJ/m^2·yr)	745	981	1,690	2,380
	Low-Energy (SI units)	EUI (MJ/m^2·yr)	279	402	766	1,050
	Baseline (SI units)	Electricity Intensity (kWh/m^{2}yr)	139	142	145	142
	Low-Energy (SI units)	Electricity Intensity (kWh/m^{2}yr)	38.6	47.2	51.0	46.0
	Baseline (SI units)	Natural Gas Intensity (kWh/m^{2}yr)	68.2	131	325	518
	Low-Energy (SI units)	Natural Gas Intensity (kWh/m^{2}yr)	38.8	64.5	162	246
	Low-Energy (SI units)	PV Power Intensity (kWh/m^{2}yr)	0.000	0.000	0.000	0.000
	Baseline (IP units)	EUI (kBtu/ft^{2}yr)	65.6	86.4	149	209
	Low-Energy (IP units)	EUI (kBtu/ft^{2}yr)	24.5	35.4	67.5	92.6
	Baseline (IP units)	Electricity Intensity (kWh/ft^{2}yr)	12.9	13.2	13.5	13.2
	Low-Energy (IP units)	Electricity Intensity (kWh/ft^{2}yr)	3.58	4.39	4.74	4.28
	Baseline (IP units)	Natural Gas Intensity (Therms/ft^{2}yr)	0.216	0.414	1.03	1.64
	Low-Energy (IP units)	Natural Gas Intensity (Therms/ft^{2}yr)	0.123	0.205	0.513	0.781
	Low-Energy (IP units)	PV Power Intensity (kWh/ft^{2}yr)	0.000	0.000	0.000	0.000
High Plug General Merchandise	Low-Energy	Percent Energy Savings	57.0%	56.3%	52.9%	54.7%
	Baseline (SI units)	EUI (MJ/m^2·yr)	918	1,110	1,770	2,430
	Low-Energy (SI units)	EUI (MJ/m^2·yr)	395	483	835	1,100
	Baseline (SI units)	Electricity Intensity (kWh/m^{2}yr)	212	214	220	209
	Low-Energy (SI units)	Electricity Intensity (kWh/m^{2}yr)	92.7	95.1	106	99.8
	Baseline (SI units)	Natural Gas Intensity (kWh/m^{2}yr)	42.8	92.8	273	465
	Low-Energy (SI units)	Natural Gas Intensity (kWh/m^{2}yr)	16.9	39.2	126	206
	Low-Energy (SI units)	PV Power Intensity (kWh/m^{2}yr)	0.000	0.000	0.000	0.000
	Baseline (IP units)	EUI (kBtu/ft^{2}yr)	80.8	97.3	156	214
	Low-Energy (IP units)	EUI (kBtu/ft^{2}yr)	34.7	42.6	73.5	96.9
	Baseline (IP units)	Electricity Intensity (kWh/ft^{2}yr)	19.7	19.9	20.4	19.5
	Low-Energy (IP units)	Electricity Intensity (kWh/ft^{2}yr)	8.61	8.83	9.80	9.27
	Baseline (IP units)	Natural Gas Intensity (Therms/ft^{2}yr)	0.136	0.294	0.864	1.47
	Low-Energy (IP units)	Natural Gas Intensity (Therms/ft^{2}yr)	0.0536	0.124	0.400	0.652
	Low-Energy (IP units)	PV Power Intensity (kWh/ft^{2}yr)	0.000	0.000	0.000	0.000

The corrected economic performance of the selected low-energy models from the abbreviated optimizations described in 4.5 is summarized in Table F-4 to Table F-6.

Table F-4 Selected Low-Energy Model Corrected Costs: Humid Climates

Building Type	Building Name	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug General Merchandise	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,500	1,480	1,360	1,370	1,290	1,300
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,340	1,330	1,230	1,220	1,170	1,170
	Baseline (SI units)	Capital Cost ($/m^2)	1,280	1,270	1,220	1,220	1,160	1,170
	Low-Energy (SI units)	Capital Cost ($/m^2)	1,240	1,240	1,180	1,170	1,120	1,110
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	139	137	127	127	120	121
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	124	123	115	114	108	109
	Baseline (IP units)	Capital Cost ($/ft^2)	119	118	113	113	108	108
	Low-Energy (IP units)	Capital Cost ($/ft^2)	115	115	110	109	104	103
High Plug General Merchandise	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,560	1,530	1,410	1,400	1,320	1,330
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,380	1,380	1,300	1,300	1,220	1,210
	Baseline (SI units)	Capital Cost ($/m^2)	1,290	1,280	1,230	1,230	1,170	1,170
	Low-Energy (SI units)	Capital Cost ($/m^2)	1,280	1,290	1,230	1,230	1,160	1,140
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	145	142	131	131	123	123
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	128	128	121	121	114	113
	Baseline (IP units)	Capital Cost ($/ft^2)	120	119	114	114	109	109
	Low-Energy (IP units)	Capital Cost ($/ft^2)	119	119	115	114	107	106

Table F-5 Selected Low-Energy Model Corrected Costs: Arid Climates

Building Type	Building Name	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug General Merchandise	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,260	1,240	1,250	1,250	1,250	1,260
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,170	1,150	1,160	1,150	1,150	1,140
	Baseline (SI units)	Capital Cost ($/m^2)	1,150	1,150	1,150	1,150	1,140	1,140
	Low-Energy (SI units)	Capital Cost ($/m^2)	1,130	1,110	1,120	1,110	1,110	1,090
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	117	115	116	116	116	117
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	109	107	108	106	107	106
	Baseline (IP units)	Capital Cost ($/ft^2)	107	106	107	107	106	106
	Low-Energy (IP units)	Capital Cost ($/ft^2)	105	104	104	103	103	101
High Plug General Merchandise	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,310	1,270	1,290	1,290	1,290	1,290
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,210	1,210	1,200	1,200	1,200	1,200
	Baseline (SI units)	Capital Cost ($/m^2)	1,160	1,150	1,160	1,160	1,160	1,150
	Low-Energy (SI units)	Capital Cost ($/m^2)	1,150	1,150	1,140	1,140	1,140	1,130
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	121	118	120	120	120	120
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	113	112	111	111	111	111
	Baseline (IP units)	Capital Cost ($/ft^2)	108	107	108	108	107	107
	Low-Energy (IP units)	Capital Cost ($/ft^2)	107	107	106	106	106	105

Table F-6 Selected Low-Energy Model Corrected Costs: Marine and Cold Climates

Building Type	Building Name	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug General Merchandise	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,210	1,230	1,280	1,310
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,120	1,120	1,150	1,170
	Baseline (SI units)	Capital Cost ($/m^2)	1,130	1,140	1,150	1,150
	Low-Energy (SI units)	Capital Cost ($/m^2)	1,090	1,090	1,100	1,100
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	113	115	119	122
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	104	104	107	109
	Baseline (IP units)	Capital Cost ($/ft^2)	105	106	107	106
	Low-Energy (IP units)	Capital Cost ($/ft^2)	102	101	102	102
High Plug General Merchandise	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,250	1,260	1,310	1,340
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,180	1,190	1,190	1,200
	Baseline (SI units)	Capital Cost ($/m^2)	1,140	1,140	1,150	1,150
	Low-Energy (SI units)	Capital Cost ($/m^2)	1,130	1,130	1,120	1,120
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	116	117	122	124
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	110	110	111	112
	Baseline (IP units)	Capital Cost ($/ft^2)	106	106	107	107
	Low-Energy (IP units)	Capital Cost ($/ft^2)	105	105	104	104

Appendix G. General Merchandise and Grocery Store Technical Support Documents: Summary and Information Request

The freely available series of Advanced Energy Design Guides (AEDGs) developed by ASHRAE, AIA, IES, USGBC and the DOE are each supported by technical analysis conducted by the National Renewable Energy Laboratory (NREL) or the Pacific Northwest National Laboratory (PNNL). The guides currently target 30% energy savings over ASHRAE 90.1-2004—the next set will target 50% energy savings.

For the past year and a half, NREL has been working to develop 50% energy savings recommendations for retail and grocery stores. Last year's work (medium box retail and grocery stores) established the basic methodology for identifying cost-effective design packages that achieve this goal in each of 15 climate zones. The results are promising, but the analysis input data needs a thorough external review to make sure that our final recommendations are accurate and useable.

This is where you, as a member of the Retailers Energy Alliance (REA), come in: We would like you to review our energy modeling inputs. The following pages list our primary assumptions concerning the layout and operation of prototypical retail and grocery stores (prototype models), plus perturbations of the prototypical designs (energy design measures (EDMs)) that we believe 1) are changes that some retailers would be comfortable with, and 2) may improve energy efficiency in one or more climate zones. Lists of specific questions and information requests are included, but please feel free to comment on any item of interest or bring up issues not specifically addressed in the following pages.

We hope you will participate so we can provide the REA and the broader community with useful, climate-specific design recommendations for retail and grocery stores. To submit your comments, please either send them to Adam Hirsch (adam.hirsch@nrel.gov) and Matt Leach (matt.leach@nrel.gov), or e-mail Adam and Matt to set up a time to convey your feedback directly over the phone.

Table G-1 TSD Prototype Characteristics and Related Questions*

Store Characteristic	Grocery	General Merchandise	Questions
Program			
Size	45,002 ft^2	40,500 ft^2	
Space types	See Table G-2.		
Operating hours	Sun. through Thursday 6:00 a.m. to 10:00 p.m., Friday and Saturday 6:00 a.m. to 12:00 a.m.	Monday through Saturday 9:00 a.m. to 9:00 p.m., Sunday 10:00 a.m. to 6:00 p.m.	
Peak occupancy	8 people/1000 ft^2.	15 people/1000 ft^2.	How does occupancy vary throughout the day/week? How does occupancy affect energy scheduling/use?
Lighting	15%/50%/95% on during unoccupied/staff-only/operating hours.		Is this a good model of lighting loads?
Plug and process	See Table G-3.		How do plug and process loads vary throughout the day?
Form			
Number of floors	1	1	
Aspect ratio	1.5	1.25	
Floor-to-floor height	20 ft	20 ft	
Window area	1400 ft^2 (0.08 WWR)	1,000 ft^2 (0.056 WWR)	
Floor plan	See Figure G-1.	See Figure G-2Figure .	
Fabric			
Wall type	Either concrete block with interior insulation (finished with drywall) or exterior insulation (finished with stucco); or a concrete block cavity wall (finished with brick), depending on climate zone.		What types of wall constructions are acceptable? What considerations affect wall construction selection?
Roof type	All insulation above deck		
Interior partitions	2 x 4 steel frame with gypsum boards		
Internal mass	45,000 ft^3 of wood		Do you have rough estimates of your stores' contents?
Equipment			
HVAC system	Unitary rooftop units with DX coils, natural gas heating, and constant volume fans.		Are other types of HVAC systems considered or used?
HVAC unit size	10 tons cooling		Are other size units used? Are units sized differently for different parts of the store or for stores in different locations?
HVAC controls	No thermostat setback.	Setback during unoccupied hours.	Is thermostat setback used? If so, what is the methodology used to determine the setback?
Refrigeration	4 compressor racks (2 med-temp, 2 low-temp); air-cooled condensers; cases and walk-in units listed in Table G-4.	N/A	Where are compressors and condensers located? Is waste heat recovered from the refrigeration system? Is HVAC return air routed under the refrigerated cases?
Service water heating	Natural gas heating with storage tank		

* All comments on any aspect of the prototypes are welcome.

Table G-2 Space Types and Sizes in the Prototype Models

Zone Name	Grocery		General Merchandise	
	Floor Area (ft^2)	Percent of Total	Floor Area (ft^2)	Percent of Total
Main Sales	22,415	49.8	30,375	75.0
Perimeter Sales	2,611	5.8	4,100	10.1
Produce	7,657	17.0	N/A	N/A
Deli	2,419	5.4	N/A	N/A
Bakery	2,250	5.0	N/A	N/A
Enclosed Office	300	0.7	300	0.7
Meeting Room	500	1.1	500	1.2
Dining Room	500	1.1	500	1.2
Restroom	675	1.5	625	1.5
Mechanical Room	600	1.3	200	0.5
Corridor	532	1.2	450	1.1
Vestibule	N/A	N/A	400	1.0
Active Storage	4,544	10.1	3,050	7.5
Total	45,002	100.0	40,500	100.0

Table G-3 Peak Plug (Electric) and Process (Gas) Loads in the Prototype Models

Zone Name	Grocery		General Merchandise: Low Plug Load	General Merchandise: High Plug Load
	Peak Plug Load (W/ft^2)	Peak Process Load (W/ft^2)	Peak Plug Load (W/ft^2)	Peak Plug Load (W/ft^2)
Main Sales	0.50	0.00	0.20	1.20
Perimeter Sales	0.50	0.00	0.40	0.40
Produce	0.50	0.00	N/A	N/A
Deli	5.00	2.50	N/A	N/A
Bakery	2.50	5.00	N/A	N/A
Enclosed Office	0.75	0.00	0.75	0.75
Meeting Room	0.75	0.00	0.75	0.75
Dining Room	2.60	0.00	2.60	2.60
Restroom	0.10	0.00	0.10	0.10
Mechanical Room	0.00	0.00	0.00	0.00
Corridor	0.00	0.00	0.00	0.00
Vestibule	N/A	N/A	0.00	0.00
Active Storage	0.75	0.00	0.75	0.75
Average	0.88	0.38	0.30	1.05

Table G-4 Grocery Prototype: Refrigerated Cases and Walk-In Units by Zone

Zone Name	Case/Walk-in Type	Case Length	Number of Units	Total Length or Area
Main Sales	Island single deck meat	12 ft	9	108 ft
Main Sales	Multideck dairy/deli	12 ft	13	156 ft
Main Sales	Vertical frozen food with doors	15 ft	18	270 ft
Main Sales	Island single deck ice cream	12 ft	10	120 ft
Main Sales	Walk-in cooler (med temp)	N/A	2	2,818 ft^2
Main Sales	Walk-in freezer (low temp)	N/A	1	1,003 ft^2
Produce	Multi-deck dairy/deli	12 ft	8	96 ft
Deli	Multi-deck dairy/deli	12 ft	1	12 ft
Deli	Walk-in cooler (med. temp)	N/A	1	127 ft^2
Bakery	Walk-in cooler (med. temp)	N/A	1	63 ft^2

Figure G-1 Grocery prototype floor plan

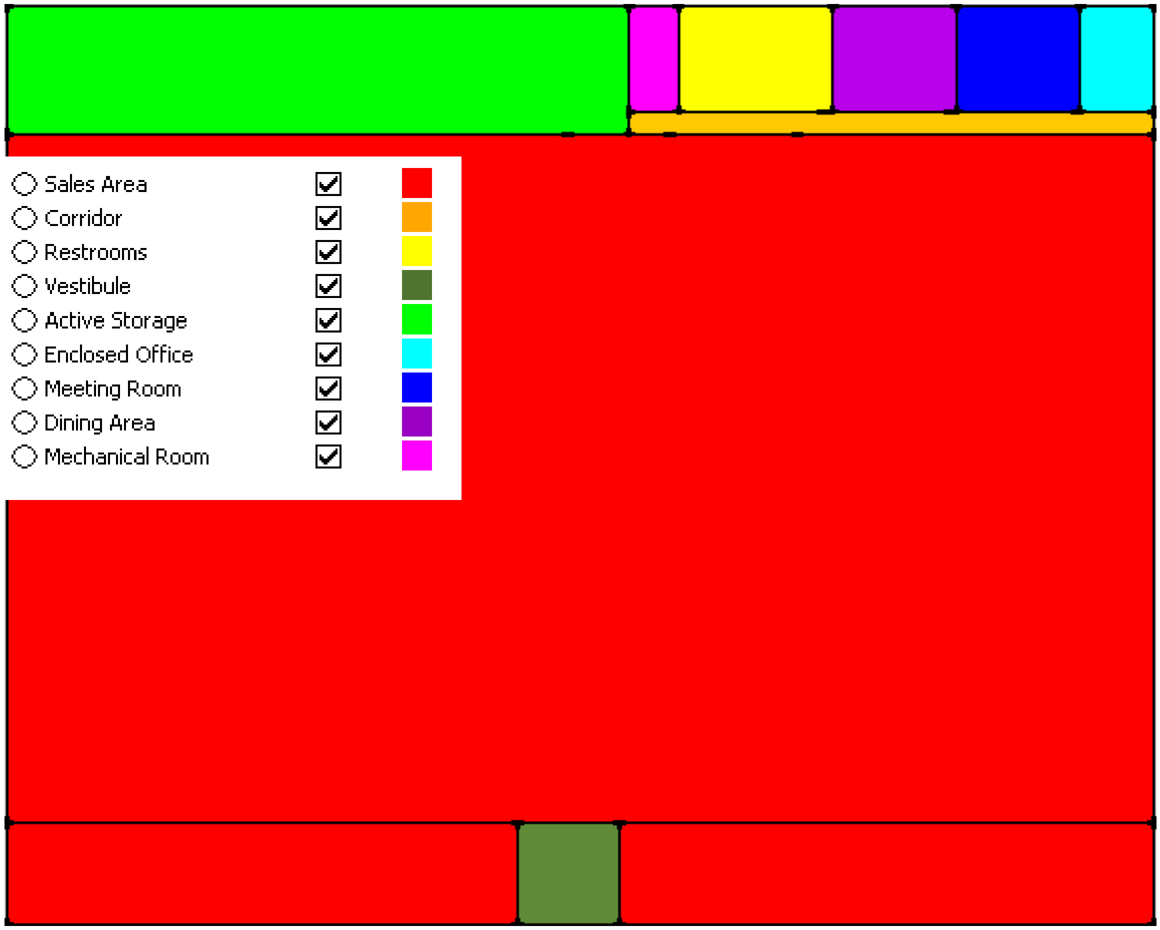

Figure G-2 General merchandise prototype floor plan

Table G-5 Energy Design Measure (EDM) Information Requests

Priority	Store Types*	EDM Category	FY 2008 Assumptions	Information Requests
High	GM, Gro	Plug loads	10% overall reduction possible; very high costs.	Possible plug load reduction strategies (novel or proven).
	GM, Gro	ERV	2000 cfm unit(s) with 60%-80% sensible effectiveness, 50%-70% latent effectiveness.	Experience with or thoughts on designing ERV systems for large one-story buildings.
	GM, Gro	Envelope infiltration	An envelope air barrier reduces envelope infiltration from 0.24 to 0.05 ACH.	Infiltration levels and sources in typical construction; proven reduction strategies.
	GM, Gro	Daylighting	400 lux (37 fc) and 600 lux (56 fc) set points.	Acceptable daylighting set points in lux or fc.
	GM, Gro	Vertical fenestration	Amount of fenestration on front façade can be changed ± 20% from 1000 ft^2 (general merchandise) and 1400 ft^2 (grocery) baselines.	Range of acceptable fenestration amounts (WWR) for each façade; acceptability of adding clerestory (high) windows to back of store for daylighting storage areas, etc.
	Gro	Refrigerated cases	Reduced display lighting; added efficient fan motors, defrost and anti-sweat heater controls; added doors to cases.	Strategies that render doors more acceptable; lighting preferences.
	Gro	Refrigeration system	Evaporative condensers.	Experience with evaporative condensers; decision criteria pertaining to compressor type; interest in particular secondary loop systems.
Medium	GM, Gro	Electric lighting	Sales floor lighting power densities of 1.36 W/ft^2 (20% below code) and 1.02 W/ft^2 (40% below code).	Typical lighting configurations; best practice/state-of-the-art configurations.
	GM, Gro	Entranceway infiltration	Adding a main entrance vestibule reduces infiltration through the door from 0.082 to 0.054 ACH.	Whether vestibules are used, and if not, why not; preferred vestibule designs.
	GM, Gro	Static pressure drop	Not included.	Typical ductwork designs for rooftop units; minimum length of ductwork runs to and from rooftop units.
	GM, Gro	Envelope	Static construction types with different levels of insulation.	List of acceptable and/or interesting construction assemblies for walls and roofs.
	GM, Gro	HVAC	More efficient rooftop units with DX cooling and natural gas heating.	Alternative HVAC systems that retailers are interested in pursuing or have considered already.
	Gro	HVAC	See above.	HVAC/Refrigeration integration strategies retailers have pursued or would like evaluated.
	GM, Gro	DCV	Modeled by having outside air requirements follow the occupancy schedules.	Experience with using DCV in real stores.
	GM, Gro	Overhangs	Framed overhangs offset 0.82 ft from the top of each window; projection factor of 0.1 to 1.5.	Current use and acceptability of overhangs; preferred materials for overhangs.
Low	GM, Gro	PV	Possible to cover 30% of the area not used by skylights with PV.	Percent of roof area available for PV panels and skylights.
	GM, Gro	Horizontal fenestration	Skylights are preferred daylighting method.	Preferences concerning skylights and skylight alternatives.

* GM = General Merchandise, Gro = Grocery

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Elaine Hale, Matthew Leach, Adam Hirsch, and Paul Torcellini

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14. ABSTRACT *(Maximum 200 Words)*
This report documents technical analysis for medium-box general merchandise stores aimed at providing design guidance that achieves whole-building energy savings of at least 50% over ASHRAE Standard 90.1-2004. It documents the modeling and integrated analysis methods used to identify cost-effective sets of recommendations for different locations; demonstrates sets of recommendations that meet or exceed the 50% goal; establishes methodology for providing a family of solutions, as opposed to a single solution, that meet the 50% goal as a means of exploring the relative importance of specific design strategies; demonstrates the dependence of the percent energy savings metric on the building standard used to establish the baseline; and explores the effect of floor area on energy use intensity.

15. SUBJECT TERMS
energy savings; general merchandise; ashrae standard; energy interaction

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